Lecture Notes in Networks and Systems 200

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Current Problems and Ways of Industry Development: Equipment and Technologies

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Comprehensive Take on Technological Development in the Digital Economy and Industry 4.0 (Introduction)

Industrial development of equipment and technologies embodies scientific–technological progress at the current stage of evolution of engineering and technologies. In the context of the Fourth Industrial Revolution, there is a need for fundamentally new technologies for manufacture of products in primary and secondary industry that would meet the requirements of the modern age; first, in the context of enhanced security both for employees of manufacturing enterprises and for consumers and second, in the context of highly accurate and improved specifications, to guarantee the highest possible quality of products.

Third, in the context of efficiency and competitiveness. Manufacturing enterprises compete head on, being responsible before their shareholders and investors, the state, and society. Being big employers in large industrial regions and city-forming enterprises in single-industry cities, they must hold stable positions in target markets in order to avoid massive job cuts and dismissals, as well as to ensure the return on investment and high margin.

Fourth, in the context of meeting sustainable development goals. Contemporary society is not ready to sacrifice current resources and living conditions, as well as the legacy of succeeding generations, for the sake of commercial interest of manufacturing enterprises. They are forced to fit in with a strict and increasingly tight framework of high environmental standards and requirements to corporate environmental responsibility.

Industry 4.0 offers a consistent response to all these requirements. Automation based on digital technologies enables the manufacture of unique products using machinofacture, which is independent of personnel and safe for a minimum staff number. High-tech industrial products are more efficient in terms of resource-intensiveness, safe for the environment, and attractive in global markets.

In this regard, for the sake of business, the state, and society, neo-industrialization—a transition to Industry 4.0, the essence of which is manifested in industrial development of equipment and technologies—is currently taking place. This book is intended to reveal and systematize current problems and ways of industrial development of equipment and technologies.

This book is concerned with the identification and systemization of technical problems and ways of industrial development of equipment and technologies. It gives consideration to emerging technologies for modern industrial development and puts forward applied solutions for the optimization of operation of enterprises in primary and secondary industry. The book analyzes and systematizes man-made factors of neo-industrialization in the digital economy and outlines the prospects for the automation of modern manufacturing enterprises.

Further, the book outlines the strategic guidelines for industrial development of equipment and technologies from the perspective of sustainable development relating to the field of development of the "green" economy based on the non-financial sector. Moreover, the book explores the integration mechanisms of industrial development of equipment and technologies and provides scientific support for their promotion.

Contents

Features of VMI Technology for Joint Stock Management of Products with a Limited Shelf Life in Cluster Logistics

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Abstract. When producing perishable products or using perishable raw materials, large producers face the problem of organizing supplies and forming stocks, taking into account this specificity of resources. Product shelf life is key in optimizing and synchronizing supply and manufacturing processes. An approach to optimization of delivery not based on VMI-technology of joint inventory management with an extended module for monitoring stocks of perishable goods is proposed. It is noted that monitoring should be carried out according to a specific algorithm based on an economic and mathematical model for managing stocks of perishable goods. The developed model provides the calculation of the optimal proportions for the purchase, storage and sale of perishable products. It is shown that this approach is applicable to the dairy cluster of the Voronezh Oblast, the structure of which includes the logistic subsystem of interaction between the producer and the consumer of the product.

Keywords: Perishable goods · Inventory management · VMI interaction · Cluster logistics · Supply chain

1 Introduction

Integration processes, manifested in the creation of cluster-type structures, have become a characteristic feature of the development of modern agriculture (Kundius and Kovalyova 2019; Melnikov et al. 2019). The need for the development of associations of this kind is determined equally by the possibilities of optimal use of existing resources, the prospects for realizing the export potential, and the boundaries of food security. The development of cluster structures presupposes the attraction of new participants, oriented in advance to solving the problems of processing and transportation, commercial and intermediary activities, issues of management of material flows of agricultural products. Therefore, this specificity of the agro-industrial complex must be taken into account when planning integrated supply chains (Serebryakova et al. 2017).

For example, the regional government of the Voronezh Oblast at one time focused on the development of the dairy sector. The formation of the Voronezh dairy cluster began

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in 2014, since 2016 more than 200 enterprises and farms of various sizes and specializations have been united in the cluster. The basic task in the creation and development of an integrated agro-industrial structure was to unite and synchronize the efforts of companies involved in related industries - from the production of feed and raw materials to the creation of the final processing product. The localization of the dairy cluster was completely determined by the development of dairy cattle breeding and milk processing enterprises in the region. The core of the cluster is its largest enterprises - EkoNivaAgro LLC, Don Agro Management Company, Molvest Group of Companies and Prodimex Group of Companies. The dairy cluster of the Voronezh Oblast has the structure shown in Fig. 1.

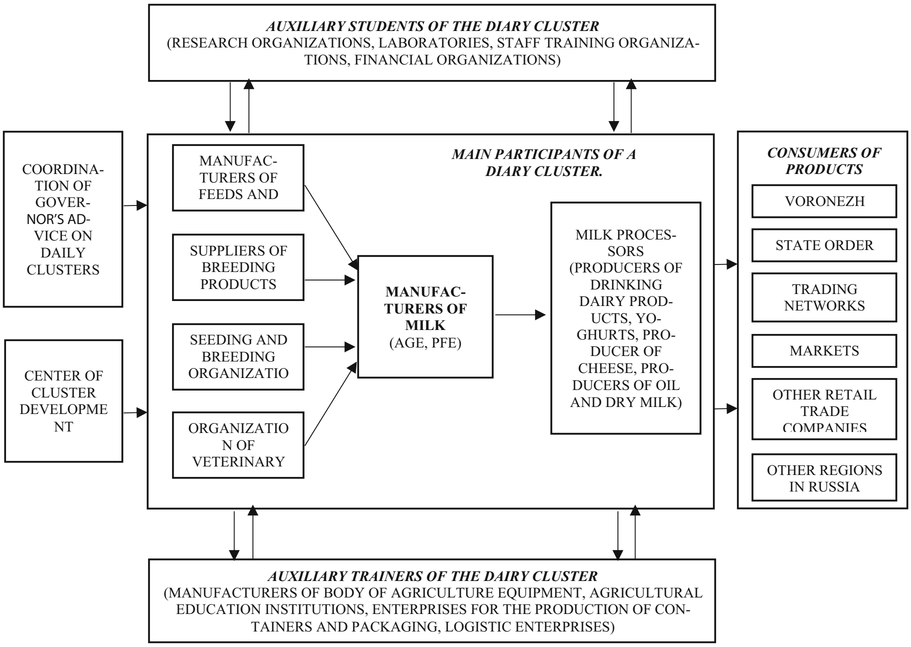

Fig. 1. The structure of the dairy cluster of the Voronezh Oblast

2 Methodology

The implementation of the program made it possible to create favorable economic conditions for the sustainable development of dairy cattle breeding, increase the efficiency of agricultural producers engaged in milk production, provide the population with milk and dairy products of domestic production, and increase the competitiveness of products (Rau et al. 2013). The effectiveness of the policy is confirmed by the rating of the Voronezh Oblast for milk production in the Central Federal District (Table 1).

Analyzing the activities of the dairy cluster, it is necessary to pay attention to the risks associated with its formation and development, namely, the management of stocks of perishable dairy products.

Table 1. Leading regions in milk production in agricultural enterprises for January-May 2019

Rating	Region	Milk production volume in January-May 2019 (thousand tons)	Change in the indicator to the same period in 2018
1	Tatarstan	480.1	+2.1%
2	Krasnodar Krai	409.7	−0.1%
3	Voronezh Oblast	308.3	+15.8%
4	Udmurt republic	295.4	+5.1%
5	Kirov Oblast	277	+6.8%
6	Leningrad Oblast	251.7	+2.7%
7	Moscow Oblast	249.1	+3.1%
8	Novosibirsk Oblast	247.6	+1%
9	Sverdlovsk Oblast	247	+1.2%
10	Altai Krai	229.9	−0.7%
11	Belgorod Oblast	219.3	+15.2%
12	Vologodskaya Oblast	217.8	+5.3%
13	Republic of Bashkortostan	216.2	−2%
14	Nizhny Novgorod Oblast	205.1	+4.8%
15	Perm Oblast	177.5	+4.2%
16	Ryazan Oblast	163	+4.2%
17	Krasnoyarsk Krai	159.9	+2.9%
18	Vladimir Oblast	156.7	+2%
19	he Republic of Mordovia	150.2	+5%
20	Tyumen Oblast with KhMAO	149.3	+9.5%
21	Kaluga Oblast	144.5	+17.7%
22	Omsk Oblast	137.9	−4.6%
23	Yaroslavl Oblast	120.4	+0.6%
24	Lipetsk Oblast	87.1	+4.4%
25	Bryansk Oblast	82.3	+4.1%
26	Kursk Oblast	72.7	−1%
27	Chelyabinsk Oblast	69.3	−1.4%
28	Penza Oblast	68.3	−4.5%
29	Pskov Oblast	65	−1%
30	Orenburg Oblast	61.7	−13.3%

Source: The DairyNews

Until recently, retailers could afford to manage goods with a limited shelf life within the overall supply chain without separating them into a separate forecasting area. Most of the sales and purchase agreements concluded between manufacturers and retailers gave the latter the opportunity to order products but after a while, at their discretion, return without paying, or force the manufacturer to buy it back. However, the adoption of Federal Laws 446-FZ "On Amendments to Article 5 of the Federal Law" On the Development of Agriculture "and" On the Fundamentals of State Regulation of Trade Activities in the Russian Federation" may radically change the current market situation.

The law provides for a ban on reimbursement of expenses related to the disposal or destruction of unsold food products for retailers and suppliers of relevant types of products. According to the authors of the law, its adoption will provide additional protection measures for domestic manufacturers in the Russian retail market.

The law actually cancels the previously established practice, when a retail chain had the right to return unsold goods to a manufacturer or demand reimbursement of its own costs for its disposal or destruction. The law also establishes a ban on the conclusion between retail chains and suppliers of contracts containing a condition on the return of goods to the supplier with a shelf life of up to 30 days inclusive, or on the replacement of these goods with the same goods, or on reimbursement of their cost, except as provided by law.

The adoption of this law presents certain benefits for manufacturers. These undoubtedly include the possibility of expanding the planning horizon, increasing assortment positions, and improving the quality of recipes. However, these advantages are forcing retailers to increase the requirements for quality control and sales planning, primarily in relation to goods with a short shelf life.

In this case, the most optimal approach can be considered the use of a logistic demand management and replenishment system VMI (Vendor Managed Inventory - supplier-managed inventory). This methodology is based on the assumption that the supplier has access to information about the consumer's inventory and plans purchase orders for him, i.e. takes over consumer functions in inventory management.

For example, consider two different approaches in Figs. 2 and 3:

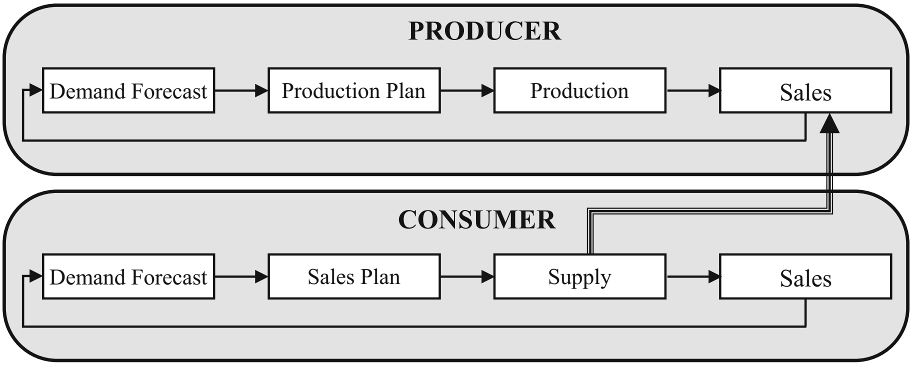

Fig. 2. Traditional scheme of interaction between Supplier-Consumer

A major stumbling block to the implementation of VMI can be the stage of establishing rules for restocking perishable goods between partners. The decision has to be made according to a whole set of criteria, such as the frequency of delivery, its minimum and maximum volume, optimization conditions, information transfer mode, levels of insurance, minimum and maximum stocks. The basic platform for solving this problem can be the methods used in the theory of inventory management according to Alpidovskaya and Popkova (2019), Inshakova and Bogoviz (2020), Popkova (2017), Popkova et al.

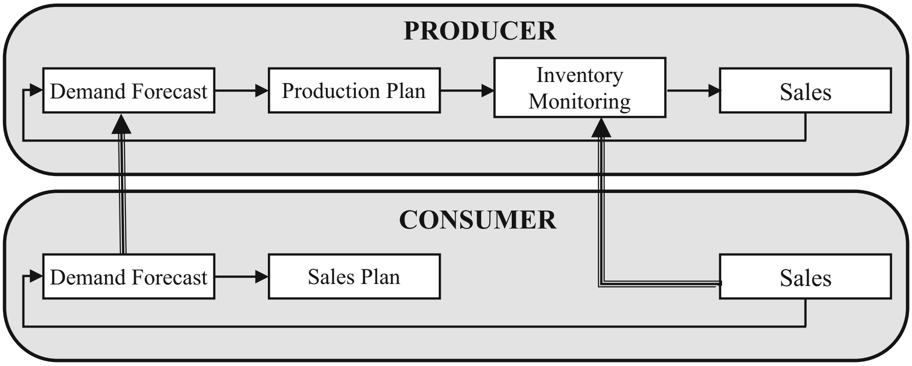

Fig. 3. VMI diagram of the supplier-consumer interaction

(2020), Popkova and Sergi (2020), Popkova and Sergi (2018), Popkova and Sergi (2019), Sergi et al. (2019), Vertakova et al. (2020) and Vertakova et al. (2019).

Historically and methodologically, it has developed so that theoretical research and areas of practical implementation in the field of inventory management are developing in two main areas, namely, in applied logistics and the theory of inventory management (Lukinskiy et al. 2018). The disadvantages of most of the approaches are obvious - the proposed solutions use a complex apparatus of theoretical mathematics, are limited to the category of stocks localized in the production-warehouse-production section, do not take into account the specifics of the organization of the delivery and sale of products within the existing logistics chain. According to Ryzhikov (2010) "only in 45% of works the formulated tasks are brought to a practical solution".

The main goal of the study is to develop an algorithm for optimizing the activities of trade enterprises that ensure the promotion of perishable products, which include the products of the dairy cluster of the Voronezh Oblast, from the manufacturer to the end consumer (Fig. 4).

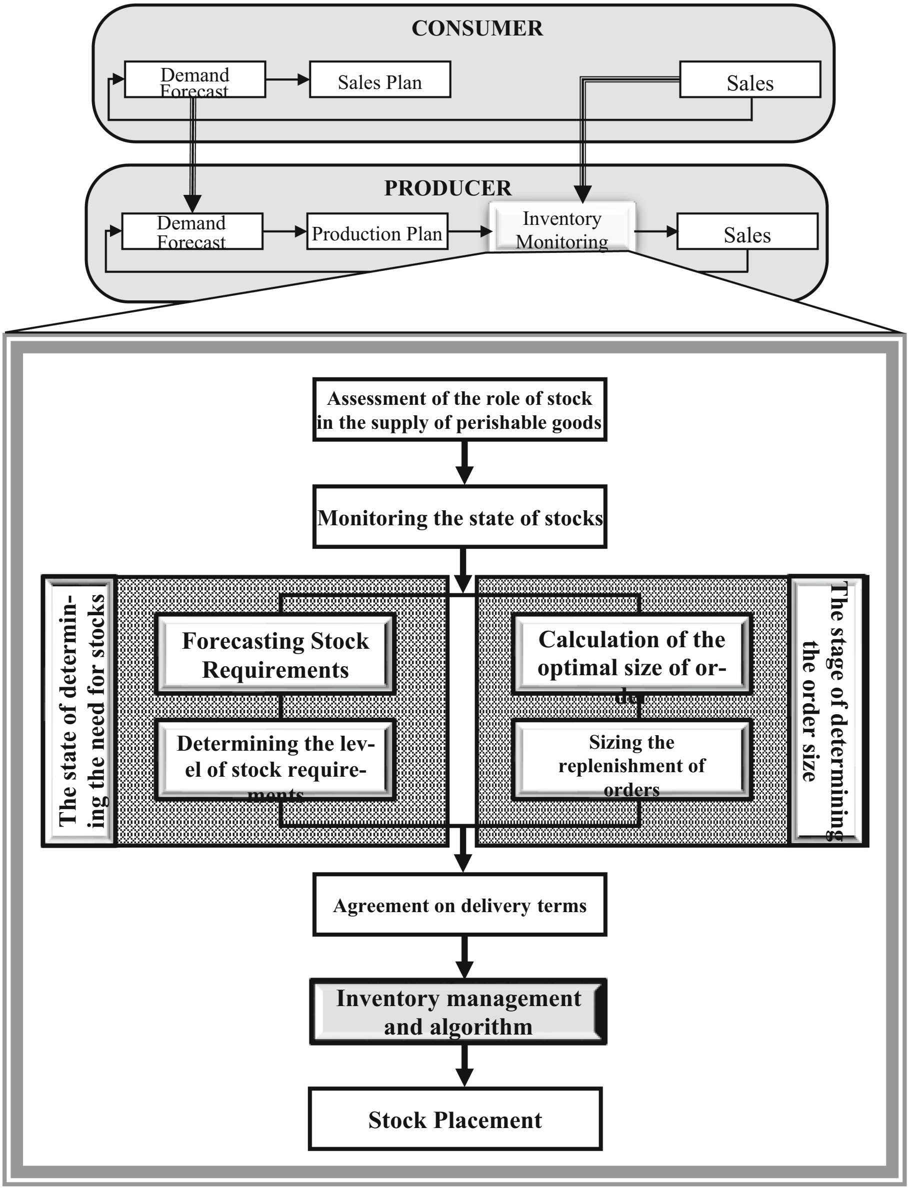

Fig. 4. The concept of expanding VMI interaction in the dairy cluster of the Voronezh Oblast

3 Results

In our assumption, the algorithm for optimizing the activities of trade enterprises should be based on the model of inventory management of perishable goods. To substantiate the proposed model, we introduce the following value $x_i^k(t)$ - volume of purchases k^{th} Trade and Intermediary Firm (TIF) i^{th} assortment position y manufacturer at time t.

The manufacturer supplies TIF products in small wholesale and retail, however there is a limitation on the minimum order volume, the profitability threshold, which depends on the type of trading company. Thus, the average weekly order amount must exceed the average fixed costs for all trading firms: $\sum_{t=t_0}^{T_0} \sum_{i=1}^{I} x_i^k(t)(p_i + \Delta p) \geq \frac{G_0}{K}(1 + \Delta_k)$, where p_i - purchase price/cost of goods, Δp - price/cost change, G_0 - fixed costs of the enterprise, Δ_k - individual threshold of profitability k^{th} TIF, k - the total number of sales representatives working with this organization, t_0 - Monday of the week in question.

This ratio is not included in the limitation of the model but only shows the specifics of the enterprise. If this restriction is not met, it is not profitable to work with this TIF.

There is a certain critical volume of goods in the warehouse, upon reaching which TIF purchases a new batch. We introduce the value V_i - average daily sales i^{th} goods. Then the critical volume of goods in the warehouse is $V_i\left(t_i'' + 1\right)$, где t_i'' - some period of time for which should be enough i^{th} goods. The purchase of products is carried out on the basis of sales for a certain period t_i', therefore, the minimum purchase lot is limited to $V_i t_i'$. In this case, it may turn out that the minimum purchase lot from the manufacturer is greater than the minimum TIF. Then the minimum purchase volume $\max\left\lfloor V_i t_i, V_{mp}\right\rfloor$ V_{mp} - minimum purchase lot limited by the manufacturer.

Products of this type have a shelf life T_i^{year}. TIF has a warehouse equipped with refrigeration units, which makes it possible to purchase and store large volumes of products for a long enough period of time throughout the shelf life. On the day of the expiration of the shelf life, as well as on the day of purchase, the sale of goods to trading firms is not carried out; however, these two days are included in the shelf life. Thus, the maximum batch is limited to $\left(T_i^{year} - 2\right) * V_i$ the product should not be more than the TIF has time to sell before the expiration date. To ensure the continuity of the sales process, on the day of purchasing a new batch, the goods of the previous batch are sold.

Taking into account the period of "life" of a product of one batch, we introduce the following notation: v_i - purchase volume i^{th} goods in this batch; T_i^{year} - expiration date for i^{th} goods from the current batch; t - shelf life of goods, $t = \overline{1, T_{\max}^{year}}$, where $T_{\max}^{year} = \max_i\left(T_i^{year}\right)$. Let p_i - purchase price i^{th} assortment position; zap_i - stock i^{th} assortment position in the TIF warehouse at the time of purchase; t_i^{year} - expiration date of the remaining assortment item from the previous batch $\left(T_i^{year} > t_i^{year}\right)$; G_0 - fixed costs of TPO, which do not depend on the degree of workload of the warehouse.

In this model, the restrictions on the volume of purchases will look like $\left(T_i^{year} - 2\right) * V_i \leq v_i \leq \left(V_i \cdot t_i', V_{mp}\right)$.

The stock of products in the warehouse is limited from below by some critical volume $zap_i \geq V_i t_i''$. The total stock for all goods cannot exceed the useful volume of the warehouse V.

The objective function for TIF will be as follows:

$$\min\left[\sum_{t=1}^{T_i^{год}} \sum_{k=1}^{K} x_i^k(t), v_i + zap_i - \overline{zap_i}\right] * \left(p_i + \Delta p_i^k\right) - v(1) * p_i + \overline{zap_i} * p_i - G_o \to \max,$$

Where $\overline{zap_i} = \max\left[zap_i - \sum_{t-1}^{t_i^{god}} \sum_{k=1}^{K} x_i^k(t), 0\right]$, Δp_i^k - individual markup for i^{th} goods.

The volume of remaining at the end of the shelf life products from the previous batch can be calculated as $zap_i - \max\left[zap_i - \sum_{t=1}^{t_i^{year}} \sum_{k=1}^{k} x_i^k(t), 0\right]$, volume of products sold for the entire period under review $\min\left[v_i, \sum_{t-1}^{T_i^{year}-1} \sum_{k=1}^{K} x_i^k(t)\right] - \min\left[zap_i, \sum_{t=1}^{t_i^{year}-1} \sum_{k=1}^{K} x_i^k(t)\right]$, the volume of missing products of the current batch is $\max\left(\left(v_i + \min\left[zap_i, \sum_{t-1}^{T_i^{year}-1} \sum_{k=1}^{K} x_i^k(t)\right] - \sum_{t=1}^{t_i^{year}-1} \sum_{k=1}^{K} x_i^k(t)\right), 0\right) + \max\left[zap_i - \sum_{t-1}^{t_i^{year}} \sum_{k=1}^{K} x_i^k(t), 0\right]$ This value must be minimized.

Taking into account all the restrictions imposed, we get the final form of the model that provides the optimal proportions for the purchase, storage and sale of perishable goods.

4 Conclusion

Obviously, the main difference between inventory management systems for products with a limited shelf life from classical inventory management systems is that when calculating an order, not only the current stock level is taken into account, but also the distribution of the stock by residual shelf life. Therefore, the recommendations given by the authors can be adapted and applied not only for agricultural producers, but also for supply chains in other industries. At the same time, companies that implement the VMI scheme of interaction between Supplier and Consumer to optimize inventory management should understand that it couldn't be used for all customers. The target should be the key customers of the company with the highest commodity turnover, high growth potential, with a developed IT structure, with an integral system of accounting for stocks, sales and deliveries.

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Modeling and Optimization of Forming Processes of Aircraft Engineering Thin-Wall Structures

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Abstract. Purpose Construct and investigate a method for optimizing the processes of forming thin-walled structures. A criterion for the optimization of deformation processes is introduced, which ensures minimal damage. Under the condition of a given tooling, the optimal control problem is posed to find the best path for deformation of the workpiece. In the space of solutions to optimal control problems developed by the methods, non-monotonic deformation trajectories should be included, taking into account partial unloading.

Design/methodology/approach. Modeling of technologies for forming double-curvature shells using CAE systems is considered. As devices for forming products from sheets and panels, equipment with numerical control is used, in particular, a reconfigurable rod punch and stretch forming equipment. Calculation of the optimal forming path of the workpiece is performed by modeling and analyzing the nonlinear deformation of the panel with contact constraints using the finite element method. A discrete optimal control problem is formulated, which is solved by the dynamic programming. The numerical method algorithms implemented in the MSC system Marc allow us to calculate the optimal parameters of the process equipment.

Findings. Calculations using the developed method of optimal trajectory for technological processes of forming are presented. The results of solving these problems are compared with known analytical and practical data.

Keywords: Elasticity · Plasticity · Creep · Shaping · Finite element method · Optimal control problem · Dynamic programming method

JEL Code: C61 · L61 · L62

1 Introduction

The use of monolithic parts in aircraft structures leads to the development of technical solutions in forming methods. Technological processes for manufacturing complex double-curvature panels include pressure treatment of materials in the plastic deformation mode under both normal and slow high-temperature conditions (Ribeiro et al. 2010;

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Yan et al. 2010; Verichev et al. 2014; Annin et al. 2010; Wang et al. 2015; Feoktistov and Pogartseva 2019; Potianikhin et al. 2019).

In this paper, we consider the manufacture of parts using the stretch forming technology on the press and forming in the creep mode using a reconfigurable rod punch (Simon et al. 2014; Molod 2011). In the first case, the required residual shape of the panel is set by wrapping a punch and stretching. In the second case, the shaping surface of both the punch and the matrix formed by two systems of coaxially arranged rods, each of which moved to an individual position by means of numerical program control, sets the necessary form workpiece.

To ensure the high quality of the product, high accuracy of the final geometric shape of the part after its release from the tooling, it is necessary to evaluate the parameters of shaping with the analysis of full-size theoretical models. In this case, numerical methods are relevant to predict the load, that forms changes in the geometry of the workpieces during deformation, and determine the optimal conditions for the process. The determination of the effects of various parameters involved in metal forming processes has been made possible by using the finite element method for the analysis of metal working processes by pressure. In particular, the evaluation of aluminum alloys springing in the forming process is considered (Huang et al. 2007; Lihua et al. 2013).

At present, aircraft enterprises are equipped stretch forming equipment with numerical program control. Stretches forming presses with program control provide the implementation of various forming schemes for single and double curvature shell. There are various ways of forming on these presses: taking into account the movement of the workpiece relative to the punch and taking into account a certain sequence of the kinematic scheme of forming process with unloading (Miheev et al. 2012; Miheev et al. 2011).

Thus, to form with these technologies, it is necessary to know the shape of the tooling (dies, punch, rod reconfigurable punch), which defines the proactive panel shape. The magnitude of the panel deviation after unloading from the required geometry depends on the temperature of the forming, material properties and the method of deformation. By varying these parameters, it is possible to reduce these deviations and, accordingly, the finishing operation.

In this paper, as a criterion for choosing the optimal deformation path, the dissipation work in plasticity and creep is specified, this characterizes the damage to the material. The admissible space for solving optimal control problems includes non-monotonic deformation trajectories that take into account partial unloading.

2 Methodology

The problem of optimal shaping in the creep mode of products from sheets and panels using a reconfigurable rod punch determines the optimal law of rods movement.

The functional of the variational principle of the creep deformation problem in the general Lagrangian formulation has the form

$$J_1(\dot{\overline{u}}, \dot{u}) = \dot{W}_c + a(\dot{u}, \dot{u}) \text{ at } \dot{\overline{u}}|_{S_c} = \dot{\overline{u}}^*,$$

where $u = (u_1, u_2, u_3)$, $\overline{u} = (\overline{u}_1, \overline{u}_2, \overline{u}_3)$ are the vectors of deformable body displacements and displacements of contact bodies, $\dot{\overline{u}}^*$ is the specified contact speed of movement at a time t; $t \in [0, T]$ is the body deformation time under load; W_c is the contact potential; the potential forms are defined as $a(\dot{u}, \dot{v}) = \int\limits_V [\partial E(\dot{u}_{i,j}) \big/ \partial \dot{u}_{i,j}] \dot{v}_{i,j} dV$, $E(\dot{u}_{i,j}) = (1/2) c_{ijpl} \dot{\varepsilon}_{ij} \dot{\varepsilon}_{pl} - c_{ijpl} \dot{\varepsilon}_{ij} \dot{\varepsilon}^c_{pl} + (1/2) \sigma_{ij} \dot{u}_{p,i} \dot{u}_{p,j}$, c_{ijpl} are the components of the elastic constant tensor, $\dot{\varepsilon}_{ij}$ are the strain rate components; $\dot{\varepsilon}^c_{pl}$ are the creep strain rate components: $\dot{\varepsilon}^c_{ij} = \gamma s_{ij}$, $\gamma = \frac{3}{2} B \overline{\sigma}^{\eta - 1}$, s_{ij} are the stress tensor deviator components, $\overline{\sigma} = \sqrt{3/2 s_{ij} s_{ij}}$ is the stress intensity, B, η are the material constants; $\dot{\varepsilon}_{ij} = (1/2)(\dot{u}_{i,j} + \dot{u}_{j,i} + \dot{u}_{p,i} u_{p,j} + u_{p,i} \dot{u}_{p,j})$, $u_{i,j} = \frac{\partial u_i}{\partial x_j}$, the dot above indicates the speed, $i, j, p, l = 1, 2, 3$. The contact surface of the rods with a deformable body is indicated by S_c ($S_c \subset S$).

Thus, the optimal control problem is formulated using the equations of mechanics of a deformable solid and the optimization functional:

$$J_2 = \int\limits_0^T \int\limits_V \sigma_{ij} \dot{\varepsilon}^c_{ij} dV dt \to \inf . \tag{1}$$

This functional represents the dissipation work and characterizes the creep damage parameter.

The displacements of contact bodies points at the boundary S_c $\overline{u}(t) = f(t)\overline{u}^*$ are considered as control functions.

Thus, using the known solution of the inverse problem (Bormotin 2013), we find the optimal function $f(t)$.

For stretch-forming technology on the press in the manufacture of double-curvature sheathing, the optimal law of clamps movement is determined by the criterion of least damage. S_b denotes the region with edge displacements that determine the clamps movement of the stretch-forming equipment. In contrast to the previous problem, t is a deformation parameter.

The functional of the variational principle of the forming problem by stretch-forming on the punch has the form

$$J_3(\dot{\overline{u}}, \dot{u}) = \dot{W}_c + a(\dot{u}, \dot{u}) \text{ at } \dot{u}|_{S_b} = \dot{u}^* .$$

In this case, the potential form is determined using $E\left(\dot{u}_{i,j}\right) = \frac{1}{2} c_{ijpl} \dot{\varepsilon}_{ij} \dot{\varepsilon}_{pl} - c_{ijpl} \dot{\varepsilon}_{ij} \dot{\varepsilon}^p_{pl} + \frac{1}{2} \sigma_{ij} \dot{u}_{p,i} \dot{u}_{p,j}$, $\dot{\varepsilon}^p_{ij}$ are the plastic strain rate components, $\dot{\varepsilon}^p_{ij} = \lambda \frac{\partial \widehat{f}}{\partial \sigma_{ij}}$, the yield function $\widehat{f} = 0$ is a function of stress.

The location of the coordinate system and the original panel model is shown in Fig. 1. The displacement trajectory of the panel edges when stretch-forming $u|_{S_b} = u^*$ is set by the components along the x, z axis.

The optimal control problem is formulated using the equations of mechanics of a deformable solid and the optimization functional

$$J_4 = \int\limits_0^T \int\limits_V \sigma_{ij} \dot{\varepsilon}^p_{ij} dV dt \to \inf . \tag{2}$$

In this case, the path will be determined with minimal damage to the material in plasticity.

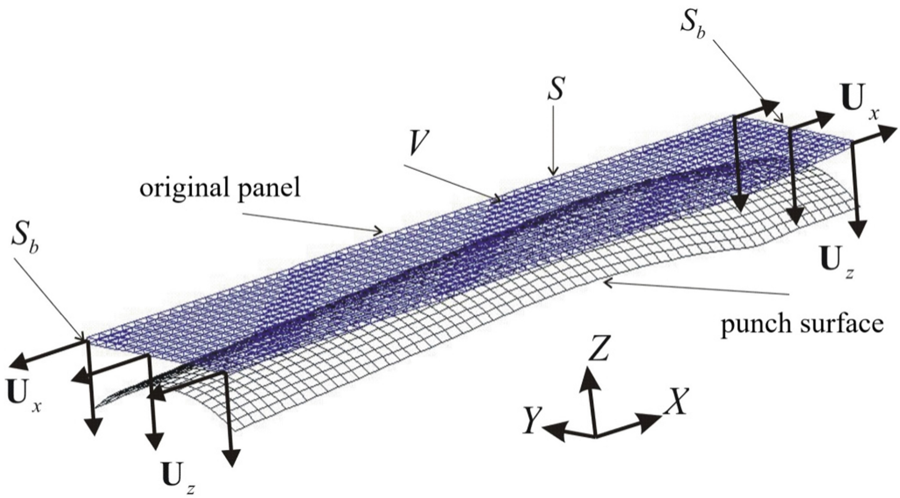

Fig. 1. Model of the original panel and punch surface. *Source*: developed and compiled by the authors

The discrete equations of the deformation problem, constructed on variational principles using the finite element method, have the form (Wriggers 2006)

$$^{t+\Delta t'}\mathbf{K}^{(r-1)}\Delta\mathbf{U}^{(r)} = {}^{t+\Delta t'}\mathbf{R}^{(r-1)}, \tag{3}$$

where $^{t+\Delta t'}\mathbf{K}^{(r-1)}$ is stiffness matrix, $^{t+\Delta t'}\mathbf{R}^{(r-1)}$ is vector of internal and external forces. The value of the loading parameter for which the value is calculated is determined by the superscripts $t + \Delta t'$, and the iteration number when refining the solution by the Newton-Raphson method is determined by the indices $(r - 1)$.

Let a vector function $\overline{\mathbf{U}}(t) = f(t)\overline{\mathbf{U}}^*$, with a known solution of the inverse problem $\overline{\mathbf{U}}^*$ (Bormotin 2013), specify the displacements of the contact bodies nodal points. For an approximate solution of the optimal control problem, an additional discretization is introduced for the parameter t: $0 < t_1 < t_2 < \ldots < t_N = T$. Under the condition $\Delta t' \leq t_{k+1} - t_k$ and solution (3), the minimized functional (1) can be represented as

$$\overline{J}_2 = \sum_{k=0}^{N-1}\sum_{t=t_k}^{t_{k+1}}\sum_{V} {}^t\sigma_{ij}\Delta\varepsilon_{ij}^c \rightarrow \inf . \tag{4}$$

In this formulation of the optimal control problem (3), (4) the Bellman function is constructed and the problem can be solved by dynamic programming (Vasil'ev 2002; Moiseev 1974).

Given the discretization of the loading parameter in the problem of bodies deformation under plasticity conditions, functional (2) takes the form

$$\overline{J}_4 = \sum_{k=0}^{N-1} \sum_{t=t_k}^{t_{k+1}} \sum_{V} {}^t\sigma_{ij} \Delta\varepsilon_{ij}^p \to \inf . \quad (5)$$

The discrete optimal control problem in this case includes Eqs. (3) and criterion (5). The clamps movements when stretch-forming is determined by the movements $\mathbf{U}(t)$ of the nodes located on the S_b (Fig. 1). The task is to find the optimal dependence of the displacement's components $\mathbf{U}_z = f(\mathbf{U}_x)$. Components of node movements depend on the loading parameter $\mathbf{U}_x(t) = f_1(t)\mathbf{U}_x^*$, $\mathbf{U}_z(t) = f_3(t)\mathbf{U}_z^*$, where $\mathbf{U}_x^*$, $\mathbf{U}_z^*$ is solving the inverse problem, providing the necessary residual shape of the panel (Bormotin 2013).

3 Results

To analyze the deformation trajectories, we consider modeling the process of multi-point forming of a square plate in an installation with an upper and lower matrix, including four rods. The calculation of the final rods position, providing the necessary proactive form of the panel, is performed by the iterative method of solving the inverse problem. Let the final position of the rods be known. As a result deformation of the plate in creep, crumples are formed at the points of contact with the rods, which causes an increase in stresses, strain and dissipation work. When the contact bodies move, the maximum value of the dissipation energy in the plate with the exception of the crumple places is formed in the bend (Fig. 2).

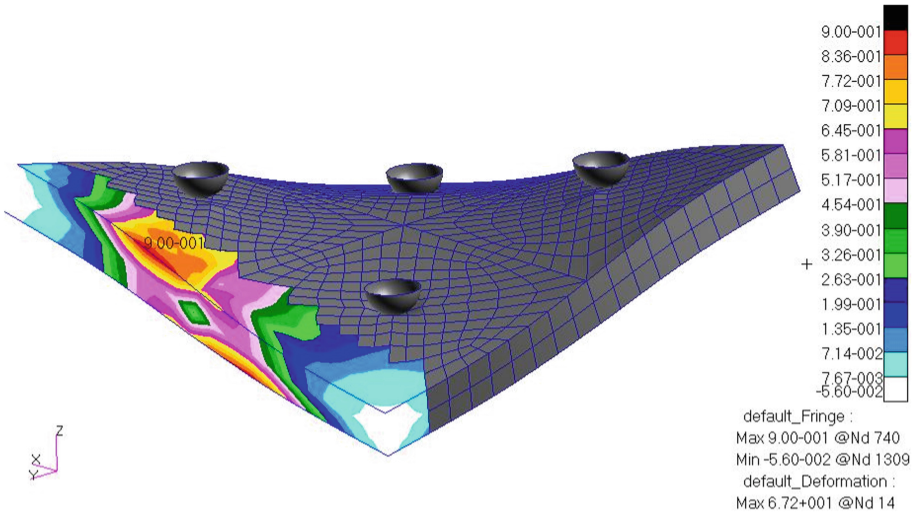

Fig. 2. Deformed plate configuration and maximum dissipation energy. *Source*: developed and compiled by the authors

The solution to the problem of optimizing the deformation path is reduced to enumerating the variants for each parameter t_k. The set of functions $f(t)$ is defined by broken lines passing from point O to point B (Fig. 3, 4). An analytical solution to the optimal deformation problem of a plate is known (Tsvelodub 1987), which is represented by a dash-dot curve. Among the given possible variants, the optimal deformation path was found by the dissipation energy criterion in the bend region at $N = 2$, $M = 6$ and $N = 3$, $M = 9$ (solid bold line in Fig. 3, 4). As can be seen, the optimal solution obtained by the dynamic programming method approaches to the analytical curve and does not coincide with the straight line.

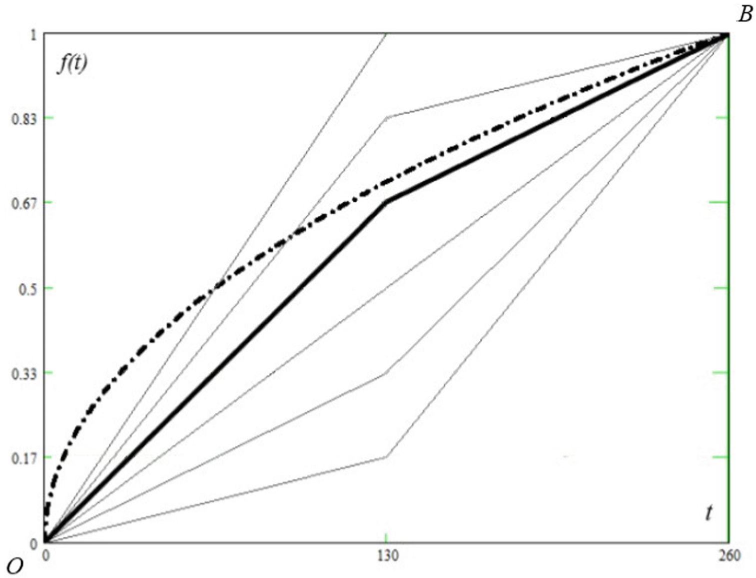

Fig. 3. Variants of trajectories and the optimal path of contact bodies motion at $N = 2$, $M = 6$. *Source*: developed and compiled by the authors

The calculation results that determine the optimal law of clamps movement of the stretch forming equipment for $N = M = 2$ are given in Fig. 5 (solid bold line is the optimal trajectory). As can be seen, the optimal trajectory provides pressing against the punch, unloading with straightening the panel and re-pressing against the punch with stretching. This stepwise stretch-forming scheme is consistent with the performance data (Miheev et al. 2011).

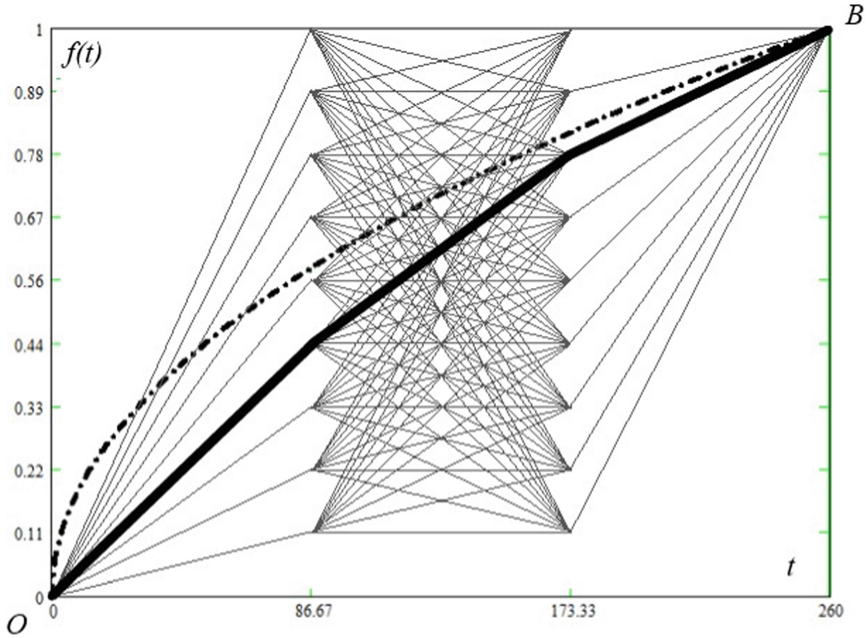

Fig. 4. Variants of trajectories and the optimal path of contact bodies motion at $N = 3$, $M = 9$. *Source*: developed and compiled by the authors

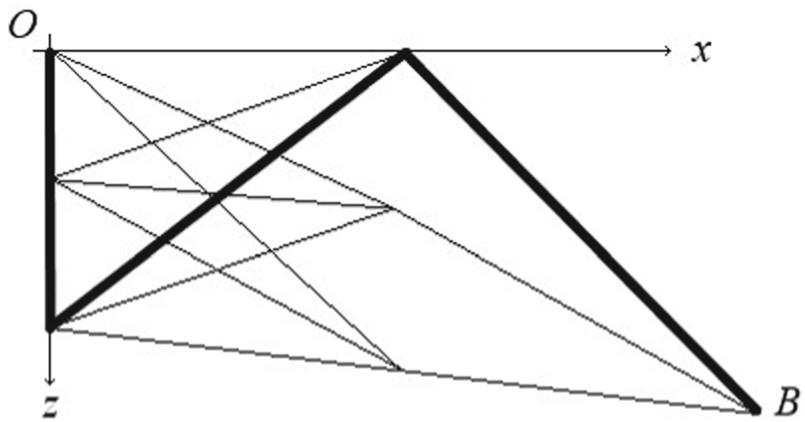

Fig. 5. Variants of trajectories and the optimal path of deformation according to the stretch forming technology at $N = M = 2$. *Source*: developed and compiled by the authors

4 Conclusion

Thus, the considered method for solving the optimal control problem leads to a sequence of auxiliary simple minimization problems. Since non-optimal trajectories are excluded in the calculation process, this method reduces the amount of calculations in comparison with full searching for all possible deformation paths. This method takes into account non-monotonic trajectories of movement with unloading areas.

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Improving the Organization of Working Space in Industrial Enterprises During the Era of Intelligent Machines

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Abstract. Trends in the formation of workspaces in various sectors of the economy, and how their organization reflects the transformation in culture, economy, construction technologies throughout the development of society. The appearance of workspaces was influenced by the changes that took place at the beginning of the 20th century in the economy, culture, and the structure of society—the emergence of gigantic "Fordist" industries and companies. In the era of intelligent machines, modern companies need to develop flexibility mechanisms that can respond to an increase in the range of products; use the latest methods of control, organization and division of labor, based on modern production technologies that meet the requirements of world standards.

In the conditions of activity expansion of the industrial enterprises, it is necessary to improve the process of production creation. The need for equipping manufactures with high-tech machines and equipment is growing, and a scientific approach to the formation of the working space is also important.

The purpose of this study is to analyze methods of organizing the workspace at industrial enterprises during the era of intelligent machines, as well as the development of a methodology for its improvement.

The research methodology includes theoretical and cognitive (formalization, ascent from the abstract to the concrete) and general logical (analysis and synthesis) methods.

As a result of the study, based on the work of domestic and foreign authors, the most popular tool for organizing the workspace was identified, and a methodology for improving it was developed.

One of the main elements of the production and technological structure of the enterprise in which the production process is carried out is the size of the scope of labor, which also depends on its nature. Combining the three basic links of this process allows achieving the main goal of production (Ergasheva 2017).

Keywords: Industry · 5S system · Workspace · Intelligent machines

JEL Code: O3 · M50

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1 Introduction

Workspace is understood as "a part of the territory of the workshop (site) where the contractor (s) performs a certain range of work on manufacturing products or servicing the process" (Ivanov 2019). Otherwise, the workplace is the area of production space in which the employee is located and works. The determination of equipment with technical and other means of production is carried out on the basis of established standards that allow solving the tasks set for employees.

The organization of the working space depends on the characteristics of work performed and the specifics of the production process (Fig. 1).

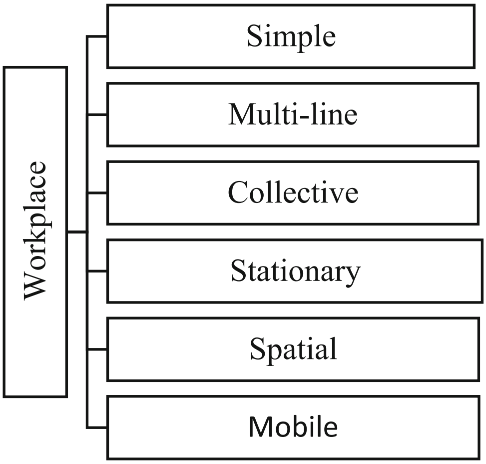

Fig. 1. Job classification

To organize the labor process in industrial production, it is necessary to create such a workspace that will enhance the content of work and protect the health of the employee. In this case, the method should be approved and a set of measures aimed at creating all necessary conditions at the workplace to be developed (Yashin et al. 2019).

Most industrial enterprises adhere to the principles of lean manufacturing, which is understood as "the concept of managing a manufacturing enterprise based on a constant desire to eliminate all types of losses" (Wumack and Jones 2011). It also means the involvement of all workers in the optimization processes of production and the greatest focus on consumers.

As part of lean manufacturing, one of the tools in the field of workspace organization is the 5S System. The purpose of this system is to develop the necessary measures for implementation of the production process, maintaining the place in the proper order, cleanliness, optimal use of time and energy (Veres et al. 2018) (Fig. 2).

Fig. 2. 5S workspace organization methodology

The process of implementing the 5 steps of this methodology is considered by a large number of domestic and foreign authors (Verna and Izzetdinova 2017). In recent years, this tool has become one of the frequently encountered areas of development of modern enterprises. Industrial enterprises that have been operating for many years under established rules and laws are making attempts to switch to new ways of optimizing work (Andryashina et al. 2020).

In the era of intelligent machines, new equipment is changing the face of industrial companies. In segments where high-performance solutions are used, any equipment must meet new standards. Therefore, using only a 5s system with its principles may not be sufficient (Chelnokova et al. 2017).

2 Materials and Method

Within the framework of the study using the tool "5S Systems" in the era of intelligent machines for the organization of the workspace was proposed a method of its improvement (Fig. 3).

At the first stage, "pilot" sites in each workshop should be identified. Then the stage is divided into two stages: a description of the place and a specification of the place of work. The first stage allows us to evaluate the overall picture of the workspace. This stage ends with the compilation of a table on the mechanism of work, work process diagrams within which parameters such as: tasks are determined; labor conditions; equipment facilities; material resources; standards; regulations. Since the analysis of the work process can

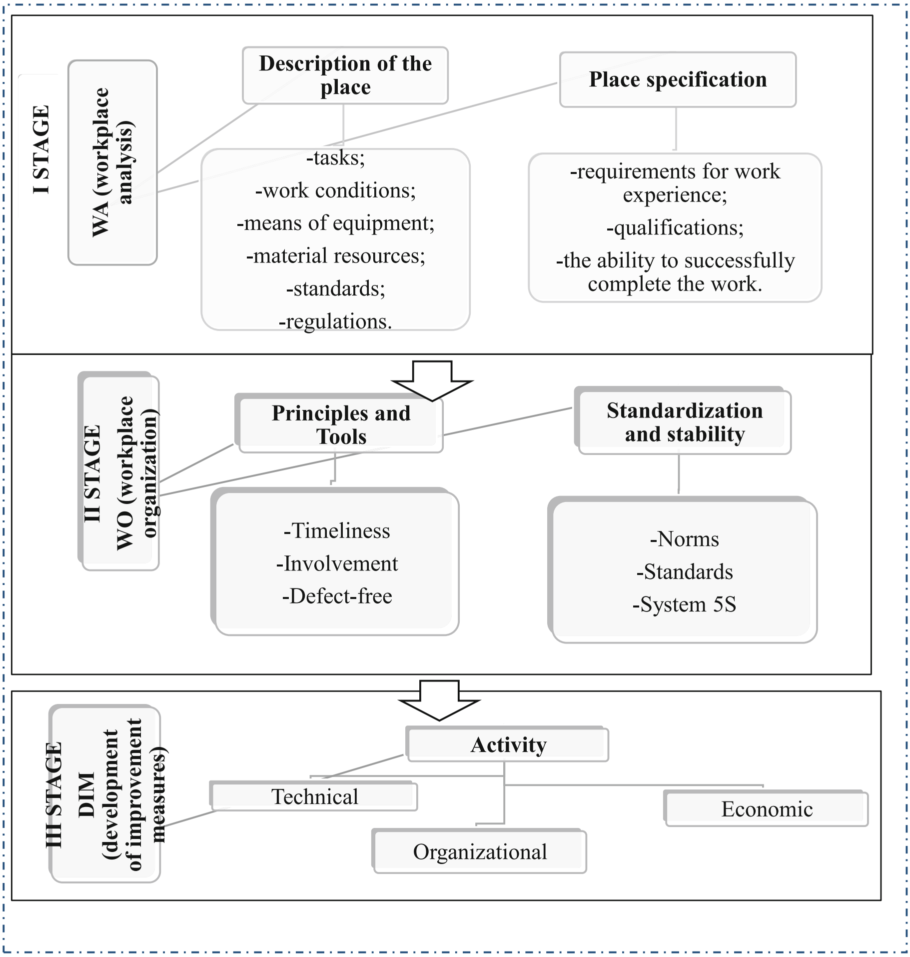

Fig. 3. Technique for improving the workplace

take a sufficiently long period of time and financial costs, it is necessary to develop a typical sample. The second stage of the first stage involves determining the specifics of a given workplace. To do this, establish requirements for work experience, qualifications, and the possibility of successful work.

Due to the fact that there is a need to timely identify all kinds of deviations from the previously planned goals, at the second stage it is necessary to determine the standards that ensure stability. To do this, it is recommended to use a tool to clean up the workplace, based on visual inspection (5S). The application of the principle of standardization is associated with the development and implementation of norms and standards for the implementation of a specific type of work. So, the principle of timeliness is characterized by the implementation of production processes at specific times. Many different tools contribute to this principle, such as workflow management, kanban information system, 5S, etc. The use of such tools will be able to reduce both material resources and time costs. There is a decrease in stocks.

At the third stage, it is necessary to develop various measures, as a result of which all jobs should be organized in accordance with established principles and standards. And by the end of the year, this practice will need to be distributed in all departments of the enterprise.

For this, it is necessary for the employee of a particular workplace to submit an action plan for their organization, with the possibility of describing the costs of additional equipment for sites that will be required to implement this plan. On the basis of the proposed activities, as well as taking into account the requests of other participants in the production process, it is possible to develop an action plan to improve the workspace (Kozlova et al. 2020a, b).

3 Results

The practical use and effectiveness of the proposed methodology are considered on the example of the enterprises of PJSC GAZ (hereinafter referred to as the Business Unit). In this work, the implementation of recommendations is presented fragmentarily, since the proposed activities are the central element in the transformation of production processes. Here, we focus on the third stage of the proposed methodology. Based on the analysis and organization of the workplace in workshop No. 7, problems such as:

- the presence of a large number of employees in operations;
- a high percentage of waste;
- high requirements for the processing result, based on quality standards of the automotive industry - Valeo, Ford, Renault, GM, etc.
- high probability of defects (bad weld cleaning);
- difficult working conditions (accidents, the appearance of the syndrome of "white fingers", low degree of sound insulation).

To eliminate these problems, it is not enough to use systems for restoring order at the workplace. It is necessary to use highly intelligent machines capable of carrying out the most difficult work without human intervention. In this regard, the company considered a proposal for the installation of an automatic cutting and grinding complex. P.S. Autogrinding Limited (PSAG), United Kingdom, for 20 years has been selling and servicing automatic cleaning systems Koyama, Japan, specially designed for the needs of the foundry industry. A unique robotic arm, a patented wiper blade with an angle of 115º, an operation and programming system designed for operators without any qualifications, allows PSAG to outperform its closest competitors in a 5: 1 ratio (Kozlova et al. 2020a, b).

This equipment will allow not only to improve the workspace but also to solve other tasks facing the business unit:

- increase profits. Foundries that have installed stripping complexes confirm that they have reduced costs by up to 50% compared to traditional stripping technologies and reduced personnel in stripping areas to 60%;

– increase productivity: Series 400 and 500 increase productivity by 3–4 times. 1 operator can serve up to 3 complexes. Effective solution for "bottlenecks" in cleanup;
– improve quality: Castings are processed by the program without deviations 23 h a day, 7 days a week, 365 days a year. The operator carries out maintenance on his own. There is practically no rejection of castings.
– become universal in changing production programs: new programs are usually programmed in less than 2 h. Changing a program takes less than 5 min.
– increase labor safety: eliminate the possibility of damage to the fingers and eyes of workers during the cleaning process, and also remove vibration

As a result of the problems identified, it was decided to purchase the Koyama 400 S/400 TT S automatic cutting and grinding complex (Fig. 4 and 5).

Fig. 4. Automatic grinding complex Koyama Series 400 TT S.

Fig. 5. Advanced workspace.

4 Conclusion

Analyzing the economic efficiency of using a highly intelligent machine in the production process, Table 1 was compiled.

Table 1. The economic efficiency of using a highly intelligent machine in the production process.

Annual savings	Measure unit	2018	2019	2020	2021	2022	Total
- costs of compensation for health damage	Thousand roubles	35	35	35	35	35	225
- expenses for the formation of a salary fund	Thousand roubles	37877.5	37877.5	37877.5	37877.5	37877.5	227,265
- expenses for current repair and maintenance of new equipment	Thousand roubles	–	–	–	(300)	(300)	(800)
Total savings on project production	Thousand roubles	37 913	37 913	37 913	37 613	37 613	245,629
General economic effect, with inflation	Thousand roubles	114,147	117,182	119,771	122,543	125,905	800,495

The implemented measure to improve the workspace can be further developed taking into account newly arising circumstances, but also supplemented, and improved.

As a result of the implementation of this measure, developed on the basis of the proposed methodology, workers are no longer affected by vibration processes. Due to the isolation of the cleaning process in an isolated chamber, the risk of injuries to the eyes and fingers was eliminated. The possibility of dust emission is practically excluded.

The degree of sound effects has decreased. Working conditions in the production process become more favorable for employees.

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Vibro-Abrasive Engineering of the High-Resource Titanium Aircraft Parts Surface

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Abstract. Purpose: capability check of removal the contact-precipitated iron from the samples surfaces of titanium alloy VT6ch after vibro-impact strengthening by steel balls using vibro-abrasive processing by ceramic granules.

Design/methodology/approach: the theory of resiliency and plasticity, of contact destruction mechanics positions are used in the article. Experimental researches were based on experiment planning theory, the data statistical processing methods, facilities of the computing engineering and software. The iron tracks presence on the samples surface was controlled by visual examination of the imposed on it filtration paper, moistened in solution, containing potassium ferricyanide. The iron tracks removal from the strengthened samples surface was conducted by two methods: by etching in nitric acid solution and vibro-abrasive processing by ceramic granules. The samples surface layer was corrosion resistance tested using the climate chamber; the surfaces were visually inspected after the test. The samples surface quantitative chemical composition was determined. The samples surface roughness was contact measured.

Findings: surface dressing by ceramic granules RXX 15/15 using process equipment Rosler during 80 и 160 min, as well as etching in nitric acid allows almost complete removal of iron embedded after vibro-impact surface strengthening. Single iron inclusions remain during any type of processing. According to the results of climatic tests of samples (strengthened, strengthened and scraped, strengthened and etched), there were no obvious signs of iron corrosion products.

Originality/value: preliminary studies of the effect of scraping on fatigue resistance have shown that vibro-abrasive processing (scraping) of strengthened samples improves fatigue resistance.

Keywords: Vibro-impact strengthening · Vibro-abrasive processing (scraping) · Tensile residual stress · Microfissures · Contact-precipitated iron · Fatigue resistance

JEL Code: D29 · L61 · L62 · O14 · O33

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1 Introduction

Currently in the global aircraft construction there is a tendency to increase the resource of designed aircraft while steadily reducing the weight of the airframe structure. Using of titanium alloys in the structural elements of the power set has important advantages over other structural materials: high specific fatigue resistance, significant mass efficiency of the structure, high corrosion resistance (Bakhmatov and Murav'ev 2017; Mouraviev et al. 2009). Fatigue resistance of chassis parts, massive beams, fittings, brackets, especially resistance to fatigue crack formation and stress corrosion can be radically increased by surface strengthening (Mouraviev et al. 2009).

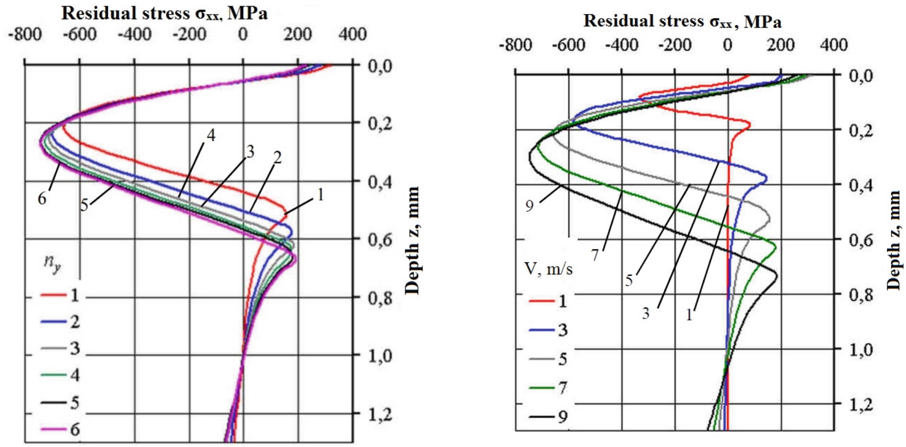
One of the technological methods of strengthening is vibro-impact treatment as a method of processing by means of surface plastic deformation. In vibro-impact processing, there is a distinction between vibro-impact surface strengthening with steel balls (when processing parts made of steel and titanium alloys) and vibro-impact abrasive treatment with granules (ceramic chips) for scraping (reducing roughness, rounding sharp edges, removing traces of previous processing).

At Russian aircraft manufacturing enterprises, vibro-impact surface strengthening occurs in accordance with the requirements of industry documents developed by JSC "National Institute of aviation technologies" (NIAT) and FSUE "All-Russian research Institute of aviation materials" (VIAM). In accordance with the regulatory documentation, vibration strengthening of titanium alloy parts is carried out in three stages: 1) preparation of the part surface by vibro-impact treatment with abrasive ceramic chips in order to reduce surface roughness, round off sharp edges and remove traces of previous technological operations (milling, turning or heat treatment); 2) creating a strengthening layer by surface plastic deformation using vibro-impact processing with steel balls; 3) removal of contact-precipitated iron from the surface of hardened parts by acid etching.

Surface plastic deformation processing creates residual stresses that are the result of two main factors – elastic-plastic deformation, due to which there are residual compressive stresses in the surface layer (Heilmann et al. 1983; Zangwill 1988, Kopylov 2011), and thermal processes that occur during impact, due to which residual tensile stresses occur at the surface (Fig. 1). It is noted that only compressive stresses improve the strength properties of parts (Zyk and Pleshakov 2016). In this case, the formation of a maximum of deformation stresses in the depth of the layer is observed. This is due to the fact that plastic deformation begins to develop in the region of maximum tangential stresses. This area is located at some depth from the surface. At the same time, plastic deformation of the area lying above, directly adjacent to the surface, begins later and proceeds less intensively (Papshev 1978).

Impact speed – 5 m/s, ball diameter – 6 mm, depending on the impact frequency

Ball diameter – 6 mm, depending on the impact velocity



а) б)

Fig. 1. Stress-strain state diagram example for titanium alloy VT-22 plate. *Source*: developed and compiled by Dyachenko et al. (2017)

It should be taken into account that when the balls are elastic-plastic embedded in the surface of the strengthened part, the formation of surface microfissures can be observed (Kolesnikov and Morozov 2007). Contact impact is accompanied by significant plastic deformations and radial microfissures are formed on the surface during dynamic contact loading. Radial microfissures do not go far into the material, but extend to a depth not exceeding the depth of the ball insertion. When a dynamic load is applied repeatedly (shock-cyclic loading), incomplete ring (segment) microfissures are formed between the radial ones. In the future, their closing leads to the formation of fragments (fragments of destruction).

A side effect of vibro-impact strengthening, resulting from the contact of steel balls with the surface to be processed, is the introduction of iron particles of working media (fragments, chips, etc.) into the surface layer of the part. The presence of contact-precipitated iron in the surface layer of a titanium alloy part negatively affects the corrosion resistance of the parts (Krupskiy and Altukhova 2019).

Taking into account all of the above, we get the following: the main part of the surface layer after strengthening by vibro-impact processing is characterized by compressive residual stresses with a favorable roughness structure and reduced porosity, but, along with this, in the upper part of the surface layer, which is insignificant in height, there are surface microfissures against the background of tensile residual stresses with contact-precipitated iron particles embedded in the surface layer. The presence of microfissures and iron particles reduces the effect of strengthening from surface plastic deformation and creates conditions for corrosion damage to titanium parts. To reduce negative effects, the existing production technology provides for the removal of traces of contact-precipitated iron by acid etching of workpieces after vibro-impact strengthening (PI 1.4.2188).

This work is devoted to determining the possibility of removing contact-precipitated iron after vibro-impact strengthening with steel balls from the surface of technological samples made of VT6ch alloy by vibro-abrasive scraping using ceramic granules. It is assumed that vibro-abrasive scraping contributes not only to the successful removal of iron traces, but also increases fatigue resistance, presumably due to the removal of the loosened upper layer, characterized by tensile stresses and incipient microfissures.

2 Methodology

Technological flat samples of the corset type made of a deformable high strength titanium alloy VT6ch were studied (OST 1 90013). The blanks of samples with a 6 mm thickness were cut in the height-share direction from a plate with a thickness of 40 mm on a bandsaw machine. The cut-out blanks were subjected to rough milling till the size of 170 × 38 mm a, then grinding in thickness in the size of 3.1 mm. The R30 concentrators were cut on a wired electrical discharge machine. The machined samples were subjected to incomplete vacuum annealing at a temperature of 850 °C for 2 h.

Before strengthening, all samples were vibro-abrasive scrapined by Rxx 15/15 ceramic granules using the Rosler R550/4000 unit for 80 min.

Vibro-impact strengthening of samples KT-1 ÷ KT-6 and KT-8 ÷ KT-11 was carried out by a VUD-4000 unit, using opening of unbalance at an angle of 110° (the vibration amplitude according to a vibroscope was ~4.5 mm).

To determine the optimal time of vibro-impact processing, the intensity of processing during surface plastic deformation was determined using the VUD-4000 unit in accordance with the production instruction (PI 1.4.2207) based on the control plates deflections measurement. When working out the modes of vibro-impact processing, a tool with samples fixed to it in a horizontal position and control plates in 4 directions (top, bottom and sides) is installed in the VUD-4000 container). The working medium had access to the samples and control plates from all sides. Vibro-impact strengthening of technological samples was taked using the VUD-4000 unit for 40 min. The deflections of the control plates were 0.95…1.53 mm with an average value of 1.18 mm, which meets the requirements of the production instruction (PI 1.4.2188).

The presence of iron traces on the samples surface was checked by applying a closely-fitting filter paper soaked in a solution containing potassium ferrocyanide in accordance with the requirements of the production instruction (PI 1.4.2188).

The quantitative chemical composition of the sample surface was obtained using a Hitachi SEM S-3400N scanning electron microscope with an EDX Thermo energy dispersive analysis attachment.

After vibro-impact strengthening and checking for iron traces, some of the samples were subjected to various technological operations presented in a Table 1.

The samples were tested for the surface layer corrosion resistance in a climate chamber for 6 cycles.

To assess the surface quality of samples subjected to various types of processing, a study of their roughness was performed on the Mitutoyo Surftest SJ-210 device with a cutoff of 0.8 mm and a track length of 4 mm.

Table 1. List of samples processed after strengthening

Sample designation	Processing
KT-1, KT-2, KT-3	Vibro-abrasive scraping with Rxx 15/15 ceramic granules on the Rosler R550/4000 unit for 80 min
KT-4, KT-5, KT-6	Vibro-abrasive scraping with Rxx 15/15 ceramic granules on the Rosler R550/4000 unit for 160 min
KT-8, KT-9	Etching in nitric acid solution 60 min

Source: developed and compiled by the authors

To determine the effect of processing technology on fatigue resistance, technological samples were tested for low-cycle fatigue. Fatigue strength tests were performed on the LFV 63-HH unit under the following conditions: uniaxial tension with a sinusoidal loading cycle; cycling frequency of 8 Hz; maximum stress of 810 MPa; coefficient of asymmetry of 0.1.

3 Results

The test samples were fixed in the container of the VUD-4000 with a horizontal arrangement of their flat surfaces. From the deflection of the control plates, it was determined that the intensity of processing the surface of the samples facing the bottom of the container (the lower side of the sample) is approximately 1.2 times higher than the intensity of processing the surface of the upper side of the samples. As a result, the intensity of the iron contact precipitation of on the lower side of the samples is higher than on the upper side. In this regard, the presence of iron was monitored on one of the sides that were subjected to the highest intensity of processing.

The presence of traces of iron on the surface of the samples was checked by applying a closely-fitting filter paper soaked in a solution containing potassium ferrocyanide (3 g/l) and sodium chloride (10 g/l) for 15 min. After washing the strengthened samples and checking for iron content, ferrous contamination of the surfaces of all samples was found: if iron is present, blue prints are formed on the paper.

Control Precipitated Iron on the Samples Surface After Vibro-Abrasive Scraping and Chemical Etching. Surface cleaning of KT-1 ÷ KT-3 samples was maked by vibro-abrasive scraping using the Rosler r550/4000 unit and Rxx 15/15 granules for 80 min, KT-4 ÷ KT-6 samples processing for 160 min, with controlling of the layer to be removed thickness (Fig. 2).

According to the results of the samples control after vibro-abrasive scraping, the presence of the iron traces on the samples surface KT-1 ÷ KT-3, which have been processed for 80 min (Table 2).

Removal of the iron traces from the surface of strengthened samples KT-8 and KT-9 was carried out by etching in a solution containing 400 g/l of nitric acid for 1 h with an intermediate control for iron content after 30 min. According to the results of the samples

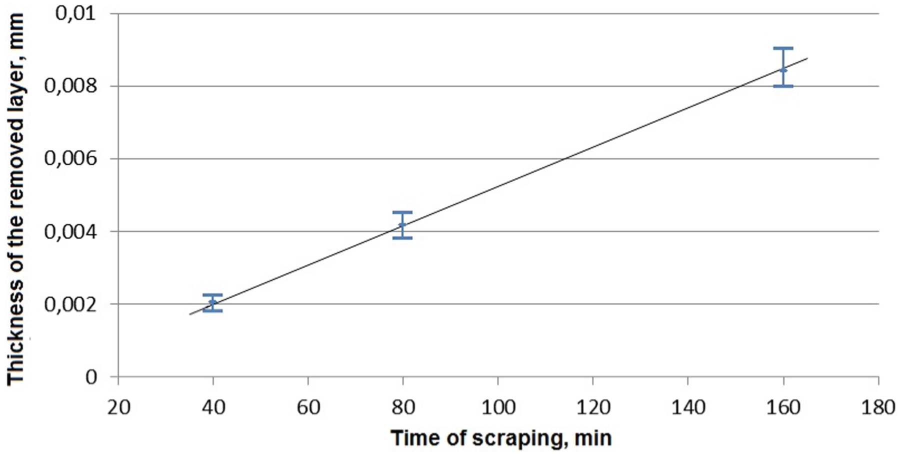
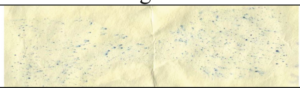
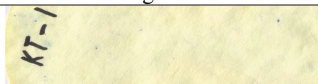
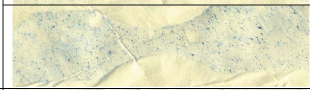
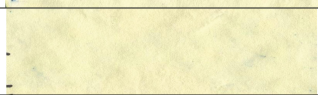
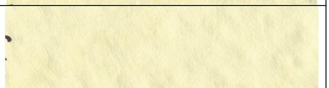


Fig. 2. The removed layer thickness on the time dependence during vibro-abrasive surface scraping of VT6ch alloy parts using ceramic granules. *Source*: developed and compiled by the authors

Table 2. Results of checking the iron presence on the samples surface after vibro-abrasive scraping by ceramic granules using Rosler unit

Sample designation	Scraping duration	After strengthening and rinsing with water	After scraping by ceramic granules using Rosler unit
KT-1	80 min		
KT-2			
KT-4	160 min		
KT-5			

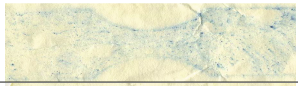
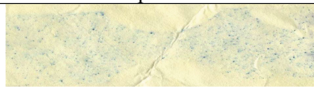
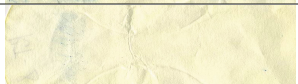
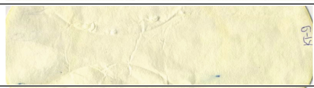
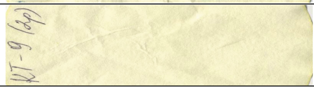
Source: developed and compiled by the authors.

control that were etched for 1 h, the presence of the iron traces on the KT-8 sample was revealed (Table 3).

The results of studying the quantitative chemical composition of the samples surface (Fig. 3) allow a comparative assessment of the removing iron from the samples surface efficiency.

After scraping with ceramic granules on the samples surface KT-1 and KT-5, iron was revealed in an amount of up to 2% of the other elements content on the surface of these samples. In this case, after the chemical removal of iron from the surface of the

Table 3. Results of monitoring the presence of iron on the samples surface after nitric acid solution etching

Processing	Sample KT-8	Sample KT-9
After strengthening and rinsing with water		
After nitric acid solution etching for 30 min		
After nitric acid solution etching for 60 min		

Source: developed and compiled by the authors.

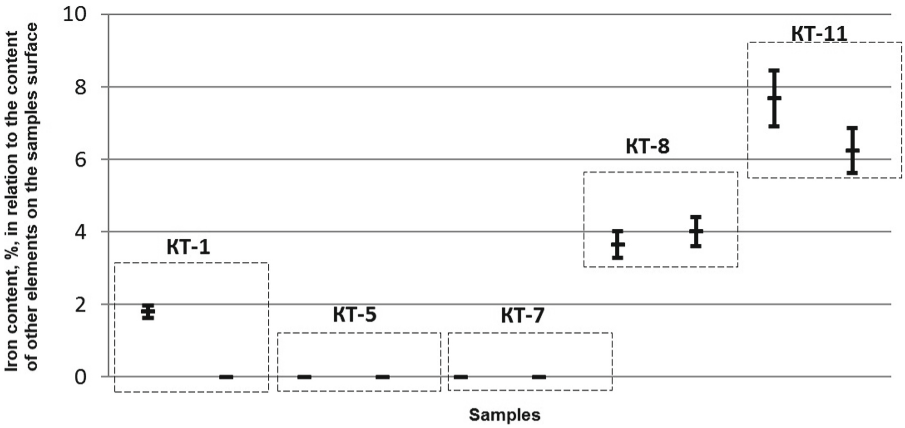


Fig. 3. Iron content, %, in relation to the content of other elements on the samples surface. Source: developed and compiled by the authors

KT-8 sample, the iron content is recorded in an amount of about 4% of the content of the remaining elements on the surface of this sample. The surface of the KT-7 sample, which has not undergone vibro-impact strengthening, is practically free of iron. The surface of the KT-11 sample, hardened by vibro-impact processing, for which no traces of iron were removed, contains this element in an amount of about 7% of the content of other elements on the sample surface.

It turns out that most of the contact- precipitated iron is removed by scraping (Table 2) and treatment with an acid solution (Table 3), but even after these procedures, locations (for example 1 and 2 in Fig. 4) are found on the surface with traces of iron.

When examining such traces under magnification, it was found that these traces are iron particles depressed to a depth of 6 μm - fragments of round steel balls. Finely dispersed iron particles are easily removed with an acid solution, and larger particles that have broken off from the steel balls are introduced when the working bodies hit

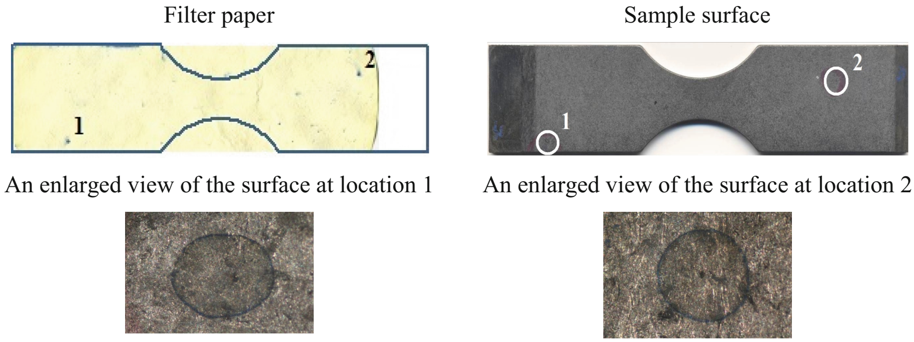


Fig. 4. Iron traces on the surface of the KT-3 sample. *Source*: developed and compiled by the authors

the surface to be treated. Such embedded particles are poorly removable with an acid solution, but are removed during surface scraping.

The results of climate tests were evaluated by visual inspection (GOST 9.311): on the samples KT-1 ÷ KT-6, dark spots are weakly expressed; on the samples KT-8 ÷ KT-11, dark spots are clearly visible. The identified spots are characteristic of deposit from condensate drying.

After wiping the samples with a soaked in a solvent of 96% ethyl alcohol cotton pad, the following was observed:

– on the samples of KT-1 ÷ KT-6, the deposit from condensate is completely removed;
– on the samples KT-8, KT-9, the deposit from condensate is erased, and insignificant spots remain on the samples surface, which are visible only at a certain angle in reflected light. While checking deposit on a cotton disc with a solution according to paragraph 9.8 of the instruction (PI 1.4.2188), the presence of iron was not detected;
– on the samples KT-10, KT-11, the deposit from the condensate is erased, minor spots remain on the samples surface, which are visible only at a certain angle in reflected light. While checking deposit on a cotton disc with a solution according to paragraph 9.8 of the instruction (PI 1.4.2188), was found single traces of iron.

Fatigue Test. The product service life is affected by the surface layer condition characterized by cold-worked structure, compressive residual stresses, and roughness parameters.

The surface roughness control revealed: for sample surfaces scraped by ceramic granules after the strengthening, the value of the parameter Ra more, on average, 0.2 µm, and the parameter RSm less, on average, 150 µm values of the parameters Ra and RSm, respectively, for the sample surfaces obtained strengthening by steel balls without subsequent mechanical processing while the scraping (Fig. 5).

There were differences in the roughness parameters values of the samples upper and lower sides.

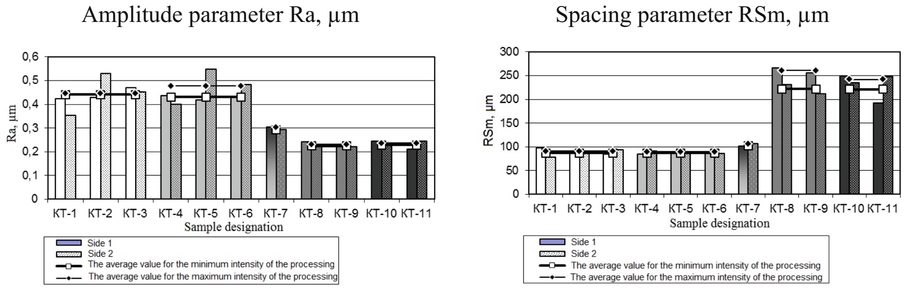


Fig. 5. Roughness of the sample's surfaces. *Source*: developed and compiled by the authors.

Preliminary studies of the effect of scraping on fatigue strength have shown that after vibro-abrasive scraping of strengthened samples, the number of cycles to fracture increases (Table 4, Fig. 6).

Table 4. Results of fatigue test

Sample designation	Sampling	Scraping	Strengthening	Processing	Environmental test	Ra, µm	Number of cycles to fracture
KT-1	Milling; Grinding; Electrodischarge machining; Annealing	For 80 min using Rosler	For 40 min using VUD-4000	Scraping for 80 min using Rosler	+	0.38	23 613
KT-2					+	0.46	21 675
KT-3					+	0.45	20 373
KT-4				Scraping for 160 min using Rosler	+	0.40	21 059
KT-5					+	0.48	21 938
KT-6					+	0.46	19 855
KT-8				Nitric acid solution etching	+	0.23	20 425
KT-9					+	0.22	19 207
KT-10				—	+	0.23	20 289
KT-11				—	+	0.21	18 723

Source: developed and compiled by the authors

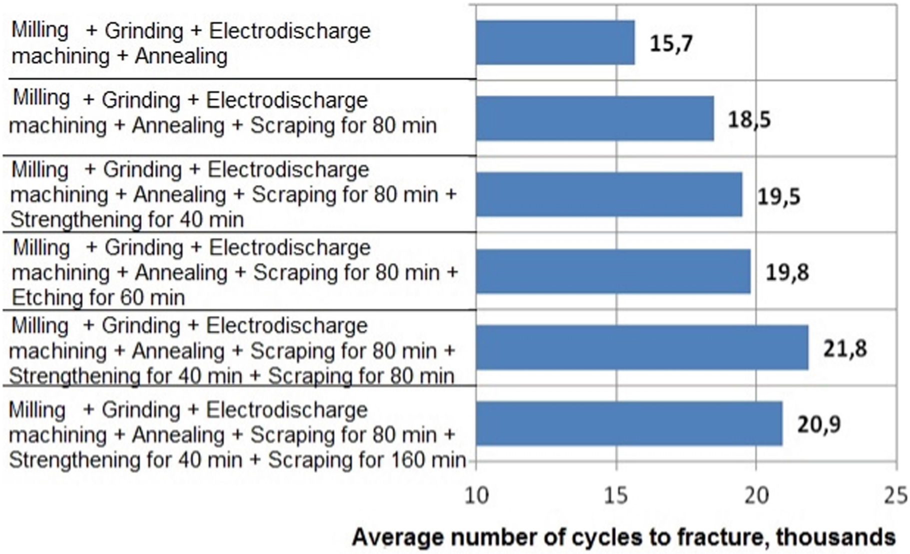


Fig. 6. Effect of processing VT6ch alloy samples for fatigue resistance. *Source*: developed and compiled by the authors.

4 Conclusions

1. The vibro-abrasive scraping by ceramic granules of titanium parts surface undergone vibro-impact surface strengthening by steel balls allows to remove contact- precipitated iron from the surface layer of the part, and allows to exclude the etching in nitric acid from the technological process.
2. The machining conditions of the vibro-abrasive scraping by ceramic granules of titanium parts for removing contact-deposited iron must be selected so that the thickness of the removed layer does not exceed the values of the surface layer thickness with residual tensile stresses. For titanium alloy VT6ch recommended value of the removed layer is 4.5…6 μm.
3. Non-removable iron particles are fragments of balls with volume indicators exceeding the values of the layer to be removed thickness. These fragments are not removed during chemical processing.
4. According to the results of climatic tests of samples (strengthened, strengthened and scraped, strengthened and etched), there were no obvious signs of iron corrosion products. The appearance does not deteriorate. The presence of iron traces is determined only when using analytical chemical reagents with high sensitivity.
5. Preliminary studies of the scraping effect to fatigue resistance have shown that vibro-abrasive scraping of strengthened samples increases fatigue resistance. This effect can be explained by removing the surface layer containing microfissures and affected by residual tensile stresses.
6. Vibro-abrasive engineering of the high-resource titanium aircraft parts surface's hardened by vibro-abrasive strengthening, allows to obtain satisfactory corrosion

properties without the use of chemical etching and increase the products service life characteristics.

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Numerical Calculation of the Heat Sink Parameters of the Shell Turbine Vanes at the Modeling of the Heat-Protective Coating with a Different Number of Layers

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Abstract. Purpose: The purpose of the research was to calculate the parameters of the heat sink of shell turbine vanes with a multi-layer heat-protective coating, dependence plotting of cooling parameters on the coating layers number for a given long-term strength of the shell material.

Design/methodology/approach: The research methodology is based on the application of the Fourier differential equation of thermal conductivity, boundary conditions of heat transfer, and the use of the developed calculation program to solve the nonlinear heat transfer problem.

Findings: The results of changes in heat exchange parameters are presented, namely: temperature fields on the boundary surfaces washed by cooling and heating gas flows, cooler flow rate, heat transfer coefficients, and the width of the heat sink channel depending on the number of layers.

Originality/value: The results obtained will allow reducing the consumption of the cooler when choosing the number of layers of heat-protective coating and changing the geometry of the cooling channels. Applying the results of calculating the cooling parameters will allow you to control the flow of the cooling process.

Keywords: Cooling · Thermal protection · Multi-layer · Mass flow · Long-term strength

JEL Code: L61 · O31 · O33 · C61 · C63

1 Introduction

Today, in scientific research related to turbine engineering, the issues of heat transfer are becoming more widespread by complex mathematical models that take into account the stress, thermal state of elements, as well as aspects of optimization. Shell elements such as rotor vanes, nozzle vanes and combustion chambers are often used as the main components of turbomachines. Optimization of their thermal protection is one of the most promising areas in view of increasing the temperature conditions of their operation. Despite a fairly large number of studies of multilayer heat-insulating coatings,

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namely Trushin (2000), Chernyshev and Ivanov (2007), the issues of combining external thermal protection and internal cooling remain poorly studied. It should be noted that mathematical models of the thermal state of turbomachine elements, as well as aspects of numerical modeling, taking into account the peculiarities of heat transfer in the cooling systems of turbine blades and combustion chambers, were investigated in the works: Trushin and Trushin (2000), Chernyshev and Ivanov (2007), Chernyshev and Ivanov (2006), Mokretsova and Zuev (2012), Bushuev and Timofeev (2012), Mayorova et al. (2016), Mubojadzhjan et al. (2005), Bychkov et al. (2014), Betsofen et al. (2014), Belykh (2018), Andrianov (2019), Stankevich (2018, 2019), Burenin (2018, 2019), Chiu et al. (2016), Liu and Han (2008). Approaches to assessing the strength resource for calculating the stress state of turbomachine elements are proposed in the works of the authors Andrianov (2019), Grinkrug (2019).

Most of the work related to the provision of thermal protection of the shell elements of turbomachines is focused on the study of the thermal state, namely: calculation of temperature fields, identification of zones of increased temperature load under given conditions of heat supply. In recent years, various software packages ANSYS, NASTRAN have become widespread in the study of the thermal state of elements of turbomachines.

2 Materials and Method

The purpose of the research was to carry out numerical calculations of the parameters of heat removal of shell turbine vanes with a multilayer heat-shielding coating, to determine the dependence of the cooling parameters on the number of coating layers at the required thermal strength of the shell. The study examines the dependence of two systems of thermal protection of shell elements of turbomachines: an internal cooling system and a multilayer thermal coating. The shell blade is subjected to the thermal effect of an external heating gas flow with a given distribution of heat transfer coefficients on the heat supply surface and a change in the shell thermal state according to the data of Andrianov (2019).

On the basis of the developed mathematical model and the numerical calculation method in the works of Andrianov (2019), a series of numerical experiments was carried out using the example of deflector blade in order to determine the minimum number of layers at which an equal-strength thermally stressed state of the turbine vane shell would be ensured. The temperature field T_a on the most thermally loaded surface of the shell remains constant, since it satisfies the required minimum long-term strength. The minimum flow rate was determined according to the relation obtained in the work of Andrianov (2019):

$$G_r^{\min} = \begin{cases} \dfrac{\int \alpha_h \left(T_h - \sum\limits_{i=0}^{n} \sum\limits_{k=0}^{m} a_{ik} ([n]\overline{\sigma})^i \tau^k \right) \Delta z ds}{c \Delta T_r}, T \in U_1 \\ \dfrac{\int \alpha_h (T_h - T^*) \Delta z ds}{c \Delta T_r}, T \in U_2 \end{cases}.$$

$$U_1 = \left\{ T_* \le T \le T^*, T \le \sum_{i=0}^{n} \sum_{k=0}^{m} a_{ik} \sigma^i \tau^k, \sum_{i=0}^{n} \sum_{k=0}^{m} a_{ik} ([n]\overline{\sigma})^i \tau^k \le T^*, [n]\overline{\sigma} \le \sigma \right\},$$

$$U_2 = \left\{ T_* \le T \le T^*, T \le \sum_{i=0}^{n} \sum_{k=0}^{m} a_{ik} \sigma^i \tau^k, T^* \le \sum_{i=0}^{n} \sum_{k=0}^{m} a_{ik} ([n]\overline{\sigma})^i \tau^k, \, [n]\overline{\sigma} \le \sigma \right\},$$

where $[n]$ – the safety factor, $\overline{\sigma}$ – the stress intensity, T^*, T_* - the maximum and minimum allowable temperatures of the heat exchange system.

On the enclosing surface of the heat-shielding layer in contact with the heat-supplying gas flow, the law of distribution of heat transfer α_h and the thermal state of the gas medium T_h are assumed to be known. The calculation of the temperature fields was carried out according to the differential equation of Fourier

$$\lambda_{l_k} \frac{\partial^2 T_{l_k}}{\partial r^2} + \frac{\partial \lambda_{l_k}}{\partial r} + \frac{\partial T_{l_k}}{\partial r} + \frac{\lambda_{l_k}}{r} \frac{\partial T_{l_k}}{\partial r} + \lambda_{l_k} \frac{\partial^2 T_{l_k}}{\partial s^2} + \frac{\partial \lambda_{l_k}}{\partial s} \frac{\partial T}{\partial s} - \frac{\lambda_{l_k}}{r} \frac{\partial r}{\partial s} \frac{\partial T_{l_k}}{\partial s} = 0,$$

$$\alpha_h \big(T_{s_n} - T_h\big) = -\left(\lambda_{l_n} \frac{\partial T_{l_n}}{\partial r} \right)\Bigg|_{r=r_{s_n}},$$

$$\alpha_r \big(T_{s_b} - T_r\big) = \left(\lambda_{l_0} \frac{\partial T_{l_0}}{\partial r} \right)\Bigg|_{r=r_{s_b}},$$

$$T_{l_{k-1}}\big|_{r=r_{s_{k-1}}} = T_{l_k}\big|_{r=r_{s_{k-1}}},$$

$$\lambda_{l_{k-1}} \frac{\partial T_{l_{k-1}}}{\partial r}\Bigg|_{r=r_{s_{k-1}}} = \lambda_{l_k} \frac{\partial T_{l_k}}{\partial r}\Bigg|_{r=r_{s_{k-1}}}, \quad k = 1, \ldots, n.$$

$$T_{l_0}\big|_{S_a} = T_a,$$

where $0 \le s \le L$, T_{l_k} – temperature of k-th shell layer; $\lambda_{l_k} = a_k + b_k T_{l_k}$ – thermal conductivity coefficient of k-th shell layer, a_k, b_k- the material constants are the input characteristics in the work, T_r – coolant temperature.

3 Results

Using the developed program in the work of Andrianov (2019), calculations of the parameters of the heat sink of the vane shell were performed. As an example, the calculation was performed for the 100-h strength of the LC-VI material. It is worth noting that any time mode of long-term strength can be considered as input data. Input data for the calculation: the distribution of heat transfer coefficients from the heater, the temperature of the heating gas medium, the geometry of the turbine vane, the stress state of the shell from the action of centrifugal and gas forces, and the characteristics of the shell material are described in the work of Andrianov (2019) and due to the large number of input data are not given here.

Figures 1, 2, 3, 4, 5, 6, 7 and 8 show the results of calculating the average values of the heat exchange process parameters for the most thermally loaded root section when changing the number of layers of the heat-protective coating of the turbine vane shell with a multi-layer heat-protective coating. Figure 1 shows the change in temperature fields in the layers of the heat-protective coating based on the specified thermal distribution on the shell layer in contact with the coating and satisfying the condition of long-term strength. Figure 2 shows the change in the optimal total refrigerant flow rate for cooling the entire shell, which provides the maximum increase in the thermal state of the shell to the limit values according to the specified long-term strength.

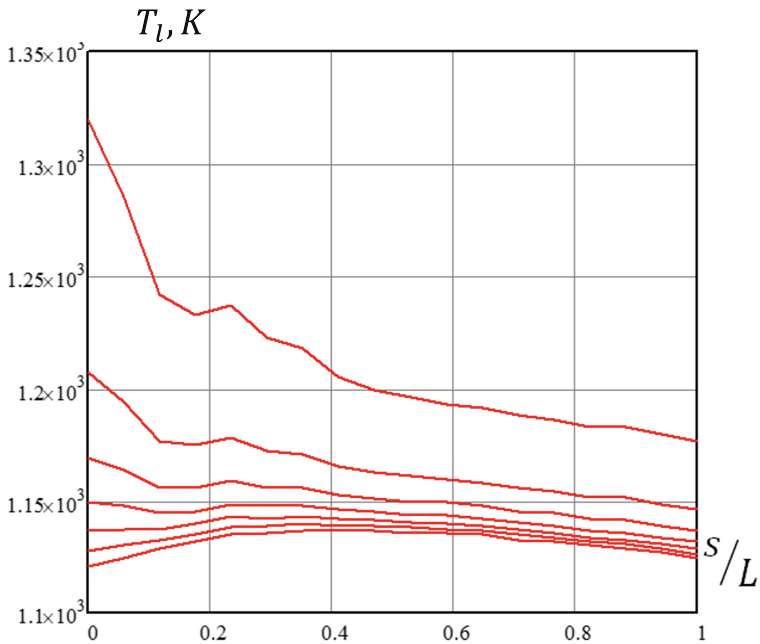

Fig. 1. Temperature change on the surfaces of a 6-layer heat-protective coating *Source*: calculated and compiled by the authors

For heat-protective coatings from 8 or more layers, according to calculations, it is impossible to realize the temperature configuration T_a, since the condition $T_a < T_b$ will be violated, where T_b is the temperature field on the cooling surface, as a result, the temperature field T_a will be lower than the calculated values according to the criterion of long-term strength, which in practice will be accompanied by unnecessary and inappropriate cooling.

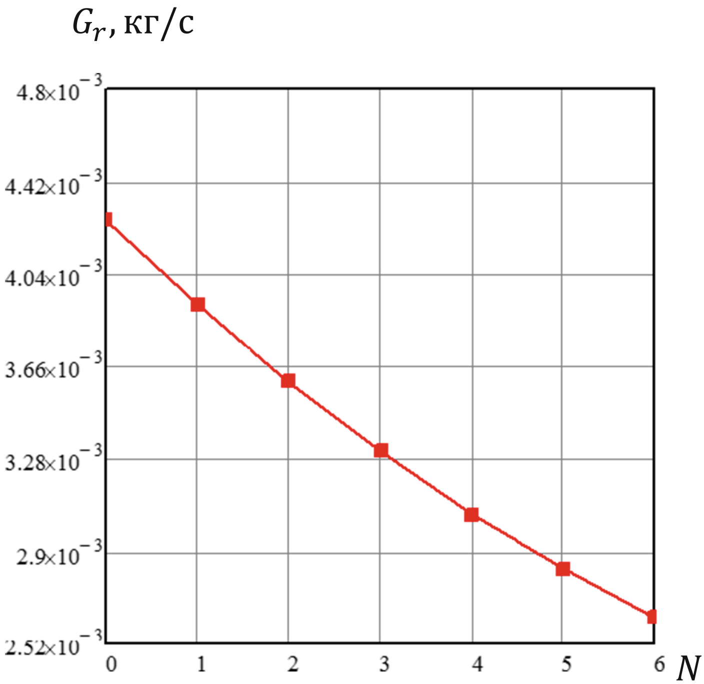

Fig. 2. Distribution of the optimal total mass flow of the cooler when choosing a different number of layers of heat-protective coating. *Source*: calculated and compiled by the authors

Figures 3, 4, 5, 6, 7 and 8 show the change in the average values of the heat sink parameters as the quantity increases for these areas, the long-term strength margin will be higher than the set value and the temperature field T_a will be lower than the values defined by the flow minimization condition.

Figures 5, 6, 7 and 8 show the results of calculating the average speed and heat transfer in the cooling channel when the long-term strength is satisfied.

The width of the heat sink channel is the most important parameter from a practical point of view, since it allows you to implement in practice this uneven cooling process of the multilayer shell in the channels, due to the uneven stress state and heat supply. The change in the geometric parameter largely depends not on the actual values of the refrigerant flow rate, heat transfer from the heater, but on the gradient of these values along the flow path of the refrigerant: how much the stress state changes along the flow path, changes in the heat transfer coefficients, and the speed of the cooler.

The calculation results are presented for 6 layers of the heat-protective coating of the shell, for which the flow rate of the cooler provides the maximum thermal state while satisfying the long-term strength. Under the conditions of this numerical experiment, increasing the number of layers more than 6 is not rational, since it will lead to a decrease in the thermal state of the T_a shell on the most stressed surface, as a result, the long-term strength reserve will not be fully realized.

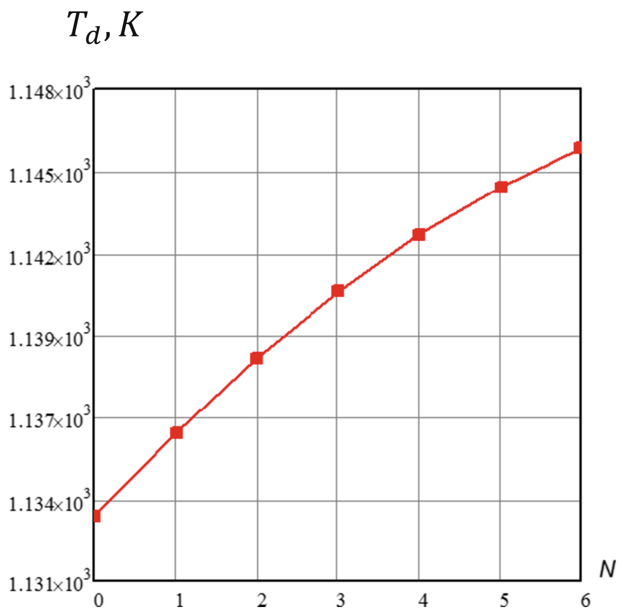

Fig. 3. Change in the average temperature of the heat-Receiving surface when the number of layers changes. *Source*: calculated and compiled by the authors

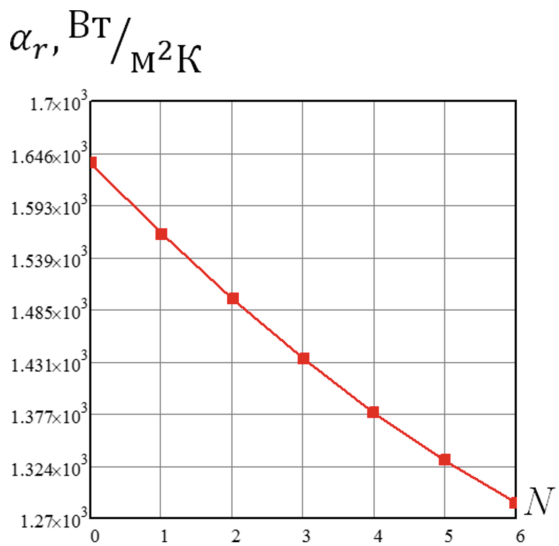

Fig. 4. Change in the average heat transfer of the cooler as the number of layers increases. *Source*: calculated and compiled by the authors

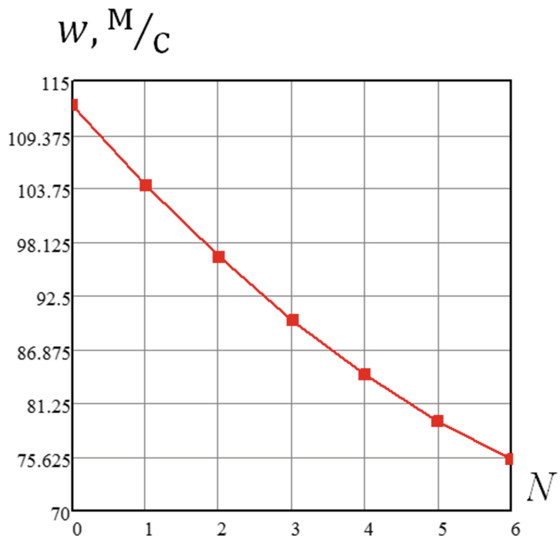

Fig. 5. Change of average speed of a cooling channel surface by changing the number of layers. *Source*: calculated and compiled by the authors

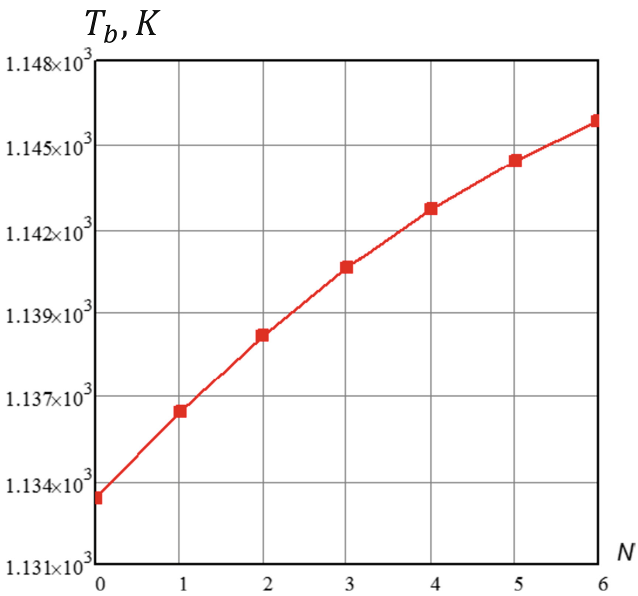

Fig. 6. Change in the average temperature of the cooled surface of the shell when the number of layers changes *Source*: calculated and compiled by the authors

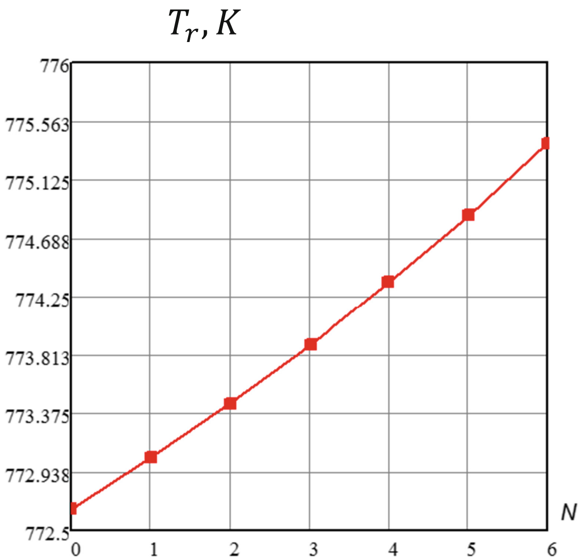

Fig. 7. Change in the average temperature of the cooler in the channel when changing the number of layers. *Source*: calculated and compiled by the authors

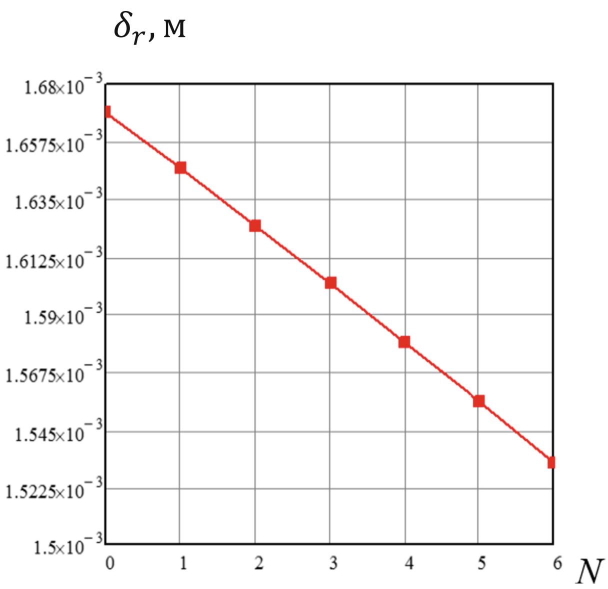

Fig. 8. The average width of the cooling channel internal heat sink *Source*: calculated and compiled by the authors

4 Conclusion

The results obtained will allow reducing the cooler consumption when choosing the number of layers of heat-protective coating to increase the vane temperature to the maximum permissible values. The application of the results of calculating the cooling parameters will make it possible to control the flow of the heat removal process by changing the geometry of the cooling channels of the shell blades of turbomachines with a multi-layer thermal insulation coating. The novelty of the work lies in the curves obtained on the basis of numerical experiment for the dependence of the cooling parameters on the number of layers, at which the temperature of the shell is increased to the limit values according to the long-term strength.

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The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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The Mathematical Model of the Stamp Material Redistribution Using Uniform Bar Structures

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Abstract. Purpose: The purpose of scientific research is to develop a mathematical model for optimizing the stamp topology used in metal forming processes. In the work, it was necessary to determine the volume of the inner region of the stamp as the target optimization function, optimization variables, which are the skeleton, replacing the stamp topology.

Design/methodology/approach: As a method of material redistribution, it is proposed to replace the stamp volume with a system of rods of various widths determined by the required volume change. The dependences of changes in the geometry of the core frame of the stamp on the coefficient of volume reduction are obtained. The mathematical formulation of the optimization problem is presented, the condition for the invariance of the stamp base is given, the loading areas, the stored boundary areas are defined.

Findings: Using the obtained relations, the dependences of the coefficient of reduction of the topology volume, the number of rods approximating the inner region of the stamp, and also the geometric characteristics of the rods, namely, the height and cross section, are presented.

Originality/value: Using the presented patterns will significantly optimize the material costs for the manufacture of forming stamps from polymer materials using additive technologies, as well as develop an algorithm and software code for creating software models of stamps of a minimized volume. The results of the study will allow us to reconsider the approach to choosing the shape of the stamp, reduce the cost of its manufacture.

Keywords: Stamp · Topological optimization · Pressure processing · Volume minimization · Rod approximation

JEL Code: C61 · C63 · L61 · L64 · O31 · O33

1 Introduction

The issues of efficient redistribution of structural material are becoming more and more relevant with the transition of the production sector towards optimization. Increasingly, an excessive margin of strength and rigidity of the structure is impractical from the position of its force loading.

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This issue is particularly important in the field of metal forming, where the main tool is dies, namely: dies, punches, reverses, etc. In most cases, they are used for forming sheet products, which are widely used in the fields of aircraft construction, mechanical engineering, automotive, and shipbuilding. Most of the research is aimed at developing methods for calculating thin-walled shell elements, in particular, this includes the work of Burenin and Tkacheva (2019), Grinkrug (2016), etc. However, stamping tools are considered as rigid bodies, made of metals and are solid. In connection with the development of 3D prototyping methods, the question of replacing metals with polymers is becoming more and more common.in a few studies, the question of the stress-strain state of polymer dies has been considered. However, there are practically no fundamental studies related to the development of methods for minimizing the volume of stamp material. Problems of metal processing by pressure were considered in scientific works: Stankevich (2017), Filippova et al. (2016), Kononov and Aksenov (2016), Petrov (2019), Borovikov et al. (2019), Maltsev and Maximov (2019), Kurkin et al. (2019), Belykh (2019), Andrianov (2019), Stankevich (2019).Questions of numerical modeling were considered in the works: Grinkrug (2016), Andrianov (2016), Safonov and Jones (2017), Fenci et al. (2017). Questions of approximating the topology of stamps are presented in the works of Maryin (2010, 2011).

The purpose of this study was to develop a model for minimizing the volume of the stamp topology using rod structures. For this purpose, it was proposed to replace the stamp area with a skeleton with a uniform distribution of vertical rods and determine the dependence of the stamp volume on the geometric characteristics of these rods.

Most dies operate under surface vertical loading, so the main carrier of optimization elements will be a vertical rod of various cross-sections, the dimensions of which are determined by the rigidity and stability of the structure during loading.

2 Materials and Method

The purpose of this study was to develop a model for minimizing the volume of the stamp topology using bar structures. It was proposed to replace the stamp region with a skeleton with a uniform distribution of vertical rods and determine the dependence of the stamp volume on the geometric characteristics of these rods. Most dies work under conditions of surface vertical loading, therefore, the main carrier of the optimization elements will be a vertical rod of various cross sections, the dimensions of which are determined by the rigidity and stability of the structure during loading.

The volume of the stamp with some given cross-sectional shape is considered. We assume that the boundary surface of the stamp is defined by the function $z = \Gamma(x, y)$.When optimizing the volume, we define a fixed region that remains unchanged - the boundary stamp surface of a given thickness, where the boundary conditions are specified: loading and fastening (Fig. 1):

$$S = S_p + S_u + S_f,$$

where $S_p = S_p^*$ is the loading region where the surface load is specified, $S_u = S_u^*$ - the area of consolidation, where restrictions are set on the movement, $S_f = S_f^*$ - region free from boundary conditions.

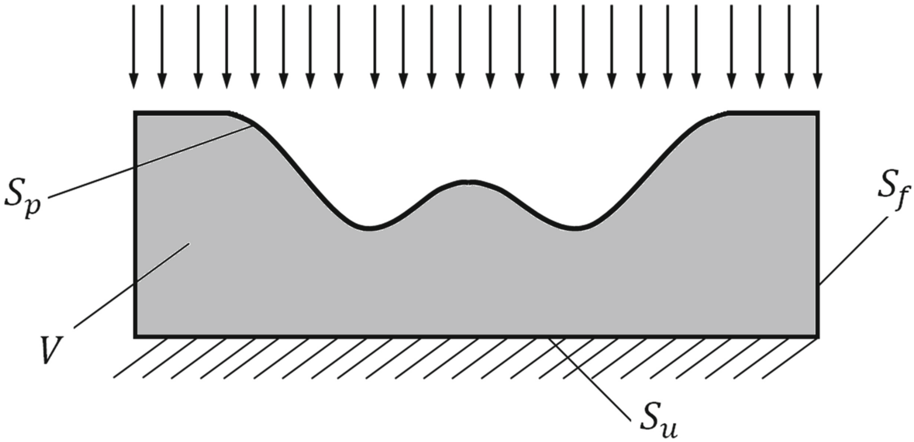

Fig. 1. Problem statement of the stamp topology optimization. *Source*: developed and compiled by the authors

Consider optimizing the stamp topology using bar structures. To this end, we represent the volume of the stamp in the form of the rod sum with different heights, determined by the boundary surface geometry, and with given section shape. Since most stamps are exposed to vertical loads, the stamp volume can be represented as a system of alternating $(n + 1)$ stored and n removable vertical rods (Fig. 2).

Define a given coefficient of the material volume reduction

$$k^* = \frac{V_{\min}}{V_0} \tag{1}$$

where V_0 is the initial stamp volume, $V_{\min}$ is the minimized stamp volume.

The initial volume of the stamp is the sum of the fixed boundary volume $V_b = \text{const}$, which is associated with fastenings and loads and the volume V_{in} of the stamp inner region, which is optimized:

$$V_0 = V_b + V_{in} \tag{2}$$

We determine the volume decreasing coefficient k of the optimized region inner stamp topology for a constant boundary according to the condition:

$$k^* V_0 = kV_b + V_{in} \tag{3}$$

3 Results

Then the objective function of the material volume optimizing can be represented as

$$V_{in}(\Delta x, \Delta y) \to \min_{\substack{\Delta x \in X \\ \Delta y \in Y}}$$

where Δx, Δy – geometric parameters of the rod system.

The minimum volume of the stamp topology is determined

$$V_{\min} = V_{in}\left(\Delta x^*, \Delta y^*\right) + V_b$$

We denote by even numbering the numbers of the stored stamp elements: $i = 0, 2, \ldots, 2k, \ldots, 2n$, and by odd numbering, the deleted elements $i = 1, 3, \ldots, 2k - 1, \ldots, 2n - 1$. A total of N elements $N = 4n - 1$. Then the volume of the topology of the stamp inner region of the can be represented as

$$V_{in} = \sum_{j=0}^{n}\sum_{i=0}^{n} z_{2i+\frac{1}{2},2j+\frac{1}{2}}\Delta x\Delta y + \sum_{j=1}^{n}\sum_{i=1}^{n} z_{2i-\frac{1}{2},2j-\frac{1}{2}}\Delta\overline{x}\Delta\overline{y} \to \min \tag{4}$$

where $\Delta x, \ \Delta y$ are the geometric parameters of the rectangular section of the retained rod, $\Delta\overline{x}, \ \Delta\overline{y}$ are the geometric parameters of the rectangular section of the removed rod, $z_{i+\frac{1}{2},j+\frac{1}{2}} = \Gamma\left(x_{i+\frac{1}{2}}; y_{j+\frac{1}{2}}\right)$ is the height of the i rod.

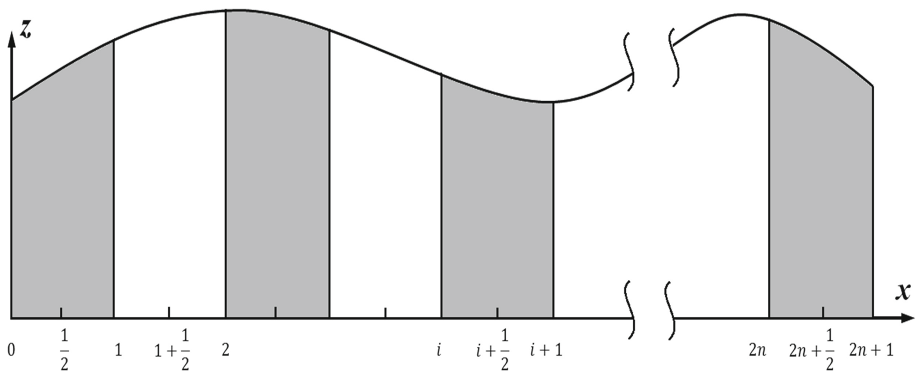

Fig. 2. Stamp topology optimization by bar structures. *Source*: developed and compiled by the authors

Consider the volume of the optimized stamp inner region, taking into account the optimization coefficient

$$(k-1)\sum_{j=0}^{n}\sum_{i=0}^{n} z_{2i+\frac{1}{2},2j+\frac{1}{2}}\Delta x\Delta y + k\sum_{j=1}^{n}\sum_{i=1}^{n} z_{2i-\frac{1}{2},2j-\frac{1}{2}}\Delta\overline{x}\Delta\overline{y} = 0 \tag{5}$$

where $z_{i,j} = \Gamma\left(x_i; y_j\right)$ – coordinates of the surface of the stamp.

We impose conditions for maintaining of the stamp base total area of the

$$((n+1)\Delta x + n\Delta\overline{x})((n+1)\Delta y + n\Delta\overline{y}) = L_x L_y \tag{6}$$

where L_x is the length of the surface of the stamp base, L_y is the width of the surface of the stamp base.

Define the ratio of the cross section geometric parameters for saved and deleted rods:

$$\frac{\Delta y}{\Delta \overline{y}} = \frac{\Delta x}{\Delta \overline{x}} = m \tag{7}$$

The areas X and Y of the rod geometric parameters variation are determined

$$X\colon\ \Delta x_{\min} \le \Delta x \le \Delta x_{\max} < \frac{L_x}{n+1}$$

$$Y\colon\ \Delta y_{\min} \le \Delta y \le \Delta y_{\max} < \frac{L_y}{n+1}$$

Taking into account the relations (6), (7), we transform the boundary condition for the stamp base relative to the retained rod geometric parameters:

$$(n + nm + 1)\Delta x = L_x$$

$$(n + nm + 1)\Delta y = L_y$$

We substitute the relation (7) into the Eq. (5) for the optimized region of topology:

$$(k-1)\sum_{j=0}^{n}\sum_{i=0}^{n} z_{2i+\frac{1}{2},2j+\frac{1}{2}} + km^2\sum_{j=1}^{n}\sum_{i=1}^{n} z_{2i-\frac{1}{2},2j-\frac{1}{2}} = 0 \tag{8}$$

We consider the sums of z-coordinates of the preserved rods entering into Eq. (8) with a fixed parameter j:

$$\sum_{i=0}^{n} z_{2i+\frac{1}{2},j} = z_{\frac{1}{2},j} + z_{2+\frac{1}{2},j} + \ldots + z_{2n+\frac{1}{2},j} \tag{9}$$

where

$$\begin{cases} z_{\frac{1}{2},j} = \Gamma\left(\frac{\Delta x}{2}; j\right) \\ z_{2+\frac{1}{2};j} = \Gamma\left(\Delta x(1+m) + \frac{\Delta x}{2}; j\right) \\ \ldots \\ z_{2i+\frac{1}{2};j} = \Gamma\left(i\Delta x(1+m) + \frac{\Delta x}{2}; j\right) \\ \ldots \\ z_{2n+\frac{1}{2}} = \Gamma\left(n\Delta x(1+m) + \frac{\Delta x}{2}; j\right) \end{cases}$$

Excluding m, taking into account the replacement (7), we represent the system (9) in the form:

$$\begin{cases} z_{\frac{1}{2},j} = \Gamma\left(\frac{\Delta x}{2}; j\right) \\ z_{2+\frac{1}{2};j} = \Gamma\left(\Delta x\left(\frac{L_x - \Delta x}{n}\right) + \frac{\Delta x}{2}; j\right) \\ \ldots \\ z_{2i+\frac{1}{2};j} = \Gamma\left(i\left(\frac{L_x - \Delta x}{n}\right) + \frac{\Delta x}{2}; j\right) \\ \ldots \\ z_{2n+\frac{1}{2},j} = \Gamma\left(L_x - \frac{\Delta x}{2}; j\right) \end{cases}$$

For removed rods, the sum of z-coordinates is determined with a fixed parameter j according to the relations:

$$\sum_{i=1}^{n} z_{2i-\frac{1}{2},j} = z_{2-\frac{1}{2},j} + z_{4-\frac{1}{2},j} + \ldots + z_{2n-\frac{1}{2},j}$$

where

$$\begin{cases} z_{2-\frac{1}{2},j} = \Gamma\left(\frac{(L_x - \Delta x)}{2n} + \frac{\Delta x}{2}\right) \\ z_{4-\frac{1}{2},j} = \Gamma\left(\frac{3(L_x - \Delta x)}{2n} + \frac{\Delta x}{2}\right) \\ \ldots \\ z_{2i-\frac{1}{2},j} = \Gamma\left(\frac{(2i-1)(L_x - \Delta x)}{2n} + \frac{\Delta x}{2}\right) \\ \ldots \\ z_{2n-\frac{1}{2},j} = \Gamma\left(\frac{(2n-1)(L_x - \Delta x)}{2n} + \frac{\Delta x}{2}\right) \end{cases}$$

We solve the system with respect to the unknown Δx:

$$(k-1)n\Delta x \sum_{i=0}^{n} z_{2i+\frac{1}{2}} + k(L - \Delta x(n+1)) \sum_{i=1}^{n} z_{2i-\frac{1}{2}} = 0 \tag{10}$$

where $$\sum_{i=0}^{n} z_{2i+\frac{1}{2}} = \Gamma\left(\frac{\Delta x}{2}\right) + \Gamma\left(\Delta x\left(\frac{L - \Delta x}{n}\right) + \frac{\Delta x}{2}\right) + \ldots$$
$$+ \Gamma\left(i\left(\frac{L - \Delta x}{n}\right) + \frac{\Delta x}{2}\right) + \ldots + \Gamma\left(L - \frac{\Delta x}{2}\right),$$

$$\sum_{i=1}^{n} z_{2i-\frac{1}{2}} = \left(\frac{(L - \Delta x)}{2n} + \frac{\Delta x}{2}\right) + \Gamma\left(\frac{3(L - \Delta x)}{2n} + \frac{\Delta x}{2}\right) + \ldots$$
$$+ \Gamma\left(\frac{(2i-1)(L - \Delta x)}{2n} + \frac{\Delta x}{2}\right) + \ldots + \Gamma\left(\frac{(2n-1)(L - \Delta x)}{2n} + \frac{\Delta x}{2}\right)$$

Thus, the solution of this Eq. (10) allows us to obtain the dependence of the cross-sectional width Δx of the rod of the saved stamp topology depending on the reduction coefficient of the stamp volume $0 < k < 1$. The form of the equation and the choice of method is determined by the function of the boundary surface of the stamp $z = \Gamma(x, y)$. The choice of the step of uniform distribution of the rod structures when optimizing the topology with the removal of rods of width $\Delta\bar{x} = m\Delta x$ is determined from the conditions of operation of the rods under loading conditions according to the criteria of stability and strength.

4 Conclusion

Using the obtained relations, the dependences of the coefficient of reduction of the topology volume, the number of rods approximating the inner region of the stamp, and also the geometric characteristics of the rods, namely, the height and cross section, are presented. Using the presented patterns will significantly optimize the material costs for the manufacture of forming stamps from polymer materials using additive technologies, as well as develop an algorithm and software code for creating software models of stamps of a minimized volume. The results of the study will allow us to reconsider the approach to choosing the shape of the stamp, reduce the cost of its manufacture.

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The study was carried out using the equipment of the Center for Collective Use “New Materials and Technologies” on the basis of KnASU.

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Removing Weld Defect Causes in Aviation Stainless Steel Piping Elements

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Abstract. Purpose: The purpose of this study is to improve the quality of permanent stainless-steel connections produced by manual gas tungsten arc welding.

Design/methodology/approach: The impact of welding conditions was studied for the ranges of welding amperage and shielding gas (argon) consumption, and electrode grind angle recommended by the operating procedure (PI 1.4.75 - 2000). The quality of the completed welds was determined and evaluated by visual and radiographic inspection. Ferrite content in the weld metal was measured with a ferrite meter; mechanical properties were determined with the Instron universal testing machine and the Shimadzu microhardness tester for standard coupons; principal alloying element distribution across the cross section of the weld was identified with the Hitachi scanning electron microscope.

Findings: The study statistically analyzed defects in the tungsten inert gas welds (TIG, Procedure 141) of structural elements made of aviation light-gauge stainless steel. The TIG welding conditions were found to affect the risk of internal defects, structure, and mechanical properties of stainless steel welds. A linear regression model capturing a correlation between weld strength and the TIG welding conditions was generated. Recommendations for the fabrication of welded piping elements from aviation stainless steel were made.

Originality/value: Correlations between weld strength and the TIG welding conditions that can optimize process parameters were identified through experiments. Selection principles for welding conditions to develop structural fabrication processes for light-gauge stainless steel were recommended.

Keywords: Austenitic steel · Welds · Microstructure · Properties · Quality

JEL Code: L610 · L950

1 Introduction

Russian and foreign researchers have dedicated a considerable amount of scientific papers to improving the quality of permanent stainless-steel connections produced by welding. A lot of studies have been conducted, and many publications focus on improving the quality of stainless-steel welds. However, practice shows that in a given facility, the

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defect rate can be quite high, which can be explained by the specific nature and features of such facility (Adaskin 2004; Solntsev and Pryakhin 2007; Gulyaev 1986; Kolachev et al. 1999).

Although austenitic stainless steel is usually measured to be easy to weld, some weldability issues may arise if appropriate precautions are not taken (Lippold and Koteki 2011). Crystallization and segregation cracking, solid-state cracks, intergranular and stress corrosion, the incompatible chemical composition of the weld for the base metal, oxidation of the outer and inner surface of the weld, internal defects such as porosity and lack of penetration may occur (Bashkov et al. 2015; Murav'ev 2011).

The above-mentioned defects in most cases are caused by the inadequate choice of the filler material, arc welding technique and conditions, and failure to comply with production practices. To compensate for the elements prone to burn, a filler wire with a higher content of these elements is recommended (Titov 2004). The chemical composition of the filler wire should also be taken into account when controlling the microstructure (Masakov et al. 2011). The article (Lippold and Koteki 2011) describes and analyzes several structural diagrams for predicting the structure of the weld metal for stainless steel; the 1956 and 1973 DeLong diagrams and the diagrams developed from them are widely used nowadays in the international welding research practice by the US Welding Research Council WRC-1988 and WRC-1992 (Kakhovsky 1968).

It has been experimentally shown that the welding conditions can impact the structure and therefore the physical and mechanical properties (Yu et al. 2018) and the resistance to hot cracking (Taban et al. 2014). It is necessary to choose the appropriate welding technique and conditions to ensure good shielding of molten metal from air and prevent loss of anticorrosive metal properties due to fast chromium oxidation (Masakov et al. 2011). It is also necessary to provide additional backing of the weld from air. The oxide layer on the inner surface of critical structures is not acceptable (Masakov et al. 2011; Sarayev et al. 2008). The article (Redchitz et al. 2002) contains data about the effect of welding conditions on the corrosion characteristics of the weld metal. But even the appropriately selected filler material and welding conditions do not always mean high weld quality. Preparing the filler and the metal to be welded before welding is of crucial importance. Shearing and grinding of the edges to be welded should be done in such a way as to avoid overheating and prevent the introduction of impurities that will negatively affect the weld quality (Titov 2004).

2 Materials and Method

The subject of this study was the welds and heat-affected zone in the pipe (Ø50 × 1 mm) and plate (150 × 80 × 1 mm) coupons made of the 12Kh18N10T nickel chrome steel by manual TIG welding with the Kemppi MasterTig AC/DC 3500W welder and the TTK 350W welding torch. The filler wire is Sv-06Kh19N9T with a diameter of 1.6 mm. The connection type is S00001-1620, OST 1 02617-87. The pipe coupons were welded in 4 segments, and the plate coupons were welded without splitting into segments (Table 1).

Weld geometry was measured with the VIK-1 visual and dimensional inspection kit. The FILIN-240/225.FP8.C-ARM X-ray television system was used to inspect for internal defects as per Procedure PI 1.4.415-92 and GOST 7512-82. The welds were

Table 1. Experimental program

Pipe coupons			
Experiment number	Welding amperage, A	Electrode grind angle, deg.	Backing
1	60	45	No
2	60	45	Argon shielding
3	50	45	Argon shielding
4	70	45	Argon shielding
5	60	35	Argon shielding
6	60	55	Argon shielding
7	50	35	Argon shielding
8	70	55	Argon shielding
Plate coupons			
Experiment number	Welding amperage, A	Travel speed, mm/min	Backing
1	50	240	Argon shielding
2	60	280	Argon shielding
3	70	320	Argon shielding
4	50	240	Argon shielding
5	50	320	Argon shielding
6	70	240	Argon shielding
7	70	320	Argon shielding

subjected to static tensile tests with the INSTRON 3382 universal testing machine (USA); the coupon type is XII, GOST 6996-69. The BLUHLER EcoMet 250 Pro grinding and polishing machine was used to prepare the coupons for microstructural testing with the NikonEclipse MA200 inverted microscope. The Hitachi S 3400-N scanning electron microscope (SEM) (Japan) was used for chemical analysis of the welds. Vickers microhardness of various weld regions was measured with the DuraScan EmcoTest microhardness tester as per GOST 2999-75. Ferrite phase content in the weld metal was measured with the MF-51NTs ferrite meter as per GOST R 53686-2009. The Multiple Regression module was used for Spirin's regression analysis in Statistica 10 (2004).

3 Results

To determine the impact of the TIG welding parameters on weld quality when welding aviation stainless steel pipe welds, all pipe mock-up coupons were externally examined and measured. The results are shown in Fig. 1.

The data in Fig. 1 show that the best welding conditions for fixed welds in aviation stainless steel pipes are the conditions corresponding to coupon 2, 5, and 8.

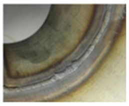
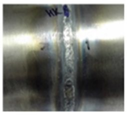
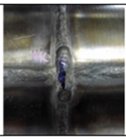
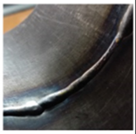
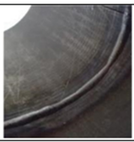
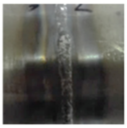
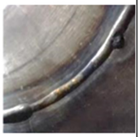
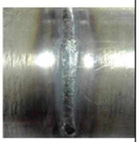
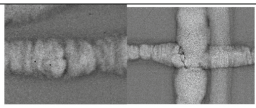
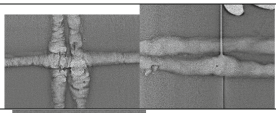
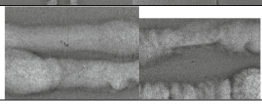
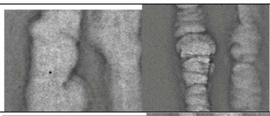
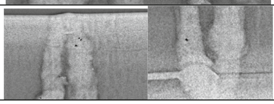
Condition number	Appearance		Visual inspection result and measurements for external defects (if any)
	Weld root	Weld reinforcement	
1			Severe oxidation of weld root; coarse, unevenly spaced ripples. Cold laps on the inner surface of the pipe at the weld root.
2			Inconsistent weld geometry but within the allowable range of variability.
3			Lack of root penetration. Undercut. Inconsistent weld geometry. The weld has external defects that need to be reworked and rectified.
4			Poor weld geometry (root concavity). Significant variations in the weld geometry. The weld has external defects that need to be reworked and rectified.
5			Poor weld geometry (root concavity). Cold laps at the weld root. Weld geometry is not consistent over the entire length but within the allowable range of variability.
6			Inconsistent weld geometry. The weld has no serious external defects, however, weld geometry is not consistent over the entire length; there are areas where the weld reinforcement is equal to zero or concave, which is not acceptable.
7			Lack of root penetration. Deviation in weld geometry. The weld has external defects that need to be reworked and rectified.
8			Minor variability of weld geometry at the stop area that does not need to be rectified or reworked. The weld does not have any external defects that need to be rectified or reworked.

Fig. 1. Results of external examination of welding coupons for first series of experiments. *Source*: developed and compiled by the authors

The results of the X-ray TV inspection are shown in Table 3. A histogram describing the occurrence of internal defects for the relevant welding conditions is generated. When compiling the histogram, the total beads welded in the relevant welding conditions were considered: 5 coupons were welded in each welding conditions; each weld was welded in 4 segments, thus, the number of beads welded in each welding conditions is 20.

Table 2. Radiographic inspection results for coupons welded in different welding conditions

	Radiographs of typical defects	Identified defects	Accepted/rejected
		Scattered porosity: 5; Linear porosity: 1; Clustered porosity: 1; Lack of root penetration: 4	Rejected
		Scattered porosity: 2	Rejected
		Scattered porosity: 2; Linear porosity: 1; Lack of root penetration: 8	Rejected
	-	Not identified	Accepted
	-	Not identified	Accepted
		Scattered porosity: 2; Lack of root penetration: 2	Rejected
		Scattered porosity: 1; Clustered porosity: 1; Lack of root penetration: 4	Rejected
	-	Not identified	Accepted

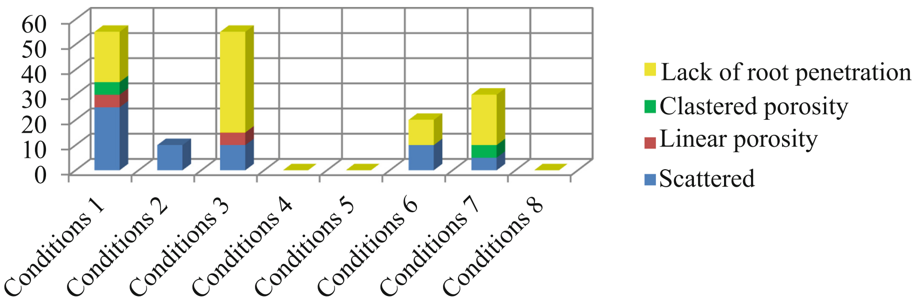


Fig. 2. Effect of welding conditions on defect type. *Source*: Correlations found by the authors

The data in Table 2 and Fig. 2 show that the best welding conditions are conditions 4, 5, and 8. Based on the visual and dimensional inspection information, the welding conditions that ensure defect-free welds with a stable and consistent weld geometry are conditions 5 and 8. The poorest conditions are conditions 1, 3, and 7 where the risk of internal defects exceeds 25%. It should also be highlighted that the main defects are porosity (of different types) and lack of root penetration.

The mechanical test results for all coupons are listed in Table 4. The data in Table 4 show that the poor welding conditions are conditions 1, 3, and 7. For these conditions, strength in static tension is less than the strength of the basic metal by more than 10%, which is not acceptable according to codes and standards. Strength of the coupons welded in other conditions meets codes and standards, however, only two conditions can be considered good: conditions 5 and 8 that ensure connections with a strength similar to the basic metal.

Table 3. Static tensile test results

Welding conditions number	Strength, MPa	Average strength, MPa	Area of failure	Strength compared to BM, %	Opinion about test results
1	605–634	620	WAZ	−17.3	Inadequate conditions
2	701–718	710	BM	−5.33	Adequate conditions
3	624–652	638	WAZ	−14.93	Inadequate conditions
4	695–704	700	BM	−6.67	Adequate conditions
5	715–738	727	BM	−3.07	Adequate conditions
6	662–707	685	BM	−8.67	Adequate conditions
7	633–684	659	BM	−12.13	Inadequate conditions
8	754–783	767	BM	+2.27	Adequate conditions

Note: 1. WAZ is the weld-affected zone; BM is the base metal; 2. Tensile strength for BM is determined experimentally and is 750 MPa.

To determine the impact of the welding heat cycle on the structure and characteristics of the plate coupon butt welds, a metallographic examination was conducted.

The subject of the metallographic examination was the representative weld zones: the weld, fusion zone, heat-affected zone (HAZ), and base metal.

Based on the measurements of the representative zone area size (Fig. 2) and the largest grain size in the fusion zone, Table 5 was compiled (Fig. 3).

Table 4. Microstructure analysis results for welding coupons

Coupon number	Welding conditions		Area, mm^2			Maximum grain size in fusion zone, mm
	I, A	υ, mm/min	Columnar grain zone	Fusion zone	HAZ	
1	50	240	0.5	0.17	0.71	0.025
2	60	280	0.35	0.145	0.76	0.021
3	70	320	1.36	0.126	0.72	0.02

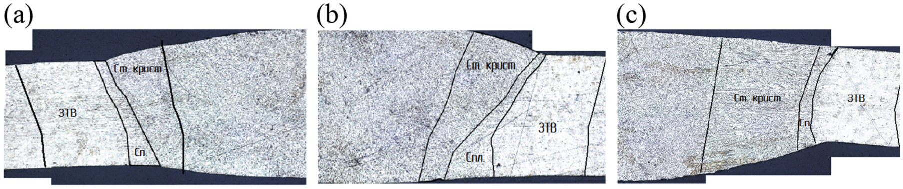


Fig. 3. Representative regions of (a) first coupon, (b) second coupon, (c) third coupon. *Source*: Images and their processing made by the authors

The data in the table and figure show that coupon 3 has a better structure (the smallest fusion and heat-affected zone and the smallest grain size in the fusion zone).

Based on the chemical analysis of the coupons, the charts showing the distribution of the main alloying elements across the weld cross section are generated (Fig. 4).

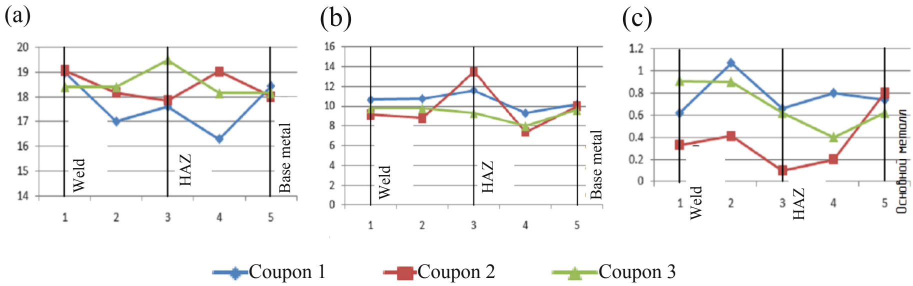


Fig. 4. Alloying element distribution in coupons (a) chrome; (b) nickel; (c) titanium. *Source*: Correlations found by the authors

Figure 4 shows that the average alloying element content in all welds is similar to or exceeds the content of these elements in the base metal. This indicates that the weld was produced with both sufficient shielding and backing. Welding with a higher amperage and travel speed results in a quite vigorous diffusion, which leads to matching chemical composition and reduces segregation. Weld in coupon 3 has a more uniform distribution of alloying elements across its cross section.

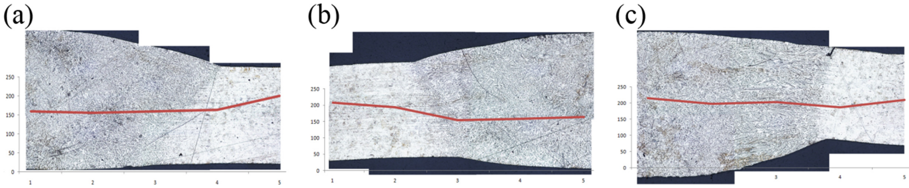


Fig. 5. Microhardness distribution across weld cross section: (a) first coupon, (b) second coupon, (c) third coupon.

The data in Fig. 5 show that coupon 1 and 2 have a heterogeneous strength: Mechanical properties of the weld and the heat-affected zone are worse than that of the base metal. Coupon 3 has a higher and more uniform microhardness across the weld cross section.

Ferrite phase content in the austenitic steel weld metal is an indicator of weld metal crystallization behavior and its associated cracking resistance.

Table 5. Average ferrite content in welding coupons

Weld number	Welding conditions		Average ferrite content, %
	Amperage, A	Travel speed, mm/min	
1	50	240	2.58
2	70	240	2.52
3	50	320	3.00
4	70	320	2.7

Based on ferrite content in the weld metal and its correlation to the welding conditions, it is clear that the minimum travel speed contributes to a higher ferrite content, and the effect of welding amperage is the opposite. Such results can be explained by a change in the base metal and filler metal ratio in the weld in different welding conditions.

The Multiple Regression module has shown a strong and statistically significant correlation between strength and welding amperage and travel speed described by the equation:

$$Y = 397 + 3{,}05 \cdot X1 - 015 \cdot X2,$$

Where X1 is welding amperage and X2 is travel speed.

4 Conclusion

1. Argon backing is a prerequisite to producing a high-quality weld. Without any backing, the risk of internal defects, even with the correct remaining process parameters is 55%, which is not acceptable. The static tensile strength of a weld made without

backing is also not adequate and lower by more than 17% than that of the base metal. As an electrode grind angle decreases, arc penetration increases; this is due to an increase in arc concentration, and as consequence, an increase in its heat output; as a result, the root width and height of the weld considerably increase, the reinforcement width remains virtually unchanged, and the reinforcement height decreases. Effect on the risk of internal defects: with a lower grind angle, the risk of defects is lower. The mechanical properties of the resulting welds are indirectly affected by changes in the arc characteristics (the arc concentration and the arc thermal efficiency). As the welding amperage increases, the risk of producing a weld with a geometry inconsistent along the length increases. This is due to an increased impact of the arc length fluctuations. The risk of porosity and lack of penetration is affected as follows: As it increases, the risk of occurrence decreases. The effect of welding amperage changes on the mechanical properties of the weld is as follows: By increasing the welding amperage simultaneously with the travel speed, a weld with higher mechanical properties will be achieved.

2. The metallographic examination results for the effect of the welding heat cycle on the microstructure, chemical composition, and microhardness. Conditions with a higher amperage and travel speed produce a weld with a better microstructure. The heat-affected zone, the fusion zone, and the grain size in such zones of the weld will be smaller. The weld produced at the maximum welding amperage and travel speed has both higher and more uniform microhardness across the weld cross section.
3. The following linear regression model describing the correlation between the strength of the 12Kh18N10T stainless steel welds with a thickness of 1 mm and the 06Kh19N9T filler wire and welding amperage and travel speed is generated:

$$Y = 397 + 3{,}05 \cdot X1 - 015 \cdot X2$$

   Where *X1* is the welding amperage, and
   X2 is the travel speed.
   This equation will facilitate the work of researchers and industrial practitioners developing welding technology for light-wall nickel chrome austenitic steels.
4. The best conditions have been determined to be as follows: Tungsten electrode diameter: 2 mm; filler wire diameter: 1.6 mm; welding amperage: 68 to 72 A; arc voltage: 12 to 14 V; travel speed: 300 to 320 mm/min; tungsten electrode grind angle: 55°; shielding gas flow to the torch: 8–10 l/min; backing: required with an argon flow rate for backing of 6 to 8 l/min minimum; welding should be direct current straight polarity (DCSP). With the above welding parameters, the weld will: Have a geometry consistent over its entire length, no internal defects, and a static tensile strength similar to that of the base metal. The welding heat cycle in these conditions ensures better microstructure and chemical and strength homogeneity.

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Impact and Effect Study of Submerged-Arc Welding Conditions on Structural Changes in Weld Metal

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Abstract. Purpose: This project aims to study the impact and effects of welding conditions and welding consumables on structural changes in the weld metal and the use of the experimental flux produced by restoring the iron oxide excess from smelter slags for automatic arc welding.

Design/methodology/approach: To study the impact of welding conditions and welding consumables on structural changes in the weld metal, four coupons were welded with the generic welding consumables and the experimental welding flux. Some coupons have been preheated to detect any reduction in the heat-affected zone and any subsequent distortions.

Findings: It has been found that heat treatment prevents areas with a coarse microstructure from forming and produces a more homogeneous fine crystalline structure of the weld and the heat-affected zone. Therefore, the preheated coupons and a coupon tempered by slower cooling of the metal under the slag deposit should have a finer crystalline structure than a coupon fabricated without preheating. It can be concluded from the observations that as the welding amperage increases, the total area of the heat-affected zone increases. It has been found that the experimental welding flux accumulates heat of the molten metal heating it up to metal austenitizing temperature and slowly cooling it down until the medium pearlite and ferrite mixture forms.

Originality/value: The collected experimental evidence confirms that the processed slag of smelters can be utilized as a welding flux and has a potential to address the challenge of smelter slag accumulation in the long term.

Keywords: Automatic welding · Welding flux · Metallurgical slag · Recycle · Microstructure · Deformations · Internal stress · Heat treatment

JEL Code: L61 · L62 · Q49

1 Introduction

Automatic submerged-arc welding (SAW) is still most cost-effective and high-productivity and, therefore, most mainstream to produce high quality welds so far. The exponential growth of SAW is supported by high productivity of this process, consistent

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welding quality, low consumption of electrode material and electricity and good working conditions. To date, large metal sheets are widely welded in shipbuilding (Andreev 2006; Vinogradov 1997). Normally, double-sided submerged-arc welding is used for these connections, but this welding process has its disadvantages. The main disadvantages are distortions during and after welding. Distortions are a consequence of metal transition from one phase to another with introduction of internal stresses (Talypov 1973). Topical in this area is the use of concentrated heat sources where the amount of filler metal and the weld cross section decrease, which certainly reduces the distortions but neither prevents the internal residual stresses from generation nor eliminates heat treatment (Li et al. 2019; Chen et al. 2018; Zhang et al. 2020). In this case, finding solutions to reduce the cooling rate for conventional methods, either by accumulating heat from the molten metal (Abashkin et al. 2016), or preheating, supplementary heating, and intelligent cooling is relevant. It is known that holding the alloy at austenitizing temperature controls metal properties including both improved strength and ductility (Frolov et al. 2012). Identity between the structure and properties of the weld and the heat-affected zone is not usually achieved that leads to a deviation in the shape of the resulting structure and underlies the relevance of studying the thermal processes in the molten metal (Shorshorov and Belov 1972) and their management techniques including changes in the welding parameters, use of heat treatment or experimental welding consumables (Babenko 2004; Kozyrev et al. 2019) where the chemical and fractional composition and distribution of the components in the mixture can be determined.

2 Materials and Method

When studying the impact of welding and heat treatment conditions, the main material used was the 09G2S steel. The 09G2S steel is a structural low-alloy steel for fabricated structures. For longitudinal butt welds, the ADF 1250 brand automatic welding machine was used together with the VDU 1250 welding rectifier. Metallographic specimens were prepared with a conventional method including grinding and polishing using the AutoMet 250 automatic machine and subsequent etching with 4% nital. The microstructure in the coupon cross section was examined with the Nikon MA200 metallographic microscope with a 100-fold magnification and a 400-fold magnification. Differences between the interfaces were assessed in terms of grain size determined with the Image-Pro Plus software (Bashkov et al. 2019). The analyzed images of the microstructure were preliminary adjusted for sharpness and underwent spatial calibration. Microhardness in the weld cross section was measured with the SHIMADZU HMV-2 microhardness tester by making indentations with a 1-mm spacing in two rows with each one placed at the center of the rollers with a load of 0.5 kg.

Welding coupons to study the impact of the submerged-arc welding conditions on structural changes in weld metal for double-sided single-pass welding without heating were fabricated from one 09G2S steel plate. Coupon 1 was double-side welded in a single pass with a 3-mm copper-coated wire ESAB OK Autrod 12.22 designed for welding carbon and low-alloy steels together with OK Flux 10.71. The chemical composition of the wire and flux are listed in Table 1 and Table 2. The coupon size is 200 × 300 × 5. The welding parameters for OK Flux are shown in Table 3.

Table 1. Chemical composition of ESAB OK Autrod 12.22 wire

				Percentage
C	Mn	Si	P	S
0.08 to 0.12	0.90 to 1.15	0.15 to 0.30	Max. 0.015	Max. 0.020

Table 2. Chemical composition of OK Flux 10.71

			Percentage
SiO_2+TiO_2	CaO+MgO	Al_2O_3+MgO	CaF_2
20	25	32	15

Table 3. Welding parameters for OK Flux

Coupon no	I, A	U, V	V, m/hr
1	300	24	28

Note: I: welding amperage; U: arc voltage; V: travel speed

Coupon 2 was double-side welded in a single pass with the experimental flux and the 3-mm Sv-08G2S copper-coated wire without heating.

The chemical composition of the experimental flux and the wire are listed in Table 4 and Table 5. The coupon size is 100 × 130 with a thickness of 4 mm. Coupon 1 and 2 were fitted up as per the S7 detail, GOST 8713-79. Welding conditions selected for the 4-mm thick experimental flux are shown in Table 6.

Table 4. Chemical composition of experimental flux

							Percentage
CaO	MgO	SiO_2	Al_2O_3	FeO	MnO	C	S
19	13.3	35.1	7.73	11.52	6.75	0.14	0.096

Table 5. Chemical composition of Sv-08G2S wire

						Percentage
C	Si	Mn	S	P	Cr	Ni
0.05 to 0.11	0.70 to 0.95	1.80 to 2.10	<0.025	<0.03	<0.20	<0.25

Table 6. Welding parameters for experimental flux

Coupon no	I, A	U, V	V_{trav}, cm/m
2	230	34	38

Note: I: welding amperage; U: arc voltage; V: travel speed

To study single-sided single-pass welding with ceramic backing and preheating and supplementary heating, coupon 3 was welded with the 3-mm ESAB OK Autrod 12.22 wire and ESAB OK Flux 10.71. The coupon size is 1500 × 160 × 5 mm. Welding and heat treatment conditions for the coupon are listed in Table 7.

Table 7. Welding and heat treatment conditions for coupon 3

Amperage Iweld, A	Arc voltage U, V	Travel speed Vtrav, cm/min	Preheating temperature, °C	Cooling speed, °C/hr
275	24	25	400	150

Coupon 4 was single-side welded in a single-pass with the AN-348A flux and the Sv-08A wire. The chemical composition of the wire and flux is listed in Table 8 and Table 9. The coupons were prepared similar to coupon 3 for single-sided submerged-arc welding with OK Flux. The coupons were fitted up with a ceramic backing strip as per the S4 detail, GOST 8713-79 (Fig. 1).

To prevent the edges from shifting during welding, tabs were welded to the workpieces with two short tacks. Welding and heat treatment conditions for the coupon are listed in Table 10.

Table 8. Chemical composition of Sv-08A wire

							Percentage
C	Si	Mn	S	P	Cr	Ni	Cu
≤0.10	≤0.30	0.35 to 0.60	≤0.03	≤0.03	≤0.12	≤0.25	≤0.03

Table 9. Chemical composition of AN-348A flux

								Percentage
SiO_2	MgO	CaO	MnO	Al_2O_3	CaF_2	Fe_2O_3	S	P
40.0 to 44.0	<7.0	<12.0	31.0 to 38.0	<13.0	3.0 to 6.0	0.5 to 2.2	<0.11	<0.12

Table 10. Welding and heat treatment conditions for coupon 4

Amperage Iweld, A	Arc voltage U, V	Travel speed Vtrav, cm/min	Preheating temperature, °C	Cooling speed, °C/hr
300	24	25	450	150

(a) (b)

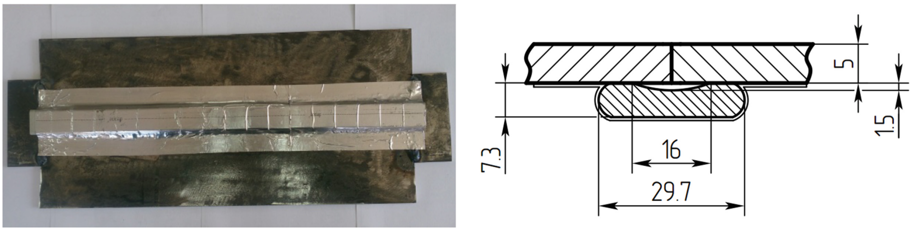


Fig. 1. Coupon fitted-up for welding with glued ceramic backing: (a) general view of fitted-up coupon; (b) coupon and ceramic backing profile. *Source*: Images made by the authors

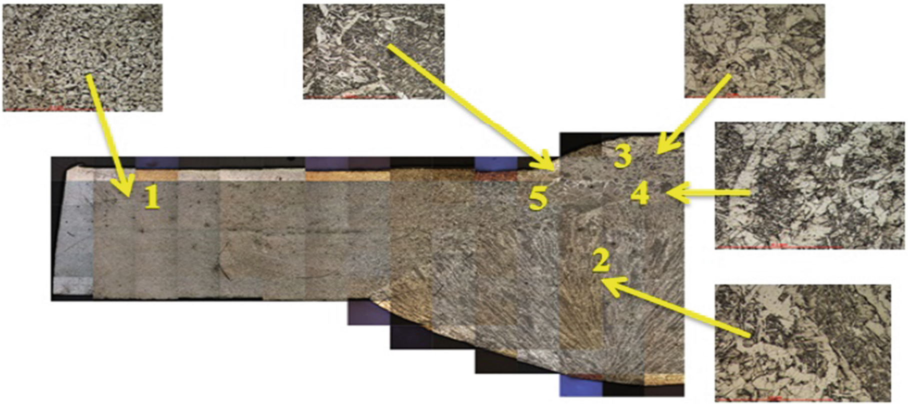
3 Results

Welding conditions selected for the S7 connection, GOST 8713-79, OK Flux, and low-carbon steel with a thickness of 5 mm are shown in Table 7.

The microstructure of the coupon 1 cross section fabricated by submerged-arc double-sided welding with OK Flux is shown in Fig. 2.

Figure 2 shows that there is no lack of penetration, i.e. the beads overlap. The structure of the first and second bead is different from each other; the structure of the second bead has dendrites with needle-like tempering bainite oriented from the fusion line at the interface of weld reinforcement toward its transverse axis. The tempering structure of pearlite and ferrite mixture with the grain size equal to the base metal is observed in the structure of the first bead. This phenomenon is described by the following mechanism: when the second bead is heated and crystallizes, the metal in the first bead is heated up to austenitizing temperature in its entire volume and slowly cools down until medium pearlite and ferrite mixture is formed.

The metal region limited by the fusion lines between the beads and the heat-affected zone is of main interest. The structure in this zone has coarse grains with a needle-like tempering bainite. It is significant that no clear fusion line between the above metal



1: base metal; 2: first weld bead; 3: second weld bead;

4: bead overlap; 5: heat-affected zone

Fig. 2. Microstructure of weld cross-section for coupon 1. *Source*: Images made by the authors

region and the metal in the first weld is observed but the fine-grained structure of the base metal smoothly transitions into the coarse-grained structure of the heat-affected zone. It is explained by the same mechanism of the second bead tempering the first bead. But due to the fact that the heat-affected zone is heated twice: once after the first bead and then after the second bead, the time when this metal region is held at high temperature doubles leading to a significant increase in grain size.

The microstructure of the reference coupon cross section is shown in Fig. 3. The figure shows that there is no lack of penetration, i.e. the beads overlap. The structure of the first and second bead is different.

The tempering structure of fine pearlite and ferrite mixture is observed in the structure of the first bead.

The dendritic structure of the second bead is due to rapid cooling caused by the temperature difference between the base metal and the filler metal. Dendrites have finer grains compared to welding with OK Flux.

This phenomenon is described by the following mechanism: during welding, due to the special properties of the experimental flux, the beads under the slag deposit cool down more slowly, thus undergoing a tempering process that forms medium pearlite and ferrite mixture.

To study the microstructure of the weld for coupon 3, photographs were taken to cover all heat cycle zones of the weld from the filler metal zone to the base metal zone (Fig. 4).

The heat cycle of the coupon under study is characterized by four zones: filler metal zone (I), recrystallization zone (II), overheated zone (III), and base metal zone (IV).

Grains in the filler metal zone are globular in shape and not significantly oriented. The grains in general do not change their size near the fusion line but are oriented from

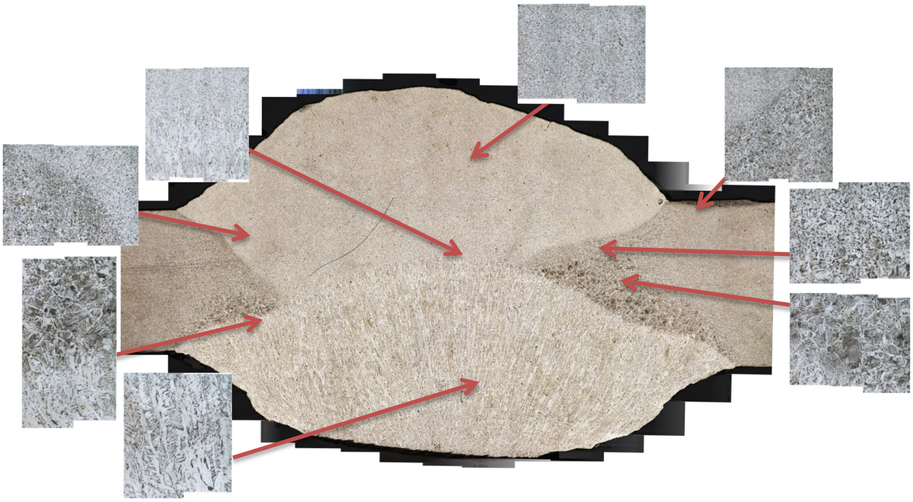


Fig. 3. Microstructure of coupon 2 cross section fabricated with experimental flux. *Source*: Images made by the authors

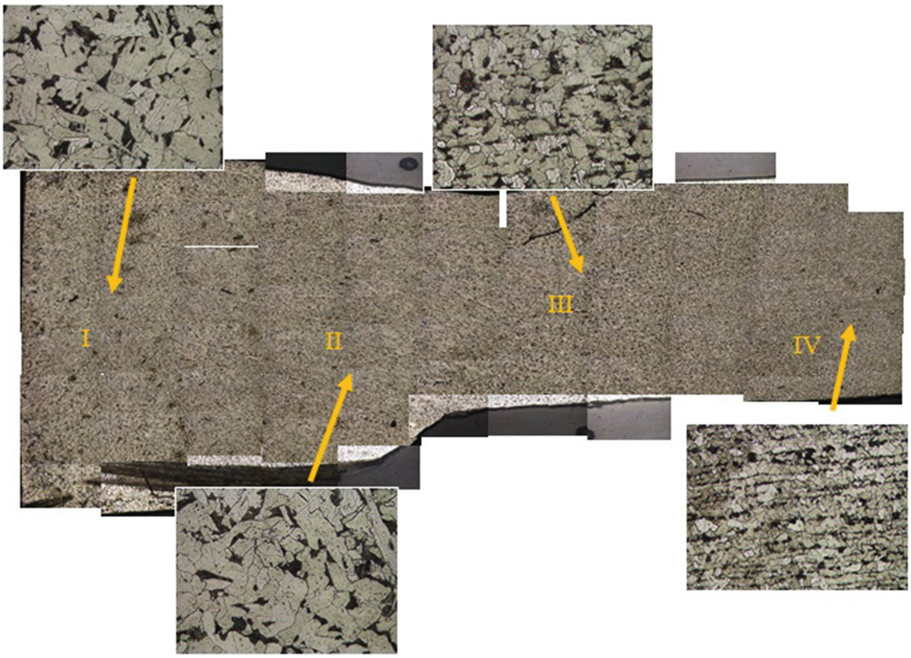


Fig. 4. Microstructure of coupon 3 cross section fabricated by single-sided welding with OK Flux. *Source*: Images made by the authors.

the fusion line toward the weld center. In general, the weld microstructure has a pearlite and ferrite type tempering structure.

Grain size from the fusion line to the base metal is similar to the grain size from the fusion line to the weld center. This zone is characterized by randomly positioned grains. There are areas with the linear structure in the center associated with rolling. This zone smoothly transitions into a finer structure of the third zone.

The fourth zone of the base metal is characterized by a linear fine grain structure.

Welding conditions selected for the S4 connection, GOST 8713-79, with the AN-348A flux are shown in Table 10.

To study the microstructure of the weld, photographs were taken to cover all heat cycle zones of the weld from the filler metal zone to the base metal zone (Fig. 5).

The heat cycle of the coupon under study is characterized by four zones: filler metal zone (I), recrystallization zone (II), overheated zone (III), and base metal zone (IV). Grains in the filler metal zone are globular in shape and not significantly oriented. The grains in general do not change their size near the fusion line but are oriented from the fusion line toward the weld center. In general, the weld microstructure has a pearlite and ferrite type tempering structure. Grain size from the fusion line to the base metal in the recrystallization zone is similar to grain size from the fusion line to the weld center. This zone is characterized by randomly positioned grains. There are areas with the linear structure in the center associated with rolling. This zone smoothly transitions into a finer structure of the third zone. The fourth zone of the base metal is characterized by a linear fine grain structure.

Fig. 5. Microstructure of coupon 4 cross section fabricated by single-sided welding with AN-348A flux. *Source*: Images made by the authors

When measuring the heat-affected zone sizes (Table 11), it has been found that coupon 3 has the largest recrystallization zone with coupon 2 having the smallest area size. Coupon 3 has the largest overheated zone with coupon 2 having the smallest area size. Coupon 3 has the largest total area of the heat-affected zone coupon 2 having the smallest total area size.

Figure 6 shows the measurements and calculated values for the perimeter and area of the microstructure features.

Table 11. Heat-affected zone areas.

Coupon number	Recrystallization zone area, mm^2	Overheated zone area, mm^2	Total HAZ area, mm^2
1	24.4	19.3	43.7
2	2.94	8.34	11.3
3	25.2	19	44.2
4	26.4	20	46.4

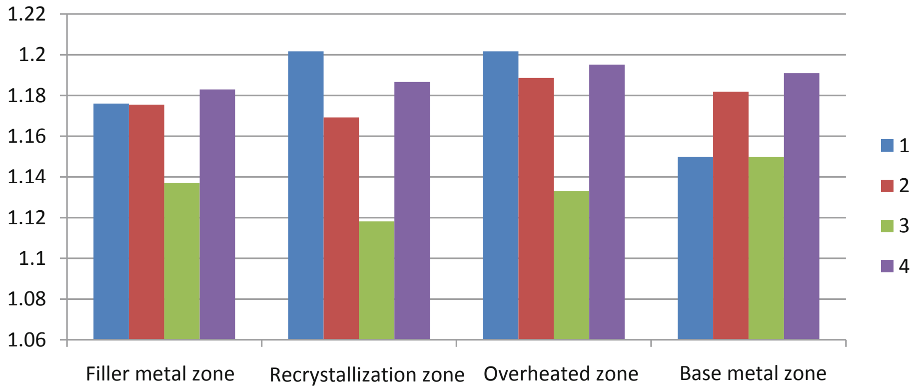


Fig. 6. Size distribution histogram. *Source*: Images made by the authors

The figure shows that grain size for coupon 1 is larger in the filler metal zone, recrystallization zone, and overheated zone compared to the base metal zone.

Grain size for coupon 2 is smaller in the filler metal zone and recrystallization zone than in the base metal zone, and the overheated zone has coarser grains.

Coupon 3 has finer grains in the filler metal, recrystallization and overheated zone than in the base metal zone that raises questions about the weld quality, since the base metal itself will have the best properties.

When examining coupon 4, an increase in grain size can be observed from the filler metal zone to the base metal zone, except for the overheated zone where grain size is slightly larger than in the base metal zone.

The general analysis of the microhardness distribution chart for the weld section (Fig. 7) shows that hardness of the weld in coupon 1 is half of the base metal hardness. The weld area in coupon 3 has hardness higher than the base metal. Coupon 2 and 4 have uniform hardness in all zones from the weld to the base metal.

As microhardness is linked to all mechanical characteristics, its fluctuation supports assessment of weld strength uniformity. The generated microhardness distribution curves have shown that microhardness distribution in all heat cycle zones is uniform without either sharp variations or softening zones observed.

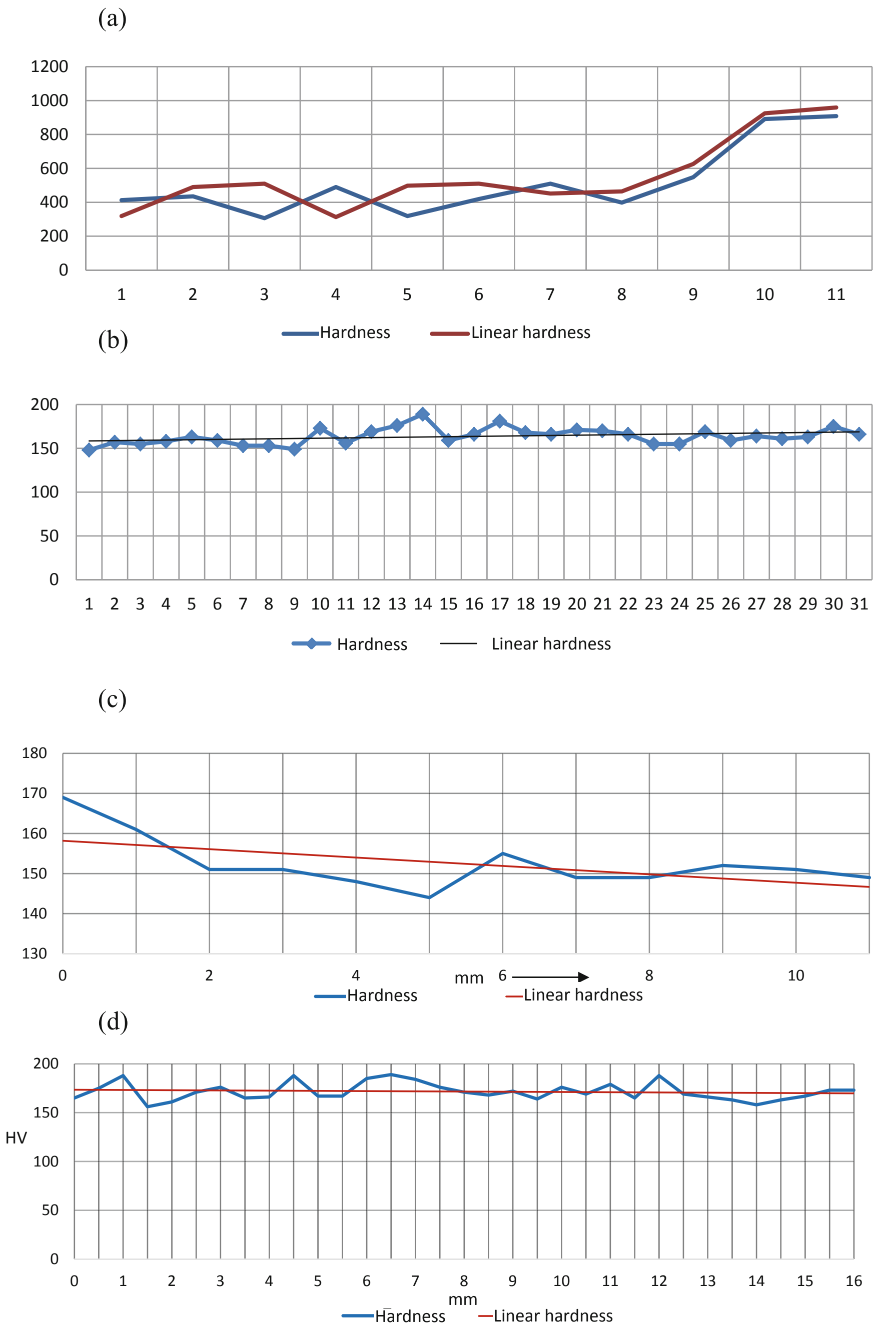


Fig. 7. Microhardness distribution chart for weld cross section (a) coupon 1; (b) coupon 2; (c) coupon 3; (d) coupon 4. *Source*: Images made by the authors.

4 Conclusions

It has been found that heat treatment prevents areas with a coarse microstructure from forming and produces a more homogeneous fine crystalline structure of the weld and the heat-affected zone. Therefore, preheated coupon 3 and 4 and coupon 2 tempered by slower cooling of the metal under the slag deposit should have a finer crystalline structure than coupon 1 fabricated without preheating. Grain size analysis supports the findings, except for the fact that the size of the crystalline structure in the filler metal zone for coupon 4 is not much higher than that of the coupon without heating; it may be caused by an inadequate choice of amperage.

It can be concluded from the observations that as the welding amperage increases, the total area of the heat-affected zone increases. Also, if we compare the parameters and grain size for the coupons fabricated using the same welding process, we can see that among double-side welded coupon 1 and 2, coupon 1 fabricated at a higher amperage has coarser grains in the heat-affected zone than coupon 2 fabricated at a lower amperage. Further, if we compare grain size for coupon 3 and 4, we can see a similar pattern.

Coupon 2 and 4 show the best results, but although coupon 4 has a satisfactory grain size and a linearly distributed microhardness in the weld section, it has the largest heat-affected zone that may have a negative impact. While coupon 2 also has a good grain size and a linearly distributed microhardness in the weld section, it has the smallest heat-affected zone exceeding the remaining coupons almost by a factor of 4.

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Experimental Validation of Identification Crack Propagation in Plates as a Source of Acoustic Emission

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Abstract. Purpose: The purpose of the chapter it to establish the relation between the nature of crack propagation and the parameters of registered acoustic emission signals in metallic plate.

Material and methodology: For research in this work, aluminum alloy 1163 was used as a sample. An initial crack was grown in the sample by means of cyclic bending. After that, the sample was loaded with a single bend with a fixed deformation using a cantilever loading device. Damage in the form of elastic waves that were generated during the crack growth was recorded by the acoustic emission method. The crack growth rate was determined after loading.

Findings: A new parameter has been proposed for determining the type of developing acoustic emission source. Based on this parameter, which is defined as the ratio of the energies of the frequency ranges of the Fourier spectrum, it was found that due to a single short-term growth of fatigue crack, the properties of the material will change. The decrease in hardness of sample occurs because the direction of fatigue crack in the specimen of alloy 1163 is leading into the zone of higher ductility.

Originality: Based on application of modern Non-Destructive Testing and Structural Health Monitoring, this article analyzes the registered acoustic emission signal due to the single crack propagating in the material.

Keywords: Acoustic emission · Wavelet decomposition · Crack propagation · Fatigue · Identification method

JEL Code: C02

1 Introduction

With the constantly increasing requirements for products, generally in the form of plate-like structure in the construction such as pipelines, aircraft industry, pressure vessels etc., the application of modern methods of non-destructive testing (NDT) and Structural Health Monitoring (SHM) becomes an urgent issue. These applications are based on the registered data from various types of sensors (piezoelectric transducer, strain gauge,

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optical-fiber, etc.), that are attached or embedded in structures to predict the resource not only during operation but also at the production stage. A review of such techniques is provided by Dwivedi et al. (2018), Kanji (2018), and Bashkov et al. (2017a, b). Still requires the research that allows establishing a relationship between the structural changes observed in the material in situ and the parameters of physical quantities that are registered additionally in the process of changing the structure of material.

As pointed out by Ohstu and Ono (1986), one of the effective methods of NDT and SHM, passive ultrasonic methods based on the registration and subsequent processing of parameters of acoustic signals in the ultrasonic range that occurs because of local restructuring of the material structure, the occurrence and development of micro - and macro-defects is called acoustic emission method. Registered AE signals contain a significant amount of information about the characteristic of source, the medium of propagation of the elastic wave, and the location of the source. Therefore, Korotaev et al. (2017), Cuadra et al. (2015), Syromyatnikova et al. (2015), and Wisner et al. (2019) have applied data driven methods to extract the information about the mechanisms of crack from the registered AE signals. Among them, one of the most critical damage studied is a fatigue crack.

The study of acoustic emission during fatigue crack growth include: crack extension (Bashkov et al. 2019), deformation of plastic zone (Chung and Kannatey-Asibu 1992) and fretting of fractured surfaces (Meriaux et al. 2010) in metals and also AE signals can be potentially generated due to matrix cracking, delamination, fiber breakage and macroscopic fracture in composite materials (Chelliah et al. 2018). The energy released from the beginning of crack zone, can be propagated different modes of guided waves in the plate like structure. These guided waves propagate in the thin metallic and composite structure depends on the types and positions of sources, the amplitude-frequency response, and geometry of the sensors, the properties of materials. Several studies are also performed to understand the science of guided waves, such as, Lamb waves, due to crack growth in plate like structure. Studies of the phenomena, that strongly influence on the shape of wave form, changing critically waveform parameters, like rise time, amplitude, rise angle (RA - ratio of rise time to amplitude of the waveforms), peak frequency were observed in the papers by Hamstad et al. (2002a, b).

Aggelis et al. (2011) described the waveform shape depends on the cracking mode, enabling the classification of crack mode, a certain shift indication the transition from the tensile mode to shear mode by using waveform parameter RA and confirmed by the visual observation of the crack geometry after the tensile fracture experiments.

Theoretical and numerical analysis of guided wave released during an acoustic emission event using excitation Helmholtz potential approach investigated by Haider and Giurgiutiu (2019). In another work of Poddar and Giurgiutiu (2017) have studied to understand fatigue growth as source of acoustic emission using physics of guided wave propagation in FEM and performed experimental validation to estimate the crack length form the recorded AE signals. Also reported the effect of the acoustic emission sensor on the acoustic emission waveforms from fatigue crack growth in a thin aluminum plate in the work of Bhuiyan et al. (2018).

Dan et al. (2017) investigated classification of AE waves that can be generated by either crack propagation (CP) or crack closure (CC) processes using an index based on wavelet power of AE signals. And proposed novel method to estimate the crack length without prior knowledge of the initial crack length, integration of AE data or real-time load amplitude. The aim of this research is to develop the relation between the registered AE signals and characteristics of a fatigue crack as a guided wave source. This result will allow predicting crack lengths from acoustic emissions and prevention the final state of failure in plate structures.

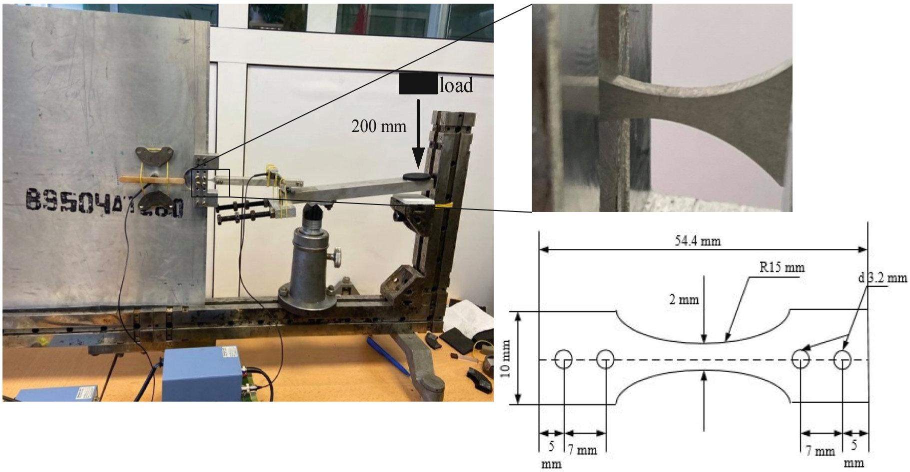
This study is devoted to the identification the characteristics of dynamics crack as an AE source in plate structure using the wavelet decomposition method. At first, introduce the experimental procedure and present detailed models for research. Then, registered and analyzed AE signals due to the crack propagation at every step of loading. Subsequently, present the microstructure of the crack propagation to develop an understanding of the characteristics of a fatigue crack as a guided wave source. Finally, proposed a method for identifying developing crack-type defects using a new criterion based on calculating the energy ratio of two Fourier frequency ranges of the spectrum components of the wavelet decomposition of registered AE signals.

2 Materials and Method

For research, the aluminum alloy 1163 with a size of 54.4 mm, a radial shape of 15 mm and a width of 2 mm in the narrowest section is used as the sample in this work. Before using this sample as the acoustic emission source, that are used in research of on low-cycle fatigue tests to have initial crack on that sample. To grow a main crack, that was not exceeding its half the cross section, the samples was placed on machine with an electromagnetic drive using the cantilever bending method. That sample was pressed against on the surface of the aluminum alloy D16 plate using a special clamp. The dimension of the aluminum plate is 500 mm × 600 mm × 8 mm. Finally, the experimental stand consisted of the aluminum alloy D16 plate with vertically position and the sample with initial crack was pressed at the edges of that plate. The cantilever scheme of the loading device is as shown in Fig. 1, which allowed the sample to be bent by a certain amount at a given speed.

For registration of acoustic emission (AE) signals, using the wide-band piezoelectric transducer GT301 (PZT), which was placed on the plate at the specified distance from the crack location. In this work presents the results for a given distance between the PZT and the AE source (crack) is equal to 90 mm.

For analyzing and identification of the acoustic emission signals using the signal processing methods such as Fourier transform and Wavelet decomposition method. To understand the relationship between the registered AE signals and the source of acoustic emission (crack propagation), has been studied the microscopic structure of crack propagation in sample as the result of every step of loading using Nikon Eclipse MA200.



(a) (b)

Fig. 1. Experimental stand (a) and the sample (b). *Source*: developed and compiled by the authors

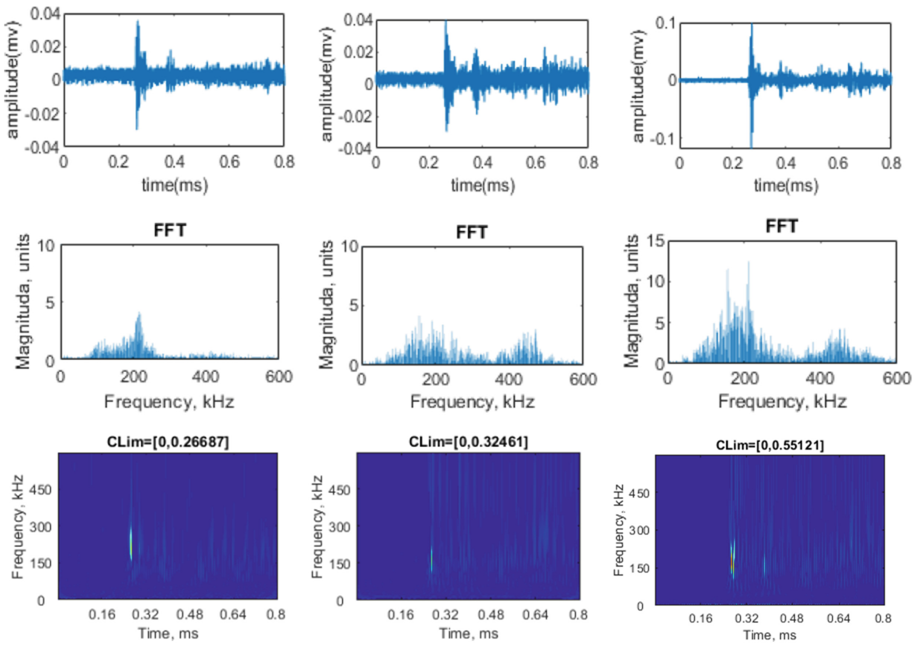
3 Results and Discussion

The bending value was determined based on the results of preliminary fatigue tests. When applying a force with a given amount of bending to the sample, AE signal was generated due to a single propagation crack. The loading was performed several times, and an analysis was performed for 7 serial loads. At each loading, the generated AE signal was registered. Figure 2 shows AE signals and their Fourier and wavelet spectra, which were recorded as a result of three consecutive one-time loads.

As a result of analysis Fourier spectra of the registered AE signals, it can be seen that two peaks are observed in the spectra, located in the frequency ranges of 100–250 kHz and 250–500 kHz.

For signals 2 and 3, such sources can be attributed to the same type, with differences magnitude between in the frequency range of 250–500 kHz. Using that feature of frequency spectra, can be prediated the length of the crack propagation and also other parameters of registered AE signals such as amplitude, the magnitude of the low and high frequency component and wavelet coefficient. Similarly, Bigus and Travkin (2015) used the criteria, that is calculated by the ratio of the maximum magnitude of low freuency range to the maximum magnitude of high frequency range to prediate the propagation crack in the sample steel 20 when applying the statistical load. For more accuracy and reliability, taking only maximum magnitude can be varied, that depend on the amplitude- frequency characteristic of using sensor type and the position of the source AE (Zelenyak et al. 2014).

In the initial stage of cyclic fatigue testing can be investigated the accumulation of damage occurred in the area of the stress concentrator. These processes generate acoustic emission signals with the signal amplitudes that do not exceed the amplitude threshold level of registration. Then, in this experiments starting with a certain number of statically



(a) (b) (c)

Fig. 2. AE Signals, their Fourier and wavelet spectra registered as a result of serial loads (a–c). *Source*: developed and compiled by the authors

loading, the registration system detects signals with amplitudes higher than amplitude threshold level as shown in Fig. 3.

To visually understand the relation between crack propagation and the registered AE signals study the microsturcture crack propagation in the sample. After performing at each step of the loading and registered the AE siganls, take the sample and look the microstructure of the crack propagation in the micorsope Nikon Eclipse MA200 as shown in Fig. 4 and Fig. 5.

To understand better the crack propagation process, additional analysis of the wavelet decomposition of AE signals was performed separately for low-frequency and high-frequency components and observed some differences for the component of the fourth level of decomposition, which has a frequency range of 260–520 kHz as shown in Fig. 6. The difference between frequency specturm of fourth level of decompostion AE signals as a result of serial loads is shown in Fig. 7.

To identify developing AE source defects, a criterion was used in which the energy for the fourth level of decomposition was calculated separately for two frequency ranges: 200–300 kHz (energy E1) and 300–400 kHz (energy E2). The energy of each frequency

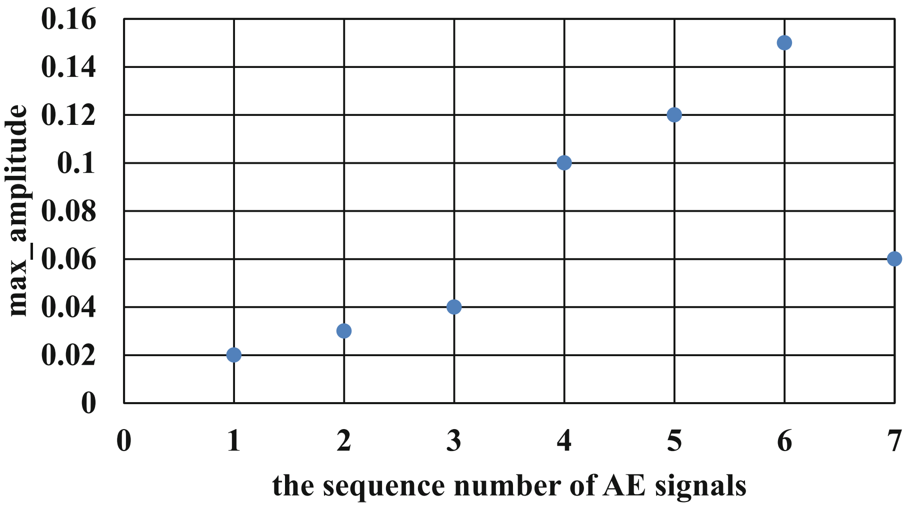


Fig. 3. Monitoring the loaded sample with maximum amplitude of AE signals before failure. *Source*: developed and compiled by the authors

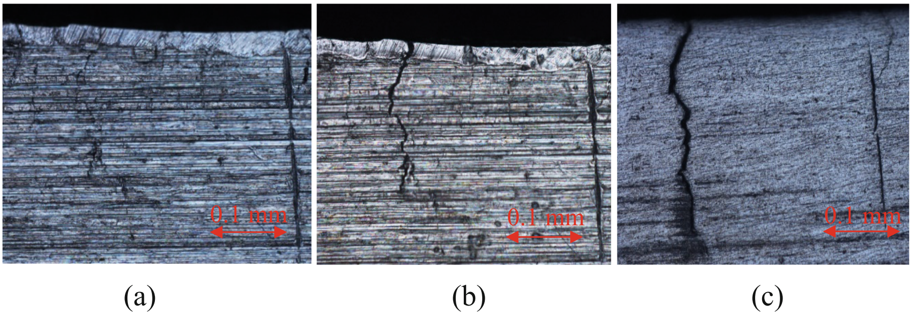


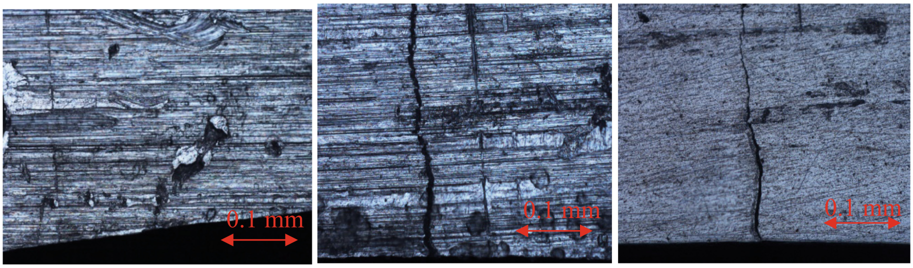
Fig. 4. Microsturcture sample crack propagation of upper site: a) preliminary crack; b) and c) the next step of crack propagation. *Source*: developed and compiled by the author.

band was calculated by the following equation.

$$E_i = \int_{f_1}^{f_2} \mathrm{fft}(d4(x_i))^2 dx \tag{1}$$

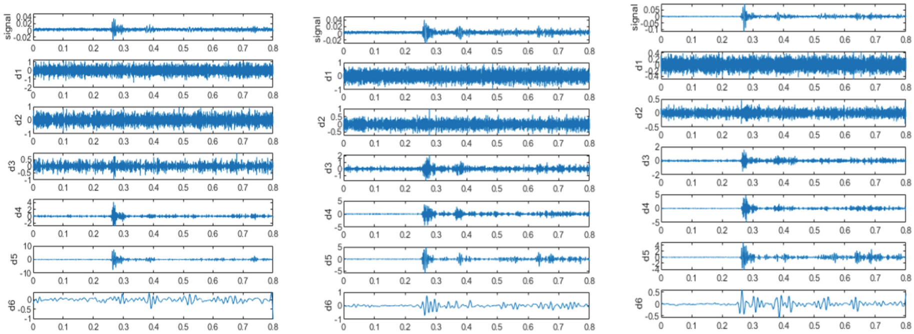
where E_i – energy of frequency band, E_1 – energy of frequency range to the left of the boundary line f_g between $f_1 = 200$ kHz and $f_2 = 300$ kHz, E_2 – energy of the frequency range to right of the boundary line f_g between $f_1 = 300$ kHz and $f_2 = 400$ kHz, $d4(x_i)$ – index of fourth level wavelet decomposition, fft – Fourier transform of the signal.

Using the ratio of these energies E1/E2 allows analyzing the nature of the transformation of the developing AE source as shown in Fig. 8.



(a) (b) (c)

Fig. 5. Microsturcture sample crack propagation of lower site: a) preliminary crack; b) and c) the next step of crack propagation. *Source*: developed and compiled by the authors



(a) (b) (c)

Fig. 6. Decomposition of AE signals registered as a result of serial loads (a–c). *Source*: developed and compiled by the authors

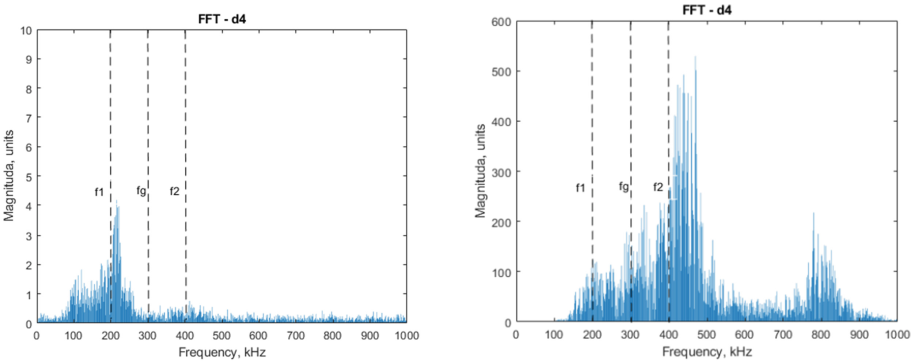


Fig. 7. The difference between frequency specturm of fourth level of decompostion AE signals as a result of serial loads. *Source*: developed and compiled by the authors

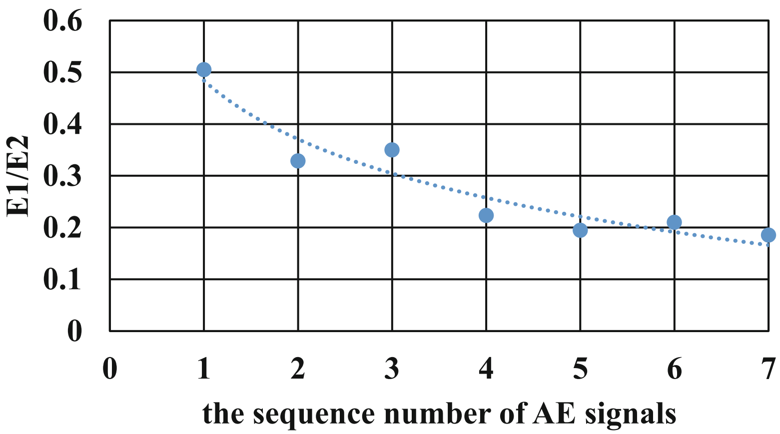


Fig. 8. Dependence of the energy ratio E1/E2. *Source*: developed and compiled by the authors

From the Fig. 8 can be noted that as the loading sequence number increases, the trend line of ratio E1/E2 is decreased to occur failure. The physical meaning of the obtained dependence in Fig. 8 can be characterized as the plastic region allows for a decrease in stress concentration and for the redistribution of inner forces into neighboring areas as shown in Fig. 9. Unfortunately, strains increase in the plastic zone in comparison with in the elastic region. Strains are also finite, when the stress limit is reached, failure will occur and inner force lines extend far from the notch tip in the elastic-plastic body.

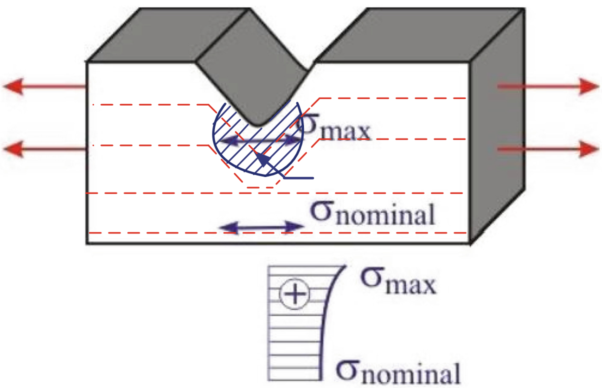


Fig. 9. Elastic-plastic stress concentration. *Source*: developed and compiled by the authors

Based on previously obtained research results by Bashkov et al. (2016), using a frequency coefficient in the analysis of AE signals, that can be characterized as increasing plasticity in the surroundings region of a single crack as the process of opening and propagate crack grows. It was found that the value of the hardness of the opening fatigue crack is higher than in other areas from the opening crack.

4 Conclusion

As a result of the research, it was found that with a single short-term loading of the material, the fatigue crack mouth emerges from the zone of the hardened material characterized by increased hardness. The hardening of the investigated material of alloy 1163 at the crack mouth occurred with the accumulation of fatigue damage.

In this work, the AE parameter was proposed, which is defined as the ratio of the energies of the frequency ranges of the Fourier spectrum of the most informative frequency components of the wavelet transform of the AE signal and can characterize the type of the AE source. The value of the calculated parameter for the AE signals, which were recorded under short-term loading of a specimen with a fatigue crack, decreases as the fatigue crack grows under repeated sequential loading. Thus, the developed AE parameter can be used to identify the AE source and material properties at local sites of developing fatigue cracks.

The resulted AE parameters can be used to identify and assess the hazard of AE sources in the event of material deformation and failure during the operation of products and structures by the stress concentration that is a location in an object where the stress is significantly greater than in the surrounding region.

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The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Investigation of the Influence of Electrical Modes on the Morphology and Properties of Oxide Coatings on Aluminum Alloy 1163, Obtained by the Microarc Oxidation

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Abstract. Purpose: Analysis of the influence of microarc oxidation modes on the properties and surface morphology of MAO coatings applied to aluminum alloy samples.

Material and methodology: The studies were carried out on samples of 1163 alloy clad with aluminum. In the study, the following parameters of microarc oxidation were changed: the rate of slow voltage growth, the period of slow voltage growth. After applying the oxide coating, the surface morphology and hardness of the coatings were investigated.

Findings: With a decrease in the rate of growth of the voltage at the anode electrode, it establishes a stable state with a slower rate of rise of potential and current, which causes a rapid accumulation of charge on the electrode surface and leads to an earlier onset of polarization. Under the condition of a steady rate of increase in the anode potential on the surface of the anode electrode, the effect of the rate of voltage rise on the polarization of the anode electrode is proportional to the rate of this increase. The morphology of the coating surface obtained at the first stage of oxidation affects the formation of the base of the future MAO coating and may be uneven. At the second stage, accumulated potential of the electric field leads to micro explosions in the breakdown channels, which contributes to the formation of a splash-like relief.

Originality: Based on obtaining new information on the effect of electric modes of microarc oxidation on the surface morphology of an aluminum alloy.

Keywords: Microarc oxidation · Morphology · The growth rate of the voltage · Microstructure · Porosity

JEL Code: C02

1 Introduction

Aluminum and its alloys are currently widely used in industry due to many valuable technological and operational qualities (low density, high thermal and electrical conductivity). Scientific and technological progress contributes to the expansion of their

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use areas, especially with oxide coatings applied to them. Both in Russia and abroad, micro-arc oxidation (MAO) has recently been considered one of the most promising methods for applying protective coatings to products made of aluminum alloy metals (Yerokhin et al. 1999).

A large number of studies dedicated to the effect of micro-arc surface treatment on aluminum and aluminum alloys have shown that physical and chemical properties (such as surface hardness, corrosion resistance, electrical insulation, wear resistance, heat resistance, etc.) have been significantly improved. Reviews of such influences are presented by Panchenko (2018), Tang et al. (2016), Suminov et al. (2001), and Mikheev et al. (2013a, b). The main indicators that determine the attractiveness of the above microarc oxidation mainly include four properties: coating thickness, density or porosity, surface morphology, and chemical composition of the coating. Electrical parameters, as one of the important factors affecting these properties during the oxidation process, directly determine the growth mode of oxide coatings (Snezhko et al. 1980). Therefore, it is still necessary to conduct research to establish the relationship between the electrical parameters, structural changes in the oxidation process, and the properties of MAO coatings.

The destruction of the surface of the formed oxide coatings at the final stages of Ta and Al anodizing under the action of electric pulses was studied in the work Klein et al. (1980). These studies mainly concerned the rate of electrical breakdown as a function of the applied voltage and the anode current density (Machkova et al. 1981).

At the same time, research on the structure and growth kinetics of the MAO coating and its formation mechanism are also continuing. The prevailing majority of scientific papers are devoted to approaches aimed at finding general principles for the formation of MAO coatings with specified physical properties of porosity and hardness (Curran and Clyne 2006). However, the conflict between two phenomenological mechanisms of growth and destruction of oxide films in the passivation mode under microarc action is still the basis for scientific research (Gordienko and Rudnev 1999; Dunleavy et al. 2009; Evans 1962).

The purpose of this work is to study the mechanism of formation and growth of the MAO coating on the surface of aluminum alloy 1163. The work presents a plan and structure of experimental research. The subject of analysis of the results was the following parameters of microarc oxidation: the current density value that changes with time or dependent on the anode voltage, the maximum value of the anode voltage, and the rate of voltage rise. These parameters were used to analyze the stages of the microarc oxidation process. In this work, the influence of oxidation parameters on the morphology and properties of MAO coatings was studied.

2 Materials and Method

The coating was formed on the 1163 aluminum alloy sample with pure aluminum plated on the surface. Therefore, the oxidized substrate can be considered as pure aluminum.

In experimental studies, electrolytes of the following composition were used: KOH (1 g/l) + Na_2SiO_3 (4 g/l). The microstructure of the surface of MAO coatings after oxidation was studied using a Hitachi S3400N scanning electron microscope at the new materials and technologies center of KnASU (Bashkov et al. 2019). The coatings were applied to prepared samples, which were aluminum alloy plates of the same size 20 mm $\times$ 20 mm. One of the problems solved in this work, which determined the planning of the experiment, was to establish the effect of the rate of increase in the voltage at the anode electrode on the shape of the graph of the change in the density of the anode current. For this purpose, the experimental studies were divided into two electrical modes. Each of the modes was characterized by two stages with different rates of voltage rise at the anode electrode, designated t_{0-1} and t_{1-2}. The total oxidation time for both modes was 600 s. In stage t_{0-1}, the voltage on the anode electrode reaches 200 V at different voltage rise rates determined by the oxidation mode. Mode 1 was characterized by a linear increase in the anode voltage at a constant rate, which for different samples varied from 1.11 V/s to 3.33 V/s. For mode 2, the rate of rise of the anode voltage was from 0.37 V/s to 3.33 V/s. At stage t_{1-2} of mode 1, the voltage ramp continues to rise to 400 V while maintaining a total oxidation time of 600 s. At stage t_{1-2} of mode 2, only the rate of rise of the anode voltage was kept constant, which was 0.37 V/s, also while maintaining the total oxidation time of 600 s. The modes of deposition of oxide coatings are shown in Table 1.

Table 1. Modes of MAO

Mode	№ sample	Voltage slew rate		Voltage at the end of the stage, V	
		Stage t_{0-1}, V/s	Stage t_{1-2}, V/s	Stage t_{0-1}, V	Stage t_{1-2}, V
Mode 1	1	3.33	–	200	400
	2	1.67	–	200	400
	3	1.11	–	200	400
Mode 2	1	3.33	0.37	200	–
	2	2.50	0.37	200	–
	3	2.00	0.37	200	–
	4	1.67	0.37	200	–
	5	1.43	0.37	200	–
	6	1.11	0.37	200	–
	7	0.83	0.37	200	–
	8	0.59	0.37	200	–
	9	0.37	0.37	200	

3 Results and Discussion

According to the program of the experiment, the registration and analysis of the current densities and voltage were performed for each mode for each sample. Figure 1 shows the dependences of the current density values on the voltage for different rates of voltage rise in the period t_{0-1}, corresponding to a typical anodic polarization curve. The authors Mikheev et al. (2013a, b), Trushkina (2014), Bespalova et al. (2012), Korotaev et al. (2017) explained this.

It is known that when the voltage potential increases in the direction of increasing positive values, the current density on the polarization curve of aluminum continuously increases to a maximum value. Then, an anode film begins to actively grow on the aluminum surface, passivation of the material occurs, and the current density drops sharply. The region of stable passivity continues until the point where the current density begins to grow (Fig. 1), and then the passivation process is repeated again.

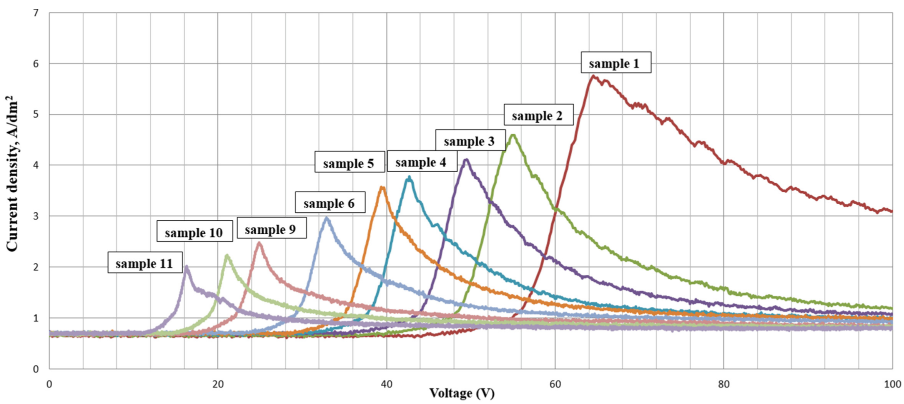


Fig. 1. Dependencies of the current density value on the voltage for the samples oxidized according to mode 2. *Source*: developed and compiled by the authors

In addition, Fig. 1 shows that when the anode voltage increase rate decreases during the period t_{0-1}, the peak current density value also decreases. The dependence of the values of the anode voltage at the peak value of the current density on the rate of rise of the anode voltage is shown in Fig. 2.

It can be seen from Fig. 2 that the voltage rise rate is linearly proportional to the voltage at the peak current density in the range of 0.37 V/s to 3.33 V/s. There is no difference between mode 1 and 2. This shows that under the condition of a steady growth rate of the anode film, the effect of the rate of voltage rise on the polarization of the anode electrode is proportional.

In the course of the investigations carried out, it was found that the peak value of the current density decreases with a decrease in the voltage growth rate in the first period of the anode film growth. This, most likely, is associated with concentration polarization, as a result of which the high rate of voltage rise changes the potential gradient in the solution and increases the ion velocity. A stable state is established at the anode electrode with a slower rate of voltage rise, which allows the charge to accumulate on the electrode surface during this period of time and contributes to the occurrence of electrochemical polarization at high values of the polarization current density.

At voltages from 80 V to 140 V, the accumulated charge on the surface of the electrode tends to balance, and the current density value reaches its lowest point (Fig. 3A).

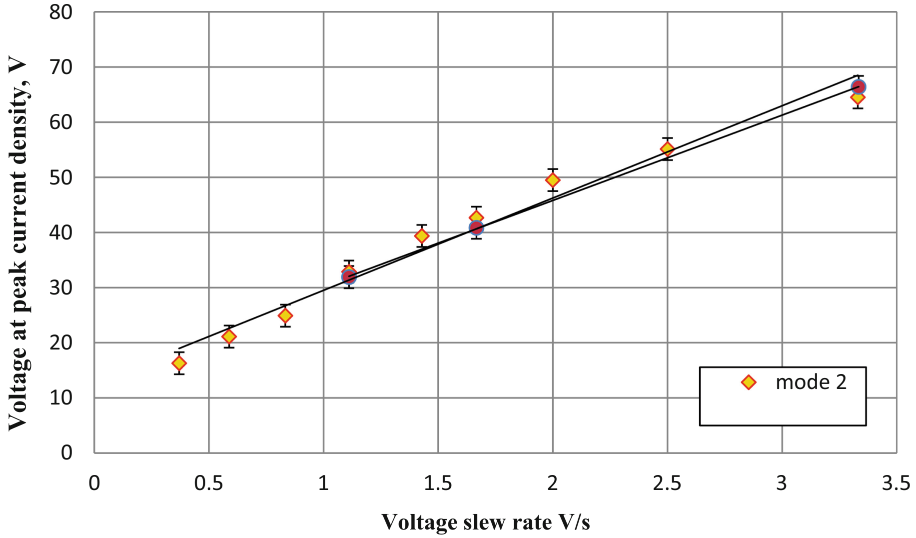


Fig. 2. Dependence of the voltage value corresponding to the attainment of the current density peak on the voltage slew rate. *Source*: developed and compiled by the authors

Figure 3B shows the relationship between the rate of rise of the anode voltage and the lowest current density. The resulting graph of dependence can be described by a cubic polynomial model, showing a tendency to power-law growth.

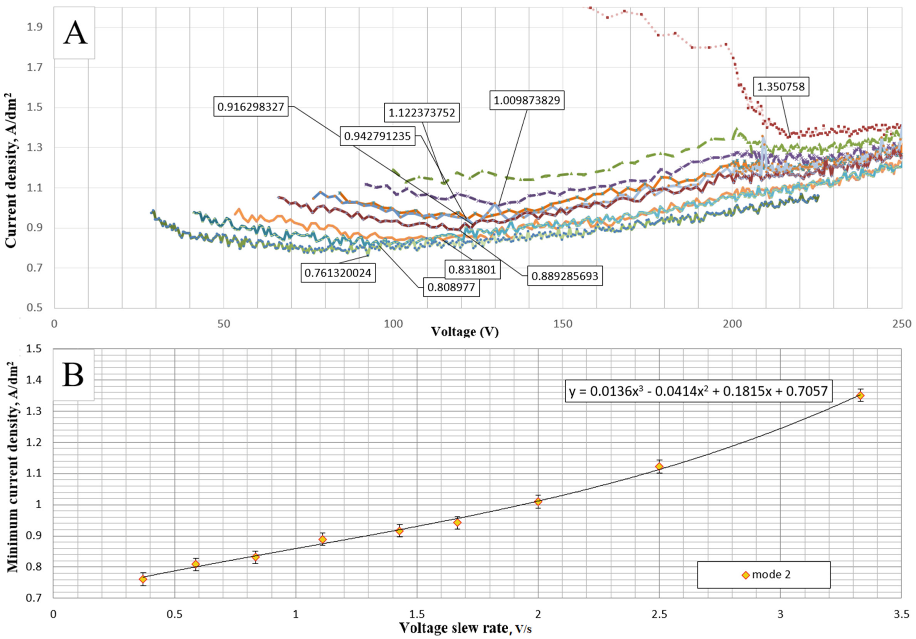
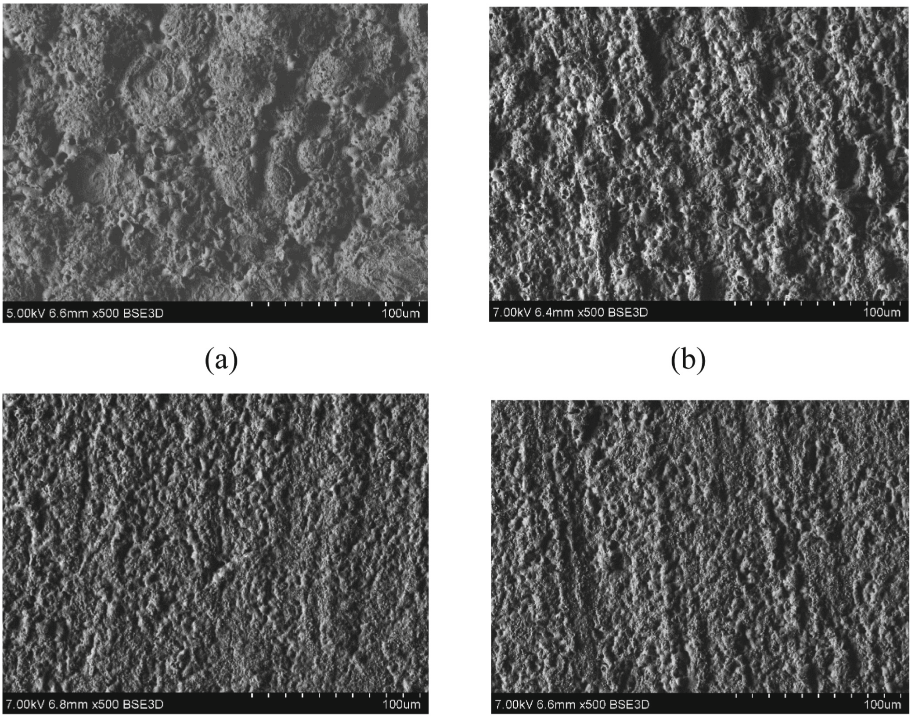


Fig. 3. The stage of the appearance of the lowest current density value (A) and its dependence on the voltage growth rate (B). *Source*: developed and compiled by the authors

When studying the surface of the obtained oxide coatings on a scanning microscope, it was found that a decrease in the rate of increase of the anode voltage leads to a decrease in the unevenness of the surface relief. However, the homogeneous cellular porous structure increases in area. In this case, the surface tends to flatten the relief (Fig. 4).



(a) (b) (c) (d)

Fig. 4. Surface morphology obtained by microarc oxidation of aluminum with different rates of voltage rise: a) 3.33 V/s; b) 1.67 V/s; c) 0.83 V/s; d) 0.37 V/s. *Source*: developed and compiled by the authors

To quantify the effect of the rate of rise of the anode voltage on the surface relief structure after MAO, the sizes and locations of pores on the coating surface were identified using Matlab software. Then the holes are classified according to the diameter distribution (Fig. 5).

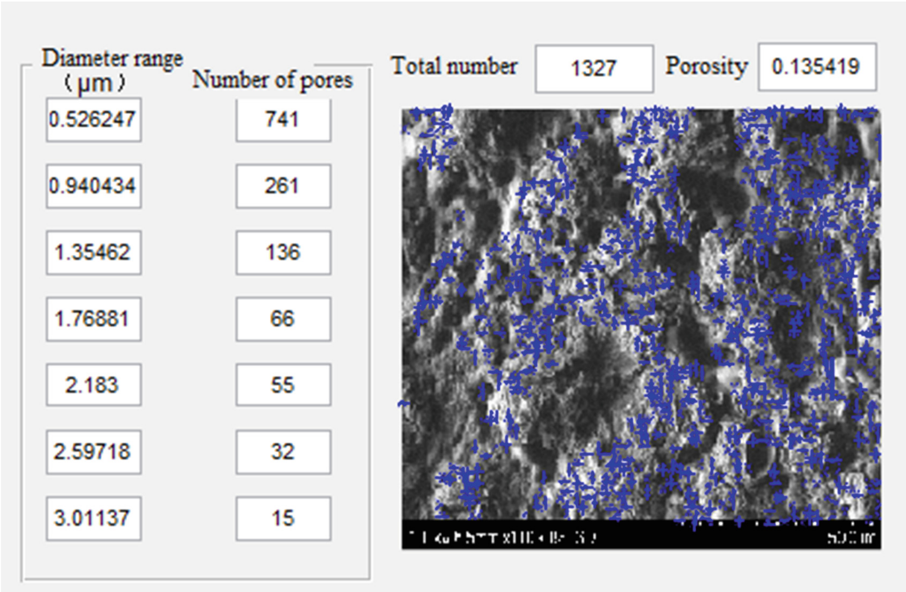


Fig. 5. Window for identifying and locating pores on the surface of micro-arc oxidation- sample 2. *Source*: developed and compiled by the authors

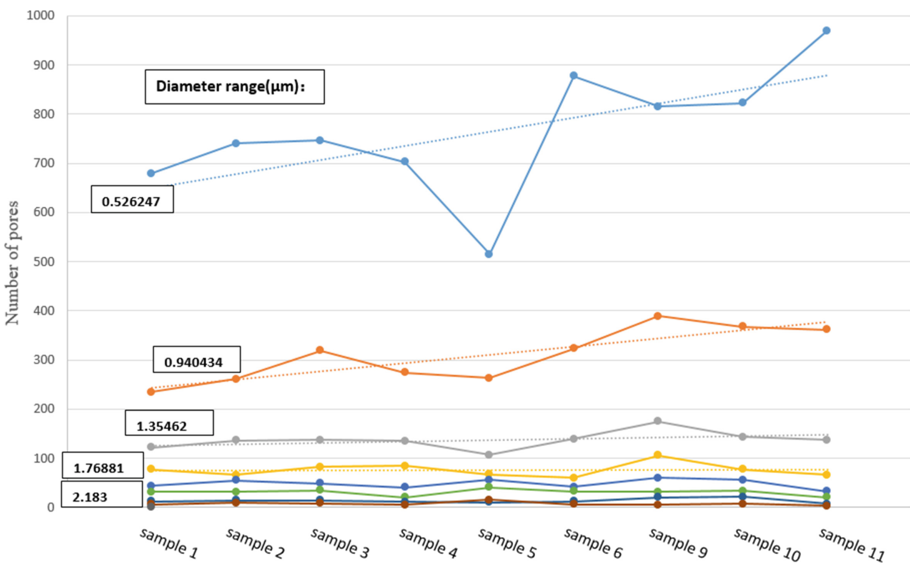


Fig. 6. Distribution of the number of pores of different diameters after MAO treatment with different stress growth rates. *Source*: developed and compiled by the authors

The results obtained show that the number of pores less than 0.526 μm is the largest (Fig. 6). A decrease in the rate of stress growth leads to an increase in the number of small pores in general.

This shows that, due to the low voltage growth rate, more fine micro-arcs are formed on the microarc oxidation surface, the breakdown is more uniform and denser, and the surface of the formed oxide coating is smoother.

This conclusion is consistent with the macroscopic observation of the oxide coating, i.e., the surface color after MAO treatment with a low voltage growth rate is lighter and whiter.

4 Conclusions

As a result of the research carried out, the following conclusions can be drawn:

1. A decrease in the voltage growth rate at the first stage of oxidation leads to a decrease in the maximum value of the current density and the maximum voltage in the passivation period, which is associated with concentration polarization. With a decrease in the rate of growth of the voltage at the anode electrode, it establishes a stable state with a slower rate of rise of potential and current, which causes a rapid accumulation of charge on the electrode surface and leads to an earlier onset of polarization.
2. Under the condition of a steady rate of increase in the anode potential on the surface of the anode electrode, the effect of the rate of voltage rise on the polarization of the anode electrode is proportional to the rate of this increase. This mutual influence can be used to plot the polarization curve by potentiostatic method.
3. The morphology of the coating surface obtained at the first stage of oxidation affects the formation of the base of the future MAO coating and may be uneven. When the MAO coating is formed at the second stage, the local accumulated potential of the electric field leads to micro explosions in the breakdown channels, which contributes to the formation of a splash-like relief.

When forming the MLM coating at the second stage, the local accumulated potential of the electric field leads to microbreaks in the breakdown channels, which contributes to the formation of a relief burst.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Development of an Intelligent Control System for an Autonomous Hybrid Solar System

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Abstract. Purpose: The purpose of the work is to form an information model in UML notation, which can be used as a basis for developing an algorithm for the operation of an intelligent control module for an automated autonomous power supply system.

Design/methodology/approach: The methodology for achieving the goal of work includes the development of a functional diagram containing the main groups of objects that make up the power supply system that supports the conversion of electromagnetic radiation into heat, according to the proposed scheme, the classification of objects over the system and subsystem of the control object with which it will work intelligent control module, a mathematical description of the interaction of classification objects, through parametric equations.

Findings: As a result, an information model is presented containing a diagram of classes in the structure of which the parameters and interrelationships between objects of an autonomous power supply system and objects of the external environment are presented, which will allow the formation of algorithmic software aimed at optimizing and increasing the efficiency of local power supply systems that support work with electromagnetic radiation converters.

Originality/value: In conclusion, an approach to the development of an algorithm for the operation of an intelligent control module of a modern solar system to increase its efficiency is presented, based on the proposed information model and assuming the use of a simulation model based on the connections proposed in the information model that describe interactions between objects of the process of converting electromagnetic radiation into warmly.

Keywords: Intelligent control systems · Optimization · Automated solar systems · UML

JEL Code: O33 · O36 · C23 · C25

1 Introduction

The efficiency of a solar plant depends on the ratio of the specific power of the system of coupled converters and the specific power of the system of coupled consuming devices. In areas with low temperatures, the most relevant are hybrid solar power plants, the configuration of which includes additional subsystems for generating energy (consuming

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non-renewable resources). If the amount of converted energy is sufficient to meet the consumption rate, the solar plant is 100% efficient. If an additional source is involved, then the percentage of efficiency decreases depending on what part of the norm is provided by an "expensive" energy source. But energy sources are only one of the groups of objects affecting the efficiency of solar plants, the parameters of the energy distribution environment also affect the parameters of the sources, in addition, it is necessary to take into account the parameters of objects within the power supply system.

In total, three groups of objects take part in the transformation process (Boldyrev et al. 2019), most of the parameters of which have a disturbing effect on the converter system, thereby limiting the process. Taking into account the identified limitations, it is possible to form an optimal control law for the system of converters to ensure high efficiency of the solar system with a minimum increase in the rate of energy consumption. In order to identify the constraints guiding the process of energy conversion, it is necessary to determine all the relationships between the parameters of the process objects. In this paper, we propose an information model in UML notation containing classes of objects involved in the process of converting electromagnetic radiation into heat, the attributes of these objects and the types of interaction between them.

2 Materials and Method

Let us define an approach to the formation of a list of objects involved in the process of converting electromagnetic radiation into heat. Consider a solar panel as the main working element involved in the conversion process. The performance of a solar panel based on a semiconductor is determined from the product of the parameters of the working surface area by thermal radiation, by the specific efficiency of the semiconductor. If the solar panel is a key element that affects the efficiency of the solar system, then it is necessary to identify objects characterized by parameters that affect its performance.

Thermal radiation is characterized by the parameters of the radiation source. If the conversion performance is directly dependent on thermal radiation, which in turn is formed from the parameters of other elements of the external environment (such as a radiation source, radiation propagation medium), then it is advisable to expand the functional diagram (Boldyrev et al. 2019) and include in consideration all objects that affect the performance of technical objects involved in the process of converting electromagnetic radiation into heat.

Figure 1 shows an extended functional diagram of a system of objects that provide the process of converting electromagnetic radiation into heat.

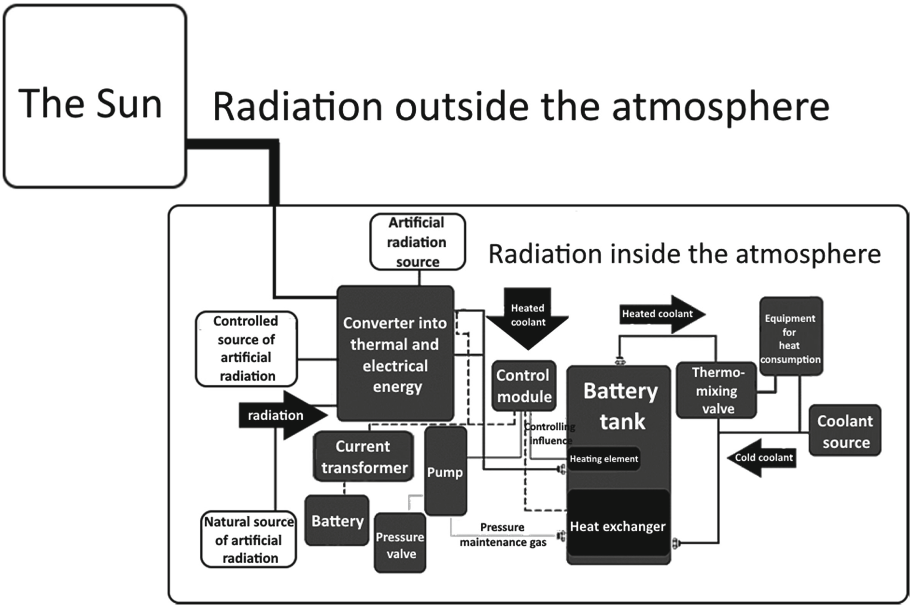

Fig. 1. Functional diagram. *Source*: developed and compiled by the authors.

The classification of the elements proposed in the figure is in Table 1.

Table 1. Classification of objects according to the law of completeness of system parts

Class "Sources"	Class "Converters"	Class "Power transmission elements"	Class "Consumers"	Class "control module"
Natural sources within the atmosphere	Converters to thermal energy based on semiconductors: - Solar panels	Under the class "Environment of propagation of electromagnetic radiation"	The heat consumption system includes: - Equipment for heat consumption (Radiators, underfloor heating systems, etc.); - Work station (pump),	Under the class "Simulation model"
Natural sources outside the atmosphere (Sun)		Heat exchange system: - Water source; - Thermo mixer; - Tank battery; - Heat exchanger;		Under the class "Information and sensory modules"
Adjustable	Converters into heat energy with a coolant include objects: - Vacuum collectors; - Flat collectors	The system for converting electrical energy into heat includes objects: - Battery; - Heating element; - Wiring - Transformer		Under the class "Optimizing modules"
Artificial sources				Under the class "Predictive modules"

Thermal radiation enters the converter (through the "Propagation Medium" energy transfer elements), which converts thermal or electrical energy transported by the corresponding system from the class of energy transfer elements to the heat consumption system, which provides the consumer with a heated coolant. Let's derive the energy equation:

$$I_{rad} * \text{Efficiency of conv.} * \text{Efficiency of trans.} - P_{cons} = P_{norm} \tag{1}$$

where

I_{rad} - thermal radiation (J/Sec.);
Efficiency of conv. - specific efficiency of converters;
Efficiency of trans.- specific efficiency of energy transportation systems;
P_{cons} - current consumption in heat consumption systems (J/Sec.);
P_{norm} - heat consumption rate (J/Sec.).

The purpose of this technical system is the conversion of thermal radiation from various sources into heat transferred by a liquid coolant, therefore, the control task in this system is reduced to regulating the operation of converters and the operation of consumption systems (Fedosov et al. 2018). The performance of the converter will be considered optimal (Rakhmatulin and Kirpichnikova 2017) when the amount of converted energy is sufficient for the consumption rate, taking into account the reduction factors of the energy transmission elements. Let us formulate the main optimization criterion (Timokhin et al. 2019) for the implementation of the control system - maintaining the performance of the system equal to the consumption rate, with a minimum consumption of irreplaceable energy. The implementation of the algorithm that forms the control rules for the optimizing modules of the autonomous solar system is the main function of the intelligent control system. The rules will be formulated on the basis of estimates of key parameters, the values of which are synthesized during the process of converting electromagnetic radiation into heat.

In the given energy equation (Falter and Pitz-Paal 2017) the efficiency parameter of the converters is expressed in terms of Efficiency of conv. Let's select the parameters of converters with p-n junction (solar panels). The solar panel power value is formed from the values of the working surface area parameter (S_{conv}), and parametrons of photocells located on this surface. Photocell parameters:

$d\lambda$ - Spectral sensitivity range (μm);
λ max - Limiting value of spectral sensitivity (μm);
Φ - Threshold of sensitivity $\Phi\left(\text{lm} * \text{Hz}^{-1/2}\right)$;

The given parameters form the value of the integral current sensitivity parameter ($S_\lambda = I_\lambda/\Phi$) ($\mu$ A/lm $*$ Hz$^{-1/2}$), reflecting the ratio of the radiation energy effectively converted by the receiver (characterizes the radiation source $I\lambda$) into another type of energy to the total radiation flux.

We get,

$$\text{Efficiency of conv. (el)} = \int S_\lambda * S_{conv}/100 \tag{2}$$

The receiver is determined by the parameters - supply voltage U_n (B), which is a component of the consumption rate (P_{norm}) and the area of the sensitive layer Sc (mm^2), which is the area of the working surface (S_{conv}). The receiver parameters can potentially be adjusted, which can be used by the control system to interact with certain radiation sources.

Energy transfer elements in a system with solar panels are determined by the parameter Efficiency of conv., Formed by the parameters of its components (Sánchez et al. 2019).

Transformer efficiency (η);
Battery efficiency (Li);
Efficiency of tubular electric heater (Heating element);

We get,

$$\text{Efficiency of trans. (el)} = \eta + \text{Li} + \text{Heating element}/100 \tag{3}$$

Next, let's select the parameters of converters with a liquid coolant (vacuum solar collectors).

$$\text{Efficiency of conv. (th)} = (\text{R}-(\text{K}_1 * \text{dT})/\ \text{I}_\lambda) * \text{S}_{\text{conv}}/100 \tag{4}$$

where

R - is the optical efficiency of the absorber;
K1 - Heat loss coefficient;
dT - Temperature difference between the heat carrier in the tube and the heat carrier of the solar system (C^0);

The optical efficiency of the absorber (R) is equivalent to the parameter (Φ), displays the ratio of the heat transfer of the absorber to the liquid heat carrier and the transparency loss of the light-transmitting coating (the nominal value indicated by the manufacturer on each model of the vacuum collector). The heat loss factor (K1) also refers to the working surface of the converter and is a nominal value related to a specific model of a vacuum collector. The temperature difference between the coolant in the tube and the coolant of the solar system (dT), a parameter determined by the energy transfer elements in the system, is (T1 + T2)/2, at;

$$\text{Efficiency of conv. (th)} = ((\text{T1} + \text{T2})/2)\ /100 \tag{5}$$

T1 - Minimum temperature at the collector inlet (C^0);
T2 - Maximum temperature at the collector outlet (C^0).

T1 takes into account the influence of the temperature of the propagation medium within the atmosphere, T2 takes into account the influence of temperature inside the elements of energy transfer.

3 Results

Figure 2 shows an information model containing classes whose attributes are parameters of objects involved in the process of transformation and work on these parameters. The main class "System for converting electromagnetic radiation into heat" is decomposed into classes in Table 1. Relationships between attributes reflect dependencies between parameters, the following of some parameters of other classes to perform class operations and implement operations in parameters of other classes.

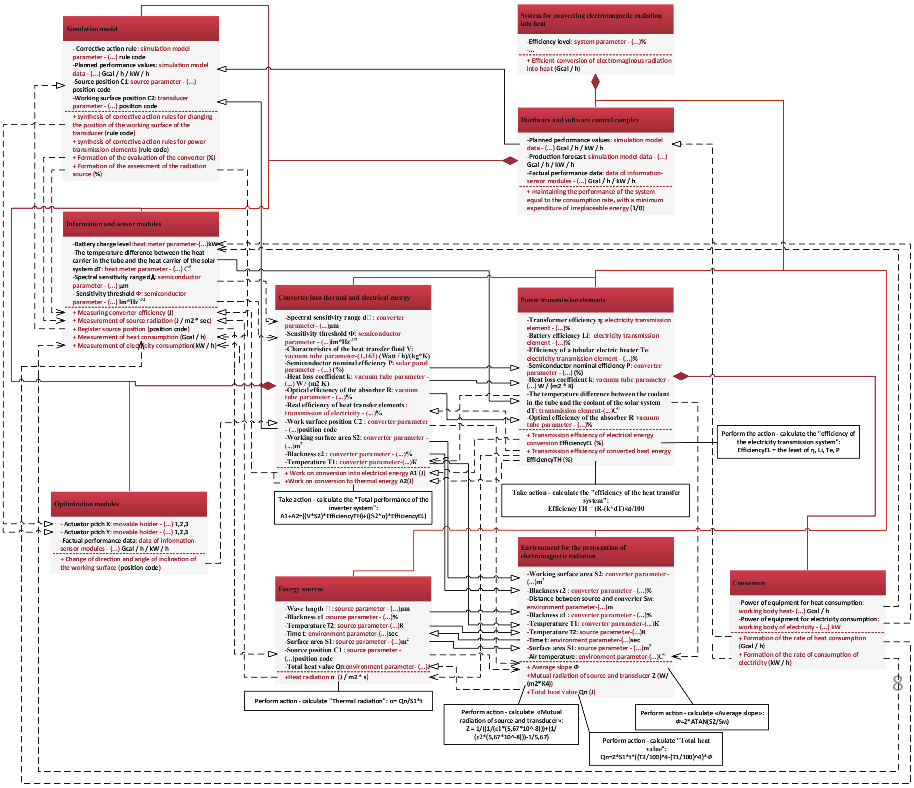

Fig. 2. Information Model UML Class. *Source*: developed and compiled by the authors.

The presented model contains the main classes of objects, the parameters of which must be taken into account when assessing the effectiveness of interaction between sources and converters. In the future, an additional decomposition of the "Hardware-software control complex" class will be presented with displaying the parameters of predictive modules and their functions. In addition, the functions of the optimization modules will be offered (Gorkavyy et al. 2018) and the method of their implementation on the holder of the working surface of the solar collector adaptable to the position of the natural source of infrared radiation (sun) (Dvoretckaiaa et al. 2020).

Figure 3 shows the "Converter into thermal and electrical energy" Class, which contains the parameters of objects that convert infrared radiation.

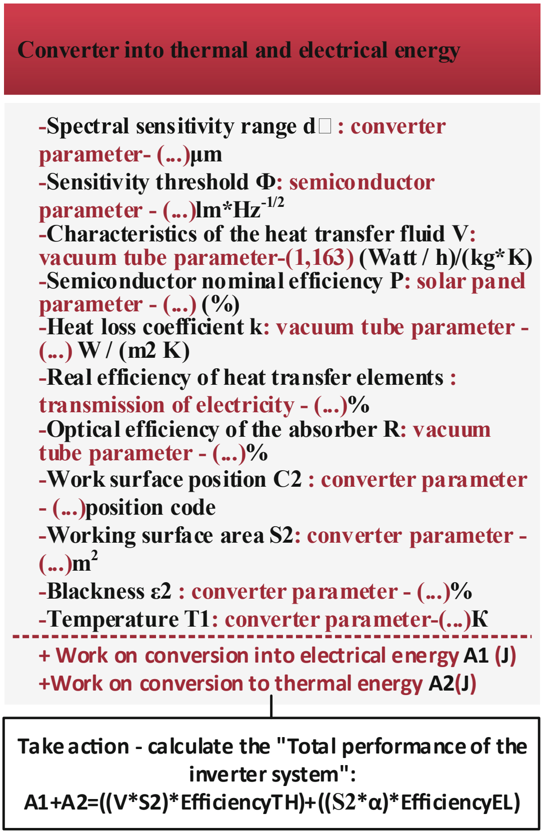

Fig. 3. Class "Converter into thermal and electrical energy". *Source*: developed and compiled by the authors.

The set of parameters of the given class, allows you to determine the total performance of the system of converters. To perform this action, parameters of other objects associated with the transducers are required. In particular, the performance is directly dependent on the source parameters. Figure 4 shows the class "Energy sources".

The set of parameters "Energy sources", allows you to calculate the thermal radiation (In'kov et al. 2017) the value of which is the main criterion for assessing the potential of the source. Thermal radiation determines the operation of the transducer and is transmitted through the propagation medium (Fig. 5).

The distribution medium is an intermediary between energy sources and converters; therefore this class mainly consists of inherited parameters. The set of inherited parameters and the parameters "Air temperature", "Time", "Distance between the source and the motor" allows you to perform actions to calculate the average slope, which determines the mutual radiation of the source and the transducer, depending on the position of the

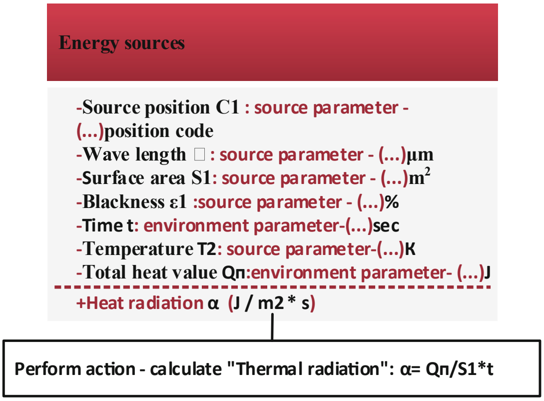

Fig. 4. Class "Energy sources". *Source*: developed and compiled by the authors.

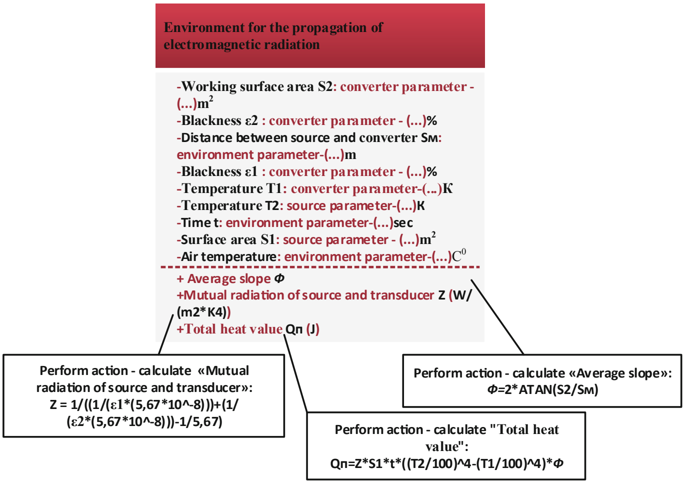

Fig. 5. Class "Environment for the propagation of electromagnetic radiation". *Source*: developed and compiled by the authors

source (Table 1). And, consequently, the total amount of heat transferred by radiation between different sources and the system of converters.

The final stage in the conversion of thermal radiation is the distribution of electrical and thermal energy among consumption elements, C^0 (Fig. 6).

Suggested actions on parameters of these classes (Sukhorukov et al. 2017), make it possible to form a mathematical model of the conversion of thermal radiation into the operation of the converter and evaluate the efficiency of their operation. A simulation model containing an algorithm for evaluating the given parameters allows determining corrective actions for optimizing modules. In the future, the proposed information model will become the basis for the development of an algorithm for an autonomous solar system with adaptable hybrid converters.

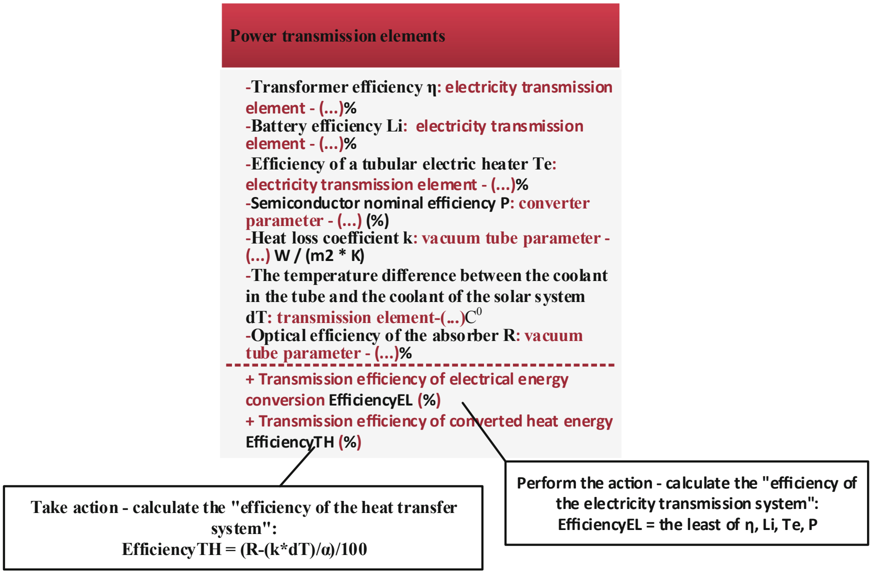

Fig. 6. Class "Power transmission elements". *Source*: developed and compiled by the authors.

4 Conclusion

The proposed information model can be applied in the development of algorithmic software for an intelligent solar control module. The proposed classes are unified frames containing attributes describing the parameters of real objects involved in the conversion of thermal radiation from various sources. The above relationships between attributes reflect interactions between objects corresponding to classes and can be used in the formation of a simulation model of processes associated with the conversion of electromagnetic radiation into other types of energy by means of objects that are part of heliosystems.

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Intelligent Control System for the Complex of Ultrasonic Gas-Oxigen Burners

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Abstract. Purpose: The control over the up-to-date processes at this stage of development of control systems is closely linked to the search for new methods which are based on the modern intelligent approaches and opportunities of implementing these systems in common process equipment, mostly in use, by applying software provided by this equipment.

Methods: The system proposed is based on different elements of conventional theories for process control and identification of control objects using the approaches centered around the fuzzy set theory, as well as dynamic and object-oriented programming.

Findings: Of this work involves developing a mathematical model of the ultrasonic lance based on existing automated process control system implemented with use of PLC followed by implementation of this system with use of an intelligent approach at the process equipment.

Originality/value: Is defined by description of a real process and implementation of an oxygen control system within the ultrasonic lance with use of the existing process equipment, and fulfillment of control procedures using a fuzzy approach.

Keywords: Intelligent control system · Programmable logic controller (PLC) · Object identification · An ultrasonic oxygen lance

JEL Code: C610 · O330 · L61 · L630

1 Introduction

The application of the ultrasonic lance in steel making has increased the metal yield while reducing the melting time. The use of different design concepts related to the shape, location and number of nozzles has significantly reduced the emissions and provided uniform oxygen supply while melting. However, it shall be emphasized that the control over the blast air flow while melting is quite difficult. One more limitation for a proper oxygen flow control is lack of an adequate mathematical model of this complex object. In order to implement the control procedures for such a complex process object, the tasks specified shall be resolved using a comprehensive solution based on the intelligent approach (Cherny and Solovyev 2017).

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In order to implement the control system of the oxygen flow in the ultrasonic oxygen lance, a control object identification procedure shall be performed.

The control object considered represents a combination of an oxyfuel burner and a lance for supersonic oxygen blasting implemented based on the supersonic lancing technology Concast Supersonic oxygen developed by Concast AG and applied with the equipment of electric arc furnace DSP 2-125, which is operated by LLC Amurmetal in Komsomolsk-on-Amur. Figure 1 shows an overview of the burner with nozzles, which introduce oxygen in the steel melting process by means of different modes (Hu et al. 1999).

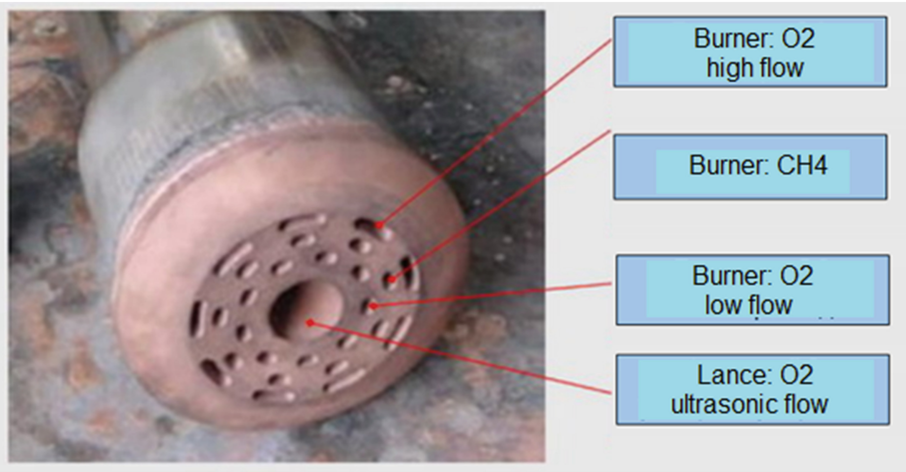

Fig. 1. Overview of Conso assembly. *Source*: developed and compiled by the authors

2 Analysis of the Existing Control System

As per the conditions and requirement for the steel-making process the burner operation mode is characterized by the constantly changing volume of the flowing gases. In order to maintain the required flow of natural gas and oxygen with desired precision, an automated control system based on SIEMENS PLC is used. This industrial logic controller allows implementation of proportional and integral control laws for each of the services, which programmatically represent identical programming module. According to the control technology and requirements for the control object, the control system implemented, particularly each of the circuits presented earlier shall ensure the following functions: bumpless switching from auto to manual mode and back, algorithmic limitation of saturation of PI integral term, algorithmic limitation of rise and fall proportional valve control signal.

In the context of classical control task resolution, the process of oxygen flow control within the ultrasonic lance is a complex non-linear system. The ultrasonic lance as a control object has several significant non-linearities, which are caused by instrument errors, delays due to filling up of the pipeline, as well as non-linearities related to description of transfer functions of the gas flow measurement channel and change in pipeline cross-section while implementation of proportional valve control (Cherny 2019).

In addition, the system as a whole is exposed to a number of disturbances, both certain, and nondeterministic disturbances, including physical processes within the arc furnace or instable oxygen pressure in the pipeline (Yao et al. 2019).

Since the existing automated control system based on standard industrial means of SIEMENS, does not provide for any kind of adjusting the PI factors, and continuous pattern of the process does not allow time to adjust them manually, problem of searching for optimal coefficients could be resolved by artificial intelligence system. However, its implementation requires a mathematical model of the control object with minimum restrictions and reduced expected uncertainty, wherever possible. The quality of identification and accuracy of mathematical description will determine the capabilities of an intelligent system and the quality of the control procedures implemented (Priyanka et al. 2018).

The identification task becomes complicated due to both continuity of the technological process and inability to eliminate the breakdown characteristics of the open-loop control system.

Considering the above mentioned factors, the control object has been identified upon the transient characteristics of the closed-loop PI system within the control loop. Figure 2 shows the structural diagram of the automated control system of CONSO ultrasonic oxygen lance (Su et al. 2019; Priyanka et al. 2018).

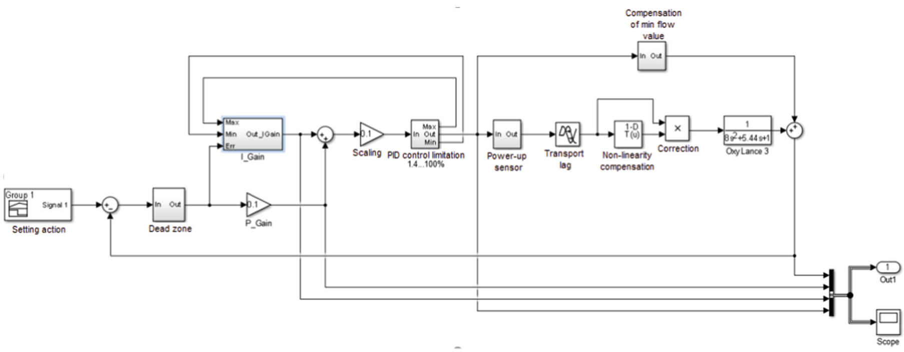

Fig. 2. Ultrasonic oxifuel lance model. *Source*: developed and compiled by the authors

According to the structural diagram in Fig. 2 the oxygen lance is described as a second-order aperiodic element with the following parameters: time constant $T = 2.82842$ s, damping factor $\xi = 0.96$, time lag $= 0.4$ s.

Non-linearity compensation unit provides correction of the gain ratio depending on the proportional valve opening rate. Gain vs valve opening rate curve is shown in Fig. 3.

The ultrasonic oxifuel lance model has been implemented using Simulink environment of MatLab engineering language. Figure 4 demonstrates the transient processes charts of a real burner, control object identified and multistage setting action, which defines delivery of oxygen into the ultrasonic lance (Susdorf et al. 2018).

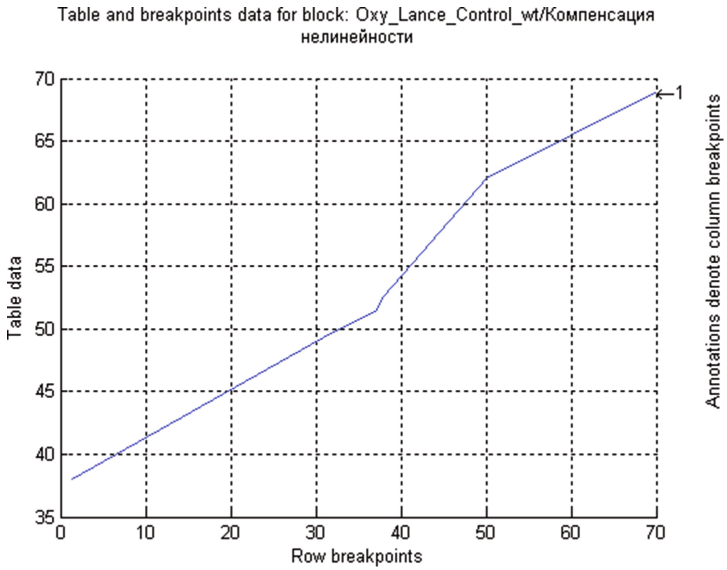

Fig. 3. Static non-linearity characteristic of control object gain. *Source*: developed and compiled by the authors

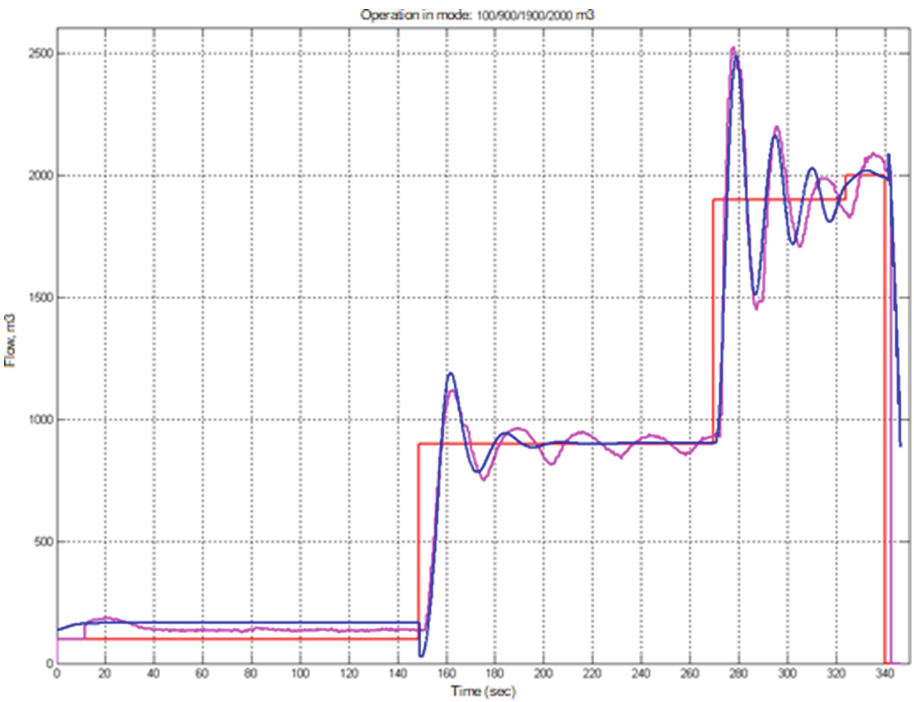

Fig. 4. Transient characteristics of oxygen flow inside of the ultrasonic lance. *Source*: developed and compiled by the authors

Figure 5 represents the transient processes charts considering the change in PI proportional term of the model identified and a real burner. Figure 6 demonstrates the change in PI integral term of the simulation model and a real burner. And Fig. 7 shows the dynamic characteristics of the PI output of a model and a real burner while multistage change of the flow rate specified (Susdorf et al. 2018).

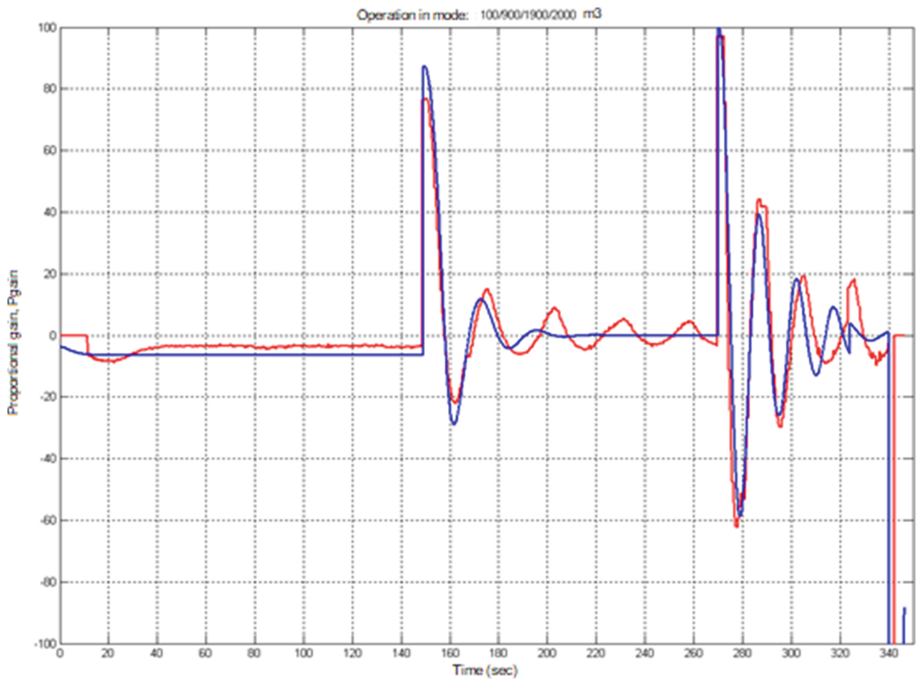

Fig. 5. The transient characteristics of oxygen flow inside of the ultrasonic lance while change in PI proportional gain. *Source*: developed and compiled by the authors

Analysis of the charts provided shows that the simulation model synthesized repeats the characteristics of a real object due to rather high accuracy. The identification of a control object - an ultrasonic oxygen lance as a second-order aperiodic element - allowed implementation of the intelligent control system and definition of PI factors providing the optimal quality indicators without any interruption in steel-making process, with the flowrate of 1900 m3/hr and overshoot reduction up to 15%. Change in PI proportional and integral terms during the tuning process is shown in Table 1 (Glazachev et al. 2018; Susdorf et al. 2017a and b):

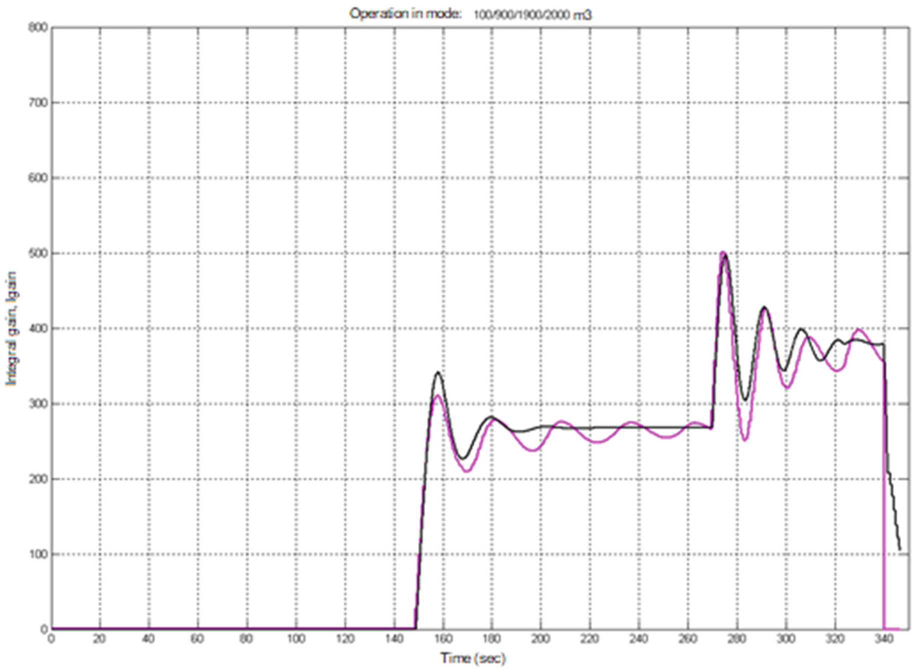

Fig. 6. The transient characteristics of oxygen flow inside of the ultrasonic lance while change in PI integral gain. *Source*: developed and compiled by the authors

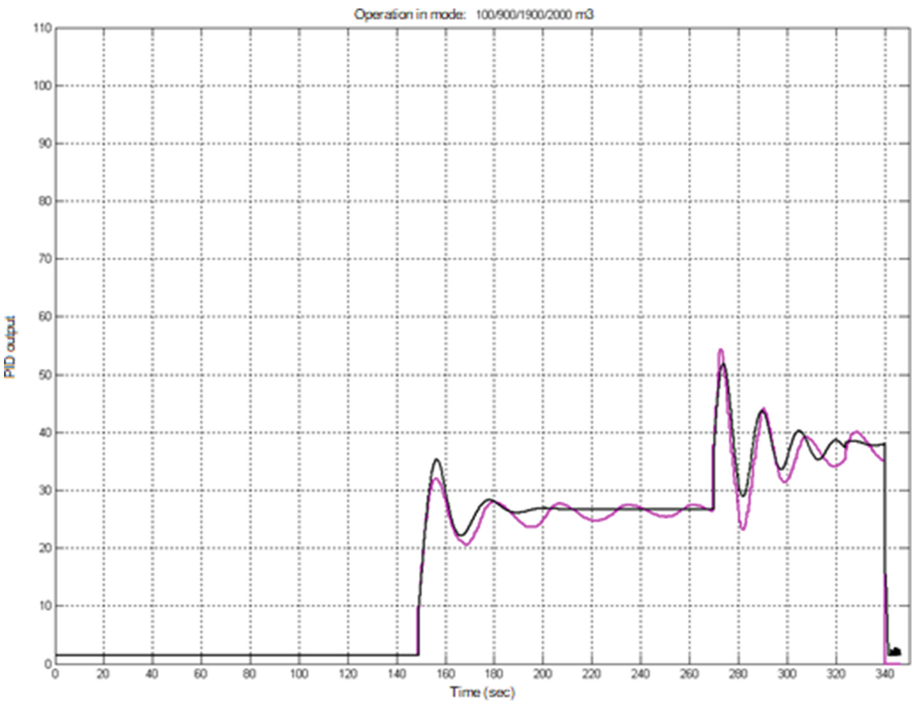

Fig. 7. Transient characteristics of controller output. *Source*: developed and compiled by the authors

Table 1.

Iteration No.	Kp	Ki
0 (base)	0.1	0.065
1	0.15	0.05
2	0.165	0.05
3	0.17	0.045
4	0.2	0.037

Figures 8, 9, 10, 11 and 12 show the dynamic characteristic of the ultrasonic lance control system while change in PI factors and multistage oxygen flow setting as obtained while tuning of the control system.

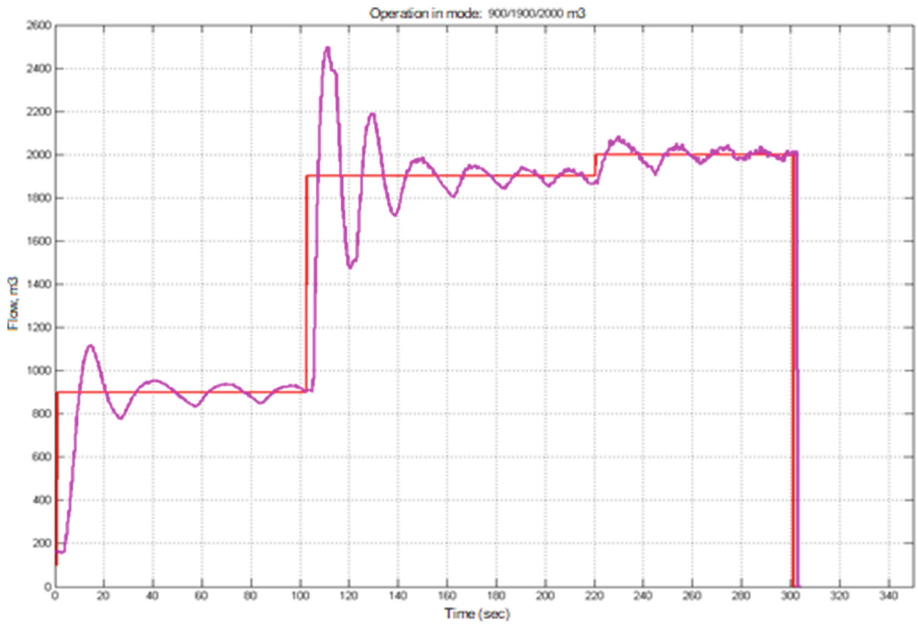

Fig. 8. Transient processes charts in the system with the following. PI factors: $K_p = 0.1$, $K_i = 0.065$. *Source*: developed and compiled by the authors.

An approach to implementation of fuzzy control system for such a complex process object will be based on several restrictions related to the features as defined by the technological process. A key task of the intelligent system will be formulation and correction of PI factors. In view of this, the basic parameters of the intelligent controller will be as follows: Sugeno fuzzy inference algorithm, triangle membership functions for input linguistic variables, number of the output linguistic variables constitutes two and is defined by PI proportional and differential terms. The knowledge base of the

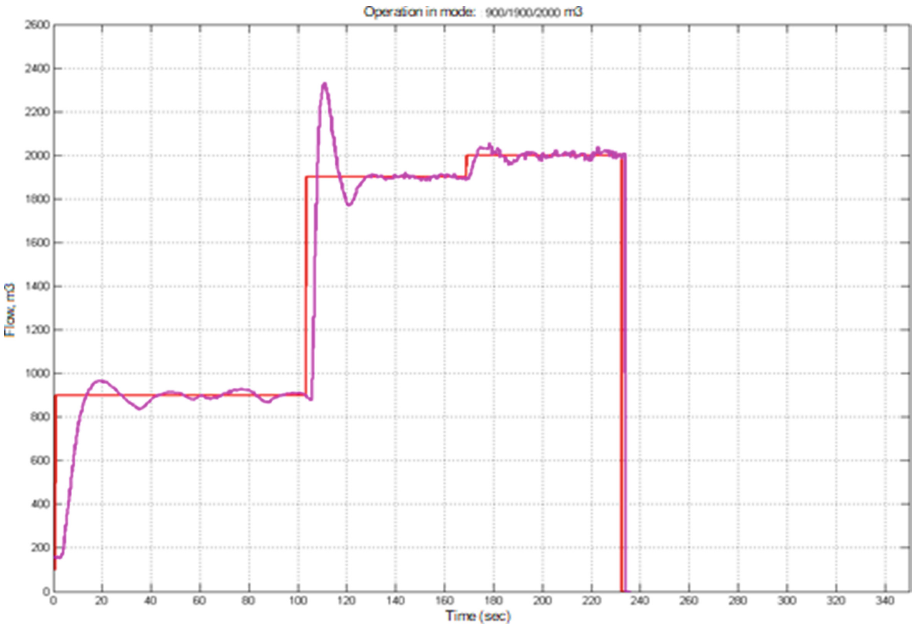

Fig. 9. Transient processes charts in the system with the following. PI factors: $K_p = 0.15$, $K_i = 0.05$. *Source*: developed and compiled by the authors

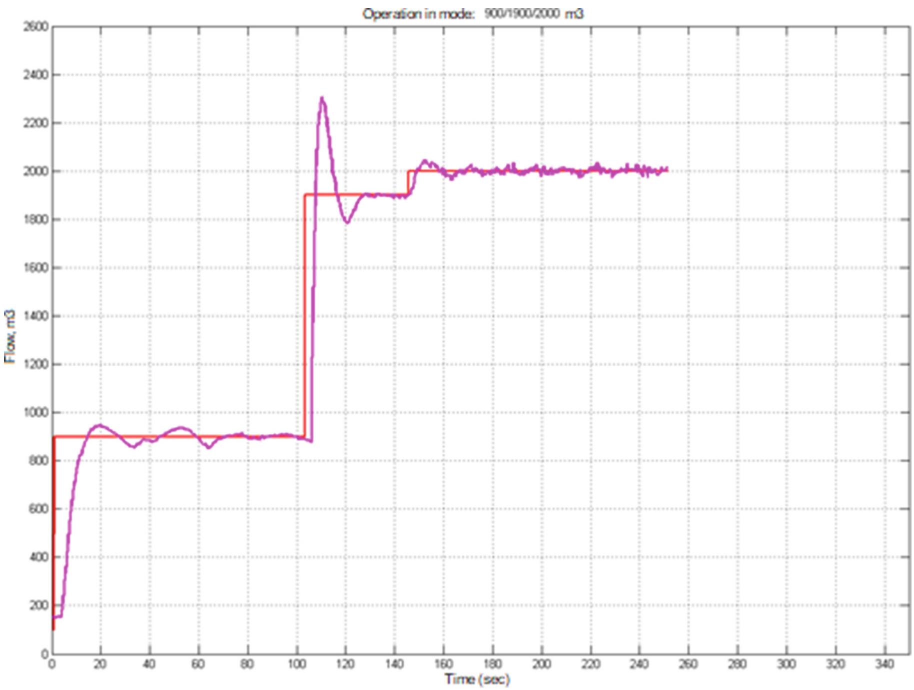

Fig.10. Transient processes charts in the system with the following. PI factors: $K_p = 0.165$, $K_i = 0.05$. *Source*: developed and compiled by the authors

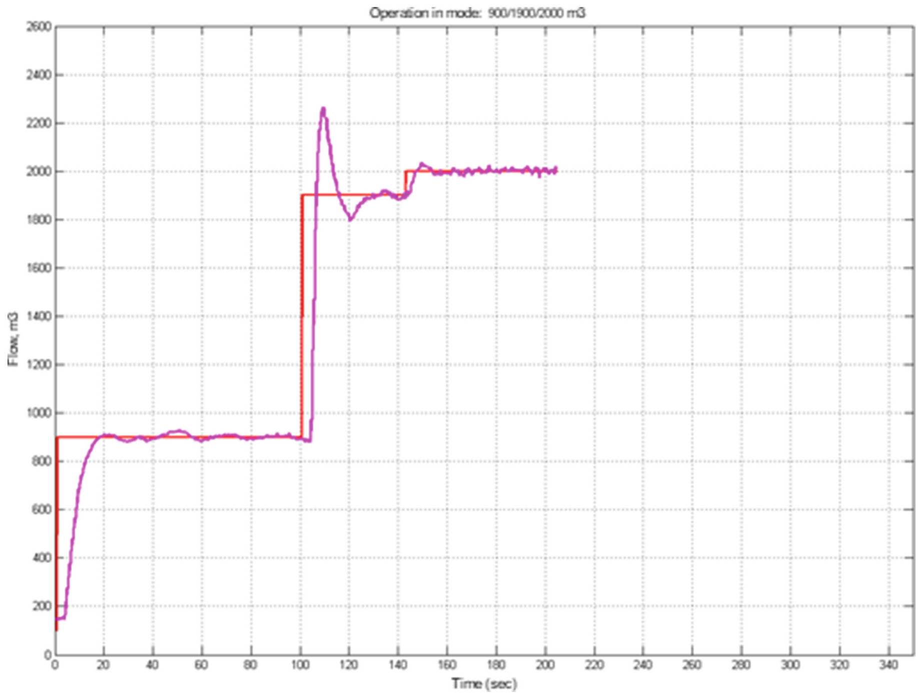

Fig. 11. Transient processes charts in the system with the following. PI factors: $K_p = 0.2$, $K_i = 0.037$. *Source*: developed and compiled by the authors

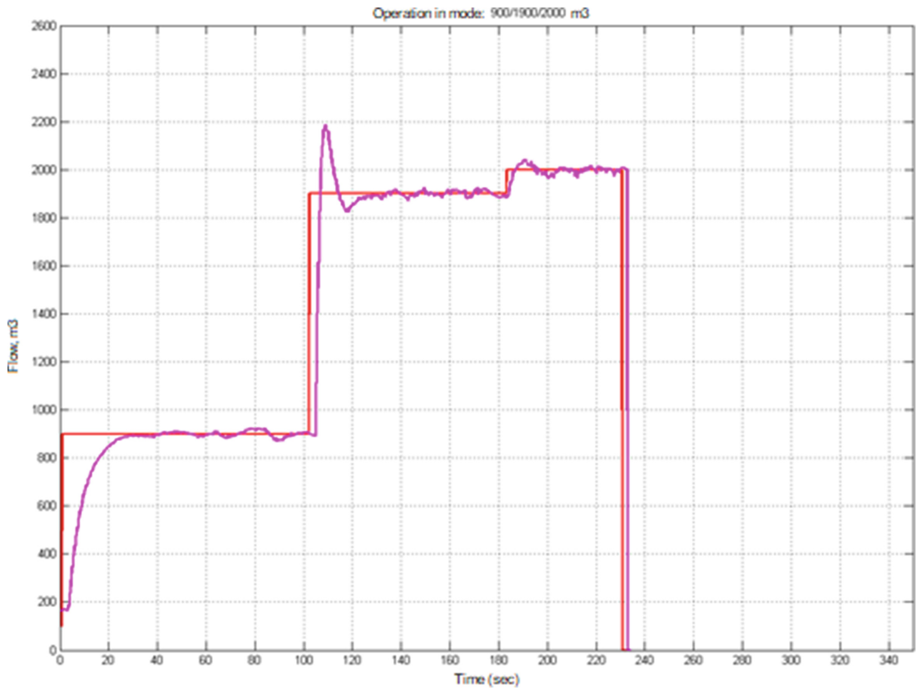

Fig. 12. Transient processes charts in the system with the following. PI factors: $K_p = 0.17$, $K_i = 0.045$. *Source*: developed and compiled by the authors

controller synthesized will be compiled by the domain experts. It will have several features targeted at resolution of a multi-objective problem as per dynamic change of the controller's control law from proportional to proportional and integral (Susdorf et al. 2017a and b; Sukhorukov et al. 2018).

3 Conclusions

The implemented model of classical oxygen flow control system in the ultrasonic lance has demonstrated its adequacy and sufficient accuracy during exercising complex multistage setting action. However, analysis of the control procedure formed by the PI controller shows that intelligent dynamic setting of proportional and integral terms is required.

Taking into account the analysis of a complex system for controlling oxygen consumption in an ultrasonic lance, it should be noted that the implementation of control procedures will be directly related to the quality of identification and mathematical description of such an object. Typical approaches to the synthesis of control procedures, implemented by classical fuzzy controllers, may turn out to be insufficient and unable to take into account the mutual influence of various coordinates of the system on each other. One of the possible solutions will be the use of a multistage control technology, which makes it possible to significantly expand the intellectual capabilities of the system while not increasing the algorithmic complexity of fuzzification blocks and the volume of the knowledge base.

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Algorithm of Fuzzy Controller Membership Function Allocation at Fuzzification Stage

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Abstract. Purposes. The modern automatic control systems represent the complexes of interacting technical devices and elements which operate based on different physical principles. Resolution of many challenging scientific and technical tasks can be simplified by using the multi-cascade fuzzy systems. Synthesis of individual modules of these complex control systems will be associated with a range of related time-consuming tasks. The approach for tuning the fuzzification blocks of fuzzy multi-cascade controllers proposed will make it possible to simplify a process of modeling this class of systems targeted at resolution of multi-objective control tasks.

Methods and approaches. Synthesis and implementation of the intelligent control system is based on integral and differential calculus elements, basic provisions of automatic control theory and standard control procedures implemented using fuzzy logic unit.

Findings: involves study and implementation of complex control laws for automation systems, which will essentially extend the intellectual opportunities while resolution of multi-objective and multifactor problems, as well as improve universality of these systems for the entire class of complex control objects. The approach for tuning the parameters of fuzzy multi-cascade systems proposed will, at the same time, reduce the efforts while the synthesis of control actions, as well as reduce the structural and algorithmic complexity of these modules with increasing the intellectual properties of automation systems as a whole.

Originality/Value: involves formulation of mathematical description of a complex multi-cascade control system considering internal and external factors, and study of different models both complex and simple multi-cascade automatic control systems, as well as implementation of multi-cascade system modeling methods taking into account all the special features of functioning of a process object.

Keywords: DC and AC drive · Multi-cascade fuzzy logic controller · Intelligent control system · Allocation of membership functions

JEL Code: C610 · O330 · L61 · L630

1 Introduction

Traditional widely-used tuning methods for automatic control systems using the fuzzy logic theory offer good results due to implementation of conventional control laws (PI

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or PID). The sophisticated weekly structured control objects require implementation of more complex control laws. These tasks can be resolved using the neural networks theory. Together with the wide range of application, they have a number of shortcomings, which come with resolution of complex, multifactor, and multi-objective tasks. Introduction of intelligent controllers into the complex process objects will allow implementation of automatic control for both the DC and AC drive systems, considering incompleteness and inconsistency of the initial data, as well as all special features and relations between the coordinates of a complex control object (Susdorf et al. 2018; Priyanka et al. 2018; Stelmaschuk and Kapustenko 2019).

2 Mathematical description of Tuning Algorithm for Fuzzification Block

More often functioning of a control object is performed either under conditions of incomplete information or significant gaps in the mathematical description both related to differential equation system, and constraints applied to the system as a whole.

Provision of qualitative control for the system with fuzzy logic controller and achievement of the output characteristics required are accompanied by a number of difficulties while tuning of the intelligent controllers: number and type of terms in the preset control range, information redundancy of linguistic variables, algorithmic complexity of production knowledge base, as well as allocation of fuzzy terms within the fuzzification block (Cherniy et al. 2018).

The complex process control objects are characterized by significant non-linearity, presence of transportation lag, time lags of the elements, as well as quite big number of control loops and cross couplings of the system. Considering those changing approaches to formalization of the control object, e.g. quality of mathematical description, presence of process optimization criteria, and presence of constraints due to process requirements, synthesis of the control system based on the intelligent approach is required.

Dynamics of the fuzzy automatic control system for the complex process objects can be described by differential equation system as follows:

$$\dot{x}(t) = A(t)x(t-\tau) + B(t)u(t) + G(t)w(t-\theta) + H(x(t)),$$

where *A(t)* is a system matrix,

B(t) is a control matrix,
G(t) is a perturbation matrix,
x(t) - system status coordinates,
u(t) is a control system,
w(t) is a perturbation action,
τ is a lag factor based on the internal parameters of a control object,
θ is a lag factor based on the external perturbation actions,
*H(*x*(t))* is a term based on non-linear properties of a control object.

Synthesis of fuzzy control system with Mamdani inference algorithm is based on three interrelated stages of soft computation theory: fuzzification, formulation of a production knowledge base, defuzzification (Susdorf et al. 2019).

A production knowledge base of the intelligent controller for n-dimensional input and one-dimensional output may be as follows:

Hypothesis: If x_1 is $A^m{}_1$ then … and x_n is Amn,
Rule: If x_1 is $A^1{}_1$ and … and x_n is $A^1{}_n$ then u is B^1,
Conclusion: u is $B^{'}$,

where $[x_1, x_2, \ldots, x_n]^T = \bar{x}$ is an input vector,
u is a scalar value of the control signal.
X_i is a universum for each linguistic variable x_i, and U is a universum of u accordingly. Considering that i-variables are designated as x_i and u through A_i^j and B^j $j = \overline{1, m}$ correspondingly, we obtain the values of membership functions $\mu_{A_i^j}(x) : X_i \to [0, 1]$ and $\mu_{B^j}(u) : U \to [0, 1]$.

A fuzzy relation for each production rule will be determined as follows:

$$\left(A_1^j \text{ and } A_1^j \text{ and} \ldots \text{ and } A_n^j\right) \to B^j;$$

$$\mu_{R^j}(x_1, x_2, \ldots, x_n, u) = \mu_{A_1^j}(x_1)\mu_{A_2^j}(x_2) \ldots \mu_{A_n^j}(x_n)\mu_{B^j}(u);$$

Fuzzy relation R for m-rules will we determined by the following equation:

$$\mu_R(x_1, x_2, \ldots, x_n, u) = \max_{j=1}^{m} \mu_{R^j}(x_1, x_2, \ldots, x_n, u).$$

In case the input linguistic variables x_i accept the fuzzy sets $A_i^{'}$, $i = \overline{1, n}$, the fuzzy set B' of the control system linguistic variable is determined by means of concise display. A membership function for B' is as follows:

$$\mu_{B'}(u) = \max_{x_1, x_2, \ldots, x_n} \left\{ \left[\prod \mu_{A_i'}(x_i)\right] \cdot \left[\max_{j=1}^{n} \left[\prod_{i=1}^{n} \mu_{A_i^j}(x_i)\right] \cdot \mu_{B^j}\right] \right\}.$$

Suppose fuzzy subsets B^j are as follows:

$$\mu_{B'}(u) = \begin{cases} 1, & u = \lambda^j \\ 0, & u \neq \lambda^j \end{cases};$$

where λ^j are discrete numeric values of the output signal (Savelyev and Gudim 2018; Kudinov et al. 2004). Then:

$$\mu_{B'}(u) = \begin{cases} \prod_{i=1}^{n} \mu_{A_i^j}(x_i), & u = \lambda^j \\ 0, & u \neq \lambda^j \end{cases}.$$

Applying the central square method at the stage of defuzzification, we obtain an equation for determination of the control signal value:

$$u = \frac{\sum_{j=1}^{m} \lambda^j \left[\prod_{i=1}^{n} \mu_{A_i^j}(x_i)\right]}{\sum_{j=1}^{m} \prod_{i=1}^{n} \mu_{A_i^j}(x_i)}.$$

Considering that

$$\zeta_j(\overline{x}) = \frac{\prod_{i=1}^{n} \mu_{A_i^j}(x_i)}{\sum_{j=1}^{m} \prod_{i=1} \mu_{A_i^j}(x_i)},$$

the formula for determination of fuzzy logic controller output (control signal) will be as follows:

$$u(\overline{x}, \overline{\lambda}) = \sum_{j=1}^{m} \lambda^j \zeta_j(\overline{x}) = \overline{\lambda}^T \zeta(\overline{x}).$$

In case the multi-cascade control technology is used (the structural diagram is shown in Fig. 1), the output signal will be formed as follows:

$$\vec{u} = \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix} = \sum_{i=1}^{k} u_i(\overline{x}, \overline{\lambda}),$$

where k is a number of internal cascade modules.

The formula specified for determination of the output signal for multi-cascade control technology is characteristic for the intelligent automated control system tuned with the use of Mamdani fuzzy inference algorithm. For external cascade controller of DC and AC drive control systems, application of Sugeno fuzzy inference algorithm is more reasonable. While synthesis of Sugeno-type intelligent controller the summation operator degeneration will be observed, and thereafter this sign can be substituted by the superposition operator.

$$\vec{u} = \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix} = \begin{matrix} k \\ sup \\ i = 1 \end{matrix} \; u_i\left(\overline{x}, \overline{\lambda}\right).$$

Therefore, in case of complete and consistent knowledge base, according to the equation obtained the fuzzy logic controller can be described as a product of two functions defined by type and allocation over the membership function control range and fuzzy inference algorithm selected, taking into account all fuzzy elements in all cascades (Mishra and Mohanty 2019; Kannan et al. 2017; Li et al. 2005).

Considering that the control object is described by simplified mathematical expressions, and the optimization criteria are known, we can find the expression for the control action which ensures the quality indicators required. In general, the quality functional which is the basis for achievement of control action, is as follows:

$$J = \int_0^{\infty} \left[m^2 \gamma^2(\Psi) + c^2 \dot{\Psi}^2(t)\right] dt;$$

where m, c are constant factors.

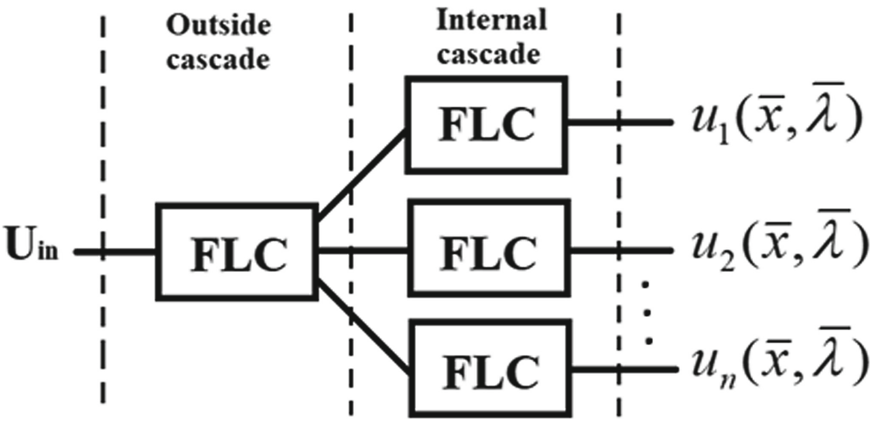

Fig. 1. Structural diagram of multi-cascade fuzzy control system. *Source*: developed and compiled by the authors.

$\Psi(t)$ is an arbitrary differentiable or piecewise continuous function, and $\Psi(0) = 0$,

$\gamma(\Psi)$ Is a single-valued, continuous, differentiable $\forall\Psi$ function, whereby $\gamma(0) = 0$ and $\gamma(\Psi) \cdot \Psi < 0$ while $\forall\Psi \neq 0$.

Minimizing this functional requires the following output signal from the fuzzy logic controller:

$$u = -\frac{1}{b}\left[\frac{\partial\Psi(\overline{x})}{\partial x_n}\right]^{-1}\left[\frac{1}{T}\gamma(\Psi) + \sum_{k=1}^{n}\frac{\partial\Psi(\overline{x})}{\partial x_k}f_k(\overline{x})\right].$$

If consider that the knowledge base is complete and consistent, then the fuzzy logic controller will allow implementation of the control law most closely approximating the required control law and depending from $\overline{\lambda}$ and $\zeta(\overline{x})$. Considering that the vector $\overline{\lambda} = const$, synthesis of the intelligent controller can be down to optimum allocation of membership functions with their fixed amount.

During synthesis of fuzzy control system for achievement of the targeted performance and response speed indicators the control criterion can be set as follows:

$$J = \begin{bmatrix} J_1 \\ \vdots \\ J_z \end{bmatrix} = \bigcup_{i=1}^{z} J_i.$$

where z is a number of preset control criteria.

The control criterion ensuring implementation of the control procedures required for the entire range of indicators, e.g. response speed and power saving, can be expressed as follows:

$$J = \begin{bmatrix} J_1 \\ \vdots \\ J_z \end{bmatrix} = \bigcup_{i=1}^{z} J_i.$$

Application of multi-cascade fuzzy control technology allows resolution of control task for the complex object, considering not only complexity of mathematical description and expected uncertainty of initial data but also varieties of interrelated criteria and restrictions applied to the system as a whole.

Application of logic and mathematical approach to synthesis of fuzzy logic controller is related to allocation of membership functions over the control range and their type.

An algorithm of searching for the type and shape of membership functions shall ensure the quality if control action obtained considering the above mentioned assumptions and the inference algorithms acknowledged.

With the preset control action the task will come down to searching for desired onto function, which would cause a number of restrictions.

1. We will assume that desired control law is implemented with one input signal of the fuzzy controller. The second input signal may be later considered as correcting.
2. As soon as in the most of stable control systems for heating processes the type of dynamic transient processes can be narrowed down to two types (aperiodic and oscillating), the further discussions will be for these cases (Kumar et al. 2016).

To prove that, we will review the coordinate frame specified in Fig. 2. The right part thereof represents ȹ unit square $x \rightarrow [0; 1]$ and $y \rightarrow [0; 1]$.

The diagonal of the square is a basic onto function φ_0 or onto axis, so that the membership functions evenly distributed along the x-axis are reflected on the y-axis and are not subject to any changes. Suppose that an output signal of the intelligent controller predicted or obtained from any other considerations, being a control signal, looks as in Figs. 2 a,b and 3.

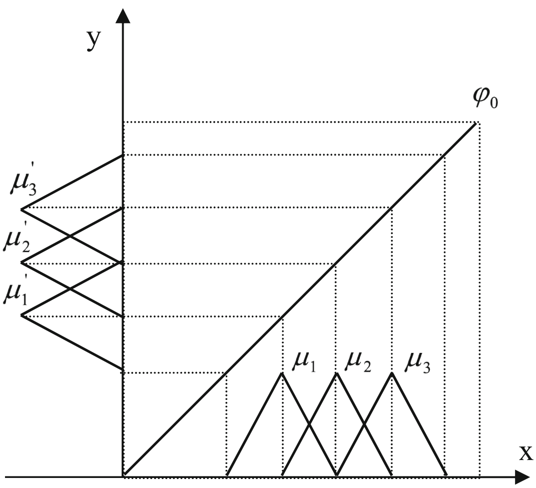

Fig. 2. Generalized coordinate frame. *Source*: developed and compiled by the authors.

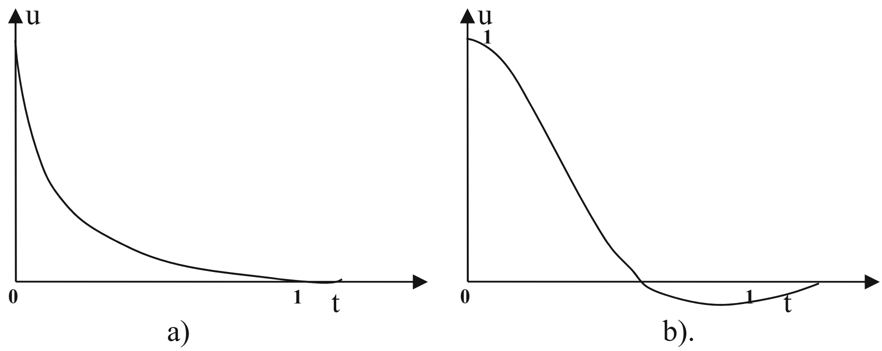

Fig. 3. Control laws. *Source*: developed and compiled by the authors.

Convert the control signal, e.g. (b) into following function $\varphi = u(-t)$ that corresponds to penetration of the control system through the fuzzy controller structure in the opposite direction (Fig. 4).

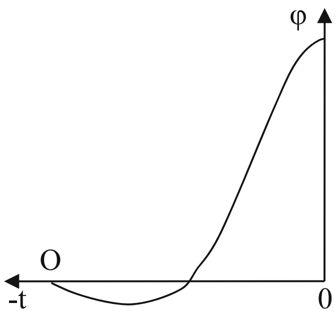

Fig. 4. Converted control signal. *Source*: developed and compiled by the authors.

Considering that the output signal of the controller tend to zero at the end of the transient process, the onto function shall tent to its normal value. Orient this function in the right part so that the tangent to O-point determined the angle of coordinate system of onto function φ. This tangent is x-axis (Fig. 5) (Mar and Lin 2005).

This type of onto function will change the evenly allocated membership functions over the entire range accumulating them near zero and spreading them in the extreme points accordingly (Abilov et al. 2002).

As soon as the membership functions synthesized near origin of coordinates stretch into a line, it is reasonable to finish their construction (for amount greater than 9) after the value x' in the area corresponding to the classical transient process end area. On the other hand, the use of a big amount of membership functions (≥9) is groundless as it results in a significant increase in algorithmic complexity of the fuzzy logic controller and information processed (Wang and Wu 2020).

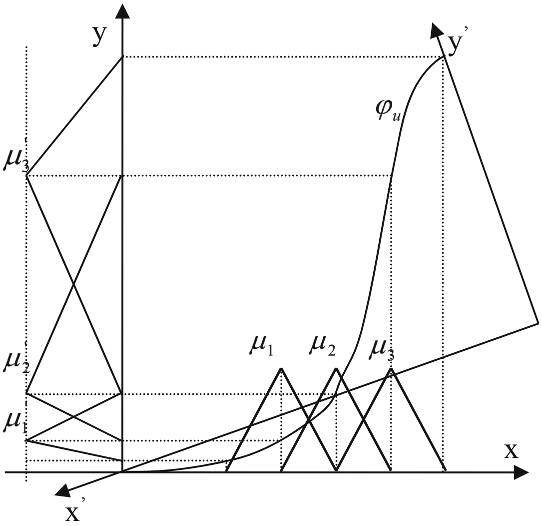

Fig. 5. Coordinate frame of membership functions. Source: developed and compiled by the authors.

Implementation and modeling of fuzzy control systems for AC/DC drives are based on the method focused on multi-cascade control technology which allows significant enhancement of functional and intellectual capabilities of these systems and reduction of time efforts during implementation of control systems based on intelligent technologies under conditions of incomplete information about the object and significant gaps in the mathematical description.

3 Conclusions

Introduction of multi-cascade fuzzy controllers into DC/AC drive control systems allows implementation of control laws of any complexity and achievement of qualitative transient processes. The first cascade performs an expert estimation of the controller, while the second cascade directly generates the control action upon the control object. The both cascades are focused on different domain, so that the control signal becomes more variable considering the changes in system parameters. The main advantage of the control system with use of soft computing is that it is flexible and robust to variety of external and internal actions. The methods of tuning and allocation of membership functions within the fuzzification blocks of the fuzzy logic allow simplifying the synthesis of these systems notwithstanding the inference algorithms and their combinations selected.

The main advantage of a soft computing control system is its flexibility and robustness to a variety of external and internal influences. The technique of tuning and distribution of membership functions in fuzzification blocks of a fuzzy multistage controller makes it possible to significantly simplify the process of synthesis of such complex systems, regardless of the selected inference algorithms and their combinations (Torreglosa et al. 2011).

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High-Speed Energy-Efficient Power Sources for Electromechanical Systems

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Abstract. Purpose: Research and analysis of energy and dynamic characteristics of energy-efficient high-speed AC-to-DC converters with multiple semiconductor switching during supply voltage period.

Methodology: In order to find the analytical expressions describing the control and energy characteristics of single-phase and three-phase converters with multiple valve switching, the electrical methods, integral calculus and Fourier series have been used. The dynamic indicators have been calculated based on Matlab simulation modeling.

Results: The control characteristics of the converters under consideration have a good linearity and steepness growing due to increase in valve switching ratio, that indirectly indicates the growing response speed of these converters with increase in switching ratio. The power factor of the converters with multiple valve switching within the entire control range of average rectified EMF, except for its terminal points, is greater than the power factor of controlled rectifiers with natural thyristor commutation. Control frequency pass band for circuit level 0.7 of the electric drive with a single-phase bridge-circuit rectifier with natural valve commutation is not less than 5 Hz; and for the current circuit based on the converter with load connection ratio of 20 it is much wider - not less than 30 Hz.

Conclusion: The converters under Consideration should be used in high-speed DC drives of medium power, operating in modes of frequent reversals or in long-term braking modes.

Keywords: Converters with multiple valves switching · Power factor · Control characteristics · Pass band · Simulation modeling · Current circuit

JEL Code: O30

1 Introduction

A DC motor is featured by good control properties, big torque capacity, ability to operate in the second control band with the speeds significantly higher than the rated speed, possibility to manufacture the motors with a greater rated power. Considering the above mentioned advantages the DC motors are still widely used in various machineries. The tasks of improving the energy and dynamic indicators of DC drives are relevant and are

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solved through the different methods, e.g. as shown in Aung and Suzdorf (2018), Aung et al. (2016). However, the response speed and static accuracy of DC motors depend heavily on the characteristics of the controlled power source utilized for motor power supply.

50 Hz AC power grid is usually used as a primary power source in the drive systems. In this case, the thyristor controlled rectifiers based on ordinary natural commutation thyristors can be used as power sources in the controlled drive systems, especially of high and medium power. These power sources are featured by small cost per power unit, good operating reliability, over-current resistance, ability to provide the rectifiers for large currents and voltages without need to use a big amount of semiconductors connected in parallel or in series (Perelmuter and Sidorenko 1988).

However, the lags which occur in this kind of power sources due to incomplete controllability of thyristors and rectifier control resolution (Pozdeyev 1975) greatly reduce the response speed of thyristor rectifiers, which is particularly evident while relatively small power supply line frequency. The lags due to control resolution can be reduced by means of reducing the discrete intervals of the rectifiers, e.g. by means of increasing the power supply line frequency or increasing the rectification pulse number. The lags due to incomplete controllability of the thyristors in the natural communication rectifier circuits can be only reduced by means of increasing the power supply line frequency. Increasing the frequency of industrial power networks is almost unachievable for well-known technical and economic reasons. Increasing the rectification pulse number beyond six will require over-sophistication of the rectifier power circuit, and is not always reasonable for technical and economic reasons.

The specific feature of the phase control of the average value of rectified voltage is related to alteration of the angle between the first harmonics of the line current and line voltage during rectified voltage control, that results in reduction of power factor of the thyristor rectifier while reduction of the rectified voltage. For this reason, the average power factor can be very low (approximately 0.3 to 4) for the electric drives operating in the lower portion of the speed control range or for the frequently reversed electric drives. (Mayevski 1978).

The above mentioned deficiencies can be very difficult to be eliminated, if single-phase AC networks are used as primary power sources, for which the rectification pulse number more than 2 cannot be achieved through the circuit design applied.

The most efficient method of improving the dynamic and static indicators of AC-powered DC drives is the use of AC-to-DC converters based on fully-controlled semiconductor valves (Sidorov and Mishin 1979). The most commonly used in this case are the pulse-width converters (Herman-Galkin 1979) connected to AC network via the non-controllable rectifier. With such a structure of a power portion there are some difficulties related to output of the braking motor energy to the AC line. Even while the short-time transient processes during the motor reverse, pretty large capacity of the rectifier filter capacitor is required, which also serves as an energy buffer of the braking motor. In case of continuous braking modes, it is impossible to use just one filter capacitor. The elements of a power circuit are required, which are capable to give up the energy or dissipate the energy as a heat.

The use of energy recuperators which return the energy of a braking motor into the AC line, will make the motor power circuit more sophisticated, and, considering electricity prices, makes more sense while possible continuous braking modes and motor output of about 75 kW. The most commonly used are the simple circuits, which dissipate the braking energy on the braking resistor as a heat, and have a decreased efficiency factor while operation with a large portion of braking modes.

All-round improvement of the energy and dynamic indicators of the con-trolled DC drives can be achieved by means of using the active rectifiers in order to power them (Kishore 2018; Davari et al. 2018). The power circuits of these active rectifiers are based on the fully-controlled semiconductor valves, and the control methods of the active rectifiers are various.

2 Methodology

To enhance the energy and dynamic indicators of the controlled DC drives, the converters with multiple semiconductor switching during voltage supply period in the AC line can be used to power their armature windings. Those are active rectifiers and are also called multiple valve switching converters. Due to the pulse-width control of the average rectified voltage and lack of DC element within such a converter (in the form of a non-controllable rectifier with a smoothing filter), the multiple valve switching converters are essentially pulse-width converters directly connected to the AC line. Meanwhile, their response speed is close to the response speed of the pulse-width converters while maintaining the simple energy exchange between the DC motor and AC line in all the operating modes of the motor (Piskarev and Dmitriev 1980; Kuznetsov 1979).

The application of the bridge circuits for implementation of the multiple valve switching converters is the most appropriate due to the known benefits. The converters shall be reversible, i.e. easily implemented in the fully-controlled AC transistor keys. Figure 1 gives the examples of the circuits of fully-controlled AC transistor keys, and the circuits of reversible single-phase and three-phase multiple valve switching converters built on these keys.

During operation of the bridge multiple valves switching converter the load is frequently connected to the network line voltages during voltage supply period, and disconnected from the network voltages followed by short-circuiting. The load is connected to the line voltages through the appropriate couple of odd- and even-numbered bridge keys, and short-circuited through the pair of anti-phase keys and an individual load-shunt key. With such a control an instantaneous load voltage represents a pulse sequence. The pulse peaks are formed by the links of line voltages in the intervals of connection to network. In the intervals between the pulses corresponding to intervals of load disconnection, the load voltage is zero.

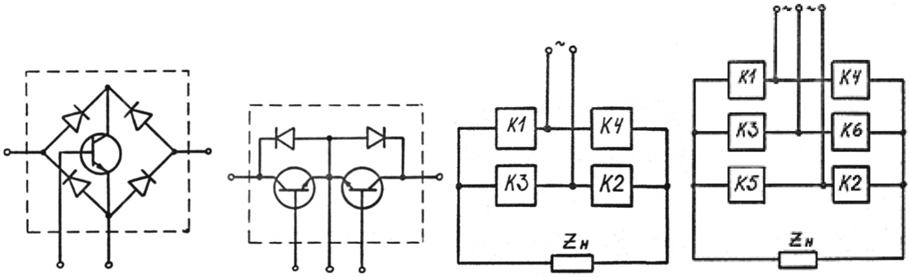


Fig. 1. Circuitries of AC keys and AC key-based converters. *Source*: developed and compiled by the authors

Figure 2 shows the diagrams of instantaneous rectified voltages (electromotive forces, hereinafter - EMF) in the diagrams of the multiple valve switching converter for the rectifying and inverter modes while the instantaneous commutations of the keys and one of possible control methods.

The average value of rectified EMF is adjusted by changing the correlations between the durations of EMF pulses and pauses between them. If during adjustment of the average rectified EMF the pulses of instantaneous EMF remain symmetrical about the vertical axis drawn through the line voltage peak, the multiple valve switching converter will operate without consuming the reactive power from the network. Should the pulse sequence of the rectified EMF be moved to the left or to the right in relation to the axis specified, generation of the reactive power into the network or consumption from the network will be observed.

An average EMF can be adjusted under the load by both the simultaneous changing the pulse front phase and falling edge phase relative to the network volt-age phase, and by changing the pulse front phase or falling edge phase only. The simultaneous changing the pulse front phase and falling edge phase of rectified EMF is more preferable, since it is time-optimal.

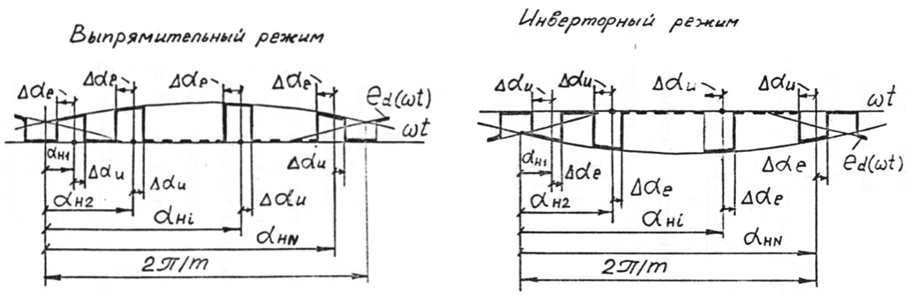


Fig. 2. Rectified EMFs of the multiple valve switching Converter. *Source*: developed and compiled by the authors.

The following designations are used: ω is a pulsation of supply voltage, m - a rectification pulse number, t - actual time, e_d - instantaneous rectified EMF α_{Hi} =

$\frac{\pi}{mN}(2i - 1)$, $i = 1, 2, 3 \ldots N$ - the initial values of activation angles, where the average value of rectified EMF is equal to 0, $\Delta\alpha_e$, $\Delta\alpha_u$ - variation of the activation angles relative to their initial values.

After integrating the instantaneous rectified EMFs shown in Fig. 2 in the interval of $2\pi/m$ and simple transformations, we obtain the equation of the control characteristic for the multiple valve switching converter, which can also be applied for both the rectifying and inverter operation modes.

$$E_d = \frac{E_{d0}}{2\sin\frac{\pi}{mN}}[\sin(\Delta\alpha_u) - \sin(\Delta\alpha_e)]$$

In the latter equation: E_d is an average value of rectified EMF, $E_{d0} = \frac{m}{\pi}\sin\frac{\pi}{m} \cdot E_m$ is a maximum value of average rectified EMF, where E_m is an amplitude value of the instantaneous rectified EMF of the converter, which is equal to line network voltage amplitude in the bridge circuits.

The latter equation in power units will be as follows:

$$\overline{E_d} = \frac{E_d}{E_{d0}} = \frac{1}{2\sin\frac{\pi}{mN}}[\sin(\Delta\alpha_u) - \sin(\Delta\alpha_e)]$$

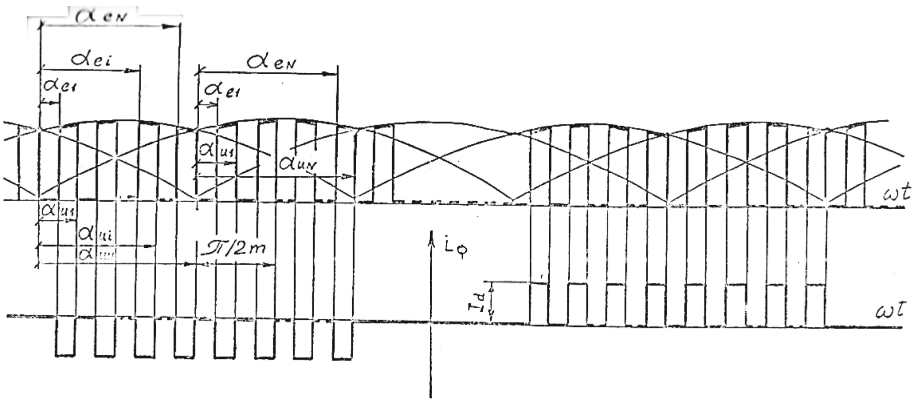


Fig. 3. Rectified EMF and phase current of three-phase bridge converter. *Source*: developed and compiled by the authors

Figure 4 and 5 show the rectified EMF and the phase current within the three-phase bridge and single-phase single-way connections of the multiple valve switching converter while the induction load and instantaneous key commutations.

To determine the energy indicators of the multiple valve switching converters as shown in Fig. 3 and 4, the phase currents are decomposed into Fourier series during their repeat period. Based on this decomposition, find the root-mean-square current of the fundamental phase current harmonic, phase-lag angle of the fundamental supply voltage harmonic and fundamental harmonic of the converter phase current. Considering that the higher harmonics are not present in the network voltage, determine the total

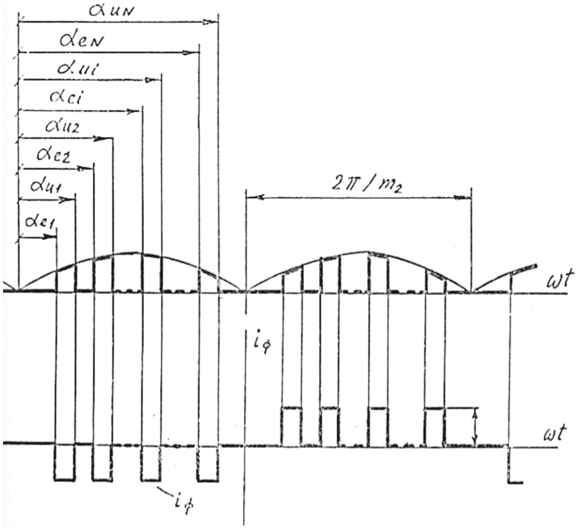


Fig. 4. Rectified EMF and phase current of single-phase bridge converter. *Source*: developed and compiled by the authors

power consumed by the converter from the line, total power of the fundamental current harmonic of the converter, active power, reactive power, distortion power, as well as power factor.

For one of the control methods for multiple valve switching converter, when the activation angles $\alpha_{иi}$ can be represented as $\alpha_{ei} = \alpha_{Hi} + \Delta\alpha_{e}, \alpha_{иi} = \alpha_{Hi} + \Delta\alpha_{и}$, the proportion $\Delta\alpha_{и} = -\Delta\alpha_{e} = \Delta\alpha$ shall be kept between the activation angles within the entire control range, and the converter shall not consume the reactive power from the supply line. Considering rather extended but simple calculations above, we have the following relative energy indicators for three-phase and single-phase multiple valve switching converters expressed as a function of the relative average value of rectified EMF.

$$\overline{E}_{d} = \frac{E_{d}}{E_{d0}}$$

For three-phase bridge converter:
power factor is

$$\chi = \frac{2\overline{E}_{d}\sin\frac{2\pi}{m}}{\sqrt{2\pi N \arcsin\left(\overline{E}_{d}\sin\frac{\pi}{mN}\right)}}$$

For single-phase bridge converter:
power factor is

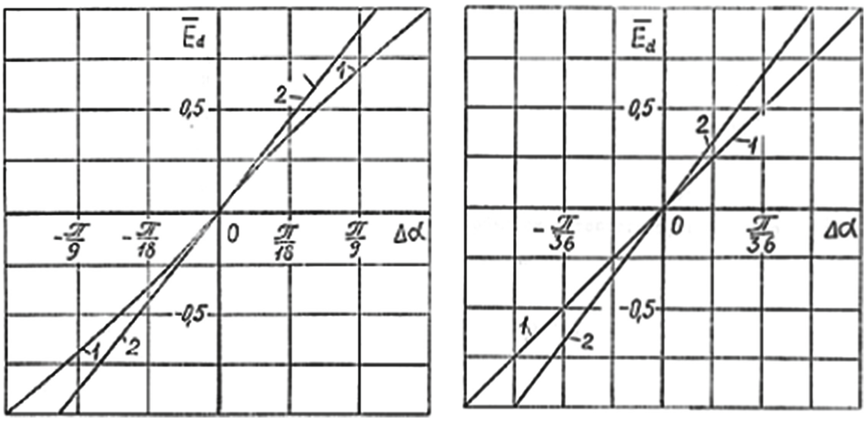
$$\chi = \frac{2\overline{E}_{d}\sin\frac{\pi}{m}}{\sqrt{\pi N \arcsin\left(\overline{E}_{d}\sin\frac{\pi}{mN}\right)}}$$

The rectification pulse number for three-phase bridge converters will be as follows: m = 6, and for single-phase bridge converters it will be as follows: m = 2.

To compare the response speed of single-phase and three-phase bridge converters with multiple valve switching and general controlled rectifiers with natural thyristor commutation used as power sources for electric DC drives, we performed the calculations of the transient processes within the current control circuits of DC motor armature using the Matlab software with simulation converter models (Vasilchenko et al. 2019 and 2020). The drive parameters are as follows: phase voltage of AC network powering the converters is 380 V; frequency is 50 Hz; the converters are loaded with the motor armature (with rated input of 45 kW, rated angular frequency of revolution of 104.7 s^{-1}, rated electromagnetic moment of 430 Nm, rated armature current of 220 A and rated armature voltage of 330 V) and the choke smoothing out the current pulsations at the level of 3% from the steady-state motor armature current, connected in parallel. The moment of inertia of the moving motor parts corrected to the motor shaft is 1.6 kg per sqm. Modeling was performed for the load connection ratio N = 20 in the single-phase converter, and N = 6 in the three-phase converter. The parameters of the current regulators are obtained as per the results of the numerical simulation.

3 Results

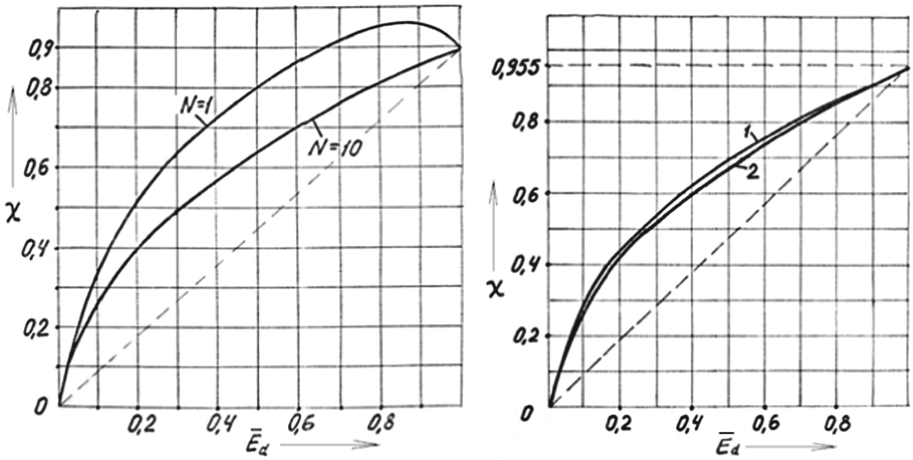
Figure 5 shows the control characteristics charts for single-phase and three-phase multiple valve switching converters built using the formula (2). The characteristics 1 in the figures correspond to N = 3, and the characteristics 2 correspond to N = 4. Figure 6 shows the power factor charts for single-phase and three-phase bridge converter built as per the formulas above. Chart 1 is built for N = 1, and chart 2 for N = 3. Dotted are the charts for controlled rectifiers with natural thyristor commutation.



single phase **three phase**

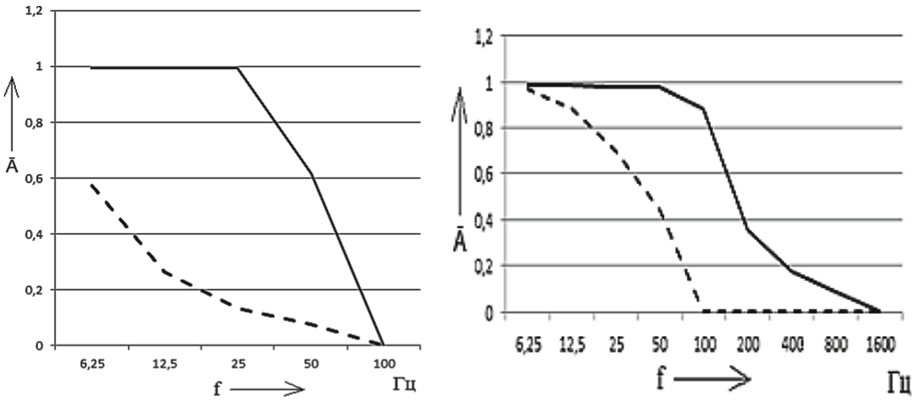
Fig. 5. Control characteristics. *Source*: developed and compiled by the authors

Figure 7 shows the amplitude-frequency characteristics of the DC drive current circuits provided that the single-phase and three-phase multiple valve switching converter is used therein. Dotted are also the similar characteristics, when the current circuit is powered from the bridge rectifiers with natural thyristor commutation. In this figure f is a frequency of the control sinusoidal input at the current regulator input, and $\overline{A}$ is a relative amplitude of 1st current harmonic within the current control circuit. During its calculation the amplitude of the current determined by the control signal has been used as a basis value.



single phase **three phase**

Fig. 6. Power factor charts. *Source*: developed and compiled by the authors



single phase **three phase**

Fig. 7. Amplitude-frequency characteristics of the current circuit. *Source*: developed and compiled by the authors

As shown on the charts in Fig. 5, the control characteristics of the multiple valves switching converters have a good linearity and steepness increasing from N ratio that indirectly indicates the growing response speed of multiple valve switching converters with increasing number of load connection N to the supply network voltages.

As shown on the charts in Fig. 6, the power factor of the converters with multiple valve switching within the entire control range of average rectified EMF, except for its terminal points, is greater than the power factor of controlled rectifiers with natural thyristor commutation, and grows with reduction of N number due to reduction in distortion power consumed from the network.

Control frequency pass band for level 0.7 of the similar circuit of the electric drive with a three-phase bridge-circuit rectifier with natural valve commutation is not less than 20 Hz; and for the circuit of the electric drive base on three-phase bridge-circuit converter with load connection ratio of N = 6 it is much greater - not less than 100 Hz. Control frequency pass band for level 0.7 of the similar circuit of the electric drive with a three-phase bridge-circuit rectifier with natural valve commutation is not less than 20 Hz; and for the circuit of the electric drive base on three-phase bridge-circuit converter with load connection ratio of N = 6 it is much greater - not less than 100 Hz.

4 Conclusions

As follows from the results obtained, transistor PMVS provide, in comparison with controlled rectifiers with natural switching of thyristors, a higher speed and a higher power factor while maintaining the possibility of two-way exchange of electrical energy between the load and the AC supply network and a better linearity of the adjustment characteristics. Considered transistor PMVV AC voltage to DC is advisable to use in DC drives of medium power, operating in modes of frequent reversals or long-term braking modes. The simplicity inherent in such converters of energy recovery of a braking electric motor in the AC supply network simplifies and consequently reduces the cost of their power scheme, compared to the schemes of pulse-width converters connected to the AC network via an unmanaged rectifier.

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Modeling the Combustion Process of Solid Fuel Boilers

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Abstract. The article discusses the issue of determining heat losses in solid fuel boilers with periodic fuel loading. The results of comparative calculations of various methods for determining heat losses are presented.

Calculation of heat losses with exhaust gases based on the equations of complete combustion has a high computational complexity and therefore is practically not used in boiler control systems. Siegert's formula for estimating the amount of heat loss with exhaust gases also has a number of disadvantages: the spread of the parameters of the fuel of one class is not taken into account, the accuracy of the formula decreases with an increase in actual losses. Modeling the combustion process of solid fuel boilers allows, based on the results of a numerical experiment, to obtain a new formula for estimating heat losses with exhaust gases. The formula presented in the article has an accuracy higher than Siegert's formula, takes into account the content of carbon, ash and humidity in the fuel, but at the same time has a low computational complexity.

The results of calculating the value of heat losses in solid fuel boilers with periodic fuel loading based on modeling of the combustion process are shown, for example, in the works of Xing et al. (2021) and Guo et al. (2020) that the existing methods and approaches have a number of disadvantages: high computational complexity for the normative method and low accuracy when using Siegert's formula.

The method proposed by the authors for calculating the magnitude of heat losses in solid fuel boilers with periodic fuel loading makes it possible to determine the magnitude of losses without reducing accuracy in comparison with the standard method, but at the same time to significantly simplify the calculation to optimize the calculations and take into account the characteristics of the fuel used in solid fuel boilers.

Keywords: Solid fuel hot water boilers · Boiler efficiency · Numerical modeling · Boiler heat balance · Fuel combustion process control · Coal combustion

JEL Code: L60 · C63

1 Introduction

As Kazakov et al. (2012) note in their study, in autonomous heating systems, solid fuel boilers with layered combustion of fuel supplied periodically by hand or by a stirring

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bar are the most common. The fuel in such boilers, is coal (brown or hard coal), and in some cases wood chips.

According to research by Belkin and Khuzhaev (2017), the efficiency of fuel use in such boilers, due to the peculiarities of the organization of the combustion process, the absence or poor development of automation and control systems, is 75% .. 80%. The main heat losses are losses with exhaust gases.

The team of authors Gordin et al. (2020) notes that in order to improve the efficiency of such boilers, it is necessary to develop and implement a system for automatic regulation of the volume of air supplied to the boiler furnace in accordance with the fuel supply and combustion modes. This article presents a method for determining the losses associated with the operation of a boiler unit, based on the results of modeling the process of fuel combustion in solid fuel boilers (Kostikov et al. 2020).

2 Materials and Method

According to Kagan (1998), Volkov (2014) and Kuznetsov (1973), in general form, the heat balance equation of the boiler unit is expressed by the following formula:

$$Q_b^r = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 \tag{1}$$

where Q_b^r is available heat per 1 kg of working fuel, kcal / kg;

Q_1 is useful heat, kcal / kg;
Q_2 is heat loss with exhaust gases, kcal / kg;
Q_3 is heat loss from chemical incompleteness of fuel combustion, kcal / kg;
Q_4 is heat loss from mechanical incompleteness of fuel combustion, kcal / kg;
Q_5 is heat loss from external cooling of the boiler unit, kcal / kg;
Q_6 is heat loss with physical heat of slags, kcal / kg;

Also, the equation for the heat balance of the boiler unit can be expressed as a percentage, if Eq. (1) is divided by Q_b^r:

$$q_1 + q_2 + q_3 + q_4 + q_5 + q_6 = 100\% \tag{2}$$

The efficiency of the boiler unit will be

$$\eta_{b.u.} = q_1 = \frac{Q_1}{Q_b^r} \tag{3}$$

Boiler unit efficiency coefficient $\eta_{b.u.}$ does not take into account the costs for own needs (circulation pumps, blowing fans, smoke exhausters, supply, etc.), therefore $\eta_{b.u.}$ is the efficiency "gross".

The value $\eta_{b.u.}$ for a boiler unit can be determined both by direct and reverse balance. To determine the value $\eta_{b.u.}$ according to the direct balance, the available heat per 1 kg of working fuel is determined by the formula:

$$Q_b^r = Q_i^r + Q_h + Q_a \tag{4}$$

where Q_i^p is lower heat combustion of the fuel, kcal / kg;

Q_h is physical heat of fuel, kcal / kg;
Q_a is heat bringing into the boiler furnace with air, kcal / kg.

For solid fuel burnt in the layer, the value Q_h, as a rule, it is not large, therefore, this value for solid fuel boilers can be neglected. According to Kagan (1998), it is possible to separately take into account the heat introduced into the boiler furnace with air, but take into account its corresponding decrease in heat loss with flue gases.

Therefore, for solid fuel boilers with layered fuel combustion to calculate $\eta_{b.u.}$ is possible to use the following formula:

$$\eta_{b.u.} = \frac{Q_1}{Q_i^r} \tag{5}$$

The heat used (Q_1) can be determined by directly measuring the heat generated by the boiler. The disadvantage of using formula (5) to calculate $\eta_{b.u.}$ is the difficulty in directly continuously measuring the weight of the fuel burned. To determine the value $\eta_{b.u.}$ the inverse balance requires determining the values Q_2, Q_3, Q_4, Q_5, Q_6. Heat loss with exhaust gases (Q_2) and from chemical incompleteness of fuel combustion (Q_3) can be determined on the basis of the results of measurements of the composition and temperature of flue gases by a gas analyzer with subsequent calculation of the indicated values.

The amount of heat loss from mechanical incompleteness of fuel combustion (Q_4) can be determined by the formula:

$$Q_4 = a_{ash+rd} \frac{F_{ash+rd}}{100 - F_{ash+rd}} \cdot \frac{A^r}{100} Q_{ash+rd} + a_{un} \frac{F_{fa}}{100 - F_{fa}} \cdot \frac{A^r}{100} Q_{fa} \tag{6}$$

where a_{ash+rd} is fraction of fuel ash in slag and riddlings, %;

a_{fa} is fraction of fuel in fly ash, %;
F_{ash+rd} is the content of combustible compounds in the slag and the fly ash,%;
F_{fa} is content of combustible compounds in fly ash,%;
Q_{ash+rd} is heat combustion of combustible compounds in slag and in the riddlings, kcal / kg;
Q_{fa} is heat combustion of combustible compounds in fly ash, kcal / kg;
A^r is ash proportion in fuel, %;

The amount of heat loss from external cooling of the boiler unit (Q_5) can be determined by the formula:

$$Q_5 = \frac{W_s \cdot S + W_p}{F_h} \tag{7}$$

where S is cooling surface over the overall boiler size, m^2;

W_s is heat loss from 1 m^2 of boiler casing surface and boiler flue gas ducts, kcal / $m^2 \cdot h$;
W_p is heat loss by pipelines, kcal / h;
F_h is hourly fuel consumption by the boiler unit, kg / h.

The amount of heat loss with the physical heat of the fuel ash (Q_6) can be determined by the formula:

$$Q_6 = a_{ash} c_a t_{ash} \frac{A^r}{100} \tag{8}$$

where t_{ash} is fuel ash temperature, ^{0}C;
c_a is average heat capacity of ash, kcal / kg.

According to GOST R 50831-95 (1996), the values Q_4, Q_5, Q_6 depend on the design of the boiler, the parameters of the combusted fuel and can be considered conditionally constant. The amount of losses $Q_4+Q_5+Q_6$ can be determined during performance tests, by direct measurements of the composition of flue gases with subsequent calculation of Q_2, Q_3, as well as by direct measurement of the useful heat received:

$$Q_4 + Q_5 + Q_6 = Q_i^r - Q_1 - Q_2 - Q_3 \tag{9}$$

Thermal calculation of losses with exhaust gases using the basic equations given in Kagan (1998), fuel combustion is performed according to the following system of formulas:

1) coefficient depending on the fuel composition:

$$\beta = 2.37 \cdot \frac{H^r - 0,126 \cdot O^r + 0,038 \cdot N^r}{C^r + 0.368 \cdot S^r} \tag{10}$$

where: H^r, O^r, C^r, S^r, N^r is content of hydrogen, oxygen, carbon, sulfur, nitrogen in fuel, respectively, %;

2) content of SO_2 and CO_2 in combustion products:

$$RO_2 = \frac{21 - O_2}{1 + \beta} \tag{11}$$

where: O_2 is the oxygen content in the flue gases measured by the gas analyzer, %;

3) excess air ratio:

$$\alpha = \frac{1659 + 21 \cdot \beta \cdot (RO_2 + CO) - 8.4 \cdot CO}{(100 \cdot \beta + 79) \cdot (RO_2 + CO) - 0.5 \cdot CO} \tag{12}$$

where: CO content measured by the gas analyzer in flue gases,%;

4) volume of air entering the boiler furnace:

$$\left.\begin{aligned} V_{dry}^{air} &= 0.089 \cdot C^r + 0.266 \cdot H^r + 0.033 \cdot (S^r - O^r) \\ V^{air} &= \alpha \cdot V_{dry}^{air} \cdot (1 + 0.0016 \cdot d_{air}) \cdot \tfrac{273+T_{air}}{273} \cdot \tfrac{760}{h_{air}} \end{aligned}\right\} \tag{13}$$

where: d_{air} is humidity content of air, g / kg;

T_{air} is air temperature, ^{0}C;
h_{air} is air pressure, mm Hg.

5) flue gas volume:

$$\left.\begin{array}{c} V_{RO_2+CO}^{flue} = 1.86 \cdot \frac{C^r}{100} + 0.684 \cdot \frac{S^r}{100}\ ;\ V_{O_2}^{flue} = 0.21 \cdot (\alpha - 1) \cdot V_{dry}^{air} \\ V_{H_2O}^{flue} = \frac{9 \cdot H^r + W^r}{80.4} + \frac{1.293 \cdot d_{air}}{804} \cdot \alpha \cdot V_{\text{сух}}^{\text{возд}}\ ;\ V_{N_2}^{flue} = 0.79 \cdot \alpha \cdot V_{\text{сух}}^{\text{возд}} + \frac{N^r}{125} \\ V_{CO}^{flue} = \frac{CO}{100} \cdot \left(V_{RO_2+CO}^{flue} + V_{O_2}^{flue} + V_{N_2}^{flue}\right)\ ;\ V_{RO_2}^{flue} = V_{RO_2+CO}^{flue} - V_{CO}^{flue} \end{array}\right\} \tag{14}$$

where: W^r, N^r is the content of humidity and nitrogen in the fuel, respectively, %.

6) enthalpy of air and flue gases:

$$\left.\begin{array}{c} J^{air} = V^{air} \cdot c_{air} \cdot T_{air} \cdot \frac{760}{h_{air}} \\ J^{flue} = \left(V_{RO_2}^{flue} \cdot c_{RO_2} + V_{CO}^{flue} \cdot c_{CO} + V_{O_2}^{flue} \cdot c_{O_2} + V_{N_2}^{flue} \cdot c_{N_2} + V_{H_2O}^{flue} \cdot c_{H_2O}\right) \\ \times T_{smoke} \cdot \frac{760}{h_{smoke}} \end{array}\right\} \tag{15}$$

where: c_{air},c_{RO_2}, c_{CO}, c_{O_2}, c_{N_2}, c_{H_2O} is heat capacity of air and combustion products, kcal kcal/m$^{3.0}$;

T_{flue} is flue gas temperature, ^{0}C;
h_{flue} is flue gas pressure, mm Hg.

7) relative flue gas losses:

$$qA = \frac{Q_i^r - \left(J^{flue} - J^{air}\right)}{Q_i^r} \cdot 100 \tag{16}$$

The flue gas loss can also be calculated using the flue gas measurement with a gas analyzer and the Siegert empirical formula.

According to MRU Rus LLC (2020) and Testo (2020), there are two options for Siegert's formula:

$$qA = f \cdot \frac{FT - AT}{CO_2} \tag{17}$$

or

$$qA = (FT - AT) \cdot \left(\frac{A1}{O_2} + B\right) \tag{18}$$

$$CO_2 = CO_2^{\max} \cdot 1 + \frac{O_2}{O_2^{\max}}$$

where: qA is flue gas losses, %

FT is flue gas temperature, ^{0}C.
AT is ambient temperature, ^{0}C.
O_2 is flue gas oxygen value (rounded towards the nearest whole number), %
f, A1, B are fuel-dependent conversion factors.
CO_2 is concentration of carbon dioxide in flue gases, %.

Both versions of Siegert's formula (17, 18) determine only the heat loss with the exhaust gases. Despite the fact that gas analyzers usually measure the proportion of CO in flue gases, they do not calculate losses from chemical incompleteness of fuel combustion, since the manufacturer assumes that the chemical incompleteness of combustion is negligible. This is true for liquid fuels, gaseous fuels and solid fuels supplied continuously. However, this statement for solid fuel boilers with periodic fuel loading may be erroneous.

Let consider the process of burning solid fuel in a water-heating boiler of the KVr type with periodic automatic loading of fuel (coal) with a stirring bar.

Fuel enters the furnace of a boiler of this type in portions according to a given schedule (period). The stirring bar provides shuffling and movement of the burning fuel layer, the supply of hot pieces of fuel under a fresh portion of fuel, and ash and slag discharge.

When the bar moves forward, all the fuel that lies on the grate moves in waves, contributing to its mixing. During the return stroke, the stirring bar captures a part of the hot fuel from the middle of the grate and moves it to the front, thereby improving the ignition conditions of the coal entering the grate, since hot particles are the hot spots for ignition of fresh fuel.

When the stirring bar moves backward, the fuel moves only 15–25% of the forward shift amount. Ash and slag are discharged from the grate by overturning the rotary grate at the rear of the furnace.

A new portion of fuel mixes with the burning fuel and lowers its temperature, which leads to poor combustion and incomplete combustion of the fuel. As the fresh portion of fuel warms up and burns up, the combustion process becomes active again, and the incompleteness of fuel combustion decreases to a minimum value.

Figure 1 shows a graph of the carbon monoxide content of undiluted flue gas (uCO). According to the results of measurements, the uCO concentration varies widely from 0 to 10,000 ppm.

The data obtained allow us to assume that for solid fuel boilers with periodic fuel loading, losses from chemical incompleteness of fuel combustion should be significant. On the basis of the obtained measurements, in order to estimate the magnitude of losses with flue gases and from the chemical incompleteness of fuel combustion, a thermal calculation of the boiler was performed according to the above formulas (10–16). The results were compared with the results of calculating losses using Siegert's formulas (17, 18).

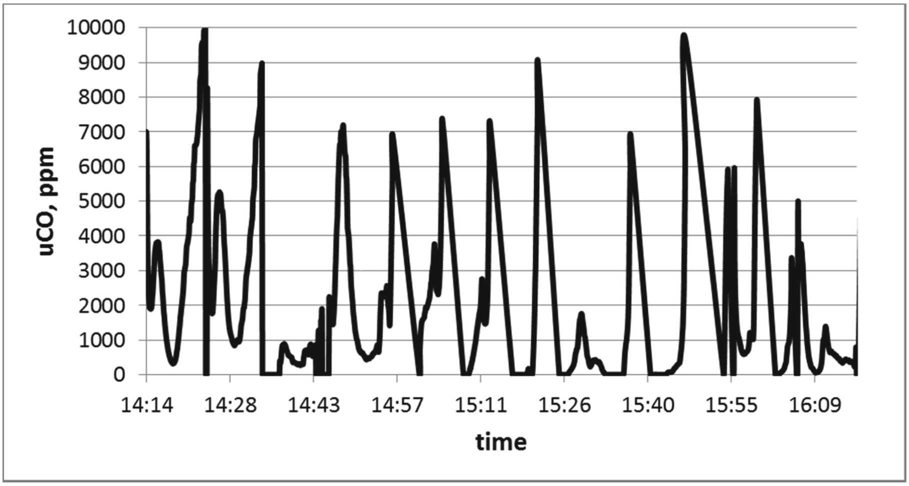

Fig. 1. CO content in flue gases of a solid fuel boiler. *Source*: developed and compiled by the authors

For convenience of comparison, the calculation results were sorted in order of increasing losses. The result of the comparative calculation is shown in Fig. 2.

The data obtained indicate that for solid fuel boilers with periodic fuel loading, the Siegert formula (17, 18) gives a value that is significantly different from the results of thermal calculation. In addition, the staggered results of calculating losses using Siegert's formulas confirms that losses from chemical incompleteness of fuel combustion for this type of boilers have a significant share in the total amount of losses.

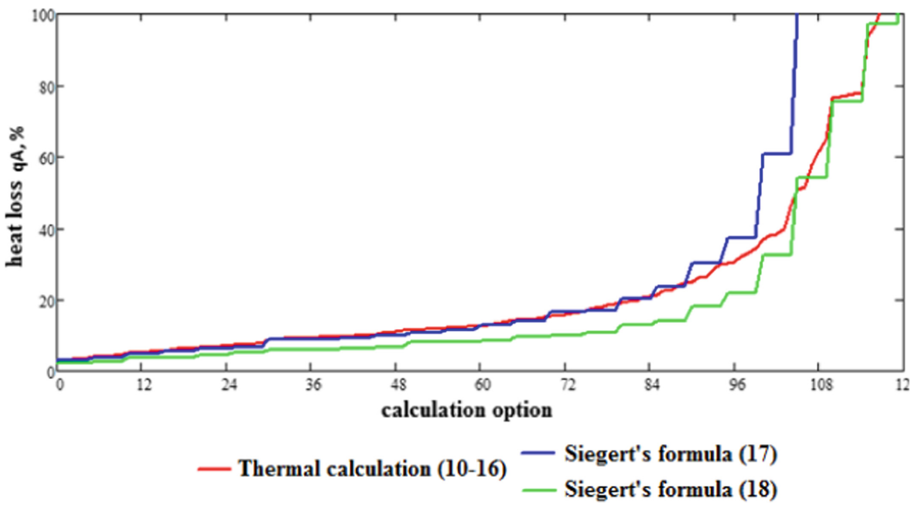

Fig. 2. Comparison of losses (Q2 + Q3) obtained by different methods. *Source*: developed and compiled by the authors

However, the use of thermal calculation formulas (10–16) to take into account losses from chemical incompleteness of fuel combustion leads to a significant increase in the volume of calculations, especially in comparison with Siegert's formulas (17, 18). Therefore, as shown by Volkov et al. (2020), their practical application, especially in boiler automation systems, is difficult.

3 Results

To build a model for calculating the losses of a solid fuel boiler with periodic fuel loading, the following assumption was made: coal or brown coal is considered as fuel, for which an essential feature is the absence of hydrogen (H2), oxygen (O_2), nitrogen (N_2) in the fuel, and the sulfur (S) content is negligible. With this assumption, for coal, the value of the coefficient $\beta = 0$ can be taken. Then the excess air ratio (α) is determined by the following formula:

$$\alpha = \frac{1659 - 8.4 \cdot CO^{smoke}}{79 \cdot \left(21 - O_2^{smoke} + CO^{smoke}\right) - 0.5 \cdot CO^{smoke}} \tag{19}$$

In this case, the main characteristics of the fuel will be humidity (W^r), ash content (A^r) and carbon content (C^r). Since these values are specified as a percentage, W^r and C^r will be chosen, as the main characteristics of the fuel, and then $A^r = 100 - W^r - C^r$.

Then the formulas for thermal calculation (10–16) can be reduced to the following form:

1) volume of air entering the boiler furnace:

$$\left.\begin{array}{c} V_{dry}^{air} = 0.089 \cdot C^r \\ V^{air} = \alpha \cdot 0.089 \cdot C^r \cdot (1 + 0.0016 \cdot d_{air}) \cdot \frac{273 + T_{air}}{273} \cdot \frac{760}{h_{air}} \end{array}\right\} \tag{20}$$

2) flue gas volume:

$$\left.\begin{array}{r} V_{RO_2+CO}^{smoke} = 1.86 \cdot \frac{C^r}{100};\ V_{O_2}^{smoke} = 0.21 \cdot (\alpha - 1) \cdot V_{dry}^{smoke} \\ V_{H_2O}^{smoke} = \frac{W^r}{80.4} + \frac{1.293 \cdot d_{smoke}}{804} \cdot \alpha \cdot V_{dry}^{smoke};\ V_{N_2}^{smoke} = 0.79 \cdot \alpha \cdot V_{dry}^{smoke} \\ V_{CO}^{smoke} = \frac{CO}{100} \cdot \left(V_{RO_2+CO}^{smoke} + V_{O_2}^{smoke} + V_{N_2}^{smoke}\right);\ V_{RO_2}^{smoke} = V_{RO_2+CO}^{smoke} - V_{CO}^{smoke} \end{array}\right\} \tag{21}$$

Let us take the following dependences of the heat capacity of flue gases on their temperature:

$$\left.\begin{array}{c} c_{O_2} = 0.000045 \cdot FT + 0.310333 \\ c_{RO_2} = 0.00019 \cdot FT + 0.392667 \\ c_{N_2} = 0.311 \\ c_{H_2O} = 0.00004 \cdot FT + 0.354667 \end{array}\right\} \tag{22}$$

Substitution of these formulas into the formula for calculating losses with flue gases from the thermal calculation results in the following formula:

$$qA = \frac{\left[0.205 + 2.783 \cdot \alpha + \left(\frac{W^r}{C^r} + \frac{d^{air}}{100} \cdot \alpha\right) \cdot 0.45\right] \cdot FT - 2.757 \cdot AT}{81 - 6 \cdot \frac{W^r}{C^r}} \cdot \frac{760}{h^{air}} \quad (23)$$

Due to the rounding of the coefficients, this formula (23) has an accuracy of 0.3% in comparison with the thermal calculation, but at the same time it makes it possible to significantly simplify the calculation of heat losses based on fuel parameters and the results of measuring the composition of flue gases.

To check the formula (23) obtained, a comparative calculation of heat losses is made for a solid fuel boiler of the KVr type. As fuel coal with the following parameters was used: humidity $W^r = 36.0\%$, ash content $A^r = 9.0\%$, carbon content $C^r = 55.0\%$; net calorific value $Q_i^p = 4247.76$ kcal/kg. The air supplied to the boiler furnace had a temperature $T_{air} = 26.6^0C$ and humidity $d_{air} = 8\%$.

The flue gas composition was measured with a Test-330 gas analyzer with a step of 10 s. The measured parameters were the content of O_2, CO and flue gas temperatures.

The results of the obtained measurements and the results of calculations of heat losses based on the proposed formula (23), heat calculation formulas (10–16) and Siegert formulas (17, 18) are shown in Table 1.

Consequently, the proposed formula (23) has a fairly high accuracy, close to the results of thermal calculation. At the same time, Siegert's formula (17, 18) for a solid fuel boiler with periodic fuel loading gives an underestimated value of losses, which can be seen from the graphs shown in Fig. 3.

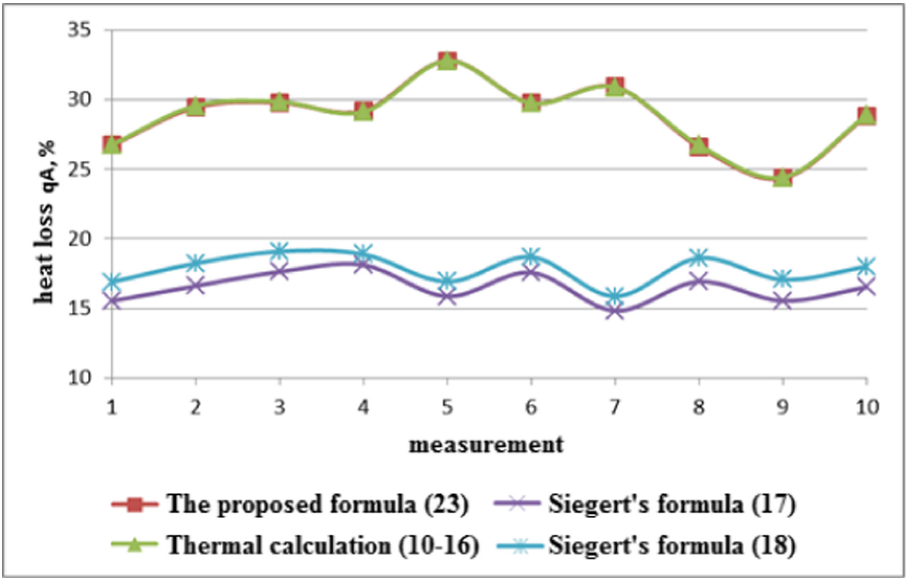

Fig. 3. Comparison of the loss calculation result. *Source*: developed and compiled by the authors

Table 1. The results of a comparative calculation for a KVr-type boiler when burning coal with periodic fuel supply with a stirring bar

№ measurement	Gas analyzer data			Calculation of heat losses, %			
	O_2, %	CO, %	T_{smoke}, ^0C	The proposed formula (23)	Thermal calculation (10–16)	Siegert's formula (17)	Siegert's formula (18)
1	16.9	0.98	175.8	26.71	26.74	15.53	16.89
2	16.4	0.83	205.9	29.45	29.55	16.60	18.23
3	17.1	0.98	187.8	29.78	29.85	17.62	19.09
4	19.0	0.89	110.8	29.16	29.10	18.11	18.88
5	17.9	0.21	141.5	32.80	32.78	15.87	16.91
6	18.0	0.87	149.8	29.74	29.74	17.56	18.69
7	17.7	0.20	140.9	30.90	30.88	14.83	15.87
8	16.3	1.53	213.3	26.63	26.73	16.91	18.61
9	16.4	1.58	194.3	24.35	24.41	15.54	17.06
10	16.8	0.89	189.3	28.82	28.88	16.52	17.99

4 Conclusion

The results obtained can be used to create an integrated automated system for controlling the boiler operation modes by regulating the air supply and the removal of combustion products, depending on the properties and amount of fuel burned.

The empirical formula (23) proposed by the authors makes it possible, on the basis of data on the composition of solid fuel and measurements of the composition of flue gases, to determine the total heat loss with exhaust gases and from the chemical incompleteness of fuel combustion.

This empirical formula (23) gives the indicated values with an accuracy similar to the thermal calculation formulas (10–16), but has a more compact form.

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Tensile Model of a Shell-Type Flat Plate at Different Displacement Velocity Fields

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Abstract. Purpose: The article is devoted to the description of the method of the step-by-step change in the state of the sample shape under the condition of a plane stress state.

Methodology: This order is presented as an algorithm for transition from one velocity field to another. A continuous velocity field is proposed as the first velocity field, and a discontinuous velocity field as the second. To solve the problem, the authors propose to use a mathematical model that describes the change in the length of a rigid-plastic strip, the sample can be made from various materials that are supposed to be used for the manufacture of various structural elements. The authors propose to use various algorithms for the behavior of structural elements, depending on the material from which they are made. This will directly affect the change in the strain rate fields and will quickly allow finding the critical point of crack initiation at the early stages of deformation.

Results: The presented article allows one to determine the exact values of the strain rate field and find the required optimal value of the Almansi strain tensor (E1). It is proposed to use it to characterize the choice of the preferred deformation flow of a test specimen made of a specific structural material.

Conclusion: This plastic flow is typical for materials, when deformed, before fracture, a neck is formed (a discontinuous strain rate field), which in turn leads to material fracture.

Keywords: Displacement velocity field · Strain tensor · Finite increments · Almansi strain tensor · Shell structure · Principal values of the strain tensor

JEL Code: C60 · C00 · C65

1 Introduction

The authors consider the problem of determining the strain rate field that arises when a flat sample is stretched (stretching a thin strip) under conditions of a plane stress state. With continuous deformation of the sample, the strain rate field can be estimated by a special criterion, which is taken as a characteristic of the magnitude of deformations. In

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this problem, the value of the first principal invariant of the Almansi tensor E_1 is taken as such a criterion. The process of deformation of the sample is proposed to be divided into stages, each stage determines its own field of displacement velocities.

It is necessary to determine the strain rate field corresponding to the given constraints and the values of the deformation parameter.

2 Materials and Methods

Tension of a flat specimen under a plane stress state and a continuous field of strain rates.

The main research method is an analytical method for solving systems and partial differential equations. Structural materials of various configurations are investigated using this method.

Let a strip's len is l_0, width is a_0 and thickness is f_0 and this strip is strip is stretched under kinematic boundary conditions at the ends of the strip with a speed V, $a_0 \ll f_0$ (Fig. 1). The von Mises condition is used as the plasticity condition, which connects the components of the stress tensor $\sigma_x, \sigma_{y,} \tau_{xy}$ by the relation, where k is the yield points:

$$\sigma_x^2 + \sigma_y^2 - \sigma_x\sigma_y + 3\tau_{xy}^2 = \sigma_s^2 = 3k^2 \tag{1}$$

According to (Kachanov 1969), the compsonents of the displacement velocity vector V_x, V_y are related to the components of the stress tensor by the equations:

$$\frac{\frac{\partial V_x}{\partial x}}{2\sigma_x - \sigma_y} = \frac{\frac{\partial V_y}{\partial y}}{2\sigma_y - \sigma_x} = \frac{\frac{\partial V_x}{\partial y} + \frac{\partial V_y}{\partial x}}{6\tau_{xy}}, \tag{2}$$

which follow from the Saint Venant-Mises relations for a rigid-plastic body.

Boundary conditions for stresses:

$$\text{for } y = 1, \sigma_y = 2k; y = -1, \sigma_y = 2k. \tag{3}$$

The stresses on the lateral surface of the sample are zero.

These boundary conditions (3) lead to a uniform stress state if the sample is in a plastic state:

$$\sigma_y = 2k, \sigma_x = \tau_{xy} = 0. \tag{4}$$

a rectilinear field of slip lines inclined to the x axis at an angle $\varphi = 54^0 44'$ (Herzberg 1989).

The boundary conditions for the displacement speeds:

$$\begin{aligned} &for\, y = 0,\ \ V_y = 0,\ \ for\, \mathrm{x} = 0,\ \ V_x = 0; \\ &for\, y = 1,\ \ V_y = V;\ \ for\, \mathrm{x} = a,\ \ V_x = const. \end{aligned} \tag{5}$$

The solution to this problem, according to (Grigorieva et al. 2019), has the form:

$$V_x(x, y) = -\frac{V}{\sqrt{2}l}x, V_y(x, y) = \frac{V}{l}y. \tag{6}$$

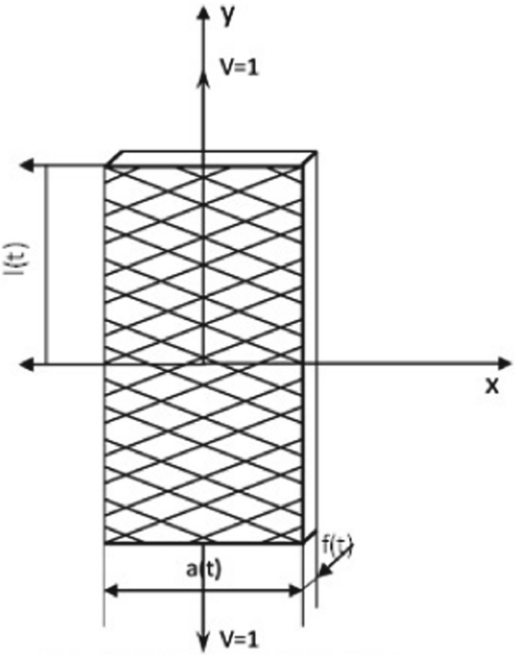

Fig. 1. Stretching a strip under conditions of a plane stress state. *Source*: developed and compiled by the authors

Strain tensor components ε_i:

$$\varepsilon_1 = -\frac{V}{\sqrt{2}l}, \varepsilon_2 = \frac{V}{l}, \varepsilon_3 = \frac{V}{\sqrt{2}l}\left(1 - \sqrt{2}\right). \tag{7}$$

Principal Values of the Almansi Strain Tensor:

$$E_1 = e + g = \frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2}, E_2 = e - g = \frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\sqrt{2}}}{2} \tag{8}$$

$$E_3 = \left(-1 + \frac{1}{(1-2E_1)(1-2E_2)}\right)/2.$$

Figure 2 shows the dependence of the first invariant of the Almansi tensor on the relative elongation of the sample in a continuous field of strain rates. Analysis of this graph shows that with an increase in the relative elongation of the sample, the value of the first invariant continuously tends to 0.5.

$$\lim_{\overline{\varepsilon}\to\infty} \mathrm{E}_1 = \lim_{\overline{\varepsilon}\to\infty}\left(\frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2}\right) = \frac{1}{2}.$$

Stretching of a strip under conditions of a plane stress state in the transition to a discontinuous strain rate field.

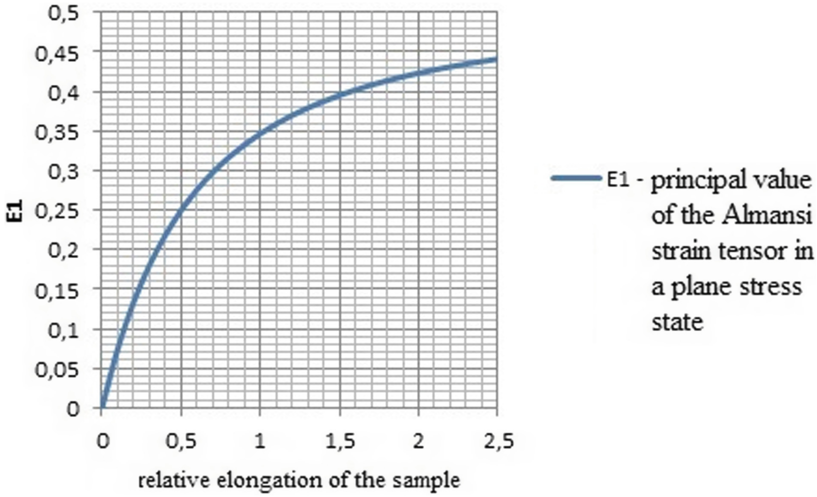

Fig. 2. Principal value of the Almansi strain tensor in a plane stress state. *Source*: developed and compiled by the authors

When a flat specimen is deformed in a plane stressed state, deformation processes can proceed in stages. The division into stages will be described by some criterion. It is proposed to take the first invariant of the Almansi strain tensor E_1^* as this quantity. The stage-by-stage separation condition can be written as:

$$E_1 \geq E_1^* \tag{9}$$

where if E_1 reaches a certain limiting value E_1^*, the strain rate field passes to the discontinuous field (Khromov et al. 2019), this leads to the formation of a neck (Fig. 3).

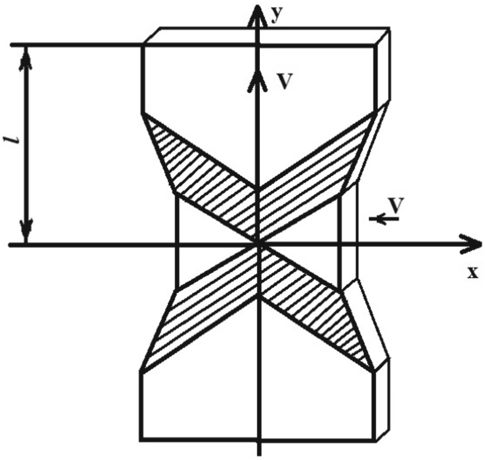

Fig. 3. Stretching of a strip under a plane stress state with a breaking field of displacement velocities. *Source*: developed and compiled by the authors

Solving the problem with a discontinuous strain rate field, according to (Khromov et al. 2019):

$$\begin{aligned}
&\mathrm{E}_1 = \frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}}-1\right),\ \mathrm{E}_2 = -\frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}}+1\right),\ \mathrm{E}_3 = 0,\\
&\overline{\mathrm{W}} = \frac{[\mathrm{V}_\tau]}{\mathrm{G}+\mathrm{V}_\mathrm{n}^+} + \frac{[\mathrm{V}_\mathrm{n}]}{\mathrm{G}+\mathrm{V}_\mathrm{n}^+}, [\mathrm{V}_\tau] = -\frac{\cos 2\delta}{\sin\delta},\\
&\mathrm{V}_\mathrm{n}^+ = \cos\delta, [\mathrm{V}_\mathrm{n}] = 0,\ G = 0,\ \delta = 35^0 56^{|}.
\end{aligned} \tag{10}$$

where V_n^+ is normal speed of a particle on the discontinuity line, $[V_j]$ are displacement velocity discontinuity vectors, V_τ is particle tangential velocity, G are normal speeds of break lines, δ is an angle between the lines of discontinuity of strain rates, $\overline{W}$ is bulk energy dissipation density (Fig. 4).

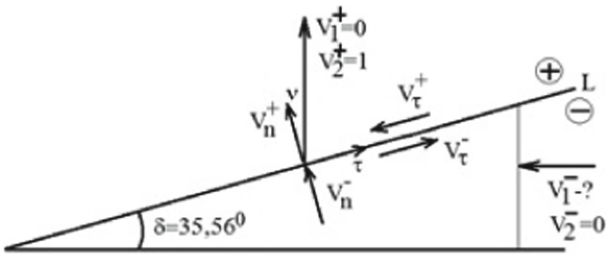

Fig. 4. Line of discontinuity of velocities at plane stress state. *Source*: developed and compiled by the authors

Stages of deformation states at different strain rate fields
Let us consider the formation of a flat sample, subject to the transition to different deformation fields (Leizerovich and Taranukha 2008), which are described by the deformation criterion E_1^* At the first stage deformation of the plate will take place with a continuous field of displacement velocities, which corresponds to the expression for the first invariant of the Almansi tensor (Letcher et al. 2012) of the form:

$$E_1 = e + g = \frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2}$$

.

With continuous deformation of the displacement velocity field, the critical value of the first invariant of the Almansi strain tensor is reached at E_1^*.

After the onset of deformation states, characterized by E_1^*, the strain rate field passes to the discontinuous strain rate lines, which in turn leads to the formation of a neck during deformation of the strip (Fig. 5).

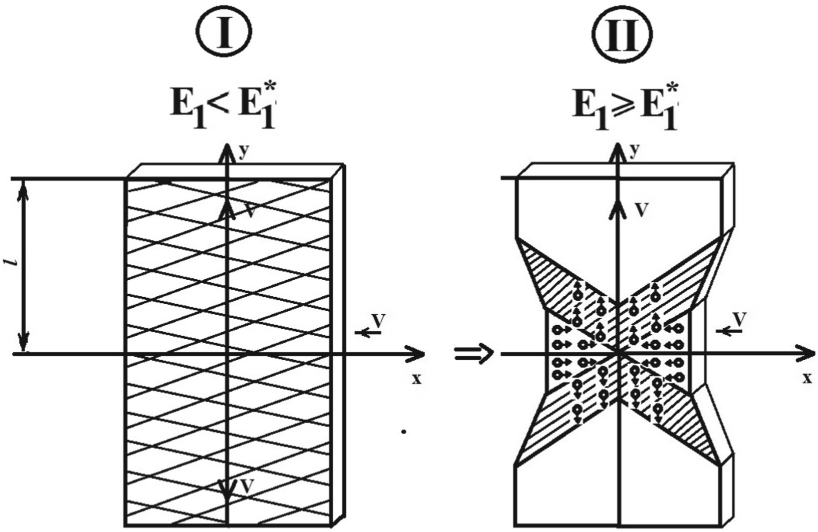

Fig. 5. Stages of transition from continuous to discontinuous field of displacement velocities in a plane stress state. *Source*: developed and compiled by the authors

Let's describe this process analytically. Using formulas (8), (10), a system was obtained that describes the transition between deformation processes:

$$\begin{gathered} \frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2} = \frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}} - 1\right), \\ \overline{W} = \frac{[V_\tau]}{G+V_n^+} + \frac{[V_n]}{G+V_n^+}, [V_\tau] = -\frac{cos2\delta}{sin\delta}, \\ V_n^+ = cos\delta, [V_n] = 0, G = 0, \delta = 35^0 56^{|}. \end{gathered} \tag{11}$$

Let take the relative elongation of the sample at which the first invariant of the Almansi strain tensor E_1 reaches the critical value E_1^*..

$$\frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2} = \frac{1}{2} - \frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}} - 1\right) \Rightarrow$$

$$\overline{\varepsilon} = \left[\frac{1}{2} - \frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}} - 1\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1.$$

$$\overline{\varepsilon} = \left[\frac{1}{2} - \frac{\overline{W}^2}{4}\left(\sqrt{1+\frac{4}{\overline{W}^2}} - 1\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1, at\, \overline{W} = -2ctg\delta,$$

$$\begin{aligned} \overline{\varepsilon} &= \left[\frac{1}{2} - \frac{ctg^2\delta}{1}\left(\frac{1}{cos\delta} - 1\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1 = \left[\frac{1}{2} - \frac{cos^2\delta}{sin^2\delta}\left(\frac{1}{cos\delta} - 1\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1 \\ &= \left[\frac{1}{2} - \left(\frac{cos\delta - cos^2\delta}{sin^2\delta}\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1 \end{aligned}$$

$$=\left[\left(\frac{sin^2\delta - 2cos\delta + 2cos^2\delta}{2sin^2\delta}\right)\right]^{\frac{2}{-1-\sqrt{2}}} - 1 = \left[\left(\frac{1 - cos\delta}{\sqrt{2}sin^1\delta}\right)^2\right]^{\frac{2}{-1-\sqrt{2}}} - 1$$

$$=\left[\left(\frac{\sqrt{2}sin^1\delta}{1 - cos\delta}\right)\right]^{\frac{4}{1+\sqrt{2}}} - 1$$

$$\overline{\varepsilon} = \left[\left(\frac{\sqrt{2}sin^1\delta}{1 - cos\delta}\right)\right]^{\frac{4}{1+\sqrt{2}}} - 1, \delta = 35^0 56^| \tag{12}$$

Thus, the relative elongation of the sample has a critical value at: $\overline{\varepsilon} = \left[\left(\frac{\sqrt{2}sin^1\delta}{1-cos\delta}\right)\right]^{\frac{4}{1+\sqrt{2}}} - 1\ at\ \delta = 35^0 56^|$ and the value of the first invariant of the Almansi strain tensor reaches E_1^*, after that, the field of strain rates goes to discontinuous.

The system of equations that describes the process of deformation of a flat sample at various stages of deformation:

$$E_1 = \begin{cases} \frac{1}{2} - \frac{(1+\overline{\varepsilon})^{\frac{-1-\sqrt{2}}{\sqrt{2}}}}{2}, 0 \le \overline{\varepsilon} < \left[\left(\frac{\sqrt{2}sin^1\delta}{1-cos\delta}\right)\right]^{\frac{4}{1+\sqrt{2}}} - 1, \\ \frac{\overline{W}^2}{4}\left(\sqrt{1 + \frac{4}{\overline{W}^2}} - 1\right), \overline{\varepsilon} \ge \left[\left(\frac{\sqrt{2}sin^1\delta}{1-cos\delta}\right)\right]^{\frac{4}{1+\sqrt{2}}} - 1, \delta = 35^0 56^|. \end{cases} \tag{13}$$

3 Results

In the presented model of deformation of a flat sample, it was found that the value of the first invariant of the Almansi strain tensor is determined by the value of the relative elongation of the sample, depending on which there will be a transition from a continuous to a discontinuous strain rate field. Figure 6 shows a graph of the transition from one deformation state to another. The figure shows that at the first stage of deformation, the solution with a continuous field of velocities (Manson, 1953; Leizerovich and Taranukha 2012; Kozlova, 2015; Onat and Prager 1954; Egorova and Egorov 2013; Anisimov 2007) leads to lower deformations of the material particles and to large forces (Fig. 7) necessary for deformation of the sample, and when the critical value E_1^* is reached, the solution with a discontinuous strain rate field gives lower deformations and greater forces than with a continuous field.

Having carried out a comparative analysis between the deformation of a flat specimen under various conditions (plane stress state and plane deformation (Fig. 8)), it becomes clear that this process in plane deformation proceeds at lower relative elongations, in contrast to the plane stress state. But the processes are very similar. Therefore, in real materials at the initial stages of deformation, both in plane deformation (Loshmanov and Perigue 2012) and in a plane stress state, it is preferable to use a continuous field of strain rates, and then, when passing through the critical value of the relative elongation E_1^*, one can go to discontinuous strain rate floor.

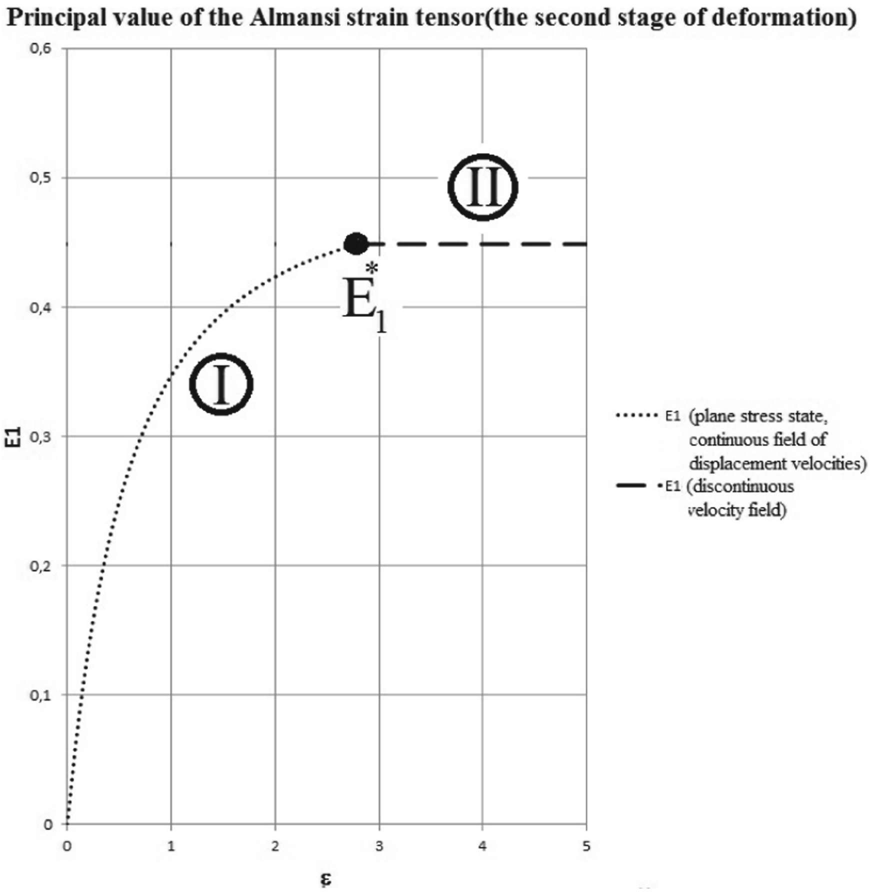

Fig. 6. Stages of deformation states in a plane stress state. *Source*: developed and compiled by the authors

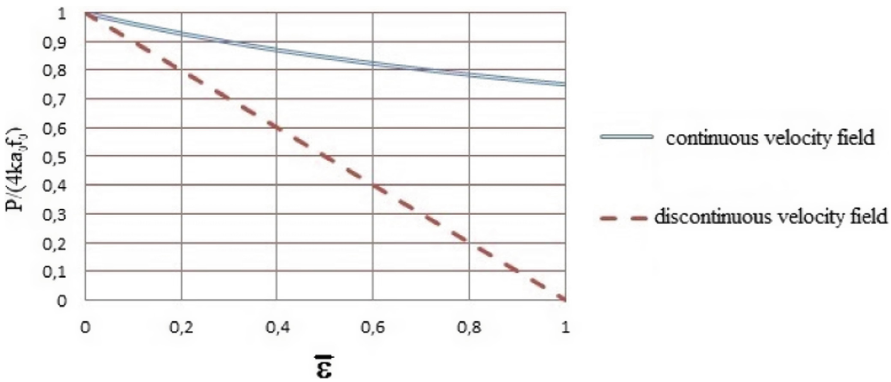

Fig. 7. The forces required to stretch the strip. *Source*: developed and compiled by the authors

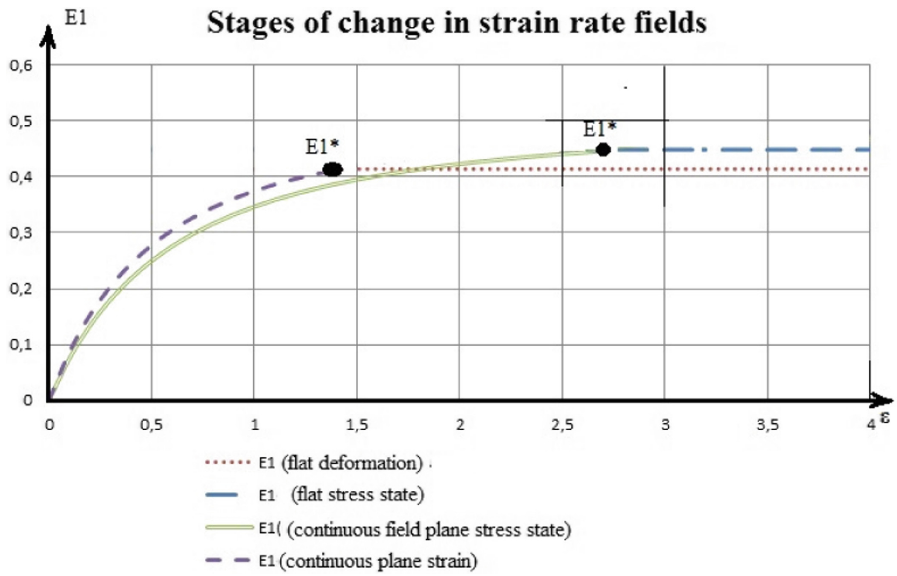

Fig. 8. Deformation stages under various deformation conditions. *Source*: developed and compiled by the authors

4 Conclusion

This plastic flow is typical for materials, when deforming before fracture, necking occurs (breaking field of strain rates) (Parton 1990, Bykovtsev and Tsvetkov 1987; Babaytsev et al. 2019), which in turn leads to material destruction. The conducted research helps to assess the state of structures in various fields of industry (construction, aircraft construction, shipbuilding, mechanical engineering, etc.) (Ruslantsev et al. 2017; Starovoitov et al. 2014; Glushenkova et al. 2019; Voronich et al. 2019), assess deformation processes and predict the destruction of various elements, which in turn will prevent the destruction of the entire structure.

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Bearing Capacity of Built-Up Structures of Multi-storey Buildings, Taking into Account Ultimate Concrete Strains and Shear Braces

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Abstract. Purpose: Analysis of load-bearing systems of frame buildings taking into account physical nonlinearity using the example of prefabricated stiffening diaphragms.

Design/methodology/approach: The article uses a discrete-continuous model to analysis the bearing systems of buildings. The stiffness characteristics of vertical elements and shear braces connecting them are taken on the basis of experimental deformation diagrams of materials and structures, including the stage of destruction. To implement nonlinear analysis, the step-iterative method is used.

Findings: The paper proposes the dependences of the change in the axial stiffness of the elements of prefabricated diaphragms during compression and the connecting them shear braces, including pseudoplastic deformation of structures. The features of the redistribution of forces between the elements of prefabricated diaphragms in the process of loading up to the exhaustion of the bearing capacity of structures.

Originality/value: When describing the behavior of compressed concrete of stiffening diaphragms, a deformation diagram consisting of three sections is used. At the stage of destruction, an expression is proposed for deformation at a stress level equal to 0.5 of the ultimate strength of concrete. The influence of the falling branch of deformation of diaphragm elements on the bearing capacity of stiffness diaphragms is revealed.

Keywords: Frame buildings · Stiffness diaphragms · Straining diagram · Shear braces · Descending branch

JEL Code: C300

1 Introduction

The load bearing systems of multi-storey buildings are multiply statically indeterminate systems. When designing such systems, the development of material nonlinearity due to formation and opening of cracks in tensile areas of concrete as well as the effects of linear and nonlinear creep in compressive areas of concrete and plastic strains of tensile reinforcement should be noted (Zalesov et al. 2005). A design taking into account reinforced concrete specific features allows identifying the true strain-stress distribution of the load

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bearing system and increases the efficiency of design solutions for reinforced concrete structures (Kottb et al. 2015; Vaghei et al. 2014; Naresh and Brahma 2019). Material nonlinearity implies the use of complete strain diagrams for concrete and reinforcement, summarizing the findings of experimental studies of these materials taking into account the strain rate constant (Karpenko et al. 2013; Tikka and Mirza 2014). Moreover, the calculation of internal forces in load bearing systems is carried out using two design models: discrete (Qahorov et al. 2020; Sysoyev et al. 2017) and discrete-continuous (Drozdov et al. 1986). Discrete model assumes that the system is divided into separate finite elements with given material properties while the discrete-continuous model maintains the discrete layout of vertical load bearing structures, vertically connected with shear braces (collar beams, floorings, embedded parts, etc.). Shear braces are considered to be continuously distributed over the height of building similar to Rzhanitsyn's compound bar theory (1986). This paper gives the investigation findings for built-up structures of multi-storey buildings in a physically nonlinear layout, using the example of prefabricated frame diaphragms.

2 Materials and Method

The discrete-continuous model was mostly developed in Drozdov's et al. (1986) and Panshin's (2006) papers where axial forces $N(x)$ in the vertical bearing bars were assumed as unknowns. Shear forces Q arise in case of horizontal loads in the shear braces of built-up system which accumulate along the height of a bar; and create axial force $N(x)$. Continuous shear force equals

$$Q^k = Q/h, \tag{1}$$

where Q is shear force in a discrete brace;
h is vertical spacing of discrete braces.

For a flat built-up system with horizontal load, equilibrium equation is as follows (Drozdov et al. 1986)

$$M^0 = -\alpha' \sum_{i=1}^{k} B_i + \sum_{i=1}^{k} N_i y_i, \tag{2}$$

where $M^0 = M(x)$ is bending moment due to external load acting in a plane of built-up system in section x;
N_i *is* direct force in a separate built-up system i-bar as a result of shear brace resistance;
y_i is distance from the bar center of gravity to the datum point;
$\sum_{i=1}^{k} B_i$ is the sum of bending stiffnesses of all built – up system bars
k is the total number of bars.

Pitch angle of built-up system i-bar with ductile shear braces equals (Drozdov et al. 1986).

$$\alpha_i = \alpha_{1_{i,i+1}} + \alpha_{2_{i,i+1}}, \tag{3}$$

where $\alpha 1_{i,i+1}$ is part of the total pitch angle determined by the difference in axial strais of adjacent vertical members;

$\alpha 2_{i,i+1}$ is the rest of total pitch angle determined by the stress-strain behaviour of shear braces between two adjacent members.

When designing a built-up system, it is preferable to use additional discretization of vertical members with fictitious joints with zero strain capacity which allows applying uniaxial compression diagrams for each discrete bar.

The elementary displacement of section x along length dx and the total displacement for individual bar will respectively equal:

$$\Delta c = f[N(x)]dx; \quad c = \int_x^H f[N(x)]dx, \tag{4}$$

where $f[N(x)]$ is the strain function of a bar.

Angle value α_2 equals

$$\alpha 2_{i,i+1} = s_{i,i+1}\left(Q^k\right) \cdot Q^k(x) \tag{5}$$

where $s_{i,i+1}\left(Q^k\right)$ is strain capacity value for shear braces.

Thus, the expression for the total pitch angle of i-bar is written using the unknown axial forces.

$$\alpha_i(x) = \int_x^H k_{i,i+1}N_i dx - \int_x^H k_{i+1,i}N_{i+1}dx + s_{i,i+1}\sum_{f=1}^{i} N_f' \tag{6}$$

where $k_{i,i+1}$, $k_{i+1,i}$ are stiffness factors of bars.

Stiffness factors in the formula (6) are the functions of applied forces which allow designing the built-up system in a physically nonlinear layout as well as taking into account the variation in strain capacity of braces and the stiffness of bars during loading of system until its load bearing capacity is depleted.

It is proposed to use the findings of Dzyuba's and Glushakova's papers (2014) to describe the concrete behavior of built-up system vertical members. The concrete compression diagram is considered as consisting of three sections: a curved section when the strain varies from 0 to ε_L and two straight sections (from ε_L to $\varepsilon_{0.25}$ and from $\varepsilon_{0.25}$ to ε_0) (Fig. 1).

The relationship between stresses and strains of compressed concrete in the ascending section and during the initial stage of collapse is expressed as follows:

$$\sigma_b = R_b \frac{D\frac{\varepsilon_b}{\varepsilon_M}}{\left(\frac{\varepsilon_b}{\varepsilon_M}\right)^2 + (D-2)\frac{\varepsilon_b}{\varepsilon_M} + 1}. \tag{7}$$

The descending branch is described as two straight lines:

- with stress range $\varepsilon_L < \varepsilon_b \le \varepsilon_{0.25}$ equal to.

$$\sigma_b = M - N\varepsilon_b; \tag{8}$$

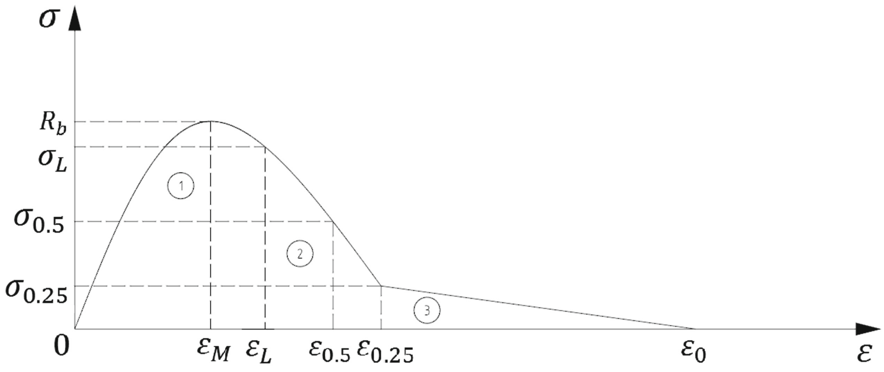

Fig. 1. Complete Compressed Concrete Strain Diagram, (Dzyuba and Glushakova 2014)

- within range $\varepsilon_{0.25} < \varepsilon_b \leq \varepsilon_0$

$$\sigma_b = M_{0.25} - N_{0.25}\varepsilon_b. \tag{9}$$

Here

σ_b, ε_b are actual stress and strain;
R_b, ε_M are prismatic concrete strength and the relevant strain; $D = \frac{E_b\varepsilon_M}{R_b}$;
E_b is tangent Young modulus;
σ_L, ε_L are stress and strain corresponding to the beginning of the first linear descending section;
$\sigma_{0.5}$ and $\sigma_{0.25}$ are values of stresses equal to $0.5R_b$ and $0.25R_b$, respectively;
$\varepsilon_{0.5}$ and $\varepsilon_{0.25}$ are concrete stress strains $\sigma_{0.5}$ and $\sigma_{0.25}$, respectively;

$$N = \frac{\sigma_L - \sigma_{0.5}}{\varepsilon_{0.5} - \varepsilon_L}; \quad M = \sigma_L + N\varepsilon_L;$$

$$N_{0.25} = \frac{\sigma_{0.25}}{\varepsilon_0 - \varepsilon_{0.25}}; \quad M_{0.25} = \sigma_{0.25} + N_{0.25}\varepsilon_{0.25};$$

$$M_{0.25} = \sigma_{0.25} + N_{0.25}\varepsilon_{0.25};$$

$$\varepsilon_{0,f} = \frac{\sigma_L}{N} + \varepsilon_L; \, \varepsilon_0 = \varepsilon_{0,f} + 10^{-2}.$$

Value ε_M is assumed according to Dzyuba's and Glushakova's data (2014).

$$\varepsilon_{0.5} = \left(-0.000011R_b^3 + 0.002093R_b^2 - 0.152310R_b + 7.789345\right)10^{-3}. \tag{10}$$

The embedded parts vertically connecting the columns and diaphragm walls will be taken as the shear braces of the investigated prefabricated diaphragms of reinforced concrete frame. The strain diagram for such braces will be assumed as composed of two sections as indicated in Dzyuba's paper (1983). The straining process of shear braces within the ascending branch and the plastic stage of the paper is described by expression

$$Q = \frac{\Delta Q_M}{\frac{\varphi_0}{\Delta_M}\Delta^2 + (1 - 2\varphi_0)\Delta + \varphi_0 \Delta_M}, \tag{11}$$

where Q_M, Δ_M is the maximum force in brace and the corresponding joint shear displacement;

φ_0 is relative initial brace strain capacity.

The factor values in formula (11) based on the processing of experimental data equal $\varphi_0 = 0.0773097$ and $\Delta_M = 0.0057$ m. The pseudoplastic behavior of brace within the descending section of diagram is represented by the formula

$$Q = \overline{Q} \cdot Q_M \left(1 - \frac{\Delta - \Delta_k^I}{\Delta_k^{II} - \Delta_k^I}\right), \tag{12}$$

where $\overline{Q} = 0.9998$ is relative shear force corresponding to the finite point of diagram according to Eq. (11);

Δ_k^I is displacement corresponding to this force and equal to $6 \cdot 10^{-3}$m;

Δ_k^{II} is displacement corresponding to the complete physical destruction of brace and equal to $17.16 \cdot 10^{-3}$m.

Thus, the analysis of flat built-up system, taking into account material nonlinearity according to the discrete-continuous model, is reduced to solving the nonlinear differential equations that are derived upon substitution in formulas for the factors of nonlinear expressions for the modulus of strains $f_1 = E(N)$ and strain capacity of braces $f_2 = S(Q)$. To linearize a nonlinear equation system, the incremental-iterative method is normally used (Karpenko 1996; Panshin and Nikonorov 2006) which allows replacing nonlinear equations in calculation with a recurrent sequence of nonlinear equation systems with variable stiffness factors. During calculations, while adjusting the stiffness of bars and the strain capacity of braces, usually the iterations converge rather quickly until the extremum of system load bearing capacity function is obtained subject to incremental loading.

3 Results

The prefabricated stiffness diaphragms of a multi-storey frame building, consisting of two diaphragm walls connected to each other and to the frame columns via welding embedded parts to the joint height are the subject of application of this investigation. The conventional sectioning of diaphragm walls with fictitious joints allows using the stiffening parameters of uniaxial compression.

With the known expression for force in the bar as a function of its strain, the variation in axial stiffness of i-th bar, taking into account the secant strain modulus E_i^c, can be written analytically as

$$E_i^c A_i = \frac{N_i(\varepsilon_i)}{\varepsilon_i}. \tag{13}$$

For example, for *i*-th reinforced concrete bar of stiffness diaphragm, the axial stiffness variation function at different straining stages is written as.

- with elastic behavior of reinforcement in accordance with expression (7)

$$E_i^c A_i = \frac{E_b A_i}{\left(\frac{1}{\varepsilon_M}\right)^2 \varepsilon_i^2 + \left(\frac{D-2}{\varepsilon_M}\right)\varepsilon_i + 1} + E_s \mu A_i; \tag{14}$$

- with plastic strains in reinforcement and strains in concrete within the descending branch of compression diagram

$$E_i^c A_i = M\frac{A_i}{\varepsilon_i} - NA_i + \frac{R_s A_i}{\varepsilon_i}\mu. \tag{15}$$

In strain analyses, the compressions in diaphragm bars were assumed as max $4 \cdot 10^{-3}$; therefore, the behavior of reinforcement during postcritical straining stage with its loss of stability was not considered.

The axial stiffness curves for reinforced concrete and concrete bars are shown in Fig. 2.

Strain capacity φ of discrete shear brace in a horizontal section x of diaphragm may be written as secant plane angle in diagram "$Q - \Delta$"

$$\varphi = \frac{\Delta}{Q}.$$

The strain capacity reduction law for continual shear braces may be expressed as

$$\varphi(\Delta) = \frac{\Delta}{Q(\Delta)},$$

resulting in the expression for ascending section in diagram

$$\varphi = \frac{\varphi_0 h}{\Delta_M Q_M}\Delta^2 + \frac{(1 - 2\varphi_0)h}{Q_M}\Delta + \frac{\varphi_0 \Delta_M h}{Q_M}$$

and for collapse stage

$$\varphi = \frac{\Delta}{\frac{L}{h} - \frac{S}{h}\Delta}$$

where L and S are descending branch parameters in the straining diagram.

The strain capsacity curve is given in Fig. 3.

The nonlinear analysis of stiffnesss diasphragms was carried out for centric and eccentric compression. In case of centric compression, uniform load patterns were used for all members of diaphragm (1) and with a load on the diaphragm wall (2) only. A diaphragm 36 m high, loaded according to pattern 1, collapsed when the column and wall reached the ultimate strength limit simultaneously, i.e. as a cast-in-situ structure.

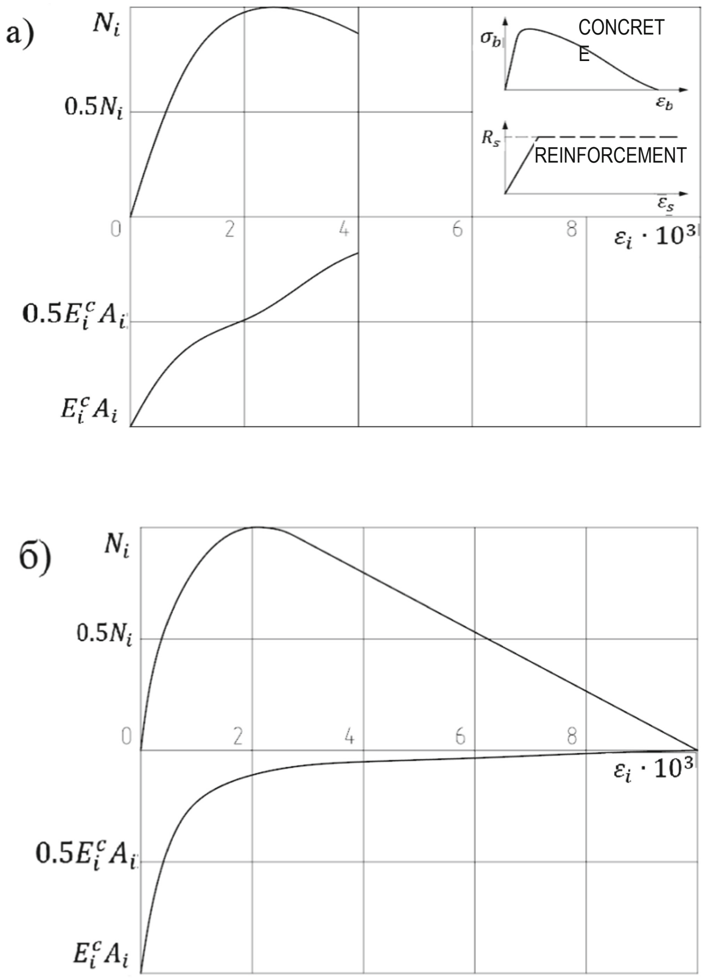

Fig. 2. Axial Stiffness Curves for Diaphragm Bars with Increasing Strains a is reinforced bar; b is concrete bar. *Source*: developed and compiled by the authors.

During the first loading stages, as long as the wall stiffness was higher than the column stiffness, the load was transmitted from the column to the wall through the shear braces. However, as the external load increases the wall stiffness in the lower section started reducing which resulted in a redistribution of forces as a whole from the wall to the column. The influence of strain capacity of braces here was insignificant. The load bearing capacity of a 36-m diaphragm loaded according to pattern 2 was almost equal to the value obtained in the first calculation; however, the redistribution process was different to some extent. In this case, the shear braces participated to a fuller extent since they had already transmitted the load from the wall to the column during the elastic stage. As the inelastic strains developed in the members of diaphragm, the forces were transmitted in the same direction and increased the strains of braces. Therefore, by the

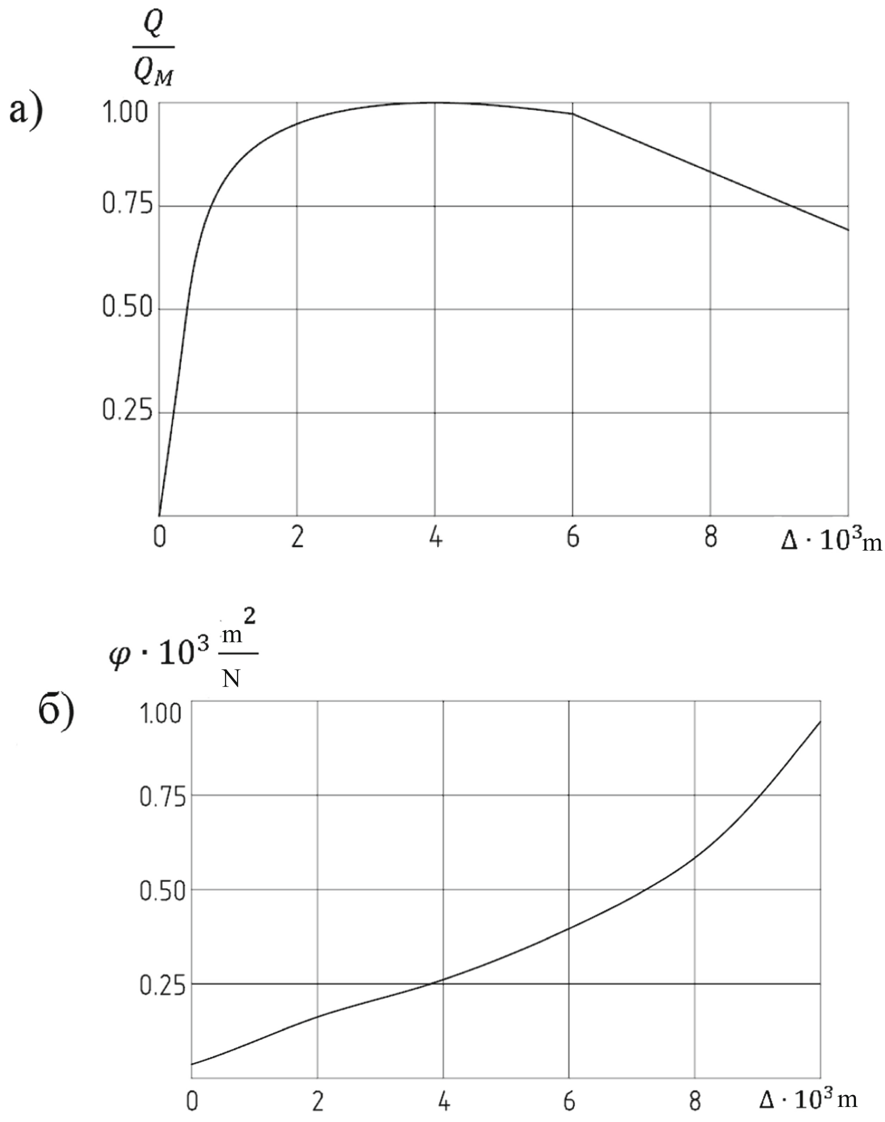

Fig. 3. Strain Capacity Curve for Diaphragm Shear Braces with Increasing Displacements. a) is shear strain variation in the embedded part; b) is strain capacity variation with increasing displacement. *Source*: developed and compiled by the authors.

time the column reached its ultimate strength limit, the strains of walls corresponded to the initial section of descending branch in its strain diagram. For a 12 m diaphragm loaded according to pattern 1, the redistribution of forces occurred in the same way as for a 36 m diaphragm, but the intensity of forces transmitted by the braces per joint length unit was considerably higher. Consequently, by the time the stiffness diaphragm reached its ultimate strength limit, the stress-strain state of wall in the critical section corresponded to the descending branch in its strain diagram. The out-of-limit wall operation stage allowed adjusting the design load bearing capacity of the diaphragm by 7.5%. The analysis of a 12-m diaphragm loaded according to pattern 2 resulted in collapse with achievement of the shear joint strength. In addition, the wall load bearing capacity was realized almost completely, but the strength of column was underused by 40%.

The eccentricity of resulting external load in eccentric compression analyses for stiffness diaphragms was assumed as 1.25 m and 2.5 m. The load bearing capacity for all diaphragms, taking into account the redistribution of forces, turned out to be 2–2.4 times higher than in case of linear analysis. The design collapse of a 36-m diaphragm occurred due to the achievement of maximum force in the most compressed column. The attempt to apply additional load to the diaphragm resulted in that the force in column began to reduce with a slight increase in the area of compression curve in the diaphragm wall which could not ensure a subsequent loading of the entire diaphragm. If such a diaphragm is used as part of a statically indeterminate structural system, then the pseudoplastic strain may arise in it due to self-support of other less loaded diaphragms. In short diaphragms, the ultimate load on the diaphragm is a result of collapse of shear joints. Moreover, "$Q - \Delta$" diagram dependent section allowed increasing the ultimate load by 5%. The strength of diaphragm columns here was underused by 13–30%.

4 Conclusion

The load bearing systems of multi-storey buildings are multiple statically indeterminate systems; therefore, such systems shall be analyzed taking into account the material nonlinearity which allows identifying strength margins and improving technical and economic efficiency of design solutions. The use of a discrete-continuous model allows performing analyses in a physically nonlinear layout. For this purpose, the experimental data on behavior of vertical load bearing elements of the system and their interconnecting shear braces shall be available at all loading stages, including the collapse stage. The use of discrete-continuous model for analysis of prefabricated frame diaphragms allows obtaining a more cost-saving solution for them, including the identification of behavior specifics for diaphragm members, the study of redistribution pattern at all loading stages and the strain analysis against resistance of stiffness diaphragms to external loads.

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Vibrations of a Rod Carrying a Small Attached Mass

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Abstract. Purpose: development of a mathematical model of vibrations for a rod carrying an attached mass, based on the general equation for rod vibrations.

Design/methodology/approach: This paper deals with vibration of a rod carrying a small attached mass in a nonlinear formulation. Rod systems are widely used in construction. Masts, towers, television broadcast stations, TV towers, vertical pipes, etc. These structures often have balconies, antennas, and other elements which influence the vibrational state of the entire structure. Neglecting this component during structural analysis leads to accidents and casualties, which should be avoided. Accidents involving these structures have occurred throughout history. In order to prevent such accidents, the analysis process should be improved based on a better insight into the shell oscillatory mechanism. Development of a new mathematical model is based on the general equation for vibrations. Consideration has been given to the attachment point of the attached mass and influence of such mass on the natural frequency response. The first and second natural frequencies have been determined. It has also been determined that the presence of a small attached mass acts as a factor which triggers interaction between the bending and radial modes.

Findings: The article presents a new vibration analysis model for a rod carrying an attached mass.

Originality/value: The new mathematical model can be used for structural analysis and in design bureaus carrying out vibration analysis for rods and rod structures.

Keywords: Vibrations · Small attached mass · Vibration equations · Variational problem formulation · Mathematical model

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1 Introduction

The overwhelming majority of critical building structures consist of rod elements (posts, brace pieces, chords, columns, ties, masts, antennas, etc.) which have small attached masses fastened to them (transceivers, cables, pipelines, and other equipment). When buildings and structures are exposed to external forces, rods carrying a small attached

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mass are subject to forced vibrations with frequency that can equal the natural frequency and cause resonance condition and, consequently, failure of the building or structure. Prevention of man-made accidents similar to the following examples: in 2018, a 120 m high tower collapsed in the town of Shchuchye; a structural building section fell from the OKO tower of the Moscow-City business center. OKO is a complex of two skyscrapers located in area 16 of the Moscow-City. It consists of the 49-storey North Tower and 85-storey South Tower. In May 2020, a 20 m high stack of a boiler-house fell on a bath-house in Bashkiria.

Prevention of man-made accidents listed in papers by Vlasov (1949), Seregin (2019a, b), Sysoev et al. (2019), Seregin (2019a, b) at structures consisting of rods which carry an attached mass requires new analytic models.

2 Materials and Method

The traditional rod vibration model is as follows:

$$\mathrm{a}^2\frac{\partial^2 u}{\partial x^2}-\frac{\partial^2 u}{\partial t^2}-\beta_1 u-\varepsilon\beta_2 u^3=0$$

When we introduce a parameter accounting for a small attached mass, as in papers by Sysoev et al. (2018), Wang et al. (2017), Seregin (2019a, b), Sysoev et al. (2019), Xing et al. (2013), into the rod motion equation, we get the following:

$$a^2\frac{\partial^2 u}{\partial x^2}-\frac{\partial^2 u}{\partial t^2}-\beta_1 u-\varepsilon\beta_2 u^3-\frac{M}{h}\delta(x-x_0)\frac{\partial^2 w}{\partial t^2}=0$$

Considering that the rod ends are rigidly fixed, as it is in most structures:

$$u|_{x=0,1}=0.$$

Here, u stands for longitudinal displacement; x is a spatial coordinate;

t is time; l is rod length; $a=\sqrt{E/\rho}$, where E is Young's modulus, ρ is rod material density; β_1, β_2 are some coefficients, ε is a non-dimensional small parameter, $\varepsilon\to 0$.

As described in papers by Sysoev (2019), Qu et al. (2013), Qu et al. (2013), Chen et al. (2013), the solution should satisfy the following periodicity: $u(x,t)=u(x,t+T)$,

where $T=2\pi/\omega$ is period, ω is the natural vibration frequency sought for.

Time conversion: $\tau=\omega t$, then:

$$\begin{aligned}u&=u_0+\varepsilon u_1+\varepsilon^2 u_2+\ldots,\\ \omega&=\omega_0+\varepsilon\omega_1+\varepsilon^2\omega_2+\ldots,\end{aligned}$$

where $\omega_0=\sqrt{(a\pi/l)^2+\beta_1}$ is the natural frequency of the fundamental vibration mode for the linear system (at $\varepsilon=0$).

Applying the expression to the original boundary value problem and equating the terms of like powers of ε, we get a recurrent system of linear equations:

$$a^2\tfrac{\partial^2 u_0}{\partial x^2}-\omega_0^2\tfrac{\partial^2 u}{\partial\tau^2}-\beta_1 u_0-\tfrac{M}{h}\delta(x-x_0,y-y_0)\tfrac{\partial^2 w}{\partial t^2}=0,$$
$$a^2\tfrac{\partial^2 u_1}{\partial x^2}-\omega_0^2\tfrac{\partial^2 u_1}{\partial\tau^2}-\beta_1 u_1=2\omega_0\omega_1\tfrac{\partial^2 u_0}{\partial\tau^2}+\beta_2 u_0^3+\tfrac{M}{h}\delta(x-x_0,y-y_0)\tfrac{\partial^2 w}{\partial t^2},$$

The boundary conditions and periodicity conditions take on the following form:

$$u_i|_{x=0,l} = 0,$$
$$u_i(x,\tau) = u_i(x,\tau+2\pi),\ i = 0,1,2\ldots.$$

Boundary value problem solution corresponds to zeroth-order approximation:

$$u_0 = \sum_{i=1}^{\infty} A_i sin\left(\frac{\omega_i^{lin}}{\omega_0}\tau\right) sin\left(\frac{\pi i}{l}x\right),$$

where A_1 is the amplitude of the fundamental vibration mode defined by the initial conditions; A_j, j = 2,3,4… are amplitudes of the subsequent harmonics; $\omega_i^{lin} = \sqrt{(a\pi i/l)^2 + \beta_1}$, $i = 1,2,3\ldots$ are natural frequencies of the harmonics in the linear case, $\omega_0 = \omega_1^{lin}$.

The next approximation is found by solving a boundary value problem. In order to prevent the occurrence of secular terms in the expansion, coefficients of the terms having the form $sin\left(\frac{\omega_i^{lin}}{\omega_0}\tau\right)sin\left(\frac{\pi i}{l}x\right)$, $i = 1,2,3\ldots$ on the right-hand side of the equation should be set equal to zero. This condition leads to the infinite system of nonlinear algebraic equations:

$$\frac{4M}{M_0}\frac{2A_i\omega_1}{\beta_2\omega_0}\left(\omega_i^{lin}\right)^2 = \frac{9}{16}A_i^2 + \frac{3}{4}A_i\left(\sum_{k=1}^{i-1}A_k^2 + \sum_{k=i+1}^{\infty}A_k^2\right),\ i = 1,2,3\ldots.$$

Similar equations are described in papers by Sysoev et al. (2017), Seregin (2019a, b). Solution of the system allows for determining the second term of the expansion ω_1, which stands for a correction to frequency due to the nonlinearity of problem. Let us analyse possible solutions of the system. Vibration mode is defined by the following expression:

$$u = \sum_{i=1}^{\infty} A_i sin(\Omega_i t) sin\left(\frac{\pi i}{l}x\right) + O(\varepsilon),$$

where $\Omega_i = \frac{\omega_i^{lin}}{\omega_1^{lin}}\omega-$ are harmonic frequencies.

In general, only one *i*-th harmonic occurs. Then:

$$A_j = 0,\ \omega_1 = \frac{9A_i^2\beta_2\omega_0}{32\left(\omega_i^{lin}\right)^2},\ j \in N, j \neq i;$$

and the sought frequency response will be written as follows:

$$\Omega_i = \omega_i^{lin} + 0.28125\frac{A_i^2\beta_2}{\omega_i^{lin}}\varepsilon + O\left(\varepsilon^2\right),$$

where i = 1,2,3… . Positive values of ε correspond to the stiff, and negative ones—to the soft characteristic of the restoring force. A distinguishing feature of distributed-parameter systems is the possibility of so-called internal resonance between the natural vibration harmonics. Within the rod longitudinal vibrations problem in question, this effect occurs at $\beta_1 = 0$.

3 Results

In this case, application of the equations described above leads to quality changes in the nonlinear system form:

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_1\omega_1}{\beta_2\omega_0}\left(\omega_1^{lin}\right)^2\\&\quad=\tfrac{9}{16}A_1^3+\tfrac{3}{4}A_1\left(A_2^2+A_3^2+A_4^2+A_5^2\right)\\&\quad+\tfrac{3}{8}(A_1A_2A_4+A_2A_3A_4+A_1A_3A_5+A_2A_4A_5)+\tfrac{3}{16}\left(A_1^2A_3+A_2^2A_3\right)\\&\quad+\ldots,\end{aligned}$$

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_2\omega_1}{\beta_2\omega_0}\left(\omega_2^{lin}\right)^2\\&\quad=\tfrac{9}{16}A_2^3+\tfrac{3}{4}A_2\left(A_2^2+A_3^2+A_4^2+A_5^2\right)\\&\quad+\tfrac{3}{8}(A_1A_2A_3+A_1A_3A_4+A_1A_2A_5+A_1A_4A_5+A_3A_4A_5)\\&\quad+\tfrac{3}{16}\left(A_1^2A_4+A_3^2A_4\right)+\ldots,\end{aligned}$$

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_3\omega_1}{\beta_2\omega_0}\left(\omega_3^{lin}\right)^2\\&\quad=\tfrac{1}{16}A_1^3+\tfrac{9}{16}A_3^3+\tfrac{3}{4}A_3\left(A_1^2+A_2^2+A_4^2+A_5^2\right)\\&\quad+\tfrac{3}{8}(A_1A_2A_4+A_2A_3A_4+A_1A_3A_5+A_2A_4A_5)\\&\quad+\tfrac{3}{16}\left(A_2^2A_1+A_1^2A_5+A_4^2A_5\right)+\ldots,\end{aligned}$$

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_4\omega_1}{\beta_2\omega_0}\left(\omega_4^{lin}\right)^2\\&\quad=\tfrac{9}{16}\mathrm{A}_4^3+\tfrac{3}{4}A_4\left(A_1^2+A_2^2+A_3^2+A_5^2\right)\\&\quad+\tfrac{3}{8}(A_1A_2A_3+A_1A_2A_5+A_2A_3A_5+A_3A_4A_5)+\tfrac{3}{16}\left(A_1^2A_2+A_3^2A_2\right)\\&\quad+\ldots,\end{aligned}$$

$$\begin{aligned}&\tfrac{2A_5\omega_1}{\beta_2\omega_0}\left(\omega_5^{lin}\right)^2\\&\quad=\tfrac{9}{16}\mathrm{A}_5^3+\tfrac{3}{4}A_5\left(A_1^2+A_2^2+A_3^2+A_4^2\right)\\&\quad+\tfrac{3}{16}\left(A_2^2A_1+A_1^2A_3+A_3^2A_1+A_4^2A_3\right)+\ldots,+\tfrac{3}{8}(A_1A_2A_4+A_2A_3A_4)\end{aligned}$$

A new asymptotic approach is used to solve the infinite system of nonlinear algebraic equations; this approach is based on introduction of the artificial small parameter μ. Let us introduce the μ parameter before each term $A_kA_iA_m$, k, l, m = 1, 2, 3 …, for which the following condition holds: $(k > i) \cup (l > i) \cup (m > i)$, on the right-hand side of each i-th equation of the system:

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_1\omega_1}{\beta_2\omega_0}\left(\omega_1^{lin}\right)^2\\&\quad=\tfrac{9}{16}A_1^3\\&\quad+\mu\Big(\tfrac{3}{4}A_1\left(A_2^2+A_3^2+A_4^2+A_5^2\right)\\&\quad+\frac{3}{8}(A_1A_2A_4+A_2A_3A_4+A_1A_3A_5+A_2A_4A_5)+\frac{3}{16}\left(A_1^2A_3+A_2^2A_3\right)\\&\qquad+\ldots\Big),\end{aligned}$$

$$\begin{aligned}&\tfrac{4M}{M_0}\tfrac{2A_2\omega_1}{\beta_2\omega_0}\left(\omega_2^{lin}\right)^2\\&\quad=\tfrac{9}{16}\mathrm{A}_2^3+\tfrac{3}{4}\mathrm{A}_1\mathrm{A}_1^2\\&\quad+\mu\Big(\tfrac{3}{4}A_2\left(\mathrm{A}_3^2+\mathrm{A}_4^2+\mathrm{A}_5^2\right)\\&\quad+\tfrac{3}{8}(A_1A_2A_3+A_1A_3A_4+A_1A_2A_5+A_1A_4A_5+A_1A_4A_5)\\&\quad+\tfrac{3}{16}\left(A_1^2A_3+A_2^2A_3\right)+\ldots\Big),\end{aligned}$$

$$
\begin{aligned}
&\tfrac{4M}{M_0}\tfrac{2A_3\omega_1}{\beta_2\omega_0}\left(\omega_3^{lin}\right)^2\\
&\qquad=\tfrac{1}{16}A_1^3+\tfrac{9}{16}A_3^3+\tfrac{3}{4}A_3\left(A_1^2+A_2^2\right)\\
&\qquad+\tfrac{3}{16}A_1A_2^2+\mu\left(\tfrac{3}{4}A_3\left(A_4^2+A_5^2\right)+\tfrac{3}{8}(A_1A_2A_4+A_2A_3A_4+A_1A_3A_5+A_2A_4A_5)\right.\\
&\qquad\left.+\tfrac{3}{16}\left(A_1^2A_5+A_4^2A_5\right)+\ldots\right),
\end{aligned}
$$

$$
\begin{aligned}
&\tfrac{4M}{M_0}\tfrac{2A_4\omega_1}{\beta_2\omega_0}\left(\omega_4^{lin}\right)^2\\
&\qquad=\tfrac{9}{16}A_4^3+\tfrac{3}{4}A_4\left(A_1^2+A_2^2+A_3^2\right)+\tfrac{3}{8}A_1A_2A_3+\tfrac{3}{16}\left(A_2A_1^2+A_2A_3^2\right)\\
&\qquad+\mu\left(\tfrac{3}{4}A_4A_5^2+\tfrac{3}{8}(A_1A_2A_5+A_2A_3A_5+A_3A_4A_5)+\ldots\right),
\end{aligned}
$$

$$
\begin{aligned}
&\tfrac{4M}{M_0}\tfrac{2A_5\omega_1}{\beta_2\omega_0}\left(\omega_5^{lin}\right)^2\\
&\qquad=\tfrac{9}{16}A_5^3+\tfrac{3}{4}A_5\left(A_1^2+A_2^2+A_3^2+A_4^2\right)+\tfrac{3}{8}(A_1A_2A_4+A_2A_3A_4)\\
&\qquad+\tfrac{3}{16}\left(A_1A_2^2+A_3A_1^2+A_1A_3^2+A_3A_4^2\right)+\ldots,
\end{aligned}
$$

Thus, at $\mu = 0$, the system takes on the "triangular" form and reduces to a recurrent system of equations, while taking on its original form at $\mu = 1$. The unknown quantities can be found through the following expansions:

$$
\begin{gathered}
\omega_1=\omega_1^{(0)}+\mu\omega_1^{(1)}+\mu^2\omega_1^{(2)}+\ldots,\\
A_j=A_j^{(0)}+\mu A_j^{(1)}+\mu^2A_j^{(2)}+\ldots, j=2,3,4\ldots.
\end{gathered}
$$

The first term of the series $\omega_1^{(0)}$ will be defined by the first equation of the system, based on the condition of non-occurrence of secular terms caused by the fundamental vibration mode in the solution, and all the next terms $\omega_1^{(j)}$, j = 2,3,4...—based on the condition of non-occurrence of secular terms caused by the additional resonance harmonics. From now on, we will limit the expansion to the first two terms.

The system solution corresponds to the case when all odd harmonics occur simultaneously:

$$
\begin{gathered}
A_{2i}=0, i=1,2,3\ldots,\\
A_3=0.014493151A_1,\\
A_5=0.000207090A_1,\\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots;\\
\omega_1=\frac{0.282688A_1^2\beta_2}{\omega_0}.
\end{gathered}
$$

The frequency response sought for can be written as follows:

$$
\Omega_i=i\omega_0\left(1+0.282688\frac{A_1^2\beta_2}{\omega_0^2}\varepsilon\right)+O\left(\varepsilon^2\right), i=1,3,5\ldots,
$$

where $\omega_0 = \alpha\pi/l$.

The solution corresponds to the internal resonance between the harmonics at $\beta_1 = 0$. Now let us consider the case when the system is close to the internal resonance state, but does not exactly achieve it, i.e. certain detuning takes place. The β_1 parameter in the equation tends to zero. The constitutive equation can be rewritten in a more convenient form:

$$a^2\frac{\partial^2 u}{\partial x^2}-\frac{\partial^2 u}{\partial t^2}-\delta\beta_1^* u-\varepsilon\beta_2 u^3-\frac{M}{h}\delta(x-x_0,y-y_0)\frac{\partial^2 w}{\partial t^2}=0,$$

where β_1^*, β_2 stand for some coefficients, $\delta=\beta 1/\beta_1^*$ is a non-dimensional small parameter indicating the degree of detuning, $\delta\to 0$.

Let us introduce time conversion. The boundary value problem will be solved through asymptotic expansions in powers of δ:

$$u=u_0+\delta u_1+\delta^2 u_2+\ldots,$$
$$\omega=\omega_0+\delta\omega_1+\delta^2\omega_2+\ldots,$$

with the expansion terms further represented in series as follows:

$$u=u_{00}+\delta u_{01}+\delta^2 u_{02}+\ldots,$$
$$\omega=\omega_{00}+\delta\omega_{01}+\delta^2\omega_{02}+\ldots,$$
$$u=u_{10}+\delta u_{11}+\delta^2 u_{12}+\ldots,$$
$$\omega=\omega_{10}+\delta\omega_{11}+\delta^2\omega_{12}+\ldots,$$

where $\omega_0=\alpha\pi/l$ is the natural frequency of the fundamental vibration mode at $\varepsilon=0$ and $\delta=0$.

Splitting the original problem in powers of δ and ε, we obtain the following linear equation sequence:

$$a^2\frac{\partial^2 u_{00}}{\partial x^2}-\omega_{00}^2\frac{\partial^2 u_{00}}{\partial t^2}=0,$$
$$a^2\frac{\partial^2 u_{01}}{\partial x^2}-\omega_{00}^2\frac{\partial^2 u_{01}}{\partial t^2}=2\omega_{00}\omega_{01}\frac{\partial^2 u_{00}}{\partial t^2}+\beta_2 u_{00}^3,$$
$$a^2\frac{\partial^2 u_{10}}{\partial x^2}-\omega_{00}^2\frac{\partial^2 u_{10}}{\partial t^2}=2\omega_{00}\omega_{10}\frac{\partial^2 u_{00}}{\partial t^2}+\beta_2^* u_{00},$$
$$\begin{aligned}a^2\frac{\partial^2 u_{11}}{\partial x^2}-\omega_{00}^2\frac{\partial^2 u_{11}}{\partial t^2}&\\ =2\omega_{00}\omega_{10}\frac{\partial^2 u_{01}}{\partial t^2}&+\beta_1^* u_{01}+2(\omega_{01}\omega_{10}+\omega_{00}\omega_{11})\frac{\partial^2 u_{00}}{\partial t^2}\\ +2\omega_{00}\omega_{01}\frac{\partial^2 u_{10}}{\partial t^2}&+3\beta_2 u_{00}^2 u_{10},\end{aligned}$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots;$$

The boundary conditions and periodicity conditions will be written as follows:

$$u_{ij}\big|_{x=0,l}=0,$$
$$u_{ij}(x,\tau)=u_{ij}(x,\tau+2\pi),\ i,j=0,1,2,\ldots.$$

The first equation of the sequence with the conditions allows for determining u_{00}:

$$u_{00}=\sum_{i=1}^{\infty}A_i\sin\left(\frac{\pi i}{l}x\right)\sin(i\tau).$$

The next approximation u_{01} can be found using the boundary value problem. In order to prevent the occurrence of secular terms in the expansion, coefficients of the terms having the form $\sin\left(\frac{\pi i}{l}x\right)\sin(i\tau)$, $i = 1, 2, 3\ldots$ on the right-hand side of the equation should be set equal to zero. The following infinite system of nonlinear algebraic equations will be obtained:

$$\begin{aligned}
&\frac{4M}{M_0}\frac{2A_1}{\beta_2}\omega_{00}\omega_{01}\\
&\quad= \tfrac{9}{16}A_1^3 + \tfrac{3}{4}A_1\left(A_2^2 + A_3^2 + A_4^2 + A_5^2\right)\\
&\quad+\tfrac{3}{8}(A_1A_2A_4 + A_2A_3A_4 + A_1A_3A_5 + A_2A_4A_5) + \tfrac{3}{16}\left(A_1^2A_3 + A_2^2A_3\right)\\
&\quad+\ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{8A_2}{\beta_2}\omega_{00}\omega_{01}\\
&\quad= \tfrac{9}{16}A_2^3 + \tfrac{3}{4}A_2\left(A_1^2 + A_3^2 + A_4^2 + A_5^2\right)\\
&\quad+\tfrac{3}{8}(A_1A_2A_3 + A_1A_3A_4 + A_1A_2A_5 + A_1A_4A_5 + A_3A_4A_5)\\
&\quad+\tfrac{3}{16}\left(A_1^2A_4 + A_3^2A_4\right) + \ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{18A_3}{\beta_2}\omega_{00}\omega_{01}\\
&\quad= \tfrac{1}{16}A_1^3 + \tfrac{9}{16}A_3^3 + \tfrac{3}{4}A_3\left(A_1^2 + A_2^2 + A_4^2 + A_5^2\right)\\
&\quad+\tfrac{3}{8}(A_1A_2A_3 + A_2A_3A_4 + A_1A_3A_5 + A_2A_4A_5)\\
&\quad+\tfrac{3}{16}\left(A_2^2A_1 + A_1^2A_5 + A_4^2A_5\right)\ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{32A_4}{\beta_2}\omega_{00}\omega_{01}\\
&\quad= \tfrac{9}{16}A_4^3 + \tfrac{3}{4}A_4\left(A_1^2 + A_2^2 + A_3^2 + A_5^2\right)\\
&\quad+\tfrac{3}{8}(A_1A_2A_3 + A_1A_2A_5 + A_2A_3A_5 + A_3A_4A_5)\\
&\quad+\tfrac{3}{16}\left(A_1^2A_2 + A_3^2A_2\right)\ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{50A_5}{\beta_2}\omega_{00}\omega_{01}\\
&\quad= \tfrac{9}{16}A_5^3 + \tfrac{3}{4}A_5\left(A_1^2 + A_2^2 + A_3^2 + A_4^2\right) + \tfrac{3}{8}(A_1A_2A_4 + A_2A_3A_4)\\
&\quad+\tfrac{3}{16}\left(A_2^2A_1 + A_1^2A_3 + A_3^2A_1 + A_4^2A_3\right)\ldots,
\end{aligned}$$

Using the above-mentioned homotopy parameter method to solve the system, we obtain the following:

$$\begin{aligned}
A_{2i} &= 0, i = 1, 2, 3\ldots,\\
A_3 &= 0.014493151A_1,\\
A_5 &= 0.000207090A_1\ldots\ldots..;\\
\omega_{01} &= \frac{0.282688A_1^2\beta_2}{\omega_{00}}.
\end{aligned}$$

The u_{01} function can be represented as follows:

$$u_{01} = \sum_{i=1}^{\infty} f_i(x)\left(C_i^{(1)}\sin(i\tau) + C_i^{(2)}\cos(i\tau)\right),$$

where $f_i(x)$, $C_i^{(1)}$, $C_i^{(2)}$– are some functions and coefficients.

Boundary value problem solution allows for finding the u_{10} term. Condition of non-occurrence of secular terms in the expansion requires that coefficients of the terms having the form $sin\left(\frac{\pi i}{l}x\right)\sin(i\pi)$, $i = 1, 2, 3, \ldots$ on the right-hand side of the equation be equal to zero. We obtain the following result:

$$\omega_{10} = \frac{\beta_1^*}{2\omega_{00}i^2},$$
$$u_{10} = \sum_{i=1}^{\infty} B_i \sin\left(\frac{\pi i}{l}x\right)\sin(i\pi).$$

Note that here correction ω_{10} to the frequency of each i-th harmonic depends on the i number of the harmonic.

The u_{11} term is found using the boundary value problem. In this case, taking into account the previously assumed relations for u_{01}, the condition of non-occurrence of secular terms in the expansion leads to the following infinite system of equations which are linear with respect to ω_{11} and B_i, i = 1,2,3…:

$$\begin{aligned}
&\frac{4M}{M_0}\frac{2}{3\beta_2}(\omega_{01}\omega_{10}A_1 + \omega_{00}\omega_{11}A_1 + \omega_{00}\omega_{01}B_1)\\
&\quad = \left(\tfrac{9}{16}A_1^2 + \tfrac{1}{4}\left(A_2^2 + A_3^2 + A_4^2 + A_5^2\right) + \tfrac{1}{8}(A_1A_3 + A_2A_4 + A_3A_5)\right)B_1\\
&\quad +\left(\tfrac{1}{2}A_1A_2 + \tfrac{1}{8}(A_2A_3 + A_1A_4 + A_3A_4 + A_2A_5 + A_4A_5)\right)B_2\\
&\quad +\left(\tfrac{1}{16}\left(A_1^2 + A_2^2\right)\tfrac{1}{2}A_1A_3 + \tfrac{1}{8}(A_2A_4 + A_1A_5 + A_3A_5)\right)B_3\\
&\quad +\left(\tfrac{1}{2}A_1A_4 + \tfrac{1}{8}(A_1A_2 + A_2A_3 + A_2A_5)\right)B_4\\
&\quad +\left(\tfrac{1}{16}\left(A_2^2 + A_3^2\right) + \tfrac{1}{2}A_1A_5 + \tfrac{1}{8}(A_1A_3 + A_2A_4)\right)B_5 + \ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{8}{3\beta_2}(\omega_{01}\omega_{10}A_2 + \omega_{00}\omega_{11}A_2 + \omega_{00}\omega_{01}B_2)\\
&\quad = \left(\tfrac{1}{2}A_1A_2 + \tfrac{1}{8}(A_2A_3 + A_1A_4 + A_3A_4 + A_2A_5 + A_4A_5)\right)B_1\\
&\quad +\left(\tfrac{9}{16}A_2^2 + \tfrac{1}{4}\left(A_1^2 + A_3^2 + A_4^2 + A_5^2\right) + \tfrac{1}{8}(A_1A_3 + A_1A_5)\right)B_2\\
&\quad +\left(\tfrac{1}{2}A_2A_3 + \tfrac{1}{8}(A_1A_2 + A_1A_4 + A_3A_4 + A_4A_5)\right)B_3\\
&\quad +\left(\tfrac{1}{16}\left(A_1^2 + A_3^2\right) + \tfrac{1}{2}A_2A_4 + \tfrac{1}{8}(A_1A_3 + A_1A_5 + A_3A_5)\right)B_4\\
&\quad +\left(\tfrac{1}{2}A_2A_5 + \tfrac{1}{8}(A_1A_2 + A_1A_4 + A_3A_4)\right)B_5 + \ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{6}{\beta_2}(\omega_{01}\omega_{10}A_3 + \omega_{00}\omega_{11}A_3 + \omega_{00}\omega_{01}B_3)\\
&\quad = \left(\tfrac{1}{16}\left(A_1^2 + A_2^2\right) + \tfrac{1}{2}A_1A_3 + \tfrac{1}{8}(A_2A_4 + A_1A_5 + A_3A_5)\right)B_1\\
&\quad +\left(\tfrac{1}{2}A_2A_3 + \tfrac{1}{8}(A_1A_2 + A_1A_4 + A_3A_4 + A_4A_5)\right)B_2\\
&\quad +\left(\tfrac{9}{16}A_3^2 + \tfrac{1}{4}\left(A_1^2 + A_2^2 + A_4^2 + A_5^2\right) + \tfrac{1}{8}(A_2A_4 + A_1A_5)\right)B_3\\
&\quad +\left(\tfrac{1}{2}A_3A_4 + \tfrac{1}{8}(A_1A_2 + A_2A_3 + A_2A_5 + A_4A_5)\right)B_4\\
&\quad +\left(\tfrac{1}{16}\left(A_1^2 + A_4^2\right) + \tfrac{1}{2}A_3A_5 + \tfrac{1}{8}(A_1A_3 + A_2A_4)\right)B_5 + \ldots,
\end{aligned}$$

$$\begin{aligned}
&\frac{4M}{M_0}\frac{32}{3\beta_2}(\omega_{01}\omega_{10}A_4 + \omega_{00}\omega_{11}A_4 + \omega_{00}\omega_{01}B_4)\\
&\quad = \left(\tfrac{1}{2}A_4A_1 + \tfrac{1}{8}(A_1A_2 + A_2A_3 + A_2A_5)\right)B_1\\
&\quad +\left(\tfrac{1}{16}\left(A_1^2 + A_3^2\right) + \tfrac{1}{2}A_2A_4 + \tfrac{1}{8}(A_1A_3 + A_1A_5 + A_3A_5)\right)B_2\\
&\quad +\left(\tfrac{1}{2}A_3A_4 + \tfrac{1}{8}(A_1A_2 + A_2A_3 + A_2A_5 + A_4A_5)\right)B_3\\
&\quad +\left(\tfrac{9}{16}A_4^2 + \tfrac{1}{4}\left(A_1^2 + A_2^2 + A_3^2 + A_5^2\right) + \tfrac{1}{8}A_3A_5\right)B_4\\
&\quad +\left(\tfrac{1}{2}A_4A_5 + \tfrac{1}{8}(A_1A_2 + A_2A_3 + A_3A_4)\right)B_5 + \ldots,
\end{aligned}$$

$$\begin{aligned}\frac{4M}{M_0}\frac{50}{3\beta_2}(\omega_{01}\omega_{10}A_5+\omega_{00}\omega_{11}A_5+\omega_{00}\omega_{01}B_5)\\ =\left(\tfrac{1}{16}\left(A_2^2+A_3^2\right)+\tfrac{1}{2}A_1A_5+\tfrac{1}{8}(A_1A_3+A_2A_4)\right)B_1\\ +\left(\tfrac{1}{2}A_2A_5+\tfrac{1}{8}(A_1A_2+A_1A_4+A_3A_4)\right)B_2\\ +\left(\tfrac{1}{16}\left(A_1^2+A_4^2\right)+\tfrac{1}{2}A_3A_5+\tfrac{1}{8}(A_1A_3+A_2A_4)\right)B_3\\ +\left(\tfrac{1}{2}A_4A_5+\tfrac{1}{8}(A_1A_2+A_2A_3+A_3A_4)\right)B_4\\ +\left(\tfrac{9}{16}A_5^2+\tfrac{1}{4}\left(A_1^2+A_2^2+A_3^2+A_4^2\right)\right)B_5+\ldots,\end{aligned}$$

Using this, we obtain the following:

$$\begin{aligned}B_{2i}&=0,\ i=1,2,3\ldots,\\ B_3&=0.014493151B_1,\\ B_5&=0.000207090B_1\end{aligned}$$

;

$$\omega_{11}=0.565352\frac{B_1A_1\beta_2}{\omega_{00}}-0.141344\frac{\beta_1^*\beta_2A_1^2}{i^2\omega_{00}^3}.$$

We can write the following final expressions for the vibration mode and frequencies:

$$\begin{aligned}u&=\sum_{i=1}^{\infty}(A_i+\delta B_i)\sin\left(\tfrac{\pi i}{l}x\right)\sin(\Omega_i t)+O(\varepsilon)+O(\varepsilon\delta)+O\left(\sigma^2\right),\\ \Omega_i&=\sqrt{i^2\omega_{00}^2+\beta_1^*\delta}+0.282688\frac{i^2\beta_2A_1^2}{\sqrt{i^2\omega_{00}^2+\beta_1^*\delta}}\varepsilon+0.565352\frac{i\beta_2A_1B_1}{\omega_{00}}\varepsilon\delta\\ &\quad+o(\varepsilon)+o(\delta)+o(\varepsilon\delta),\ i=1,2,3\ldots,\end{aligned}$$

where $\omega_{00}=\alpha\pi/l$. Parameter accounting for a small attached mass.

A new mathematical model has been obtained for analyzing natural vibrations of a rigidly fixed rod carrying an attached mass; this model is necessary for analysis of load-bearing structures of the facilities consisting of rod systems which carry a small attached mass. Availability of such analysis method enables using a more accurate model described in this paper, which is necessary to avoid accidents.

4 Conclusion

Introduction of a new parameter accounting for a small attached mass in the general equation for a rod leads to obtaining a different result more accurately reflecting the actual oscillatory process of the rod. This solution is consistent with the results obtained above.

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The Typical Settings for Automatic Control Systems

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Abstract. Purpose: To propose the typical settings that expand the range of involved problems of closed automatic control systems synthesis and improve the dynamic characteristics of the resulting systems.

Design/methodology/approach: The relationship between the length of the mid-frequency part of the open system logarithmic amplitude-frequency characteristic and the stability of the closed system is studied for the existing standard setting to a symmetrical optimum. The proposed typical settings are obtained based on this dependence and the principle of analogy.

Findings: Three typical settings for closed automatic control systems calculating are proposed: setting -3-1-3; modified setting -3-1-3; symmetrical setting with a given oscillation index. For each setting, the main characteristics of the synthesized automatic system are given.

Originality/value: The proposed settings concentrate many years of experience in the design of multi-purpose closed automatic systems. Their use allows us to formalize the closed system synthesis procedure and significantly reduce the system calculation time.

The setting -3-1-3 and the modified setting -3-1-3 should be used in the synthesis of servo-systems that position the motor shaft angle of rotation. In this case, the highest possible quality factor of the servo-system can be achieved.

Symmetric setting with a given oscillation index includes in many solutions a standard setting to a symmetrical optimum and, while maintaining all the other positive properties of setting to a symmetrical optimum, reduces the closed system oscillation by increasing the duration of the transition process.

Keywords: Typical setting · Closed control system · Symmetric setting · Oscillation coefficient · Regulator

JEL Code: C69

1 Introduction

Standard settings for technical optimums (Kessler 1958a, b) are known for their simplicity and significantly reduce the calculation time of technical object closed control system. Among practical applications of the settings we can call a vector control system of AC motors. It is no exaggeration to say that synchronous and especially asynchronous AC machines are the main type of electric drive in modern industrial production.

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Setting to the symmetrical optimum (Basharin et al. 1982) is optimized for the speed-stability of a closed system. This setting allows giving the property of astatism on indignation to the system, but it has a significant overshoot, which is not always acceptable.

The article suggests the typical settings for closed automatic control systems synthesis based on the obtained analytical relationships between the closed system oscillation coefficient and the width of the mid-frequency part of the open system logarithmic amplitude-frequency characteristic.

2 Methods

The analytical dependencies underlying the proposed typical settings of automatic control systems were obtained using:

- methods of automatic control theory (frequency characteristics method, the term of a closed system stability, sequential method of system correction, the functional relationship between the open system phase margin and the closed system oscillation coefficient) (Besekersky and Popov 2003);
- methods of mathematical analysis (studying of the open system phase-frequency function to extremum) (Bronshtein and Semendyaev 1980);
- methods of computational mathematics (numerical solution of differential equations, solution of transcendental equations, function interpolation) (Demidovich and Maron 1970).

3 Results

3.1 Typical Setting -3-1-3

The name of the setting corresponds to the slopes of the low-frequency, mid-frequency and high-frequency sections of the asymptotic logarithmic amplitude-frequency characteristic of the open system: −60, −20 and −60 decibels, respectively.

Key settings features:

- desired open system transfer function

$$W_{\text{жр}}(s) = \frac{(16 * T_\mu s + 1)^2}{(16 * T_\mu s)^2} \frac{1}{4 * T_\mu s} \frac{1}{(T_\mu s + 1)^2}$$

  where T_μ – equivalent small time constant of the system;
- phase margin – 34°;
- overshoot – 53%;
- transition time – $t_{\Pi\Pi} \approx 60 * T_\mu$.

The frequency characteristics of the open system corresponding to the desired transfer function of the open system, provided that the model has a small time constant $T_\mu = 1$, are shown in Fig. 1.

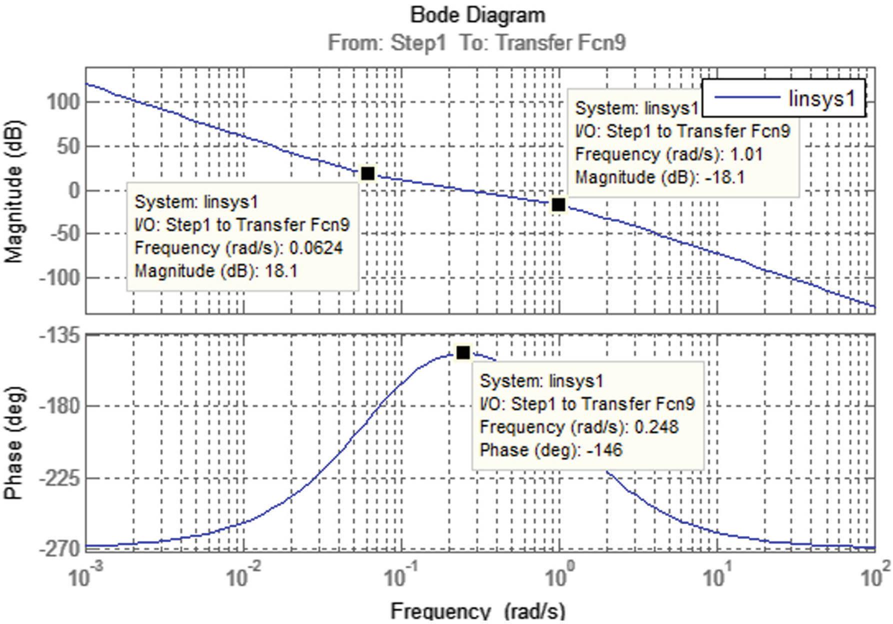

Fig. 1. The frequency characteristics of the open system with setting -3-1-3. *Source*: developed and compiled by the authors

From Fig. 1 it follows that:

- the frequency of the first break of the asymptotic logarithmic amplitude-frequency characteristic is $1/(16 * T_{\mu})$;
- the system cutoff frequency – $1/(4 * T_{\mu})$;
- the frequency of the second break of the asymptotic logarithmic amplitude-frequency characteristic is $1/T_{\mu}$.
- phase margin – 34°.

The asymptotic open system frequency characteristic with a -3-1-3 setting is centrally symmetric about the cutoff frequency and has a corner frequency two octaves apart from the cutoff frequency.

The transient response of a closed system with a setting of -3-1-3 is shown in Fig. 2.

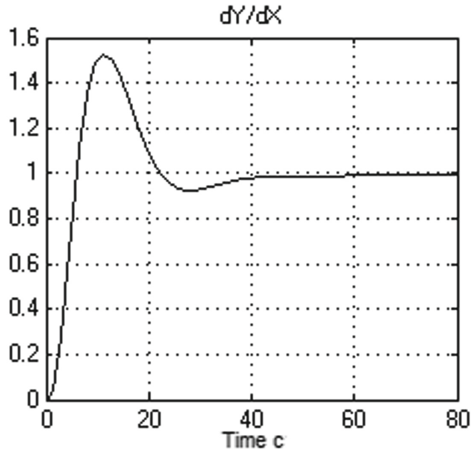

Fig. 2. The transient response of a closed system with a setting of -3-1-3. *Source*: developed and compiled by the authors.

Figure 2 shows that the overshoot is 53%, and the transition time is approximately 60 small time constants of the control object.

3.2 Modified Typical Setting -3-1-3

The essence of the modification of the typical setting described above is to obtain an analytical relationship between the width of the mid-frequency part of the logarithmic amplitude-frequency characteristic of the open system and the stability of the closed system, expressed in terms of the oscillation coefficient. This will allow at the stage of calculation, having asked the required oscillation of a closed system, to obtain the required overshoot of the system transient response.

Key features of the setting:

– desired open system transfer function

$$W_{\text{жр}}(s) = \frac{(HT_{\mu}s+1)^2}{(HT_{\mu}s)^2}\frac{1}{\sqrt{H}T_{\mu}s}\frac{1}{(T_{\mu}s+1)^2}$$

where H – the width of the mid-frequency part of the desired logarithmic amplitude-frequency characteristic of the open system.

The width of the mid-frequency part of the desired logarithmic amplitude-frequency characteristic of the open system is determined from the expression

$$\frac{H-1}{2\sqrt{H}} = 2\cdot\tan\left(\frac{1}{2}(\arccos\left(\frac{2M_{\omega cp}^2-1}{2M_{\omega cp}^2}\right)+\frac{\pi}{2})\right)$$

where $M_{\omega\text{cp}}$ – oscillation of a closed system at a cutoff frequency.

The results of solving the given transcendental equation are summarized in Table 1.

Table 1. Dependence points $H = f(M_{\omega cp})$ for the modified setting -3-1-3

$M_{\omega cp}$	H	$(\sqrt{H})$
1.05	47.20	6.87
1.10	40.02	6.33
1.15	34.85	5.90
1.20	30.96	5.56
1.25	27.95	5.29
1.30	25.55	5.05
1.35	23.60	4.86
1.40	21.99	4.69
1.45	20.64	4.54
1.50	19.49	4.41
1.55	18.49	4.30
1.60	17.63	4.20
1.65	16.88	4.11
1.68	16.00	4.00
1.70	16.21	4.03

The expression of the dependence $H = f(M_{\omega cp})$ also allows us to obtain the break frequencies of the desired asymptotic logarithmic amplitude-frequency characteristic of the open system, depending on the oscillation index of the closed system at the cutoff frequency.

These frequencies are determined by the relations

$$\omega_1 = \frac{1}{HT_\mu}, \omega_2 = \omega_{cp} = \frac{1}{\sqrt{H}T_\mu}, \omega_3 = \frac{1}{T_\mu}.$$

where $\omega_1 < \omega_2 < \omega_3$; ω_{cp} – the open system cutoff frequency.

Figure 3 shows the transient characteristics of a closed system with a modified setting of -3-1-3, when changing the system oscillation coefficient in the range from 1.10 to 1.68.

The maximum oscillation coefficient of 1.68 corresponds to the maximum overshoot of 53%, and the minimum coefficient of 1.1 corresponds to the overshoot of 26%.

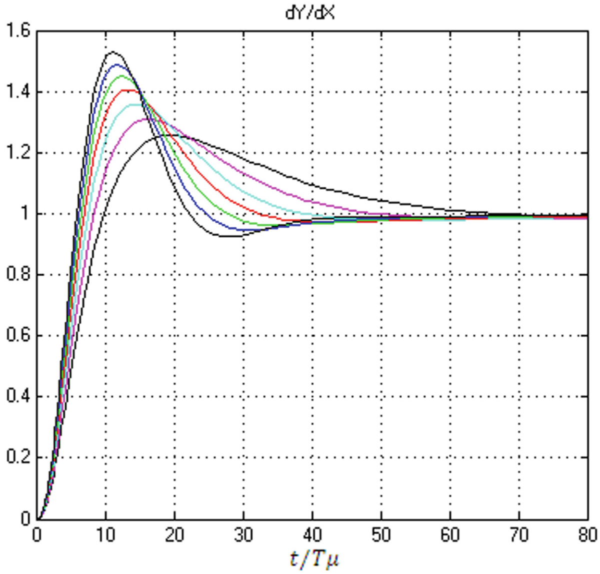

Fig. 3. The transient characteristics of a closed system with a modified setting of -3-1-3, when changing the system oscillation coefficient in the range from 1.10 to 1.68. *Source*: developed and compiled by the authors

The dependence of overshoot on the closed system oscillation coefficient with a modified setting of -3-1-3 is shown in Fig. 4. From the figure it follows that overshoot decreases linearly, with a decrease in the closed system oscillation coefficient. This dependence can be described by the expression

$$\sigma = \frac{49 - 26}{1.6 - 1.1}(M_{\omega\text{cp}} - 0.53) = 46(M_{\omega\text{cp}} - 0.53),$$

where σ – the overshoot of the closed system transient characteristics.

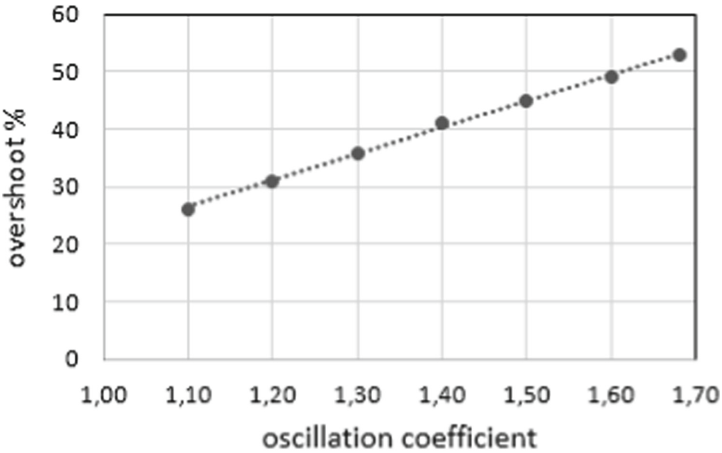

Fig. 4. The dependence of overshoot on the closed system oscillation coefficient with a modified setting -3-1-3. *Source*: developed and compiled by the authors

The last expression allows you to calculate a closed automatic system by setting the required overshoot.

3.3 Symmetrical Setting with a Given Oscillation Index

The setting allows you to calculate the controller of an automatic system with feedback, taking into account the required closed system oscillation index, and includes a standard setting for a symmetrical optimum in a variety of solutions.

Key features of the setting:

– desired open system transfer function

$$W_{\text{жр}}(s) = \frac{HT_\mu s + 1}{HT_\mu s} \frac{1}{\sqrt{H} T_\mu s} \frac{1}{T_\mu s + 1}$$

where H – the width of the mid-frequency part of the desired logarithmic amplitude-frequency characteristic of the open system.

The width of the mid-frequency part of the desired logarithmic amplitude-frequency characteristic of the open system is determined from the expression

$$\frac{H - 1}{\sqrt{H}} = 2 \cdot \tan\left(\arccos\left(\frac{2M_{\omega cp}^2 - 1}{2M_{\omega cp}^2}\right)\right)$$

where $M_{\omega\text{cp}}$ – oscillation of a closed system at a cutoff frequency.

The results of solving the given transcendental equation are summarized in Table 2.

The characteristic points of the desired asymptotic logarithmic amplitude-frequency characteristic of the open system are described by the expressions:

$$\omega_1 = \frac{1}{HT_\mu}, \omega_2 = \omega_{cp} = \frac{1}{\sqrt{H} T_\mu}, \omega_3 = \frac{1}{T_\mu}.$$

Table 2. Dependence points $H = f(M_{\omega cp})$ for symmetrical setting with a given oscillation index

$M_{\omega cp}$	H	$(\sqrt{H})$
0.80	81.5	9.03
0.85	40.15	6.34
0.90	25.27	5.03
0.95	18.06	4.25
1.00	13.93	3.73
1.05	11.31	3.36
1.10	9.51	3.08
1.15	8.22	2.87
1.20	7.25	2.69
1.25	6.50	2.55
1.30	5.90	2.43
1.35	5.41	2.33
1.40	5.01	2.24
1.45	4.67	2.16
1.50	4.38	2.09
1.55	4.14	2.03
1.60	3.92	1.98

where ω_1 – the first break frequency; ω_{cp} – the cutoff frequency; ω_3 – the second break frequency.

Figure 5 shows the transient characteristics of a closed system with a symmetrical setting and given oscillation index, when changing the system oscillation coefficient in the range from 1.00 to 1.60.

The maximum oscillation coefficient of 1.60 corresponds to the maximum overshoot of 44%, and the minimum coefficient of 1.00 corresponds to the overshoot of 19%.

The dependence of overshoot on the closed system oscillation coefficient with a symmetrical setting and a given oscillation index is shown in Fig. 6. From the figure it follows that overshoot decreases linearly with a decrease in the closed system oscillation coefficient. This dependence can be described by the expression

$$\sigma = \frac{44 - 19}{1.6 - 1.0}(M_{\omega \mathrm{cp}} - 0.53) = 41.6(M_{\omega \mathrm{cp}} - 0.53),$$

where σ – the overshoot of the closed system transient characteristics.

The last expression allows you to calculate a closed automatic system by setting the required overshoot.

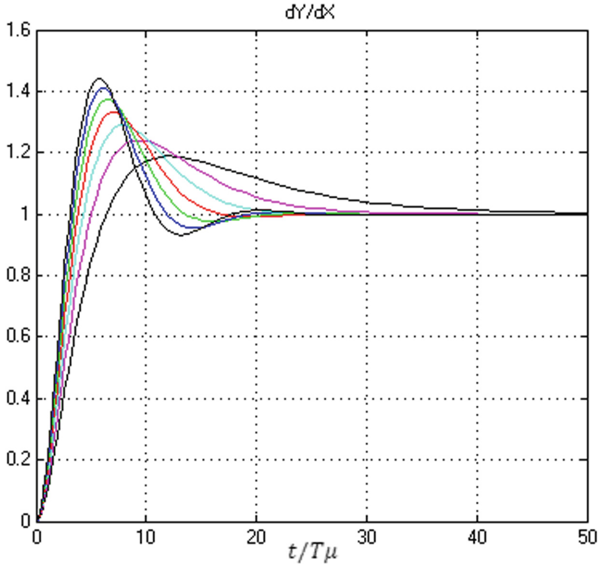

Fig. 5. The transient characteristics of a closed system with a symmetrical setting and given oscillation index, when changing the system oscillation coefficient in the range from 1.00 to 1.60. *Source*: developed and compiled by the authors

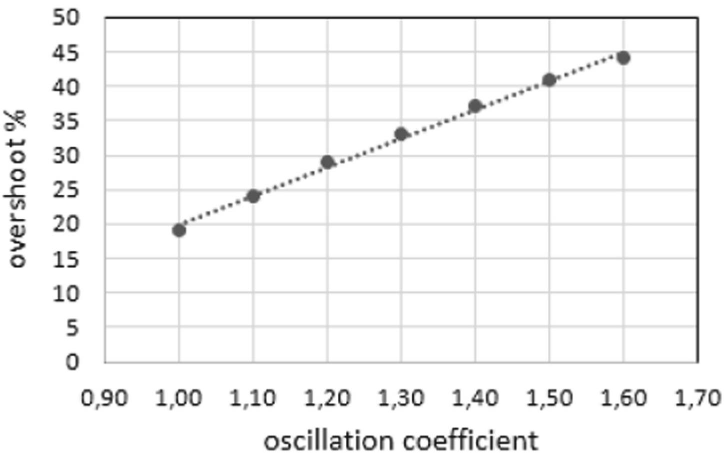

Fig. 6. The dependence of overshoot on the closed system oscillation coefficient with a symmetrical setting and a given oscillation index. *Source*: developed and compiled by the authors

4 Conclusion/Recommendations

The proposed typical settings are conveniently used in the synthesis of a closed automatic control system using the sequential correction method. In this case, the system controller is calculated in the following order:

- choose a setting based on the purpose of the system and the control object transfer function;
- set the necessary oscillation index $\left(M_{\omega \text{cp}}\right)$ or overshoot (Δ) of the closed system;
- using the dependence $H = f(M_{\omega \text{cp}})$ determines the length of the mid-frequency part of the desired logarithmic amplitude-frequency characteristic of the open system H;
- calculate the sequential correction device (regulator) using the ratio

$$W_{\text{p}}(s) = \frac{W_{\text{жр}}(s)}{W_o(s)},$$

where $W_{\text{жр}}(s)$– desired open system transfer function corresponding to the selected setting; $W_o(s)$ – object transfer function. (Examples of closed systems calculation are given in (Egorov 2019a, b)).

The setting -3-1-3 and the modified setting -3-1-3 should be used in the synthesis of servo-systems that position the motor shaft angle of rotation. In this case, the highest possible quality factor of the servo-system can be achieved.

Symmetric setting with a given oscillation index includes in many solutions a standard setting to a symmetrical optimum and, while maintaining all the other positive properties of setting to a symmetrical optimum, reduces the closed system oscillation by increasing the duration of the transition process.

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Process Automation for Robot-Based Manufacturing Components of Prospective Aviation Complexes

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Abstract. Purpose: To assay the ways of process performance improvement for robot-based production. To reduce negative impact of the human factor.

Methodology: The relevance of the study is determined by the proven effectiveness of the robot-based system implementation in aircraft production. The hardware and software complex concept based on automated systems with intelligent output was used in this study. The intelligent control system is based on the mathematical and algorithmic apparatus of neural networks and fuzzy logic (Zade 1976; Kruglov 2001). This concept contributes to the optimization of production tasks and can be used to improve the effectiveness of high intelligence robot-based technological complexes. The operating benefits of the intelligent system are ensured by the capabilities for the process simulation, a knowledge base and a decision support system. This complex allows implementing the digital alter ego synthesis, aimed at eliminating the causes of defects in the process operations, and minimizing the negative impact of the human factor.

Results: A solution has been proposed to improve the process performance of manufacturing items for Prospective Aviation Complexes (PAC). A conceptual model of the robot-based electrical resistance welding (ERW) process is presented.

Conclusions/Recommendations: An industrial robot-based complex equipped with a computer vision system controlled by an intelligent system will ensure the minimization of defects when connecting multilayer material.

Keywords: Process · Automation · Robotic automation · Prospective aviation complexes · Complex configuration product · Electrical resistance welding · Defects · Digital alter ego

JEL Code: O3

1 Introduction

The processes of manufacturing piece and small-scale military aviation products (AP) are characterized by high rates of manual labor associated with continuous sequential upgrading of the product. Currently, the unsatisfactory performance is partially compensated through the introduction of highly adaptive process complexes based on industrial

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robots and intelligent control systems into the manufacturing process (Efimov 2019; Egorova 2019).

However, the currently available concepts (due to the lack of unified and uniquely effective methods, models and algorithms for designing and control of systems with variable design) are unique and do not allow replicating experience to other manufacturing processes without significant additional resources. Also, it should be noted that in most cases, there is a limiting number of employees operating the manufacturing systems with a variable design who have a high level of professional skills (Cherniy and Solovyev 2018). This firstly determines the risk component when achieving the set process results, and, secondly, forces the process management to attract less qualified personnel, which, in turn, reduces the stability of product quality assurance and the repeatability of the process operations. These events result both in additional processes for rework of finished products and significant increase in the cost of the final production result. The process operations most sensitive to the procedure violation include making joints of multilayer products of complex design for aviation purposes by ERW (due to melting and subsequent solidification of the metal at the contact points). The permanent joint specificity (Oreshenko 2013) narrows rather strongly the possibilities for eliminating the defect if it is revealed. The resulting defect can be found to be critical, and an expensive part of a high level reworking can be rejected. To maximize the process performance when making joints in aircraft products by electrical resistance welding, we provide a brief review of the cause-and-effect relationships that determine the risk of defects, the classification of the most common defects in this process; a concept for upgrading the existing process structures and their control systems is proposed.

2 Methodology

ERW is widely used in the state-of-art process of manufacturing aircraft products due to a large nomenclature of items made of sheet material and profiles well connected by ERW in the manufacturing process. The second factor in favor of this type of connection is higher cost effectiveness compared to rivets as a typical connection in the aviation. In addition, the replacement of the riveting process with ERW makes the manufactured parts significantly lighter, which is an indisputable advantage for the AC. The following types of electrical resistance welding: spot arc welding (SAW) and seam welding (as per GOST 2014) are most widely used in aircraft construction. The quality of joints made by ERW is mainly determined by a solid metal bond over a certain joint area (Kataev 2015), which is determined by the action degree of two types of disturbances: disturbances caused by an arbitrary deviation of the process factors (the joint gap size, dimensions and state of the electrode working surface, the quality indicators of the component surface preparation, unreliable fastening of components in the joining machine clamps, etc.); disturbances caused by arbitrary fluctuations in the electrical and mechanical parameters of the welding equipment during the welding process, as well as the human factor influencing the product manufacturing process. In the study, we used the proven methods of automation and robotization of the manufacturing processes, algorithms for intelligent control, and simulation tools.

3 Results

Defects in joints made by ERW can be caused by violations of the procedures practically at all stages of the manufacturing process: surface preparation of components for welding; assembly of a product into a tooling; tacking of the product, welding, heat treatment and straightening. In this study, we considered only defects associated with the non-compliance of the welding process and options for reducing their frequency, many of which are determined by the design of the organization of process operations.

Design of a typical ERW process for multilayer AP within the piece and small-scale manufacturing process is shown in Fig. 1.

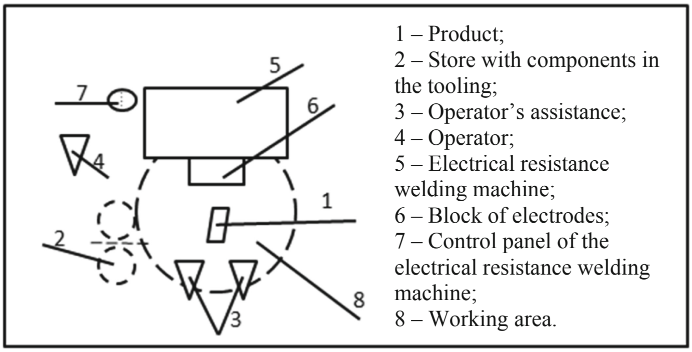


Fig. 1. Design of a typical ERW process for multilayer AP. *Source*: developed and prepared by the authors

Understanding the specifics of the process functions will help to identify key problems and define the ways to solve them by improving the process performance. A multilayer product from the previous process, fixed in a tooling with marked welding points, is placed on a rack. Further, by operator command, the assistants place the product in the working area of the ERW machine and sequentially, according to the manufacturing technology and following the operator's commands, position the product from point to point. In this case, the product is positioned manually, despite the fact that the product weight in the tooling can reach 30–40 kg. The operator, when the assistants implement the next positioning stage, having previously visually checked the relative position of the machine electrodes and the point mark (the mark coordinates, the coordinates of the upper and lower electrodes, the alignment of the electrode group and the normal to the surface at the contact points and the electrode state are simultaneously controlled), sends manually the control signal to the ERW machine for welding the joint. It should be noted that the overwhelming number of multilayer products for the aviation have a complex geometric shape (they combine surfaces of different curvature radii, stiffeners and metal thicknesses heterogeneity). This fact together with the equipment specifics, does not allow the assistants to approach to electrodes from any position, due to its geometric shape, makes the product positioning process in the working area of the machine extremely difficult, and requires for significant physical strength and skills of the operator and his assistants. In addition, the operator's duties also include ensuring the electrode condition control, timely cleaning, and removal of the contact marking planes, while the electrodes can burn several times during the process. All the process complexity and responsibility is further aggravated by the technology of manufacturing these products, which requires for the implementation of all process operations sequentially without stopping in order to exclude residual metal stresses. The high workload of the process personnel (manufacturing a complex product, for example, requiring 2000–2500 joints often takes up to 1.5–2 work shifts), determines the risk of connection defects. While the overall process performance is significantly reduced. A brief description of defects specific to the production under consideration is provided in Table 1, as well as in (Kataev 2015; GOST 2012).

Table 1 below shows the main defects that reduce the process performance and their signs in the electrical resistance welding [12]. Defects of ERW include complete or partial lack of penetration, external or internal splash of metal, internal cracks and cavities, external cracks, point dark surface, angular displacement between two welded elements [13], rupture and external cracks in the metal at the overlap edges, excessive dents from the electrode, large gaps between the parts, metal extrusion on the surface of points, poorly prepared surface area for connecting electrodes, point offset from the marked line. In some cases, defects can be prevented by eliminating the causes. In addition, in some cases, defective joints are allowed to be re-welded. But nevertheless, additional work increases the process time, affecting the process performance as a whole. Table 1 the correction and prevention methods.

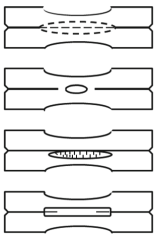
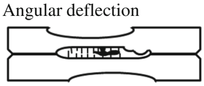
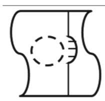
Depending on the process parameters and the manufacturing requirements, defects can be classified according to the certain grounds. The classification grounds can include the defect significance, admissibility, etc., which, together with the cause classification grounds can be used as starting points when making and implementing decisions to eliminate the defects or minimize their impact on the final product.

To eliminate most of the defect causes in order to increase the process performance in the current work, we propose to upgrade the process by introducing an intelligent robot-based system into the production (Fig. 2) (Gorkavyy 2018). However, the process control system is proposed to be built in the man-machine system format (the control system block diagram is shown in Fig. 3).

The key feature of this concept is the high adaptability of the software and hardware automated complex based on an intelligent control system (Gorkavyy 2017) with support for algorithms for prompt correction of the control program. Table 2 shows the parameters used for the conformity assessment of the actual and virtual state of the facility, the process (digital alter ego). However, the current state of the facility is monitored by an auxiliary robot (Fig. 2), equipped with a computer vision system, and synchronized with the main robot, positioning the product (Fig. 3).

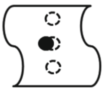
A multi-layer product from the previous process is fixed in the tooling with marked welding points and placed in the product store in the tooling. Then the operator (decision maker) initiates the start of the intelligent system that starts the process program for execution in accordance with the Xin task. The industrial robot grabs the product from the tooling store and moves it to the ERW working zone. Then the robot moves sequentially the component, according to the manufacturing process, from point to point. Following the intelligent system U control law and focusing on the virtual state of the facility Xo,

Table 1. External or internal defects of electrical resistance welding.

Defect	Description	External signs/causes
1. Complete or partial lack of penetration 	Weld areas with lack of penetration between the welded components, for example, between the base and the deposited weld metal (along the edge) or between adjacent layers of the deposited weld metal.	None, since the defect is located inside the welded joint. Revealed by non-destructive examination methods.
2. External or internal metal splashoff 	Spitting of a part of molten metal from the weld zone. Internal splashoff often impede further core growth due to increased current spreading and metal cooling. Final splashoff is often accompanied by cracks, cavities, and deep dents.	Excess metal within the joint area. The defect is visible by a naked eye during visual examination. X-ray radiographic examination.
3. Internal cracks and cavities 	A) Radial cracks – cracks radiating from one point. B) Microcrack – a crack with microscopic dimensions, which is revealed by physical methods with at least 10x magnification.	Microscopic breaks along metal grain boundaries. X-ray radiographic examination.
4. External cracks 	Transverse crack – a crack oriented across the weld axis. Longitudinal crack – a crack oriented along the welded joint.	Longitudinal hot cracks have a yellowish-orange tint at the fracture; Cold cracks – a clean, shiny appearance of crystals; Cracks in the base metal – metal color. The defect is visible with a naked eye or with a small (2-4x) magnifying glass during visual examination.
5. Dark (oxidized) point surface 	Dark weld spot is a sign that the metal has oxidized.	The defect is visible by a naked eye. The thinning size is determined by measurement examination. Degradation of the electrode contact spot plane. Careless work of the operator. Untimely cleaning of electrodes.
6. Angular deflection 	Misalignment between two welded elements, when their surfaces are located at an angle that does not comply with the requirement.	Two welded parts are located at an angle relative to each other. The defect is visible by a naked eye. The deflection size is determined by measurement examination. Misalignment of the electrode group and the normal to the surface at the connection point. Careless work of the operator.
7. Rupture and external cracks of the metal at the overlap edges 	Discontinuity caused by local break in the joint.	The defect is visible by a naked eye. Untimely cleaning of electrodes.

(*continued*)

Table 1. (*continued*)

8. Excessive dents from the electrode 	A dent from the electrode between the two welded parts.	Visual examination and measurement of the dent depth with an indicator. Degradation of the electrode contact spot plane. An error in the spatial comparison of electrodes and the mark. Careless work of the operator. Untimely cleaning of electrodes.
9. Large gaps between the components 	Large gaps when assembling the components.	Visual examination and measurement of the gaps with clearance gauge. An error in the spatial comparison of electrodes and the mark. Careless work of the operator.
10. Extrusion from metal on the point surface 	Extrusion of metal on the surface of the electric resistance welding points.	Visual examination
11. Irregular shape of the cast area within the joint plane 	Low quality of prepared surface area.	Using the process specimens. Misalignment of the electrode group and the normal to the surface at the connection point. An error in the spatial comparison of electrodes and the mark.
12. Offset of points from the marked line 	Spot offset for electric resistance welding	Visual examination using a measuring device. Misalignment of the electrode group and the normal to the surface at the connection point. An error in the spatial comparison of electrodes and the mark. Careless work of the operator.

the ERW machine makes the connections. In this case, the auxiliary robot monitors the actual state of the facility using the computer vision system and transmits the measured and estimated state of the facility to the intelligent system input through the feedback channel $\hat{X}^{h}_{out}$. Typical industrial vision systems are capable of ensuring the accuracy of defect identification, reading codes, and markings, and are also able to record the geometric deviations in space of a few millimeters ±0.05–0.1. This accuracy exceeds the actual point positioning accuracy in space by an operator by at least an order of magnitude. If the intelligent system or the operator identifies an out-of-range mismatch between the virtual and real state of the facility, the program execution interrupts and the problem is corrected. For example, the electrodes are cleaned, the equipment is adjusted, and the program is adjusted. However, most of the causes for the interruption in the program execution can be corrected automatically. If applicable, the operator can intervene in the process and fix the problem manually.

This approach completely eliminates the risk of exceeding the geometric distortion tolerances of the product-tooling-electrodes system. The positioning procedure is significantly accelerated, while the accuracy of manufacturing an aircraft product is significantly increased. Possible violations within the robot-based process are monitored by the intelligent system and also by an operator. The listed advantages of the proposed concept

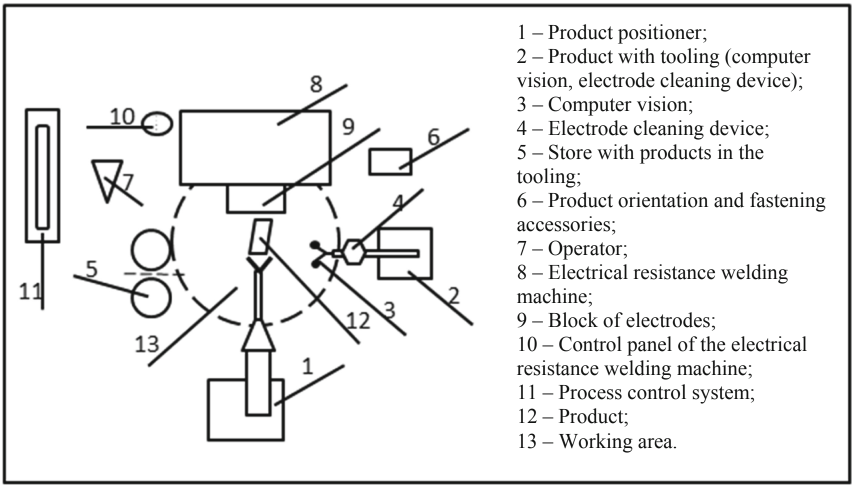


Fig. 2. Conceptual diagram of ERW area with automated workstations. *Source*: developed and prepared by the authors

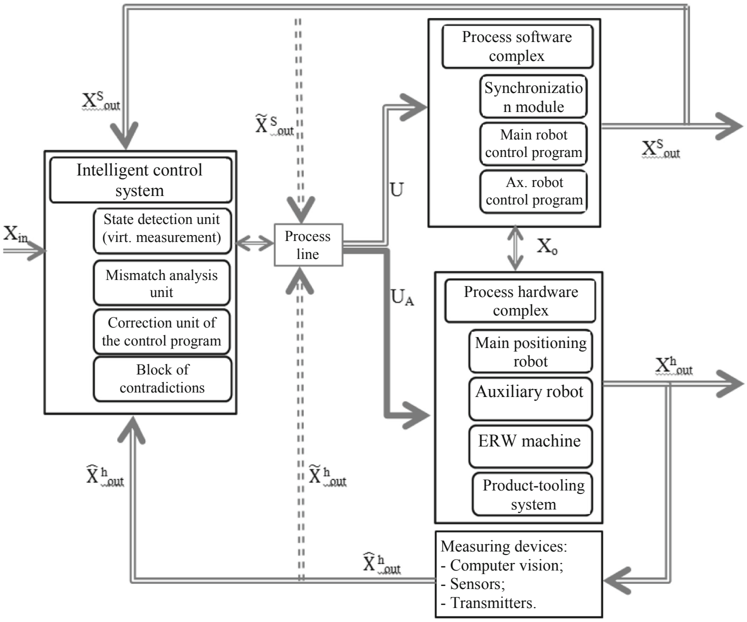
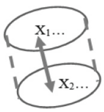
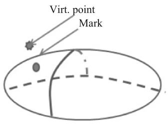
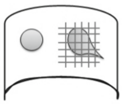
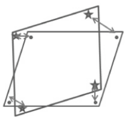


Fig. 3. Block diagram of a robot-based process control system for manufacturing items of prospective PAC. Source: developed and prepared by the authors

will improve the performance of both the considered subsystem (robot-based manufacturing process) and the auxiliary system (production of AC), as well as interconnected subsystems.

Table 2. Parameters included in the simulation model

Item No.	Parameter	Characteristics
1	RMSE (root-mean-square error array) of the contact plane points of the first and second electrodes from the model position. 	Optimization problem (performance criterion), RMSE →min. In case of an unsatisfactory indicator: → program execution pause; → cleaning of electrodes; → program start.
2	Array of linear deviations of mark from the virtual connection point $R=\{x_b-x_M, y_b-y_M, z_b-z_M\}$. 	Performance criterion. $\min^{(abc}(R))=\min^{(abc}\{x_b-x_M, y_b-y_M, z_b-z_M\})/$ In case of an unsatisfactory indicator: → program execution pause; → cause investigation; → operator notification; → making a decision; → manual search.
3	Visual Image Check, visual check by system, spots and joint conditions. 	Performance criterion. Visual Image Check and Visual Image Check Class = = ok Attributes: - color; - area; - shape (on the plane); - color gradient; - shape (three-dimensional).
4	Play of the component displacement relative to the tooling. 	Performance criterion min(L), min(D)→0 $L=\sum_{i=1}^{n}\sqrt{[G_0 - C_d]^2}$ $D= G_0-C_d$ where G_0 – array of coordinates of the tooling mark points, G_d – array of coordinates of the product mark points
5	Actual time taken for the main program execution plus the forced stop time.	$T_{t=t_{t.p.}}$ – performance criterion, t_t-$t_{t.p.}$ →0.

4 Conclusion

The proposed concept for improvement of the process performance when manufacturing multilayer AP by ERW will provide a high degree of the manufacturing process automation and reduce the negative impact of the human factor. According to preliminary expert estimates, the intelligent robotization of the welding process can reduce product defects by up to 30%, free up 50% of labor resources (excluding operator assistants from the process). The industrial robot-based complex equipped with the computer vision system controlled by the intelligent system will ensure minimization of defects in the joint of multilayer materials. A digital alter ego of the product can be created based on the results of each process operation, by saving the in-process monitoring results of the facility condition [2].

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Experimental Verification of the Mathematical Model for Thin-Walled Cylindrical Shell Vibrations on Exposure to Uniform Temperature, Based on Variational Formulation

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Abstract. Purpose: To verify the mathematical model for thin-walled cylindrical shell vibrations on exposure to uniform temperature, based on a variational formulation and using different methods, including the experimental one.

Design/methodology/approach: Today, expressive and cost-effective forms of buildings and structures are widely used in construction; these are represented by thin-walled cylindrical shells. Such buildings and structures are exposed to the action of temperatures and external forces, which cause forced vibrations leading to man-made accidents. Prevention of accidents requires analyzing buildings and structures in terms of their frequency response. Dynamic change in the shell temperature leads to changes in the elastic modulus of the building structure material, which affects the frequency response dynamics. The existing vibration analysis models for thin-walled cylindrical shells do not give due consideration to this; therefore, it is required that new—improved—analytic models be developed and their high quality be confirmed. Experimental verification is one of the most common methods of verifying mathematical models. The parameters of a theory are verified using a realistic scaled-down model of the structure, with comparison of the experimental and theoretical data.

Findings: The paper presents a new vibration analysis model for thin-walled cylindrical structures exposed to uniform heating, based on a variation formulation. The obtained analytic model has been verified by experiment, and its application range has been determined.

Originality/value: The new verified mathematical model can be used for performing structural analysis, in design bureaus carrying out vibration analysis for cylindrical shells.

Keywords: Thin-walled cylindrical shell · Forced vibrations · Analytic model · Experimental studies · Variation formulation

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1 Introduction

Thin-walled cylindrical shells are frequently used for construction of buildings and structures because of their high economic efficiency that is determined by the favorable relation between the internal volume of the building and its external surface area. Such buildings are erected both at the equator and in the Polar Regions, with daily and seasonal temperature variations sometimes exceeding 150 °C. This can result in high expenses for heating or cooling of buildings. The shape of a thin-walled cylindrical shell will change due to its thermal expansion (contraction), as described in papers by Vlasov (2020), Seregin (2019a), Sysoev et al. (2019), Seregin (2019b), with the elastic modulus of the shell structural material changing as well. These two factors have a significant influence on the frequency response of the natural and forced vibrations of thin-walled cylindrical shells precisely due to thinness of the shell walls, as described in papers by Sysoev et al. (2017), Wang et al. (2017), Seregin (2020a), Sysoev et al. (2019), Xing et al. (2013). Coalescence of the natural and forced vibration frequencies of a thin-walled cylindrical shell can cause resonance (which is pointed out by Sysoev et al. (2017), Seregin (2020b)) and structural failure. For example: in 2010, one of the roof sections collapsed at a stadium in Minnesota (USA) burying the underneath stand; in 2015, the accident at the tank under construction at an oil refinery (Komsomolsk-on-Amur), which occurred due to vibrations caused by wind loads; in 2015 (Verkh-Irmen settlement in the Novosibirsk Region), the roof of a covered ice rink collapsed under the combined wind and snow loads; in 2017, a school roof collapsed in Murino residential settlement; in 2018, catastrophic deformation of the roof occurred at the skating rink under construction in the town of Istra; the accident in the city of Balashikha in 2018 lead to collapse of the roof of an arc-shaped steel parking lot; the environmental accident due to diesel fuel spill near Norilsk occurred on May 29, 2020 as a result of an emergency tank rupture at CHPP-3 owned by JSC NTEK. Therefore, when designing thin-walled cylindrical shells, structural analysis should be performed and the natural and forced vibration frequency response of the shell should be taken into account in order to avoid man-made accidents.

2 Materials and Method

Uniform heating of a thin-walled cylindrical shell is the most simple and common temperature action. In order to develop an analytic model for the vibration frequency of a uniformly heated thin-walled cylindrical shell, let us use the traditional model of determining displacements and strains; this model is described in papers by Sysoev (2019), Qu et al. (2013a), Qu et al. (2013b), Chen et al. (2015).

$$T_1 = \int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_{11} dz = \frac{E}{1-\nu^2}(\varepsilon_{11} + \nu\varepsilon_{22}) - \frac{E\alpha_T}{1-\nu}\int_{-\frac{h}{2}}^{\frac{h}{2}} \theta dz = \frac{Eh}{1-\nu^2}(\varepsilon_{11} + \nu\varepsilon_{22} - \alpha_T(1+\nu)N_T), \left(\begin{matrix}\leftrightarrow \\ x, y\end{matrix}\right);$$

$$S = \int_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_{12} dz = \frac{E}{2(1-\nu)}\varepsilon_{12}; \tag{1}$$

where $N_T = \frac{1}{h}\int\limits_{-h/2}^{h/2} \theta dz$ stands for thermal force.

The following formulas are used to determine the moments:

$$M_1 = \int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \sigma_{11} dz = D(æ_{11} + væ_{22}) - \frac{E\alpha_T}{1-v}\int\limits_{-\frac{h}{2}}^{\frac{h}{2}} dz = D(æ_{11} + væ_{22} - \alpha_T(1+v)M), \begin{pmatrix} \leftrightarrow \\ x, y \end{pmatrix}; \quad M_{12} = \frac{D(1-v)}{2}æ_{12}, \tag{2}$$

where $\mathrm{D} = \frac{\mathrm{E}h^3}{2(1-v^2)}$ stands for flexural rigidity, $M_T = \frac{12}{h^3}\int\limits_{-h/2}^{h/2} \theta z dz$ is the thermal moment.

The first two Eqs. (1) are solved for tangential strains of the middle surface, and the following is obtained:

$$\varepsilon_{11} = \frac{1}{Eh}(T_1 - vT_2) + \frac{\alpha_T}{h}\int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \theta dz, \begin{pmatrix} \leftrightarrow \\ x, y \end{pmatrix}; \quad \varepsilon_{12} = \frac{2(1+v)}{Eh}S. \tag{3}$$

we will ultimately obtain the following equilibrium equation:

$$-D\nabla^4 w - \frac{E\alpha_T}{1-v}\nabla^2 \int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \theta z dz - \rho\frac{h^3}{12}\nabla^2\frac{\partial^2 w}{\partial t^2} + k_1 T_1 + k_2 T_2 + \frac{\partial}{\partial x}\left(T_1\frac{\partial w}{\partial x} + S\frac{\partial w}{\partial y}\right) + \frac{\partial}{\partial y}\left(S\frac{\partial w}{\partial x} + T_2\frac{\partial w}{\partial y}\right)q - \rho h T_1\frac{\partial^2 w}{\partial t^2} = 0. \tag{4}$$

Taking into account (3) and (4), we obtain:

$$\frac{1}{Eh}\left(\frac{\partial^2 T_1}{\partial y^2} - v\frac{\partial^2 T_2}{\partial y^2} - \frac{\partial^2 T_2}{\partial x^2} - v\frac{\partial^2 T_1}{\partial x^2}\right) + \frac{\alpha_T}{h}\nabla^2\int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \theta dz - \frac{2(1+v)}{Eh}\frac{\partial^2 S}{\partial y\partial x} = -\frac{1}{2}L(w,w) - \nabla_k^2 w. \tag{5}$$

If p_1 and p_2 are absent, we obtain the following system of equations governing the motion of a thin-walled cylindrical shell in the thermal field:

$$\begin{gathered} \frac{1}{Eh}\nabla^4 F + \frac{\alpha_T}{h}\nabla^2\int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \theta dz = -\frac{1}{2}L(w,w) - \nabla_k^2 w; \\ D\nabla^4 F + \frac{E\alpha_T}{1-v}\nabla^2\int\limits_{-\frac{h}{2}}^{\frac{h}{2}} \theta z dz + \rho\frac{h^3}{12}\nabla^2\frac{\partial^2}{\partial t^2} = q - \rho h\frac{\partial^2 w}{\partial t^2} + L(w,F) + \nabla_k^2 F; \\ C_\varepsilon\frac{\partial\theta}{\partial t} - \lambda_q\left(\frac{\partial\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2} + \frac{\partial^2\theta}{\partial z^2}\right) = -\frac{E\alpha_T T_0}{1-2v}\frac{\partial}{\partial t}(e_{11} + e_{22} + e_{33}) + W_0; \end{gathered} \tag{6}$$

where $\nabla^4 = \nabla^2\nabla^2$ is two-dimensional double Laplacian, and

$$L(\theta,\theta) = \frac{\partial^2\theta}{\partial x^2}\frac{\partial^2\theta}{\partial y^2} - 2\frac{\partial^2\theta}{\partial x\partial y}\frac{\partial^2\theta}{\partial x\partial y} + \frac{\partial^2\theta}{\partial y^2}\frac{\partial^2\theta}{\partial x^2};$$

represents the known nonlinear operator which determines irregularities of the thin-walled cylindrical shell.

$$\begin{gathered}\lambda_q\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial z^2}\right)\\ = -W_0 + C_3\frac{\partial\theta}{\partial z} + \frac{E\alpha_T T_0}{1-2v}\frac{\partial}{\partial t}\left\{\frac{1-2v}{1-v}\left[\frac{1-v}{Eh}\left(\nabla^2 F-(p_1+p_2)\right)+\frac{2\alpha_T}{h}\int_{-\frac{h}{2}}^{\frac{h}{2}}\theta dz - z\nabla^2 w\right]+\frac{1+v}{1-v}\alpha_T\theta\right\};\\ \frac{1}{Eh}\nabla^4 F + \frac{\alpha_T}{h}\nabla^2\int_{-\frac{h}{2}}^{\frac{h}{2}}\theta dz + \frac{1}{2}L(w,w) + \nabla_k^2 w = 0\end{gathered} \tag{7}$$

Finally, below we introduce geometrically linear system of equations of a coupled problem of the theory of shells in the thermal field:

$$\begin{gathered}\lambda_q\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial z^2}\right) - W_0\\ -\frac{E\alpha_T}{1-2v}\frac{\partial}{\partial t}\left\{\frac{1-2v}{1-v}\left[\frac{1-v}{Eh}\left(\nabla^2 F-(p_1+p_2)\right)+\frac{2\alpha_T}{h}\int_{-\frac{h}{2}}^{\frac{h}{2}}\theta dz - z\nabla^2 w\right]+\frac{1+v}{1-v}\alpha_T\theta\right\} = C_\varepsilon\frac{\partial\theta}{\partial t};\\ D\nabla^4 F + \frac{E\alpha_T}{1-v}\nabla^2\int_{-\frac{h}{2}}^{\frac{h}{2}}\theta z dz - \nabla_k^2 F = -\rho h\frac{\partial^2 w}{\partial t^2} + q.\end{gathered} \tag{8}$$

All the above-mentioned systems of equations have been obtained for general distribution of the thermal field over the thickness of the shell; however, this can be neglected, taking into account thinness of the shell walls.

To verify the model obtained, a test bench (Fig. 1) was engineered in the Laboratory of Building Structures at Komsomolsk-on-Amur State University.

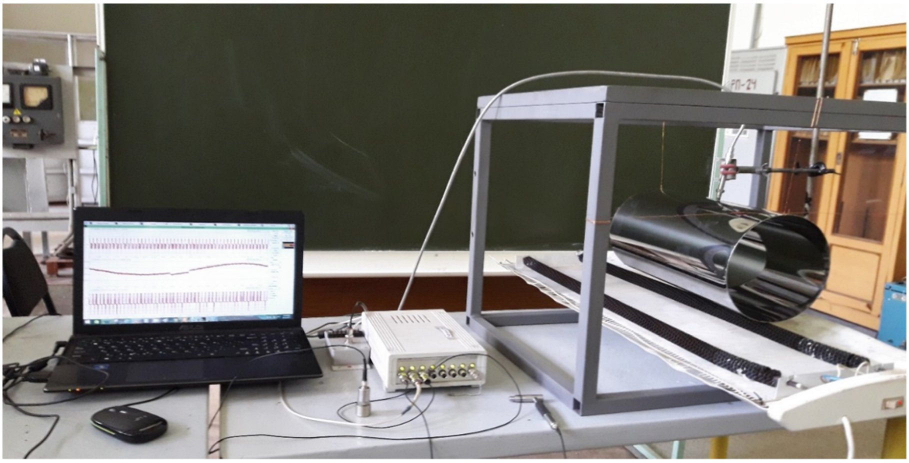

Fig. 1. Test bench. *Source*: developed and compiled by the authors.

The test bench works as follows (Fig. 2): an eddy current proximity probe ZET 701 records forced vibrations of the thin-walled shell induced by means of a test impulse hammer AU03 which is used during dynamic testing of mechanical systems and structures in order to determine their frequency response and can be utilized for both diagnostics and simulation of dynamic characteristics; a AC21 force sensor is used for measuring the momentum of the force applied to the object; analog signal from the eddy current proximity probe arrives at the signal amplifier; after that, it is processed at the analog-to-digital converter and transmitted to the personal computer (PC) where the experimental data are processed using ZETLAB software; the temperature is set by means of a heating element located inside the shell in order to ensure uniform heating of the latter (Fig. 3).

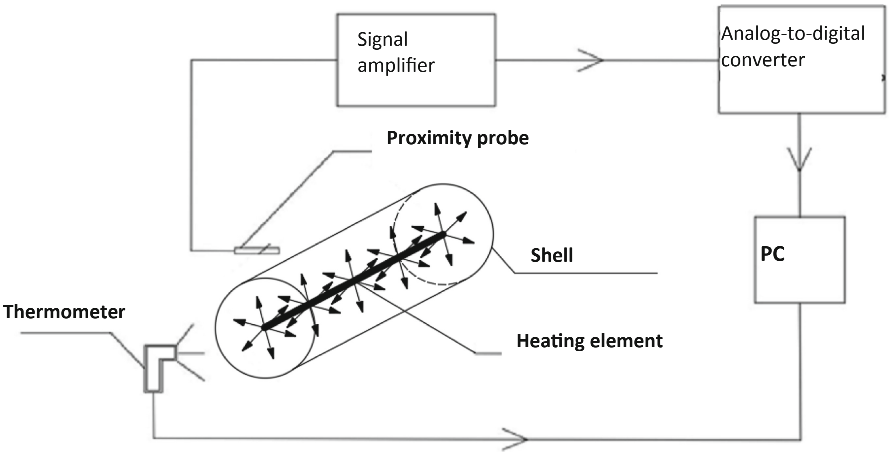

Fig. 2. Test bench diagram. *Source*: developed and compiled by the authors.

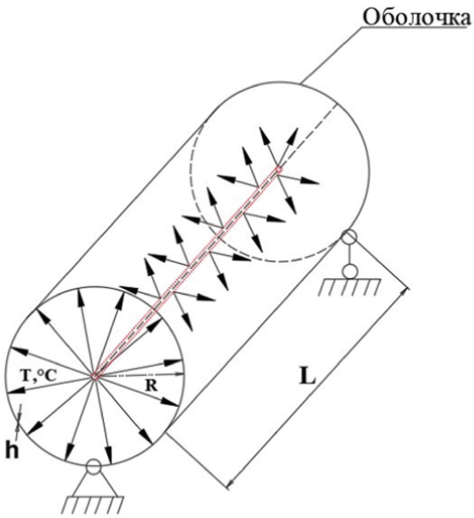

Fig. 3. Analytic model of a simply supported uniformly heated thin-walled cylindrical shell. *Source*: developed and compiled by the authors.

Fig. 4. Visual appearance of ZET 701 eddy current proximity probe. *Source*: developed and compiled by the authors.

A DT-8802 infrared thermometer is used for shell heating temperature monitoring; it enables non-contact precision measurement of temperature in different areas of the shell. The DT-8802 device operates within the temperature range from 20 °C to 300 °C, with the measurement accuracy of 0.1 °C (0.1°F) (Fig. 4).

A thin-walled (б = 0.5 mm) cylindrical shell with the diameter of 200 mm and height H = 400 mm, made of X17 steel, was used as the model test piece.

3 Results

Figure 5 shows the theoretical data for the relation between the thin-walled cylindrical shell vibration frequency and uniform heating temperature as per the traditional model, as well as in accordance with the variation-formulation-based model, and the results of the full-scale experiments performed for a thin-walled cylindrical shell with the diameter of 200 mm and height H = 400 mm, made of X17 steel.

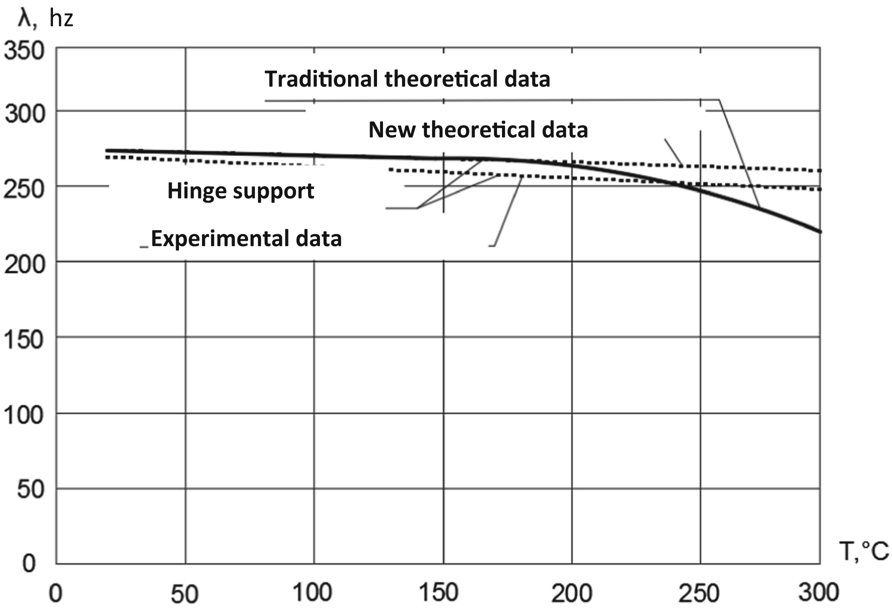

Fig. 5. Relation between the thin-walled cylindrical shell vibration Frequency and Uniform Heating Temperature as per the Traditional Model and Variation-Formulation-Based Model, as well as Experimental Data. *Source*: developed and compiled by the authors.

4 Conclusion

We can see (Fig. 5) that, starting from the temperature of 200 °C and above, the new variation-formulation-based model matches the full-scale test data better than the traditional one. That is why the variation-formulation-based analytic model obtained can be used for analyzing the frequency response of thin-walled cylindrical structures operating in the uniform-heating conditions.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Optimization of Technological Parameters of Robotized Mechanical Processing Processes of Aviation Products

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Abstract. Purpose: This paper is devoted to the development of an approach that allows evaluating the feasibility of implementing energy-saving technologies in robotic processes, as well as evaluating the effectiveness of optimization measures for specific robotic complexes.

Design/Methodology/Approach: The paper analyzes the parameters of robotic technological processes, and highlights the most significant ones in terms of their impact on the final energy costs of the process. During the analysis, an integral indicator that allows implementing the procedure for evaluating the feasibility of implementing an energy-saving module and evaluating the effectiveness of optimization measures was identified. A model was developed on the basis of which a complex of calculations is performed automatically. The graphical user interface is designed.

Findings: The results obtained made it possible to form a tool that allows for an unambiguous and objective assessment of the robotic technological process in order to further make a decision on the introduction of an energy-saving module. Also, using the results obtained, it is possible to identify quantitative indicators of the effectiveness of optimization measures aimed at reducing the energy costs of the process. Using the obtained model, the simulation procedure was implemented and the dependence of the module operation efficiency on the key variable parameters of the technological process of mechanical processing of aviation products was presented.

Originality/Value: The scientific novelty of this research consists in the development of a new approach to evaluating the effectiveness of implementing energy-saving technologies in robotic processes, as well as in a modernized approach to substantiating the feasibility of implementing energy-saving technologies.

Keywords: Industrial robots · Optimization · Automation · Energy saving · Robotics

JEL Code: O31 · O32 · O33

1 Introduction

Among the current trends in the global industry, robotics occupies one of the key positions and is one of the most promising tools for improving labor efficiency in the next

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decade (Kenichi 2017; Agostinelli et al. 2019). At the same time, industrial robots are increasingly replacing CNC machines when implementing technological processes for machining products (Asatiani and Penttinen 2018). This trend is due to the fact that in recent years, industrial robots are becoming more widespread and more accessible to industrial enterprises, including small and medium-sized ones. Along with that, the main characteristics of robotic equipment, such as accuracy, repeatability and others, are constantly improving with the release of new robot models (Munasypov et al. 2019). At the same time, research in the field of optimization of existing industrial robotic installations is carried out quite a bit.

In most cases, one of the main conditions for the cost-effective operation of industrial robots is their sufficiently high load. This, in turn, leads to a significant consumption of electrical energy by enterprises that use industrial robots in their technological processes. The paper (Gami et al. 2017) provides a justification for the feasibility of conducting research in the field of reducing the energy consumption of industrial robots, and, in particular, for machining operations.

As part of the research (Gorkavyy et al. 2018a), an approach was formed, and a specific tool were developed to achieve a reduction in energy consumption of up to 15% within individual technological cycles. Segmentation of the industrial robot's workspace was performed, as well as power measurements were performed in each of the obtained segments in order to assess their energy potential. The obtained data allowed forming a model of energy consumption by an industrial robot. This model, in turn, made it possible to implement a procedure for calculating energy costs based on data from the control program. The obtained data made it possible to develop an algorithm for searching for the optimal (in terms of energy consumption) location of the control program's complex of trajectories. At the same time, the main parameters when using the developed software energy-saving module (Gorkavyy et al. 2018b) (process time, tool feed rates, etc.) remained unchanged. Despite this, the use of the developed tools is not appropriate for all types of operations in which industrial robots are used or can be used.

At the stage of final development of the software module, the question arose about the unambiguous identification of technological processes in which the use of the module is reasonable and appropriate. To do this, it was necessary to identify typical changeable parameters that are characteristic of robotic processes and then determine a key integral indicator that allows comparison of various options for implementing technological processes.

2 Materials and Methods

Among the integral indicators, according to sources (Kubela et al. 2016; Yatskiv et al. 2019), one can distinguish labor intensity, productivity, accuracy, stability and reliability, technological cost, etc. Most of the indicators remain unchanged when using the developed module (this is one of the conditions for its functioning). The most acceptable indicator was the technological cost, since it includes all the parameters that are subject to changes during the integration of the module into the technological process.

The technological cost of the product in the implementation of robotic machining processes can be represented as a set of parameters such as:

– cost of materials;
– cost of remuneration of main production workers;
– the cost of paying for the work of adjusters;
– depreciation;
– cost of the tool;
– energy cost;
– cost of maintenance and repair of equipment.

Thus, the technological cost of a single technological operation can be represented as an expression:

$$C_{op} = C_m + C_z + C_d + C_a + C_{in} + C_e + C_o, \tag{1}$$

where C_{op} – technological cost of a separate technological operation, RUB; C_m – total cost of materials, RUB; C_z – total labor costs for production workers, RUB; C_d – total cost of labor remuneration for process operation adjusters, RUB; C_a – depreciation charges for equipment and equipment, RUB; C_{in} – cost of consumable tools, RUB; C_e- cost of energy consumed, RUB; C_o - cost of maintenance and repair of equipment in terms of technological operation, RUB.

As a result of integration and operation of the energy-saving module, the values of the parameters C_m, C_z, C_{in}, C_o do not change, so the technological cost of the robotic machining process can be represented as the following expression:

$$C_t = \sum_{i=1}^{n} (C_i^d + C_i^a + C_i^e) * P_i, \tag{2}$$

where C_t – technological cost of the robotic machining process, monetary unit; C_i^d - cost of labor compensation for adjusters of the i – th technological operation, monetary unit; C_i^a - depreciation charges for equipment and equipment of the i – th technological operation, monetary unit; C_i^e - the cost of energy consumed for the implementation of the i - th technological operation, monetary unit, i – number of the process operation, n – the number of products manufactured in a separate technological process; P_i – number of technological cycles within the i – th technological operation.

The remuneration of robotic equipment adjusters is considered as a one-time payment as part of debugging the manufacturing process of an individual product and is calculated based on the hourly rate of the specialist and the time spent on debugging.

$$\mathrm{C}_i^d = S_i^t * t_i^d, \tag{3}$$

where C_i^d – the cost of labor for robotic equipment Adjusters in the framework of debugging the i – th technological operation, monetary unit; S_i^t – tariff rate of the specialist-adjuster in the framework of debugging the i - th technological operation, monetary units/hour; t_i^d – time spent by the specialist during debugging of the i - th technological operation, hour.

Depreciation charges when using an energy saving module are changed by increasing the initial cost of purchasing equipment and are determined by the expression

$$\mathrm{C}_i^a = \frac{K_e * h_i * t_o^i}{100 * t_e}, \tag{4}$$

where C_i^a - depreciation charges for the i - th technological operation, monetary unit; K_e – cost of equipment, monetary unit; h_i - the established annual rate of deductions for depreciation of equipment for the i – th operation, %; t_o^i – operating time of equipment for the i – th operation, hour.; t_e – the period of operation of robotic equipment, hour.

The cost of electrical energy spent for the implementation of the technological process depend on the number of technological operations within a single technological process, energy-intensive operations, energy costs, and the number of technological operations within a process. The cost of energy required to implement the machining process is described by the expression:

$$C_i^e = S_w * W_i * m, \quad (5)$$

where C_i^e- the energy cost of the technological process, monetary unit; S_w – cost per kW*h, monetary unit/kW*h; W_i – the amount of energy spent on the implementation of the technological operation, kW*h; m – number of operations within the process.

Figure 1 shows a block diagram of the technological cost, reflecting the set of parameters presented above.

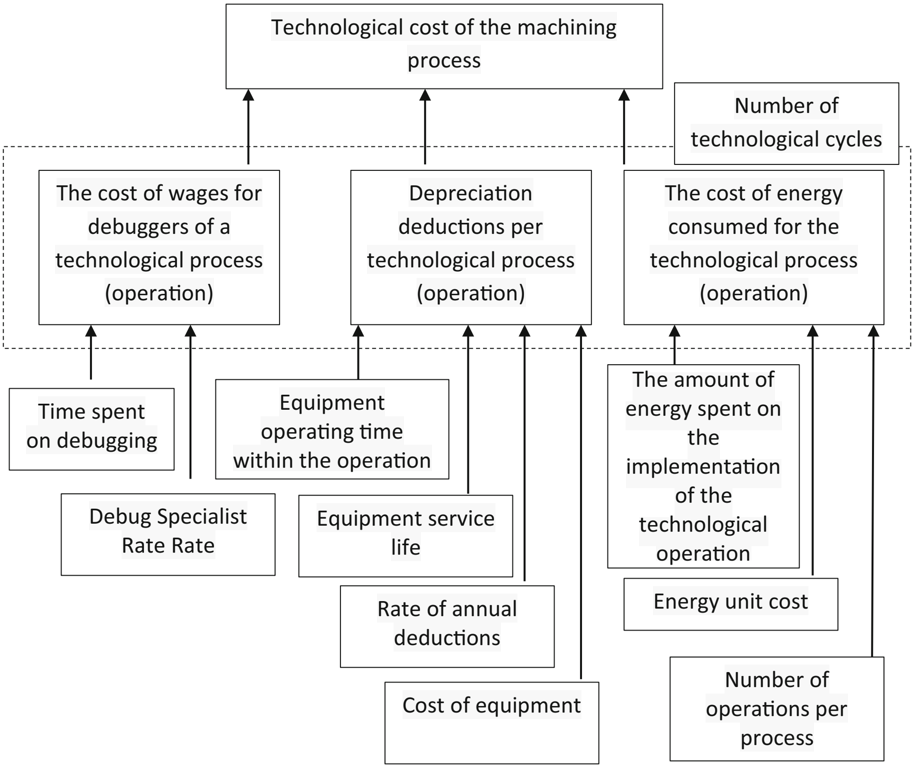

Fig. 1. Block diagram of the process of evaluating the technological cost of robotic machining operations. *Source*: developed and compiled by the authors

Thus, it is possible to obtain the efficiency coefficient K of the energy-saving module, which shows whether the integration of the module is appropriate in terms of obtaining an economic effect from its operation

$$K = \frac{C_t^b}{C_t^a}, \tag{6}$$

Expression (6) is valid only under the condition that the values P_i and i are the same for different variations of the calculation of the technological cost C_t.

It should also be noted that the calculations assume that the time of all additional (auxiliary) operations is taken into account in the parameter t_o, since it changes proportionally when calculating the technological cost and does not affect the final value of the coefficient K.

3 Results

The expressions presented above became the basis for building a model that allows evaluating the feasibility of using an energy-saving module in certain technological processes. The interface shown in Fig. 2 was designed to make calculations easier.

The resulting model, in turn, allowed to observe the effect of changing parameters on the value of the coefficient K_e. The simulation was based on data obtained during the study of the technological process (Egorova et al. 2019) for manufacturing welded flanges at the robotic machining site. Figure 3 shows a three-dimensional model of the product.

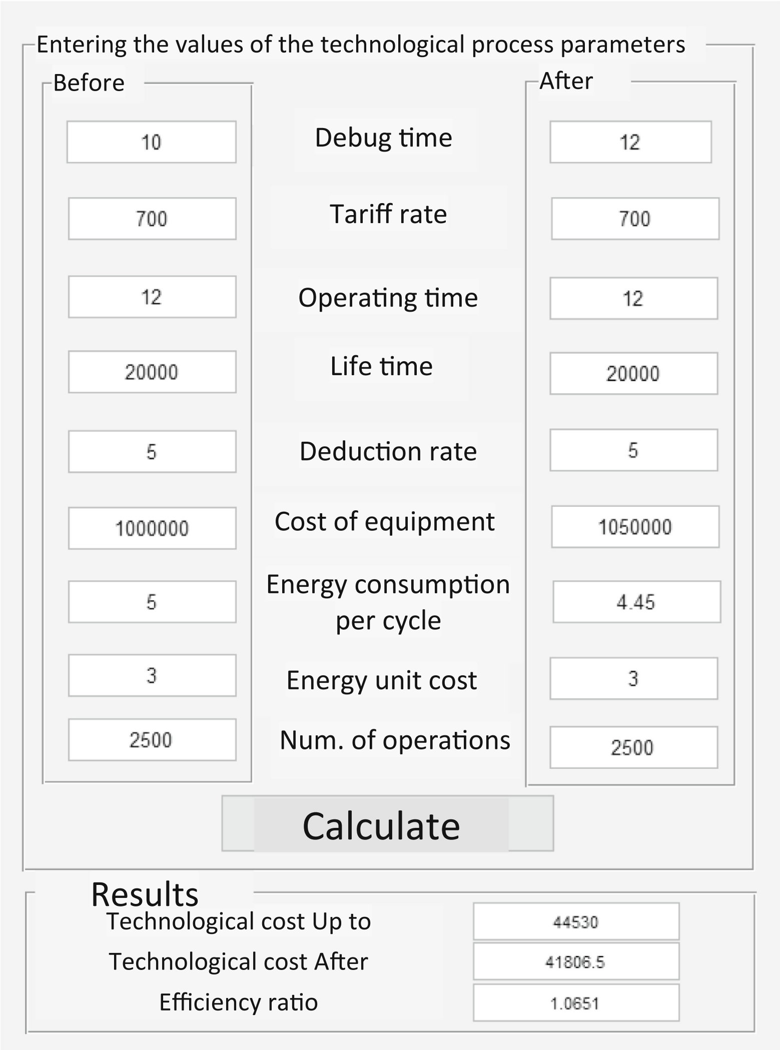

Fig. 2. Interface for performing calculations *Source*: developed and compiled by the authors

Tables 1, 2 and 3 shows the parameters for which the simulation was performed. In Figs. 4, 5 and 6 shows the graphs of dependence.

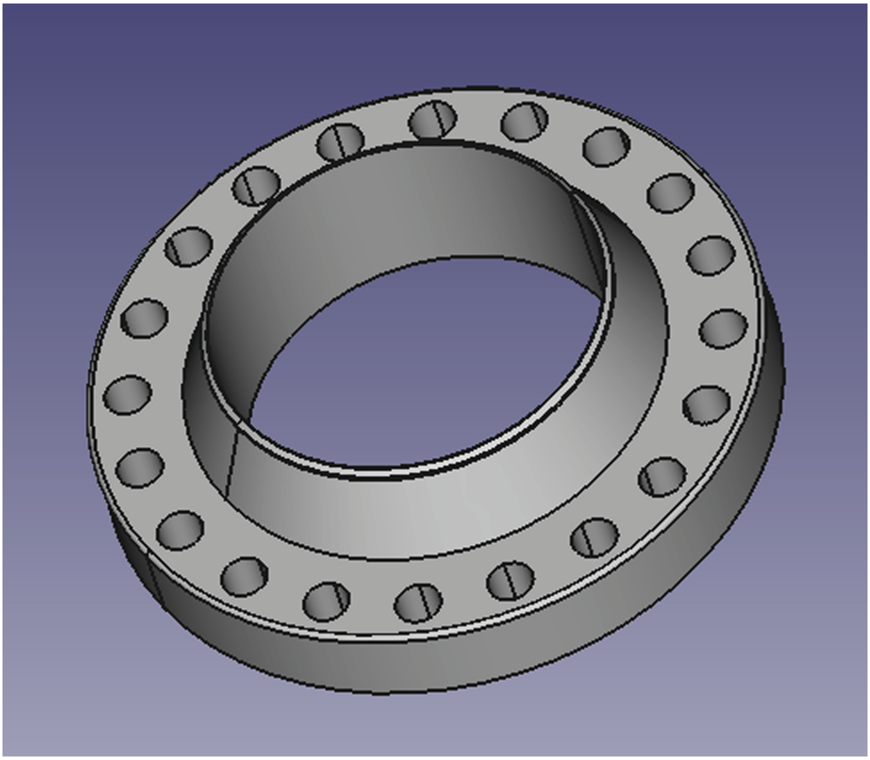

Fig. 3. Three-dimensional model of the product under study *Source*: developed and compiled by the authors.

Table 1. Modelling parameters N1

Variable	n	S^t	t^d	K	h	t_o	t_e	S_w	W	m
Value for calculation C_t^a	1	800	12	1260000	10	0.9	20000	3	1.615	100:100:5000
Value for calculation C_t^b	1	800	10	1200000	10	0.9	20000	3	1.9	100:100:5000

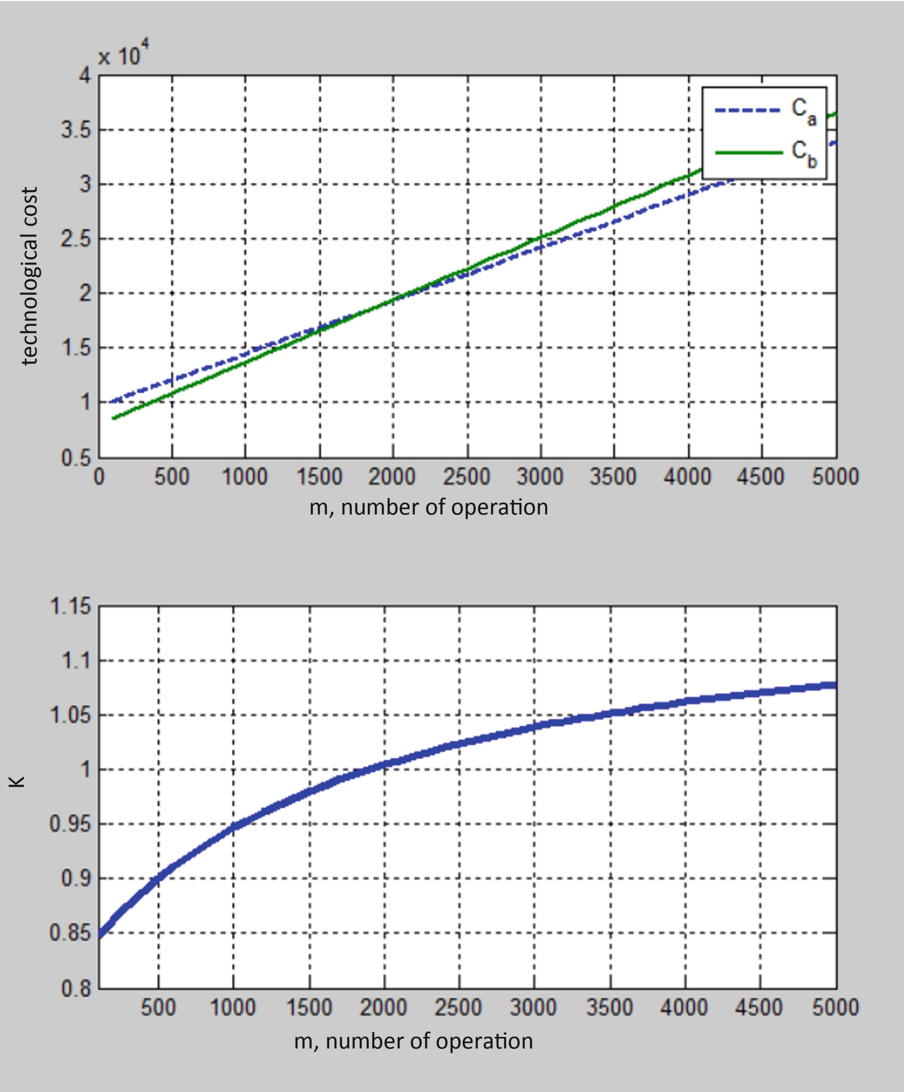

Fig. 4. Graphs of the dependence of the technological cost of the product (a) and the efficiency coefficient of the module (b) on the number of operations *Source*: developed and compiled by the authors

Table 2. Modelling parameters N2

Variable	n	S^t	t^d	K	h	t_o	t_e	S_w	W	m
Value for calculation C_t^a	1	800	12	1260000	10	0.9	20000	3	0.425: 0.425: 4.25	1500
Value for calculation C_t^b	1	800	10	1200000	10	0.9	20000	3	0.5:0.5:5	1500

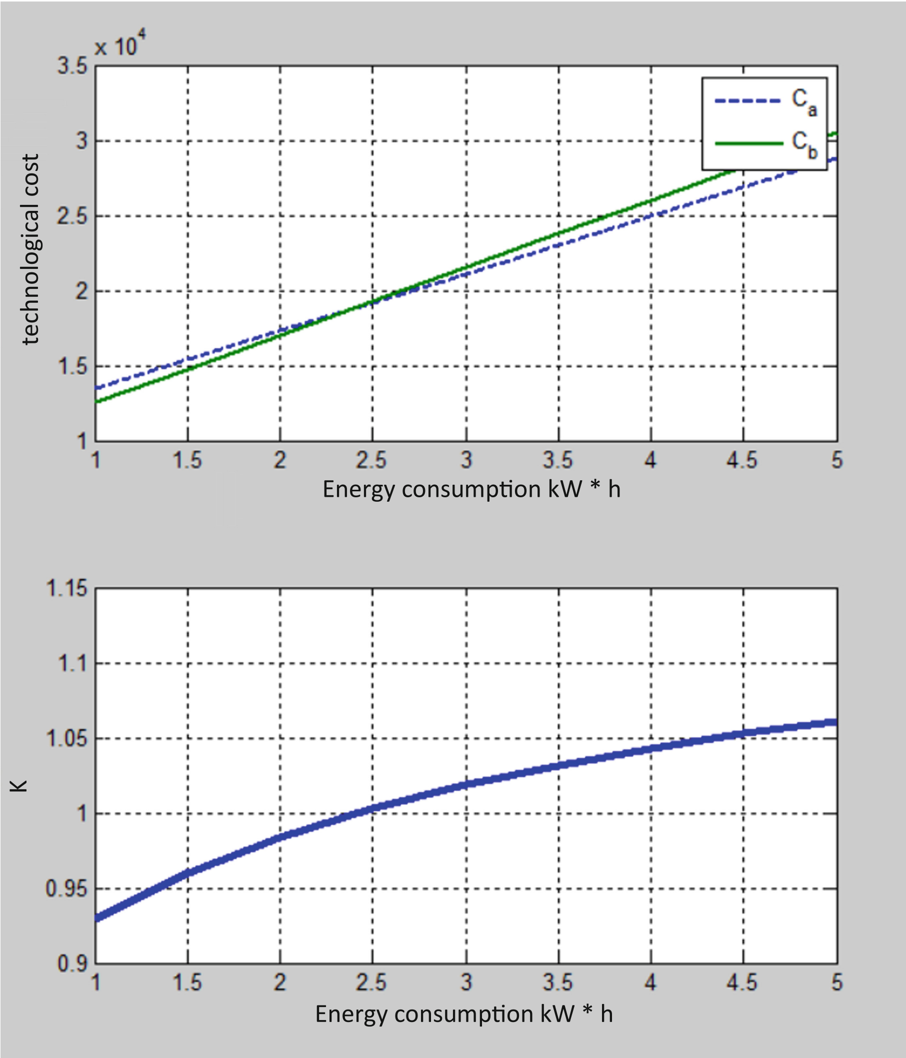

Fig. 5. Graphs of the dependence of technological value of the product (a) and coefficient of efficiency of module (b) from the process energy outlays *Source*: developed and compiled by the authors

Table 3. Modelling parameters N3

Variable	n	S^t	t^d	K	h	t_o	t_e	S_w	W	m
Value for calculation C_t^a	1	800	1.2:1.2:18	1260000	10	0,9	20000	3	1,615	1500
Value for calculation C_t^b	1	800	1:1:15	1200000	10	0,9	20000	3	1,9	1500

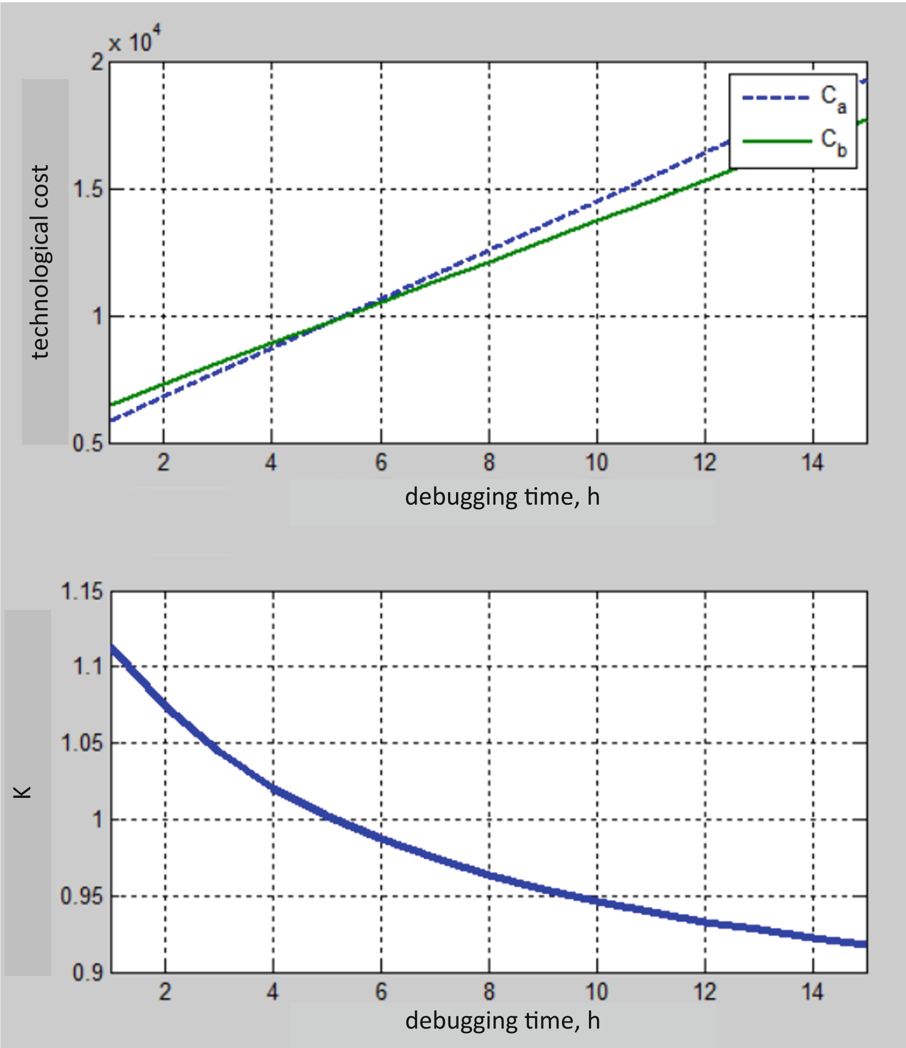

Fig. 6. Graphs of the dependence of the technological cost of the product (a) and the efficiency coefficient of the module (b) of the debugging time *Source*: developed and compiled by the authors

4 Conclusion

The data obtained as a result of modeling allowed concluding that the number of technological operations, the indicator of energy costs of the technological operation, and the time required for debugging the technological process, having the greatest impact on the efficiency of the module operation.

The most appropriate way to integrate the module is robotic machining processes, characterized by the production of a significant number of similar products, high energy costs, and low debugging time of technological operations. At the same time, in most cases, integration and operation of the module will not be effective in cases where a large range of different types of products is produced within the technological process, especially in situations of piece production or production of small batches, since frequent debugging of new processes is required. The module is also ineffective in cases when it is used in processes characterized by a high proportion of auxiliary operations, where robotic equipment is not involved. It should be noted that most of the newly designed technological processes are unique and should not be considered in terms of a separate criterion. A qualitative assessment of efficiency and a decision on whether to integrate an energy-saving module is possible only if all the key parameters are taken into account and considered in a comprehensive manner.

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Research and Calculation of the Interference Structure Parameters in the Cross Section of a Diffraction-Bounded Laser Beam

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Abstract. Purpose: Analysis of spatial-geometric parameters and amplitude-phase changes in the laser beam structure due to the interaction of wave aberration and diffraction-bounded of laser beam at the output of an axially symmetric optical system.

Methodology: The technique consists in assessing the nature of the change in the curvature of the wave front surface in the initial position that is formed at the exit pupil aperture of the optical system, which is located directly on the behind of last refractive surface.

Findings: The results show the features of the transformation of laser radiation parameters on space, that is allow to calculate the dimensions of the optical system to obtain an interference structure in the cross section of the laser beam.

Originality: Based on the application of modern optical system technologies, this article analyzes the problems of laser beam changing in spatial-geometric parameters, amplitude-phase and to obtain a measuring system by using interference structure in the cross section of the laser beam.

Keywords: Laser beam diffraction limit · The spatial parameters · Interference structure

JEL Code: L61

1 Introduction

One of the directions in the field of using low-intensity laser radiation for performing high-precision control and measuring works is the use of small-sized semiconductor injection-type lasers. Studying these types of laser are discussed by the authors Zvelto (2008), Klimkov (2009) and Klimkov and Kuzmina (1975), Nosov et al. (2011) and Shirankov (2008). Technological requirements for the implementation of such operations usually the need to imply collimating of the initial laser radiation using an axially symmetric optical system in order to create laser beams extended in a given direction with a minimum angle of divergence. If such a transformation of the initial laser radiation is carried out under conditions of aberration-diffraction limitation, then this circumstance leads to changing in its amplitude-phase state at the exit from optical system, which

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were observed in the papers by Nosov et al. (2011) and Kuzmina (1981). In this case, an interference structure is formed in the cross-sectional plane of converted laser beam. The interference field in this case is a system of concentric stripes in the form of rings of variable width and radius. The redistribution of intensity between concentric annular stripes has a sufficiently high degree of contrast and the width of the stripes decreases towards the center of cross section. The analysis and methodology for calculating the spatial-geometric parameters, as well as amplitude-phase changes in the structure of converted laser beam depend mainly on the parameters of the axially symmetric optical system and that are described in detail in the paper of Zaikov (1990, 2014) and Nosov et al. (2010) .

The results of survey described by (Pakhomov et al. 2010) and (Auslender et al. 2020) have of some the interested in terms of their relevance. The researchers, using software processing of the obtained research results, determined that the use of optical methods of calculation loses its meaning when the ratio of the beam size and the size of the limiting diaphragm is equal to 0,8 ÷ 1,0. In this case initial laser radiation should be characterized by the amplitude phase distribution of electromagnetic field in the plane of limiting aperture, and the beam transformed by diffraction effects. Pakhomov et al. (2008) demonstrated a detailed analysis of the parameters of a diffractive laser beam. As a result of diffraction by an optical element, the Gaussian character of the intensity distribution is violated. The reactive region arises immediately behind the limiting diaphragm, in which a non-monotonic change in axial intensity manifests itself.

2 Materials and Method

Purpose of work is to develop a method for calculating the spatial and geometric parameters of a converted laser beam under action of diffraction limitation and wave aberration on the output component of a symmetric axially optical system.

Significantly, at the output of the optical system the transformed wave front of laser beam will distortions, due to aberration-diffraction limitation of initial radiation. For the subsequent analytical study, it seems possible to use a model of a laser-optical system in form of a wave front surface, and each point of that surface is a source of coherent monochromatic radiation. The initial position of wave front should be considered in the plane of exit pupil aperture of optical system, which is located directly behind the last refractive surface. In this case, the direction of radiation of each source should be oriented in direction of normal to the given surface at the point where the source is located. The spatial shape of wave front surface and the nature of its distortion in the initial state determine general geometric parameters of the converted laser beam and the structure of amplitude-phase energy distribution in its cross section.

In this case, it makes sense to consider the model of converted laser beam that are perpendicular to wave front surface. By using this technique, it can be approximated the formation of an interference structure in the cross section of converted laser beam is carried out due to the superposition of spatially limited spherical waves emanating from the wave front surface at a certain convergence angle. Based on the results of Nosov et al. (2010, 2011), Bashkov et al. (2017a) it can be said that the nature of the formation of the interference structure in the cross section of the laser beam at a certain measuring distance is interconnected with the angular divergence of the elementary light beams forming the given laser beam.

3 Results

The analytical expression (Pakhomov et al. 2010) with a high degree of accuracy describes the nature of the change in the angle of inclination of light rays in the plane of the output pupil relative to the axis of the optical system:

$$\omega_i' = Ah_{oi}'\left(h_{oi}' - r_k'\right)\left(h_{oi}' + r_k'\right), \tag{1}$$

where, h_{oi}'- the beam height in the plane of optical output element systems r_k'- the radius of the laser beam converted by the aberration optical system;

This functional dependence allow to calculate the parameters of interference structure in the cross section of an extended laser beam using initial data for the considered model of laser-optical system in the form of a wave front surface. In accordance with the results of study, the Eq. 1 defines the trend of distribution of elementary light rays that combine with the perpendicular direction to the wave front. In this moment, a variable radius of curvature should characterize the wave front surface. The value of radius decreases to minimum because the incline angle of elementary light beams is greatest in the peripheral cross section zone of laser beam. The functional dependence for calculating radius of curvature of the wave front surface using the obtained results can be represented as expression:

$$R_i' = \frac{h_{0i}'}{\omega_i'} \tag{2}$$

As the parameter h_{oi}' decreases, curvature of the wave front surface will decrease, and in the corresponding zone $h_{oi}' = r_k'$, (r_k'- is the radius), the wave front surface degraded into a plane. This zone is a kind of circular inflection line of the function describing change in the curvature of wave front surface. Further, with the ratio $h_{oi}' \leq r_k'$, elementary light beams change the direction of propagation relative to the axis of the laser beam, and at a certain distance from the axis, the inclination angle reaches the maximum value in absolute value. The radius of curvature on the wavefront surface reaches the smallest value at $\omega_i' = \omega_{ext}'$.

Figure 1 shows the beam travel in the laser beam and a schematic representation of the spatial structure.

Laser beam transformed by aberration optical system is formed symmetrically to axis. Surface of wave front also has axis of symmetry coinciding with axis of laser beam.

Formation of interference rings in cross section of laser beam is carried out due to superposition of light waves coming from surface of wave front. The axially symmetric optical system is designed to form an extended laser beam of an interference structure. In the process of calculating the beam parameters, as well as the subsequent synthesis of the axially symmetric optical system, the required parameters of the interference structure, such as:

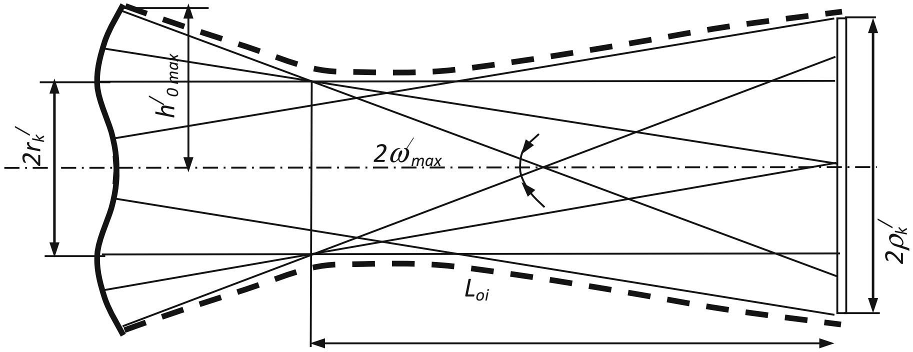

Fig. 1. Spatial structure of the transformed laser beam. *Source*: developed and compiled by the authors

- the width of interference ring band of the first order of interference ρ'_1 at a given distance *Li* from the aperture plane of output element of the optical system;
- the minimum width of the interference first order interference $2r'_1$ ring band at a given distance *Lp* from the aperture plane of optical system output element;
- interference field size $2\rho_K$ (diameter of the cross section of a long laser beam) at a given distance *Li* from the aperture plane of optical system output element.

Changing the stroke difference from zero level to a certain value $\Lambda = k\lambda$ (k - order of interference) in the trend of distribution of light waves that released by elementary coherent sources from the wave front surface. Then throughout the field of cross section laser beam, the interference structure is formed. The maximums brightness produce when the values $k = (0, 1, 2, 3 \ldots)$ and the minimums emit when the value $k = (1/2, 3/2, \ldots)$. Changing the given the properties axially symmetrical of wave front surface curvature, when that is on the axis of laser beam in the center of the interference structure of its cross section, will be observed that the value of a maximum illumination changing to zero order interference.

Distance between coherent monochromatic wave sources whose superposition provides for the formation of an interference structure at a given distance *Li*, with a stroke difference of equal $2\frac{\lambda}{2}$, is determined from the ratio

$$h'_{0i} = \frac{\lambda L_i}{2\rho'_1}, \tag{3}$$

where, $2h'_{0i}$- the distance on wave front surface between elementary coherent radiation sources forming the first maximum intensity of interference structure. Such a zone represents the first $2p'_1$ interference ring band with its center on the axis of a long laser beam of the interference structure. An image of this zone is as shown in Fig. 2.

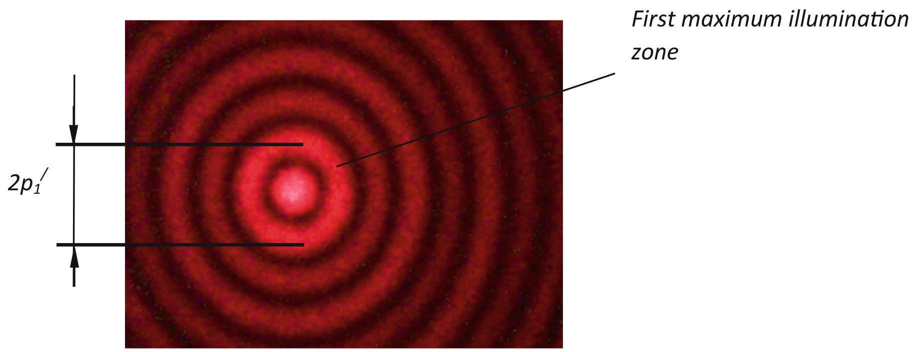

Fig. 2. The image of maximum intensity in the cross-section of laser beam of the interference structure on observation plane. *Source*: developed and compiled by the authors

As part of the theory of calculating interference structure parameters, it has been established (Zaikov 1990; Korotaev et al. 2017) that a change in $2p'_1$ parameter along the axis of laser beam corresponds to a change in the angle of convergence between interfering light beams, the value of which can be obtained from Eq. 2 as a result:

$$\sigma_1 = \frac{2h'_{0i}}{L_i} = \frac{\lambda}{\rho'_1}. \tag{4}$$

To specify maximum value of the stroke difference for light beams need to implement this function into the observation plane. The superposition of that value provide the formation of an interference structure throughout the cross section of the laser beam.

In this case, the size of the interference field in a given observation plane is characterized by such a parameter as $2\rho_\kappa$ where ρ'_κ - the distance between the trend of distribution from the axis of interference structure and the midpoint of κ-order interference ring band.

By the nature of the change in the value of this parameter, it is possible in general terms to determine the geometric dimensions of the converted laser beam. This shape is roughly the shape of the surface of a single-strip hyperboloid of revolution. Then approximately the parameters of the converted laser beam can be represented as (Korostik and Stetsik 2006; Wevers et al. 2006, 2007),

$$\frac{\rho'^2_\kappa}{r'^2_\kappa} - \frac{4L^2_{oi}}{R'_э} = 1, \tag{5}$$

$$\frac{h'^2_{oi}}{r'^2_k} - \frac{4L^2_{ri}}{R'^2_э} = 1, \tag{6}$$

where, L_{oi} - the distance from the plane of pulling of transformed laser beam to the observation plane; $R'_э$ - the equivalent confocal parameter of transformed laser beam.

Alternately, the dependence of equivalent confocal parameter effect the radius of curvature of the wave front section from production of coherent surface and the interference structure is formed. This types of function in hyperbolic approximation is as following expression (Nosovet al. 2011):

$$R'_h = \frac{R'_э}{4L_{ri}} + L_{ri}. \tag{7}$$

Equations 3, 4 and 5 were obtained by extrapolating the equivalent confocal resonator method for calculation of spatial parameters of the transformed laser beam (Zaikov 1990). On the other hand, in deriving the ratio of Eq. 2 it was assumed that $R'_h \approx L_i = L_{oi} + L_{ri}$. This assumption makes it possible to convert Eq. 6 to the form:

$$R'^2_э = 4L_{oi}L_{ri}, \tag{8}$$

and combine the result of Eq. 6 from Eq. 3 and 4 allow to establish the relationship between the transverse and longitudinal parameters of the transformed laser beam on the meridional plane:

$$\frac{\rho'^2_\kappa}{r'^2_k} = \frac{L_i}{L_{ri}}, \frac{h'^2_{oi}}{r'^2_k} = \frac{L_i}{L_{oi}}, \frac{\rho'^2_\kappa}{h'^2_k} = \frac{L_{oi}}{L_{ri}} = \frac{4L_{oi}}{R'^2_э}, \frac{1}{r'^2_k} = \frac{1}{\rho'^2_k} = \frac{1}{h'^2_{oi}} \tag{9}$$

Considering with the Eq. 8, the Eq. 3 should take the form after relevant conversion.

$$\sigma_1 = \frac{2h'^2_{oi}}{L_i} = \frac{\rho'_k R_э}{L_{oi}L_i} = \frac{\lambda}{\rho'_1}, \tag{10}$$

The difference maximum stroke value for light beams whose superposition provides for the formation of an interference structure across the entire field of the laser beam cross section can be obtained by integrating this function into the observation plane.

$$\frac{R_э}{L_{oi}L_i}\int^{\rho'_k} \rho'_k d\rho'_k = \frac{\rho'_k R_э}{2L_{oi}L_i} = \frac{2r'^2_k}{R_э} = k\lambda. \tag{11}$$

Differentiation of the ratio $\frac{2r'_k}{R_э} = k\lambda$ by parameter r'_k (at $k = 1$) allow to determine the minimum size of zone corresponding to the value of first maximum intensity of the interference structure of transformed laser beam:

$$r'_1 = \frac{\lambda R_э}{4r'_k}. \tag{12}$$

4 Conclusion

In this paper we have presented a study to understand the behavior of changing in spatial-geometric parameters, amplitude-phase and to obtain a measuring system by using interference structure in the cross section of the laser beam. The transformation of the initial laser radiation under the conditions of aberration-diffraction limitation should be considered in conjunction with the nature of the distortions of the wavefront surface at the exit from the optical system. Within the framework of the hyperbolic approximation, the regularities reflect the change in the properties of changes in the spatial parameters of laser radiation and the formation of an interference structure in the cross section. Using relation (10), which determines the path difference, it is possible to calculate the dimensions of the optical system and represent the magnitude of the wave aberration.

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Intelligent Deep Neuro-Fuzzy System of Abnormal Situation Recognition for Transport Systems

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Abstract. Purpose: To develop an algorithm of automatic abnormal situation recognition for autonomous vehicles using the deep learning methods and test it in the virtual simulation environment of World ship simulator and Ship Simulator Extremes.

Design/methodology/approach: The authors use deep neural networks and classical methods of image processing as a pattern recognition algorithm. A fuzzy logic apparatus based on the International Regulations for Preventing Collisions at Sea (COLREG) is used to generate the control actions. The efficiency evaluation of the recognition algorithms is carried out using the universally accepted metrics: Accuracy, Recall, Precision, AUC.

Findings: Application of the efficient (in terms of speed) neural network architecture based on the GhostNet models for computing on embedded devices is proposed. The suggested approach allows achieving up to 97% classification results in real-time mode. Simulation results using the Python language are presented. Simulation of the developed algorithms based on graphic simulation in a virtual gaming environment has been carried out.

Originality/value: A characteristic feature of the proposed approach is a combined use of fuzzy logic and computer vision systems based on the deep learning algorithms to create an intelligent software and hardware complex for controlling an unmanned vessel in difficult sea conditions.

Keywords: Unmanned surface vehicles · Object recognition · Convolution neural network · Fuzzy logic · COLREG

JEL Code: C45

1 Introduction

The automatic navigation system for unmanned boats is usually GPS or GLONASS, as well as radar and lidar. However, under certain conditions, the sensor readings become inaccurate or unavailable. An alternative data source for navigation in the onboard control systems of an unmanned surface vehicle (USV) can be a digital video surveillance camera.

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Further development of fully autonomous USV is necessary to minimize the need for human control. Moreover, the control decisions should be made on the basis of rules and laws. The International Regulations for Preventing Collisions at Sea (COLREG 1972) are the basis for all navigation solutions in the open sea.

Various groups of researchers carried out their work relating to the prevention of abnormal situations at sea. Larson et al. (2007) used a two-level 2D obstacle map to create a near-field reactive control technique. COLREGs are included in their solution using a pathfinding rule-based approach. Another approach proposed by the authors (Benjamin 2004) uses a multi-objective optimization and a behavior-based interval programming, but their solution cannot be called COLREGs compatible. Naeem et al. (2012) proposed a pathfinding that uses line-of-sight information between the points. To avoid the obstacle, it is necessary to turn to the starboard side.

Space-time predicates have also been considered as a way of translating the COLREG rules into computer-readable ones. Kreutzmann et al. (2013) and Wolter et al. (2011) propose to use the oriented point relation predicate algebra (OPRA) to represent the position of vessels and the relative course. Lee et al. (2004) combine fuzzy logic with the modified virtual force fields to create a COLREG compatible algorithm. The used set of fuzzy logic rules consists of about two hundred rules which can be computationally complex. The authors, however, mention that the set of rules can be ordered. Fuzzy logic is also applied by a group of authors (Perera et al. 2012) using Bayesian networks.

Though, if each case is viewed as an isolated situation, it can lead to the contradictory judgments involving multiple vessels. It is also important to take into account the vessel class. A light motor boat can, for example, give way to a large tanker in a short time, although the tanker must give way.

Thus, when developing the efficient algorithms for an unmanned vehicle control, it is critically important to take into account visual information.

2 Methodology

Let us give a mathematical formulation of the problem for an unmanned boat control (Ivanov et al. 2019).

Let there be a USV state vector $\mathbf{x} = (\mathbf{x}_{\mathrm{VP}}^T, \mathbf{x}_{\mathrm{SC}}^T, \mathbf{x}_{\mathrm{OE}}^T, \mathbf{x}_{\mathrm{CD}}^T, \mathbf{x}_{\mathrm{DP}}^T, \mathbf{x}_{\mathrm{EC}}^T)^T$, where $\mathbf{x}_{\mathrm{VP}}^T$ – state vector of the vehicle parameters; $\mathbf{x}_{\mathrm{SC}}^T$ – surveillance camera state vector; $\mathbf{x}_{\mathrm{OE}}^T$ – state vector of the observed environment; $\mathbf{x}_{\mathrm{CD}}^T$– vehicle control devices status; $\mathbf{x}_{\mathrm{DP}}^T$– vector of the design parameters; $\mathbf{x}_{\mathrm{EC}}^T$ – vector of the environmental conditions; and vector of the output signals (measurements) for USV $\mathbf{y} = (y_{\mathrm{PF}}, \mathbf{y}_{\mathrm{OE}}^T, \mathbf{y}_{\mathrm{CD}}^T, \mathbf{y}_{\mathrm{EC}}^T)^T$, where y_{PF} – presence of the frame $\mathbf{I}^t = \mathbf{V}(t)$ from the surveillance camera of the video stream $\mathbf{V}$, represented by a multidimensional array; $\mathbf{y}_{\mathrm{SC}}^T$ – signal from the surveillance camera, thus $\mathbf{y}_{\mathrm{SC}}^T = \mathbf{I}_t$; $\mathbf{y}_{\mathrm{CD}}^T = (y_{\mathrm{RD}}, y_{\mathrm{E}})$ = signal from the control device (steering gears and engines); $\mathbf{y}_{\mathrm{EC}}^T$– vector of signals from sensors fixing the environmental conditions. It is necessary according to the observation results $\mathbf{y}$ of the observed environment states $\mathbf{x}$ to develop the assessments of states $\tilde{\mathbf{x}}$ and necessary control actions $\mathbf{u}$ on the controllable object, $\mathbf{u} = (\mathbf{u}_{\mathrm{CD}}^T, u_{\mathrm{DB}})^T$, $\mathbf{u}_{\mathrm{CD}} = (u_{\mathrm{RD}}^T, u_{\mathrm{E}})^T$, where u_{RD}– signal for turning the rudder blade, u_{E} – signal to the engines, u_{DB} – signal for recording an event in the database. Each of the elements belongs to the corresponding set: ones of states $\mathbf{x} \in \mathbb{X}$, their assessments

$\tilde{\mathbf{x}} \in \tilde{\mathbb{X}}$, video streams $\mathbf{V} \in \mathbb{V}$, output signals $\mathbf{y} \in \mathbb{Y}$ and control $\mathbf{u} \in \mathbb{U}$. $\mathbb{T}$ – set of time points, then $t \in \mathbb{T}$ – arbitrary point of time. Functional dependencies for $\mathbb{X}$, $\mathbb{Y}$ and $\mathbb{U}$ can be represented in the form of "input-state" $\mathbf{F}_1$:$\mathbb{T} \times \mathbb{U} \to \mathbb{X}$ and "state-output" $\mathbf{F}_2$:$\mathbb{T} \times \mathbb{X} \to \mathbb{Y}$ mappings, i.e.: $\mathbf{y}(t) = \mathbf{F}_2(\mathbf{F}_1(\mathbf{u}(t)))$.

Thus, the task is stated as follows: to determine, on the basis of a video stream frame, the state of the observed environment including the presence and number of the obstacle objects (NOO) n, parameters of each object (OP), including β_k – a class, α_t^k – a bearing angle (an angle between the compass needle direction and the direction in which the object is visible), L_t^k – distance, w^k, h^k – width and length of each object $k = \overline{1, n}$ at a point in time t. $\mathbf{F}_3$:$\mathbb{V} \to \tilde{\mathbf{X}}$. Then, mapping $\mathbf{F}_3$ realizing the optimal nonlinear filter (NF) function for assessing the observed environment state can be represented as follows $\tilde{\mathbf{x}}_{\text{OE}} = \mathbf{F}_3(\mathbf{I}_t)$, where $\tilde{\mathbf{x}}_{\text{OE}} = (\tilde{x}_{\text{NOO}}, \tilde{\mathbf{x}}_{\text{OP}}^T)^T$, and form a pattern recognition problem.

Let there be: an image set $\omega \in \Omega$ prescribed by the features x_i, $i = \overline{1, n}$, the complex of which for image ω is represented by vector descriptions $\mathbf{\Phi}(\omega) = (x_1(\omega), x_2(\omega), ..., x_n(\omega)) = \mathbf{x}_{\text{OE}}$; a set of classes $\mathbb{B} = \{\beta_1, \ldots, \beta_k, \ldots, \beta_c\}$, c – a number of classes. A priori information is represented by a training set (dataset) $\mathbb{D} = \{(\mathbf{x}_{\text{OE}}^j, \beta^j)\}, j = \overline{1, L}$ given by a table, each line of which j contains a vector image description $\mathbf{\Phi}(\omega)$ and a class mark β_k, $k = \overline{1, c}$. Let us note that the training set characterizes the unknown mapping $^*\mathbf{F} : \Omega \to \mathbb{B}$.

According to the available frames $\mathbf{I}_t$ of the video stream $\mathbf{V} = (\mathbf{I}_1.., \mathbf{I}_t, .., \mathbf{I}_\tau)$ and a priori information represented by the training set $\mathbb{D} = \{(\mathbf{x}_{\text{OE}}^j, \beta^j)\}, j = \overline{1, L}$ for deep learning of the neural network with a teacher it is required to solve the pattern recognition problem: to detect the patterns ω in the form of features assessment $\tilde{\mathbf{x}}$ by applying the neural networks realizing the mapping $\mathbf{F}_4 : \mathbf{I}_t \to \tilde{x}_{\text{NOO}}$, and classify them using the mapping $\mathbf{F}_5$:$\tilde{\mathbf{x}} \to \beta_k$, $k = \overline{1, c}$ according to the given criterion P($\tilde{\mathbf{x}}$) minimizing the classification error probability.

Mapping $\mathbf{F}_5$ is nothing else than determining the values of vector elements $\tilde{\mathbf{x}}_{\text{OP}}^T$ and is a set of functions and neural network and classical computer vision algorithms $\mathbf{f}_i$, $i = \overline{1, N_f}$.

According to the parameters $\tilde{\mathbf{x}}_{\text{OE}}$ the comparison element (CE) checks the parameters compliance and determines normal or abnormal situations $s = \mathbf{F}_6(\tilde{\mathbf{x}})$, where $s = \{0, 1\}$– a normal or an abnormal situation.

Actions $\mathbf{u}$ to the vessel control devices are described by the mapping $\mathbf{F}_7 : \tilde{\mathbb{X}} \to \mathbb{U}$ and can be represented by a set of knowledge base rules.

It is proposed to realize $\mathbf{F}_1$–$\mathbf{F}_7$ using fuzzy logic, neural networks, and computer vision.

Deep neural networks and classical methods of image processing will be used as a pattern recognition algorithm.

A fuzzy logic apparatus can be used to generate the control actions.

The universally accepted metrics: Accuracy, Recall, Precision, AUC will be used for efficiency evaluation of the recognition algorithms.

Evaluation of the control algorithm will be carried out by means of simulation and semi-natural experiments to recreate the problematic sea situations: presence of an obstacle, interaction of vessels when overtaking, crossing courses, opposite courses, etc. As expert opinions, the GOLREG base will be used.

3 Results

Solution of the USV control problem is divided into a number of subtasks:

1. To detect and classify a surface object and calculate its parameters by the frame $\mathbf{I}_t$.
2. To make a decision on the presence of an abnormal situation and work out a control action to the rudder blade and vessel engines.

The output recognition unit data is input data for the control unit (Fig. 1).

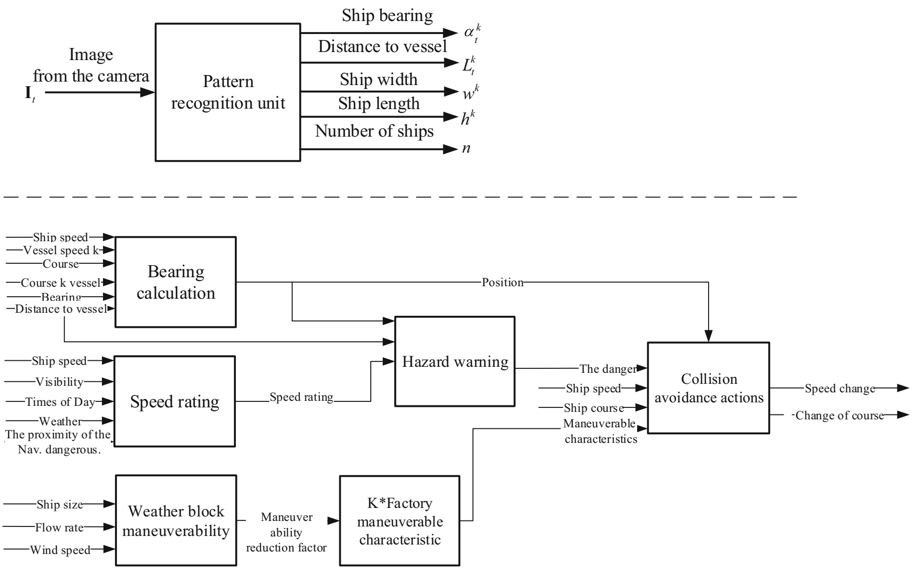

Fig. 1. Interaction of blocks. *Source*: designed by the authors

We solved the problem of vessel class recognition in the paper (Ivanov et al. 2019) using the MobileNet neural network architecture (Howard et al. 2017) based on deep convolution layers.

Kernel convolution $\mathbf{K}$ in the layer l is performed according to the formula:

$$\mathbf{h}^l_{conv} = \sigma^{\mathrm{Re}LU}\left(\mathbf{h}^{l-1} \cdot \mathbf{K} + b^l_{conv}\right),$$

where $\mathbf{h}^l_{conv}$– an output of the convolution layer l representing as a multidimensional array; $\sigma^{\mathrm{Re}LU}$ – ReLU (Rectified linear unit) activation function; b^l_{conv} – a shear coefficient.

The essence of deep convolution consists in dividing a 3D kernel into two operations: 2D kernel convolution for each of the channels and point-to-point convolution with 1D kernels (Fig. 2). This approach allows reducing the number of performed arithmetic operations more than twice.

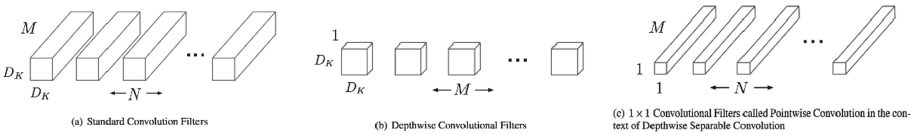

Fig. 2. Deep divisible convolution algorithm. *Source*: (Howard et al. 2017)

However, recent studies in the field of neural networks (Amosov et al. 2020) for the embedded devices such as Nvidia Jetson (Amosov et al. 2018) have proposed more efficient architectures and approaches. In particular, the authors (Kai et al. 2020) offered the GhostNet architecture which was able to achieve higher recognition performance (for example, 75.7% top-1 accuracy) than MobileNetV3 with similar computational cost for the ImageNet ILSVRC-2012 classification dataset.

This model uses the Ghost blocks which allow calculating fewer feature maps of objects at the same performance.

To improve the proposed system accuracy (Kim and Ivanov 2019), a neural network architecture using the GhostNet approaches and modules is suggested. The neural network architecture for classifying the ships is shown in Fig. 3.

Input	Block	Kernel	Expansi on size	Means the number of output channels	Using squeeze-and excitation	Stride
$224^2 \times 3$	CBR2D (3x3)	3	-	16	-	2
$112^2 \times 16$	GhostBottleneck	3	16	16	-	1
$112^2 \times 16$	GhostBottleneck	3	48	24	-	2
$56^2 \times 24$	GhostBottleneck	3	72	24	-	1
$56^2 \times 24$	GhostBottleneck	5	72	40	True	2
$28^2 \times 40$	GhostBottleneck	5	120	40	False	1
$28^2 \times 40$	GhostBottleneck	3	240	80	-	2
$14^2 \times 80$	GhostBottleneck	3	200	80	-	1
$14^2 \times 80$	GhostBottleneck	3	184	80	-	1
$14^2 \times 80$	GhostBottleneck	3	184	80	-	1
$14^2 \times 80$	GhostBottleneck	3	480	112	True	1
$14^2 \times 112$	GhostBottleneck	3	672	112	False	1
$14^2 \times 112$	GhostBottleneck	5	672	160	True	2
$7^2 \times 160$	GhostBottleneck	5	960	160	-	1
$7^2 \times 160$	GhostBottleneck	5	960	160	False	1
$7^2 \times 160$	GhostBottleneck	5	960	160	-	1
$7^2 \times 160$	GhostBottleneck	5	960	160	True	1
$7^2 \times 160$	CBR2D (1x1)	1	-	960	-	1
$7^2 \times 960$	AvgPool2D (7x7)	-	-	-	-	-
$1^2 \times 960$	CBR2D (1x1)	1	-	1280	-	1
$1^2 \times 1280$	Fully connection (Softmax)	-	-	23	-	-

Fig. 3. The proposed neural network architecture. *Source*: designed by the authors

For training, the dataset given in the paper (Kim and Ivanov 2019) was used. The dataset consists of 23 vessel superclasses and contains 40 552 images.

The proposed NN architecture was trained on the Nvidia GeForce 1080Ti graphics processor (GP). The total training time was 12 h and 3 325 200 iterations. Loss curve has reached a value of 0.11, and accuracy was 97% after 120 epochs.

Precision and Accuracy algorithm metrics for the test sampling were 78% and 78.3%.

To develop a USV control algorithm, it is necessary to formalize the parameters and rules. The best formalized vessel model was proposed by the authors (Perera et al. 2012). Their fuzzy model consists of 4 prerequisites, 2 consequences, and 200 rules. By prerequisites, the authors understand the relative orientation and the course of vessels, the distance between them and the ratio of their speeds. The bearing angle [0°, 360°] of the main (own) vessel is divided into 10 sectors. The relative course [0°, 360°] of the vessel *k* is divided into 8 sectors.

The total of distances from three vectors represents the radii $R_a R_b$ and R_{vd} around the own vessel. R_{vd} is an area that cannot be entered by another vessel. R_a and R_b – an area in which other vessels are found. Moreover if a vessel is detected in R_a, then the own vessel has to give way, and if it is found in R_b, the own vessel must take appropriate actions to avoid collision due to the lack of actions from the target vessel *k*. $R_{i(k)}$ represents the distance to the vessel *k* at this moment. To calculate the velocities, we used the ratio υ^k / υ assessed as <1, ≈1, >1. This formalization is shown in Fig. 4. It is proposed to take this formalization as a basis, but modify the rules since they do not take into account the vessel classes, the traffic density, the dimensions and other information.

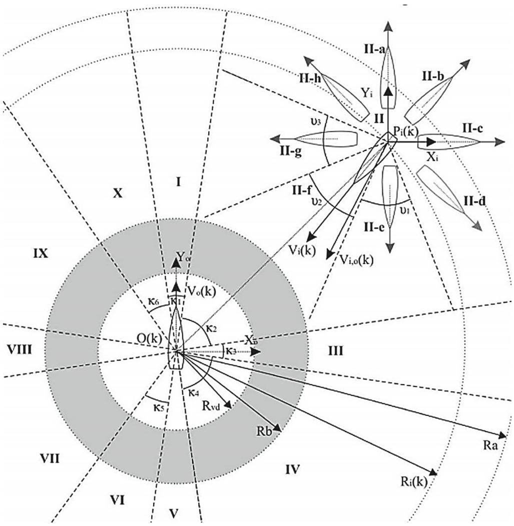

Fig. 4. Formalization of vessels location. *Source*: (Perera et al. 2012)

The collision prevention algorithm was implemented in the MATLAB system. The first input variables (Fig. 5) are: the own vessel domain, the vessel k domain, the own vessel speed and the vessel k speed.

The following are indicated as output variables (Fig. 6): a change in the own vessel's course, a change in the own vessel's speed, a risk level.

The variant of using the fuzzy model, proposed in this paper (Kim and Ivanov 2019) to calculate the change in the own course and speed, is based on the Mamdani algorithm and consists of 440 basic rules. Let us simulate the system activity with different input

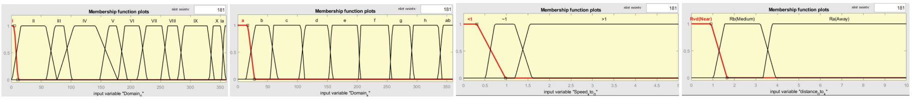

Fig. 5. Input variables. *Source*: designed by the authors

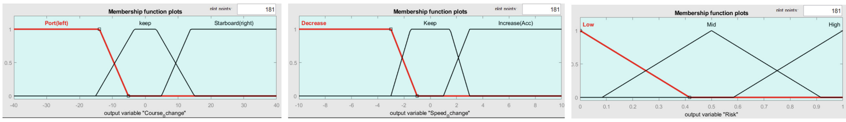

Fig. 6. Output variables. *Source*: designed by the authors

data. The vessel k's bearing angle is 45° – this is domain II. The own vessel bearing angle in relation to the vessel k is in domain e (we indicate 170°), the ratio of the vessel k speed to the own vessel's speed is 2 and the distance between the own vessel to the vessel k is 3 km. We received an output command to change the own course by 0.0286 to the left and a command to change the own speed by 6.03 knots. Thus, the risk is average −0.5.

An additional set consists of 200 rules and takes into account the classes of vessels, their maneuverability, visibility, and the traffic density.

The developed algorithms were ported to the embedded JetsonTX2-based computation module (Fig. 7).

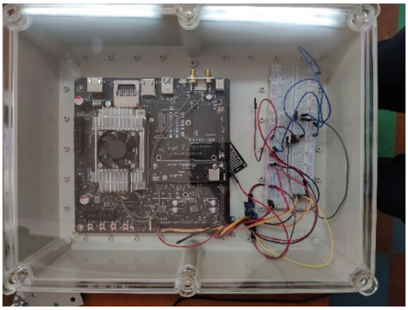

Fig. 7. Laboratory prototype of the computation module. *Source*: designed by the authors

Testing the machine learning algorithms in the real world can be difficult and not always safe. To develop the control algorithms for the unmanned vehicles, various ROS and Gazebo-based environments are used. However, they are limited by the realistic rendering of the environment and AI agents. Recently, for the purpose of algorithm analysis, researchers have begun to use various game simulations with extremely high image detailing, realistic physics and already programmed agents.

Sea mission simulators World ship simulator and Ship Simulator Extremes were used to test the developed algorithms.

Images coming to the monitor were captured and transmitted to the neural network input. To control the virtual ship, keystrokes on the keyboard were emulated.

Various segmentation, detection and classification algorithms were tested (Fig. 8).

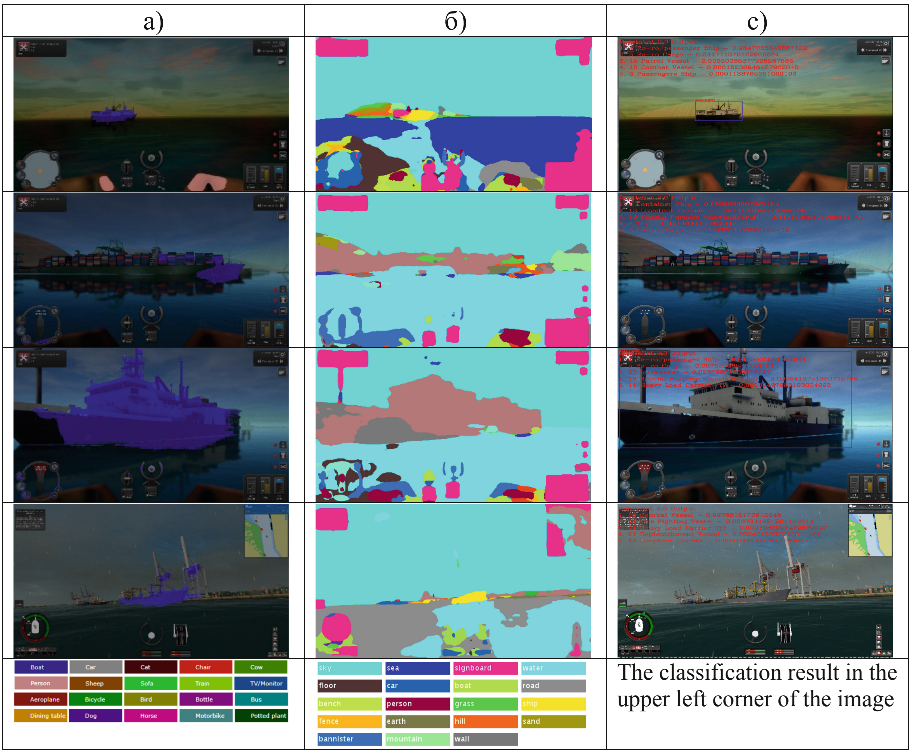

Fig. 8. Testing of algorithms: a) RNN, b) HRNet, c) YOLO and GhostNet. *Source*: designed by the authors

As seen in Fig. 8, some pretrained algorithms have difficulties on the synthesized images, while the proposed architecture fully copes with classification problem.

The collision prevention algorithm was tested as follows. In default, the user maintained the ship's course and speed. When there was a risk of emergency situation (an output variable: Risk > 0.4), the program took control and only the program commands were read. The following situations were simulated: overtaking, crossing of courses (Fig. 9).

The implemented experiment shows the possibility of using the developed algorithms as an emergency collision prevention system.

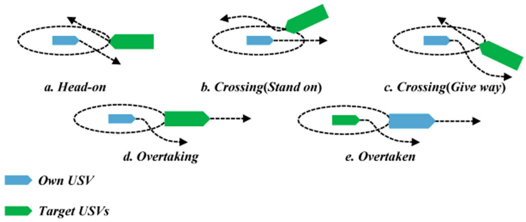

Fig. 9. Situations requiring COLREG application. *Source*: https://www.mdpi.com/2077-1312/8/4/264/htm

4 Conclusion

Application of the deep neural networks on the modern embedded graphics accelerators for the surface object detection and recognition is proposed.

Application of the efficient, in terms of speed, neural network architecture based on the GhostNet models for computing on the embedded devices is suggested.

A characteristic feature of the proposed approach is a combined use of fuzzy logic and computer vision systems to create an intelligent software and hardware complex for controlling an unmanned vessel in difficult sea conditions.

The proposed approach allows achieving up to 97% classification results in real-time mode.

Simulation results using the Python language are presented. Simulation of the developed algorithms based on graphic simulation in a virtual gaming environment has been carried out.

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Multipoint High-Temperature Forming of High-Strength Aluminum Alloy Plates in the Process of Manufacturing Large-Sized Ribbed Double-Curvature Panels

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Abstract. Purpose: The purpose of the work is to determine the possibility of using multi-point high-temperature forming of high-strength aluminum alloy billets (plates) for milling large-sized ribbed double-curvature panels.

Design/methodology/approach: The work uses the provisions of the mechanics of deformation of a solid body, taking into account large displacements and rotations, the theory of elasticity, plasticity and creep.

The reliability of the research results is determined by the use of modern software engineering analysis tools, as well as by comparing the obtained numerical solutions with a full-scale experiment. To improve the technological parameters of the ribbed panel manufacturing processes, a numerical simulation of high-temperature multipoint forming of the plate with following heat treatment and its mechanical treatment, was carried out. Pilot studies on the development of the process of high-temperature multipoint forming of plates were carried out on an UFP-1M rod type installation with numerical control.

Findings: The mechanical characteristics studies of the heat-hardened V95och alloy at various temperatures and in various states made it possible to obtain more accurate results when modeling the processes of ribbed panel manufacturing. Developing of manufacturing technology of ribbed alloy V95och panels by milling preformed plates on structurally similar samples showed good repeatability and coincidence with the results of mathematical modeling.

Originality/value: The technology of multipoint high-temperature forming has shown the ability to fulfill deformation of large-sized samples with high precision in a wide temperature range. The developed technology allows, at low material consumption, to produce large-sized high-quality ribbed panels with specified mechanical characteristics.

Keywords: Monolithic ribbed panel · Multipoint forming · High-temperature forming · Reconfigurable puncheon

JEL Code: D29 · C63 · L61 · O14 · O33

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1 Introduction

With the development of aviation technology, the requirements for strength and weight reduction are increasing. Therefore, the usage of monolithic ribbed panels is increasing in the airframe design. At the same time, there is a tendency to increase the dimensions of the panels, which is accompanied by the complication of both bypass-forming surfaces with variable thickness of the plate, and with the complication of the ribbed structure (change in the height of the ribs along the length and their location). The ribbed panel is a reinforced cover that is made together with high-strength alloy stiffeners billet. Due to the high complexity of the ribbed panels structure and high-quality requirements, the manufacturing process is one of the most laborious with a low material utilization rate.

To reduce the material consumption of a structure while increasing the specific strength and rigidity of airframe parts, high-strength heat-strengthening aluminum alloys (V95och, AK4–1, 1163, V1461, etc.) are widely used. Manufacturing of high-strength aluminum alloy details imposes additional restrictions on the technological process in terms of heat treatment conditions and ultimate deformations.

The manufacturability of ribbed panels is influenced by such characteristics as the type of ribbing and the type of surface, which affect the choice of the type of billet (Kolganov et al. 2003). Table 1 shows a comparison of methods of manufacturing complex spatial shape ribbed panels of various type billets.

Table 1. Methods of manufacturing complex shape ribbed panels

Billet type	Milled reamer bending	Forging milling	Stamping milling	Preformed plate milling
	Plate	Forging	Stamping	Plate
Technological processes	1. Milling a flat pattern 2. Reamer bending (cold, low temperature creep) 3. Finishing	1. Manufacturing of forging 2. Rough milling of a billet 3. Hardening 4. Finish milling 5. Aging 6. Finishing	1. Manufacturing of stamping 2. Hardening 3. Aging 4. Milling 5. Finishing	1. High-temperature plate forming (in annealing mode) 2. Hardening 3. Straightening (straightening in aging mode) 4. Milling 5. Aging 6. Finishing
Advantages	- High MUF - Low machine time for milling - Sufficient 3-axis milling machine	- Relatively simple billet forming	- Highest MUF - Low machine time	- High MUF - Low machine time
Disadvantages	- Deformation constraints (detail curvature) - The complexity of defect-free deformation of thin-walled details - Requires highly qualified specialists in forming and finishing of details	- Low MUF - Dimension restrictions - Low hardenability - Necessary 5-axis milling machine	- High cost of billet manufacturing - Dimension restrictions - Expensive stamp tooling - Necessary 5-axis milling machine	- Requires versatile forming equipment - Necessary 5-axis milling machine

The panel shape-forming process usually consists of two stages. The first stage is to make an internal ribbed engraving. As a rule, the ribbing is obtained by milling the initial panel billet in the form of a reamer of the required part, after which it is given an aerodynamic shape by deforming the reamer. Sometimes they do the opposite: first, an aerodynamic contour is created, after which ribbing is performed. The manufacturing of double-curvature ribbed panels by shape-forming reamers has a number of limitations that do not allow using this method effectively. The main limitation is the shape-forming of panels with a large rib height to a small radius of curvature, which leads to under-forming of the ribbed sections with high rigidity, and the formation of corrugations in non-reinforced sections, rib creases and cracks.

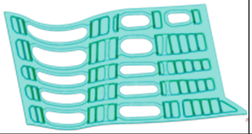
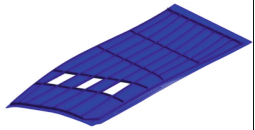
Forming reamers of large-sized complex spatial shape panels is often an impossible task; therefore, mechanical processing of large-sized forging-type billets is usually used. Milling a large-sized complex spatial shape detail billet can have many transitions, including heat treatment and straightening. At the same time, the utilization rate of the material is very low, and the entire process of making the panel is time-consuming and expensive. Material consumption and machining time can be reduced by changing the type of billet, from forging to stamping or molded plate. For the manufacture of large-sized complex spatial shape stampings, heavy duty pressing equipment and a set of expensive stamping equipment are required. Plate forming does not require such great efforts as during stamping, but due to the greater thickness of the resulting billet, an in-depth development of the processes of forming, heat treatment and subsequent machining is necessary.

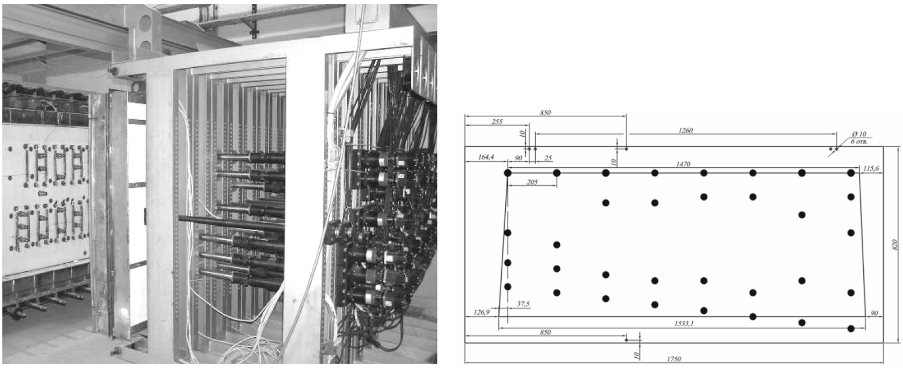
On the example of 3 different ribbed panels, a comparison was made of the economic indicators of the manufacturing large-sized ribbed double curvature panel technology of using forgings and molded plates as billets (Table 2). The panels under consideration are made of high-strength aluminum alloys, have a double curvature with variable thickness of the cover and a developed ribbing scheme. When replacing a billet from a forging with a formed plate, material costs are reduced by about 90% and labor costs by 84%.

The bottleneck of large-sized ribbed panels manufacturing technology by milling pre-formed plates is the process of billets forming. When forming large-sized billets, multi-stage processes of forming or stamping in several stamps are widely used. Also, there is a more progressive approach to the process of billets deformation, which is based on multi-point shape-forming using a reconfigurable core punch (a matrix) (RU2251464 C2, 2005; SU 1147471 A1, 1985; Cai and Li 2001; Su et al. 2012). Forming elements of the punch and matrix are coaxially located rods, which are set in a given position by means of numerical control. Depending on the selected deformation mode, the automation system can perform multi-point shape-forming with control of speed or load on each forming core. To intensify the deformation process, the billet is heated. This approach was implemented in the reconfigurable rod type pilot plant UFP-1M (Fig. 1) (LLC "STC-Creep", 2011), which is used for shaping the side titanium alloys panels of aircraft at the Novosibirsk Aviation Plant named after Chkalov.

Rod type installation UFP-1M is universal technological equipment that allows combining the process of forming with heat treatment of material. The ability to change the temperature and deformation rate makes it possible to make shape-forming of billets in

Table 2. Comparison of material and time consuming for the panels manufacture using different types of billets.

Panel characteristics			
Dimensions, mm	254×1640×2,495	170×1,700×2,400	175×1,055×2,285
Web thickness,mm	2…7	1,5…10,5	1.5…3
Rib height, mm	to 23	to 27,5	to 32
Rib thickness, mm	1.5; 5	2…6	2…4
Panel weight, kg	**39.10**	**33.77**	**11.18**
Billet type – Forging – Billet weight, kg	**3,690**	**2,375**	**2,200**
Billet type – Forging – Milling time, h	**471.50**	**720.50**	**491.70**
Billet type – Shape-formed plate – Billet weight, kg	**498**	**469**	**320**
Billet type – Shape-formed plate – Milling time, h	**77.55**	**142.28**	**77.82**



a) b)

Fig. 1. Multipoint forming plant UFP-1M (a) and the scheme of the billet hanging in the heat chamber (b). *Source*: developed and compiled by LLC "STC-Creep" (2011)

creep and superplasticity modes (Gorev 2008, Gorev and Masanov 2009). Slow deformation of a billet due to irreversible creep deformations reduces the forces on the forming elements (Bormotin et al. 2016; Bormotin 2014). When a billet is deformed according to a given program, the position of all forming elements changes simultaneously, which leads to the geometry evolution of the punch and matrix in time. The coaxial arrangement of the forming elements allows, in one technological stage, to form billets of single and double curvature, including billets of alternating curvature (convex-concave) without plastic fractures and without geometric loss of stability.

2 Methodology

To assess the possibility of ribbed double curvature panels manufacturing of shape-formed heat-strengthened aluminum alloy V95och plates, the technology of high-temperature multipoint shape-forming of plates on an UFP-1M rod installation at annealing temperature with following hardening, straightening, aging and panel milling was tested (Fig. 2).

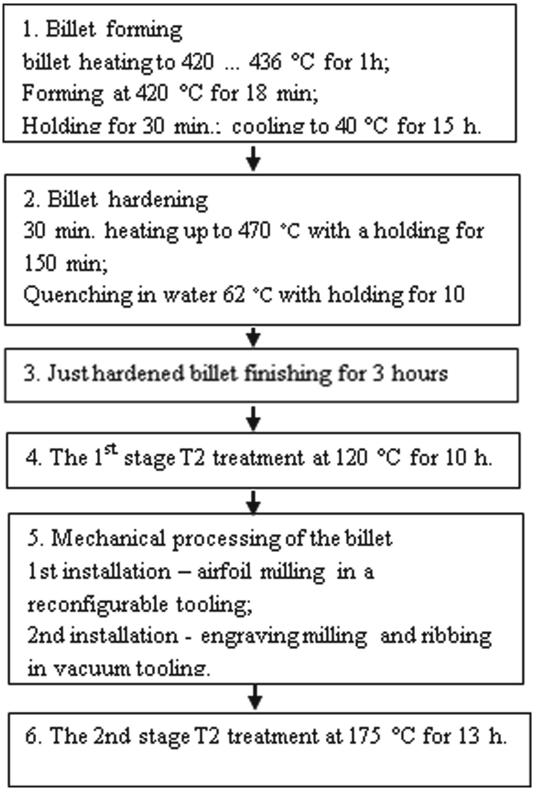


Fig. 2. Technological scheme of ribbed double-curvature alloy V95och panel manufacturing. *Source*: developed and compiled by the authors

The efficiency of high-temperature modes application of V95och alloy deformation requires, when choosing processing modes, taking into account all the features of the temperature effect on the material properties. When obtaining the shape of a detail, an important task is to maintain and ensure the required level of mechanical and operational characteristics. To select the optimal modes of V95och alloy billets deformation at high temperatures and in a just hardened state, a number of physical and mechanical characteristics researches of the material were carried out. Pure bending tests were carried out on flat-beam V95och alloy samples with dimensions of 12.5 × 30 × 300 mm at LLC "STC-Creep". The study of the physical and mechanical characteristics of the V95och alloy during high-temperature shape-forming showed that at the temperature of 420 °C, stress relaxation in the material occurs quickly: in the first 5 min, the stresses in the material reduce by almost half, then the relaxation rate sharply decreases, and within 30 min the relaxation stops (Fig. 3). These data were used in the development of the billet loading program and the calculation of the control program for the movement of point forming elements (rods).

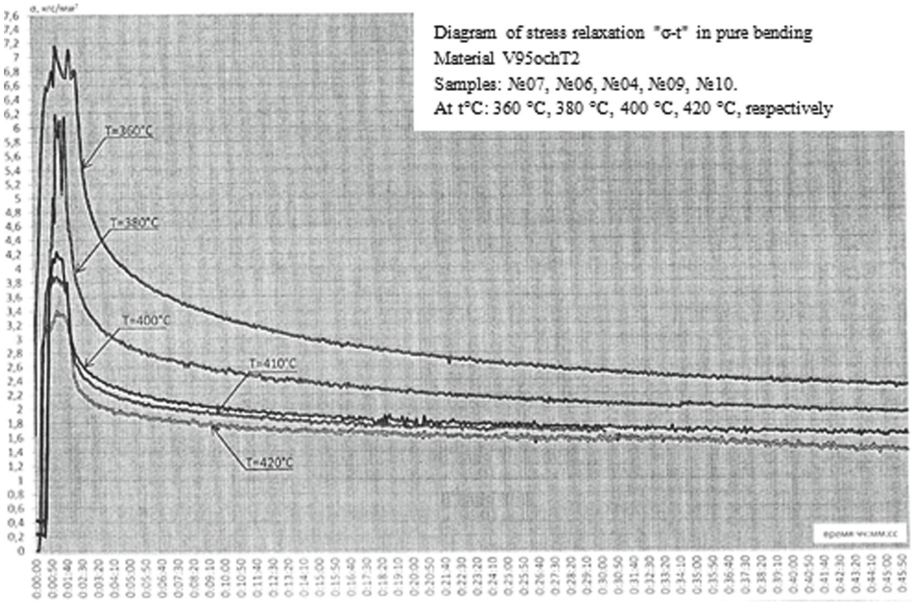


Fig. 3. Stress relaxation in pure bending of alloy V95och samples. *Source*: developed and compiled by LLC "STC-Creep" (2014).

For numerical simulation of the panel manufacturing process, a multifactorial finite element (FE) model was developed in the CAE system MSC.Marc (Fig. 4) (Marc 2016, Vol. D). In the FE model, the material was specified as isotropic, with the dependence of the mechanical and physical properties of the material on temperature. When specifying the control program, a four-stage billet loading mode was selected. At the end of the first three stages, there is a slight de-loading to reduce the shear loads on the shape-forming rods. In this case, in areas with a large deflection, the point of forming rod contact with the billet is displaced. The duration of one stage is approximately 5 min. At the end of the last stage, the billet remains in a fixed state until it has completely cooled down; this ensures a decrease in residual stresses in the billet material.

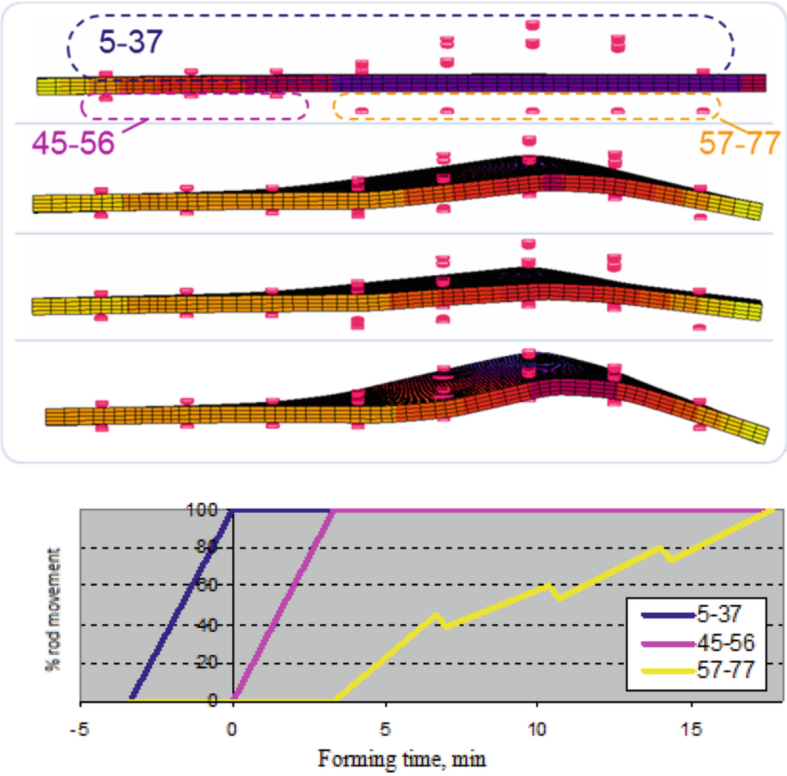


Fig. 4. Modeling of the multipoint shape-forming of a billet by stepwise deflection increase process. Source: developed and compiled by the authors.

3 Results

The high-temperature multipoint shape-forming process was tested on an UFP-1M rod installation using one program on three billets with dimensions of $40 \times 820 \times 1{,}750$ mm. After the billets were formed, the geometry of its surface was measured using GAGE-2000 contact measuring machine and ARTEC EVA 3D scanner (Fig. 5). The scanning result showed a good agreement of the real billet geometry with the calculated detail geometry, which ensures that the ribbed panel fits into the shape-formed billet with allowances of at least 5 mm per side.

In the numerical simulation of the process of machining the billet, the method of deactivation (removal) of elements was used. The billet is machined in two stages:

1 - milling the airfoil of the panel in a reconfigurable milling tooling;

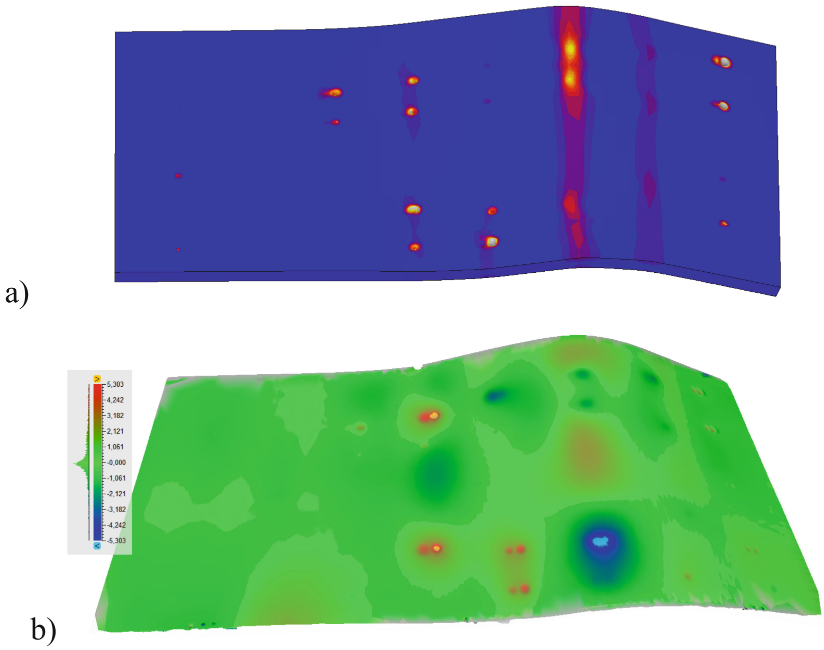


Fig. 5. The result of the FE billet forming modeling (a) and discrepancy card of formed billet from the task geometry (b). *Source*: developed and compiled by the authors

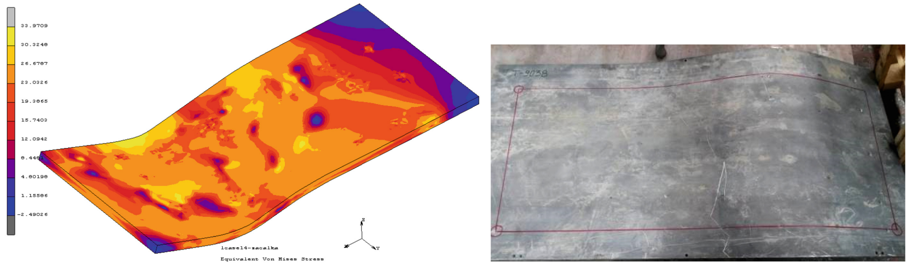
2 - milling of engraving and panel ribbing in vacuum milling tooling.

Figure 6 shows the results of numerical modeling and photographs of the results of full-scale testing of the processes of ribbed panel manufacturing. In general, the results of numerical modeling of the panel manufacturing processes have good agreement with the full-scale experiment, which confirms the adequacy of the developed FE model. Based on the results of full-scale milling process testing of shape-formed V95och alloy panel, high-quality panel without cracks and gouges was obtained.

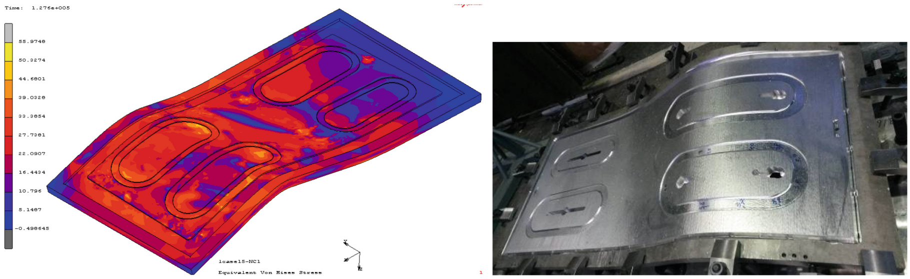
After the 1st stage of milling, the billet aerodynamic surface warped. According to the geometry measuring results of the milled surface at the ends of the billet, the deviations were approximately ±4.5 mm. The billet, with a maximum remaining thickness of 35 mm, was fully attached to the milling tooling for the 2nd stage of milling. After completing all the milling stages, the panel warpage at the ends was approximately ±15 mm. After the benchwork and peen forming, the panel took the required shape. Analysis of panel warpage during its forming plates milling showed the level of deflection of the airfoil; it was 6 times less than when it was milled of large-sized forgings.

The mechanical tests of the check test pieces cut from the billet allowances (Fig. 7) showed that the material characteristics of the made ribbed V95ochT2 alloy panels on average comply with Technical Conditions TU 1–92-81–87 (Table 3).

a) Billet after forming and harding



b) after the aerofoil milling in the 1st installation



c) after milling of engraving and ribbing in the 2nd installation

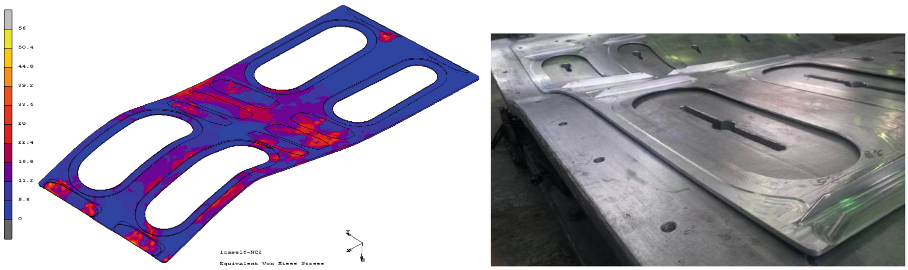


Fig. 6. Modeling and testing of panel manufacturing processes. On the left is the diagram of equivalent von Mises stresses (MPa), on the right is the results photo of a full-scale experiment. *Source*: developed and compiled by the authors

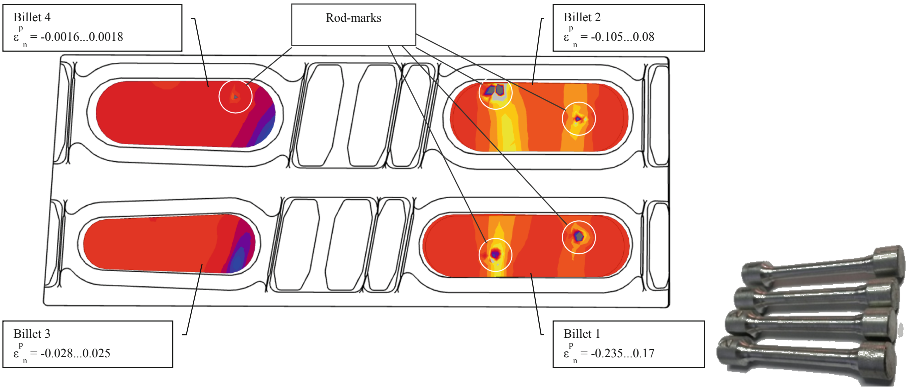


Fig. 7. Cutting areas of check test pieces for mechanical tests. *Source*: developed and compiled by the authors.

Table 3. Comparison of the mechanical characteristics of the manufactured V95ochT2 alloy panels comply with technical conditions

	$1/\rho$ (MS/m)	$\sigma_{0,2}$ (MPa)	σ_B (MPa)	δ (%)
Tests	$\frac{20.8\ldots22.0}{21.5}$	$\frac{387\ldots459}{433}$	$\frac{478\ldots529}{514}$	$\frac{10\ldots14}{12}$
ТУ 1-92-81-87	≥20.7	≥430	≥510	≥7

4 Conclusion

On totality of features, the quality of ribbed panels made using the proposed technology can be considered as high. The warpage level of a ribbed panel, when it is milled from a shaped plate, is significantly lower than when it is milled from a large-sized forging. As a result of the technology development of large-sized ribbed high-strength double curvature aluminum alloy panels manufacture by milling preformed plates, we obtained the process that allows, with low material consumption, to produce high-quality parts with specified mechanical and resource characteristics. The researches have shown that the technology of multipoint forming, based on reconfigurable rod systems with numerical control, allows a wide range of material deformation modes to be realized, ensures high forming accuracy of billets and good repeatability of the process.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Impact of Single Laser Pulse on Surface of Steel Used in Fabricated Structures

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Abstract. Purpose: The purpose of this study is to determine the impact of the pulse shape and the pulsed laser spot welding conditions on the spot weld geometry making a permanent connection and the formation of the spot weld zone structure.

Design/methodology/approach: Laser pulse impact was studied in the St3 steel coupon. The chemical composition of the coupon was analyzed with the NEXT CJ energy dispersive X-ray fluorescence spectrometer" . Spot (stake) welds were welded by a single laser pulse with the BULAT LRS 300 laser welding machine. The diameter and penetration depth of the resulting stake welds were measured. Microstructure and macrostructure were analyzed using the Nikon Eclipse MA200 metallographic microscope with the Vickers hardness measurements with the Shimadzu HMV-2 microhardness tester.

Findings: By changing the pulsed laser spot welding parameters, the geometry of the resulting connection can be managed.

Regardless of the single laser shot conditions, the spot weld always has three areas: 1: base metal area, 2: heat-affected area, 3: filler metal area.

The volume ratio of the main spot weld areas can be controlled by changing the operating parameters of the laser machine.

The spot weld has different properties in different areas, which is caused by a different structure of these zones. In general, the heat-affected zone and the filler metal have higher microhardness than the base metal.

Originality/value: The collected experimental evidence demonstrates the impact of a single laser shot on carbon and low-carbon steel that facilitate the selection of laser welding conditions.

Keywords: Permanent connections · Laser welding · Laser pulse · Austenitic steel welding · Precision laser welding · Pulsed solid-state laser

JEL code: L61 · L62 · L6 · O33

1 Introduction

Conventional arc welding processes are mostly not efficient and, in the process of welding permanent connections, lead to the accumulation of internal stress and distortion of structural components; further, heat-induced distortion largely determines the performance of parts and structural components (Smirnov et al. 2016).

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The development of technology related to the use of concentrated beam heat sources for welding can help address this issue (Cao and Jahazi 2009; Yunlian et al. 2000; Abdel-Monem 1997). Laser welding minimizes the heat-affected zone (HAZ) and increases travel speed by a factor of several times (Kim and Thein 2020; Kim et al. 2020).

The main features of laser welding (LBW) are as follows (Grigoryants et al. 2006; Ready et al. 2001):

- high-density power concentrates in the area hit by the laser beam enabling the mechanism of deep narrow knife-like shape penetration that minimizes the heat-affected zone size;
- energy efficiency of the welding process is high;
- physical and mechanical properties of the weld are high;
- energy supply to the welding area will be precise and controlled.

The specifics of laser material processing are local heat impact, minimum heat distortion, the wide control range of laser beam energy characteristics providing the abusive heat conditions with high heating and cooling rates, high-quality welds, and high-strength surface layers (Nemecek et al. 2012; Birger et al. 2017).

Characterization of laser welding condition impact on the change in the weld metal structure and also their effects on mechanical properties is a front-and-center task for today's welding engineering. Understanding the processes occurring in the molten metal pool induced by a laser pulse will facilitate the development of production processes that will lead to a greater introduction of laser welding in the production of fabricated structural components and jigs and fixtures (Bakhmatov and Pletnev 2019; Grigoryants et al. 2018).

2 Materials and method

A 40 × 40 mm rectangular coupon was studied; the thickness of the coupon was 5 mm. The coupon was made of the St3 steel. The chemical composition of the coupon was analyzed before the study. The chemical composition of the coupon was assessed through the

Table 1. Welding coupon chemical analysis with NEXT CJ energy dispersive X-ray fluorescence spectrometer

Percentage										
Value	Chemical composition									
	C	Si	Mn	Ni	S	P	Cr	N	Cu	As
	0.207	0.244	0.464	0.055	0.015	0.026	0.057	–	0.037	–
	0.171	0.215	0.468	0.052	0.015	0.024	0.055	–	0.035	–
	0.188	0.238	0.470	0.057	0.015	0.026	0.057	–	0.037	–
	0.171	0.222	0.479	0.056	0.015	0025	0.056	–	0.037	–
Average	0.184	0.23	0.47	0.055	0.015	0.025	0.056	–	0.037	–
GOST 380–2005	0.14 to 0.22	0.15 to 0.3	0.4 to 0.65	0.3 max.	0.05 max.	0.04 max.	0.3 max.	0.01 max.	0.3 max.	0.08 max.

NEXT CJ energy dispersive X-ray fluorescence spectrometer. The chemical composition is listed in Table 1 and shows that it meets GOST 380–2005.

Spot (stake) welds were welded by a single laser pulse with the BULAT LRS 300 laser welding machine in the following conditions: trapezoidal and rectangular pulse shape with a focal length at a maximum operating voltage of 450 V, a pulse frequency and duration variation varying between 2 and 4 Hz and 5 and 15 ms; laser operating conditions are single-shot and pulsed: when spot welding in the pulsed conditions, the pulse on-time was 2 s (the conditions are shown in Table 2). The minimum spacing between spot welds was 5 mm. The coupon appearance after the laser process is shown in Fig. 1.

Table 2. Single laser pulse conditions

Coupon number	Spot weld number	Operating voltage, V	Pulse duration, msec	Pulse frequency, Hz	Pulse shape
1	2	3	4	5	6
1	1	450	5	–	R
	2		8		
	3		10		
	4		13		
	5	350	5	–	
	6		8		
	7		10		
	8		15		
2	1	450	5	4	
	2		8	2	
	3		10	2	
	4		13	4	
	5	350	5	2	
	6		8	4	
	7		10	4	
	8		15	2	
3	1	450	5	–	T
	2		8		
	3		10		
	4		13		
	5	350	5		
	6		8		
	7		10		
	8		15		
4	1	450	5	4	
	2		8	2	
	3		10	2	
	4		13	4	
	5	350	5	2	
	6		8	4	
	7		10	4	
	8		15	2	

Note: R: Rectangular pulse shape; T: Trapezoidal pulse shape

Finally, the diameter of the resulting stake weld was measured in different conditions of a single laser pulse shot.

To analyze the microstructure of the spot welds, the welding coupon (Fig. 1) was cut along the spot weld centerline, and metallographic specimens were prepared. The welding coupon was cut with the Buehler DeltaAbrasiMet tabletop abrasive machine with active cooling of the cutting edge.

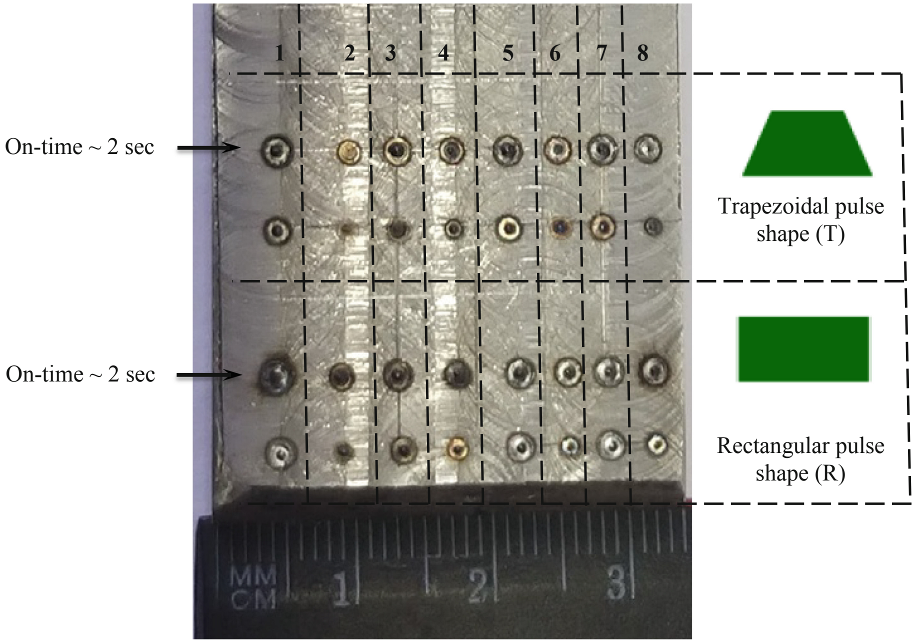

Fig. 1. The St3 steel coupon after laser stake welding. *Source*: Prepared and compiled by the authors

The metallographic specimens were prepared with the EcoMet 250 grinder and polisher machine with the AutoMet 250 semi-automatic head. Then the metallographic specimens were etched in a 5% nital solution to highlight the metal structure.

The metallographic examination was performed with the Nikon Eclipse MA 200 optical microscope.

After structure evaluation, metallographic coupons were used to measure microhardness in different zones of the spot weld (the base metal, the heat-affected zone, and the filler metal). Microhardness was measured with the SHIMADZU HMV-2 microhardness tester.

The metallographic coupons were used to assess the impact of the pulse shape and pulsed laser welding conditions on the following:

– laser stake weld penetration depth;
– stake weld structure development pattern;
– microhardness distribution pattern in the zones produced by a laser shot.

3 Results

After welding the coupon, the main parameters of the resulting spot welds were measured: spot weld diameter and penetration depth. It should be highlighted that the penetration depth was determined using the microstructure images.

In its initial condition, the St3 steel structure is formed by the small equiaxed ferrite and pearlite crystals located mainly at the ferrite grain interfaces and forming a kind

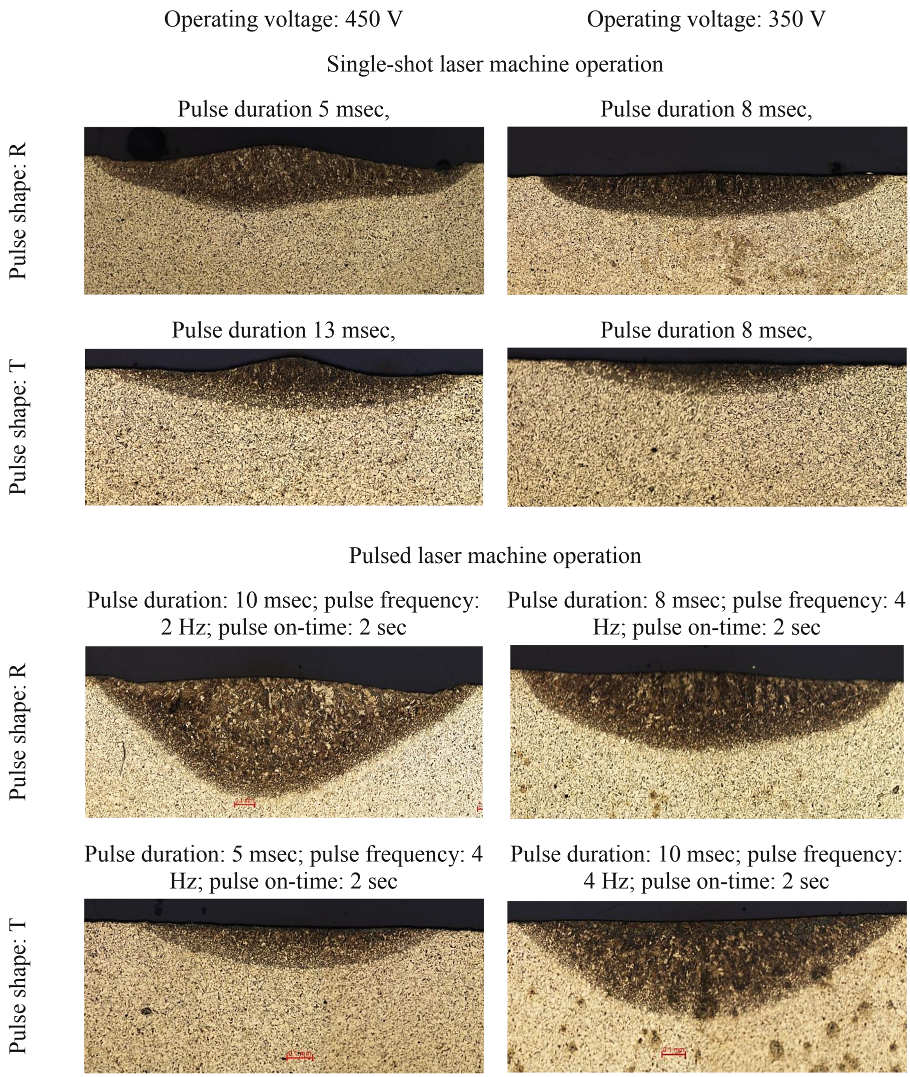

Fig. 2. Microstructure of laser stake welds at 100× magnification under MA-200 metallographic microscope at various pulsed laser spot welding conditions *Source*: Prepared and compiled by the authors.

of a grid or embedding between the grains. The structure of the laser stake welds is drastically different from the initial one. The structure of spot welds made in different laser welding conditions is shown in Fig. 2.

By grouping the different spot weld diameter and penetration depth by certain features, the impact of the main pulsed spot welding conditions, such as the output voltage or pulse time, on the geometry of laser stake welds will be identified (Figs. 3, 4, 5 and 6). The overall impact of each pulsed laser spot welding conditions on the spot weld parameters is of particular interest.

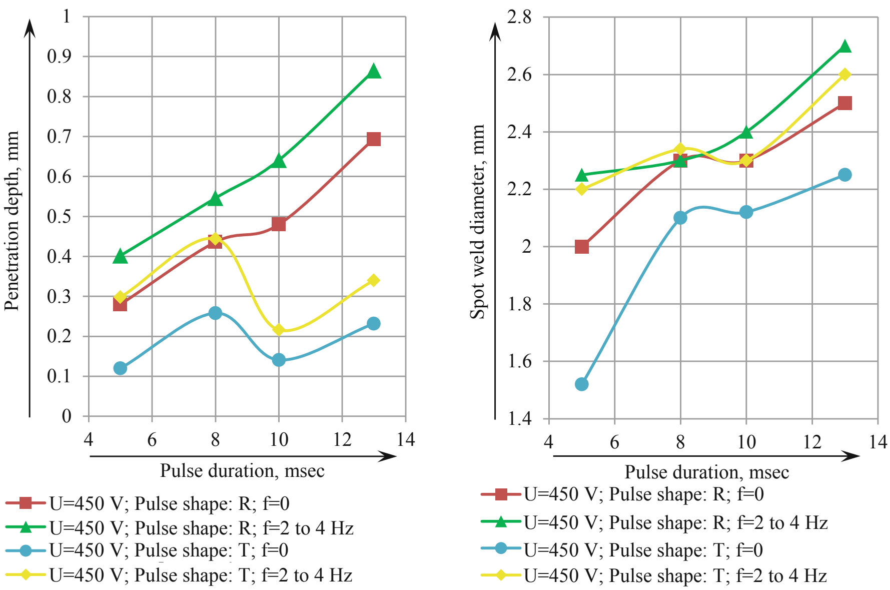

Fig. 3. Impact of pulse shape and pulsation on spot weld geometry at output voltage of 450 V. *Source*: Prepared and compiled by the authors

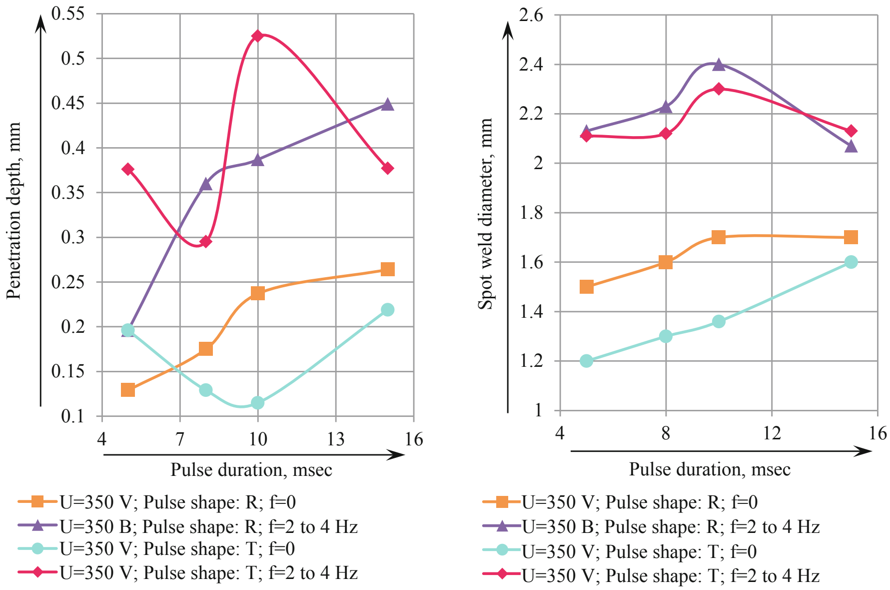

Fig. 4. Impact of pulse shape and pulsation on spot weld geometry at output voltage of 350 V. *Source*: Prepared and compiled by the authors

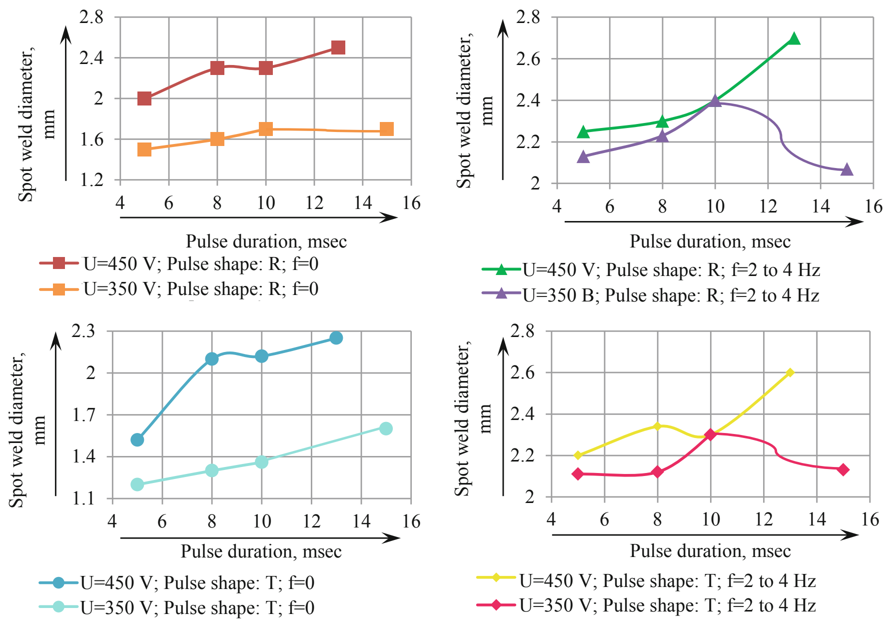

Fig. 5. Output voltage effects on spot weld diameter. *Source*: Prepared and compiled by the authors

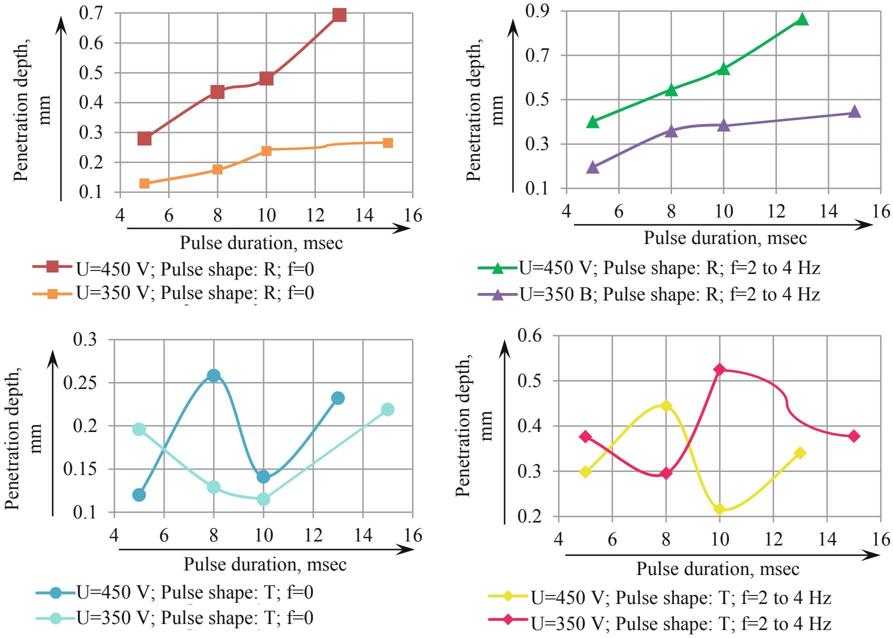

Fig. 6. Output voltage effects on penetration depth. *Source*: Prepared and compiled by the authors

4 Conclusion

By changing the pulsed laser spot welding parameters, the geometry of the resulting connection can be managed.

Regardless of the single laser shot conditions, the spot (stake) weld always has three areas: the first area is the base metal area without any considerable changes in the structure; the second area is the heat-affected area with several structural components typically occurring in the transition from the base metal to the filler metal, and the third area is the filler metal area where the structure is completely different from the base metal. In this case, the base metal structure is ferrite; the metal structure in the heat-affected zone is tempering bainite, and the filler metal structure is tempered pearlite.

The volume ratio of the main spot weld areas can be controlled by changing the operating parameters of the laser machine. A rectangular pulse provides a smaller metal share in the heat-affected zone as contrasted with a trapezoidal pulse. The impact of other laser spot welding parameters on the filler metal/heat-affected metal ratio within the resulting spot weld is ambiguous, and further research is required to detect correlations.

The spot weld has different properties in different areas. The results of the study support this: an increase in the microhardness of the heat-affected zone over that of the base metal is 39% for coupon 1; an increase in microhardness of the heat-affected zone for coupon 2 is not so high, being just 6%; the hardness increase in the filler metal area is 110% for coupon 1 and 61% for coupon 2.

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Technological Principles of Regulating the Kinetics of Carbon Fiber Reinforced Plastic Curing Process Under Conditions of Difficult Temperature Programs

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Abstract. Purpose: This work is devoted to the study of CFRP hardening processes. Anisotropy assessment of ultimate strength in static bending is presented. Particularly interesting work is in the fact that the study of carbon fiber-reinforced plastic obtained by hardening in a complex temperature regime.

Design/methodology/approach: The method of dielectric spectroscopy was used to study the curing of the composite. It was found that, due to a temperature gradient of 8 °C, the gel point of colder prepreg layers occurs at 4.2 min. A method for estimating the gelation time by dielectric spectroscopy is proposed.

Findings: It was found that the point of gel formation coincides with the minimum extremum on the graph of the derivative of the tangent of the dielectric loss angle versus time. In the graph of the tangent of the dielectric loss angle versus time A technique for modifying carbon fiber reinforced plastic is presented, which contributes to the achievement of uniform gelation throughout the entire thickness of the prepreg. The effect is achieved by introducing a curing catalyst in specified concentrations into various layers of the prepreg. The ultimate strength in static bending of modified CFRP increases by 1.2 times. The anisotropy of the static bending strength in the modified sample is reduced by 11.9%.

Originality/value: In general, this research is relevant for manufacturing multi-layer PCMs that are subject to increased requirements in terms of uniform strength in the direction perpendicular to the plane of the product.

Keywords: Polymer-matrix composites (PMCs) · CFRP · Dielectric analysis · Gelation point · Strength · Anisotropy

JEL Code: E22

1 Introduction

Today, polymer composites are used in various industries Mangalgiri (1999), Mitchell (2004), Koushyar et al. (2012), Bashkov et al. (2017a), Fleischer et al. (2018), particularly, in aircraft and helicopter manufacturing, due to the fact that such structural

O. G. Shakirova et al. (Eds.): *Current Problems and Ways of Industry Development: Equipment and Technologies*, LNNS 200, pp. 254–264, 2021.
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materials can significantly reduce the weight of the vehicle. The most common high-strength and high-modulus polymer composite materials (PCMs) are carbon, glass, and organic fiber-reinforced plastics Kablov (2012).

When manufacturing PCM products, the low thermal conductivity of prepregs prevents a uniform temperature field from forming over the cross section of the product and causes the more heated zones to cure first. The temperature gradient Xie et al. (2013) leads to anisotropy of the PCM strength properties over the thickness of the products Whitney, Nuismer (1974), Tsai, Azzi (2008), Bashkov et al. (2017b) and contributes to warping of the parts as a result of internal stresses Hahn (1976), Soo and Lee (1997), Stone et al. (1997). It is possible to prevent internal stresses in the composite and improve the physical and mechanical properties of the plastic by introducing curing catalysts into less heated layers of the prepreg in order to change the kinetics of the binder curing process in a controlled manner and eliminate uneven curing Protsenko,Telesh (2015), Protsenko et al. (2020). Also known several methods to improve properties of the polymer composites using different physical treatment methods Erenkov et al. (2011, 2013).

2 Materials and Methods

The study was carried out using a hot curing epoxy binder based on 4,4'-Methylenebis(2-chloro-N,N-bis(oxiran-2-ylmethyl)aniline), 4,4'-Diaminodiphenyl sulfone and a complex of boron trifluoride with benzylamine. By impregnating the UOL-300 carbon tape with a binder, a prepreg was obtained and then studied further.

2-Methylimidazole (2-MI) was used as a curing catalyst, also catalytical activity could show different metals compounds with heterocycles Shakirova et al. (2018).

The study of the curing process was conducted in a laboratory autoclave Protsenko and Telesh (2015). This apparatus allows for curing using a vacuum of up to 0.002 MPa, pressure of 0.8 MPa, and heating of up to 473 K.

The polymer composite curing process was monitored using the NETZSCH DEA 230/10 Sheppard, Senturia (1986) multichannel dielectric analyzer. For a more accurate assessment of the curing kinetics, the 15-layer prepreg was conditionally divided into 5 sets of 3 layers each. IDEX sensors were inserted between the sets (Fig. 1). An electromagnetic frequency of 10 kHz was used for dielectric measurements. The tangent of the dielectric loss angle was used as a structure-sensitive parameter since this parameter does not depend on the geometrical arrangement of the measuring cell but characterizes only the state of the substance. The point of gel formation was determined based on the dielectric spectra in accordance with Protsenko, Telesh (2015), Protsenko et al. (2020).

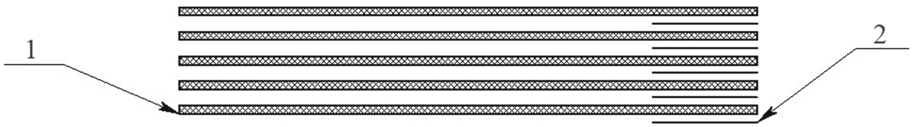

Fig. 1. Diagram of integrating dielectric sensors into prepreg: 1 - prepreg package, 2 – sensor. *Source*: developed and compiled by the authors

For manufacturing PCMs, the following technological mode was adopted (Fig. 2): creating a vacuum of 0.005 MPa, stepwise heating to 175 °C at a rate of 1.8 deg/min, supplying a pressure of 6 atm and removing the vacuum, holding for 6 h, and subsequent cooling at a rate of 1 deg/min up to 40°.

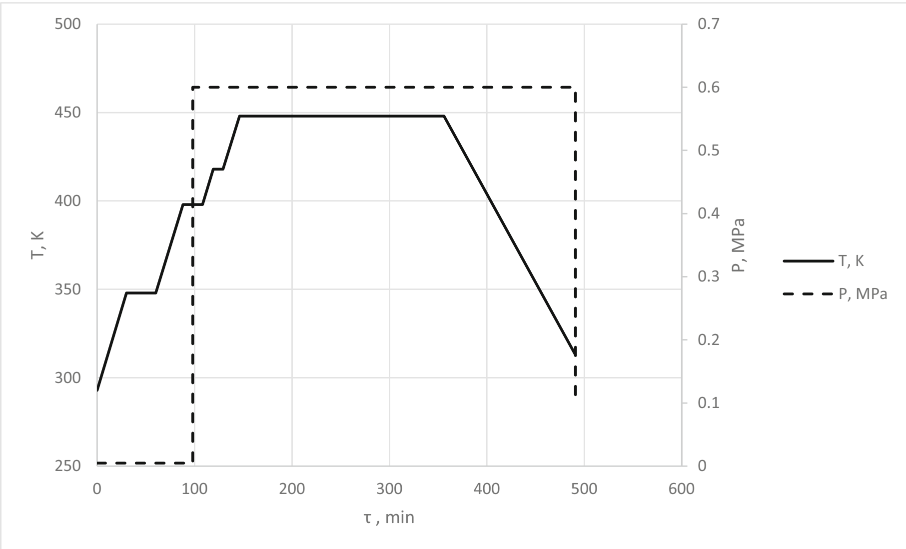

Fig. 2. CFRP curing mode. *Source*: Protsenko (2020a)

Carbon fiber reinforced polymer (CFRP) samples were subjected to a three-point bend test (ISO 14125:1998) using an Instron 3382 testing machine. To study the anisotropy of the static bending strength, adjacent samples obtained from the same CFRP plate were tested by applying a load to opposite sides. In one case, the load was applied to the side in contact with the heating element, in the other, the opposite colder side was used. The anisotropy was calculated using formula 1:

$$a = \frac{\sigma_h - \sigma_c}{\sigma_h} \cdot 100\% \tag{1}$$

where σ_h and σ_c are tensile strength values with load being applied from the hot and from the cold surfaces, respectively.

3 Results

To test the hypothesis, a series of experiments were conducted in the following order.

First, curing experiments were conducted on single-layer samples with the binder in the delivery stage to determine the gel formation point.

The laboratory autoclave is equipped with a polymerization basin. A sample of the investigated binder weighing 5 g was placed in the basin. A prepreg set was also placed in the autoclave. The PCM curing process was monitored by means of dielectric spectroscopy. The method of thermomechanical analysis by means of pulling the binder strands was used to control this process in the polymerization basin.

The results of the dielectric analysis of the polymer composite curing process based on the binder at the stage of delivery are given in Fig. 3.

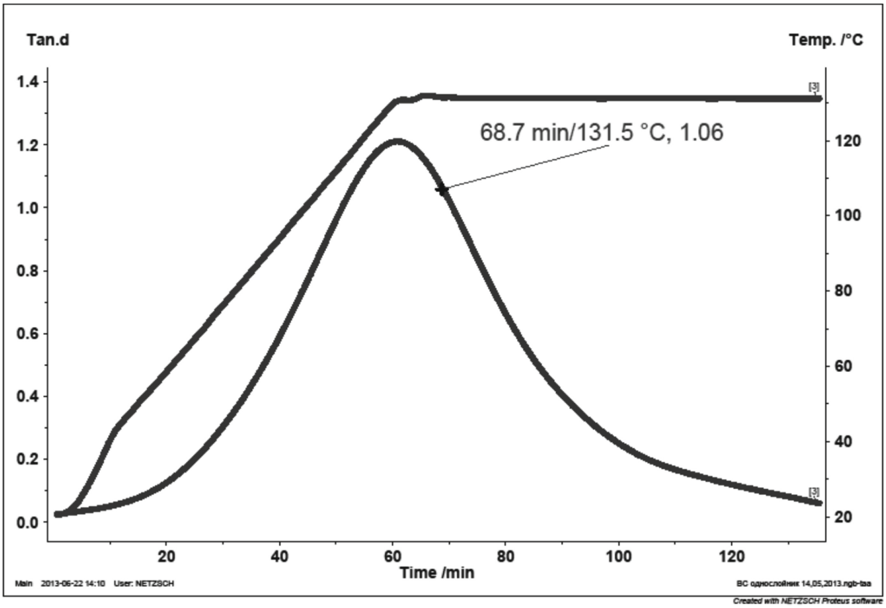

Fig. 3. Dependence of tan (δ) on time for single-layer samples with a pure binder. *Source*: Protsenko (2020a)

Through a series of experiments, it was found that the point of gel formation coincides with the minimum extremum on the graph of the derivative of the tangent of the dielectric loss angle versus time. In the graph of the tangent of the dielectric loss angle versus time, this point is defined as an inflection point using the Proteus Analysis software (NETZSCH).

Experiments were carried out on the curing of multilayer samples of CFRPs based on a binder at the delivery stage according to the mode shown in Fig. 2. This multistage mode ensures that the exothermic effects of curing multilayer composites level out, and the temperature gradient decreases. The curing parameters of the 15-layer sample are given in Fig. 4.

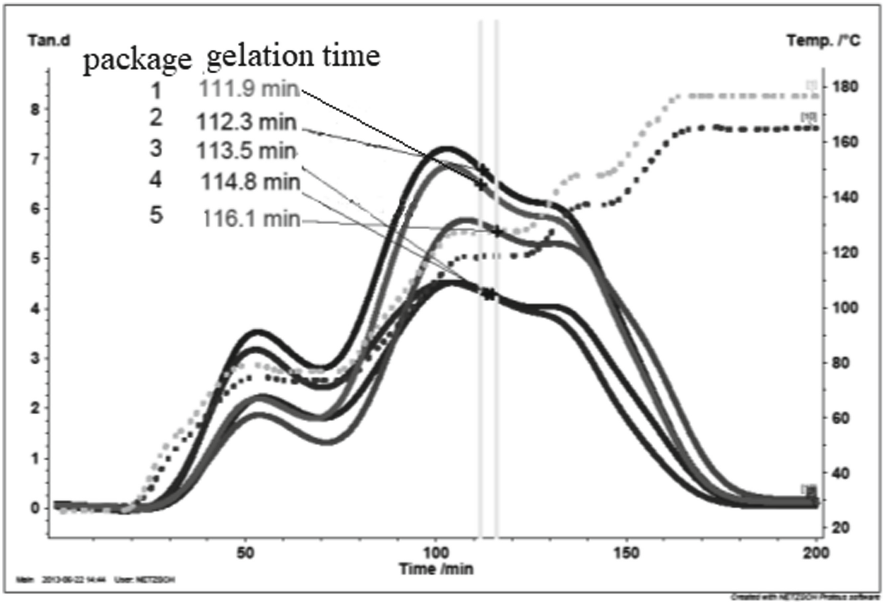

Fig. 4. Dependence of tan (δ) on time for a 15-layer sample with a pure binder. *Source*: Protsenko (2020a)

The temperature of the lower layer on the heat supply side is higher than the temperature of the upper layer of the sample at any given point in time. As a result of the temperature difference, the curing rate varies by layer, which is confirmed by the shift of the dielectric loss tangent maxima.

The graph shows that the point of gel formation occurs sequentially for each set. This is due to the fact that the heating in the autoclave is carried out from below—that is, the temperature gradient throughout the thickness of the PCM affects the curing time of subsequent layers. Thus, uneven curing of the composite leads to internal stresses and, as a consequence, deteriorates the strength and physical and mechanical characteristics.

Due to the fact that curing the binder for a longer period than the gel formation time causes the composition to completely lose its fluidity and processability, it was decided to achieve simultaneous gel formation in all layers of the composite by introducing a catalyst in order to synchronize shrinkage across the entire thickness of the sample and thereby reduce internal stresses.

Therefore, it was necessary to select the optimal concentration of catalyst that would ensure a minimal difference in the onset time of gel formation over the thickness of the cured polymer—that is, the minima of the derivatives of the dielectric loss tangent should coincide in time for all sets.

To evaluate the effect of the catalyst on the gel formation time depending on the concentration of 2-Methylimidazole, a series of experiments were conducted on the curing of reference samples. Five prepregs with different catalyst contents in the binder were placed in the autoclave. The first prepreg did not contain any catalyst, in the second prepreg the content of 2-Methylimidazole was 1.5%, in the third it was 1.75%, in the fourth it was 2%, and in the fifth it was 2.5%.

The results of curing the reference samples with different concentrations of 2-Methylimidazole are shown in Fig. 5.

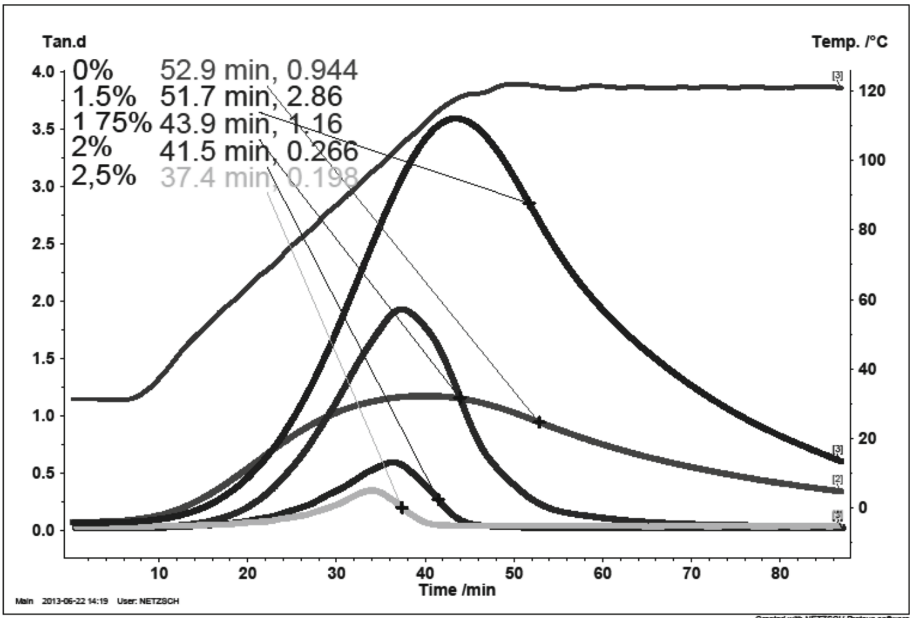

Fig. 5. Dependence of tan (δ) on time for reference samples containing different concentrations of 2-MI. *Source*: Protsenko (2020a).

The decrease in the gel formation time along with the increase in the concentration time of 2-MI in the prepreg under otherwise equal conditions indicates that the introduced substance is a catalyst.

4 Conclusion

The processing of experimental data is aimed at establishing the dependence of the effect of 2-MI concentration on the gel formation time. To achieve this, formula 2 was used to determine the time shift of the gel formation (Δτ):

$$\Delta\tau_i = (\tau_i - \tau_0) \cdot 60, \tag{2}$$

where τ_i is the start time of gel formation of the i-th sample, min,

τ_0 is the start time of gel formation in the sample without a catalyst, min.

The values obtained as a result of experiments and calculated according to formula (2) are shown in Table 1.

Table 1. Results of experiments with standard samples

Package number	τ_g, min	$\Delta\tau_g$,c	C, %
1	52.9	0	0
2	51.7	72	1.5
3	43.9	540	1.75
4	41.5	684	2
5	37.4	930	2.5

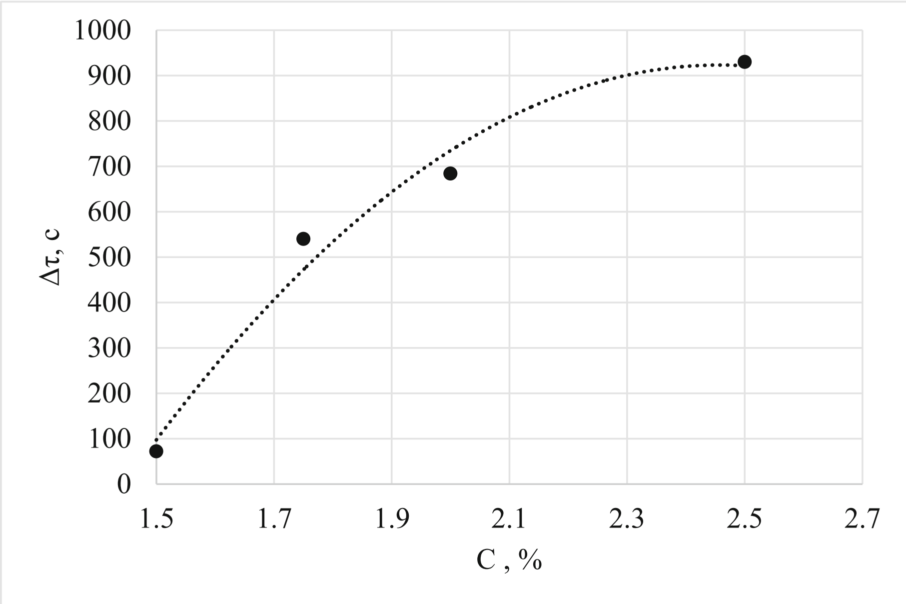

Fig. 6. Dependence of the gelation time shift on the concentration of 2-MI. *Source*: Protsenko (2020a)

The dependence of the gelation time shift on the concentration for standard samples is shown in Fig. 6.

On the basis of experimental data, it was found that such a dependence is well described by parabola Eq. 3:

$$y = -901.09x^2 + 4,428.5x - 4,518 \tag{3}$$

By introducing the catalyst into the upper colder layers of the prepreg, a sample can be obtained for which, when cured, the gel formation points of all sets will be in approximately the same region. Since the catalyst accelerates the curing process, all gel formation points must gather in the area of the fastest set. The fastest set is the one in the area of contact with the heating element, for which the time of the gel formation point is 111.9 min.

To determine the concentration of the catalyst in each set of prepreg according to the curing experiment for the unmodified 15-layer prepreg (Fig. 3), we calculate the gel formation time lag of each set from the first set according to formula 4:

$$\Delta_i = \left(t_{gi} - t_1\right) \cdot 60, \tag{4}$$

where τ_i is the time of the gel formation point of the i-th set, min,

τ_1 is the time of the gel formation point of the 1st set, min.

By inserting these values into function 3, we obtain the catalyst concentration values (Table 2) required to achieve synchronous gel formation.

Table 2. Calculated catalyst concentrations in prepreg sets

Package number	$\tau_i{}'$,s	$\Delta\tau_i$,s	Concentration, %
1	111.9	0	0
2	112.3	24	1.45
3	113.5	96	1,5
4	114.8	174	1.55
5	116.1	252	1.59

Based on these results, a 15-layer CFRP sample was created. The results of monitoring the curing process of this sample by means of dielectric spectroscopy are given in Fig. 7.

As seen in the graph, curing of all layers occurs simultaneously, and the gel formation points are close to each other. This confirms that the introduction of 2-Methylimidazole makes it possible to achieve the simultaneous curing of all layers of the composite without disrupting the technological process.

The final stage of the work was to determine the ultimate strength when subjected to static bending. The results of testing are given in Table 3.

Thus, the introduction of a certain amount of 2-MI catalyst into the cooler sets of prepregs helps reduce the spread of gel formation time by a factor of 9 and, as a consequence, decreases internal stresses in the PCM samples. The latter is confirmed by an increase in the ultimate bending strength by 20.6% when a load is applied from the colder side and by 4.2% when a load is applied from the side in contact with the heating element. The anisotropy of the static bending strength in the modified sample is reduced by 11.9%. These results are due to the achievement of synchronous gel formation during curing of the polymer composite.

The data obtained show that it is possible to apply the technological solutions described in the work Protsenko, Telesh (2015) to systems cured according to more complex temperature programs. We also used a more complex binder containing a catalyst based on BF_3 in this study. Therefore, it is not possible to use the catalytic system and

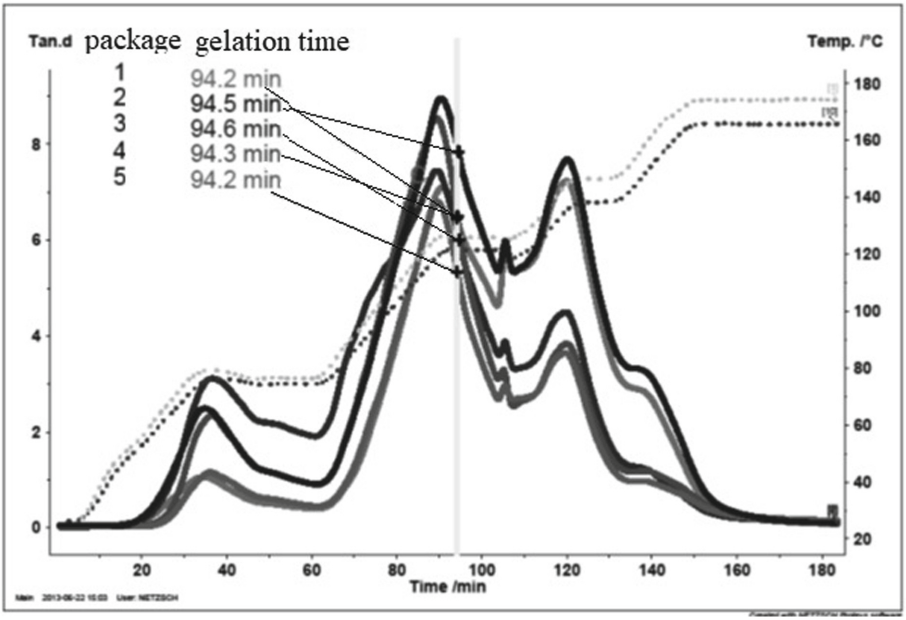

Fig. 7. Dependence of tan (δ) on time for a 15-layer sample containing the calculated concentrations of 2-MI. *Source*: Protsenko (2020a)

Table 3. Summary table of mechanical test results

Plastic	Average value of flexural strength under load application, σ_f (MPa)		Anisotropy, %	Gelation time shift, min
	From above	From below		
CFRP	567.4	745.0	23.8	3.8
Modified CFRP	684.4	776.5	11.9	0.4

dependencies proposed in the work Protsenko and Telesh (2015). In spite of this, 2-MI has a catalytic effect in this study, as in the work Protsenko and Telesh (2015). Moreover, in the case of using a binder based on 4,4'-Methylenebis(2-chloro-N,N-bis(oxiran-2-ylmethyl)aniline), 4,4'-Diaminodiphenyl sulfone, and a complex of boron trifluoride with benzylamine, 2-MI also exhibits a catalytic effect. However, in the concentration range up to 1.4%, the catalytic effect of 2-MI is not observed in this system.

In general, this research is relevant for manufacturing multilayer PCMs that are subject to increased requirements in terms of uniform strength in the direction perpendicular to the plane of the product.

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Shakirova, O., Kuratieva, N., Lavrenova, L., Protsenko, A., Tkachenko, I., Petkevich, S., Potkin, V.: Syntheses, structures and properties of magnetically active copper(II) compounds with 3-amino-5-(4-methylphenyl)isoxazole. Polyhedron **146**, 121–128 (2018). https://doi.org/10.1016/j.poly.2018.02.025

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Structure and Properties of Copper(II) and Cobalt(II) Halide Complexes with N–Heterocycles of Composition $(HL)_n[MHal_4]$

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Abstract. Purpose: The research objective is to expand the class of coordination compounds of copper(II) and cobalt(II) with polyfunctional properties. Moreover, the targeted synthesis of Cu(II) and Co(II) complexes with cationic N-heterocycles as well as their versatile physicochemical study using state-of-the-art methods in order to establish the "composition–structure–property" relationship is an urgent task for modern inorganic chemistry.

Methodology: To solve the problem of the relationship between the composition, structure and properties of compounds, a number of modern physical and chemical methods were used, such as elemental analysis, infra-red (**IR**) spectroscopy, X-ray diffraction analysis, differential scanning calorimetry (**DSC**) and thermogravimeter (**TG**).

Findings: A number of new coordination compounds of copper(II) and cobalt(II) with nitrogen-containing heterocyclic cations have been synthesized: $(L^1)_2[CuCl_4]$, $(L^1)_2[CoCl_4]$, $(L^1)_2[CuBr_4]$, $(H_2L^2)[CuCl_4]$, $(H_2L^2)[CoCl_4]$, $(H_2L^2)[CuBr_4]$ (where $(L^1)^+$ is 2,3,5-triphenyltetrazolium, and $(H_2L^2)^{2+}$ is trans-2,5-dimethylpiperazinium).

Value: By means of differential scanning calorimetry for $L^1{}_2[CuCl_4]$ and $L^1{}_2[CuBr_4]$ copper(II) compounds, monotropic phase transitions were revealed, which are of the "order/disorder" type and are accompanied by thermochromism, as well as first-order phase transitions corresponding to the melting process. Based on the X-ray structural analysis, the relationship between the parameters in the $MHal_4$ coordination node is revealed: the maximum values of the M-Hal bond lengths and Hal-M-Hal coordination angles are linearly dependent on their minimum parameters.

Keywords: Synthesis · Copper(II) · Cobalt(II) · IR spectroscopy · X-ray structural analysis · 2,3,5-triphenyltetrazolium chloride · Trans-2,5-dimethylpiperazine

JEL Code: E22

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1 Introduction

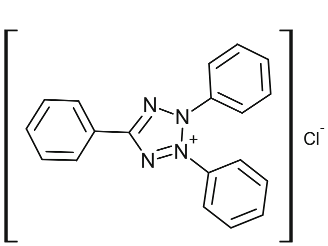
Among the new materials, a class of halide coordination compounds of 3d transition metals (namely, Cu(II) and Co(II)) with organic nitrogen-containing heterocyclic cations can be identified. Such compounds have useful magnetic, catalytic, thermochromic (color change due to temperature changes), and biological properties, which allows them to be used in various scientific and technological fields (Davies and El-Sayed 1983; Bushuev et al. 2006). For instance, copper(II) complexes are applied as additives for polymerization catalysts and catalytic systems based on superacid ionic liquids in the isomerization reactions of light gasoline fractions and reaction activators (Burdakova and Petrov 2020). Depending on the temperature, they can exhibit specific magnetic properties, such as antiferromagnetic or ferromagnetic exchange interactions and phase transitions (Turnbull et al. 2002). The practical use of thermochromic substances covers a wide range of industries. In medicine, thermochromic substances are used as warning indicators and tests for detecting narcotic substances as well as for detecting subdermal cancers and diagnosing vascular diseases, etc. Thermochromic substances are used in the development of microwave ovens, internal combustion engines, and various turbines as well as in aerospace and other engineering applications. In addition, these substances have found applications in the design industry, including advertising, jewelry, textiles, and clothing (Bhattacharya et al. 2002). In medicine, coordination compounds are attracting the attention of researchers as promising drugs for the diagnosis and treatment of cancer (Artem'ev et al. 2017).

2 Materials and Methods

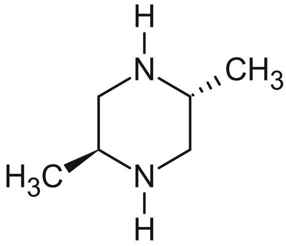
For the synthesis of complex compounds of copper(II) and cobalt(II), $CoCl_2{\cdot}6H_2O$ (high-purity grade), $CuCl_2{\cdot}2H_2O$ (high-purity grade), CuO (high-purity grade), $CuCO_3$ (high-purity grade), concentrated acid HBr, C_2H_5OH, nitrogen-containing compounds 2,3,5-triphenyltetrazolium chloride (reagent grade) **(L^1Cl)**, and trans-2,5-dimethylpiperazine (high-purity grade) **(L^2)** were applied (Fig. 1).

Elemental analysis for C, H, N of all compounds was carried out at the Microanalysis Laboratory of the NIIC SB RAS, by the elemental analyzer EURO EA 3000 produced by EuroVector (Italy). Analysis for the copper(II) and cobalt(II) contents in the complexes was carried out after decomposition of samples (10–20 mg) boiled for 2–3 h in a combination of concentrated H_2SO_4 and $HClO_4$ (1:2). After boiling down the solution, the formed precipitates were dissolved in water and neutralized with ammonia. Copper(II) and cobalt(II) ions were titrated with Trilon B ($C = 0.0100$ mol/L) with a murexide indicator while observing the color transition from yellow to red-violet and blue-violet, respectively (analysis data listed in Table 1).

The IR absorption spectra of the compounds were obtained applying an IRAffinity-1S FTIR spectrometer (Shimadzu) in the range of 400–4000 cm^{-1} (Komsomolsk-na-Amure State University) with 0.5 cm^{-1} resolution and 30000:1 signal-to-noise ratio (peak to peak). Samples were organized in the form of pellets in KBr.



2,3,5-triphenyltetrazolium chloride (L^1Cl)



trans-2,5-dimethylpiperazine (L^2)

Fig. 1. Nitrogen-containing heterocyclic compounds. Source: developed and compiled by the authors

The NIIC SB RAS make X-ray structural analysis of the complexes in accordance with the standard procedure, with the help of a Bruker-Nonius X8Apex automatic four-circle diffractometer equipped with a two-coordinate CCD detector at temperatures of 150(2) °K or (293(2) °K) with the help of radiation from a molybdenum anode (λ = 0.71073 Å) and a graphite monochromator. They measure reflection intensities by θ-scanning of narrow (0.5°) frames. Absorption was accounted empirically due to the SADABS program (Bruker AXS Inc. 2004). The structure was completed using the direct method and refined by full-matrix least squares in anisotropic approximation for nonhydrogen atoms using the SHELXTL software package (Sheldrick 2015). Hydrogen atoms for organic ligands were refined using the rigid body approximation.

Thermal analysis of the samples was carried out at Komsomolsk-na-Amure State University, using an STA 409 PC Luxx NETZSCH. The kinetic parameters were determined using the Kissinger method (Kissinger 1956; Protsenko et al. 2020). The samples were heated at rates of 5, 10, and 20 °C/min.

Table 1. Data of elemental analysis of complexes.

№	Compounds	Formula	Found / calculated, %							
			C		H		N		Cu or Co	
I	$(L^1)_2[CuCl_4]$	$CuC_{38}H_{30}N_8Cl_4$	56.6	56.6	3.6	3.6	13.8	13.9	7.6	7.8
II	$(L^1)_2[CoCl_4]$	$CoC_{38}H_{30}N_8Cl_4$	57.2	57.2	3.7	3.7	14.1	14.1	7.5	7.4
III	$(L^1)_2[CuBr_4]$	$CuC_{38}H_{30}N_8Br_4$	47.8	46.4	3.0	3.0	11.7	11.4	6.4	6.5
IV	$(H_2L^2)[CuCl_4]$	$CuC_6H_{16}N_2Cl_4$	22.3	22.4	4.7	5.0	8.6	8.7	19.6	19.7
V	$(H_2L^2)[CoCl_4]$	$CoC_6H_{16}N_2Cl_4$	22.7	22.7	4.7	5.0	8.8	8.8	18.4	18.6
VI	$(H_2L^2)[CuBr_4]$	$CuC_6H_{16}N_2Br_4$	14.3	14.4	3.0	3.2	5.6	5.6	12.5	12.7

Synthesis of $(L^1)_2[CuCl_4]$ (I) and $(L^1)_2[CoCl_4]$ (II). To a solution of 0.001 mol of $CuCl_2 \cdot 2H_2O$ (0.1704 g) or $CoCl_2 \cdot 6H_2O$ (0.2378 g) in 1 ml of conc. HCl was added quickly a solution of **L^1Cl** (0.001 mol, 0.3348 g) in 10 ml of H_2O. Crystals formed from the solution within a few days after mixing the starting solutions. The crystals were kept in solution for several days and then filtered, washed twice with distilled water.

Synthesis of $(L^1)_2[CuBr_4]$ (III). To a solution of 0.001 mol of CuO (0.2233 g) in 5 ml of conc. HBr was added quickly a solution of **L^1Cl** (0.001 mol, 0.3348 g) in 10 ml of H_2O. Crystals formed from the solution within a few days after mixing the starting solutions. The crystals were kept in solution for several days and then filtered, washed twice with distilled water.

Synthesis of $(H_2L^2)[CuCl_4]_2$ (IV) and $(H2L^2)[CoCl_4]$ (V). To a solution of 0.006 mol $CuCl_2 \cdot 2H_2O$ (1.024 g) or $CoCl_2 \cdot 6H_2O$ (1.422 g) in 5 ml of 10% HCl, a solution of L^2 (0.006 mol, 0.685 g) in 5 ml of ethanol was quickly added. Crystals of complexes are formed from the solution for some time after mixing the initial solutions. The crystals were filtered, washed with distilled water several times, and air-dried.

Synthesis of $(H_2L^2)[CuBr_4]$ (VI). To a solution of 0.006 mol $CuCO_3$ (0.744 g) in 2 ml conc. HBr was quickly added L^2 solution (0.006 mol, 0.685 g) in 5 ml of ethanol. Crystals of the complex are formed from the solution for some time after mixing the initial solutions. The complex was filtered, washed with pure H_2O several times and dried.

3 Results

a. X-ray structure analysis

All synthesized samples are anionic complexes. Coordination compounds **I–III** have an isotypic structure (see Figs. 2, 3) and crystallize in a monoclinic system. The structural unit of crystals is $[MHal_4]^{2-}$ anion with two $(L^1)^+$ cations. The complex anion is a distorted tetrahedron with Hal-M-Hal coordination angles ranging from 99.7º to 132.4º.

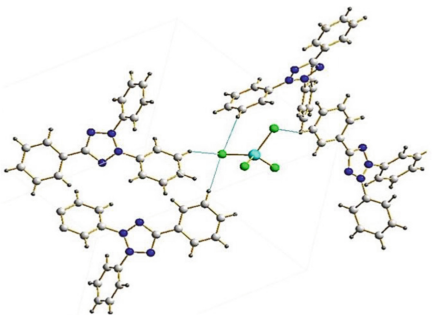


Fig. 2. Structure of the complex **$L^1{}_2[CuCl_4]$**. *Source*: developed and compiled by the authors

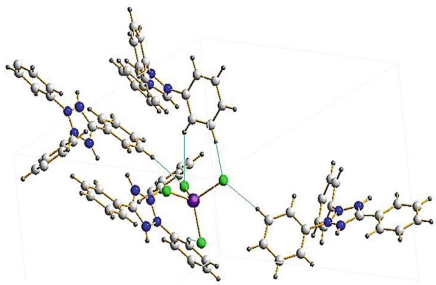


Fig. 3. Structure of the complex **$L^1{}_2[CoCl_4]$**. *Source*: developed and compiled by the authors

In complex **II**, the coordination core is close to an ideal tetrahedron (the Cl-Co-Cl angle is 109.5°). The Cu-Hal bond length in complexes **I** and **III** is 2.2622 (0) and 2.2888 (0) Å, respectively, and the Co-Cl bond length in complex **II -** is 2.273(0) −2.3032 Å. Each anion forms a network of hydrogen bonds with four neighboring $(L^1)^+$ organic cations, and a similar structure was observed in the work by Tuikka et al (2013).

In the $\mathbf{L^1{}_2[CuBr_4]}$ complex (see Fig. 4), inorganic anions are arranged chequerwise to each other by their edges, and organic cations are settled between them.

a) b)

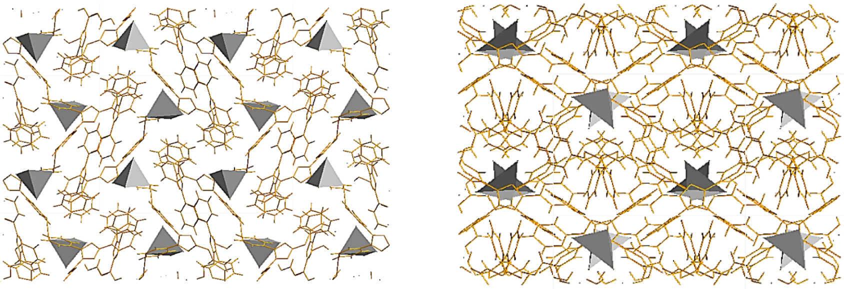


Fig. 4. Spatial structure of the $\mathbf{L^1{}_2[CuBr_4]}$ complex: a) - projection on the plane *bc*; b) - projection on the plane *ab*. *Source*: developed and compiled by the authors

X-ray diffraction analysis demonstrates that ion-type IV-VI complexes do not have identical structures. The piperazinium cation in all synthesized complexes has a chair conformation. The anion $[CuCl_4]^{2-}$ of the **IV** includes a flat square with Cl-Cu-Cl angles of 89.7 °C and 90.2 °C. The Cu-Cl bond length is 2.27 and 2.36 Å. The copper(II) coordination polyhedron is supplemented to the octahedron by chlorine ions of adjacent anions. The crystal structure of the complex contains endless chains of shared $CuCl_6$ octahedra

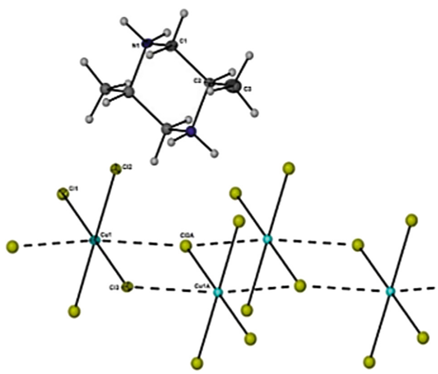


Fig. 5. Structure of the complex $\mathbf{(H_2L^2)[CuCl_4]}$ *Sources*: developed and compiled by the authors.

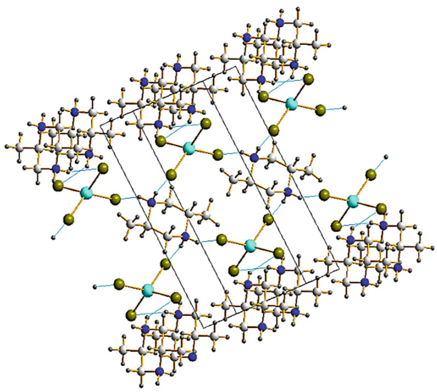


Fig. 6. Structure of the complex $\mathbf{(H_2L^2)[CuBr_4]}$ *Sources*: developed and compiled by the authors.

along the C axis. These anionic chains set up a primitive packing, and the interchain space is taken up by organic cations. Hydrogen bonds between the chlorine ions of the chlorocuprate ion and the hydrogen atoms of one of the N-protonated piperazine stabilize this structure. Each inorganic anion is hydrogen-bonded with two piperazinium cations that are positively charged (see Fig. 5). The $\mathbf{[CoCl_4]^{2-}}$ and $\mathbf{[CuBr_4]^{2-}}$ inorganic anions of compounds **V** and **VI** are isolated distorted tetrahedra. In **VI**, we can observe only hydrogen bonds between the chlorine and hydrogen atoms. These atoms are protonated to heterocyclic nitrogen atoms (see Fig. 6). In **V**, besides such hydrogen bonds, there are also $\mathbf{[CoCl_4]^{2-}}$hydrogen bonds with methylene groups (see Fig. 7).

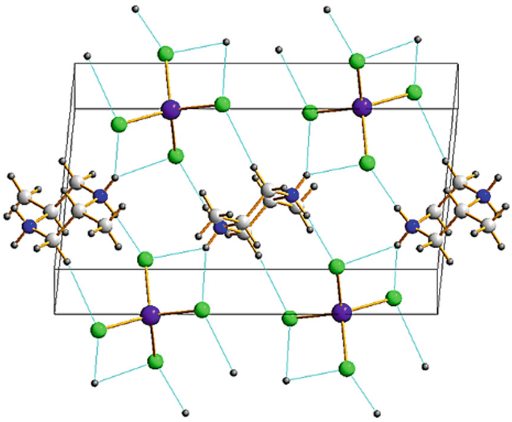


Fig. 7. Structure of the complex $\mathbf{(H2L^2)[CoCl_4]}$. *Source*: developed and compiled by the authors

b. IR spectroscopy

In the high-frequency region of the IR spectra of the $\mathbf{L^1Cl}$ compound and **I–III** complexes, bands of deformation vibrations of the tetrazole ring are observed at 1527–1528 and 999 cm^{-1}, and in the region of 1600 cm^{-1} there are stretching vibration bands of benzene rings. The intensity and position of these bands do not very significantly, which points to the fact that the structure of the initial cation $(L^1)^+$ remains unchanged in the obtained coordination compounds of copper(II) and cobalt(II). In the IR spectrum of the organic base, the broad band at 3224 cm^{-1} refers to the N-H vibrations of the free amine (unprotonated), while the band at 2944 cm^{-1}, 2997 cm^{-1}, and 3000 cm^{-1} in the spectra of coordination compounds $\mathbf{(H_2L^2)[CuCl_4]}$, $\mathbf{(H_2L^2)[CoCl_4]}$ and $\mathbf{(H_2L^2)[CuBr_4]}$ (respectively) is explained by the NH^+ protonated group vibrations. Since no doublet is noticed in the spectra of the complexes in the region of 3200 cm^{-1}, the protonation reaction proceeded symmetrically (for both nitrogen atoms in the cycle). In the 1000–1100 cm^{-1} region, a doublet is noticed at 1050 and 1040 cm^{-1}, corresponding to the ν(C-N) vibrations (Srinivasan et al. 2009). In the IR spectra of the complexes, the bands assigned to the heterocycle shift to lower frequencies of ~20 cm^{-1} relative to the corresponding bands in the base spectrum because of nitrogen atom protonation (Shakirova et al. 2012) (Table 2).

Table 2. IR spectroscopy data for complexes

Assignment	L^1Cl	$L^1{}_2[CuCl_4]$ I	$L^1{}_2[CoCl_4]$ II	$L^1{}_2[CuBr_4]$ III	L^2	$(H_2L^2)[CuCl_4]$ IV	$(H_2L^2)[CoCl_4]$ V	$(H_2L^2)[CuBr_4]$ VI
R(ring)	1527 1495 1454 999	1527 1495 1455 999	1528 1484 1546 997	1527 1484 1456 997				
ν(ring)	1608	1608	1604	1606				
ν(N-H) $\nu(N\text{-}H^+)$					3224 2963 2940	3224	2944	2997
ν(C-N)					1170 1120	1070	1046	1050 1040
$\delta(CH_3)$					1460 1400 1345	1375 1250	1390 1300	1380 1280
$\nu(CH_2)$					2850 2800	2820 2800	2820	2816
$\delta(CH_2)$					1280 1245	1345 1310	1360 1330	1360 1330

c. **Thermal data**

In accordance with the TG data, in air, the **$L^1{}_2[CuCl_4]$** compound is stable up to 277 ºC, the **$L^1{}_2[CoCl_4]$** compound, up to 250 ºC, and the **$L^1{}_2[CuBr_4]$ compound,** up to 180 ºC. DSC revealed the existence of reversible phase transitions in **I–III**, corresponding to the process of melting compounds: for **$L^1{}_2[CuCl_4]$** t = 247 ºC $\Delta H_p = 9.0$ kJ/mol; for **$L^1{}_2[CoCl_4]$** t = 278 ºC; for **$L^1{}_2[CuBr_4]$** t = 186 ºC. In addition, complexes **I** and **III** have one monotropic phase transition. In compound **I**, the phase transition at t = 216 ºC ($\Delta H_{ph.tr.} = 35.0$ kJ/mol) refers to the "disorder/order" type and arises due to the orientational ordering of the deformed $[CuCl_4]^{2-}$ tetrahedra and orbital ordering in them. The transition is accompanied by thermochromism, which is a color change from yellow to orange-red. The study of the phase transformation kinetics was made using the Kissinger method (see Figs. 8, 9). The activation energy E_a was calculated as 769 J/mol.

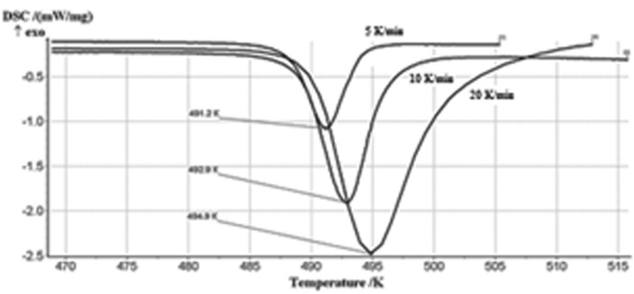
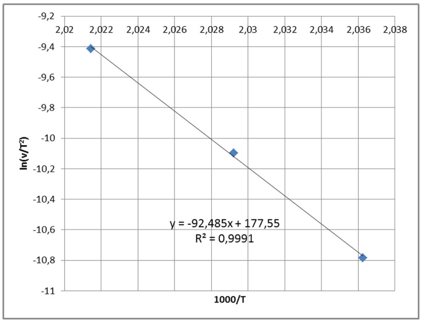


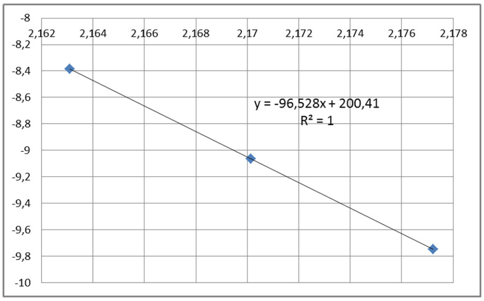
Fig. 8. DSC of **$L^1{}_2[CuCl_4]$** at different heating rates. *Source*: developed and compiled by the authors.



E_a= - (-92.485·8.314) = 768.2 J/mol

Fig. 9. Dependence of ln(v/T^2) on 1000/T for complex **I**. *Source*: developed and compiled by the authors.

The calculated value aligns well with the data given in other literature (776 J/mol) for chlorocuprates(II) (Riley and Hitchman 1987).



E_a= - (-96.528·8.314) = 802.5 J/mol

Fig. 10. Dependence of ln(v/T^2) on 1000/T for complex **III**. *Source*: developed and compiled by the authors.

In compound **III**, there is a phase transition at t = 184 °C (E_a = 802.5 J/mol, see Fig. 10). The transition is accompanied by thermochromism in the form of a color change from maroon to blue. The color change means a change in the coordination type of the copper (II) ion; as a rule, the color blue is characteristic of the amine complexes of copper(II), and the Cu-N bond probably also appears.

According to the DSC of the **IV**, **V** and **VI** complexes, the samples decompose at temperatures of 212.4 ºC, 269.0 ºC, and 247.1 ºC, respectively, as evidenced by the loss of mass on the TG curve.

Based on previously obtained data and data from this paper, for tetrahalide complexes Cu(II) and Co(II), we achieved interrelationships between the structural characteristics in the $[MHal_4]^{2-}$ coordination polyhedron and the dependences of the ratio of the maximum and minimum values of the M-Hal bond lengths (d_{max} and d_{min}) on their variety (see Fig. 11) as well as the relationship between the maximum and minimum values of the polyhedron trans-angles (θ_{max} and θ_{min}) (see Fig. 12).

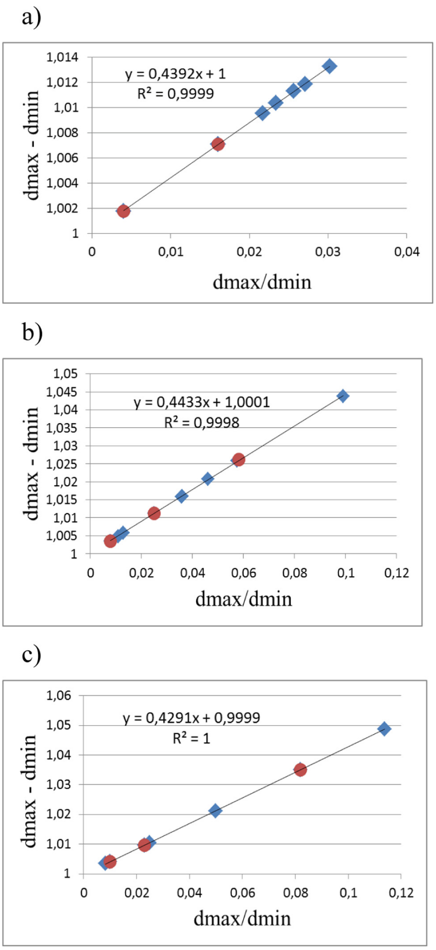


Fig. 11. Dependences of maximum and minimum values of M-Hal bond lengths in a polyhedron: a) $[CoCl_4]^{2-}$, b) $[CuCl_4]^{2-}$, c) $[CuBr_4]^{2-}$ ■- data from this paper, ●– literature data

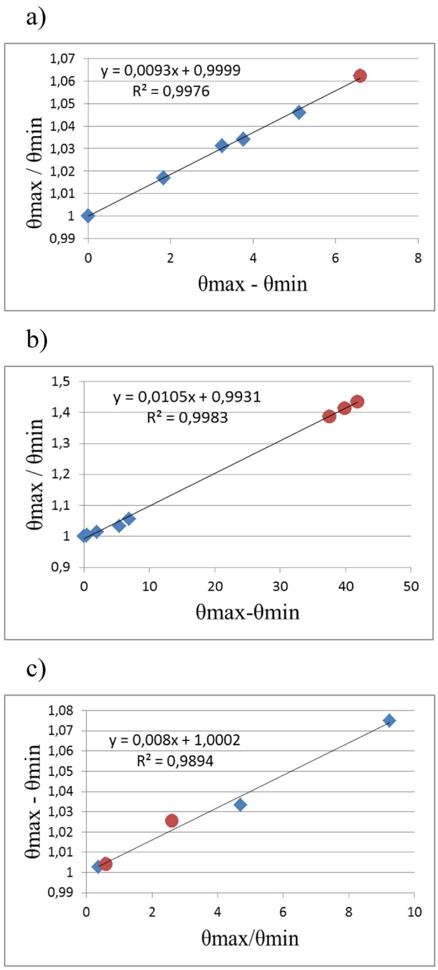


Fig. 12. Dependencies of maximum and minimum values of trans-angles Br-Cu-Br in polyhedron: a) $[CoCl_4]^{2-}$, b) $[CuCl_4]^{2-}$, c) $[CuBr_4]^{2-}$ ■- data from this paper, ●– literature data

4 Conclusion

Thus, six new complex compounds of Cu(II) and Co(II) halides with nitrogen-containing heterocyclic compounds were synthesized. Compounds were identified using modern physicochemical methods: elemental analysis, IR spectroscopy, X-ray diffraction analysis, differential scanning calorimetry, and thermogravimetry. By means of differential scanning calorimetry for $L^1{}_2[CuCl_4]$ and $L^1{}_2[CuBr_4]$ copper(II) compounds, monotropic phase transitions were revealed, which are of the "order/disorder" type and are accompanied by thermochromism, as well as first-order phase transitions corresponding to the melting process. Based on the X-ray structural analysis, the links between the parameters in the $MHal_4$ coordination node are revealed: the maximum values of the M-Hal bond lengths and Hal-M-Hal coordination angles are linearly dependent on their minimum parameters.

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Influence of Technological Parameters of Centrifugal Casting of Aviation Aluminum Alloy on the Physical and Mechanical Properties of Castings

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Abstract. Purpose: The main technological feature of centrifugal casting is that the filling of a casting mold with some melt, solidification and cooling of the casting in the mold takes place under the action of centrifugal forces arising during the rotation of the casting mold relative to its vertical or horizontal axis. At the same time a determining effect on the structure and quality of the obtained castings have the factors that regulate the temperature regime in the system "metal – form" and the kinematic characteristics of the equipment, which specify the magnitude of the force impact during casting solidification. Improving the sustainability of the technological process of casting production by controlling technological parameters of the process based on their interrelation will allow predicting and controlling the quality of the castings even at the stages of designing a technological process of their production.

Design/methodology/approach: The area of the research is to improve the quality of castings by controlling technological parameters of their formation. The interrelation of physical and mechanical properties with the technological parameters of their production has been established based on a complex of experimental studies.

Findings: Linear models have been constructed, which describe the dependence of physical and mechanical properties of castings on the main process parameters in technologically based intervals of their change. The obtained data allowed to determine rational parameters of the process of producing castings from aluminum alloys ($T_i = 220–250$ °C; $T_m = 690–720$ °C; $\omega = 210–240$ rad/sec).

Keywords: Centrifugal casting · Technological parameter · Tensile strength · Impact strength · Temperature of the poured melt · Mold rotation speed

JEL Code: C61 · L61 · L62

1 Introduction

Increasing requirements for mechanical engineering products necessitate solving the problem of improving the quality of workpieces and the stability of their production.

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The main technological feature of centrifugal casting is that the filling of a casting mold with some melt, solidification and cooling of the casting in the mold takes place under the action of centrifugal forces arising during the rotation of the casting mold relative to its vertical or horizontal axis. This casting method is widely used in industry, especially to obtain free surface castings in the form of revolution bodies (Mirzoyan 2007; Zanko et al. 2012; Serebryakov et al. 2007; Pathak et al. 2006; Jayakumar et al. 2016; Kulakov et al. 2014; Xu et al. 2016). At the same time a determining effect on the structure and quality of the obtained castings have the factors that regulate the temperature regime in the system “metal – form” and the kinematic characteristics of the equipment, which specify the magnitude of the force impact during casting solidification (Lyashkov et al. 2012; Marukovich et al. 2017; Stetsenko et al. 2010; Huisman et al. 1995; Kim et al. 2002; Ebhota et al. 2017). With all its advantages (high hydrodensity associated with minimal gas and shrinkage porosity in castings, simplicity and low cost of foundry equipment, etc.), this technological process has low stability, when casting aluminum alloys prone to segregation (Konkevich et al. 2008; Trapeznikov and Goncharenko 2015; Kyung et al. 2000).

Increasing the stability of the technological process of manufacturing castings by controlling the technological parameters based on their relationship, which will make it possible to predict and control the quality of castings even at the design stages of the technological process by their production (Serebryakov et al. 2008; Zhang et al. 1996; Gao and Wang 2000). For centrifugal casting, the main technological parameters influencing the crystallization processes and, as a consequence, the quality of castings includes the factors that determine the temperature conditions and power characteristics of the process. The theoretical description of the processes is occur in the system “crystallizing metal – casting mold” under the action of centrifugal-forces field, which is associated with a number of difficulties arising in solving the associated temperature (taking into account the phase transition) and deformation problem, as well as with the verification of the simulation results (Rajan et al. 2012; Albermany et al. 2016; Mondal et al. 2015; Odinokov et al. 2019; Evstigneev et al. 2016). Thus, the actual direction of research is the improvement quality of castings by controlling the technological parameters of the process from their formation.

2 Method of Research

Cylindrical castings with a free surface of the “bushing” type were chosen as the object of research (Fig. 1), produced on a centrifugal machine with a vertical axis of rotation of aluminum alloy Ak7ch (GOST 1583-93) with a height of 80 mm, an outer diameter of 85 mm and an inner diameter of 60 mm.

Fig. 1. The type of casting. *Source*: developed and compiled by the authors

The following factors were selected as independent factors: the temperature of the mold (mold) before pouring (X_1); the temperature of pouring the melt into the mold (X_2); and the angular speed of rotation of the mold (X_3). The other factors of the process were fixed at a constant level and accepted as equal constants. Due to the small number of independent factors, a two-level full factorial experiment of type 2^X was used. To determine the levels of variation, independent factors used expert evaluation of technologically acceptable values of factors at the lower and higher levels, obtained from the analysis of technical literature on centrifugal casting of aluminum alloys. Based on the good assessment, the following levels were selected as variation levels: for X_1–150-2500 C; for X_2–670-7500 C; for X_3–155-265 rad/s. Based on the exclusive method of the experiment, an experimental plan was improved, it's seen in the Table 1.

Table 1. The experiment plan

No	Factor level			The numerical value of the factor		
	X_1	X_2	X_3	X_1	X_2	X_3
1	–	–	–	150	670	155
2	+	–	–	250	670	155
3	–	+	–	150	750	155
4	+	+	–	250	750	155
5	–	–	+	150	670	265
6	+	–	+	250	670	265
7	–	+	+	150	750	265
8	+	+	+	250	750	265

As responses to the full factorial experiment, the parameters characterizing the mechanical properties of the resulting castings were selected: the tensile strength (Y_1) and the impact strength (Y_2). The results of experimental studies were processed using the least squares method.

The chemical composition of the aluminum alloy was analyzed using a Rigaku Nex CG x-ray fluorescence analyzer (Applied Rigaku Technologies, Inc., USA) four samples from each series of experiments. The average value of the percentage composition of elements in the alloy is shown in Table 2.

Tensile testing of the samples was produced according to GOST 1497-84 on a testing machine model INSTRON 3382. The impact test was produced at room temperature on standard samples with a U-neck (KCU) according to GOST 9454-78 using a JB-W300 model.

Table 2. The chemical composition of the alloy Ak7ch (AL9)

An object	The content of elements in the alloy, %				
	Al	*Si*	*Mg*	*Cu*	*Fe*
Ak7ch (GOST 1583-93)	89.6–93.8	6–8	0.2–0.4	to 0.2	to 1.5
Ak7ch Casting	91.6	7.2	0.28	0.12	0.86

3 Results and Discussion

During the mechanical tests, results were obtained for each of the presented series of experiments (Table 1). The sample for each series of experiments was at least 4 samples for each type of test. Using data on the average arithmetic values of the tensile strength and impact strength, we made a matrix of experimental responses to mechanical tests (Table 3). This matrix includes input data for building linear models. Using the data obtained using the STATAN application program; we built linear models for the formation of the physical and mechanical properties of castings, taking into account the combined influence of the main process parameters. The adequacy of the obtained models was evaluated using the Fischer criterion (F-criterion), and the statistical significance of the coefficients of the regression equation according to the student's criterion (t-criterion). When analyzing the statistical significance of the constructed linear models, the relative approximation error was additionally estimated (δ, %) and the correlation coefficient (R) with a confidence probability of 0.9. The conditions $F_P \geq F_T$ and $t_P \geq t_T$ are met for all equations, δ does not exceed 4.5%, and R ≥ 0.93, therefore, the constructed models are adequate, and their coefficients are statistically significant.

Table 3. The responses of the experiments of mechanical testing of samples

No series	The numerical value of the factor			The numeric value of the response	
	X_1, °C (T_i)	X_2, °C (T_m)	X_3, *rad/sec* (ω)	Y_1, *MPa* (σ_B)	Y_2, *J/cm*^{2} (*KCU*)
1	150	670	155	183.87	2.05
2	250	670	155	210.70	2.28
3	150	750	155	200.02	2.29
4	250	750	155	182.91	2.44
5	150	670	265	226.18	2.41
6	250	670	265	220.50	2.39
7	150	750	265	215.14	3.04
8	250	750	265	210.70	2.54

$$\sigma_B = -833 + 3.9 \times T_i + 1.43 \times T_m + 2.7 \times \omega - 5.2 \times 10^{-3} \times T_i \times T_m - 1.6 \times 10^{-3} T_i \times \omega$$
$$-3.1 \times 10^{-3} \times T_m \times \omega;\ 150 \leq T_i \leq 250;\ 670 \leq T_m \leq 750;\ 155 \leq \omega \leq 265, \quad (1)$$

$$KCU = 5.8 - 5.05 \times 10^{-3} \times T_m - 3.96 \times 10^{-2} \times \omega - 4.53 \times 10^{-6} \times T_i \times T_m + 2.01 \times 10^{-5} \times T_i$$
$$\times \omega + 5.64 \times 10^{-5} \times T_m \times \omega;\ 150 \leq T_i \leq 250;\ 670 \leq T_m \leq 750;\ 155 \leq \omega \leq 265, \quad (2)$$

Where T_i – initial temperature of the mold (mold), °C;
T_m – the temperature of the poured melt, °C;
ω – angular speed of rotation of the mold (mold), rad/sec.

Graphical analysis of linear models (1) and (2) was used to find rational parameters of the technological process for obtaining castings. In Fig. 2, as an example, the response surface for σ_B is given for a fixed value of the angular rotation speed of the mold ω = 160 rad/sec fixed at the main level.

The response surface σ_B is clearly non-linear with peak values at T_i = 220–250 °C and T_m = 690–720 °C. The response surface of the KCU is more consistent with the linear distribution with the maximum value range of T_i = 230–250 °C and T_m = 670–690 °C, respectively. Considering the general intervals of rational parameters for each response, it is possible to establish rational modes for obtaining castings by the centrifugal method from AK7ch aluminum alloy. The limit values of independent factors are: T_i = 220–250 °C; T_m = 690–720 °C; ω = 210–240 rad/sec.

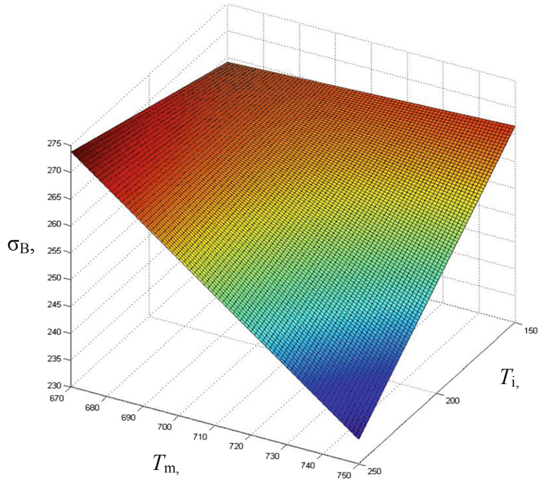

Fig. 2. The response surface $\sigma_{B.}$ *Source*: developed and compiled by the authors

4 Conclusion

The temperature of the poured melt is systematically modifying the physical and mechanical properties of castings, the angular speed of rotation and preheating the mold are constructed. Linear models describing the requirement of the physical and mechanical properties of castings on the main process parameters in technologically justified intervals of their change are constructed. This research results can be used to verify the results of mathematical modeling and develop technological recommendations for the implementation of the process of obtaining castings from aluminum alloys using the centrifugal casting method in real production conditions.

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Fabrication Specifics and Study Results for Metal Items Produced by Surfacing

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Abstract. Purpose: This project aims to determine the additive technology parameters for automatic arc surfacing and their impact on the metal structure and properties in a product.

Design /methodology/approach: Automatic gas-shielded arc surfacing was performed with a modified 3D plasma cutting gantry machine controlled by the Mach 3 software. During surfacing, the welding torch weave pattern was generated by the G codes. The shapes obtained by layer-by-layer surfacing were evaluated by geometry and the analysis of microhardness and microstructure in the wall cross section. The coupons were prepared for microstructure testing with the EcoMet 250 Pro grinder and polisher machine. The microstructure was studied using the Nikon MA200 metallographic microscope; Vickers hardness was measured with the Shimadzu HMV-2 microhardness tester at the indentations with a spacing of 0.5 mm, with each one placed at the center of the rollers with a load of 1.961 N $\approx$ 0.2 kg.

Findings: The article describes the study of metal product fabrication (growth) by the layer-by-layer surfacing technique. The layer-by-layer surfacing technique, various surfacing processes, and selection of the conditions are reviewed. Preparation and analysis of metallographic specimens and the equipment used are described. The main results of metallographic and microhardness tests are listed.

Originality/value: Rectangular shapes are obtained by layer-by-layer growth with automatic arc surfacing on a steel plate using various techniques. The impact of welding torch weave on the geometry, structure, and properties of the welding beads is identified. Recommendations are given on the selection of a specific surfacing technique.

Keywords: Additive technology · Arc surfacing · Structure and properties · Weave · Welding engineering

JEL Code: L61

1 Introduction

Welding engineering has now become a major area of mechanical engineering. High-performance and cost-efficient welding, surfacing, soldering, thermal cutting, and metal

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spraying processes are widespread in production. They help successfully process almost all structural materials with a thickness between dozens of micrometers to several meters.

The variety of structural components to be welded and material properties encourage researchers to develop new fabrication processes for machine parts and workpieces (Sviridov et al. 2017; Evstigneev et al. 2016; Zhu et al. 2010; Zhang et al. 2002, 2003; Hur et al. 2002; Aiyiti et al. 2012; Song et al. 2005).

The use of additive technology makes it possible to produce any product layer-by-layer based on a computer 3D model (Huang et al. 2010; Xiaomao et al. 2011; Kulkarni et al. 2000; Dutta et al. 2001; Jamieson and Hacker 1995).

2 Materials and Method

A welding torch mounted on a 3D manipulator serves as an actuator to weld the beads. Power supply for surfacing was the MIG 3500 (J93) welding inverter with the MS 36 torch. The torch was attached to the manipulator with a specially designed bracket that holds the torch perpendicular to the weld centreline (Fig. 1).

Fig. 1. Diagram of welding torch orientation on machine. *Source*: Images made by the authors.

The Sv-08GA-O copper-coated steel solid wire with a diameter of 1.2 mm was used for surfacing. Surfacing was made with a 10-mm thick steel backing in the down hand position. Three rectangular shapes were welded in three layers. All the shapes were welded continuously in the same conditions:

- amperage $I_{weld} = 215$ to 250 A;
- voltage $U_{eff} = 23$ V;
- surfacing speed: 1,500 mm/min.

A distinctive feature of bead welding is the surfacing technique (weave) shown in Fig. 2. During surfacing, the welding torch was designed to be automatically lifted by the welding bead height when moving to the next bead.

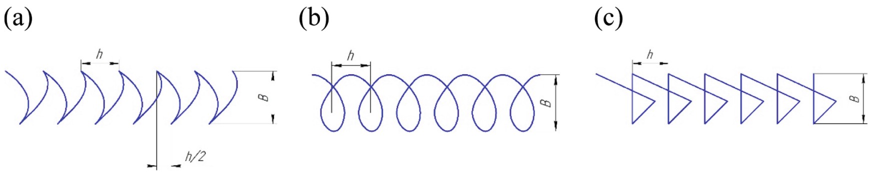

Fig. 2. Weave pattern for shape buildup (a) shape 1; (b) shape 2; (c) shape 3. *Source*: Prepared and compiled by the authors.

Figure 3 shows the appearance of the buildup shapes in the sequence of their welding (indicated by number 1, 2, and 3).

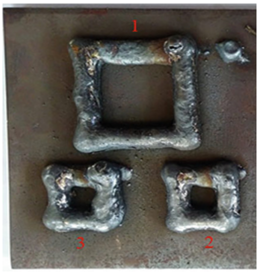

Fig. 3. Appearance of buildup shapes. *Source*: Prepared and compiled by the authors.

Epoxy resin was used to prepare the cross-section coupons of the buildup shapes by filling the special inserts with a diameter of 40 mm. After polishing, the coupons were etched until the structure of the welding beads had been revealed. Etching was performed in a 5% nital solution for two seconds with subsequent rinsing in water and drying with alcohol.

The microstructure was studied using the Nikon MA200 metallographic microscope, and the Kolor Autopano Giga software.

3 Results

Figure 4, 5 and 6 shows the cross-section macrostructure and microstructure of the buildup shapes. The merged structure at 100x magnification (macrostructure) is located at the center of the figure. The microstructure images of the typical areas at 400x magnification (bead 1, 2, and 3; the heat-affected zone; the fusion lines; the base metal) indicated in the macrostructure are placed around the macrostructure image.

This study helped to identify the transition zones between the surfacing layers and the heat-affected zones and determine the structural components in each bead. Analyzing the above, we can conclude that the softer and more ductile coupons are those with a high share of ferrite grains.

The study has shown that the weave pattern during surfacing directly affects the duration of thermal exposure of the preceding surfacing layer and, consequently, the change of the metal structure (Figs. 4, 5 and 6).

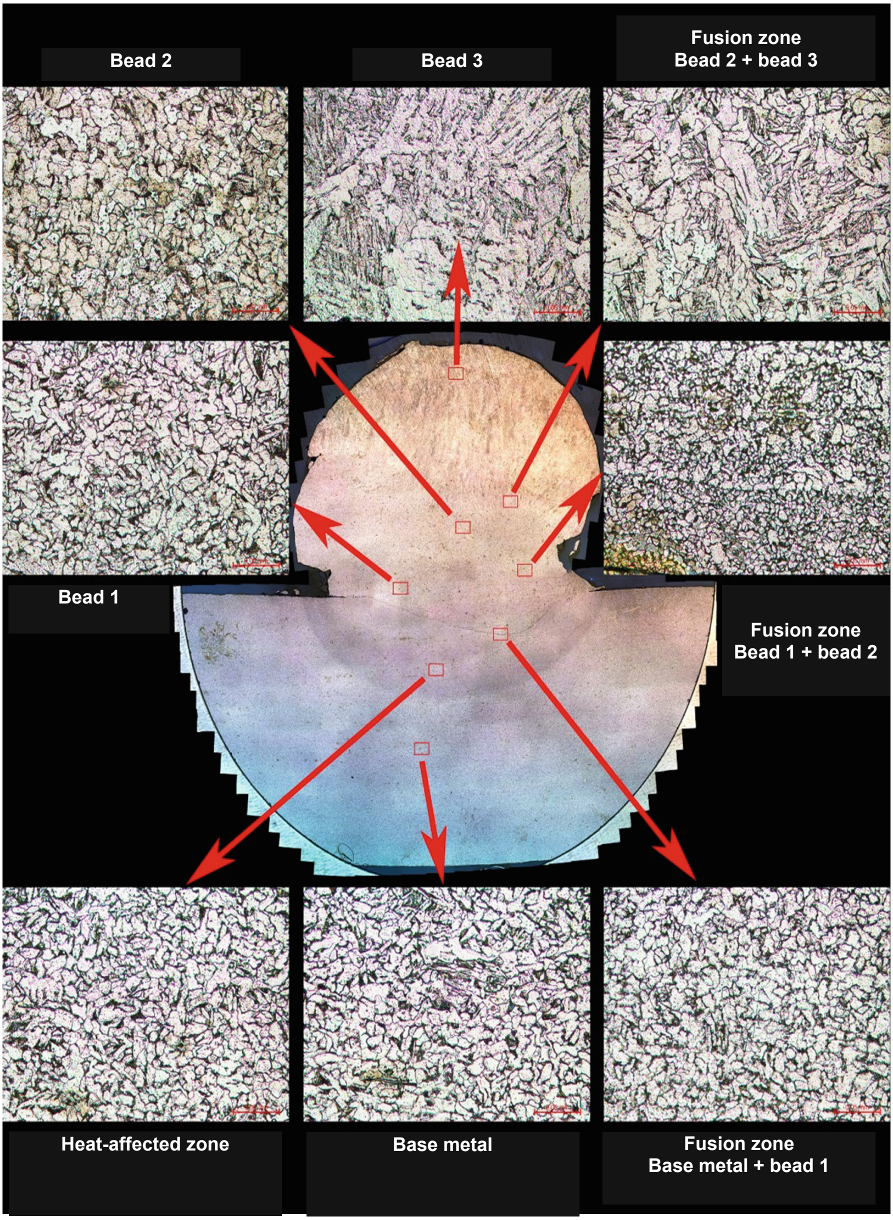

Fig. 4. Microstructure of shape 1. *Source*: Prepared and compiled by the authors.

It is found that the material microstructure is different across the coupon cross section: the upper bead has a larger grain size in the structure compared to the preceding surfacing layers causing coupon hardening and brittleness from the lower layer to the upper one.

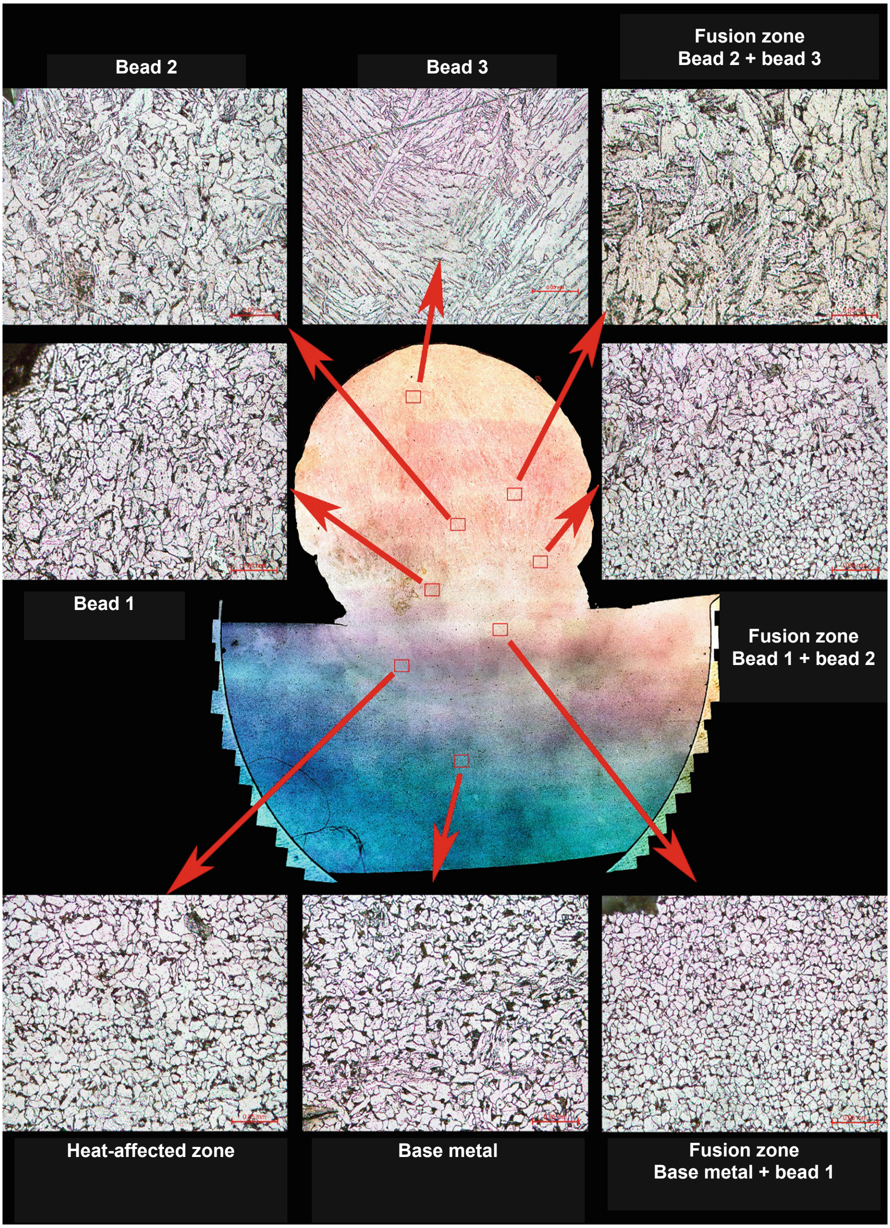

Fig. 5. Microstructure of shape 2. *Source*: Prepared and compiled by the authors.

Based on the microhardness measurements in the coupon cross section, the charts were plotted (Fig. 7) to visually represent the areas of value changes. The resulting charts show that microhardness distribution across the cross section increases from the lower

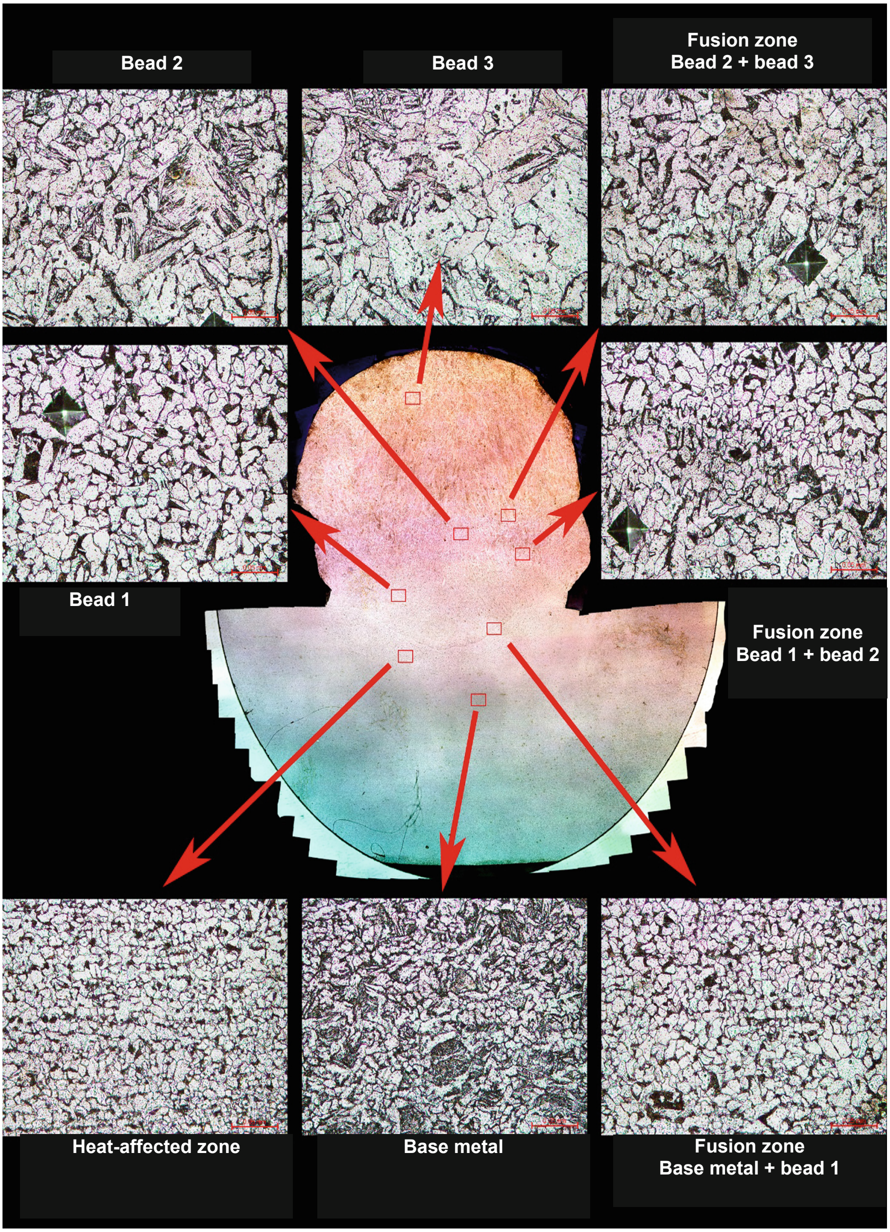

Fig. 6. Microstructure of shape 3. *Source*: Prepared and compiled by the authors.

layers to the upper layers that can be explained by the duration of the thermal exposure of different surfacing layers.

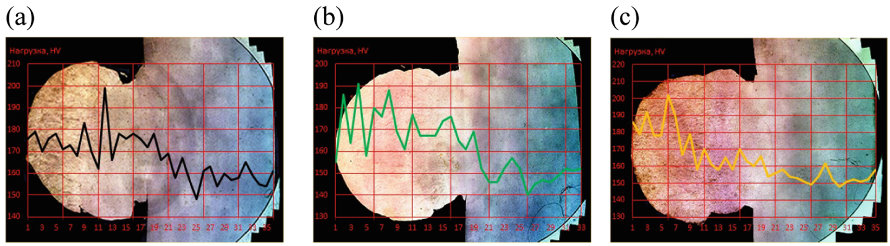

Fig. 7. Microhardness distribution across shape cross section: (a) 1, (b) 2, (c) 3.

The surfacing technique efficiency was assessed by the amount of waste generated when producing a uniform wall. The assessment was performed analytically by processing the buildup shape cross section with the KOMPAS software and cutting off the nonlinear sections of the bead from the most rectangular wall, Fig. 8.

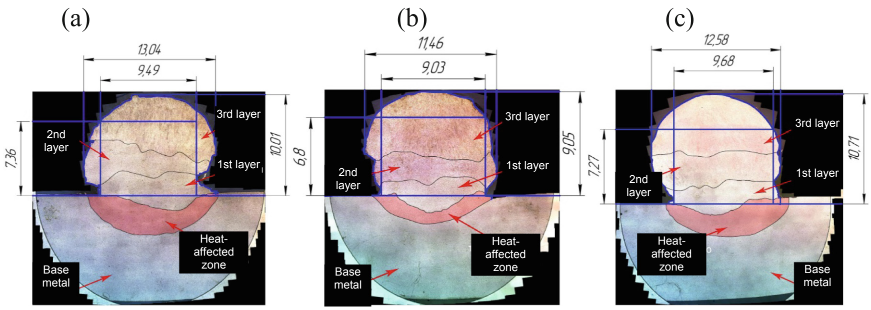

Fig. 8. Surfacing technique efficiency.

The calculation results for the acceptable wall are shown in the table below.

Table 1. Calculation of acceptable wall

Coupon	Waste, %	Total surfacing area size, mm^2	Area size of omitted ele-ments, mm^2	Acceptable wall thickness, mm	Acceptable wall height, mm	Acceptable area size, mm^2
1	34.2	106	36.23	9.49	7.36	69.84
2	37.5	112.6	42.2	9.68	7.27	70.4
3	29.1	86.7	25.23	9.03	6.8	61.46

As Table 1 shows, the coupon produced by the second technique has the largest surfacing area. Despite a quite high amount of waste, it has the maximum acceptable cross-section area size characterized by higher wall thickness and height.

In general, for the same welding parameters, the bead technique certainly affects the volume of the filler metal. The weave pattern changes the total travel speed and affects the boundary blurring of the bead welded.

The higher the volume of the filler metal, the greater the percentage of waste, that is, the more metal needs to be machined when forming straight walls.

4 Conclusion

The following conclusions can be drawn from these studies:

1. The project studied the workpiece growing process by layer-by-layer surfacing. The layer-by-layer surfacing technique was reviewed. Metallographic specimens were prepared and subsequently analyzed for microstructure and microhardness. The structural pictures of the coupons and the microhardness charts showing the effects of the surfacing process were generated.
2. The study has shown that the weave pattern during surfacing directly affects the duration of thermal exposure of the preceding surfacing layer and, consequently, the change of the metal structure.
3. It is found that the material microstructure is different across the coupon cross section: the upper layer of the bead has a larger grain size in the structure compared to previous surfacing layers causing coupon hardening and brittleness from the lower layer to the upper one. The strength across the part cross section will fluctuate, which may be attributed to the deficiencies of the coupon fabrication process.
4. Microhardness distribution across the cross section was shown to increase from the lower layers to the upper layers that may be explained by the duration of the thermal exposure of different surfacing layers.
5. It was shown that, when fabricating the workpieces, an increase in the heat-affected zones depending on the surfacing process and a considerable change in the metal structure across the part cross section and a higher machining complexity of the final part should be considered.
6. The triangle weave pattern is more practical during surfacing, as it requires less post-processing of the completed product, and the weld is wider, respectively, the wall thickness in the product is higher.

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High Productivity Turning of Stainless Steel 06Cr14H6Cu2MoNbTi

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Abstract. Purpose: The purpose hereof is improving the efficiency of turning stainless steel parts using high-performance equipment.

Design/methodology/approach: Stainless steel 06Cr14H6Cu2MoNbTi is used as work material. This type of steel is used in aerospace industry to manufacture glider bearing frame parts. Material chemical composition and performance characteristics are analyzed. Issues that negatively affect turning process and lead to high part production cost are specified. Experimental studies were performed on a turning machining center with computer numerical control (CNC). Turning cutters with inserts of hard material with protective coating were used as a cutting tool. The inserts were of different geometrical parameters. CVD- and PVD-coated inserts were used. Output turning parameters such as cutting forces and temperature were measured. Cutting forces were measured with a three-component dynamometer. Cutting temperature was measured with a thermal camera. Process productivity and cutting power were calculated.

Findings: experimental functional connections between cutting power and performance were obtained. They allow determining cutting data which minimize specific power consumption per a unit of removed material. Experimental functional connections between cutting area temperature and productivity obtained when variating different turning parameters allow determining cutting data, which ensure set productivity at the least heat release.

Originality/value: Recommendations on cutting tool choice and cutting data purpose were given for development of stainless-steel turning processes at actual production. The course of further studies aimed at improving the efficiency of high-performance SS part machining was determined.

Keywords: Stainless steel · Turning · Cutting power · Productivity · Cutting temperature

JEL Code: L61

1 Introduction

Operational processes in modern plants and machines occur with a significant load on all structural elements. Part operation at high speed, pressure and temperature results

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in quick destruction of elements made of usual constructional steels. Such conditions require special alloys. These alloys include stainless steel. Such properties as corrosive resistance, high strength, plasticity, non-magnetization, good mechanical properties at high temperatures, good weldability and other properties made these metals the most suitable for various items in all areas of human life (Poduraev 1974).

However, alloying agents giving these steels their properties also complicate machining.

The following issues should be considered when machining stainless steel:

1) strain hardening;
2) limited tool life;
3) chip removal;
4) chemical element influence on workability.

When cut, the alloy is strained elastically and machined. Then it quickly goes into the hardening stage. At this stage cutting can only be performed using significant force (Stroshkov et al. 1977).

Low thermal conductivity of stainless steel is its advantage during service, but it is a drawback during machining. Temperature rises significantly in the cutting area, which can lead to strain hardening. This is why temperature control in the cutting area is a relevant issue (Reznikov 1973).

Stainless steel retains its strength and hardness even at high temperatures. These properties combined with strain hardening do not allow machining at high speeds (Tumorsha 2010). Friction during stainless steel machining is significantly higher than during similar operations with carbon steels.

Using modern equipment such as turning machining centers and high-productivity cutting tools with novel design and optimized geometry is not enough to achieve the productivity in line with the best world standards. Taking into account the above-mentioned stainless steel machining issues, achieving maximum efficiency of turning for a specific process system is possible on the basis of studies aimed at determination of cutting modes ensuring high material removal speed with little power consumption and guaranteed quality of machined parts which is noted in the papers Vereschaka et al. (2018), Belhadi et al. (2005), Karaguzel et al. (2017), Serebrennikova et al. (2018), Jagadesh and Samuel (2014), Savilov et al. (2018), Mavliutov and Zlotnikov (2018).

The goal hereof is improving stainless steel 06Cr14H6Cu2MoNbTi turning performance on high performance machine tools using a novel cutting tool.

2 Materials and Method

Stainless steel 06Cr14H6Cu2MoNbTi is the material under study. It is alloyed steel, resistant to corrosion both in the atmosphere and in aggressive media. Its main chemical element is chromium (Cr). It is the main reason for its corrosion resistance. Stainless steel contains other alloying elements aside from chromium (Ni, Mn, Ti, Nb, Co, Mo) which give it useful physicomechanical properties as well as corrosion resistance.

Steel 06Cr14H6Cu2MoNbTi is a corrosion-resistant maraging steel. It is recommended for load-carrying airplane parts (parts manufactured from punching's, forgings, extrusion profiles) operating at temperatures −70 °C to +300 °C in general climatic conditions and in contact with fuel.

As a workpiece, a bar with a dimeter of 50 mm was employed in the experiment.

The CNC DMG NEF 400 turning center was used in the experiment. Turning was performed without removing the work piece from the center during turning mode change, which allowed maintaining location and positioning accuracy.

Two turning cutters with inserts of hard material DCLNL 2020K 12 and SDJCL 2020R 11 (Fig. 1) were used as cutting tools.

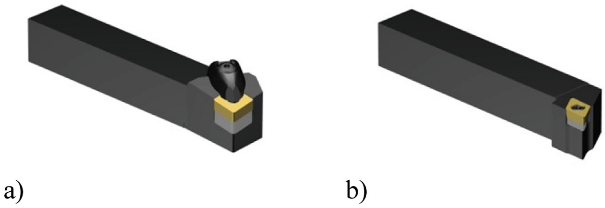

Fig. 1. Turning cutters: (a) is DCLNL 2020K 12; (b) is SDJCL 2020R 11. *Source*: developed and compiled by the authors

DCLNL 2020K 12 used inserts CNMG 12 04 08 MM 1115 and CNMG 12 04 08-MM 2025 (Fig. 2). The inserts have the following geometry: nose angle 80°, relief angle 0°.

Fig. 2. Inserts for tool holder DCLNL 2020K 12: (a) is CNMG 12 04 08 MM 1115; (b) is CNMG 12 04 08 MM 2025

SDJCL 2020R 11 used inserts DCGT 11 T3 04 UM 1115 and DCMT 11 T3 08-MM 2025 (Fig. 3). The inserts have the following geometry: nose angle 55°, relief angle 7°. *Source*: developed and compiled by the authors.

Fig. 3. Inserts for tool holder SDJCL 2020R 11: (a) is DCGT 11 T3 04-UM 1115; (b) is DCMT 11 T3 04-MM 2025

Inserts have different types of coatings. Inserts CNMG 12 04 08 MM 1115 and DCGT 11 T3 04-UM 1115 have PVD TIALN + ALCR2O3, and inserts CNMG 12 04 08 MM 2025 and DCMT 11 T3 04-MM 2025 have CVD TICN + AL2O3 + TIN.

Source: developed and compiled by the authors.

The experiment evaluated the following output process parameters: turning productivity Q, cutting power P_c, cutting force $P_{x,y,z}$.

Dynamic force analysis method was used during the experiment. Cutting forces $P_{x,y,z}$ were measured by a three-component dynamometer Kistler 9129AA (Garg et al. 2016). Method of specific power consumption during material removal was used (Kara and Li 2011).

Material removal rate or productivity Q is the volume of material removed for a specific period of time, measured in cm^3/min and calculated by formula:

$$Q = a_p \times V_c \times f_n,$$

where a_p is cutting depth, mm;

V_c is cutting speed, m/min:

f_n is feed, mm/revolution.

Cutting power P_c is calculated by formula:

$$P_c = (P_t \times V_c)60 \cdot 10^3,$$

where P_t is the tangential component of cutting force, N.

The main component of cutting force P_y acts in the cutting plane in the main cutting movement direction by y axis for turning machine. This is why calculations used this cutting force detected by a dynamometer as P_t (Table 1).

Table 1. Cutting data

Insert	Cutting data		
	f_n, mm/revolution	V_c, m/min	a_p, mm
CNMG 12 04 08 MM 1115	0.1, 0.2, 0.3	140, 160, 170, 180, 200	1.5, 2.5, 3.5
CNMG 12 04 08 MM 2025	0.2, 0.3, 0.4	55, 80, 120, 140, 160, 180	1.5, 2.5, 3.5
DCGT 11 T3 04-UM 1115	0.1, 0.2, 0.3	120, 140, 160, 180, 200, 220	1.5, 2, 2.5
DCMT 11 T3 04-MM 2025	0.1, 0.2, 0.3	120, 140, 160, 180, 200, 220	1.5, 2, 2.5

Thermal control method using camera FLIR SC7000 was used to measure cutting temperature.

3 Results

The functional connections obtained in the course of experimental analysis are given in Fig. 4, 5, 6, 7, 8 and 9.

Figure 4 shows functional connections of cutting power P_c from productivity Q at changing cutting speed V_c using inserts CNMG 12 04 08 MM 1115 and CNMG 12 04 08 MM 2025. Feed $f_n = 0.2$ mm/revolution, cutting depth $a_p = 2.5$ mm. The connections are linear. CNMG 12 04 08 MM 1115 provides higher productivity. Power consumption is directly related to productivity for both types of inserts.

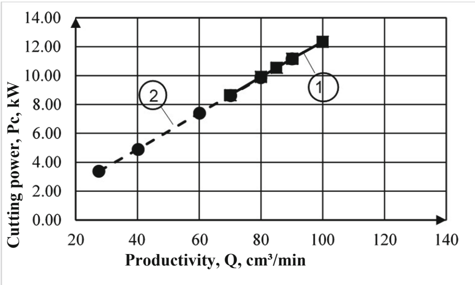

Fig. 4. Diagram of functional connection between cutting power P_c and Productivity Q when Changing Cutting Speed V_c: Curve 1 is CNMG 12 04 08-MM 1115, Curve 2 is CNMG 12 04 08-MM 2025. *Source*: developed and compiled by the authors

Figure 5 shows the connection between cutting power P_c and productivity Q when changing feed f_n. CNMG 12 04 08 MM 1115: cutting power $V_c = 170$ m/min and cutting depth $a_p = 2.5$ mm. CNMG 12 04 08 MM 2025: cutting power $V_c = 80$ m/min and cutting depth $a_p = 2.5$ mm.

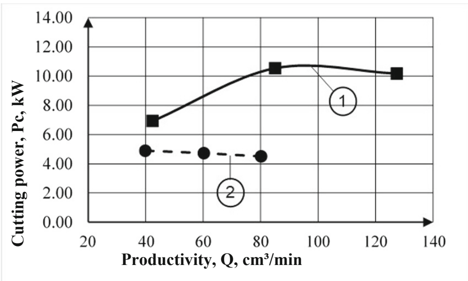

Fig. 5. Diagram of functional connection between cutting power P_c and Productivity Q when Changing Feed f_n: Curve 1 is CNMG 12 04 08-MM 1115, Curve 2 is CNMG 12 04 08-MM 2025. *Source*: developed and compiled by the authors

It is obvious that CNMG 12 04 08 MM 1115 provides higher productivity due to higher cutting speed, but cutting power at efficiency ≈130 cm^3/min is 10 kW; whereas, productivity 100 cm^3/min corresponded to 12 kW in the previous experiment. CNMG 12 04 08 MM 2025 with CVD coating shows the best power consumption parameters in the limited productivity mode 40–80 cm^3/min.

Figure 6 shows the connection between cutting power P_c and productivity Q when changing cutting depth a_p. CNMG 12 04 08 MM 1115: cutting speed $V_c = 170$ m/min and feed $f_n = 0.2$ mm/revolution. CNMG 12 04 08 MM 2025: cutting speed $V_c = 160$ m/min and feed $f_n = 0.2$ mm/revolution. In this case both inserts have close productivity values and CNMG 12 04 08 MM 2025 shows an insignificant advantage in power efficiency.

Similar connections were obtained when turning with DCGT 11 T3 04-UM 1115, DCMT 11 T3 04-MM 2025.

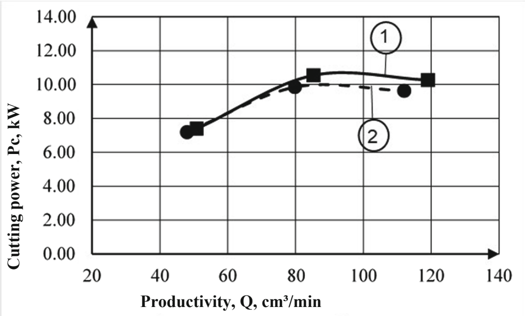

Fig. 6. Diagram of functional connection between cutting power P_c and Productivity Q when Changing Cutting Depth a_p: Curve 1 is CNMG 12 04 08-MM 1115, Curve 2 is CNMG 12 04 08-MM 2025. *Source*: developed and compiled by the authors

Figure 7 shows the connection between cutting power P_c and productivity Q when changing cutting speed V_c. Feed $f_n = 0.2$ mm/revolution and cutting depth $a_p = 2$ mm. Efficiency and cutting power are almost the same for both inserts and have a connection which is close to being linear.

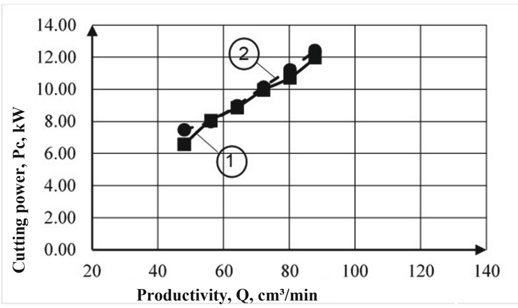

Fig. 7. The diagram of a functional relationship between Cutting Power P_c and Productivity Q when varying Cutting Speed V_c: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, and Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors.

Figure 8 presents the relationship between cutting power P_c and productivity Q when varying feed f_n. Cutting speed is $V_c = 160$ m/min and cutting depth is $a_p = 2$ mm.

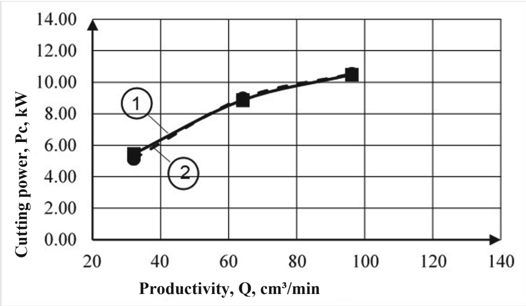

Fig. 8. The diagram of a functional relationship between cutting power P_c and productivity Q when varying Feed f_n:Vc: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, and Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors

It was identified that the cutting productivity and the cutting power are similar for both inserts. However, when increasing feed, specific cutting power increases (the similar increase was observed during the previous experiment). Productivity of 90 cm^3/min was observed at 10 kW; in the previous experiment, cutting power was equal to 12 kW.

Figure 9 presents the relationship between cutting power P_c and productivity Q when varying cutting depth a_p. Cutting speed is $V_c = 200$ m/min and feed is $f_n = 0.2$ mm/revolution. The relationship is different from the one in the previous experiment. It is linear for DCGT 11 T3 04-UM 1115 insert. Specific power decreases with an increasing efficiency for DCMT 11 T3 04-MM 2025 insert.

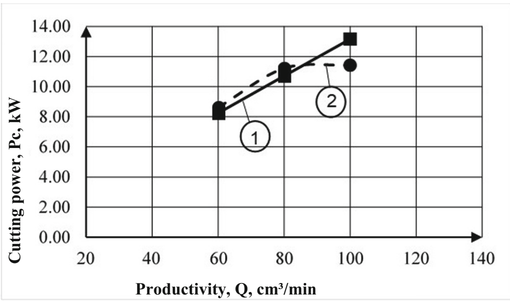

Fig. 9. The diagram of a functional relationship between cutting power P_c and Productivity Q when varying Cutting Depth a_p: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, and Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors.

Figures 10, 11, 12, 13 and 14 present the relationships between the temperature of the cutting area and productivity Q.

The relationships can be employed to determine permissible cutting parameters for each type of inserts during cutting area heat generation and check whether they are able to ensure required mechanical properties of parts.

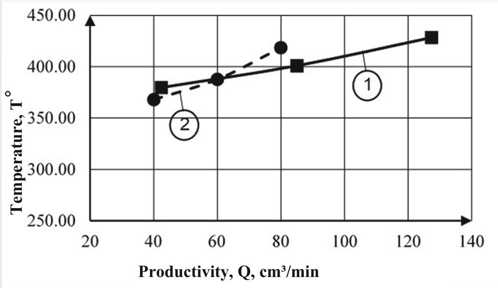

Fig. 10. The diagram of a functional relationship between temperature of the cutting area and productivity Q when varying Feed f_n: Curve 1 corresponds to CNMG 12 04 08-MM 1115 insert, and Curve 2 corresponds to CNMG 12 04 08-MM 2025 insert. *Source*: developed and compiled by the authors

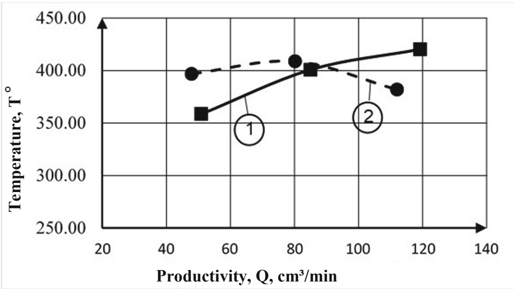

Fig. 11. The diagram of a functional relationship between temperature of the cutting area and productivity Q when varying Cutting Depth a_p: Curve 1 corresponds to CNMG 12 04 08-MM 1115 insert, and Curve 2 corresponds to CNMG 12 04 08-MM 2025 insert. *Source*: developed and compiled by the authors.

Inserts of different geometry covered with different coatings have different temperatures under different cutting modes (Mokritskii et al. 2017). In some cases, optimums can be determined. However, it is impossible to determine efficient insert designs and coating types due to the minimization of cutting area temperatures. It was identified that DCGT 11 T3 04-UM 1115 inserts and DCMT 11 T3 04-MM 2025 inserts can ensure maximum productivity.

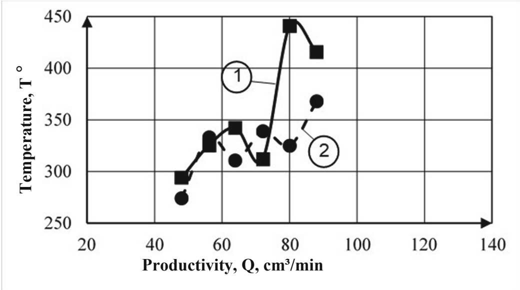

Fig. 12. The diagram of a functional relationship between temperature of the cutting area and productivity Q when varying Cutting Speed V_c: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, and Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors

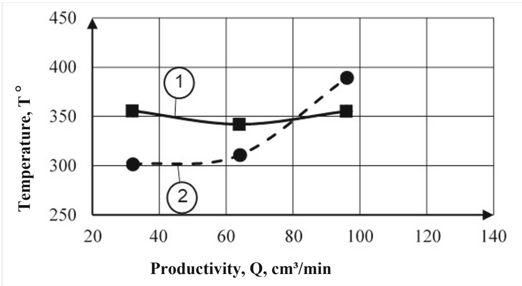

Fig. 13. The diagram of a functional relationship between temperature of the cutting area and productivity Q when varying Feed f_n: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, and Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors

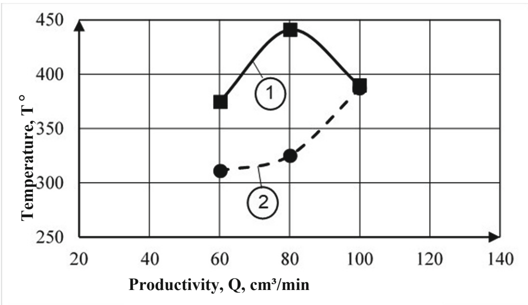

Fig. 14. The diagram of a functional relationship between temperature of the cutting area and productivity Q when varying Cutting Depth a_p: Curve 1 corresponds to DCGT 11 T3 04-UM 1115 insert, Curve 2 corresponds to DCGT 11 T3 08-MM 2025 insert. *Source*: developed and compiled by the authors

4 Conclusion

The following conclusions can be made:

1. The functional relations between cutting power and productivity allow for selection of cutting data that are optimal and can minimize the specific power consumption for material removal;
2. Increasing machining productivity by increasing tool feed is the best way of improving efficiency.
3. Inserts with CVD coating ensure higher power efficiency when turning stainless steel than inserts with PVD coating in some cases.
4. The impact of varying geometric parameters of inserts for tool holders DCLNL 2020K 12 and SDJCL 2020R 11 on output turning parameters is minimal and can be neglected when selecting a tool;
5. Coating type influence on cutting area temperature is ambiguous and requires additional studying.

The results obtained can be employed in turning process development for stainless steel 06Cr14H6Cu2MoNbTi parts in actual production conditions. Further studies may be devoted to cutting mode impact on residual stresses in a machined part (Nikolaeva and Mashukov 2017).

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Gantry Technology in Agriculture Greening

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Abstract. Purpose: the systems analysis study of the modern agricultural technologies is aimed at identifying the optimum approaches to solving the problems of excessive soil compaction and creating conditions for robotic automation of agriculture.

Design/methodology/approach: a considerable portion of technical solutions in this sphere are related to controlled traffic options, which are represented by extended-axle tractors. Work is in progress for engineering of wide-span tractors, such as the Swedish BIOTRAC, David Dowler's gantry tractor, wide-span tractors produced in Israel, Australia, and other countries. However, these innovations do not solve the issues of maneuver and cross-country capability, precision agriculture problems, etc., which reduces the prospects of their large-scale application in production.

Findings: in this paper, we propose to consider one of the gantry agriculture options. It consists of three units: an automotive gantry platform, a process module, and a specially equipped ground. The platform is represented by a structure with the dimensions of approximately 10 × 10 m made of metal T-pieces; it has hollow side members which house rail beams; these rail beams move in increments of 10 m and are laid on the concrete supports of the ground; the platform moves along these rail beams and carries out process operations.

Originality/value: the capacity of such system is about 3–4 ha/hour. One such plant will provide for cropping within an area of 1.5–2 thousand hectares per growing season. Rigidity of the gantry platform support system solves the problems of precision agriculture, as well as accurate and timely implementation of the cultivation procedure at a high level of environmental friendliness and with significant energy cost reduction.

Keywords: Agricultural gantry system · Compaction · Soil · Tramline

JEL Code: Q10

1 Introduction

Increasingly greater attention has been paid in the recent years to agriculture greening with ensuring environmental-friendliness and minimization of the adverse impact on the environment in the course of soil treatment, sowing, and harvesting of crops, while

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reducing energy costs. In agriculture, soil is considered as the object and instrument of labor, but at the same time, it is the basic component of the biosphere and is crucial for the existence of life on Earth. Therefore, any anthropogenic alterations should prioritize preserving the ecological functions of soils and soil cover, as well as soil conservation and soil fertility improvement.

The fertility level is strongly influenced by the activity of the soil biota (bacteria, protozoa, arthropods, earthworms, etc.).

Soil bacteria activity results in soil enrichment with organics and important nutrients, P, S. CaK, as well as C and N in moldy substances. Under favorable conditions, soil bacteria and fauna (animal life) occupy the whole interaggregate pore space of the soil. Protozoa, rotifers, and small nematodes inhabit capillary water; bugs (mites, springtails, etc.) live in the spaces between soil particles; bigger faunal forms (earthworms, various insects, burrowing vertebrates) burrow holes there. 1 m^2 of soil can house from a dozen to several hundreds of bigger invertebrates (earthworms, myriapods, bug larvae, etc.). Many nematodes amounts to dozens and hundreds of thousands in each gram of soil; up to 200 billion of individual protozoa represented by various bacteria can occupy 1 $m^3$of soil, which is pointed out in the book by Babyev et al. (1989).

Earthworms whose mass amounts to 4–5 thousand kg/ha (according to Zharikova 2005; Chernikov et al. 2000) make the major contribution to the soil zoomass, along with mites, springtails, nematodes, etc.

Soil bacteria and animals facilitate soil fertility through transforming the mineral part of soils, soil water and air, as well as dead roots and green matter of plants and animals in the course of their life processes. During their life, soil inhabitants mix up various soil layers, dragging down various substances; cause mechanical damage to plant tissues (especially roots); degrade and mineralize leaf litter and dead organisms; produce biologically-active substances, initiating the growth of plant roots; burrow holes, which facilitates improvement of temperature conditions as well as water and gas composition of the soil.

Intense activity of soil bacteria and fauna requires ample water and air. Soil air contains (in percent by volume) carbon dioxide (0.3%–10%), oxygen (1.0%–20%), and nitrogen (78%–80%), which are essential for soil biota and plants. Deficiency of air in the soil creates anaerobic conditions, which causes lack of oxygen for root respiration and life processes of aerobic bacteria and fungi; this also leads to accumulation of insufficiently oxidized organic compounds (which are toxic for most higher plants), as well as hampers mineralization of organic substances, as noted by Yeliseyeva (2020). The normal composition is maintained through air exchange enabled by capillary and—to a greater extent—non-capillary soil porosity.

Soil water is instrumental to soil biota life processes and soil fertility. Soil water conditions determine the soil processing properties, and operating efficiency of tillage and other agricultural machinery. Plants use soil water for producing organics during photosynthesis; they use it as a means for transporting nutrients from the soil to the green matter; soil water is also used for dissolving inorganic compounds as well as in a number of other physiological processes.

Disturbance of air and water conditions inhibits functioning of the soil biota, as well as growth and development of roots and cultivated plants. This leads to deterioration of soil processing properties. Soil overdrying lowers the treatment quality, while waterlogging degrades the cross-country capability of machinery, as well as quality of basic cultivation and other agricultural operations.

2 Materials and Method

Soil compaction resulting from human impact is the root cause of air and water condition disturbance and, consequently, diminishing of soil fertility. Agricultural machines and technologies play the major role in this process.

Current agricultural issues are mainly solved through the use of high-performance machinery and intensive technologies.

Increase in agricultural machinery performance is usually related to increase in its weight, and intensive technologies imply repeated treatment, which causes significant compaction of the soil in the course of cropping.

The weight of MTZ-80 wheel tractors, which were most commonly used in the middle and at the end of the last century, was 2.9 t, while the weight of modern K-701 tractors is 7.9 t. Specific soil pressure from the running gear for these tractors is 1.2 and 2.5 kg/cm^2 respectively. The soil density after one pass of MTZ-80 tractor is 1.32 g/cm^3, and compaction after a pass of K-701 tractor is 1.42 g/cm^3. The data were taken from the paper by Kamnin (2020).

Implementation of intensive technologies is, to a considerable extent, ensured by repeated (up to 4–8 times) soil treatment; as a result, the density increases to the critical values of 1.65–1.70 g/cm^3, with significant reduction in soil porosity (by 40%), as noted by Kamnin (2020), Zakharov et al. (2020). This creates extremely unfavorable air and water conditions for soil biota, with activation of anaerobic processes and formation of protoxidic chemical compounds which are harmful to the majority of higher plants; water permeability of the root layer drops; soil structure is damaged, and the humus is subject to dispersion and other types of intense erosion, causing soil exhaustion.

The problem of reducing compaction of soils by machinery was first addressed at the end of the 19th century, when the first agricultural machinery was put into operation in the fields. This was a plough engineered by Max Eyth; it could be moved across the field by means of a steam-driven cable-winch: Zaytsev et al. (2020). Later, in the nineteen-thirties, agricultural gantry system designs by Pravotorov and other authors appeared: Chernyshev et al. (2020).

Nowadays, the issue of reducing compaction of soils by agricultural machinery is approached from different angles. The key focus areas are as follows:

- options for redesigning the running gear (wheeled running gear, tracks) of tractors and combine harvesters through increasing their soil contact area by using twin and triple wheels, extra-low-pressure tires, pneumatic tracks, etc.: Chamen et al. (2020), Zhalbin et al. (2020);
- various redesign options for tractors, to provide for their running along the tramlines, Burlak (2020);
- gantry systems, which, in our opinion, should be considered as a revolutionary approach to agricultural machinery development.

A considerable portion of gantry structures proposed do not exactly correspond to their name (for example, David Dowler's gantry tractor, the Swedish BIOTRAC, etc.), since a gantry, according to the classical definition, is a structure having such integral parts as supports (piers, abutments) and spans, while the mechanisms proposed have no proper fixed supports for the process module running. Wheels of these machines cause significant soil compaction; the systems are extremely unstable and can hardly solve agriculture precision problems; they have a lot of other shortcomings (poor cross-country capability, wide headland, etc.).

The following systems can be classified as gantry systems: Yunitskiy's bridge and AMAK engineered by Yu. N. Zhukov. However, the string bridge by Yunitskiy requires considerable expenses for mast arrangement and has other shortcomings. AMAK gantry is, in fact, an agricultural plant supported by a railway track; it provides high degree of environmental friendliness, possibility of robotic automation, and other advantages. High cost of its construction and operation, high material consumption, as well as special evenness-of-terrain requirements reduces the prospects of implementation for this project.

3 Results

The gantry system we propose to consider in this paper provides a number of radically new design solutions. It consists of three units:

– a specially equipped ground, automotive gantry platform traveling along extension rail beams which are supported by reinforced-concrete pads; and the third unit is an automated process module with a set of working attachments.

The schematic diagram showing the layout and movement of the system is provided in Figs. 1 and 2.

The ground (the piece of land under cultivation) should be of relatively level. It is rice lands that meet such requirements more than other lands. According to Burlak, the area of such lands (provided that land-improvement activities are carried out) in Primorye and the Amur River basin within the Far Eastern Federal District is over 420 thous. ha; moreover, hundreds of thousands of hectares of similar lands are currently used for planting soybeans as well as cereal and forage crops in the farms of the region. The ground for gantry farming (Fig. 1) is a rectangular piece of land bounded by roads. The roads (1) are used for transport purposes as well as for platform (2) shifting to the next field section; road dead ends (3) are used for platform movement to side roads and further performance of works when check-row technologies are applied for cultivation of potatoes, vegetables, and other crops. Supports (4) represented by reinforced-concrete blocks (slabs) with the dimensions of $1.0 \times 1.0 \times 0.30$ m laid on gravel-pebble beds are spaced in a square pattern at the intervals of 10 m. They are higher (thicker)—at least 35 cm, i.e. bund height—in the fields used for rice cultivation.

The gantry platform (Fig. 2) is a square structure with the dimensions within 10 m.

1. Longitudinal Hollow Beams; 2. Rail Beams; 3. Vertical Hydrocylinders; 4. Horizontal Hydrocylinders; 5. Rail Beam Rollers; 6. Flanges of Longitudinal Hollow Beams;

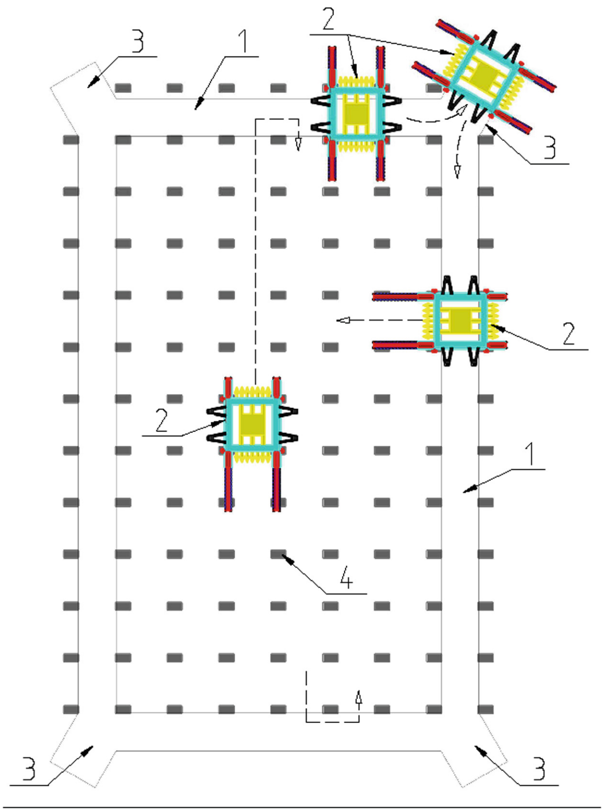
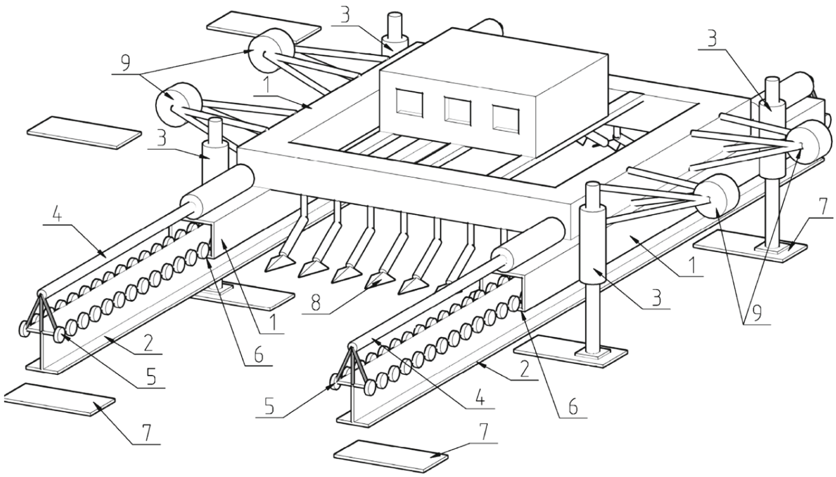


Fig. 1. Ground diagram. 1—Road between the fields. 2—Gantry platform. 3—Road dead end for turning. 4—Concrete supports. *Source*: developed and compiled by the authors.

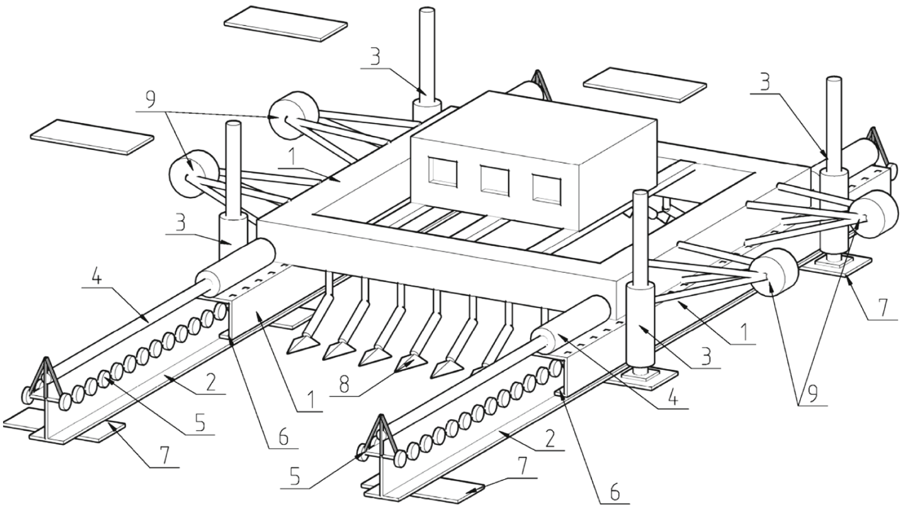
7. Concrete Supports; 8. Working Attachments; 9. Wheels for Turning the Platform. *Source*: developed and compiled by the authors.

The longitudinal hollow beams (1) of the platform house rail beams (2) which are pushed along the flanges (6) to the next supports (7) by means of horizontal hydrocylinders (4) and rollers (5) when the platform is in raised position (Position 1, Fig. 2) (the raising is performed by means of vertical hydrocylinders (3)).

Then, the action of the vertical cylinders (3) is neutralized (Fig. 2, Position 2), and the platform together with the power-and-process module descends by gravity to the rollers (5) of the rail beams (2) whose lower T-sections are lowered onto the concrete blocks of the supports (7). After that, the horizontal hydrocylinders (4) are put into operation to move the process module (platform) on the rollers (5) of the rail beams (2) which rest on the supports, with the module performing the required process operation by means of its working attachments (8).



Position 1



Position 2

Fig. 2. Gantry platform layout

4 Conclusion

Thus, the agricultural gantry system under consideration causes practically no compaction of the cultivated layer of soil. The concrete supports provide for good cross-country capability in any weather. Rigidity of the platform structure with the process module and their traveling along metal beams resting on concrete blocks provide for precision in the performance of the required process operations, as well as efficiency and reliability of the robotic systems, and high level of greening in agriculture.

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Demercaptanization of Straight-Run Kerosene Fraction According to "Demerus Jet" Technology

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Abstract. Purpose: This paper shows the practical significance of the "Demerus Jet" catalytic demercaptanization process which is designed to produce a kerosene fraction with a mercaptan sulfur content of less than 30 ppm from ESPO sour crude oil at refineries in the Far East.

Methodology: The main industrial processes of fuel purification from mercaptans were considered, such as Merox, Menalk (developed by the American company UOP), Mericat (merichem Co) and others. The essence of all these processes is the oxidation of mercaptans to disulfides by molecular oxygen in the presence of catalysts.

Findings: Optimal parameters of static and dynamic equipments and selected heat exchange equipment are calculated for the basic technological scheme "Demerus Jet" of demercaptanization of kerosene fraction. Calculated payback period of the proposed installation with a capital investment of 40 million rubles is three years.

Value: We believe that the technology "Demerus Jet" is easy to implement and maintain, reliable, capital and operating costs lower than hydrotreating. An environmental advantage is the absence of sulfur-alkaline effluents and exhaust air.

Keywords: Demercaptanization · Kerosene fraction · Sweetened kerosene · Mercaptan sulfur · Catalyst · Promoter

JEL Code: O33

1 Introduction

According to the content of oil thiols, oils are divided into mercaptane and non-mercaptane. Thiols (mercaptans) are mainly concentrated in light fractions of oil, where their content can vary from 40 to 70–75% of the total number of sulfur compounds. Currently, more than 50 different mercaptans with the number of carbon atoms in the molecule from 1 to 8 have been found in oil. There are more than 40 alkyl thiols, in which the H–S group is in most cases found in the secondary and tertiary and much less often in the primary atom of the carbon skeleton of the molecule.

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Mercaptans are corrosive components that accelerate the processes of oxidation and resin formation. Their presence in jet fuel contributes to the formation of carbon deposits and varnish deposits on engine parts, precipitation in fuel tanks and reservoirs.

There are various options for removing mercaptans from kerosene fractions (in particular, the process of hydrodemercaptanization at low pressure of hydrogen-containing gas (Nikitin et al. 2014), however, one- and two-stage (depending on the composition of the hydrocarbon raw materials, the amount and type of mercaptans present in it) heterogeneous and homogeneous processes of oxidative catalytic demercaptanization are used more often in the world and domestic practice (Zorin et al. 2009; Podlesnova et al. 2019; Asatryan et al. 2020).

2 Methodology

Lets review the main industrial processes of fuel purification from mercaptans such as Merox, Menalk (developed by the American company UOP), Mericat (merichem Co), and others (Manovan 2001). The essence of all these processes is the oxidation of mercaptans to disulfides by molecular oxygen in the presence of catalysts (Ismagilov et al. 2020; Shcherbachenkoet al. 1979). The most active and widely known catalysts for the oxidation of sulfur compounds of petroleum distillates are phthalocyanines of metals with variable valence (Sharipov et al. 1998; Samokhvalov et al. 1998). The content of total sulfur in the raw material does not change, but the chemical form of sulfur changes: toxic, corrosive, and foul-smelling mercaptans are converted to inert disulfides:

in one stage

$$2RSH + 0,5O_2 \rightarrow RSSR + H_2O \tag{1}$$

or in two stages

$$RSH + NaOH \rightarrow RSNa + H_2O \tag{2}$$

$$2RSNa + 0,5O_2 + H_2O \xrightarrow{Kt} RSSR + 2NaOH \tag{3}$$

In the MERICAT FIBER-FILM process, an alkaline solution containing a homogeneous catalyst (an aqueous-alkaline solution of cobalt phthalocyanine) and air is used to oxidize mercaptans to disulfides in a gasoline medium. The MERICAT II FIBER-FILM process is used for cleaning kerosene and/or jet fuel. It uses a heterogeneous catalyst (cobalt phthalocyanin on a solid carrier) in combination with purification in a layer of activated carbon saturated with the same catalyst. In the presence of cobalt phthalocyanine, mercaptans are rapidly oxidized at low temperatures (25–50 °C) (Lastovkin et al. 1986).

In the process of NAPFINING FIBER-FILM, an alkali is used to reduce the acidity of kerosene and/or jet fuels and higher-boiling medium distillates (Meyers 2012) (see US patents N 4033860, 4481106, etc.). The main disadvantages of these methods are a low degree of oxidation of mercaptans in petroleum distillates and a significant consumption of alkali.

The Russian joint-stock company "Volga Research Institute Of Hydrocarbons" (JSC VRIHC) offers a DMD process for demercaptanization of kerosene fraction, which consists in the oxidation of mercaptans with air oxygen to disulfides at a temperature of 50–60 °C and a pressure of 0.5–1.5 MPa in the presence of a heterogeneous IVKAZ catalyst (cobalt phthalocynanin is one of the components, the developer and supplier of JSC VRIHC), applied to activated carbon grades AG-3 or AG-5. The surface of the catalyst must be periodically wetted with a 2% NaOH solution. Modern technology allows to purify raw materials (both oil and gas condensate) from toxic low-molecular mercaptans C1-C2 with a single-stage cleaning up to 10 ppm (DMD-1 process); from mercaptans C1-C4 with a two-stage cleaning up to 30 ppm (DMD-3 process); from hydrogen sulfide (which is oxidized to elemental sulfur) to a residual content of less than 5 ppm (DMD-2 process).

The domestic process "Demerus Jet", which is developed by the STC "AhmadullinS-Science and Technology" (patents of the Russian Federation No 2173330, No 2603635), is the most promising. Selective oxidation of mercaptans to disulfides is achieved by contact with the catalyst "KSM-X" (patents of the Russian Federation No. 2110324 and No. 2529500), which is a composition of water-soluble cobalt dichlorophthalocyanine with potassium hydroxide and metal oxides with variable valence located on low-pressure polypropylene or polyethylene (HDPE), which does not require the presence of an aqueous solution of alkali. As metal oxides with variable valency, manganese(IV) oxide and/or copper(II) oxide, and/or Nickel(II) oxide, and/or cobalt(III) oxide are used.

This process has successfully passed pilot tests at the Moscow oil refinery in 1998 and 2008, and qualification tests at All-Russian research Institute for oil refining (2018, in accordance with contract no. 4907/29/222) (Technical note 1997). The efficiency of the Demerus Jet process depends largely on the degree of mixing of kerosene and air. Pilot tests found that the most effective is the upper direct-flow supply of kerosene, air and the KSP promoter (TU 0258–015-00151638-OP-99) to the reactor with a catalyst. The CSP promoter (dark brown liquid) is formed during the operation of the unit on the surface of a heterogeneous CSM-X catalyst (there is no need to purchase CSP). KSP is insoluble in kerosene and it is separated from kerosene with gravi-metric advocacy; it consists of a bright heavy parts with d = 1.3–1.5 kg/dm^3 and time full settling on kerosene is 20–30 min, and the dark light part (potassium salt of naphthenic acids) with d = l,15–1,25 kg/dm^3 eventually settling on kerosene about 90 min.

In January 2015 in Bahrain (International Station for Manufacturing of Refining, Bahrain) the plant of deep deodorization of kerosene using the Demerus Jet technology on the KSM-X catalyst for the production of white spirit was put into operation. Capacity of the plant is up to 2.5 m^3/h, the content of mercaptans in the raw material is 20.0 ÷ 30.0 ppm, at the output from the plant is no more than 5.0 ppm.

3 Results and Discussions

Straight-run distillate (kerosene fraction) from an amosphericavcuum column with a temperature of 50–60 °C at a pressure of 0.8 MPa according to the direct supply scheme with a flow rate of 50.0 t/h enters the MX-101 mixer. In the MX-101 mixer with the H-101A/B pump from the sump E-101 with a flow rate of 2.5–5.0 m^3/h is also fed to the

KSP promoter (heavy part). In the MX-101 mixer, acidic impurities (aliphatic, aromatic and naphthenic acids, phenols, etc.) are extracted from kerosene by reaction:

$$RCOOH + KOH \rightarrow RCOOK + H_2O + Q$$

The KSP-promoter (liquid) with the formed layers of acidic impurities (the light part of the promoter) is separated from the kerosene fraction in the tank-sump D-101, the mixture is entered into the tank D-101 through the masterbatch. The heavy and light parts of the promoter are removed from he bottom of the tank-sump D-101 to the sump of the promoter D-102 (Fig. 1).

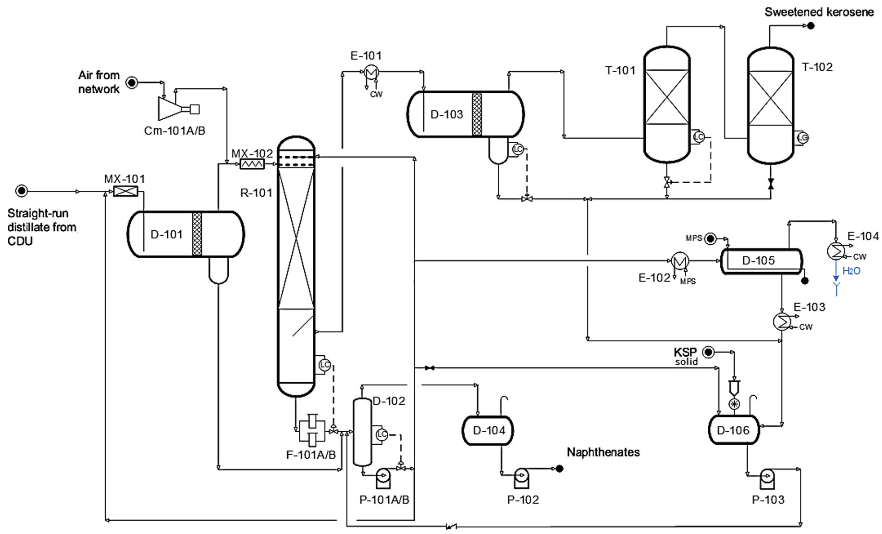

Fig. 1. Basic technological scheme of demercaptanization of kerosene fraction. *Source*: developed and compiled by the authors.

From the top of the sump D-101 kerosene fraction enters the mixer MX-102. The MX-102 mixer is also supplied with an estimated amount of air at a pressure of 1.0 MPa. Air supply to the liquid phase is made by the Cm-101A/B compressor. The technology uses the minimum amount of air necessary and sufficient for the oxidation of mercaptans. Air is supplied continuously in an amount that depends on the capacity of the plant and the content of mercaptan sulfur in the raw material.

The kerosene fraction with the air dissolved in it flows up the R-101 reactor through the switchgear. If an air cushion is formed in the R-101 reactor, air is discharged to the candle from the upper part of the reactor.

To the top of the R-101 reactor from the D-102 tank with the P-101A/B pump with a flow rate of 2.5 = 5.0 m^3/h, the KSP-promoter (liquid) is supplied. The input of the KSP-promoter is carried out through a distribution device above the catalyst layer. The reaction mixture passes from top to bottom of the R-101 reactor through the KSM-X catalyst layer and on the surface of the KSM-X catalyst, mercaptans are oxidized by air oxygen (50 °C, 0.4 MPa) to disulfides.

The technology uses a minimum (stoichiometric) amount of air required to ensure the oxidation of mercaptans. Air is supplied continuously in an amount that depends on the capacity of the plant and the content of mercaptan sulfur in the raw material.

The KSP-promoter (liquid) is separated from the kerosene in the lower part of the R-101 reactor. From the lower part of the reactor R101, the demercaptanized kerosene is sent through the side fitting in the refrigerator E-101, where it is cooled to 40 °C and enters the sump D-103. In the sump D-103 there is a gravitational separation of kerosene from the residual KSP-promoter. From the sump D-103, kerosene is sent to the T-101 filter, which is filled with porcelain balls with a diameter of 3 mm to clean the kerosene from the carried-out KSP promoter, then it is sent to the T-102 clay filter for adsorption post-treatment of kerosene and it is removed from the installation to the tanks. From the pocket of the D-103 sump and the T-101 filter, the settled KSP-promoter is periodically dumped into the promoter concentration tank D-104.

The KSP-promoter separated from the kerosene in the R-101 reactor cube is fed through the F-101A/B filter to the sump of the D-102 promoter, where naphthenic acid salts with a lower density float up;they are separated at the level of the phase separation and from the top of the D-102 under its own pressure enter the storage tank of naphthenic acid salts (the light part of the promoter) D-103. F-101A/B filter is necessary for capturing poorly soluble inorganic salts (bicarbonate, sodium carbonate),which are accumulated in the KSP-promoter and are crystallized during operation of the demercaptanization unit (Akhmadullina et al. 1993, 1994).

From the cube of the sump D-102, the KSP-promoter, separated from naphthenic acid salts, returns to the R-101 reactor with help of the P-101A/B pump. When the promoter activity decreases because of its dilution with reaction water, part of the promoter from D-102 is sent through the heater E-102 to the evaporator D-105 to steam excess moisture. The steamed promotor is cooled in the refrigerator E-103 and enters the container D106. From the container D-106, water vapor is condensed in the refrigerator-condenser E-104 and sent to the second sewage system of the refinery. When the volume of the promoter decreases due to its consumption for the absorption of acidic impurities, part of the promoter enters the reinforcement unit in the container D-106. A solid promoter(potassium hydroxide) is additionally introduced into the D-106 container (through the upper hatch) at atmospheric pressure.

The obtaining of the fuel TS-1 (jet A-1), which meets the requirements of Def Stan 91–091, by demercaptanization of the kerosene fraction using a catalyst "KSM-X" and alkaline promoter "KSP (liquid)"and the stage of adsorption cleaning on clay, is almost analogous to the process "Merox", which has additional stages of cleaning the kerosene fraction on a sand filter and drying the demercaptanized fraction from water on a salt filter.

The optimal parameters of static equipment are calculated in accordance with Federal standards and regulations in the field of industrial safety (Safety rulesapproved by order of Rostechnadzor dated March 29, 2016 No. 125) and are presented in Table 1. The selected heat exchange equipment is characterized by the parameters, which is shown in Table 2, dynamic equipment is shown in Table 3.

Table 1. Static equipment

Index by scheme	The name of the device	Diameter, mm	Height (length), mm	Volume, m^3	Working pressure, MPa	Operating temperature, °C	Environment	Remark
D-104	Storage capacity of naphthenates	1,600	2,500	6.3	Atm	20–60	Naphthenates	Horizontal capacitive device SEE1–1-6.3–0.6
D-105	Capacity-evaporator	1,000	(1,400)	1.1	0.1	110	KSP-promoter (liquid), water	–
D-106	Concentration capacity of the alkaline promoter	2,000	2,500	10.0	Atm	20–60	KSP-promoter (liquid)	Horizontal capacitive device SEE1–1-10–0.6
T-101	The sump of the kerosene fraction	3,800	15,066	160.0	0.7	30–40	Demercaptanized kerosene fraction, traces of the KSP-promoter (liquid)	Nozzle-porcelainballs
T-102	A column of fine purification of kerosene fractions	3,000	12,000	100.0	0.8	30–40	Demercaptanized kerosene fraction	Nozzle-bleachingclay
F-101 A/B	The liquid filter mesh	80		0.03	0.8	40	Demercaptanized kerosene fraction, KSP-promoter (liquid)	To prevent clogging of the rebar with the sediment of inorganic salts that accumulate in the circulating CSP promoter. Filtermeshsize is 1 × 1 mm

Source: developed and compiled by the authorsbased on available Internet resources

Table 2. Heat exchange equipment.

Index by scheme	The name of the device	T at the entrance, °C	T output, °C	Working pressure, MPa	Flow rate, m^3/h	Environment
E-101	Kerosene fraction refrigerator	60	40	0.8	56.0	Demercaptanized kerosene fraction, disulfides, KSP promoter (liquid)
E-102	KSP-promoter heater	40	110	0.2	0.5	Heavy and light parts of the KSP promoter (liquid)
E-103	KSP-promoter refrigerator	110	40	0.1	0.5	Heavy and light parts of the KSP promoter (liquid)
E-104	Water vapor condenser-refrigerator	100	45	0.1	-	Watervapor, water

Source: developed and compiled by the authorsbased on available Internet resources.

Table 3. Dynamic equipment

Index by scheme	The name of the device	Suction pressure, MPa	Discharge pressure, MPa	T_{work}, °C	Flow rate, m^3/h
P-101 A/B	Centrifugal pump (Heavy and light parts of the KSP-promoter (liquid))	0.1	1.0	60 ÷ 80	10.0
P-102	Centrifugalpump (Naphthenates)	Atm	0.3	10 ÷ 40	3.0
P-103	Centrifugal pump (KSP-promoter (liquid))	Atm	1.0	10 ÷ 60	3.0
Cm-101A/B	Compressor (Air)	Atm	1.0	Environment	10.0 nm^3/h

Source: developed and compiled by the authors based on available Internet resources

4 Conclusion

With using the “Demerus Jet” technology, the main waste or emissions of kerosene fraction from the demercaptanization unit are catalyst spent, porcelain balls and sorbent (clay), which are taken to the landfill for disposal at the end of their service life. The environmental advantage is the absence of sulfur-alkaline effluents and waste air.

Calculated payback period of the proposed installation with a capital investment of 40 million rubles is 3 years, which is less than the duration of its operation, so, it indicates a high profitability of the "Demerus Jet" process.

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Thermally Induced Spin Crossover in Iron (II, III) Complexes with Tripodal Ligands

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Abstract. Purpose: This review analyzes the properties of magnetically active iron(II) and (III) complexes with tridentate ligands, in which the phenomenon of spin-crossover (**SCO**) and thermochromism (color change with temperature change) is observed. The most widely studied systems with SCO are hexacoordinated iron(II, III) complexes with the FeN_6 coordination node.

Methodology: To identify and reliably characterize the obtained compounds, were used a combination of various physical and chemical research methods: CHNS; metal analysis by atomic absorption spectroscopy and complexometry, X-ray diffraction, differential scanning calorimetry (DSC), thermogravimetric analysis, electronic (DRS), IR, Messbauer, and NMR (in solution on ^1H) spectroscopy. An important part of this work is the study of the magnetic properties of compounds by static magnetic susceptibility: spin-crossover in iron(II) complexes.

Findings: New achievements in the synthesis and research of coordination compounds of iron(II) with tris(pyrazol-1-yl)methane, which exhibit a high-temperature spin-crossover accompanied by a "purple ↔ white" thermochromism, are shown. The analysis of changes in structural parameters during spin transitions is performed.

Value: Great progress has been shown in the development of bistable materials containing Fe.

Keywords: Spin-crossover · Bistable complexes · High-spin and low-spin complexes · Iron (III) · Iron (II) · Tris(pyrazol-1-yl)methane

JEL Code: O33

1 Introduction

Octahedral metal complexes of the first transition series with an electronic configuration from d^4 to d^7 (Cr^{2+}, $Mn^{2+/3+}$, $Fe^{2+/3+}$ and $^{Co2+/3+}$) can exist either in high-spin (**HS**) or low-spin (**LS**) states. The HS state will contain the maximum number of unpaired electrons, whereas the LS state will have the maximum number of paired electrons for each electron configuration. From the point of view of the crystal field theory, strong field ligands cause an increase in the energy gap (Δ_o) between the two types of symmetry of

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d-orbitals, low-energy t_{2g}-orbitals and high-energy e_g-orbitals, which, in turn, is greater than the spin pairing energy (**P**). Thus, the obtained complexes are stabilized in the LS state ($\Delta_o > P$), the number of paired electrons is maximum. In the case of weak field ligands, the value of Δ_o is less than P, which results in the stabilization of complexes with the maximum number of unpaired electrons, i.e. the HS-state. In some cases, ligands can create an energy field in which the value of the spin pairing energy (P) and the splitting energy of the ligand field (Δ_o) are approximately the same (intersection point, crossover), so the influence of an external stimulus can lead to a reversible switch between HS and LS-states (Hauser 2004).

The most common and widely used external factor that causes a spin crossover is temperature. However, there are examples of other external stimuli capable of switching the spin state of SCO-active complexes, such as: pressure, an external magnetic field, light of a certain wavelength and light-controlled ligand isomerization and solvation/desolvation.

A change in the spin state leads not only to a change in the number of electrons inhabiting orbitals separated by energy (Δ_o), and thus to a change in paired and unpaired electrons, which in turn changes the magnetic properties of complexes, but also to a change in physical and chemical properties, such as: color, bond lengths and metal-ligand angles, permittivity and electrical resistance. SCO-active complexes that show a sharp and reversible interconversion (spin transition, ST) between two possible spin states HS $\leftrightarrow$ LS (or {0}/off and {1}/on states), can be considered as molecular switches. Figure 1 shows possible electronic configurations of iron (II, III) ions in the octahedral field of ligands.

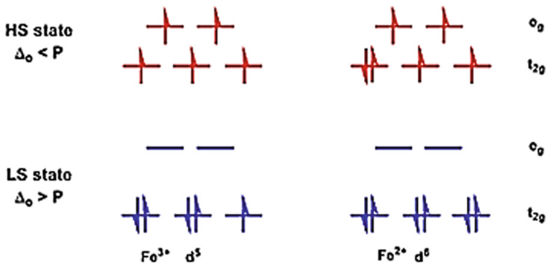


Fig. 1. Diagram of d-orbitals splitting in the octahedral field of ligands and electron arrangement for HS and LS states for d^5 and d^6 electron configurations. Source: developed and compiled by the author.

2 Methodology

At the current level of research, SCO-active compounds can be characterized by a wide range of methods based on the study of changes in physical and chemical properties during the spin transition. One of the most widely used methods is magnetometry, since the magnetic properties change dramatically when the amount of HS of the complex shape changes in proportion to the molar magnetic susceptibility (χ_M) according to the formula $\chi_M T = \gamma_{HS}\chi_{HS} + (1-\gamma_{HS})\chi_{LS}$. Modern equipment (superconducting quantum interference device, SQUID) allows us to vary the temperature, pressure and magnetic field during measurements, which allows to study SCO caused by heat, pressure and magnetic field, in addition to the samples, light radiation can be applied to measure light-induced transitions. All the above research methods allow us to determine the proportion of HS or LS forms of the complex in the sample for constructing graphs of spin transition dependencies, which are dependency graphs $\gamma_{HS} = f(T)$, $\chi_M T = f(T)$ or $\mu_{eff} = \sqrt{\frac{3k}{N_A\beta^2}\chi_M T} = \sqrt{8\chi_M T} = f(T)$.

Each SCO-active complex can be characterized by its own transition temperature $T_{½}$, which is defined as the temperature at which the HS and LS States coexist in a 1: 1 ratio, or T_c, which is determined as the maximum of the derivative of magnetic susceptibility with respect to temperature $\partial\chi/\partial T$. In some cases, the curves may show hysteresis-a phenomenon when the transition temperature during cooling ($T_{½}\downarrow$) differs from the transition temperature during heating ($T_{½}\uparrow$), Fig. 2, which leads to a hysteresis loop ($\Delta T_{½}$) – this gives the system a memory effect (bistability). Abrupt transition and hysteresis favor crystallographic phase changes and/or connections between metal centers (cooperative effect), which can be achieved through intra - and/or intermolecular interactions, such as bridging ligands, hydrogen bonds, π-π-stacking, van-der-Waals interactions, etc. This type of bistable molecular switches can be in demand for a wide range of applications, including in the field of nanotechnology (Bousseksou et al. 2011), namely as display and memory devices, sensors, MRI contrast agents (Molnár et al. 2018), thermoelectrochemical cells (Nik Ibrahim et al. 2020), etc.

The most widely studied systems in which the SCO phenomenon is observed are hexacoordinated iron(II) complexes with a FeN_6 coordination node. In this review, information is limited to new Fe(II) and Fe(III) complexes with tridentate ligands to avoid duplication other manuscripts.

Directed search for new iron compounds with SCO is necessary not only for their practical application, but, more importantly, for the development of spin-crossover theory. Note that SCO is not always implemented (and not only) in complexes with a FeN_6 coordination node. The current level of development of the synthetic direction of coordination chemistry convincingly proves the importance of many factors and does not give a 100% guarantee of successful production of a material with the desired properties. Therefore, the authors of research papers pay great attention to the methods and conditions of synthesis, isolation, storage and identification. The chemical, physical, and magnetic properties of iron complexes with different degrees of oxidation differ and are unique. The synthesis of new thermosensitive magnetically active compounds – affordable, environmentally friendly, changing the spin state and color at different temperatures – is an important task for the chemist.

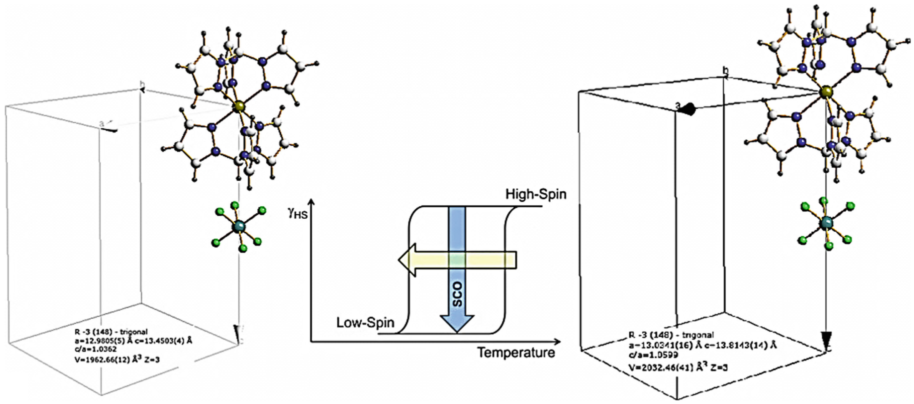


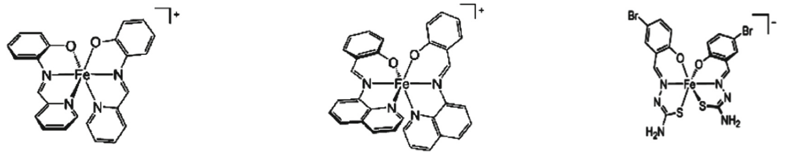
Fig. 2. SCO with hysteresis, which is accompanied by a structural phase transition. Source: developed and compiled by the author.

In general, the first difference between Fe(III) complexes and Fe(II) complexes is that the spin-crossover $^2T_2 \Leftrightarrow {}^6A_1$ in them is often gradual and incomplete, and in most cases is at low-temperature. The second difference between Fe(III) complexes is that both spin states are paramagnetic, S(LS) = 1/2 and S(HS) = 5/2, which can lead to states of mixing and/or (anti)ferromagnetic exchange interaction, making it difficult to analyze magnetic properties. However, the fact that both spin states have unpaired electrons may contribute to the manifestation of other properties in such complexes, such as monomolecular magnetism, single-ionic "inclined" anisotropy, spin frustrations in multi-core systems, etc.

Cationic iron (III) complexes are shown in Fig. 3a and 3b, $[Fe(pap)_2](BF_4)$, $[Fe(pap)_2](ClO_4)$, $[Fe(qsal)_2](NCS)$ (Hayami et al. 2001), $[Fe(qsal)_2](NCSe)$ (Craig et al. 2013) there is a sharp spin transition with a hysteresis width from 15 to 70 K (Hayami et al. 2009). The strong spin-crossover cooperativity can be explained by a three-dimensional network of intermolecular π-π -stacking between complex cations in the material. At the same time, there is a gradual SCO in $[Fe(pap)_2](PF_6)\cdot CH_3OH$ (Juhász 2002), $Fe(qsal)_2](I_3)$ (Takahashi et al. 2010).

It is known that the $Fe(pap)_2ClO_4{\cdot}H_2O$ complex exhibits a spin transition and under irradiation (with a wavelength of 300 nm) at a temperature of 5 K demonstrates the LIESST effect: the transition from a low-spin (LS) state to a metastable high-spin (HS) state. Magnetometry shows that the value of $\chi_M T$ for this complex at room temperature is 3.9 $cm^3\ K\ mol^{-1}$, which corresponds to what is expected for the high-spin state in iron (III) compounds (Fig. 4a). When cooling, the value of $\chi_M T$ decreases sharply, $T_{1/2}\downarrow =$ 165 K. the value of $\chi_m T$ at 100 K is 0.51 $cm^3\ K\ mol^{-1}$, which is a low-spin state. In the heating mode, a sharp change in $\chi_M T$ was observed at $T_{1/2}\uparrow = 180$ K. A fairly sharp transition with a hysteresis loop ($\approx$15 K) indicates the presence of a strong cooperative interaction. Another important characteristic is that this complex exhibits a freezing effect. This property is observed when the cooperability is high and, consequently, the relaxation rate is quite slow.

For the $Li[Fe(5Brthsa)_2]{\cdot}H_2O$ (Floquet et al. 2003) complex, whose anion is shown in Fig. 3c, the two-stage spin transition $s = 1/2 \leftrightarrow S = 5/2$ of the iron ion is accompanied by a fairly wide hysteresis ($\Delta T = 39$ K) with a center of about 313 K (Fig. 4b). Investigation by powder x-ray diffraction at various temperatures demonstrates the occurrence of a first-order crystallographic phase transition associated with spin transformation. Changes in the enthalpy and entropy of SCO were estimated from the results of DSC measurements: $\Delta H = 5.7 \pm 0.5$ kJ mol^{-1} and $\Delta S = 18 \pm 2$ J $mol^{-1}\ K^{-1}$. This phase transformation can occur as a result of modification of the extended network of hydrogen bonds.

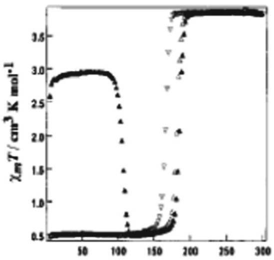


$[Fe(pap)_2]^+$ (a) $[Fe(qsal)_2]^+$ (b) $[Fe(5Brthsa)_2]^-$ (c)

Fig. 3. Iron(III) complexes. Source: developed and compiled by the author.

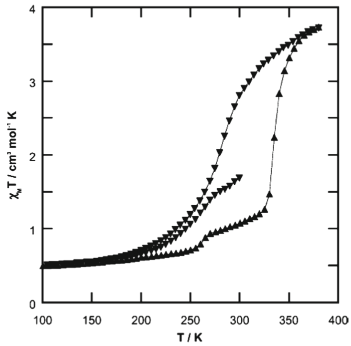
Some well-known coordination compounds of iron (II) that exhibit SCO, are conveniently presented in the form of Table 1.

In general, the $^1A_1 \Leftrightarrow {}^5T_2$ spin crossover in them is always unique-sharp or gradual, complete or incomplete, reversible or not, with or without hysteresis, single or two - stage. The number of examples covers a wide temperature range of $80 < T < 500$ K. The second difference of Fe(II) complexes is that the spin states are different, S(LS) = 0 and S(HS) = 2, which makes the analysis of magnetic properties very simple. The fact that the low-spin state is diamagnetic makes it possible to track the residual fraction of high-spin forms of the complex at low temperatures and simultaneously study temperature independent paramagnetism of John Hasbrouck van Vleck or exchange interactions between paramagnetic anions of an antiferro-or ferromagnetic nature.



$[Fe(pap)_2](ClO_4)\cdot H_2O$. Sample was cooled from 300 to 5 K (∇) and then warmed from 5 to 300 K (Δ) at a rate of 2 K min^{-1}. Sample was warmed at a rate of 2 K min^{-1} after it was quenched to 5 K (▲).

(a)



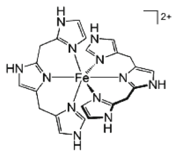
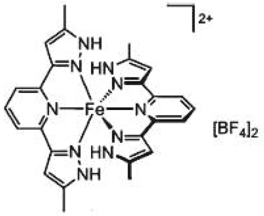
$Li[Fe(5Brthsa)_2]\cdot H_2O$ (decreasing ▼ and increasing ▲ temperatures).

(b)

Fig. 4. $\chi_m T$ versus T plots. Source: compiled by the author based on papers of (Hayami et al. 2001) and (Floquet et al. 2003).

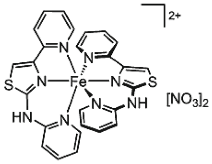
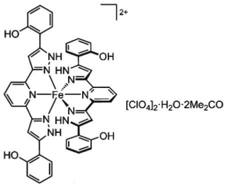
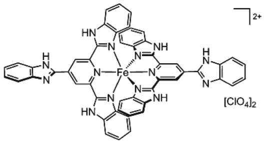
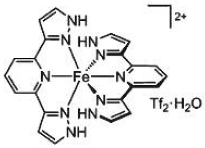
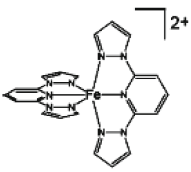
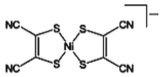
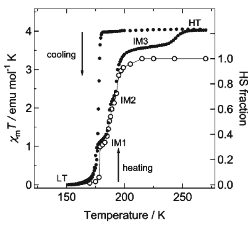
Thus, the steric aspects of the ligand design for controlling the spin state of iron(II) ions are intuitive. Bulky substituents in the vicinity of ligand donor atoms, which prevent compression of metal-ligand bonds, stabilize the state in the high-spin form of the complex. The steric volume at the periphery of the ligand sphere can contribute to a low-spin

Table 1. SCO characteristics of iron (II) complexes. Source: developed and compiled by the author

Complex	SCO characteristic
 **1**	Strengthening the hydrogen bonds of the cation and anion reduces the basicity of the neighboring ligand, and thus contributes to the high-spin state of the complex 1. This trend is clearly observed for its halide, $T_{1/2}$ of which follows the expected order: I- (380 K) > Br^- (340 K) > Cl^- (180 K) > F^- (20 K)
 **2**	A complex phase behavior is observed for compound 2, which is obtained as anhydrous crystals (A) that absorb atmospheric moisture with an output of A*$2H_2O$.dehydration of which in a vacuum at a temperature of 350K gives a new anhydrous material (B), which differs from the original crystal phase A by powder diffraction. Phase B undergoes two closely separated phase transitions when cooled at 303 and 270K, and then exhibits a thermal spin transition centered around 200 K, which includes another crystallographic phase transition. ΔT = 37K ($T_{1/2}$↓ = 190 and $T_{1/2}$↑ = 227 K). The isotope complex with perchlorate anions (ClO_4) exhibits only one phase transition when cooled from 350K, rather than two, and preserves the C phase, in which the SCOphenomenon does not manifest (Roberts et al., 2013).

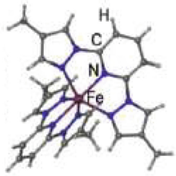
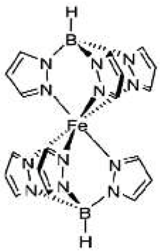
(*continued*)

Table 1. (*continued*)

<table>
<tr><td>
3</td><td>Complex 3 demonstrates a similar behavior in which the compound exhibits a spin-crossover with a wide hysteresis at a slow temperature scan (ΔT = 34K). (Ritter et al., 1978).</td></tr>
<tr><td>
4</td><td>Compound 4 has $T_{1/2}$ = 153K andΔT = 40K (Craig et al., 2014). Hysteresis occurs due to large changes in the shape of molecules (both in the ligand conformation and in the orientation of peripheral phenoxy substituents) between their high-and low-spin states.</td></tr>
<tr><td>
5</td><td>The complex 5*2H_2O compound exhibits a sharp spin transition at T=323 K with a hysteresis loop width of ΔT = 35K and undergoes a hysteresis of ca. 35 K. there is no structural data for the connection (Boča et al., 2005).
In the range from 503 < T < 523 K irreversible changes occur: release of crystalline water, color change (blue-green) followed by a change in structure.The following heat cycles are reproducible, although the heating / cooling paths differ from the first heating.</td></tr>
<tr><td>
6</td><td>In compound 6, a two-stage spin transition is observed when heated (Sung et al., 1999).Interestingly, the two stages are not equal in height; the first stage causes 1/3 of the sample to become high-spin, and the second stage covers the remainder.It is for junction 6 that the strongest cooperativity is shown, the hysteresis loop spans 140 K.
Other compounds with this cation are less noticeable, showing 39 <ΔT < 82K.</td></tr>
<tr><td>
$[Fe(dpp)_2]^{2+}$

$[Ni(mnt)_2]^-$</td><td>For the compound $[Fe(bpp)_2][Ni(mnt)_2]_2$•$MeNO_2$ (bpp = 2,6 bis (pyrazol-1-yl)pyridine; nt = maleonitrildithiolate), the authors (Nihei et al., 2010) observed a very complex temperature dependence of structural and magnetic changes, which allowed them to distinguish five phases in the temperature range 0-250 K.
</td></tr>
</table>

(*continued*)

Table 1. (*continued*)

 **$[Fe(dmbpp)_2]^{2+}$**	The compound $[Fe(dmbpp)_2](ClO_4)_2$has a sharp SCO with a small hysteresis ($T_{1/2}\downarrow$= 231 K, $T_{1/2}\uparrow$= 234 K) (Carbonera et al., 2006). This compound also exhibits a remarkable light-induced excited spin state capture (LIESST) effect; the photo-induced HS state generated by light radiation at 10 K remains stable up to 85 K, above which it relaxes back to the LS ground state.
 **$[Fe(HB(pz)_3)_2]$**	**$[Fe(HB(pz)_3)_2]$ -** this well-known Fe (II) complex with two tridentate ligands may not seem particularly interesting, since it exhibits a very gradual and completely reversible SCO between 300 and 450 K.However, a more thorough study has shown that this behavior is typical for a monoclinic thermodynamically stable polymorph, but depending on the crystallization conditions, a metastable tetragonal polymorph can be isolated (Salmon et al., 2009). When heated, a freshly prepared tetragonal polymorph first exhibits a gradual SCO at 340 K, which becomes very sharp at 410 K and again gradual above this temperature.It is shown that a sharp change in the conversion rate of LS → HS occurs due to an irreversible phase transition from a tetragonal structure to a monoclinic one.

state if it prevents the expansion of the metal coordination sphere, or a high-spin state if it leads to a distortion of the dative ligand → metal interaction.These effects can be reliably predicted in individual compounds using molecular modeling.

3 Results and Discussion

This review is a logical continuation of own work and is devoted to the latest studies of spin-crossover in Fe (II) complexes with tris(pyrazol-1-yl)methane $HC(pz)_3$ (Fig. 5).

Fig. 5. Schematic structure of C-scorpionatetris(pyrazol-1-yl)methanes $RC(R'\text{-}pz)_3$ (pz = pyrazolyl; R = H substituent at the methine carbon; R' = H or any substituent at the pz ring) and comparison with a scorpion; and the structure of the complex cation $[Fe(HC(pz)_3)_2]^{2+}$. Source: developed and compiled by the author.

Tris(pyrazol-1-l)methane (**HC(pz)$_3$**) and its derivatives are ligands that show promising prospects for SCO. The most important feature of these compounds is the presence of nitrogen atoms in three pyrazole cycles that can coordinate with the metal, which leads to the formation of an octahedral complex with a FeN_6 coordination core in the case of coordination of two ligands. For iron(II) compounds, this means that SCO is possible. It is shown that these ligands coordinate with the metal mainly tridentate-cyclically (symmetry group C_3), while forming cationic complexes, $[Fe(HC(pz)_3)_2]^{2+}$. Any modification of the ligand leads to a change in the inner sphere of the complex and its properties. Thus, the researcher can modify the ligand and replace the anion to study the effect on the properties of not only the inner sphere of the complex, but also the outer one. In addition, it is necessary to take into account the influence of the crystallization solvent.

The synthesis of several iron(II) compounds with unsubstituted $HC(pz)_3$, such as $[Fe(HC(pz)_3)_2]A_2$ (a = Br^-, ClO_4^-, BF_4^-,NO_3^-), was poorly described in the last century. Measurement of magnetic susceptibility at variable temperature in the solid state of complexes $[Fe(HC(pz)_3)_2](ClO_4)_2$ and $[Fe(HC(pz)_3)_2](BF_4)_2$ assumes the existence of a single-stage spin crossover when heated. While the $[Fe(HC(pz)_3)_2]Br_2$ complex was mistakenly recognized as diamagnetic. The crystal structures of α-and β-polymorphs $[Fe(HC(pz)_3)_2](NO_3)_2$ were presented.

By now our group has synthesized complexes $[Fe(HC(pz)_3)_2]A_2{\cdot}nH_2O$, где A = Cl^-, Br^-, I^-, NO_3^-, $CF_3SO_3^-$, $C_{10}H_7SO_3^-$, $C_{12}H_{25}SO_4^-$, 7,8-$C_2B_9H_{12}^-$, $C_2B_9H_8Br_4^-$, $C_2B_9H_8I_4^-$, $C_2N_3^-$, $C_8H_5O_4^-$, ReO_4^-, $[B(C_6H_5)_4]^-$, $[Ni(dmit)_2]^-$, $TCNQ^{\cdot-}$; и $[Fe(HC(pz)_3)_2]A{\cdot}nH_2O$, где A = SO_4^{2-}, SiF_6^{2-}, $[Mo_6Br_{14}]^{2-}$, $[Mo_6Cl_{14}]^{2-}$, $[W_6I_{14}]^{2-}$, $[W_6Br_{14}]^{2-}$, $[W_6Cl_{14}]^{2-}$, $B_{10}H_{10}^{2-}$, $B_{10}Cl_{10}^{2-}$, $B_{12}H_{12}^{2-}$, $[Eu(dipic)_2(Hdipic)]^{2-}$, $[Fe(NO)(CN)_5]^{2-}$; n = 0–7; and $[Fe(HC(pz)_3)_2]_2[Re_6S_8(CN)_6]{\cdot}2H_2O$. Complexes were obtained by exchange reactions between water-alcohol solutions of $FeSO_4$ (≈0.05 mol/l) and $HC(pz)_3$ with an aqueous salt solution of the corresponding anion at a different ratio of iron: ligand: anion, usually 1: 2–6: .3–6.Most of synthesized iron (II) complexes with $HC(pz)_3$ are stable under long-term storage in air at room temperature and are non-hygroscopic.

The compounds were studied using static magnetic susceptibility, diffuse reflection and IR spectroscopy, as well as powder and single-crystal X-Ray diffraction. The parameters of the molecular and crystal structure of most of the selected compounds were determined. According to X-Ray, the complexes are mononuclear and have an octahedral structure of the coordination polyhedron with the coordination node FeN_6. The Fe-N bond lengths in complex cations are in the range of 1.96–1.98 Å, which corresponds to the LS form of the iron(II) complex. In crystals, complex cations exhibit slight distortion of the octahedral polyhedron.

Magnetochemical study of a number of complexes showed that all of them exhibit reversible SCO $^1A_1 \leftrightarrow {}^5T_2$, most often with a small hysteresis on the curves $\mu_{eff}(T)$. There are many examples of different $\mu_{eff}(T)$ dependences: $[Fe(HC(pz)_3)_2](SO_3CF_3)_2$ – SCO with hysteresis; $[Fe(HC(pz)_3)_2]SiF_6$– SCO without hysteresis; $[Fe(HC(pz)_3)_2][Eu(dipic)_2(Hdipic)]$ – incomplete SCO with exchange interactions between metal ions of an antiferromagnetic nature; $[Fe(HC(pz)_3)_2]B_{12}H_{12}$ – complete and sharp SCO; $[Fe(HC(pz)_3)_2][\{W_6(\mu_3\text{-}Cl)_8\}Cl_6]$

– two stage SCO; $[Fe(HC(pz)_3)_2](1,5,6,10\text{-}Br_4\text{–}7,8\text{-}C_2B_9H_8)_2$– incomplete and continues SCO; $[Fe(HC(3,5\text{-}(CH_3)pz)_3)_2]B_{10}H_{10}\cdot H_2O$ – incomplete SCO with exchange interactions between metal ions of an antiferromagnetic nature; $[Fe(HC(3,5\text{-}(CH_3)pz)_3)_2]B_{12}H_{12}\cdot H2O$ – only exchange interactions between metal ions of an antiferromagnetic nature. In all cases, the transition is accompanied by a thermochromic effect.

Data analysis shows that there is a significant temperature dependence SCO (including transition sharpness, presence, or absence of hysteresis) the structure of the ligand and its composition, the nature of the anion of the outer sphere, as well as the presence of solvent molecules. This pronounced dependence of T_C can be explained by the ability of anions and a crystallized solvent to form a hydrogen network with coordinated ligands. Effective intermolecular interactions can also be created using π-stacking. The effect of the anion of the outer sphere is also manifested in the creation of an additional electrostatic field by the anion (ionic atmosphere), which leads to additional splitting of the members of the HS and LS electronic configurations of the central atom and causes SCO.

Thus, the prediction of T_C by the nature of the ligand and anion can be used with a number of limitations, since the SCO phenomenon depends on several factors working synchronously. The resulting series shows no relationship between the size of the anion and the increase in T_c. Data on the maxima of the reflected light length for complexes of different anions make it possible to make sure that there is no direct connection between T_c and λ_{max}.

The introduction of alkyl substituents leads not only to a decrease in the temperature of the spin transition. In some cases, it has been observed that the transition does not occur due to steric difficulties. It should be remembered that SCO is not only a two-electron, but also a phase transition, the main driving factor of which is the change in entropy. According to the calculations, the vibrational component makes the most significant contribution to the change in entropy at SCO.

4 Conclusion

Correlations between changes in spin states of iron complexes and parameters of their crystal structure are of great importance for the realization of bound magneto-structural phase transitions. A number of examples discussed above allow us to classify these transitions as those associated with immediate changes in structural organization that occur during SCO; associated with the creation of nonequivalent coordination nodes in HS and LS under incomplete SCO; associated with disorder-order transitions for peripheral ligand substituents or counterions/solvent. Only the first variant of the phase transitions provides the case of sharp SCO, and thus is particularly relevant for the construction of SCO materials that can demonstrate other functionality based on symmetry breaking, such as ferroelectricity or optical nonlinearity. This review will serve as an incentive for researchers interested in the problems of creating SCO materials.

Analysis of the results accumulated for Fe (II, III) complexes with tripodal ligands shows that promising classes of compounds with SCO systems, despite the significant array of data obtained, deserve further research.

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Digitalization of the Economy and the Problems of Industrial Production

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Abstract. Matters of sustainable development of industrial production are becoming increasingly popular among researchers, which is explained by national security issues that are directly related to the intensification of industrial production. Especially important is the study of the sustainability and development of the industrial complex in the region. The purpose of this article is to study the opinion of workers in industrial enterprises of the Nizhny Novgorod region on various aspects of sustainable development and to identify the underlying factors influencing this process, among which knowledge and technology are particularly highlighted in the context of digitalization. As a research method, a questionnaire with detailed processing of the results was chosen. Interviewed 48 respondents employed in the enterprises of the region related to various industries. The interrelation of the problems of sustainable development of industrial enterprises in the modern period of economic transformation has been studied and priority conditions have been identified that allow to growth the labor productivity, cost reduction, and increase competitiveness especially in high value-added industries. In this case, in the digital economy requires special attention to innovation, intellectual capital, environmental and social priorities. Conclusions are drawn about the understanding of sustainability by representatives in the industrial community, goals of enterprises and the need to adjust or even modernize industrial policies, especially at the regional level.

Keywords: Sustainable development · Digitalization · Innovation · Technology transfer · Industry · Industrial enterprise · Economic risks

JEL Code: L52 · O25 · P42

1 Introduction

It is advisable to study the economic development of the government in many aspects through indicators of economic development in individual regions. Russian regions differ

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significantly in terms of GRP, income level of the population, the development of various types of production and infrastructure security. Nizhny Novgorod region could be related to the so-called industrialized regions in the sectoral structure which occupies a high proportion of industrial production.

Interest in studying the industrial development of regions has increased in recent years. In our opinion, this is due to three key factors. Firstly, the ongoing sanction pressure on the Russian economy brings to the fore the tasks of import substitution and the development of the industrial complex in order to ensure various aspects of national security. Secondly, enactment at the end of 2014 of Federal Law "On Industrial Policy in the Russian Federation" prompts researchers to make a detailed comparison of federal and regional levels of industrial policy implementation in order to identify problems inherent in the regulation of the industrial complex. Thirdly, the uneven economic development of the regions makes us look for solutions through the intensification of industrial development.

It should be noted that in the digital economy when creating new industrial goods, the role of intellectual capital and new forms of business organization is growing. Therefore, it is important to use innovative processes at all stages of industrial production, and the role of technology transfer is increasing.

This article describes the results of a study, organized by the Institute of Economics and Entrepreneurship NNSU named after N.I. Lobachevsky in the second half of 2018 - beginning of 2019. The purpose of the study was to examine the opinion of workers in industrial enterprises on various aspects of sustainable development of regional industry and implementation of industrial policy.

2 Materials and Method

Currently, the concept of sustainable development is one of the most popular, but at the same time, causing all sorts of discussions. With an interdisciplinary nature, the category of sustainable development is seen in the writings of economists, ecologists, geographers, sociologists and others. And here is a close connection with the digitization, which suggests paying serious attention to tightening requirements for energy efficiency, environmental protection, and social issues. Controversial nature of the category and the differences of views have generated a large number of existing definitions. Some interpretations of the concept "sustainable development" gives in his work T. V. Uskova (2009). We will note some of them.

1) "Supported economic development without endangering the depletion of existing resources for future generations" (G.S. Rosenberg, G.P. Krasnoshchekov, Y.M. Krylov).
2) "The progressive movement of the country (region) on the chosen strategic trajectory, which is ensuring the achievement of an objectively progressive system of social goals" (N.T. Agafonov, R.A. Islyaev).
3) "Such a development of the economic, political, social and environmental spheres with their inherent desire for balance and reduction of disparity as their internal characteristics, which ensures a balanced, progressive movement of the region as a whole, which should result in an improvement in people's lives" (M.Yu. Kalinchikov).

Considering the goals of sustainable development, the authors of the Report prepared by the Analytical Center under the Government of the Russian Federation cite, in our opinion, very precise words—"continuity directed towards the future" (Bobyleva and Grigorieva 2016).

Sustainable development of the industry are devoted in works of Malakhov (2012), Sukhina et al. (2018), a group of authors under edition of Bezdudnaya (2019) and other authors. Thus, almost all the authors note, the effect of following basic factors: environmental, social, innovation, as well as a clear path to digitalization.

Kostygova (2014) highlights three key points reflecting the need for sustainable industrial development in Russia:

- A powerful scientific and technical potential;
- "Significant developments in economic potential" under the influence of NTP;
- The largest concentration of opportunities for economic development in the industrial sector.

At the same time, it is necessary to create an adaptation mechanism that provides an adequate response to changes in the external environment through internal transformations of the industrial enterprise (Strelkova 2004): And to do that we need to find out the main problems.

The methodological basis of the study was the questionnaire method. The methodology proposed by Gurkov (2003) and described in detail in the work was chosen as the basis for the preparation of the questionnaire.

Questionnaire includes 44 questions, divided into three blocks. The first block concerns the various aspects of sustainable development of the industry, and the enterprise in which the respondent works. For an analysis of the economic situation in the industrial enterprise devoted half of survey questions. Two-thirds of questions in the first block are borrowed from the work of Gurkov (2003). The wording of about half of the borrowed questions is slightly changed. The second block is devoted to the analysis and evaluation of the need for a variety of industrial policies. The questions of the third block are aimed at obtaining brief information about respondents.

48 Respondents took part in the questionnaire.

3 Results

The first question of the questionnaire was open and contained a request to define the sustainable development of industry in the region and highlight its main components. The depth of answers varies - from two to eight to nine components. We can distinguish the following components of sustainable development, to which the respondents drew attention (we immediately note that the calculation of answers to this question is somewhat approximate in nature due to the enumeration by some respondents of components and factors that are similar in value):

- Environmental factor, accounting for the region's natural resources and environmental conservation, rational use of the resource potential - 26 answers;
- The social factor, ensuring the needs of society, improving standards of living - 20 answers;
- Introduction of new technologies and innovations - 11 answers;
- Ensuring economic efficiency - 9 answers;
- Increase in production capacity, upgrading the material and technical base of enterprises, improvement of equipment - 8 answers;
- Development of new markets, the expansion of regional exports - 7 answers;
- Increase in the number of jobs - 5 answers;
- Training and retraining - 5 answers;
- Development of transport infrastructure - 4 answers;
- An increase in the number of enterprises, the opening of new enterprises - 4 answers;
- Improving the competitiveness of enterprises - 4 answers;
- Development of social sphere - 3 answers;
- Investment factor, creation of favorable conditions for attraction of investments - 3 answers;
- The progressive development and the increase in growth - 2 answers;
- Improving product quality - 2 answers;
- Formation of production clusters - 2 answers;
- Innovative susceptibility - 2 answers;
- The balance of economic, social and environmental aspects - 2 answers;
- Taking into account the characteristics of the economy and potential opportunities of cities - 2 answers;
- Creating conditions for business development - 2 answers;
- Increase in production - 2 answers;
- Increase in GRP and GDP - 2 answers.

Respondents characterized the sustainable development of the industry as a complex process of quantitative and qualitative changes, and the coordinated development of industrial enterprises (11 answers). In addition, respondents indicated principles interconnectivity (2 answers), innovation (answers 2), and safety (3 answers).

When asked about the main economic opportunities characterizing sustainable development in the region's industry, it was proposed to choose no more than three answers. 47 respondents gave the following answers:

- Optimization of production - 40;
- Increase in sales - 33;
- Increase in the portfolio of goods and services - 19;
- New business models - 19;
- Improving the quality of customer service - 18.

One respondent wrote as an answer the following: the development of new products and entering new markets.

The main economic risks for the sustainable development of industry in the region are:

- Problems of technology implementation - 37;
- Development of solutions for market demand - 28;
- Data security - 20;
- Standardization issues - 13;
- The problem of moving staff - 12.

Two respondents also pointed to the problem of the lack of qualified personnel, and one noted the poor development of the monetary mechanism and poor investment climate.

Respondents see the need for cooperation in the framework of sustainable development between various enterprises and organizations in the following related areas:

- Research and development - 41;
- Training and professional development - 36;
- Access to talented personnel - 22;
- Access to venture capital - 8;
- Business models - 7.

Another open-ended question is devoted to identifying the benefits that enterprises bring to the sustainable nature of industrial development in the region. Multiple components were allowed to be selected. The result is present in 45 questionnaires. The answers can be grouped as follows:

- Expansion of markets and opportunities for the sale of products - 16;
- Improving the competitiveness of enterprises and products - 14;
- Increase in production, sales and profits, by reducing the costs and efficient use of resources - 13;
- Improvement of technological processes, development of the production base and implementation of innovations - 10;
- Stability in operation of the business - 8;
- The possibility of long-term planning and forecasting - 7;
- Financial support from the municipality, subsidies, tax benefits - 5 (it is interesting that one respondent, on the contrary, indicated independence from subsidies as an opportunity);
- Increasing the availability of investment - 4;
- Increase in the number of suppliers, strengthening resource supply links - 4;
- Increasing the number of skilled workers - 4;
- Infrastructure development - 3.

On the question of defining the necessary conditions for enterprise involvement in cooperation requires only one answer. The results were processed for 42 questionnaires (the rest were not processed because more than one answer was selected). The majority of respondents (26 out of 42 or 61.9%) believe the main conditions are a positive image and impeccable business reputation for the potential partner. In addition, strict execution of contractual discipline (7 answers), detailed regulatory and legal regulation (5 answers), and personal contacts (2 answers) are also chosen.

The form of the enterprise was indicated by 47 respondents. Most of the representatives are from newly created private enterprises (17). Privatized enterprises were represented by 12 respondents, government enterprises - 6, joint ventures - 2 respondents. Another 10 respondents indicated a different form. Distribution of enterprises by field of activity is presented in Fig. 1.

The age of the enterprises represented (indicated in 47 questionnaires, in some - approximate) ranges from three to more than 260 years. Four respondents represent enterprises founded in the pre-revolutionary period, 15 - are employed at enterprises founded in the Soviet era, and 28 - at enterprises that appeared already in the post-Soviet period.

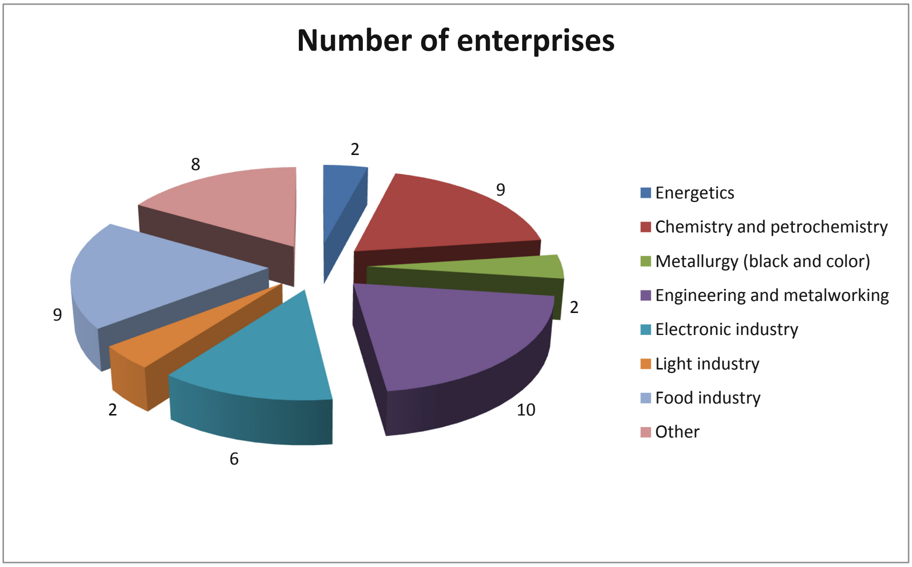

Fig. 1. Distribution of enterprises by sphere of activity

Most of the respondents are employed in enterprises with a large number of employees: from 200 to 1000 people - 16 respondents, more than 1,000 people - 19 respondents. Only 15 respondents are employed at enterprises with up to 200 employees (of which: up to 20 people - 2 respondents, from 20 to 100 people - 8 respondents, from 100 to 200 people - 3 respondents).

The level of sustainability of the development in their enterprise in comparison with the industry average level of 48 respondents was evaluated as follows:

– Considerably higher than the average - 5 responses (10.4%);
– Above average - 22 response (45.8%);

– Medium - 18 responses (37.5%);
– Below average - 3 responses (6.3%).

A positive signal is a fact that none of the respondents rated the sustainability level of development of their enterprise significantly below average.

The sales volumes of their enterprises were estimated by 45 respondents. The answers were as follows:

– Less than 10 million rubles - 3 answers;
– 10 - 100 million rubles - 8 answers;
– 100 - 500 million rubles - 8 answers;
– 500 million - 1 billion rubles - 2 answers;
– 1 - 5 billion rubles - 10 answers;
– More than 5 billion rubles - 14 answers.

Assessment of the economic situation, given by 47 respondents, was distributed as follows:

– Good - 24 answers;
– Satisfactory - 15 answers;
– Excellent - 7 answers;
– Bad - 1 answer.

As a positive signal, it is worth noting that there is no assessment of the economic situation of the enterprise as close to bankruptcy.

Let us conditionally express the following answers in points: close to bankruptcy - 1 point, bad - 2 points, satisfactory - 3 points, good - 4 points, excellent - 5 points. Then the average evaluation score was 3.8.

When asked about the goals that the company's management is currently pursuing, respondents were allowed to choose several answer options. Analysis of responses showed the following results:

– Strengthening the position in the domestic market - 31;
– Production corresponding to the world level - 30;
– Maintaining the reputation of the enterprise - 23;
– Development of foreign markets - 14;
– Increase in the value of the company - 11;
– Preservation of the workforce - 10;
– Ensuring high earnings of workers - 7;
– Contribution to the prosperity of the Russian economy - 6.

One respondent indicated his option (the development of new types of products).

4 Conclusion

The concept of sustainable development is becoming increasingly popular in various fields of science, but it has a debatable nature regarding the content of sustainable development and the role of each of the components. And as a separate issue, one can single out the sustainable development of the industrial complex, which, in turn, is closely related to the sustainable development of industrial enterprises and with the new trends that brings the digitalization of the economy. Identified problems, as shown by our study, are closely interrelated.

To study the sustainable development of the region's industry through the prism of industrial policy implementation, a questionnaire method was used with subsequent processing of the results.

When understanding sustainable development, respondents most often identify the following components: environmental factor, social factor, innovation factor, ensuring economic efficiency, updating the material and technical base and increasing the export of industrial products.

The main economic opportunities characterizing the sustainable development of industry in the region, most respondents consider the optimization of production and an increase in sales. The main economic risks for the sustainable development of industry in the region are considered the problems of technology implementation and the development of solutions for market demand. The need for cooperation between different enterprises and organizations is most often noted in such related fields as research, development, training, and professional development.

Among the advantages that enterprises bring to the sustainable nature of industrial development in the region, the greatest attention is paid to expanding sales markets and product sales opportunities, increasing the competitiveness of enterprises and manufactured products, increasing production, sales and profits, improving technological processes and introducing innovations, and finally the stability of the enterprise. The main condition for involving enterprises in cooperation is recognized as a positive image and impeccable business reputation of a potential partner.

The questionnaire contains the most respondents employed in newly created private and privatized enterprises. The time of occurrence is dominated by enterprises founded in the post-Soviet period. The predominant areas of activity are mechanical engineering, metalworking, chemistry, petrochemistry, and the food industry. Most of the respondents are employed in enterprises with a large number of employees (the number of employees is more than 200 people). More than half of responding respondents are employed in enterprises with a large sales volume (more than 1 billion rubles).

Regarding the goals that the company's management is currently pursuing, respondents most often noted the strengthening of their positions in the domestic market, the production of products corresponding to the world level, maintaining the reputation of the enterprise, and expansion of foreign markets. A negative moment can be assumed that only 6 respondents as one of the goals indicated contribution to the prosperity of the Russian economy.

Thus, the sustainable development of enterprises is most often associated with strengthening positions in the domestic and foreign markets, increase economic indicators, and a high level of business reputation. However, there is a separation of business goals and objectives of the national economy as a whole. It is necessary to carry out work to orient business leaders not only toward effective work in the industry but also to contribute to the prosperity of the Russian economy and its position on the international economic arena. For this purpose, it is necessary to identify the main problems of industrial production development, and to take into account the influence of the underlying factors and to determine the leading priorities of industrial policy, which are innovative, environmental, and social.

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Russian Economy and Digitalization Trends of Our Time

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Abstract. Purpose: To analyze current trends in the digital economy and the state of digitalization in Russia; to assess prospects in the field of information protection taking into account the pace of development.

Design/methodology/approach: Digitalization was a new round of society development that had followed informatization and computerization, which had relied on the use of various computer technologies, computers and information technologies to solve specific problems. Currently, the digital representation of information that is common everywhere has led to the fact that digitalization forms already holistic environments in which the user can solve already entire classes of tasks.

Findings: The rapid introduction of digital technologies and their integration into all sectors of life, intensively changes the economic and socio-cultural climate. The leading and high-tech economies of the world, within the framework of existing trends, have relied on the digitalization of the economy as the main tool for consolidating and strengthening the world market. Russia has also actively engaged in digitalization processes at various levels and has identified the development of the digital economy as one of the priority areas of the state's domestic and foreign policy and an indicator of competitiveness, taking into account the intensification of the globalization of market relations.

Keywords: Digital technology · Digitalization · Digital economy · Security of the digital economy · Tort risks

JEL Code: R01 · F22 · F63 · O15 · R11 · R58 · Z18

1 Introduction

An analysis of contemporary literary sources shows that there are many definitions of the concept of "digital economy", emphasizing a certain aspect of the integration of digitalization into the national economy, for example, the use of innovation and digital information and communication technologies; implementation of information and communication technologies of interactions; using the Internet, the Internet of Things, smart devices, mobile and touch networks; application of electronic document management systems in various fields, electronic communication channels, including open and secure ones, methods of recording, storage, processing and protection of information;

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on the application of innovative business models, alternative markets and consumers, etc. Each definition covers a substantial area of digitalization and can be considered as fundamental.

Currently, the following definition of the digital economy is generally accepted in Russia:

- digital economy - a business activity closely related to digital processing of information, processing of large volumes of data and the use of the results of analysis of which make it possible to increase the efficiency of various types of economic activities. It forms a single information space taking into account the needs of society, the individual and the state in obtaining reliable and consistent information, develops the information infrastructure of Russia, promotes the intensive use of Russian information and telecommunications technologies, and forms a new technological basis for the economy.

Comparing the concepts of "digitalization" and "digital economy", it should be borne in mind that the basis is digitalization and, according to Rogers (2016), it forms the digital economy, contributes to the improvement of all business processes, increasing the speed of information exchange in digital representation, its consistency, confidentiality, integrity, accessibility, and automation as the basis.

Digitalization in Russia

For modern Russia, there is almost unlimited potential for development in the introduction of information technologies in all sectors of the national economy. According to a study by Usanov, Usanov (2019), the allocation of specialized zones in Russia as points of growth of the digital economy favorably affects the investment climate. Based on the study of Oblasov (2019a, b), we note that the existing problems of digitalization of the regions can be extrapolated for the entire territory of the country, but enterprises, according to Dignam, Galanis (2016), need to be ready for digital transformation. The ICT Development Index (IDI) is published annually by the International Telecommunication Union (ITU). In 2019, according to the results of 2018, Russia took 39th place in the ranking with the Development Index equal - 8.17 points.

As follows from the reports of official sources, the index of development of IT in Russia from 2009 to 2019 increased by 39.5%. A significant separation of Russia is obvious, (39th place), from 180 place - the last in the ranking of 2019 (Fig. 1).

The trend for Russia is positive. It has been up for 9–7 positions in the ranking in the year. For example, from 40th place, it will take 10–20 years to take first place. Technology will not stand still all this time, it is developing intensively, and the pace of development is constantly increasing. Unstable conditions create the need for forecasting for 10–20 years ahead, on which the effectiveness of investments in the economy will depend.

On the other hand, there are also strengths - education and research potential. Over the past few years alone, Russia had achieved high performance in the development of e-government, the improvement of information and communication networks covering more than 92% of the territory, in ensuring national cybersecurity and information

International digital economy and society index: 2019						
Country	International digital economy and society index, I-DESI	Inluding subindexes				
		Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
Denmark	0.76	0.77	0.80	0.79	0.71	0.71
Republic of Korea	0.75	0.80	0.6	0.74	0.64	0.83
Finland	0.74	0.72	0.73	0.78	0.67	0.83
Netherlands	0.74	0.75	0.69	0.76	0.75	0.76
UK	0.73	0.74	0.65	0.72	0.68	0.90
Iceland	0.73	0.72	0.80	0.76	0.76	0.54
Norway	0.73	0.76	0.69	0.85	0.66	0.73
Sweden	0.72	0.75	0.69	0.78	0.65	0.73
Switzerland	0.71	0.70	0.65	0.78	0.80	0.48
Luxembourg	0.70	0.65	0.67	0.79	0.77	0.64
Australia	0.68	0.57	0.81	0.58	0.57	0.89
Japan	0.68	0.73	0.70	0.75	0.53	0.75
Canada	0.67	0.60	0.67	0.66	0.65	0.82
USA	0.67	0.71	0.56	0.71	0.62	0.79
Estonia	0.66	0.62	0.66	0.70	0.53	0.85
New Zealand	0.66	0.55	0.79	0.58	0.56	0.82
Germany	0.64	0.64	0.62	0.66	0.59	0.69
Belgium	0.63	0.68	0.60	0.62	0.61	0.61
Ireland	0.63	0.63	0.77	0.56	0.51	0.66
Spain	0.63	0.64	0.62	0.58	0.55	0.82
Austria	0.62	0.63	0.59	0.60	0.59	0.72
France	0.62	0.59	0.62	0.59	0.53	0.82
Malta	0.58	0.64	0.48	0.57	0.57	0.66
Hungary	0.56	0.60	0.62	0.55	0.51	0.46
Lithuania	0.56	0.61	0.53	0.58	0.6	0.63
Israel	0.56	0.54	0.57	0.59	0.45	0.65
Czech Republic	0.54	0.67	0.58	0.58	0.39	0.43
Slovakia	0.54	0.57	0.65	0.59	0.40	0.38
Slovenia	0.53	0.60	0.44	0.53	0.43	0.67
Italy	0.51	0.51	0.30	0.42	0.47	0.68
Latvia	0.51	0.65	0.47	0.58	0.32	0.56
Croatia	0.50	0.54	0.45	0.49	0.46	0.56
Serbia	0.50	0.52	0.44	0.50	0.44	0.61
Poland	0.49	0.53	0.53	0.51	0.33	0.57
Portugal	0.49	0.60	0.43	0.47	0.39	0.55
Bulgaria	0.48	0.61	0.47	0.42	0.36	0.45
Cyprus	0.48	0.54	0.45	0.54	0.39	0.49
Greece	0.48	0.50	0.48	0.46	0.45	0.48
Russia	0.48	0.30	0.54	0.49	0.30	0.57
Chile	0.54	0.48	0.43	0.33	0.41	0.61
China	0.45	0.46	0.41	0.45	0.41	0.59
Romania	0.44	0.61	0.43	0.48	0.27	0.39
Mexico	0.43	0.45	0.42	0.30	0.34	0.67
Turkey	0.42	0.43	0.53	0.36	0.28	0.43
Brazil	0.40	0.40	0.39	0.34	0.28	0.62

Fig. 1. Digital economy index *Source*: Ministry of Digital Development, Communications and Mass Media of the Russian Federation (2020)

security at various information facilities. According to official statistics, the key security indicator of Russia in 2017 is equal to 0.878, in 2018 it already had a value of 0.936. At the same time, the place in the ranking in 2017 is 8th, and in 2018 - 24. Of course, there was a negative dynamic associated with the rapid development of the European Union and the strengthening of the role of States in ensuring security in the information space (Fig. 2).

Ranking in 2019	Change in the position 2018/2019	Ranking in 2018	Change in the position 2017/2018	Ranking in 2017	Change in the position 2016/2017	Ranking in 2016	Economy	Points 2019	Research and development intensity 2019/18	Added value Activity 2019/18	Efficiency 2019/18	Hi-tech density 2019/18	Higher educational efficacy 2019/18	Research concentration 2019/18
1	0	1	0	1	0	1	**South Korea**	87.38	2	2	18	4	7	7
2	+2	4	-1	3	-1	2	**Germany**	87.30	7	3	24	3	14	11
3	+4	7	-2	5	+2	7	**Finland**	85.57	9	16	5	13	9	8
4	+1	5	-1	4	+1	5	**Switzerland**	85.49	3	4	7	8	13	3
5	+5	10	0	10	+1	11	**Israel**	84.78	1	33	8	5	36	2
6	-3	3	+3	6	0	6	**Singapore**	84.49	13	5	11	17	1	13
7	-5	2	0	2	+1	3	**Sweden**	84.15	4	15	9	6	20	5
8	+3	11	-2	9	-1	8	**USA**	83.21	10	25	6	1	43	28
9	-3	6	+1	7	-3	4	**Japan**	81.96	5	7	22	10	39	18
10	-1	9	+2	11	-1	10	**France**	81.67	12	41	13	2	11	20
11	-3	8	0	8	+1	9	**Denmark**	81.66	8	21	15	12	19	1
12	0	12	0	12	+1	13	**Austria**	80.98	6	11	12	24	8	9
13	+1	14	-1	13	+3	16	**Belgium**	80.43	11	26	10	9	41	16
14	-1	13	+3	16	-1	15	**Ireland**	80.08	32	1	1	16	15	14
15	+1	16	-1	15	+3	18	**Netherlands**	79.54	16	29	21	7	42	12
16	+3	19	+2	21	0	21	**China**	78.35	14	13	47	11	6	39
17	-2	15	-1	14	0	14	**Norway**	77.79	17	46	23	15	17	10
18	-1	17	0	17	0	17	**UK**	75.87	20	45	26	14	5	21
19	-1	18	0	18	+2	20	**Australia**	75.38	19	56	17	20	18	15
20	+2	22	-2	20	-1	19	**Canada**	73.65	22	39	27	22	31	19
21	-1	20	+4	24	+2	26	**Italy**	72.85	24	22	20	19	29	29
22	-1	21	+1	22	+1	23	**Poland**	69.10	36	20	40	18	16	18
23	1	24	+1	25	+3	28	**Iceland**	68.41	15	36	2	-	46	4
24	-1	23	-4	19	+3	22	**Russia**	68.12	26	35	19	32	32	23
25	+3	28	0	28	+3	31	**Czech Republic**	68.09		6	29	47	38	22
26	0	26	-3	23	+2	25	**Malaysia**	67.61	23	9	46	21	37	40
27	-2	25	+1	26	-14	12	**New Zealand**	66.81	33	37	51	25	10	24
28	+4	32	+2	34	+1	35	**Luxembourg**	66.37	23	47	3	48	58	6
29	+6	35	+3	38	-	38	**Romania**	64.78	55	18	32	23	24	47
30														

Fig. 2. Index of international ratings and indices. *Source*: iLibrary (2020)

One of the main advantages of Russia was the high involvement of the population in the digital economy and its desire to use new technologies in everyday life. In the future, the strengthening of positions on the world stage is seen.

Based on the experience of the leading countries in digital development ratings, a breakthrough in the field of the introduction of digital technologies without the participation of the State is simply impossible. In accordance with the development strategy in Russia in 2020 and 2025, the state will support the digitalization process and one of the main guidelines has determined the creation of a favorable in-investment climate. In addition, the increase in the performance of export-related information and communications technology goods and services required urgent solutions to reduce the gap in ratings.

Digital Security of the Economy

The document defining the development trend in Russia is the national project "Digital Economy", the main postulate of which is the widespread introduction of digital technologies.

The main priorities of the national Digital Economy Programme are described in the relevant document. The main priorities include:

1. Develop, implement and maintain a high-speed information and telecommunications infrastructure for the transmission, processing and storage of big data accessible to all users.
2. An increase of up to 5% in Russia's share in the global volume of digital services.
3. Tripling domestic spending on the development of the digital economy.
4. Use of domestic software by government bodies, local governments and organizations. Implement the concept of import substitution not only in the field of operating systems and other software of certain departments, but also the total introduction of various software for all users.

The national project "Digital Economy" includes several federal projects.

Federal project "Regulatory Regulation of the Digital Environment" - aimed at strengthening the activities of the legislative and executive branches of government in the development of the digital economy.

The federal project "Personnel for the digital economy" is the main goal of the evolution of the education system. It is designed to provide the economy with high-class specialists with an appropriate set of competencies.

The federal project "Information Infrastructure" was aimed at developing and implementing a single information and communication space, taking into account import substitution trends.

The federal project "Information Security" is aimed at protecting against cyber threats in a single international information space, protecting the interests of the individual, society and the state.

The federal project "Digital Public Administration" is designed to transform public services and services, develop electronic government, the concept of a single window.

Federal project "Digital Technologies" - focuses on the development of revolutionary technologies radically changing existing and opening new markets.

Unfortunately, national and federal projects set only a generalized concept of development, without describing step-by-step instructions for implementing the proposed approaches.

The national program "digital economy" does not contain a direct directive on the protection of various confidential information, including personal data. In addition, some of the proposed measures could create new information security risks.

Based on existing mechanisms for ensuring information security, two approaches to minimizing such risks can be distinguished - legal and technical, the combination of which, according to Treshchev (2018), will achieve maximum effect.

Technical Approach. Specialized technical and software tools should be developed and implemented in organizations that process sensitive information. For example, scanning tools not only for vulnerabilities, but also for evidence of illegal storage of data, monitoring-ring systems of transmitted information both over networks and when sent to alienated media, systems for monitoring employees and preventing illegal actions, systems for automating the investigation of digital incidents, systems for collecting and analyzing information.

Legal Approach. According to Matthew (2017), it is necessary not only at the legislative level to implement information protection in the new conditions, but in the context of enterprises and citizens to determine the boundaries of the use of certain information.

The question of methods and ways to protect confidential information for users in the digital economy remains unresolved. Obviously, with the active development of information and digital technologies, the volume of confidential information is constantly increasing, the number of those who store, accumulate and process this data increases. The number of threats is also growing, and identifying mechanisms that will protect user data becomes a very urgent task.

2 Conclusion

The public sector of Russia has the most critical amount of data. Current examples of positive trends in digitalization are electronic medical records of citizens, electronic work books. Among the main potential threats, the number of which is also increasing, is the fact that the volume of versatile confidential information of great interest to attackers, who have long assessed the development potential and the scale of digitalization of modern society, using virtual space to realize tort risks, has sharply increased. Potential financial losses from misconduct today can be very significant. An example is telephone terrorism, reports of mass mines of retail chains, schools and kindergartens, which swept through Russia in a wave. The repeated recurrence of such cases, together with the lack of media coverage of the problem, made it impossible to eliminate all potential risks in the field of information and digital technologies. According to the work of Oblasov (2019a, b), in practice we used a response strategy rather than a decision, so the use of information protection measures aimed at ahead of possible delicts at the State level was the only way, in the context of a digital transformation in the economy, to ensure the protection of society, the individual and the State.

The development of modern technologies also requires the evolution of protection mechanics. The use of protection against unauthorized access, firewall, intrusion detection and prevention systems, antivirus protection systems in the context of implementation, for example, additional and virtual reality, as described by Treshchev (2019), is no longer sufficient to ensure the confidentiality, integrity and availability of information.

In the context of the total introduction of new information technologies and the mass use of computer equipment to solve a wide range of problems, setting a trend for digitalization of the economy is a priority area for the development of society and the state.

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Approaches to Assessing the State of Transport Services in the Region

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Abstract. Purpose: The purpose of this study is to identify approaches for creating an integrated index that reflects the relationship between transport service development indicators and GDP dynamics.

Methodology: the approach of the authors is to assume that if we have reliable information on trends in the level of development and quality of the transport service system, it will be possible to create a model by which it is possible to assess future trends in the generalizing indicators of economic development of the region or state (for example, GDP). At the same time, at the first stage of the study, an integral indicator of the development of the transport service system of the region can be formed on the basis of primary indicators.

Conclusions: as a result of the study, the dynamics of the development of the transport system and GDP were analyzed, the impact of investments in infrastructure on the development of the economy was estimated, the existing integral indicators of the assessment of the transport service system were analyzed, a methodology for the formation of an integral indicator of the transport service system of the region from the point of view of targeted management of GDP growth was proposed.

Scientific relevance: proposed method of estimating the state of a transport service system of a region enables to obtain an integral index value over several retrospective periods, to make a forecast and to form a proactive control model based on primary indices included in the model.

Keywords: Transport system · Development · Transport · Region · Model · Gross domestic product · Economic growth

JEL Code: R40 · R42 · R10 · E6

1 Introduction

Over the past forty years, the growth rate of world GDP has had negative values only twice: in 2009, due to the global financial crisis and in 2015, as a reaction to the imposition of economic sanctions. According to forecasts from various organizations, including Oxford Economics, the global economy could lose 1.3% due to the spread of coronavirus infection. Despite these phenomena, the overall trend is quite positive. The Organization for Economic Cooperation and Development (OECD) gave a fairly positive assessment

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of global GDP growth. Its estimates are related to the projected growth of world GDP by 2035 by 70% (at a world growth level of 3.3–3.4%). This projection is related to two main factors - the constant growth of the world population and the pace of urban population growth, increasing consumption, the growth of world trade and tourism in the context of globalization. At the same time, the load on the global transport infrastructure will clearly increase both in passenger flows and in cargo flows. At the same time, the real throughput of the main existing transport corridors will be one of the main deterrents to increasing passenger turnover and cargo turnover. This relationship is obvious and can be used with a correct methodological approach for purposes not only for estimation and analysis, but also for forecasting world GDP. At the same time, GDP is a direct single-factor indicator, and the state of transport infrastructure is associated with a number of quantitative and qualitative primary indicators, according to the dynamics of which it is sometimes difficult to draw an unambiguous conclusion on the trajectory of transport infrastructure development. It is therefore important to consider approaches to the development of an adequate integrated indicator (index) of transport infrastructure that can be responsive to changes in transport infrastructure and on which proactive conclusions can be drawn on the dynamics of GDP. In our study, we proposed the indicator STSR - the state of the transport service system of the region.

2 Materials and Methods

The main indicators reflecting the results of the activities of business entities in the transport industry, such as cargo turnover and passenger turnover, are primary statistical indicators that have very similar dynamics to GDP over a fairly large retrospective period.[1] Therefore, a hypothesis can be made about their close relationship and interdependence.

At the same time, it can be noted that the dynamics of GDP growth "lags" behind the growth dynamics of the main indicators that characterize the state of the transport system, but graphically coincides in the directions of change. We can hypothesize that changes taking place in the transport infrastructure and expressed in cargo turnover, passenger turnover, cargo and passenger transportation appear earlier than changes in the same direction in the GDP indicator. There is a certain time lag between them. In addition, this gives us reason to hypothesize that the indicators of the transport system can be used in proactive forecasting of GDP dynamics. Therefore, investment in transport infrastructure is a driver of GDP growth.

"EY" company conducted a survey of industry specialists, experts of state and investment structures and foreign investors doing business in Russia. The results of the survey generally showed that there is a positive direct relationship between investment in infrastructure and the development of the Russian economy.

The special importance of transport infrastructure for the Russian economy is noted in the works of many authors. So Pinchuk D. I. (2017) considers investing in transport infrastructure an effective and reliable way to stimulate the economy. Roslyakova N. A. (2013) quantified the indicators of GRP transport infrastructure and noted the existence of a stable relationship. Scherbanin Yu. A. (2011) speaks about the positive impact of

[1] Based on materials: Ganelin M, Vasin S. Infrastructure of Russia. A great ship asks deep waters. https://elitetrader.ru/?newsid=218004.

investments in transport infrastructure on economic growth. Some authors, for example Kazakova M. V. and Pospelov E. A. (2017), pay attention to the restraining factors of the development of the Russian economy, among which, noting its insufficient development, distinguish transport infrastructure.

To date, there are certainly options for integral assessment of the state of the transport system at various levels. As an example, we can look at the infrastructure development index, which also included the transport infrastructure development index. These indices are presented in the report "Infrastructure of Russia: Development Index". The authors of the report noted that in Russia there is no single statistics and assessment of the state of the infrastructure. In the transport infrastructure development index, they included the density of road and rail networks, the quality of pavement and cargo, as well as the level of mobility of the population and some other indicators. The interregional comparison is quite correct, since it uses a single methodology for calculating the integral indicator. At the end of April 2019, an order of the Ministry of Transport of the Russian Federation No. 129[2], was issued, which presents a methodology for calculating the indicators included in the state program of the Russian Federation "Development of the transport system". One of the indicators presented and the methodology is the "transport infrastructure quality index" - indicator No. 1 in the methodology. It is an integral indicator, includes 13 private indicators, including both traditional statistical indicators, both the length of federal roads, cargo turnover, and indicators from administrative information (for example, the share of civil aviation airfields closed as not meeting safety requirements, the share of federal public roads serving traffic in overload mode). At the state level, the "Comprehensive Plan for the Modernization and Expansion of Trunk Infrastructure (CPMETI) in 2018–2024", developed on the basis of the May decrees of the President of the Russian Federation, provides for financial costs of about 6.35 trillion rubles.

"Iindex of the development of the transport complex of megacities" was developed at Moscow State University. It included 69 calculated indicators out of 200 primary (2018). There are also several global indices in the world that reflect the state and development of the transport system, infrastructure or their aspects.

Some scientists (Chhavi Dhingra 2011) use a whole system of indicators to assess the effects in the activities of transport systems. At the same time, primary indicators are also grouped, for example, indicators of sustainable transport development; transport planning indicators; Indicators of strategic and short-term public transport planning.

It is worth noting that scientists both in Russia and abroad paid attention not only to the integral indicators of the transport system and infrastructure but also to the study of the relationship between these systems and economic development. Kataeva Yu. V. (2013) proves the connection between the economy and transport infrastructure, and also quantifies the development of the Volga transport system based on the index of the development of transport infrastructure. Maksimov V. L. (2014) examines passenger

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[2] Appendix to the Methodology of calculation of the indicator of the National program of the Russian Federation "Development of the transport system", transport part of a complex plan of modernization and expansion of the trunk infrastructure for the period until 2024 and federal projects: https://www.consultant.ru/document/cons_doc_LAW_325438/d138086ec1ea01afc5cd606cd0a168d22f2ca4c7/.

turnover, conducts a cluster analysis of regions according to a number of primary indicators. Radchenko D.M. and Ponomarev Yu.Yu. (2019) cite the results of the assessment of the transport security index, showing the importance of transport infrastructure and the framework for the Russian economy.

Some works (Išoraite 2005) show that State-level transport programmes should have indicators against which the effectiveness of programmes can be judged. At the same time, a system of such indicators should be formed either before the start of the implementation of programs, or at the very first stage of their implementation. This condition is related to the need for statistical observations and data collection on these indicators. Such indicators often have programme-specific targets (levels).

The development of science and technology, the processes of digitalization of all spheres of the economy led to a discussion among scientists of new forms of development of transport systems, which were also reflected in program documents. So in the works (for example, Djordjevic and Krmac 2016) intelligent transport systems are considered as part of "smart cities". Such systems allow collecting a large number of data, which are considered as "big data" (Timothy and Alyas 2019; Karatsoli and Nathanail 2018). These data can be analyzed and aggregated into groups of similar indicators (e.g. Li et al. 2014): transport structure, traffic information service, traffic efficiency, traffic safety, etc.). In Russia, by Order of the Government of the Russian Federation of December 21, 2019 No. 3136-r[3] about 25.2 billion rubles are allocated to 56 regions to stimulate the creation of intelligent transport systems.

In our study, we introduce the concept of a transport service system (TSS), a transport service system of the region (TSSR), the integral assessment of which can be carried out both by region (subject of the Russian Federation) and at the national level. At the level of an individual region, it is a region transport service system (TSSR). At the same time, in the transport service system we allocate three main groups for compiling indicators: transport infrastructure, rolling stock, investments. We conducted the study in two areas: the first is related to the formation of approaches to the integral indicator of the transport service system of the region; second is related to possibility of prediction of GDP trajectory based on estimation of trajectory of integral index of transport service system. At the same time, in the second direction, it is first necessary to evaluate the relationship between the development of the economy (main indicators) and the state of the transport service system.

The formation of an integral indicator is always associated with the combination of a sufficiently large amount of indicators reflected in statistics, available in administrative data, data of individual companies, analytical reports into a single indicator according to any methodology. At the same time, there are a large number of factors that affect the dynamics of primary indicators (state programs, projects, monopolies, etc.). Comparability of available data over different time periods and homogeneity (consistency) of the study methodology are important factors for obtaining results and conducting comparative analysis and analysis of the TSSR dynamics. The collection "Transport in Russia" (2018) contains data for 2005, 2010, 2015–2017, for the periods 2006–2009, 2011–2014 data should be taken from other statistical yearbooks, on the official website of Rosstat, the open data portal. The specific volume of comparable data by year and region also

3 https://www.consultant.ru/document/cons_doc_LAW_341430/.

affects the ability to use different methods of data processing and the convergence of primary indicators into a composite integral index.

We will present the methodology for developing the TSSR integral index according to three blocks of indicators but their number may be larger.

3 Results and Discussion

In our case, the integral index was defined as the "state of the transport service system of the region" (STSSR). When calculating the integrated index of the state of the transport service system of the region, the main indicators available in official statistics were initially selected, reflecting the volume of passenger traffic, freight traffic and the number of accidents with victims by 100 tons. At the same time, we used data throughout Russia. The next phase involved the inclusion of these indicators in the targeted economic management model of the region (country). At the same time, the STSSR state is one of their sub-goals of a lower level, changes in which certainly affect the state of GRP or GDP. Depict this in the format of the "target tree" (Fig. 1). The goal of the highest level is to increase the level of GRP. Sub-target - improve the STOR condition. Sub-goals of the third level: to reduce the number of accidents (accidents), to increase the efficiency of passenger transportation, to increase the efficiency of freight transportation. At the same time, there may be sub-goals of a lower level.

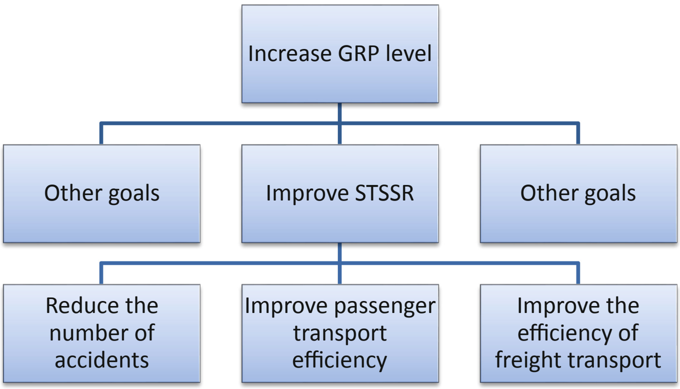

Fig. 1. Example of a target system

The priority of sub-goals for achieving the goal can be quantified based on known expert methods. For our case, the mathematical expression of the STSSR integral index will look like this:

$$\text{STSSR} = \sum_{i-1}^{n} a_i x_i, \tag{1}$$

where a_i, - is the value of the coefficient at x_i, determined by expert means; x_i, - value of the i-th primary statistical indicator;

n – number of indicators.

This formula is universal and can be used for different levels of targets. When revealing the sum sign, it is necessary to take into account the real economic dependence of the primary indicator on the integral one and put the corresponding mathematical sign "plus" or "minus". It is logical that increase in number of accidents (numbers of road accident with victims) is adverse for STSSR therefore we put the sign "minus", growth of volume of freight transportation (in a formula (2) - OGP), or increase in volume of passenger traffic (in a formula (2) - OPP) - will well be reflected in a condition of STSSR therefore we put the sign "plus".

The result of the calculations of priority vectors according to the T Saati method is the formula for determining the STSSR index:

$$\mathrm{STSSR} = 0,292 \cdot \mathrm{OPP} + 0,605 \cdot \mathrm{GSV} - 0,103 \cdot \mathrm{RTIF}. \tag{2}$$

As an example, the calculations for the Russian Federation as a whole are presented in Table 1.

Table 1. Results of calculation of normalized STSSR index

Indicators	2005	2010	2015	2016	2017	2018
Transported cargo, million tons	9,167	7,750	7,898	7,954	8,071	8,265
Passengers transported, million people	30,128	22,065	19,122	18,689	18,482	18,144
Number of accidents per 100 thousand people	155.6	139.6	125.7	118.4	115.4	114.5
STSSR	14,327.38	11,117.35	10,348.97	10,257.16	10,267.81	10,286.58
STSSR (scaled)	1.291	1.001	0.932	0.924	0.925	0.927

We calculated as the absolute value of the STSSR indicator in conditional units, which serves as the basis for determining the normalized STSSR value $_{\text{(scaled)}}$. The normalized value is obtained by dividing the STSSR value for a specific period (year) by the average STSSR value for the entire period. Such normalization shows the deviation of the value of a particular year from the average.

The dynamics of the normalized STSSR index is shown in Fig. 2.

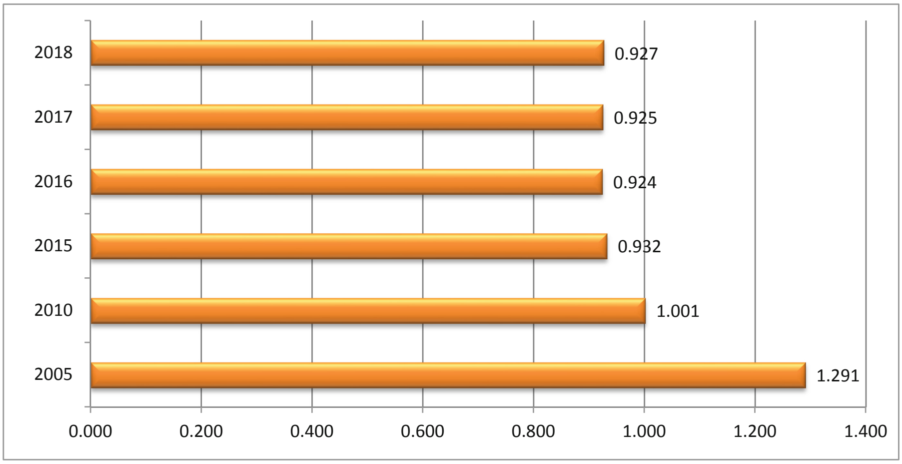

Fig. 2. STSSR value $_{\text{(scaled)}}$, units.

4 Conclusion

This technique allows you to obtain an integral indicator of the state of the transport service system of the region, is universal, can be used in calculating the STSSR of any region or country. In addition, the TSSR value can be used to estimate the degree of communication between the transport service system and GDP (GRP). Normalization allows the use of the STSSR index in interregional studies. The inclusion of the transport services index in the target regional management model reflects the relationship and impact of transport infrastructure on economic growth.

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Directions of Digital Financial Technologies Development: Challenges and Threats to Global Financial Security

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Abstract. Purpose: This paper is aimed at studying the problem of methodology development of threats and challenges to society, the economy and people that arise in the course of human-digital interaction in the financial sphere.

The goal is global in scope, allowing linking the financial activity of individuals (micro-level) with the financial security of the country (macro-level) from "Cifrogenic" ("digital-genous", derived from causes related to digital technology) challenges and threats, with a supranational character.

Design/methodology/approach: The tools of systemic, structural functional and institutional approaches were used in the process of substantiation of theoretical provisions, data analysis, conclusions and recommendations that allowed analyzing and taking the complex areas of financial development of digital technology and human interaction and digital technology in the financial sector are analyzed as the studied material.

A review of the literature on the selected topic has shown that relations arising in the course of human-digital interaction in the financial sphere are discussed in many papers of such scholars as Alifanova et. al. (2019), Alifanova et. al. (2018), Reshetnikova et al. (2019), Zmiyak et al. (2019), Reshetnikova andMagomedov (2020).

Findings: There are opportunities to form a "digital financial profile" of a person who becomes an object of advertising, marketing, sociological, political research, and ultimately can become a subject of social rating and a source of information for managing the financial behavior of a person and the country's population as a whole.

Originality/value: The functionality of digital technologies creates a new platform for human financial activity: supporting the adoption of credit and investment decisions, the availability of financial products and services and their personification through processing and analysis of big data, new types of investment assets resulting from blockchain technology and much more. At the same time, moving ever-increasing volumes of financial activity into virtual space, changing the format of interaction (from traditional Business-to-Customer to Peer-to-Peer and even Digital Profile-Digital profile), the emergence of Fintech companies, digitalization of the financial sector has wide range of consequences. So, financial organizations no longer interact with a person, but with his "digital profile", with a psychological-digital portrait.

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Keywords: Financial globalization · Financial safety · Threats and challenges · "Cifrogenic"/"digital-genous" · Digital economy · Fintech

JEL Code: E44 · E69 · F20 · G10 · G18 · H87

1 Introduction

In the modern world, social philosophy, sociology and other areas of humanitarian knowledge are constantly looking for a balance between the attractive prospects of transforming social reality under the influence of technology and the risks of manipulating a person's consciousness and his behavior in a society of mass communications and big data. A separate area of this scientific problem is the interaction of man and digital technologies in the financial sector, leading to a change in the model of financing the economy.

This increases the relevance of solving the problem of human-digital interaction in the financial sector. On the one hand, the functionality of digital technologies creates a new platform for human financial activity (including new types of investment assets resulting from blockchain technology, the availability of financial products and services and their personification through the processing and analysis of big data, etc.) but, on the other hand, moving more and more financial activity into virtual space, changing the format of interaction (from traditional Business-to-Customer to Peer-to-Peer and even Digital Profile-Digital profile).

From a scientific point of view, an understanding of the duality of digital financial technologies is required: as the basis for the development of innovative processes in the financial sphere and as a source of risks for society, the economy and man. Scientifically based decisions are needed to identify "Cifrogenic" challenges and threats, identify the directions of their impact on global and national financial security, determine the qualitative parameters and quantitative characteristics of these challenges and threats, assess the consequences of their implementation for financial security, analyze the effects of using digital financial technologies, and on this basis, forecasting future transformations and developing preventive solutions.

Digitalization of the economy involves the transition of economic processes into a digital environment, which is accompanied by significant changes and updates in many aspects.

The strategy for the development of the information society in the Russian Federation for 2017–2030, approved by Decree of the President of the Russian Federation dated May 9, 2017 No. 203, is aimed at creating conditions for the development of a knowledge society in the Russian Federation.

In Russia, ensuring the accelerated implementation of digital technologies in the economy and social sphere is one of the national development goals (Decree of the President of the Russian Federation of May 7, 2018 No. 204 "On National Goals and Strategic Tasks of the Development of the Russian Federation for the Period until 2024").

2 Materials and Method

In the context of the problem posed it is necessary to pay attention on key aspects:

1. Global problems, threats and challenges, its influence on the modern condition of national safety;
2. Flourishing of digital Fintech, their essence and impact on the state, people, and society.

An analysis of the current state of research on these aspects is given below.

1) The globalization of the world economy leads to the fact that international organizations are increasingly controlling the world economy. Gradually, a process occurs in which the management powers of a particular country are redistributed to the international level as written at work of Silvestrov (2014).

Currently, the world economy is entering a new phase of geo-economic development, where competition is becoming a major factor between the leading areas of economic interaction. Economic competition will be carried out mainly between internationally developed territories, regions and enterprises, including such as transnational corporations, losing their nationally oriented significance. Accordingly, Russia and its regional entities are faced with a difficult choice: either to shut down from the influence of globalization and strive to do everything necessary on their own for their domestic market (autarky), or to take the path of creating an innovative, open world, competitive economy, attractive for investment and multilateral cooperation in the framework of strategic partnership (Shevchenko 2019).

2) Authors Bratersky et al. (2019) formulate a number of signs of a new regional order of the Asia-Pacific countries, which may develop into a new international (global) order. This type of system, according to the authors, will be more competitive and less hierarchical, within its framework there will not be a single dominant force or ideology, it will be based on many centers of power. Such a world order is more attractive to Russia than a unipolar Atlantic order. It will give the country the opportunity to use its own comparative advantages, such as territory, resources, hard power, a fairly rigid political organization and the ability to mobilize resources for strategic purposes.

In the work of the author Bauer et al. (2019), an analysis of a new trend that replaces the computerization and informatization of society, - global society digitalization.

Schueffel (2016) explores the complexity of Fintech and defines it as a new financial industry that uses technology to improve financial performance by creating innovations in financial services. In his article on evolution, Fintech, Arner et al. (2015) describes the development of Fintech as a continuous process, "during which finance and technology evolved together" and which led to numerous gradual and destructive innovations, such as Internet banking, mobile payments, crowdfunding, peer-to-peer, Robo -Advisory, online identification, etc. Authors Chishti and Barberis (2016), Ferreira et al. (2015), Heap and Pollari (2015) provide a number of examples of how the interaction of finance and technology has led to innovation. In the financial services sector (eToro), in operating companies (Citi), at the government level (for example In Israel), SWIFT. In each of these cases, Fintech significantly stimulates innovation.

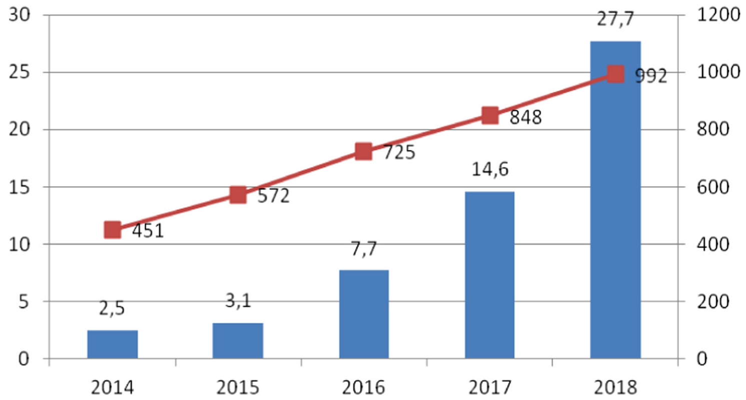
The authors Kuladzhi et al. (2019) see the use of digital technologies in solving national projects and programs.

An analysis of the implementation of modern digital technologies in the financial sector is carried out by the authors Nikonov et al. (2018).

The work Karabarbounis et al. (2014) studied the stages of development of society under the influence of industrial revolutions, identified positive effects, identified risks and threats to economic development from the massive introduction of digital technologies.

3 Results

With the growing interest in this area of digitalization of financial technologies, the volume of investment in the Fintech industry is also increasing. Large financial companies sponsor research into the implementation of a distributed database registry in relation to their specializations and activities. So, in 2017, the total volume of investments in the global economy in the sphere of Fintech startups amounted to $ 14.6 billion, which is almost twice as much as in the previous 2017, a further increase in market volumes continued in 2018 (Fig. 1).



Source: Based on data from CB Insights «Global FinTech Report». URL: https://www.cbinsights.com/research/report/fintech-trends-q3-2017 (date of access: 12.03.2020) and completed by the authors.

Fig. 1. Annual total investment in Fintech startups in the global economy for 2014–2018; Investment size, US Dollars bullions; Amount of deals.

Fintech often comes with a large price tag. Usually, this is an upfront cost and can cause quite a bit of sticker shock. However, the technologies like artificial intelligence and blockchain are aimed to optimize financial services and banking.

There are many fields affected by Fintech, particularly:

- Banking
- Insurance
- Loans
- Personal finance
- Electronic payments
- Loans
- Venture capital
- Wealth Management

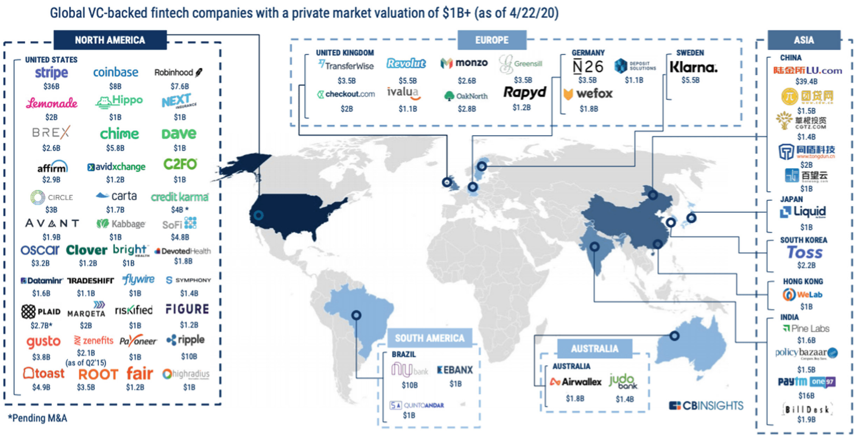
In the coming years, all of these are getting a digital facelift. The tides are turning and more than ever, companies need to get on board or risk sinking the ship. Brands who are pioneers in the Fintech sector include:

- Apple
- Goldman Sachs
- PWC
- JP Morgan
- Samsung
- Amazon
- Paypal

To drive the point home, we've compiled a list of some of the most recent stats to support the argument that Fintech is the future and won't be going anywhere, anytime soon.

- The global financial sector is expected to be worth US dollars 26.5 trillion in 2022 with a CAGR of 6%.
- The Fintech market share across 48 Fintech unicorns is now worth over US dollars 187 billion (as of the first half of 2019). That is slightly over 1% of the global financial industry (Fig. 2).

- In a 2015 Goldman Sachs study, it was estimated that Fintech may eventually disrupt up to US dollars 4.7 trillion of revenue that traditional financial services now make.
- 60% of credit unions and 49% of banks in the U.S. believe that Fintech partnership is important.
- One of the biggest Fintech products is digital payment, which holds 25% of the Fintech market.
- E-commerce is one of the biggest growth drivers of Fintech, with a CAGR of 10–12% thanks to consumer behavior.
- 60% of consumers want to transact with financial institutions that provide a single platform, such as social media or mobile banking apps.
- 96% of global consumers are aware of at least one Fintech service or company.



Source: CB Insights. «Global FinTech Report» The world's Fintech unicorns.

Fig. 2. The largest "Finteh-unicorns" as of Q1 2020, the market value of Dollars US 252 billion.

- By the year 2022, mobile transactions are projected to grow by 121%. This will eventually comprise 88% of all banking transactions.
- Consumer spending in an app store is projected to increase by 92% to US dollars 157 billion worldwide in 2022.
- By the year 2022, almost 78% of the United States millennial population will become digital banking users.
- By the year 2021, credit cards, debit cards, and e-wallets are projected to surpass cash at all point of sales.

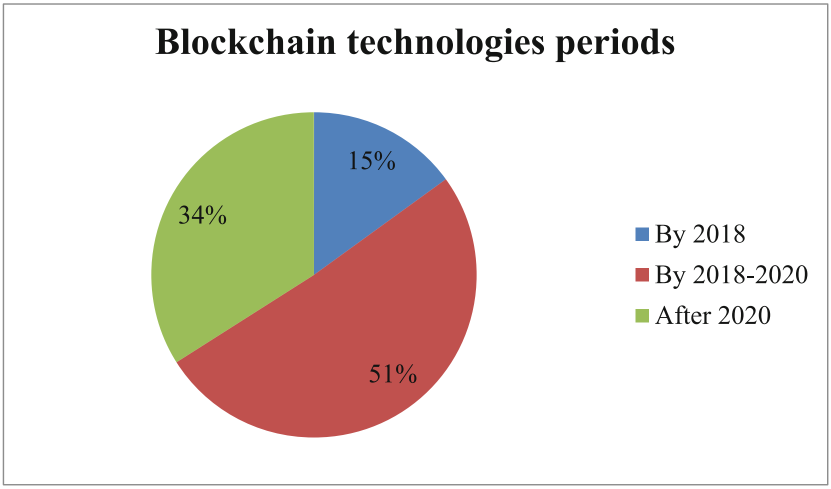
Blockchain is a distributed ledger technology (DLT) that allows data to be stored globally on thousands of servers.

Approximately 24% of people around the world are already familiar with blockchain technology.

- Blockchain and regtech (regulatory technology) are two of the fastest-growing segments of the Fintech industry.
- By 2024, blockchain tech is set to hit US dollars 20 billion.
- Peer-to-peer (P2P) (digital lending) was worth US$43.16 billion in 2018 and is expected to rise to US dollars 567.3 billion in 2026 with a CAGR of 26.6%

According to 2017 data from the analytical agency IBM, the majority of large banks included in the survey group of 200 companies plan to implement blockchain technology in their business processes from 2018 to 2020. Blockchain will demonstrate the peak of its development in the field of applicability with respect to financial markets by 2025 (Fig. 3).

The use of blockchain technology is driving changes in many elements of supervision and accounting. Trading processes and the exchange of information become transparent, faster and significantly cheaper, due to the absence of various kinds of costs (for example, the costs of specifying and concluding a contract, the costs of legal defense, bank



Source: Based on data: «IBM» «Power of blockchain in financial services». URL: https://www.ibm.com/blogs/systems/power-blockchain-financial-services (date of access: 12.03.2020) and completed by the authors.

Fig. 3. The distribution terms of the technology blockchain introduction, world's largest banks in their business processes according to 2018.

commissions). For banking institutions, stock exchanges and other financial institutions, this technology opens up global prospects for the development of the entire system of operations. But despite its potential, blockchain is also a serious threat to the financial intermediary industry.

Digitalization of the economy, on the one hand, is the basis for the innovative development of modern economic systems; on the other hand, it creates new threats and risks.

4 Conclusion

The process of globalization and the digital transformation of society form in the global economic space previously difficult to predict phenomena, and also contribute to a change in the ratio of financial capabilities of all players on the world stage. The creation of the Internet of things (industrial Internet), artificial intelligence and blockchain technology, the accelerating capitalization of cryptocurrencies served as the basis for the emergence of an innovative financial ecosystem that is fundamentally different from the traditional one, which is forced to confront new challenges and threats.

The current situation caused by the pandemic of COVID-19 infection has made serious adjustments to the economy of most countries of the world. Anti-epidemic measures led to the shutdown of enterprises in various industries.

According to The Financial Action Task Force (FATF) report "COVID-19-related Money Laundering and Terrorist Financing: Risks and Policy Responses", the main risks associated with money laundering and terrorist financing in connection with COVID-19:

- The increase in COVID-19-related crimes, such as fraud, cybercrime, misdirection or exploitation of government funds or international financial assistance, is creating new sources of proceeds for illicit actors.
- Measures to contain COVID-19 are impacting on the criminal economy and changing criminal behavior so that profit-driven criminals may move to other forms of illegal conduct.
- The COVID-19 pandemic is also impacting government and private sectors' abilities to implement anti-money laundering and counter terrorist financing (AML/CFT) obligations from supervision, regulation and policy reform to suspicious transaction reporting and international cooperation.

These threats and vulnerabilities represent emerging money laundering (ML) and terrorist financing (TF) risks.

At the international level, the FATF is working with the Committee on Payment and Market Infrastructures and the World Bank to help ensure coordinated policy responses for the continued provision of critical payment services against the backdrop of the COVID-19 crisis. The FATF, International Monetary Fund, World Bank, and United Nations are working with their membership to mitigate the impacts of the COVID-19 crisis, including through the use of AML/CFT measures, where relevant. In addition, the FATF is working with its members and the FATF-Style Regional Bodies to identify and share good practices in response to common issues faced in many affected countries.

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Digital Economy Development Problems in Russia Under the Conditions of Venture Projects Elevated Uncertainty

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Abstract. Purpose: The purpose of the study consists in the assessment of the current level of digital economy development in Russia, as well as in the identification and analysis of the digitalization progression problems with the consideration of the challenging business environment.

Design/methodology/approach: In the course of the research, methods of analysis and synthesis, comparison and generalization, abstract-logical method and other methods of scientific cognition are applied to study the current economic situation, factors affecting digital economy development in Russia, to highlight and assess the barriers for digital transformation.

Findings: Based on the results of the study, the conclusions are drawn regarding the current level of digital economy development, the main problems of its progression are determined, which require solutions to ensure effective digital transformation of business in Russia.

Originality/value: The results of the study, the conclusions made are of theoretical significance and can be used for further research in the field of digital economy development. The practical significance of the work can be observed in the results of assessing the current level of digital economy development in Russia and highlighting the problems, which hinder the process of digital transformation that can be useful to Russian companies planning to digitalize their business.

Keywords: Digital economy · Digital transformation of business · Challenging business environment · Digital skills

JEL Code: 011 · O12 · P47 · M20 · M21 · L81

1 Introduction

Most of the changes observed today around the world are caused by such a quintessential driver as the economy digital transformation. The digital economy represents the socio-economic system based on digital data and technologies, the management of which with the help of correspondent skills, devices and communications allows providing effective solution to the technological, economic, social, environmental, cultural, organizational and other tasks (Babkin et al. 2017; Zozulya 2018). The digital transformation changes

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the means of communication inside and outside the company, the means of service provision and product sale, the ways of product manufacturing and delivery, business models, along with the other activities of companies. The key features of the digital economy include flexibility and adaptability. In the digital economy the use of the Internet is expanding, e-commerce volumes are growing rapidly, new products, services and markets are arising, and the transparency of transactions and payments is provided.

Under the conditions of COVID-19 pandemic, visible acceleration of digital economy growth is observed, the significance of which can hardly be underestimated in the situation when companies and consumers are obliged to carry out operations entirely in the digital environment. However, the existing problems of digital economy development in Russia do not allow achieving the desired level of business efficiency.

2 Materials and Methodology

Foreign and Russian scientists such as Burton B., Brennen S., Karlsson V., Queen J., Morrar R., Nichols D., Pfol G., Tucker K., Fong D., Schwab K., Avdeeva I.L., Babkin A.V., Galimova M.P., Dobrynin A.P., Kryukova A.A., Kupriyanovsky V.P., Sudarushkina I.V., Khalin V.G. and others made a significant contribution to the study of the essence, features and problems of digital economy development.

It should be clarified that in order to identify and study the barriers, which hinder the economy transformation into digital environment, it is necessary to apply a holistic approach and consider the challenging conditions, that are currently prevailing in the Russian business environment. Emphasizing the importance of existing researches in this field of knowledge, it should be noted, that some of them address global problems of digital economy development, while others focus on the one or more barriers for digitalization. The purpose of this study is to analyze the current level of digital economy development in Russia, to identify the existing problems of its progression in complicated conditions of elevated uncertainty of the implementation of venture innovative projects. Within the framework of the research, the following methods of scientific knowledge are applied: methods of analysis and synthesis, generalization, abstract-logical research method, induction, deduction and trend analysis.

3 Results

It should be noted that at this time the digital economy development in Russia is complicated by the influence of many factors. The country is only in the primary stage of digital economy development. The dynamics of digital economy contribution to the gross domestic product of Russian Federation for the period from 2015 to 2018 is shown in Fig. 1.

According to the studied statistical data (Fig. 1), the contribution of digital economy to the GDP of Russian Federation has slightly changed during 2015–2017. For the purpose of contribution measurement it is considered, that the digital economy refers to market segments in which value added is created with the use of digital technologies. In 2017 the decrease of this indicator is observed from 2.8% in 2016 to 2.1%. In 2018 the share of digital economy in the country's GDP increased 2.5 times to 5.1%. However,

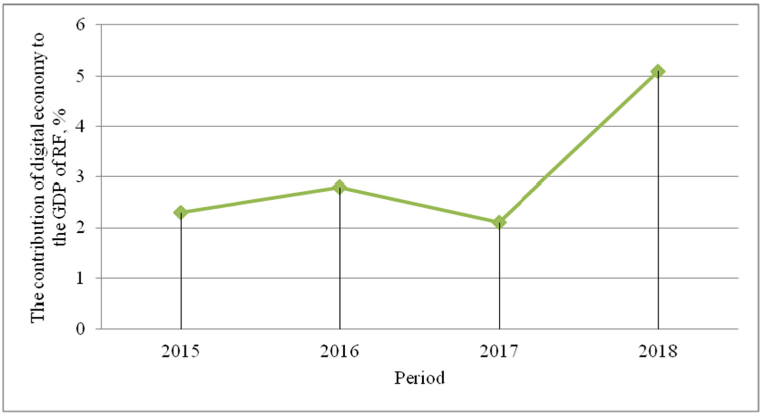

Fig. 1. The contribution of digital economy to the GDP of RF for the period 2015–2018, %. *Source*: compiled by the author with the use of statistic data of the Federal State Statistics Service.

this indicator remains at the low level. For reference, in 2017 the contribution of digital economy to the GDP of the USA was 6.9% (Digital Economy Accounted for 6.9 Percent of GDP in 2017 2019), the similar indicator for China was 32.9% (Miura 2018), which represents the relatively high growth rate of digitalization in the leading countries in this field. In 2018, when assessing the share of digital economy in the GDP of Russian Federation, the following segments were studied: infrastructure and communications, electronic commerce, marketing and advertising, digital content. Approximately 50% of Russia's digital economy is accounted for by e-commerce (2 trillion rubles in 2018).

The dynamics of the business digitalization index in Russia and leading countries by this indicator for the period from 2017 to 2019 is shown in Fig. 2.

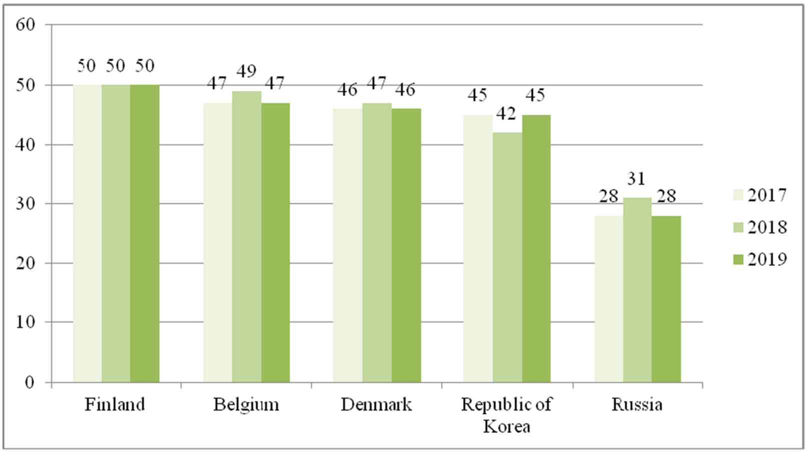

Fig. 2. The dynamics of business digitalization index in Russia and leading countries by this indicator for the period 2017–2019. *Source*: compiled by the author with the use of NRU HSE issues for 2017, 2018, 2019 (Digital economy: express information, business digitalization index).

The business digitalization index represents the speed of business adaptation to digital transformation and integrates five indices (the development of digital skills of company employees, the use of digital technologies in the organization's activities, etc.). In conformity of the data shown in Fig. 2, there is a significant lag of Russia behind the leading countries in the field of digitalization. Finland ranks first in the rating (50 points) throughout the study period, in 2019 Belgium ranks second (47 points), Denmark ranks third (46 points) and the Republic of Korea ranks fourth (45 points). Russia ranks 31st with 28 points versus 30 points in 2018.

It is worth to mention low indicators of the use by the Russian business sector of systems which automate business processes (Digital Economy: 2020: brief statistics digest 2020):

- 21.6% of companies use ERP-systems (systems designed for planning and managing the company's resources for their optimization);
- 17.6% of companies use CRM-systems (customer relationships management systems);
- 10.1% of companies use SCM-systems (supply chain systems).

The percentage of Internet users in the business sector of Russian Federation and other countries is shown in Table 1 (data of 2018 or of the years for which data are available).

Table 1. The use of internet by business sector in Russia and other countries

Country	The share of companies using Internet (as a percentage of the total number of companies)	
	For procurement	For product sales
Sweden	78	32
Czech Republic	61	25
Finland	51	24
Germany	56	22
United Kingdom	53	22
Estonia	26	20
Russia	20	15

Source: compiled by the author with the use of statistic data (Digital Economy: 2020: brief statistics digest 2020)

According to the data from 2018, only 15.4% of Russian business organizations use Internet for product sales and 19.9% of companies use it for procurement. However, a rather high percentage of enterprises use Internet for procurement in developed economies: 78% in Sweden, 61% in the Czech Republic, 56% in Germany, 53% in the United Kingdom, 51% in Finland. On the whole, far fewer companies use Internet for electronic trade (32% of enterprises in Sweden, 25% in the Czech Republic, 24% in Japan and Finland).

In the rating of the countries of the world in terms of global digital competitiveness IMD World Digital Competitiveness Ranking, the leaders in 2019 are the USA, Singapore, Sweden, Denmark, Switzerland, Netherlands, Finland, ranking from first to seventh respectively (IMD World Digital Competitiveness Ranking 2019). In this rating at the sum of the three studied criteria (knowledge, technologies and readiness for the future) Russia is in 38th place. According to the rating of the most innovative countries of the world Bloomberg Innovation Index 2019, which is composed by the American company Bloomberg, Russia is in 27th place, giving way to South Korea, Germany, Finland, Switzerland, Israel, Singapore and other countries which are leaders in the field of digitalization (Bloomberg Innovation Index 2019).

It is important to mention, that at present a number of factors complicates business transformation to the digital reality, implementation of venture projects and development of the new economy in Russia. These factors include the following:

- conflicts emerging in the world commerce;
- crisis caused by the economic contraction during the COVID-19 pandemic;
- “price war” in the oil market;
- low level of investment in business activity and insufficient support of small and medium-sized businesses;
- inflation rate increase;
- high business rates;
- increase of government budget expenditures for the remediation of crisis consequences, etc.

Based on expert estimates, according to the results of 2020, the Russian economy is expected to contract by 15–20%, basically because of the “price war” in the oil market and crisis consequences of COVID-19 pandemic. In the days ahead a lot of companies may exit from the market and close up projects due to the lack of investments, labor forces and physical resources for their implementation, budget cut for marketing and advertising campaigns, reduction of staff and other negative crisis outcomes. Digitalization of business would solve a number of financial, organizational, managerial and marketing problems, but to achieve these solutions it is necessary to overcome the existing barriers in the field of digital economy development in Russia.

As known, the digital economy is based on digital technologies and complex processes. Corresponding personnel are needed to build digital platforms and develop software, improve equipment, implement various kinds of functions in the digital environment. In the context of digital economy the demand for traditional jobs is decreasing and the demand for personnel with digital skills is increasing (Valenduc and Vendramin 2016). Such personnel should include advanced PC users, be able to work in word editors and spreadsheets, in programs for editing photo, audio and video materials, adjust software configuration settings, install software and operation systems, and so on. The demand for new generation personnel with a new set of skills that can accomplish functions of innovative products’ development, maintenance of complex computer and engineering systems and control of autonomous systems is increasing (Zozulya 2018).

One of the basic skills is the ability to develop software and mobile applications using programming languages. It should be noted that according to the statistics for 2018, only 1.1% of the Russian population aged 15 years and older has the specified skill. 50% of the population of the Russian Federation does not at least one of these digital skills, and 31.7% of the population aged 15–74 have a lack of Internet skills (Digital Economy: 2020: brief statistics digest, 2020). The problem lies not only in the shortage of personnel for working in the digital environment, but also in the lack of effective educational programs and training practices. Both public and private investments are required for the development of practice-oriented training programs for teaching digital skills and computer knowledge, along with the organization of personnel education for building digital competencies to solve new problems.

The lack of a regulatory framework is one of the significant problems of digital economy development in Russia. Various experts highlight the legal complications which prevent digitalization from progressing in the Russian business environment, including issues of data cybersecurity, protection of intangible assets, defining the nature of new digital and electronic assets of companies, issues of digital business state regulation, etc.

Another problem of digital economy development in Russia under current conditions is the underdeveloped digital infrastructure, which is considered as a combination of technologies and equipment, which create digital space, including computing and telecommunication capacities, digital markets, and electronic networks (Oleynikova 2019). Apart from relatively quickly spreading components of digital infrastructure, including Internet, Wi-Fi networks, mobile telecommunications services, efforts should also be made to develop digital platforms, software, digital systems and computer equipment, robots, sensors, vehicles and satellites.

No less important for digital economy progression can be solution of information infrastructure problems. Russia does not have any database or integral information content concerning digital business projects, which is necessary to familiarize venture investors and business angels with proposed and ongoing projects, as well as inform businessmen about tenders, subsidies, grants, and digital business supporting measures. The challenging issue is also a lack of statistical and analytical information describing the digitalization level of various sectors and regions, necessary for tracking and processing indicators, developing and correcting digitalization strategies at the regional level.

In the eyes of some experts, the underestimation of digital business transformation advantages by entrepreneurs is a fundamental barrier to digitalization. So, according to the data from October 2019, 21% of the leaders of Russian companies are not interested in switching their business activity to the digital format (Medium and small-sized business is insufficiently involved in the digital transformation process 2019). This situation may be due to the fact that at the moment the management of Russian small and medium-sized businesses are not sufficiently informed about the concept and technologies of the new economy, the advantages and challenges of their use, the possibilities of introducing digital technologies and restructuring business models, the ways of using digital technologies to improve business processes, as also about the support measures that are provided by the state as part of the implementation of digital business development programs (Galimova 2019). The management of many companies refuse to switch to the digital level due to the high risks of digital business transformation (Brennen and Kreiss 2014) associated with:

- cybersecurity;
- investments;
- organizational, technical, marketing and other changes;
- limitation of financial capacities;
- lack of experience, comprehension and practice of company transformation to the digital level;
- lack of information needed;
- problems concerning organizational culture and structure changes.

For another thing, the prospects for digital transformation of business and society in Russian Federation strongly depend on the efficiency of overcoming existing administrative burdens. Achievement of such key characteristics of digital economy as high speed, mobility, and flexibility of business processes' accomplishment is highly hampered by administrative barriers. The problems of bureaucratization, agreement of management decisions and various issues, access to credit, lack of standards in the field of digital products require companies to spend high time and financial resources, thereby slowing down the most important key processes implemented in the organization. Radical changes of established practice of business regulation are needed to accelerate digitalization.

It appears that digital economy development also requires adjustment of the tax policy of Russian Federation. Against the backdrop of new digital models of entrepreneurial activity, complications arise in the field of tax determinancy of procedures related to the implementation of one or another disruptive business model, price setting, digital platforms' use, etc.

4 Conclusion

The changes affecting business and society as a whole due to the COVID-19 pandemic and other unfavorable factors for economy development, on a first-priority basis test companies and consumers for flexibility, since such changes require dynamic restructuring of business models and consumer behavior. The reorganizations are observed in many companies in order to allow their personnel to perform functions in the digital environment on a remote basis. In the process of such transformation, it becomes possible to develop a flexible digital ecosystem of companies operating in different time zones and locations. To achieve this goal, companies should develop digital infrastructure, provide their business with the required information, communication and other technologies, along with the equipment needed. The advantage of digitalization is the stimulation of business innovation-driven growth and introduction of new opportunities for economic growth (Knickrehm et al. 2016). However, many Russian entrepreneurs continue to carry out traditional analog business activity, choosing not to implement venture digital projects for a number of reasons, which are studied in this paper.

The following problems of digital economy development in Russia in current economic conditions are discussed in the paper:

- lack of personnel with digital skills;
- lack of efficient educational and training programs for digital competences' development;
- insufficiently developed digital infrastructure;
- lack of regulatory framework in the field of digital economy;
- financial problems, lack of investments;
- problems of informational infrastructure;
- demotivation of the management of small and medium-sized businesses in digitalization, insufficient awareness of digital transformation opportunities;
- high risks of digital transformation;
- administrative barriers;
- the necessity of tax policy adjustment for businesses operating in digital environment.

The solution of listed problems seems to be a long and complicated process, especially in the current crisis environment for Russian economy development. However, it should be noted, that crisis is not only a negative phenomenon for the economy, but it can also serve as a necessary driver for business digital transformation, since the digital format of business processes' accomplishment can significantly increase the efficiency of company's activity.

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Forming the Human Resources Potential for Innovative and Technological Development of the Region Within the Framework of the "Triple Helix" Model

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Abstract. This paper is aimed at searching for new approaches to assessing and developing human resources for innovative and technological development of the region.

In attempt to conceptualize the influence technological changes exert on labor market as a whole and specifically on engineering occupations, the authors underline non-linear nature of such influence and further substantiate the need for employing for its analysis the labor market design concept and flow-oriented approach. Taking into account the network nature of communications in the environment system and the stakeholder approach, the possibility of using "horizontal" mechanisms for skills development within the framework of the triple helix model is considered.

Forming triple helix model of cooperation requires strengthening engagement of business, science, society and education in human resources accumulation. Due to geographical differences, in Russia labor market design and establishing collaboration mechanisms can and should be conducted on a regional scale, with education, small businesses and society involved.

The authors arrived at a conclusion that due to fragmentary dynamics of the innovative market, development of key scientific and technological areas can be ensured by means of changing priorities in the engineering personnel training while taking into account current trends in high technology and innovation industries on both national and international levels. With labor market for high-technology expertise designed by the three actors of the triple helix model on a regional scale, not only will the market failures be avoided, but conditions for innovative growth will also be created.

Keywords: Human resources potential · Labor market design · "Triple helix" · Stakeholder approach · Skills and expertise

JEL Code: E24 · J21 · J22 · J24 · O33 · R11 · R13

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1 Introduction

Nowadays scientific groups, entrepreneurs and existing establishment have reached the consensus that new technologies determine the future of the economy, shift the scope of industries and alter requirements for skills. Despite the high expectations for the impact modern technologies might exert on economic growth, potential disproportions on the labor market should not be overlooked. Such lack of balance may well arise from obsoletion of popular occupations as well as from insufficient supply on the labor market that could substantially impede the introduction of new technologies and even discredit them.

Given the technological changes, it is necessary to obtain a clear understanding of the effects of the imminent technological revolution on the labor market, especially on the engineering personnel. Forecasting based on traditional methods for labor trends assessment cannot be applied for projecting innovative and technological development. The problem is not limited to random behavior of economic entities acting as employers on the market: the essence of occupations and skills, human behavior on the labor market, their preferences and expectations are undergoing a dramatic change. Traditional methods for assessing predilections and preferences of employers and employees become invalid, with uncertainty increasing progressively as generation Z representatives enter the labor force.

2 Methodology

Historical records of accumulating human resources for a technology leap cannot be applied for the current situation. To prove that, K. Schwab lists the following reasons such as "velocity of change (everything is happening at a faster pace than ever throughout the history), its breadth and depth (numerous radical changes are taking place at the same time) and transformation of the entire system" (Schwab 2017). Ironically, with productivity on the rise and active introduction of innovation, dwindling average earnings and massive job cuts are evident; people are starting to lag behind, for our skills cannot keep up with rapidly evolving technologies" (Brynjolfsson and Hitt 2000). Since engineering personnel determine the "quality" of any development, the need for such human resources should be assessed in a different manner taking into account their role and the need for proactive approach to the matter in question. Non-linear nature of the influence exerted by new technologies on the labor market is also proved by the study conducted by Deloitte Touche Tohmatsu Limited (Smith and Bishop 2016).

Since in the Russian science the influence of technology leaps on the labor market remains understudied, in terms of theory and methodology this article is based on relatively systematized foreign researches. Given the fact that innovation makes the process of recruitment needs assessment uncertain, it is essential to base such assessment on systemic constants of innovative growth that are external with respect to the labor market itself.

Since network use of information is typical of an information society (Castells 2000), human resources potential of the region should be nurtured by means of utilizing horizontal connections. Efficiency of such links was proved by the "triple helix" model

(Itzkowitz 2011) allowing for bilateral and trilateral cooperation sectors (Leydesdorff 2012). A term “configuration with negative overlap among the subsystems” was coined to refer to bilateral cooperation (Carayannis and Grigoroudis 2016). Nowadays such bilateral mode of coordination is definitely prevalent in Russia, which does not eliminate possibility of creating “a positive overlap configuration” on a regional or cluster scale.

The efficiency of such cooperation including the labor market and innovation sector is proved by the example of Latin America and India. Methodologically, modes of cooperation employed in these countries are inclined towards “Sabato triangle model” (Sabato 1979), with a role of an “orchestrator” allotted to the government.

In order to discern the distinct features of implementing this concept in Russia, we suggest considering the object of the study as an environment system based on the method proposed by G. Kleiner (Kleiner 2010). Triple helix actors cannot violate requirements to a sustainable business model. “Searching for models that ensure sustainability of the system within the given time, geographical and other scopes is ultimately aimed at reducing the cost of managing the system” (Melnikova and Bezrukikh 2017).

Labor market design concept and flow-oriented approach serve as the modern methodological basis for labor market researches. According to the DMP model, given the equal time spent on searching for a job, both unemployment and job vacancies may be present on the market at the same time while the correlation between the level of education and unemployment is inverse (Vechkanov 2014). The scope of labor market design concept embraces so-called unraveling market (Niederle et al. 2008). Such phenomenon occurs in case of a substantial disproportion between vacancies and job-seekers, which is natural under the circumstances of technological changes. Instead of comparing supply and demand structure, the authors suggest measuring time spent on job searching (Voronov 2012). The essence of searching for a vacant position or for an employee consists in finding a perfect match that will ensure the largest terminal payoff for both the sides. Three problems of such market have been identified, namely 1) market overload; 2) scope; 3) “security” (Niederle et al. 2008).

3 Results

In Russia the triple helix model is present in a skewed way: among the “scientific actors” the largest role is attributed not to universities accounting for 8,2% of research and development spending but to specialized research institutes. The connections between business and science are weak, which can be proved by the investment structure: 53,7% of total investment are attributed to the government spending whereas entrepreneurs account for 28,1% of the total investment[1]. At the same time the level of innovativeness is rather low, with imitation and reverse engineering being the prevalent methods for development.

While assessing innovative potential small innovation companies (SIC) represent a separate subject for research. Since 2012 the cumulative growth of small innovation companies appears to be in decline (*Accountancy and Monitoring*, 2020). Judging by

[1] N. Gorodnikova, L Gohberg et al. Science. (2017) Technology. Innovation: brief statistics.. Moscow: National Research University Higher School of Economics, 80.

the number of such companies, Siberian Federal District ranks second trailing only the Central Federal District and accounting for 20,23% of the total SICs (Turko et al. 2016). The Krasnoyarsk Region occupies the sixth place in the ranking with 89 small innovative companies. Prevalent products of the local SICs are know-how and inventions (although utility models and industrial designs are more cost-effective); the main scientific and technological area of operations of such companies is information and communications system. Although the number of universities and research centers in the region is far from being large, the share of small innovative companies is relatively large compared to other regions. At the same time the fraction of SICs possessing intellectual property rights is fairly little, with such enterprises accounting for 8.3% of SICs in the Krasnoyarsk Region compared to 17% in the Siberian Federal District (Ledeneva and Goosen 2014). Is there a feasible possibility of establishing a regional innovative system in strict accordance with the triple helix model?

A large share of small businesses performing technological innovations, fixed capital renewal rate, the number of supported innovative projects per 1 000 000 people, as well as innovative activities score of regional administration and public event in the sphere of innovations are considered as the advantages of the innovation ecosystem of the Krasnoyarsk region[2]. Most of the key indicators marked by low performance of the region are connected to the efficiency of innovation activities. We surmise that such state of affairs is testimony to government playing the dominant role in the innovation ecosystem, with trilateral coordination of the triple helix actors remaining underdeveloped.

Administrative methods for stimulating innovations are to a greater extent consistent with the “Sabato triangle” concept. However, such practices do not allow reaching the positive overlap point of the “triple helix” model actors: the model is undergoing “the initial stage of its formation” (Dezhina 2011). The involvement of society is necessary in order to strengthen the scientific actors including universities, which initiate technological and social innovations and projects, and to reduce the contribution of government to the secondary factor forming environment for collaboration. It is no accident that institutional development researchers advocate the importance of another actor – the society – and formation of a “quadruple helix” model (Carayannis and Grigoroudis 2016). It is the local society of innovators that is capable of catalyzing an adaptive mechanism for establishing a regional innovative ecosystem. Abundance of public innovation-oriented events in the region serves as another indirect evidence proving the efficiency of such approach.

Analysis of methods officially applied for forecasting human resources needs has demonstrated a simplified perception of the “triple helix” as a model of bilateral cooperation. With trajectories of technological development being inertial, we may well expect and even notice “technology traps” (Dezhina and Kiselyova 2008) which may be evident in universities expressing no interest in developing new technologies. Studies focused on the motivation of the economic agents aggravate the problem of measuring direct and inverse implications of innovations for employment. At least, there is political will to overcome the effects of “technology gaps”.

[2] The rating of the innovative regions in Russia (2017). https://i-regions.org/images/files/airr17.pdf Access: 20.05.2020.

In terms of methodology there is no solution to the problem of measuring direct and inverse impact of innovations on employment. The research (Caroli and Reenen 2001) demonstrated directions of mutual influence of innovations and demand for qualified workforce, which was further proved by data collected by Deloitte. For instance, qualified yet underestimated personnel contribute to creating innovations, which is typical of excessive supply on the market. In practice it is important to create opportunities and motivation for highly skilled professionals to establish a start-up instead of moving abroad on a massive scale. Opportunities can be generated through collaboration of the triple helix actors, while motivation can be ensured by means of developing meta-skills, especially project-oriented ones, among the students, when personal traits can be easily transformed.

Data on the students' involvement into project activities and statistics concerning start-ups created by the youth allow to measure the inverse effect of highly skilled labor supply on innovation activities and following the S-shaped curve forecast the increase in demand for human resources for technological and innovative development in the mid-term. One of the signs of conformity with the triple helix model is the absence of clear disproportions in the sphere of the highly skilled labor on the scale of innovation system localization.

Empirical data further substantiate the connection between technology, organizational changes and human resources (Brynjolfsson and Hitt 2000). Organizational changes result in decentralizing decision-making and strengthening teamwork, which contributes to the need for highly skilled labor growing. Understanding the labor design concept allows discerning the distinct feature of engineering personnel market: while establishing strong links between employees and high-technology segments of economy, influence of salaries on choosing particular industry can be neglected.

It is in case of engineering personnel necessary for innovative development that the labor market collapse is highly likely. Being the reason for disproportions in the market design model in view of streamline effects, the deficit of human resources can be eliminated by adjusting the waiting time, however, generally employers expect such situation to result in impeding the development of a company. If the above-mentioned disproportion is due to the absence of vacant positions, waiting for a specialist may well be fraught with skills and knowledge obsoletion as well as finding other opportunities for their application such as establishing a high technology small business.

Employers can effectively evade market collapses by "importing" skilled personnel from other regions. Inviting graduates of the Tomsk region universities to work at the Krasnoyarsk region business incubator for innovations and technology as well as highly skilled professionals in the sphere of medicine can serve as an example of such strategy. The chances of successfully evading market collapses depend on the personnel flow intensity, which can be amplified by rising fluidity of skilled labor in the innovative sphere (see above). The function of creating such flow should be assigned to universities. The needed skilled labor resources are highly unlikely to downflow to the Siberian federal district without external stimuli.

Some risks of failure to overpass market disproportion exist both for companies and graduates. The scarcity of personnel has negative impact on innovation-connected activities, while the absence of vacant positions damages the image of educational programs and education areas. The main reason for that is insufficient awareness of the parties. Both educational institutions and potential employers need to engage with the youth and their parents in order to create proper expectations with regard to the profession in question. Developing professional skills can also reduce the risks of absent demand for such personnel; such skills increase the readiness of a graduate to combine jobs and alter the functions performed within a profession. Given the flow effect and adequate awareness of the parties, there is no need for detailed forecasts of the demand for engineering personnel with regard to aggregate professions, industries and occupations. It is enough to enumerate criteria for highly skilled labor and divide employers into more and less attractive, large and small.

Market design model does not need to be regulated externally. This model has a built-in self-regulation mechanism that is based on flow principles. In the framework given the only task that the government needs and has to perform is overcoming the decentralized market problems, namely overloads, ensuring the scope of its reach and adequate awareness of the parties as well as security in terms of information reliability and independent proficiency testing.

4 Conclusion and Recommendations

While establishing a forecasting mechanism it is necessary to establish a network data model so that organizational and informational model corresponds with the modelled system. Apart from the forecast, it is necessary to construct clusters capable of self-regulation with respect to human resources needs. Entrepreneurial initiative should be supported and to some extent instigated by preemptive personnel training in the new professional areas. The perfect scenario is assessing and correcting innovation-oriented behavior of companies, educational expectations of high school and university students. Such approach will give educational institutions a momentum necessary to strengthen the role universities and scientific organizations play in the cooperation between the helix actors.

In terms of methodology, given the positive overlap of triple helix model actors, forecasting human resources needs for high technology and innovation sectors of economy should be based on short- and long-term prospects of development taking into account foresight technologies. Such approach is not void of risks for employment. In the beginning redundancy of engineering and management programmes graduates will increase market imbalances without expansion of innovation-related activities. Under such circumstances the two other triple helix actors are to step in: government should ensure adequate quality of education and develop the certification system; business should support universities and graduates by organizing internships. A graduate possessing appropriate credentials and developed metaprofessional skills can either find a job or create it for themselves by means of creating a start-up and using government support measures. The configuration mentioned changes fundamentally coordination between the actors, fosters self-organization mechanisms within the network structures provided with human resources possessing adequate skills.

The labor design concept is fully consistent with the triple helix model. Design solutions having potential for improvement and adjustment can be implemented by the numerous market participants including the triple helix actors. If the triple helix has not been formed yet, which implies the absence of network connections and collaboration mechanisms, the labor market uncertainty in some of its segments may be exorbitant. Provided the non-linear nature of innovations process such scenario seems highly likely, since “interactive process should take course in the interactive environment” (Smorodinskaya 2011).

In Russia due to geographical differences labor market designs and collaboration mechanisms should be implemented on a regional scale. The absence or weakness of the network coordination may be evident in labor market “failures”. For instance, on the market there might be little demand for “Medical cybernetic” program graduates, although their education program is essentially innovation-oriented. Collaboration mechanisms allow to bridge the gap between supply and demand and thus support the innovative development trends.

The above mentioned allows us to draw the following conclusion:

1. Labor market researches should be geographically located.
2. The impact of new technologies is evident not only in the appearance of new occupations, but also in the qualification-based structure of employment: medium-qualified occupations are gradually diminishing.
3. Disproportions in the Russian labor market are eliminated by means of adjusting salaries. At the same time the waiting time for new vacant positions among the young specialists and skilled professionals increases, which serves as an indirect proof of market transformation towards the model of “search frictions”.
4. Judging by its scope and education expenditures the Russian labor market is not ready for technological changes. The readiness criteria are the share of personnel involved in training (no less then 50%) and personnel training expenditures as percentage of total staff spending (more 1,5%). In Russia these indicators are 3–5 times lower[3].
5. The pattern “qualification produces qualification” remains. The higher level of education and skill is, the stronger is involvement into the processes of education, training and re-training.
6. Interindustrial flow of workforce does not result in falling employment. Technological and structural shifts in the Russian economy have been accompanied with painless reallocation of staff to other industries. There is no point expecting that labor market will continue giving such response in the future, for the closer the technological boundary is, the more substantial the requirements to qualification are.
7. The gap between education and business is widening, with longstanding links breaking. Consecutively, research projects in science and technology are no longer in line with the challenges of the reality.

Lagging behind in terms of innovations and technological development in the globalized environment, Russia cannot count on treading in the steps of technological leaders

[3] Gimpelson V., Kapelyushnikov R, Roshchin S. (2017). The Russian Labor Market: Trends, Institutions, Structural Changes Report of the Centre for Labour Market Studies and the Laboratory for Labour Market Studies of Higher School of Economics. Moscow: HSE University, 148.

with some delay. New innovation-based technological chains will be aligned without our participation. Hence, forecasting skilled labor needs should perform more comprehensive functions decreasing the time-gap between emerging human resources needs and even taking some preemptive measures based on foresight researches.

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Strategies for the Development of Complex Organizational and Economic Systems in the Conditions of Digitalization

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Abstract. Purpose: to consider strategies for the formation of major modern forms of complex integrated economic systems, such as clusters and special economic zones, using digital platforms.

Methodology and methods: The authors in the article consider various complex organizational and economic systems (COES), which actively began to enter the turnover of the economic activities of the Russian economy in the early 2000s. To implement strategic management in complex economic systems, development strategies are developed, presented in the article as a hierarchical complex. The implementation of strategies for the development of complex economic systems is carried out on the basis of organizational structures and management bodies. To implement management models in modern conditions of digitalization of the economy, digital platforms are used, which have a number of advantages and characteristics. Methods used at different stages of the study include classifications, comparative bibliographic analysis, comparison of data from domestic and foreign studies, comparison of theoretical models and primary data analysis obtained from different sources.

Results: The characteristics of such complex economic systems, such as clusters, special economic zones, territories of advanced development, industrial and industrial parks, are given. The concept is given and the main features of strategic management in relation to COES are highlighted. A model of strategic management of a complex organizational and economic system has been developed. Within the framework of the strategic management system, a set of strategies for the development of COES is presented. To implement development strategies, organizational structures and management bodies in the strategic management system of COES were considered. The concept, essence and structure of a digital platform for smart production at an industrial enterprise is formulated. The advantages and characteristics of digital platforms of COES are formulated.

Originality/Value: The presented results can be used in practical activities in the development and implementation of strategies for the development of complex organizational and economic structures, including clusters, special economic zones, etc.

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JEL Code: I23 · I25 · M15 · O21 · O32

1 Introduction

In the context of modern economic development, characterized by the acceleration of market integration processes, the deepening of international specialization, the increase in the role of knowledge and the strengthening of the role of innovation and the results of intellectual labor, there is an increase in the role of integration processes in the economy. At the same time, economic, innovative, legal, demographic, socio-cultural, natural and political factors determine the nature, features and essence of these processes (Chacko 2019; Chaniasa et al. 2019). New forms of integrated organizational and economic systems appear, to which the authors include special economic zones (SEZs), territories of advanced development (TAD), industrial clusters, innovative-active clusters, industrial parks, etc. (Novikov and Babkin 2014).

The development of information and telecommunications technologies, the expansion of the Internet, its penetration into all spheres of human life have contributed to such a new phenomenon in the economy and industry as the digitalization of business processes. Digitalization and digital transformation also contribute to the processes of integration and, accordingly, the formation of complex organizational and economic systems. If we consider some background of the formation of COES in the Russian economy, then it is necessary to note the territorial production complexes (TPC), which were implemented in the planned economy. This form of integration was first proposed by Kolosovsky (1958) in the 50s of the XX century.

As part of the planned economy, the TPC concept was effectively implemented in a number of regions and industries of the Soviet Union (Kiseleva et al. 2016).

With the formation of market principles of economic management in the Russian economy, clusters and special economic zones become widespread forms of COES. Cluster structures are the most developed form of development of integrated structures (Novikov and Babkin 2014; Selentyeva et al. 2018).

In the classification system, the most common cluster associations include (Selentyeva, et al. 2018): industrial, innovative-active, logistics, construction. Cluster structures are actively developing both in the Russian and foreign economies. For example, in accordance with the data of the Association of Clusters and Technology Parks of the Russian Federation, industrial clusters at various stages of development in 2019, there were 86 in 38 subjects of Russia (List of industrial clusters in Russia-2019, 2019).

Special economic zones are another major form of COES in the Russian economy. At the legislative level, they began to be created at the same time as clusters (2005–2006 years), and in reality the processes of their formation arose even earlier (1990–1992 years). In accordance with the statistical data of the Ministry of Economic Development, 25 SEZs are operating in the Russian Federation at the end of 2019 (Consultant Plus 2020; Ministry of economic development of the Russian Federation, 2020).

An important aspect of the creation and development of COES is the implementation of strategic management and the formation of a strategy for functioning, which leads to the sustainable competitive development of these systems in the presence of global and local destabilizing factors in modern conditions, including such as coronavirus COVID-19.

In accordance with this, the present study of the authors was aimed at analyzing modern models of complex organizational and economic systems and the peculiarities of shaping their development strategies in the modern conditions of digital transformation of the economy. ***The objective of the research*** **is** to consider strategies for the formation of complex integrated organizational and economic systems in some modern forms of operation, as which the authors identify clusters and special economic zones that implement the platform digital concept.

2 Methodology

Methods used at different stages of the study include classifications, comparative bibliographic analysis, comparison of data from domestic and foreign studies, comparison of theoretical models and primary data analysis obtained from different sources. Data from the Ministry of Economic Development of the Russian Federation, the Association of Clusters, and Technology Parks of the Russian Federation, the Association of Industrial Parks of the Russian Federation and other sources were used.

Based on the analysis and experience of the functioning of Russian and foreign clusters and SEZs, we will give a brief description of innovative models of COES.

Advanced development territories are a special legal regime for carrying out entrepreneurial activities in a limited territory (Consultant Plus 2020). According to official statistics in 2019, 99 such entities in 85 territorial entities are represented on the list of ASEZ of Russia (Fincan 2019).

Another variety of COES is an industrial or industrial park (Association of Industrial Parks of Russia 2020). This integrated structure is a complex of real estate objects managed by a single operator (specialized management company), consisting of a land plot (plots) with production, administrative, warehouse and other premises and structures, provided with energy, engineering and transport infrastructure and administrative and legal conditions for the placement of production facilities. According to the Association of Industrial Parks of Russia in 2019, it included more than 130 economic entities that are part of 89 industrial parks of 46 constituent entities of Russia (Industrial parks and techno-parks in Russia 2020).

A common model of COES is technological parks. They are an integrated COES, providing its participants with a scientific, production, infrastructure, intellectual base for the creation and commercialization of innovative projects (Kostin and Uporova 2018). According to official statistics for 2019, there were more than 70 large technology parks in the Russian economy and more than 60 more being formed in the near future (Industrial parks and technoparks in Russia 2020).

3 Results

It should be noted that the availability of a scientifically **development strategy** will be an essential factor in the development and effective functioning of any COES model. At the same time, the authors note that strategic management tools can be used for these studies of the activities of such structures (Arnoldo, 1994; Baikov et al. 2015; Jin et al. 2019). Strategic management in COES is a means of achieving its objectives. We highlight the following main features of strategic management in relation to COES: it is oriented towards the long-term; strategic management and strategies determine the main directions for the development of the organizational and economic system; COES control system is detailed as planning horizon decreases; The mission and purpose of the activities are to ensure the long-term sustainability of enterprises and integrated groupings.

The policy guidance for the strategic management of many of the abovementioned COES structures is based on common approaches. However, as the analysis shows, in some cases for cluster formations they can be used to a much lesser extent (Ovechkina 2017).

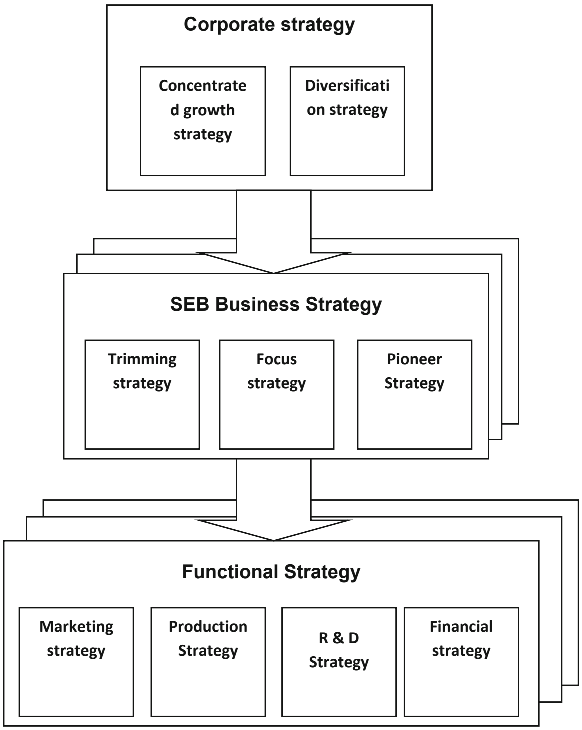

Fig. 1. Hierarchy of complex development strategies organizational and economic systems. *Source*: developed and compiled by the authors

Within the framework of the strategic management system, a hierarchy of COES development strategies is formed, at the upper level of which the corporate strategy will be located (Fig. 1).

The strategy of concentrated growth will ensure the development of COES through the production of innovative high-tech products and the provision of modern services. A diversification strategy, on the contrary, should include new industries and new markets.

At the lower level of the hierarchy of strategy of integrated entities should be functional strategies, including in the field of production, financial, scientific, logistical activities.

To implement these development strategies, COES must have appropriate organizational structures, facilities and management entities in the strategic management system.

Management companies and supervisory boards are common governing bodies of COES (Fig. 2).

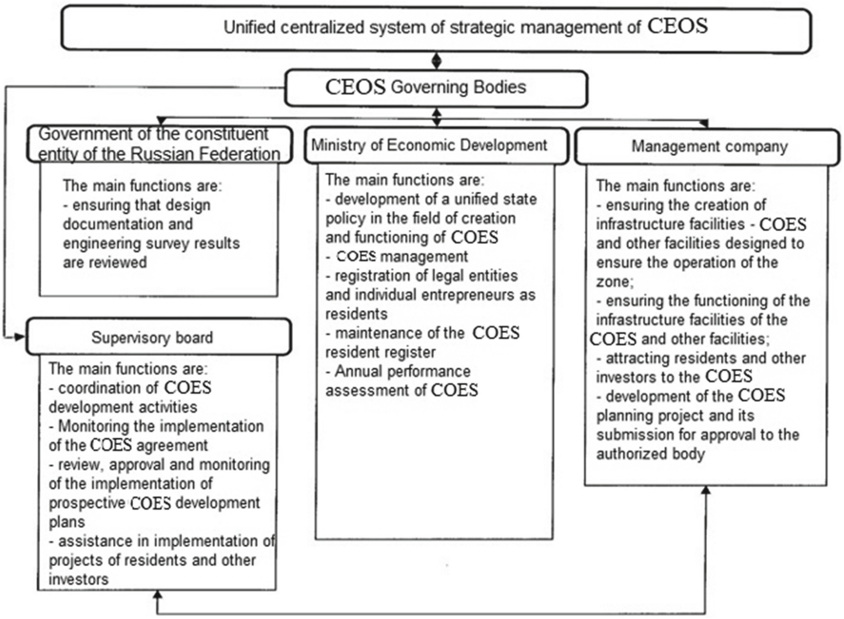

Fig. 2. Consolidated structure of the strategic system management in COES. *Source*: developed and compiled by the authors

The Supervisory Board in COES is created to form planned strategic documents and monitor their practical implementation.

For the operational management and conduct of economic activities of the economic entities of COES, management companies are formed (Ovechkina 2017).

The development of the digital economy both in Russia and abroad, the introduction of modern end-to-end digital technologies (Babkin et al. 2018; Burdakova et al. 2019) causes a significant change in the business processes of enterprises and integrated structures. The digital transformation of economic systems leads to a significant increase in the economic efficiency of their activities (Kostin and Uporova 2018). Digitalization of activities is carried out on the basis of digital platforms, which replace, in practice, many services: production, supply, sales, marketing, personnel, etc.

Based on the analysis, the authors consider the digital platform as a kind of organizational and technical system, the creation and functioning of which is possible through the use of specialized software and various digital tools and technologies, as well as Internet and Intranet networks, designed to effectively operate all processes of the economic system and simplify communication between participants (Tashenova and Babkin 2019).

Digital platforms of COES are inextricably connected with "smart production" at industrial enterprises, the essence of which is summarized in Fig. 3 (Tashenova and Babkin 2019).

It is important to note that the digital platform for implementing the "smart manufacturing" enterprise in turn is part of the global digital platform of the corresponding integrated structure.

It is possible to distinguish the advantages and some characteristics of digital platforms that can be used by COES:

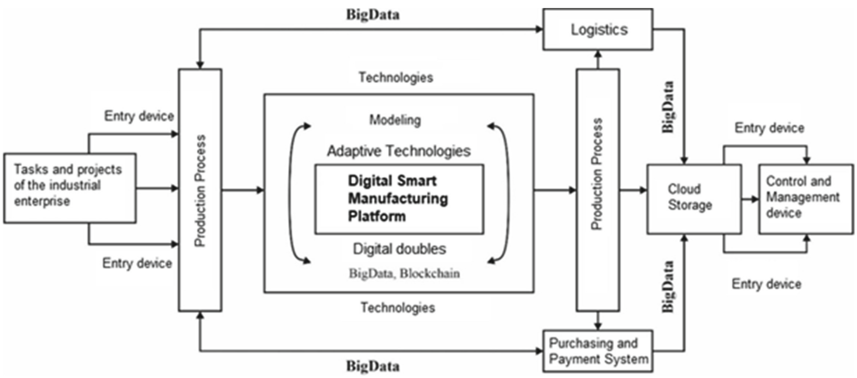

Fig. 3. Digital platform for smart manufacturing in an industrial enterprise. *Source*: developed and compiled by the authors

– Significantly reducing the time for development and testing of prototypes based on the use of digital twins in an integrated cyber-physical environment;
– Reduce different transaction costs by creating a single information environment;
– reformatting of their business models in order to exclude intermediary entities, mutually beneficial relations of participants;
– have the ability to connect additional software, configure software depending on the task being performed or the project being implemented (a kind of "matrix" structure of the organization of the digital process adjusted for specific tasks);

– work 24/7 online, processing significant amounts of information using BigData technologies.

4 Conclusion

Integration processes and digitalization of the economy have led to the formation of new forms of complex organizational and economic systems.

The authors describe and reflect some features of such COES so clusters, special economic zones, territories of advanced development, industrial and industrial parks.

The concept is given and the main features of strategic management in relation to COES are highlighted. Within the framework of the strategic management system, a set of strategies for the development of COES is presented.

To implement development strategies, organizational structures and management bodies in the strategic management system of COES were considered.

The concept, essence and structure of a digital platform for smart production at an industrial enterprise is formulated. The advantages and characteristics of digital platforms of COES are formulated.

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Strategies of Digital Transformations of Higher Educational Institutions: Experience, Methodological Aspects of Choice and Implementation

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Abstract. Purpose: To study the experience of digitalization of educational activities of higher educational institutions, develop recommendations on the choice and implementation of digital transformation strategies in universities.

Design/Methodology/Approach: Digital changes taking place in the educational services market radically change approaches to the implementation of the educational process, thereby causing the need to review strategic tasks and establish priority areas for digital development. The choice of digital transformation strategies should be based, inter alia, on determining the current level of digitalization and analyzing key factors in the internal environment of universities. An assessment of the level of digitalization can be carried out using a system of indicators that allow you to determine possible areas of strategic development and the necessary tactical measures for their implementation.

Results: The authors reviewed the experience and formalized the main directions of strategic development of universities in the field of digitalization of educational activities. It was shown that the key factors of the internal environment, which determine the possible choice of strategies for the digital development of educational activities of universities, can be: the achieved technical and technological level of digitalization of the educational environment and the level of competence of higher-education teaching personnel in the field of digital technologies and the use of remote educational technologies. It was revealed that these factors are interconnected and determine the possibility of implementing the chosen strategy of digitalization of educational activities at a certain level of their development. There are offered groups of indicators allowing to assess the achieved level of digitalization. The necessary conditions and tactical measures to implement the selected strategies of digital transformations are defined.

Originality/Value: The results of the research and the recommendations proposed on their basis can be used in the practice of developing and implementing strategies for digitalizing the educational process in higher educational institutions.

Keywords: Higher education institutions · Assessing the level of digitalization · Choosing a digital transformation strategy · Tactical measures

JEL Code: I23 · I25 · M15 · O21 · O32

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1 Introduction

Due to desire to accelerate the digitalization of various fields of society, the government of the country approved and implements a number of federal programs and projects aimed at creating an integrated system of legal regulation of the digital economy. In accordance with the Federal Project "Personnel for the Digital Economy," phased changes are expected until 2024 and in the higher education system. The issues are touched upon: the development of new educational programs; updating of the FSES HE in terms of requirements for the formation of competencies corresponding to the digital economy, the development of the electronic educational environment of universities; digital learning technologies.

The indicated areas require a review of strategic tasks, the development and implementation of digital transformations of educational activities of universities. A number of universities have already developed and are implementing appropriate strategies (Babin 2018).

Analysis of programs for the development of higher educational institutions of Russia until 2025 (Russian State Social University, St. Petersburg State Economic University, Krasnoyarsk State Pedagogical University, Bashkir State Agrarian University, Orenburg State Pedagogical University, etc.) allows summarizing the main directions of strategic development of universities in the field of digitalization of the educational process. The formalization of this sphere of activity of universities was carried out using the I. Ansoff matrix (Kalinin and Maryucht 2015). Different ways of digital transformation depend on the combination of educational programmes in different educational services markets (Table 1).

Since 2017–2018, the country's universities have been preparing their students in the following areas: "Augmented and virtual reality technologies in printed materials" (Moscow Polytechnic University); "Virtual Prototyping Technologies in Mechanical Engineering," "Virtual Engineering Technology" (Peter the Great St. Petersburg Polytechnic University); "Game design and virtual reality" - HSE, "Virtual and augmented reality technologies VR/AR" - FEFU (new program/traditional market).

By 2022, the Ministry of Economic Development plans to implement the Digital University project. The created educational platform will provide universities with access to the best practices for implementing the educational process, they will not only be developed by the universities themselves for universities, but also consolidated for public use through network interaction.

FEFU is implementing a new model of educational partnership with employers of the Far East. The university is involved in the development of personnel strategies for enterprises that come or already work in the macro region. It plans to expand educational programs for Roscosmos, to develop technologies for the production of small satellites for various purposes. Since 2018, he has been preparing masters in the field of "Remote Earth Sensing Technologies," in 2019 he opened the first management training program for the digital economy in the Far Eastern Federal District and Siberia (new product/new market).

Table 1. Strategies for digital transformation of educational activities of universities

		Educational programs	
		Old	New
Education Marker	Old	**Market Penetration Strategies** – Digitalization of traditional educational programs (courses) for training and retraining of personnel – Development and implementation of disciplines/modules forming competencies in the field of digital literacy – Improving the implementation of the educational process based on the use of digital technologies – The use of information, educational platforms and services (Heliskhanov et al. 2018)	**Strategies for the development of educational programs** – Development and implementation of training/retraining programmes in the field of digital technology and economics – Organization of network interaction on implementation of programs with other universities*
	New	***Market development strategies*** – Implementation of own open online courses, placed on various sites (own, regional, federal, international); Expansion of the list of educational programs/courses for training/retraining of personnel implemented using distance education technologies (DET), including inclusive education – Organization of network interaction on implementation of programs with other universities*	***Diversification strategy*** – Development and implementation of new educational programs (courses) for training/retraining of personnel based on digital technologies for the needs of specific external customers, including in other regions

*The strategy on the one hand implies the implementation of its own educational programs in new segments/markets, on the other hand - the use of electronic educational resources of partner universities in the implementation of traditional training programs at the university (Burdakova et al. 2019).

2 Methodology

Topical issues of digital transformations in higher educational institutions are reflected in the works of domestic and foreign scientists: Babin (2018), Molotkova et al. (2018), Mavlyutova (2018), Nalivaiko and Granina (2020), Nemtinov et al. (2020), Tyukavkina (2019), Schophuizen et al. (2018), Debrok (2018).

The choice of the strategy of digital transformation of the educational process is due to a number of factors of the external and internal environment of educational institutions. The external environment is represented by factors influencing and determining the need/possibility of implementing digital transformations in universities. The internal environment determines the ability of an educational institution to transform, master the opportunities that open up and offset the threats of the external environment. Analysis of the internal environment allows you to determine the current level of digitalization and possible directions for its development.

At the moment, studies on assessing the level of digitalization of higher educational institutions are local in nature, there are no generally accepted assessment methods and indicators. A significant contribution to the formation of approaches to assessing the level of digitalization of higher educational institutions was made by a group of authors: Plotnikova, Efremova and Zaborovskaya in the work “Comprehensive Assessment of the Level of Digitalization of Leading Universities of the Russian Federation.” It proposes a methodology for determining weighted average indicators of digitalization of universities in the following areas: “production process, information infrastructure, information security, human capital and R&D” (2019).

The “information infrastructure” factor assesses the availability of resources that provide access to the necessary information and interaction between various categories of educational participants. The “technological process” reflects the provision of the educational process with digital technologies. The assessment of Human Capital can be carried out on the basis of indicators: the number of retraining and advanced training programs for professors and teachers in the field of digitalization, as well as the number of undergraduate, graduate and graduate programs related to digital transformation “(Plotnikova et al. 2019)”. These indicators reflect the level of digitalization of the educational process.

The key factors of the internal environment, which determine the possible choice of strategies for the digital development of educational activities of universities, are: the achieved technical and technological level of digitalization of the educational environment and the level of competence of higher-education teaching personnel in the field of digital technologies and the use of remote educational technologies (RET) (Fig. 1).

The technical and technological level is determined by the availability of technical means and technologies (personal computers, electronic environment, remote technologies) that open up the possibility of online interaction between the teacher and the student; digital learning tools (electronic educational resources, online courses, virtual laboratories, software used in the educational process) (Nemtinov et al. 2020).

The level of competence of higher-education teaching personnel will be determined by: skills and skills in working with information and computer technologies, abilities of higher-education teaching personnel to create and use electronic educational resources and remote technologies (Debrock 2018; Molotkova et al. 2018), the presence of competencies for training personnel in the field of digital technologies and economics, professions of the future. These factors are interconnected and determine the possibility of implementing a certain strategy for digitalization of educational activities at a certain level of their development.

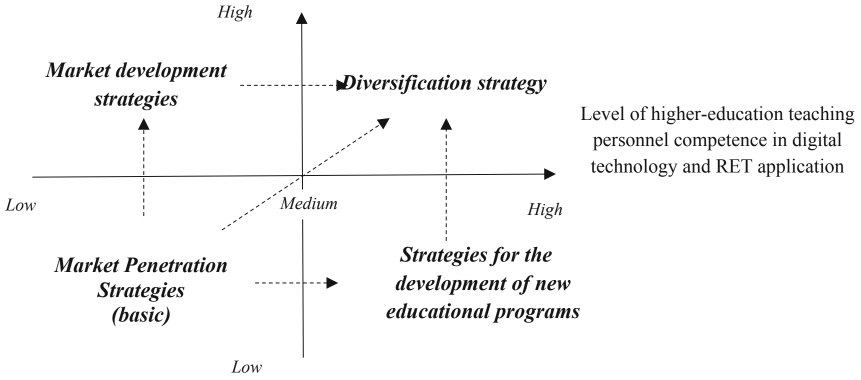

Fig. 1. The relationship of the level of digitalization of the university with the possible choice of strategies for digital transformations of universities. *Source*: developed and compiled by the authors

3 Results

Assessment and monitoring of the level of digitalization of the educational process can be carried out using a group of indicators (IK1-3 - indicators of assessment and monitoring of higher-education teaching personnel competence in the field of digital technologies

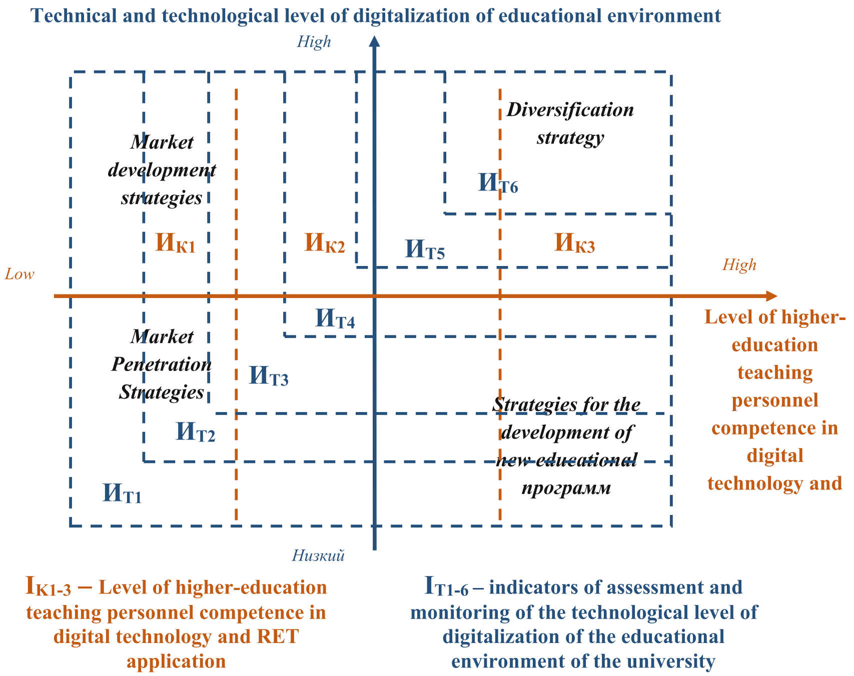

Fig. 2. Possible indicators for assessing and monitoring the level of digitalization of educational activities of the university. *Source*: developed and compiled by the authors

and the use of RET, IT1-6 - indicators of assessment and monitoring of the technical and technological level of digitalization of the educational environment of the university), necessary for the selection of specific strategies (Fig. 2).

Moving to the implementation of a specific matrix strategy makes it necessary to achieve a certain level value of the lower order indicator (from the technological level indicator 1 to the indicator 6, from the higher-education teaching personnel competence indicator 1 to the indicator 3).

Each group of indicators allows you to evaluate a certain area of digital transformations, and, therefore, focus on the development of tactical measures in this direction for the implementation of the selected strategy (Table 2).

Table 2. Possible indicators for assessing and monitoring the level of digitalization of educational activities of the university

Indicator Group	Evaluation and monitoring area	Indicators
Indicators for assessment and monitoring of higher-education teaching personnel competence in digital technology and RET application		
I_{K1}	ICT skills	Percentage of higher-education teaching personnel retrained/advanced in ICT programmes
I_{K2}	EER development and RET use	Percentage of higher-education teaching personnel retrained/advanced in digital programs in education
I_{K3}	Competencies in the field of digital technologies and economics, professions of the future	Percentage of higher-education teaching personnel that have undergone retraining/advanced training in highly specialized programs for the formation of necessary competencies in the corresponding subject area of implementation of new educational programs associated with digitalization
		Share of higher-education teaching personnel using digital services in their activities
Indicators of assessment and monitoring of the technological level of digitalization of the educational environment of the university		
I_{T1}	Technical Tools and Internet Access	Number of PCs per student
		Specific weight of equipment cost (not older than 5 years) in total equipment cost
		Proportion of higher-education teaching personnel with simultaneous access to high-speed Internet

(*continued*)

Table 2. (*continued*)

Indicator Group	Evaluation and monitoring area	Indicators
I_{T2}	Electronic Education Environment	Proportion of students and higher-education teaching personnel with simultaneous access to the electronic educational environment
I_{T3}	Access to E-education resources (EER)	Percentage of students and higher-education teaching personnel with free access to electronic educational resources
		Proportion of e-education resources provided for educational programmes
I_{T4}	Development of EER	Share of own electronic educational resources to disciplines (modules) of training curricula
I_{T5}	Remote educational technologies	Percentage of students studying with RET in the whole population
		Share of implemented using RET
		Proportion of E-education programs/courses hosted in open educational digital platforms
		Proportion of programs implemented on the basis of network forms of interaction
I_{T6}	Dedicated virtual labs and software	Share of software implemented using specialized virtual laboratories
		Percentage of students studying using specialized virtual laboratories and software

The calculation of indicators is possible by the method of aggregating private indicators by finding average arithmetic estimates (Borisova et al. 2019).

It should be noted that the proposed indicators can be used both to assess and monitor the overall level of digitalization of the educational process in universities, as well as individual training/retraining programs.

Based on the values of integral indicators of the level of competence of faculty and the technical and technological level of digitalization of the educational environment, it is possible to determine the most acceptable for the implementation of the strategy, as well as their corresponding tactical measures (Table 3).

The values of integral indicators It/IK $\leq$ 0.3 indicate an insufficient level of digitalization of educational activities, which makes it necessary to implement a market penetration strategy. The main tactical measures should be: digitalization of traditional educational programs; formation of digital environment at the university; Development of higher-education teaching personnel skills in the use of information and computer technologies.

Indicators in the range of 0.3 $\leq$ It/IK $\leq$ 0.6 determine the possibilities of implementing market development strategies and developing new educational programs. Necessary

Table 3. Possible strategies and corresponding tactical measures to digitalize the activities of universities

<table>
<tr><td colspan="2" rowspan="2">Integral indicator value</td><td colspan="3">Level of competence of higher-education teaching personnel in the field of digital technologies and the use of remote educational technologies</td><td rowspan="2">Tactical activities within the framework of implemented strategies</td></tr>
<tr><td>$I_K \leq 0,3$</td><td>$I_K \leq 0,6$</td><td>$I_K > 0,6$</td></tr>
<tr><td rowspan="4">Technical and technological level</td><td rowspan="2">$I_T \leq 0,3$</td><td colspan="3">Possible strategies</td><td rowspan="2">Digitalization of traditional educational programs and the formation of a digital interaction environment at the university</td></tr>
<tr><td>Market Penetration Strategies</td><td>Market Penetration Strategies</td><td>Market Penetration Strategies</td></tr>
<tr><td>$I_T \leq 0,6$</td><td>Market Penetration Strategies</td><td>Strategies for developing markets and developing new software</td><td>Strategies for developing markets and developing new software</td><td>Development/use of EER, development of remote educational technologies</td></tr>
<tr><td>$II_T > 0,6$</td><td>Market Penetration Strategies</td><td>Strategies for developing markets and developing new software</td><td>Diversion strategy</td><td>Creation/use of dedicated virtual laboratories and software</td></tr>
<tr><td colspan="2">Tactical actions within the framework of implemented strategies</td><td>Development of higher-education teaching personnel skills in the use of information and computer technologies</td><td>Development of higher-education teaching personnel skills in the development of electronic education resources and the application of RET</td><td>Development of higher-education teaching personnel competencies in the field of digital technologies and economics, professions of the future</td><td>Possible strategies:
$I \leq 0.3$ - market penetration;
$0.3 \leq I \leq 0.6$ - market development and development of new software;
$I > 0.6$ - diversification</td></tr>
</table>

conditions: the development of higher-education teaching personnel skills for the development of electronic educational resources and the use of RET; creation/use of electronic educational resources, application of remote educational technologies.

Values of IT/IK > 0.6 indicate a sufficient level of digitalization for diversification of educational activities and determine the need to implement tactical steps to develop higher-education teaching personnel competencies in the field of digital technologies and economics/professions of the future, creation/use of specialized virtual laboratories and software.

4 Conclusion

Universities that want to take a strong position in the educational services market should timely develop and implement appropriate strategic and tactical measures in the field of digitalization of educational activities.

The planned directions should be synchronized with the achieved level of digital development, determined by the key factors of the internal environment of the university.

It is proposed to evaluate the current level of digitalization with the help of a group of indicators of the technical and technological level of digitalization of the educational environment of the university and the competence of faculty in the field of digital technologies and the use of remote educational technologies.

The choice of strategy should be based on the assessment and monitoring of the current level of digitalization, which will determine the directions and necessary tactical measures for its implementation.

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Improving the Efficiency of Financial and Economic Activities of an Enterprise on the Basis of a Comprehensive Analysis of the Economic Situation in the Context of Transition to the Digitalization of Agricultural Production

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Abstract. The purpose of the work is to develop proposals to improve the efficiency of financial and economic activities of an enterprise on the basis of a comprehensive analysis of the economic situation in the context of transition to the digitalization of agricultural production.

Methodology - in the research process, the following methods were used: systematic approach, factor analysis, extrapolation, correlation, moving average method, modeling, and expert methods.

Results - implementation of the developed methods and approaches into the practice of functioning of an agricultural enterprise, in particular:

– factor analysis based on the method of active experiment;
– least squares method;
– economic-mathematical approach to analysis, allowing the transition to digitalization of agricultural production.

Conclusions/recommendations. Introduction to the analysis of mathematical methods for forecasting increases its reliability and a qualitatively new measurement of the economic condition of the enterprise in the context of digitalization of agricultural production. A new approach to improving the analysis is proposed, namely:

– in the development and application of regression modeling methods in the study of agricultural production efficiency factors;
– in the development and use of the least squares method in predicting the economic results of an agricultural enterprise;
– in the development of new methodology provisions for improving the efficiency of agricultural production.

Keywords: Enterprise · Forecasting methods · Digitalization · Agricultural production · Efficiency

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JEL Codes: C02 · C38 · F63 · O13

1 Introduction

In modern Russian conditions, the digital economy has been established as a priority area of informatization until 2025, where programs for the development of these areas will be implemented in all areas of activity, including agriculture (Lavrentieva and Yashkova 2018), (Lavrentieva et al. 2018), (Yashkova et al. 2020).

However, it is worth noting that the state of the modern Russian economy is undergoing changes in its development, destabilization, unpredictability in the action of buyers, competitors, suppliers, government legislative and regulatory bodies, under sanctions from European countries and the United States, all this entails disruptions in the work of industrial and agricultural enterprises (Balabanov 2015). In the conditions of a high probability of insolvency in Russian enterprises, the need to form an effective anti-crisis strategy of import substitution, and its development. The leading importance acquires the question of objective assessment of the current economic condition, and especially — development of directions of its development in the near future. In particular, it is noted that the implementation of digital technologies directly affects the growth of national welfare and material profit of traditional forms of management, especially with regard to agricultural production in the Russian Federation (Keshelava et al. 2017). As noted by V.V. Putin in his annual appeal to the federal assembly: "… Agriculture in the current conditions did not slow down the pace of development, but was the fastest to be included in the import substitution program and in 2018, it grew 2.2% in GDP." All of the above aspects have determined the relevance of the selected topic.

2 Materials and Method

Economic analysis as a scientific problem is devoted to research by Russian scientists such as Borodin (2015), Kovalev (2015), Ionova (2016), Sheremet (2017), Lavrentyev (2017), et al. Among the studies of foreign scientists, the works of Braille (2015), Myers (2015), Van Horne (2018) and Bernstein (2015), Holt (2016), Bush (2016), Stone et al. (2014).

The issues of the digital economy in Russian practice: Kozyrev (2011) and Koshelava (2017); Dobrolyubova et al. (2017) and others. Abroad: Thompson (2014), Simmons (2015), Keller (2015), Dunleavy (2016), Canberra (2016), Gray and Rumpe (2017), Lindgren et al. (2018).

The theoretical and methodological aspects of measuring the economic condition of an agricultural enterprise is a comprehensive study of the technical level of production, providing production with material, human and financial resources and the efficiency of their use. As a result, the quality and competitiveness of sold products, based on a systematic approach, taking into account the information received, comprehensively with various factors. It is an important management function (Balabanov 2015), (Vasilyeva 2016), (Ionova and Selezneva 2016).

The economic condition of the enterprise can be stable, unstable and crisis.

1) Steady state when inequalities of SOK ≥ 0 are observed,

SDI > 0; OI > 0,
where SOK - change in working capital for the analyzed period;
SDI - change in own and long-term borrowed sources of reserves for the analyzed period;
OI - change in the total value of the main sources of formation of stocks for the analyzed period.

2) Unstable economic condition when inequalities of SOK < 0 are observed; SDI < 0; OI > 0,

where SOK - change in working capital for the analyzed period;
SDI - change in own and long-term borrowed sources of reserves for the analyzed period;
OI - change in the total value of the main sources of formation of stocks for the analyzed period.

3) Crisis economic condition when inequalities of SOK < 0 are observed; SDI < 0; OI < 0,

where SOK - change in working capital for the analyzed period; SDI - change in own and long-term borrowed sources of reserves for the analyzed period;
OI - change in the total value of the main sources of formation of stocks for the analyzed period.

3 Results

The study proposes a comprehensive approach to carrying out predictive analysis using economic-mathematical methods based on the basic principles of the "digital" approach.

The experiment was conducted on an agricultural site for the production of potatoes of the company LLC Agropromresurs in the village of Sliznevo, Nizhny Novgorod region. Organization of the experiment is carried out by an expert group of enterprise specialists. The technical support of the experiment is carried out by a modern complex of power units and agricultural tools used at the enterprise.

For the experiment, fourteen experimental plots on potato production lands were allocated. The area of each plot is 10 acres (0.1 ha). The total area of the experimental plots involved in the experiment is 1.5 ha.

Analyzing the results of the conducted studies, we can draw the following conclusion. Approaches to establishing many factors that significantly affect the economic condition of an agricultural enterprise, now, unlike in past periods, depend not on traditional risks (objectively existing natural and organizational and technical factors), but from the risks associated with the so-called "human factor", such as:

1. Inadequate investment in the production process associated with the erroneous forecasting of the results of the enterprise in the near term periods.

2. Low efficiency of control for technological operations.
3. The level of automation for technological operations.
4. Selection of planting material variety (selection by one criterion without taking into account the rest).
5. The number of cultivations.
6. Norms for making mineral fertilizers and organics.
7. A number of harvesting and storage periods of potatoes in a potato storage facility with active ventilation.
8. The cost of spare parts and assemblies associated with centralized maintenance.
9. Professional training of personnel (in particular, from class and experience of mechanizes).
10. Transportation Logistics.

Below are the main conclusions from the results of the regression analysis and a factor set is formed with the establishment of the main directions for their optimization.

In this case, factors are ranked by significance using the Steudent criterion, as shown in Table 1.

Introduction of factor analysis and least squares method as a method of basic economic-mathematical approach used for forecasting and optimization of processes parameters of different nature. It was essentially a necessary and final regression modeling option, where in both cases the prediction procedure is based on linear and, in complex cases non-linear regression implemented by sample data. Moreover, the principle of minimizing the sum of the squares of its deviations is applied in order to approximate the point values of the output characteristic in the analyzed process. In this study, the technique is performed in the form of algorithmic and mathematical justification, formed in a single complex. The algorithm of the method is shown in Fig. 1.

As mentioned above, when studying the economic condition of agricultural enterprises, the use of regression analysis is completely logical and justified. In this case, the least squares method is used as an additional option.

The study proposed an integrated approach, including the standard least-squares method and the moving average method. At the same time, the moving average method should be considered as an additional option correcting the resulting trend. The moving average method was considered and developed according to the results of the activities of LLC “Agropromresurs” in 2018–2019. According to the results of 2018–2019 quarterly potato sales are presented graphically in Fig. 2.

By calculating, a trend is established that allows us to make a forecast of the number of product sales in the next period. The model of actual values of sales can be represented through the trend value in the form of the formula:

$$\mathrm{A} = \mathrm{T} + \mathrm{S} + \mathrm{E}; \tag{1}$$

where: A is the actual value;

T is the trend. The trend is the main trend in the development of the dynamic series (to increase or decrease its levels).

S is the seasonal component. Seasonal variation is the repetition of data over a short period of time. A season can be understood as a day, a week, a month, or a quarter.

Table 1. List of influencing factors

Designation of influencing factors by the regression model	Name of influencing factors Units measurements Range of variation significance of factor	The main directions for establishing optimal values of influencing factors
X_1	The volume of investment in experimental plots (fields) during the experiment thousand rubles Interval of variation 100–60 Significance 66.85	Improving the investment climate through innovative planning and forecasting the results of the agricultural enterprise
X_2	The number of cultivations Interval 5–3 Significance 65.0	Optimization of cultivations and weeds
X_3	Non-affecting factor	
X_4	Number of harvesting and shelf life of potatoes in storage Storage days 40–30 with two and three harvesting Significance 63.12	Introduction of modern methods of active ventilation in potato storages
X_5	Production automation level Percentage of technological operations using automation 40–30 Significance 62	Optimization of the number of technological operations using innovative technologies
X_6	Quality and quantity of control operations on the technological process in percent 19–6 Significance 54	Optimization of the number of control operations on technological process
X_7	Professional training of machine operators of a wide profile Class 1–3 Significance 7,7	Improving the quality of professional training
X_8	Costs of spare parts and assemblies. Downtime due to lack of fuel and lubricants and spare parts in thousand rubles 120–80 Significance 4.8	Organization of the supply of spare parts for agricultural machinery, fuels and lubricants from suppliers
X_9	Not significant factor	
X_{10}	Logistics of transportation in km. 200–100 Significance 1.9	Transport optimization

E - forecast error. Error values are calculated by the trend equation and past data, and allow us to estimate the quality of the forecast 20 (E = 0, with a confidence level of 0.75).

The algorithm for calculating the forecast value of product sales is as follows:

1. The value of the seasonal component is calculated.
2. The seasonal component is subtracted from the actual values, which will provide a trend calculation.
3. Definition of errors as the difference between trend and actual values.

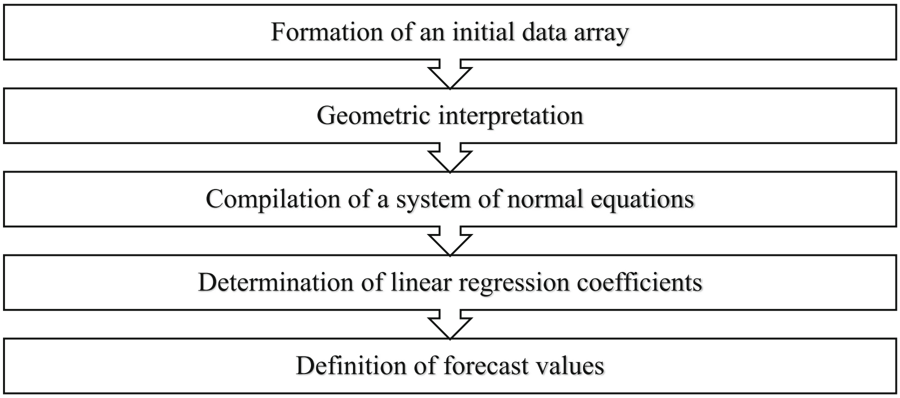

Fig. 1. The structure of stages of the implementation of the least squares method.

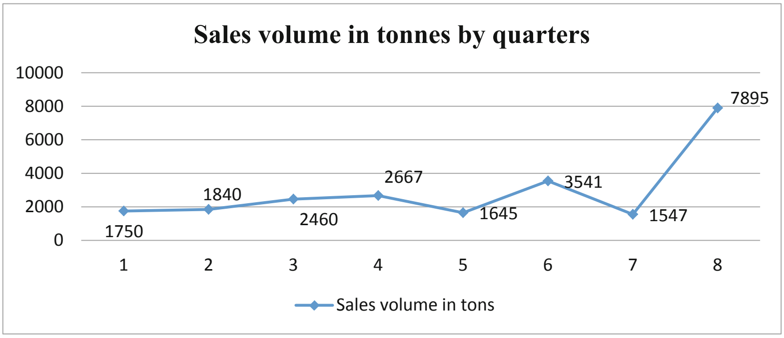

Fig. 2. The volume of potatoes sales by quarters

4. Calculation of the average deviation to select the best model for calculating forecast values.

In order to exclude the influence of the seasonal component, we apply the moving average method. Summing up the values of four quarters, we get the sales volume for 2018.

$$(1{,}750 + 1{,}840 + 2{,}460 + 2{,}667) \ = 8{,}717$$

To find the average sales in each quarter, we divide the result by four: 8717/4 = 2179. This value does not contain a seasonal component, since it is the average value for the year, this figure can be considered the average trend estimate for the middle of the year (the point that lies between the second and third quarter). Experimental data on the values of the variables x and y are given below.

	$i = 1$	$i = 2$	$i = 3$	$i = 4$	$i = 5$	$i = 6$	$i = 7$
x i (year of study)	2012	2013	2014	2015	2016	2017	2018
y i (thousand tons)	10.570	11.420	11.540	12.210	12.290	12.670	13.510

Unknown regression coefficients A and B are determined by standard formulas, in our experiment they will be equal to B = 0.26. A = 11.980. Y (2019) = 11.980 + 0.26 x 8 = 14.060 (thousand tons) - the forecast value of the gross harvest of potatoes in 2019.

4 Conclusion

During the experiment, a factor analysis of the financial and economic activities of LLC Agropromresurs was carried out. As a result of this analysis, it was revealed that the main disadvantages of the enterprise are:

1. A decrease in the volume of product sales, as a result of dependence on seasonal components, which will gradually lead to a decrease in the financial independence of the enterprise.
2. A negative indicator of the enterprise's activity is the low modernization of production, which goes against the policy of "digitalization" in all sectors of the national economy.
3. As a result of the analysis of key financial indicators of the enterprise, we have established the following. The financial condition of Agropromresurs LLC as of December 31, 2019 is significantly worse than the financial condition of half of all microenterprises engaged in the type of activity growing vegetables, melons, root crops and tubers, mushrooms, and truffles (code OKVED 38 01.13). The same conclusion can be drawn when comparing the performance of the enterprise with an average performance for all sectors of the Russian Federation.

As methods that will improve the financial condition of the enterprise, a method for predicting the volume of sales is proposed, which will not depend on the seasonal characteristics. The advantage of this study is the implementation of methods and approaches that will eliminate seasonal dependence in sales of potatoes as the main product of the country's population, in particular: factor analysis based on the method of active experiment; a method for determining influencing factors; economic-mathematical approach to analysis, which is allowing the transition to digitalization of agricultural production.

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The Impact of Artificial Intelligence on the Socio-economic Development of Society in Modern Conditions

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Abstract. The purpose of the study: is to identify trends in the development of artificial intelligence, algorithms, big data, bots, business models, forecasting, pricing, training strategies, and to assess the readiness of various spheres to use it effectively for the benefit of society.

Methodology: includes benchmarking, comparative analysis of trends in the creation of artificial intelligence and its impact on socio-economic development of society, the needs of market research in artificial intelligence and the ability to learn new skills and competencies of staff; collection methods; administration; data processing; predictive analytics.

Results: The structure, intelligent systems, stages of creating artificial intelligence, specific results at each stage of its use by organizations, possible errors, and risks are proposed.

A new paradigm of working with analytics of platform-type business models has been developed.

New approaches to competition under changed conditions are substantiated.

New tools that are emerging in the world of cloud services, open platforms, APIs, and crowdsourcing are summarized.

The mechanisms of predictive cooperation and interaction of “Human-Machine” with understanding the possibilities for both under changing conditions are proposed.

Directions of training and retraining of personnel with unique and constantly changing skills, and competencies, as well as subversive technologies, are defined.

Conclusion/Recommendations: Improvement for the structure of intelligent systems, robots, algorithms, methods of collection, introduction of representative, relevant, correctly marked data, data processing, identification, classification of business models, and component equipment.

Expanding work for existing jobs with robots and manipulators.

Creation of work with new competencies, which will amount to expert estimates about 10% in the next 10 years of the total number of jobs.

Identification of the risks associated with the use of artificial intelligence, evaluation and development of proposals for leveling risks.

Improving DMP platforms, DSP, SSP, AdExchange, DMH.

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Creation of a training and retraining program of personnel and constantly changing knowledge, skills, competencies, as well as subversive technologies.

Keywords: Algorithm · Big-data · Software · Artificial intelligence · Classifier · Disruptive technologies · Predictive mechanisms of cooperation and interaction between the system "human-machine"

JEL Codes: O1 · O3

1 Introduction

The leaders of large and small companies are faced with questions about how to use artificial intelligence, algorithms, bots, big-data to achieve future success, occupying an increasing market share, showing high product growth and increasing profitability. The new technology will not become the sphere of several companies, but the territory of many. Product innovation can and should be implemented quickly, as well as sharply reduced life cycle. About these technologies and artificial intelligence it has been written many scientific papers. As early as 1956, the computer scientist McCarthy wrote that once any artificial intelligence system started to work well and produce a result, no one else will call it artificial intelligence. Russian scientists Kolmogorov and Arnold in 1957 proved the theorem that any continuous function of several variables can be represented as a combination of a finite number of functions of fewer variables; this was the mathematical basis for the construction of neural networks. But in order to train the neural network, very large computing power and huge data arrays with codes and classifiers are currently being created.

The first attempts to build learning machines were made within the framework of cybernetics. It was based on the mathematical foundations of control processes in living organisms and society. Works by Glushkov, Kitov, and Lyapunov are noted in this area.

The complex of artificial intelligence, algorithms, bots, and big-data is already becoming a decisive factor in the further development of the 4.0 industry and the transition to 5.0 industry with new business models, which are occupying an increasing market share, show significant growth, and increase profitability, provide the opportunity to develop new products and create completely new industries.

Production automation and effective innovations in many areas of advanced technology, do not concern individual companies, and many who can take advantage of the industry 5.0.

Global expert analysts estimate the global market for artificial intelligence and neurotechnology by 2025 over $500 billion. The size of the Russian market should be more than $30 billion US. In many countries, the government identified the artificial intelligence technology as the most important factor of competitiveness.

The range of technologies used with artificial intelligence is quite wide; especially these technologies play a huge role in the process of the digital transformation of business (Frunk et al. 2017).

To do this, we need to understand and assess the possibility of big-data, new machines, and artificial intelligence. Today researches and business models conducted on high - tech and ready to digitalize firms, which show the following staff expectations:

– Automation of work operations can lead to a reduction of jobs in the next 10 years by 15%;
– Expansion of work for existing jobs will be changed or supplemented by robot programs and will amount to at least 75% of the total number of jobs;
– Creation of work with new competencies will be about 10% in the next 10 years of the number of vacancies;
– Increase in productivity and efficiency can be doubled and the quality of its execution;
– Society gets higher standards of living.

The intelligent system includes software (algorithms, business rules, machine learning code, predictive analytics), hardware (servers, sensors, mobile devices, connectivity to big-data, the human part (often estimate or queries)) (Tolstykh et al. 2020).

The first step in creating artificial intelligence is a step of allowing to create it for a particular purpose and fulfillment of business objectives within a specific product context, services or business process (litigation, accounting, vehicle management, inspection X-ray studies, credit history and so on.)

In the field of development and use of artificial intelligence systems, in general, the following results can be noted:

– Recognition (speech recognition, information from sensors, computer vision, gesture, biometric, and character recognition);
– Action (use of industrial and home robots, software agents, drones);
– Natural language processing (analysis and synthesis of speech, information search, text analysis, dialogue in a natural language, translation);
– Data analysis (expert systems, a set of forecasting methods, forecasting systems, data processing according to a given scheme for solving specific problems) (Perez 2013).

Therefore, such artificial intelligence is applicable in those types of human activity that machines can do. They try to repeat what people already doing well (Fig. 1).

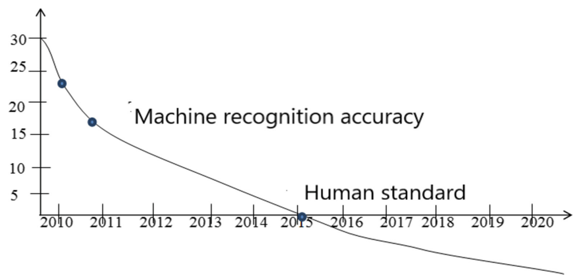

Fig. 1. Time graph of errors in object recognition

The second step is to create a common artificial intelligence that can mimic a person's decision making, that is, acting in the same way as a person (Alexa application for Amazon).

The third stage involves the creation of artificial intelligence general collective mind of humanity in all spheres, but for the third stage is necessary in the coming decades to solve many problems.

2 Materials and Method

Artificial Intelligence, created in the first stage is used as a good tool for obtaining high business results of the modern company. Currently, there are services, algorithms that consist of three main networks:

– A strategic network - layer that touches in the memory of all of business processes;
– The estimated network - layer, which evaluates the effectiveness of the current position;
– Tree search purposes - layer, which predicts the most efficient business process.

DMP platform collected three types of data:

– Own data (First party data) - User data, including personal and contact, as well as information about its activities in digital is - channel (mobile application, website, search), which collects itself.
– Data on the marketing activity (Second party data) - the results of marketing campaigns; information that could buy the company from other sources where the user is.
– Third party data—segments and analytics provided by special data providers through cookie synchronization with different data providers (Lovelace 2014).

3 Results

In practice, the cutting-edge companies provide consumers with: 3D diagram, process map of how the product is made, the technological passport and instructions for operation and maintenance, i.e., as the product needs to be serviced. Successful companies - Alibaba, Amazon, Facebook, and others use business models that enable multiple parties (producers and consumers) connect to them, interact, create, and exchange value. Technology is not becoming the domain of selected companies, but the territory of many. Product innovation can and should be implemented quickly. Organization managers are increasingly aware of the fact that the Internet of Things has every opportunity to get the right information about technologies, markets, and buying behavior. To do so, it is necessary to digitalize enterprises and organizations in a short time and to use data transmitted by devices from the Internet of Things, digital platforms (DMR, DSP, SSP, AdExchange), intelligent systems that combine hardware, software with artificial intelligence, human resource data that is included in value creation, commercial models, monetizing intelligent systems based services and solutions (Kwinberg et al. 2017).

Expert research and evaluation of the development of industries allow us to determine the level of industry uncertainty for the use of business intelligence (Table 1).

Table 1. Areas of uncertainty level of activity

Areas of activity	Uncertainty measures	
	% R&D of sales	Income volatility %
Medical equipment	9.2	91.7
Computers	6.8	99.8
Pharmaceutical equipment	18.4	62.8
Control and measuring equipment	10.3	98
Engineering	4.2	101.5
Agriculture	11.8	124.5
Electronic equipment	6.2	62.4
Chemical industry	4.2	72.5
Electrics	10.8	37.0
Business services	4.2	47.2
Business supply	2.4	30.8
Shipping containers	1.0	66.2
Estate	2.3	59.6
Beer and alcoholic beverages	4.3	13.9
Personal services	1.0	62.7
Tobacco products	2.0	18.3
Insurance	3.2	35.4
Wholesale	1.15	15
Utilities	0.9	50.6
Precious metals	1.1	50.1

The company, which leverages business analytics through smart systems, reduces costs by 9.5% and increases revenues by 9.8%.

Expert analysis and evaluation show that everything that surrounds a person in the next 10–15 years with the help of "Internet" will be technically equipped and connected by computer functions in devices or objects:

- CiscoSystems predicts that the number of connected devices already by 2022 will grow to 50 billion.
- Intel assumes that by 2022 will be connected to the communication devices 200 billion.
- MCkinsey predicts that global spending on devices and services for "Internet-Things" will reach $11 trillion by 2025. US.
- IDC expects the market for mobile devices will be 200 billion dollars US by 2022.
- GeneralElectric predicts that the Internet market will increase GDP from $10 trillion to $15 trillion over the next 20 years (Rose 2015).

Research shows that 281 respondents (large and medium-sized business) in the fields of: banking and finance, medical services, insurance, retail trade experienced revenue growth and cost reduction due to the digitization of the economy (Table 2).

Table 2. The increase in revenues and decrease in costs associated with digital variable

Field of activity	The increase in revenues %	Cost reduction %
Banking and Finance	9.8	8.1
Payment for medical services	8.2	5.5
Insurance	11.6	10
Retail	9.6	8.2

In each case, business executives turn their products into code generators, thus creating data for the digital economy. Algorithms and artificial intelligence integrated into intelligent systems convert this data into chain insites that drive business results and set new limits of performance.

Using new business processes and intelligent systems, competitors are changing the base cost, as well as the speed of operations and the ability to receive insights on all aspects of the business. Whether it is the automation of a business process, reducing the price of an existing product, by collecting environmental information, expanding human activities with digital instruments, the organization of mass demand for a market product, or the creation of a completely new offer based on a technological invention.

When automation is directed at internal processes, it is possible to achieve significant savings in the company. And when automation is aimed at products and services, the benefits are gained by consumers in the form of a mass supply.

Intelligent systems are the latest set of technologies that create the basis for which new areas of activity and new jobs will be built. Ultrafast machine learning greatly accelerates scientific and technological progress. In the face of digital progress, products, and services will be digitized, personalized, filled with intelligence and offered at a price level that opens up new markets (Evans 2011).

Digital expansion in all spheres allows rapid productivity growth and reduced costs, increasing the chances of providing the growing global population with everything needed for life.

By automating and equipping all processes with meters and creating codes and classifiers, new data clouds are formed, allowing us to see a forecast of facts and trends that could not be identified before.

Companies that combine new raw materials of the digital age of big-data, new machines (smart systems), and new models (business—models that optimize the monetization of commercial supply), based on personalization data.

Information gathering is expensive, but artificial intelligence necessarily requires big data, both to create, function, and improve it. Thanks to artificial intelligence, forecasts will become cheaper and the value of complementary factors will increase. Artificial intelligence can better identify factors of complex interaction of individual indicators (A Guide to the Internet of Things).

For artificial intelligence to give a forecast, it is necessary to indicate what exactly should be predicted. If an event has never occurred, the machine will not be able to work with it without providing a person with a formulated judgment with an adequate analogy, allowing one to make a prediction using information about other events.

4 Conclusion

In the prognostic cooperation "Human-machine", an understanding of the limit of capabilities is required.

Artificial intelligence better than humans analyzes the complex interactions between different attributes in the presence of a large amount of data. But a person surpasses artificial intelligence in cases where understanding the origin of the data provides a prognostic advantage with a small amount of data. Price per unit of forecast decreases with decreasing frequency of forecasts. A person follows a cognitive model of everything happening in the world and therefore a person can make predictions based on a limited amount of data, meaning a person can provide a prediction of exceptions. A person predicts and makes a judgment at the same time.

Since artificial intelligence provides an accurate, fast and cheap forecast in the context of big data, but it is not capable of judgments. Since judgments require an understanding of the outcome of any interaction "Action + situation". The idea is to determine the relative results for all possible outcomes of decisions.

A study conducted in organizations shows that out of 2040 people surveyed, 70% are afraid of losing their jobs, 30% believe that now it is necessary to predict what employees will do. What qualities they should pay attention to when hiring new staff, and first of all, how it will change the functioning of the organization in digitalization through experimentation and modeling.

Analysis shows that previous types of industrial revolution are constantly evolving (Fig. 2).

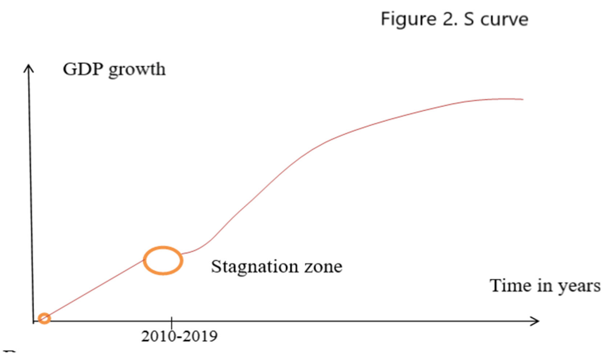

Fig. 2. S curve

Currently, we are in the end zone of stagnation and enter into an era of rapid change.

Artificial intelligence cannot predict judgment if the situation has not been repeated many times. Technological platforms create new mechanisms by which an effective labor market is formed.

Thus, society must incorporate artificial intelligence into its life consciously and thoughtfully so that it creates more value for everyone than it destroys. It is hybrid artificial intelligence we must create in the first place.

Entrepreneurial and inventive activity requires a kind of intellectual arbitration, i.e. understanding the gap between what is possible, and what has been achieved so far.

Managers of companies should identify the goals that they want to achieve; study the work processes and determine what tasks must be completed to achieve the goals. Then predict what role artificial intelligence can play for them; the following algorithm must be observed:

forecast - judgment - action - result.

The wider the forecasts the higher the value of judgment. Predictive data will add value to additional components, including judgments, actions and data.

Possession of forecast-dependent actions can provide a competitive advantage, which allows traditional companies to also capitalize on some of the artificial intelligence.

China is investing heavily in the development of artificial intelligence, they are growing rapidly, from 10% in 2012 to 23% in 2017, and the US share for the same period fell from 41% to 37%. In the field of artificial intelligence, it is required to simultaneously develop algorithms and data. Chinese developers have the opportunity to get big-data.

For this reason, the dawn of artificial intelligence will bring society a multitude of choice options: productivity or distribution, innovation or competition, productivity or confidentiality.

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Applications of Computer Vision in Cross-Sectoral Tasks

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Abstract. Purpose: Development of a universal automated system that allows building a map containing n characteristics at each point, with the identification of areas corresponding to emergency situations on the basis of specified features.

Approach: The authors use a combination of methods: spectral analysis, analysis of heights, analysis of changes to detect emergencies, both embedded in the system being developed and absent by it. The emphasis is on the fact that different objects can be analyzed by the same methods, but the final result will depend on the scope.

Findings: In addition to monitoring forests and agricultural land, the system modules make it possible to control production facilities:

– detection of fires in the enterprise;
– monitoring the state of the oil pipeline;
– control of oil spills in production;
– identification of offenders at objects, calculation of their unique features for identification.

Originality: The developed system is flexible; it is easily supplemented with new software modules, the maps of properties of which expand the vector of characteristics in each pixel of the final map. The system is capable of solving cross-sectoral problems: its functionality depends entirely on the software modules included in it.

Keywords: Computer vision · Video monitoring · Spectral analysis · Vegetation · Water · Production

JEL Code: C02 · C60 · C61 · C80 · C88

1 Introduction

Improving human safety in production, monitoring enterprises, processes and workers, detecting and classifying abnormal operations - these tasks can be solved by creating an intelligent video surveillance system that will promptly report violations.

Relevance: the human factor plays an important role: Lukyanitsa (2009) in his work notes that working with a sufficiently large number of cameras entails the quality of

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detection of abnormal effects (for simultaneous viewing of 16 cameras, after 20 min of continuous observation, the probability of detection emergencies is only 20–30%). It is worth noting that such situations can be very different in nature: work at height without helmets, absence of a person from the workplace, improper riveting technology, pipeline breakthrough, industrial fires, forest fires, plant diseases, illegal logging, and so on. Separate tasks of the system have already been solved by scientists from different countries: in (Amosov et al. 2019), a neural network method for processing a video stream was proposed for detecting and recognizing moving objects and their trajectories; in Ballari et al. (2016), Berra et al. (2016), Berra (2017), Ganthaler et al. (2018), Hua et al. (2017) describe development of a system for detecting the state of vegetation using spectral analysis; in Meng et al. (2018), Du et al. (2017) methods of remote sensing of the earth were used to monitor the state of agricultural crops; Systems for detecting and monitoring forest fires are described in Pla et al. (2017), Lin et al. (2015), Von Wahl et al. (2010), Yuan et al (2017).

Thus, there is a need to develop a universal automated system that allows, on the basis of the given features, to build a map that exists at each point, with the detection of corresponding emergency situations (Zharikova et al. 2020). The proposed system makes it possible to solve cross-industry problems: its functionality should completely depend on the software modules included in it. The scheme of the system's functioning is shown in Fig. 1. When a new module is added, all states analyzed by it are automatically recorded in a separate file, which is one of the general set of characteristics processed by the system.

2 Methodology

The object of the research is emergency situations.

The subject of research is the methods of computer vision, spectral analysis, modeling of environmental objects.

As you know, computer vision algorithms are aimed at finding images and key features in images, which allows characterizing the properties of an object or situation. It should be noted that for different objects and situations, the set of properties would be radically different:

- object "vehicle": number, color, model;
- object "person": gender, age, etc.;
- object "forest fund": felling, vegetation depression, burning;
- situations: the length of the stages observed in time; interaction of dynamic objects within a situation.

To demonstrate the operation of the system, the following software modules have been developed:

- module for detecting oppressed vegetation;
- combustion detection module;

– cutting control module;
– module for monitoring the state of water bodies.

This set of modules allows solving the problems of monitoring the state of the forest fund or agricultural land. The software modules receive video streams in visible (RGB), near (NIR), medium (MIR), far (FIR) infrared, etc. ranges.

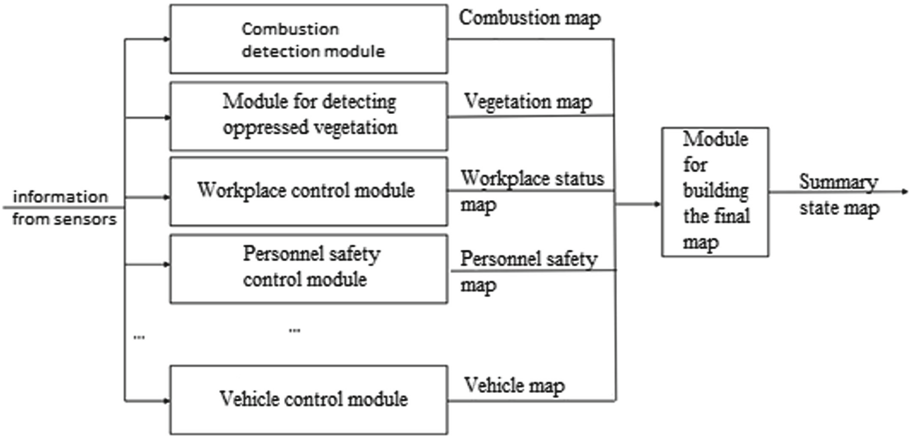

Fig. 1. Scheme of the system. *Source*: developed and compiled by the authors.

Inhibited Vegetation Detection Module

To obtain information about the state of vegetation, let us assume that each pixel p_i^j corresponds to two values from the sets NIR and RGB, but for small distances the statement is not true, so we introduce the concept of the neighborhood of a pixel. This is due to the fact that the IR camera and the RGB camera are at a distance of len from each other (Zharikova et al. 2019). The vegetation index (VI), the value of which indicates the state of vegetation, in this case, will be calculated based on (1):

$$NDVI = \frac{NIR(i,j) - RGB(i,j,0)}{NIR(i,j) + RGB(i,j,0)} \tag{1}$$

where IR(i,j) and RGB(i,j) – the value of the pixels entering the neighborhood corresponding to the average of this neighborhood (2): (Zharikova et al. 2019)

$$P_{pic}(i,j) = \frac{\sum_{oki=i-k}^{oki=i+k} \sum_{okj=j-k}^{okj=j+k} P_{pic}(oki, okj)}{k^2}, \tag{2}$$

where $P_{pic}(i,j)$ - average pixel value IR(i,j) or RGB(i,j) in some neighborhood with diameter 2k. The general model (3) of the change in the radius of the neighborhood was derived by analyzing the obtained VI and the real state of the biomass when measured at different distances. Studies have shown that the neighborhood of a pixel changes according to the laws of power regression (Zharikova et al. 2019).

$$k = koef \cdot dist^{st\_koef} \quad (3)$$

restrictions:

$$dist \geq \frac{len \cdot tg\frac{\pi-\alpha}{2}}{2}, \quad (4)$$

where koef and st_coef – coefficients obtained by approximation (displayed for each sensor separately. This procedure is performed once and does not affect the speed of the system in the future), dist – distance to stage, α - sensor viewing angle, len - distance between sensors.

Combustion Detection Module

A multifunctional approach described in Zharikova et al. (2020) was used to detect fire. The idea is to find such signs, the combination of which makes it possible to detect a fire with a high probability.

Fire has distinctive features such as color, movement, shape, height, and smoke.

The first step in the operation of the algorithm is to find areas of the video stream in which movement occurs, determined by the algorithm:

1) Getting the matrix D_i by subtracting from the matrix A_i, the matrix describing the current frame A_{i-1}, this describes the previous frame. Matrix D_i described by the relation (5):

$$D_i = A_i - A_{i-1} \quad (5)$$

2) Converting the matrix D_i to binary by element-wise comparison with the threshold value 0 < MOTION_THRESHOLD < 255. (6)

$$d_i^{j,k} = \begin{cases} 0, d_i^{j,k} \leq MOTION\_THRESHOLD \\ 1, d_i^{j,k} > MOTION\_THRESHOLD \end{cases}, \quad (6)$$

where $d_i^{j,k}$ - matrix element D_i, from numbers j,k.

The second step of the algorithm is to process the pixels of the matrix A_i in accordance with the rule (7):

$$Arez_i^{j,k} = \begin{cases} 1, A_i^{j,k,1} > min\,and\,A_i^{j,k,1} > A_i^{j,k,2} > A_i^{j,k,3} \\ 0 \end{cases}, \quad (7)$$

where $\min = \frac{1}{N+M}\sum_j^N\sum_k^M\left(A_i^{j,k,1}\right)$, $A_i^{j,k,1}$- matrix value in one of three color channels, varies from 0 to 255.

The third step is to obtain the final fire map according to the rule (8)

$$fire_i^{j,k} = \begin{cases} 0, d_i^{j,k} = 0\,or\,Arez_i^{j,k} = 0 \\ 1, d_i^{j,k} = 1\,and\,Arez_i^{j,k} = 1 \end{cases} \quad (8)$$

Cutting Control Module

Existing developments, which aim to scan the land, allow the creation of a 3D map, but they do not allow automatic analysis of deforestation.

The process of analyzing the state of the forest consists in constructing a 3D map of the area using laser rangefinders. On the basis of the obtained map, the "roughness" of the surface is estimated by searching for local extrema. Changing the roughness parameters allows determining both the presence of a tall forest and the presence of a field. (Zharikova et al. 2020).

A two-dimensional array (depth map) is fed to the program input, the values of which vary from *length_min* to *length_max* - it corresponds to the capabilities of the installed sensor. The resulting array B3 is formed, containing information about the presence of a forest, which is built on the basis of matrices B1 and B2. B1 is structured according to the block diagram shown in Fig. 2.

The matrix B2 is formed in a similar way, but already from the columns of the matrix A. The formation of the B3 array occurs in accordance with the rule (9).

$$b3_{i,j} = \begin{cases} 0, \ if\ b1_{i,j} = b2_{i,j} = 0 \\ 1, \ if\ b1_{i,j} = 1\ or\ b2_{i,j} = 1 \end{cases} \tag{9}$$

A more accurate result can be obtained by systematic monitoring of a given area, which allows storing data of the previous state of the area and giving a more accurate description of the state of the forest. Refinement of data is also possible using vegetation indices, which are described above (Zharikova et al. 2020).

Water Body Condition Monitoring Module

To obtain information on the state of water bodies, it is necessary, initially, to determine the boundaries of the water surface area using the water index. This index uses the values of the spectral characteristics of water in the visible green spectrum, which is many times higher than the corresponding values of vegetation and soil. The spectral characteristic of water in the near infrared range is also used, which is many times lower than the corresponding values for vegetation and soil. Thus, the relation for detecting the water surface (water index) has the form (10):

$$NDWI = \frac{RGB(i, j, 1) - NIR(i, j)}{RGB(i, j, 1) + NIR(i, j)} \tag{10}$$

The value of the current pixel is also calculated using formula 2, as for NDVI (1).

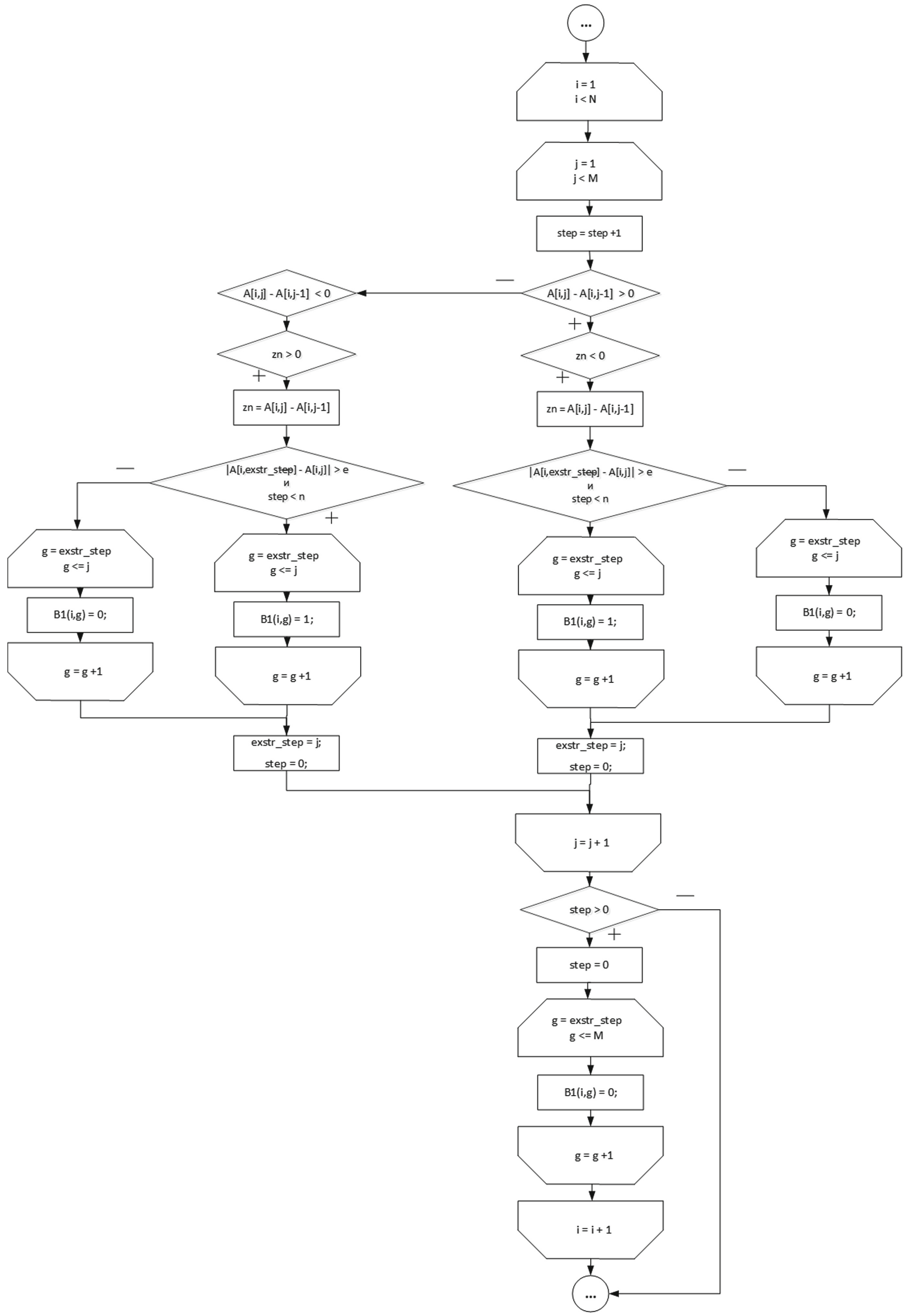

Fig. 2. Block diagram of the formation of the matrix B1. *Source*: developed and compiled by the authors.

Non-water pixels are "suppressed" and have zero or negative values (Fig. 3).

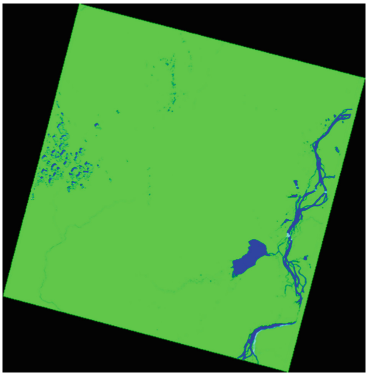

Fig. 3. NDWI calculation results (blue - water surface). *Source*: developed and compiled by the authors.

The information received contains a large amount of noise generated by the presence of anthropogenic objects. For more accurate image analysis, a modified normalized difference water index (MNDWI) is used (11):

$$MNDWI = \frac{RGB(i, j, 1) - MIR(i, j)}{RGB(i, j, 1) + MIR(i, j)}, \tag{11}$$

where MIR(i,j) – the mid-infrared pixel value.

The pixel indices corresponding to water are larger than in the NDWI, since water absorbs more radiation in the mid-infrared than in the near. The building area, soil and vegetation have negative values, since they reflect much more radiation in the MIR range than in visible green. Consequently, the contrast between the MNDWI indices belonging to water and non-water areas is even greater in comparison with the NDWI.

After identifying the area of the reservoir, a contour analysis of the resulting area is performed to determine the heterogeneity of the water surface, which indicates the presence of some pollution of the reservoir.

3 Results

During the experiments, charts of characteristics were obtained, reflecting the state of various areas:

1. analysis of the state of vegetation is presented in Figs. 4, 5, and 6.

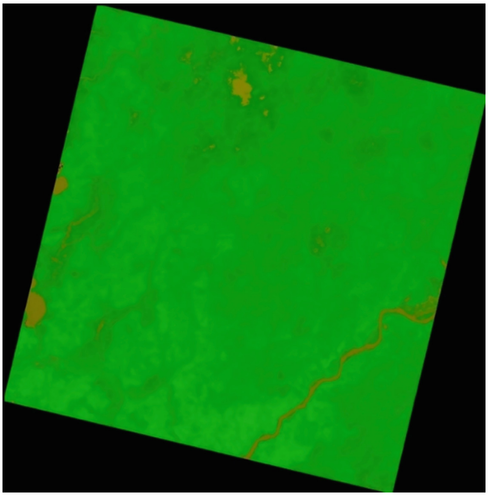

Fig. 4. The result of calculating the vegetation index for the area of the earth's surface, the data were obtained from the satellite. *Source*: developed and compiled by the authors.

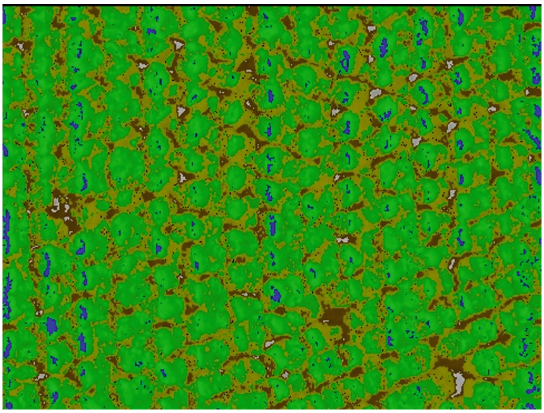

Fig. 5. The result of calculating the vegetation index for the area of the earth's surface, the data were obtained from the drone. *Source*: developed and compiled by the authors.

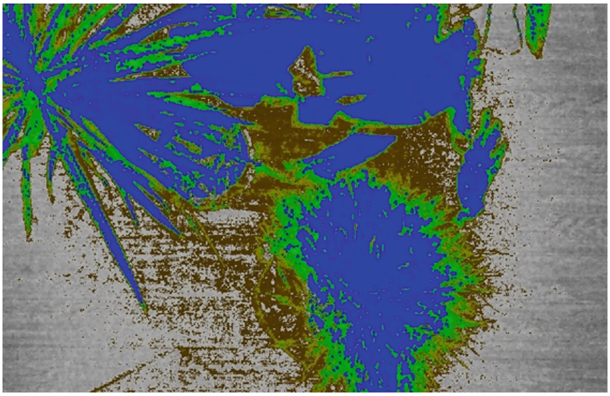

Fig. 6. The result of calculating the vegetation index for the area of the laboratory surface. *Source*: developed and compiled by the authors.

In the final maps presented above, the colors have the following meanings: gray is artificial materials (concrete, asphalt, flooring); brown is soil; yellow is diseased vegetation; green and blue are healthy vegetation.

2. the result of fire detection is shown in Figs. 7, 8.

Fig. 7. Binary map of the found fire. *Source*: developed and compiled by the authors.

3. An example of processing an image of a water surface is shown in Fig. 9.

Fig. 8. Original image with automatically highlighted fire areas. *Source*: developed and compiled by the authors.

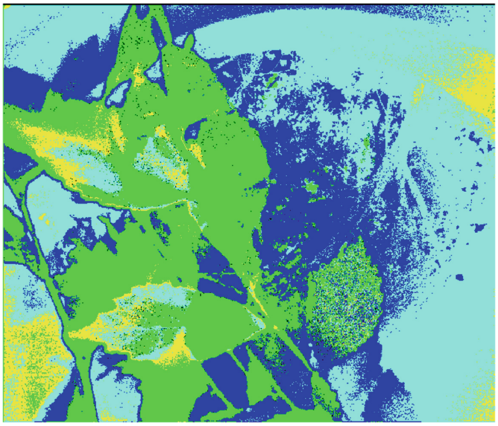

Fig. 9. Detection of vegetation on the water surface. *Source*: developed and compiled by the authors.

The paper considers the application of models to the problems of monitoring the state of forests and agricultural land, but the proposed methods can also be used in the analysis of production facilities. The combination of methods allows the following modules to be developed:

– the fire detection module can be used to detect fires at the enterprise;
– the module for detecting diseased vegetation is applicable for monitoring the state of the oil pipeline, since when oil spills, the state of the vegetation changes, which can be seen on the obtained maps with a high probability (add about reservoirs);
– the module for monitoring the state of reservoirs is applicable for monitoring oil spills in production.

– the blocking detection module is applicable for detecting unauthorized intrusions into an object, calculating the trajectory of an intruder.

4 Conclusion

The proposed approach is focused on the base of previously described emergencies, but the purpose of the study is to build models that allow identifying the state of a process or object that may precede an abnormal situation that does not have previously described characteristics. The analysis is based on dynamic characteristics: time, speed, direction, spectrum, and so on. This approach differs from the proposed one by the absence of the need to form an initial base, but, at the same time, it requires tuning the system relative to its initial state. All cyclical processes in production, subject to video surveillance, can be assessed with respect to average statistical indicators. Any deviations outside the confidence interval may precede an abnormal situation, multiple or continuous deviations indicate the most abnormal situation. The system constructed in this way requires regular expert evaluation in connection with possible changes in factors.

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Algorithmic Bases of Research of Combined Energy Converters by Engineering Analysis Methods

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Abstract. Purpose: The purpose of the is to develop an algorithm for an integrated approach to solving combined multiphysical problems using the example of a multifunctional electrical device.

Design/methodology/approach: The article considers an electromechanical AC converter based on an asynchronous machine. The electromagnetic calculation was performed using the ELCUT software package. The solution of the problem of hydraulic calculation taking into account the heat transfer is related to the equations of energy, heat transfer, motion, continuity, and also the initial and boundary conditions.

Findings: An algorithm for CFD modeling of the heat and mass transfer process was developed, which includes three successive stages. The basic theoretical provisions of the associated electromagnetic, thermal, and hydraulic calculations are given. The electromagnetic calculation is based on the Maxwell equations implemented in the Elcut program. In solving the problems of hydrodynamics, a three-layer model of the Schlichting turbulent flow is used. The calculation of the average heat transfer was performed using the generalized dependence in the form of a modified Nusselt criterion.

Originality/value: The results of CFD modeling of the fluid velocity field in heat transfer and mass transfer zones allow us to design highly efficient combined energy converters.

Keywords: CFD-modeling · Three-dimensional parameterization · Algorithm · Combined energy converters · Related tasks

JEL Code: L94 · L95

1 Introduction

One of the main trends of the development of modern technical systems is improving their operating characteristics. The carried out process analysis of the existing technological complexes allows to select the devices for transporting and distributing working liquids as the most energy-intensive elements. As an example, we can consider the

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energy scheme of an oil refinery. It is a complex structure including the pumping equipment with an installed power from 5.5 to 1250 kW. It has an efficiency of no more than 50…80% depending on the pump power (Kim et al. 2019). This is typical even for the well-known global manufacturers of pumps and pumping equipment for the chemical and oil industry (Shin Nippon Machinery, Teikoku Electric, Mitsubishi Heavy Industries (Japan), Oilgear, Sundyne International S. A. (USA), HAUKE-MP, ENCE GmbH (Austria, Switzerland)).

Therefore the main purpose to be solved in this work is the development of an algorithm for studying the effect of design parameters on the operating characteristics of alternative versions of the combined energy converters (CEC) for transporting liquid media.

The object of the research is a converter of electrical energy into mechanical and thermal energies. In this case the drive and executive mechanisms make up the one rotating rotor (the executive mechanism). The pressure blades are fixed inside it.

This is due to the fact to improve the energy efficiency of the equipment in question can be first achieved by combining multi-functional mechanisms in one device.

The main advantages of this solution are:

– the absence of intermediate elements;
– improving the technical and economic characteristics while simplifying the design;
– the ability to automate design, production and research processes using the CAD/CAE/CAM methods.

2 Materials and Method

In spite of some progress in the development and the relative diversity of the designs of combined energy devices (Kim et al. 2019) we can mark two main elements in them. The motionless part is a stator (in some cases it is sealed by the composite polymer) and a rotating rotor in the form of a hollow cylinder with pressure blades located inside. The rotor is a power executive element (EE).

The gap between the stator and the rotor is formed by a dielectric self-lubricating composite material. The basis of the material is the fluoroplast or its analogues, which carry out the functions of a radial sliding bearing. The design feature is he motionless heating element (MHE) placed on the stator. For this reason the converter carry out the functions of heating and transporting the liquid.

The principle of operation of the device is described in detail in Kim et al. 2019. The obvious disadvantage of such a design of the low-power CEC is the relatively large gap between the motionless and rotating parts. This can lead to increasing the magnetizing current, reactive power consumption and increased heating of the stator. Therefore we must take into consideration the thermal state of the stator when we the study mass transfer processes in such devices.

The solution of the problem is to determine the algorithmic sequence of studying the influence of the EE parameters on the characteristics of the output. Here we develop an object adapted to simulation.

Usually the mathematical model of a complex technical system is used for a complex research. The reasonable replacement of the object of researching with a mathematical model allows us to analyze it and predict the mutual influence of multiphysical processes taking place in it.

On the initial stage we construct a solid-state parameterizable 3D model to determine the design parameters of the EE of the CEC. This model links all the forms and sizes of the mating elements and the complete description of the three-dimensional geometric shape. The result of this stage is the mathematical model with parameters. By changing these parameters we may get the different versions of the design schemes of the IE of CEC. Another result is the preparing of the files of a neutral standard format for transferring the geometry to the next stages of researching by the export/import operation. The presence of a parameterizable 3D model makes it possible to carry out the further stages of designing like as conducting a computational experiment based on the automated engineering analysis systems creating a physical model, testing it and analyzing the experimental data.

The T-FlexCAD system was chosen to create a three-dimensional solid-state parametric model of the EE of the CEC. It provides the ability to create a solid object in the layers based on the virtual three-dimensional model and research it using the modern CAE/CAM systems.

The simulation experiment with simultaneous taking accounting the multiphysical processes is realized in the SolidWorks Flow Simulation system. The SolidWorks Flow Simulation system is configured for any value of the design parameters of the EE of the CEC. It allows determining the dynamic characteristics and visualizing the velocity fields of the working liquid. The obtained results are the basis to determine the most significant parameters of the EE based on the analysis of response surfaces.

The final stage of the research is checking the model adequacy by comparing the values of the performance characteristics of the CEC obtained as a result of the computational and natural experiments on a physical sample obtained by the rapid prototyping with the help of 3D printing on a three-dimensional printer Dimension 3D Printers from Stratasys.

Defining the area of scientific research we can select the following components of the algorithm of the development of the combined energy converters by the engineering analysis methods:

– the development of a mathematical model of the CEC with the help the theoretical analysis of the processes;
– the calculation of the EE CEC design parameters;
– the building of the three-dimensional solid-state parametric model of the IE of the CEC;
– the justification of the target areas of operation in the CEC;
– the simulation of the speed fields in the target areas;
– the determination of the dependencies of the device performance characteristics on the EE design parameters;
– the calculation of the main design parameters of the EE of the CEC;

– the calculation of the optimal (suboptimal) values of important design parameters of the EE of the CEC taking into account the optimization criteria;
– the experimental verification of the obtained results.

3 Results

The changing of the converter design associated with the combination of its main elements is the reason of the increasing mutual influence of the main processes of power conversion and it significantly complicates to research them.

The basic variant of the CEC is shown in Fig. 1. Let us highlight the main elements of the CEC: 1 is the magnetic stator core; 2 is the motionless heating element having the thickness Δ_{MHE} and the length L_{MHE}; 3 is the executing element; 4 is the pressure blade; 5 is the inner magnetic core; 6 is the hermetic stator; 7 is the end cap combined with the radial-thrust bearing; 8, 9 are the fittings; 10 is the sealing ring; 11 is the spacer ring.

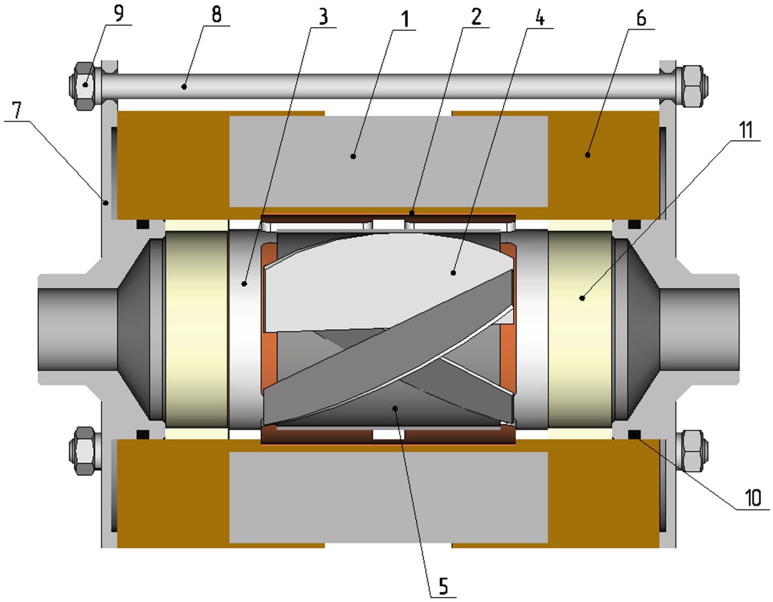

Fig. 1. The variant of the design of the CEC. *Source*: developed and compiled by the authors.

The a priori we don't know the quantitative influence of individual parameters of the EE on the characteristics of the CEC at the beginning of the research. We take the characteristic geometrical values of the EE into account which can theoretically affect on the effectiveness of the device: the thickness t, the length l and the execute element external diameter d; the quantity of the ribs $\mathrm{n_{rib}}$ and the rib width w_{rib}; the quantity of the rings n_r and the ring width w_r; the quantity of the blades $\mathrm{n_b}$, the length of the blade l_b, the thickness of the blade $\mathrm{t_b}$, the height of the blade $\mathrm{h_b}$ and installation angle α of the blade; the diameter of the inner magnetic core d_c; the length of the inner magnetic core l_c and the thickness of the inner magnetic core d_c (Fig. 2).

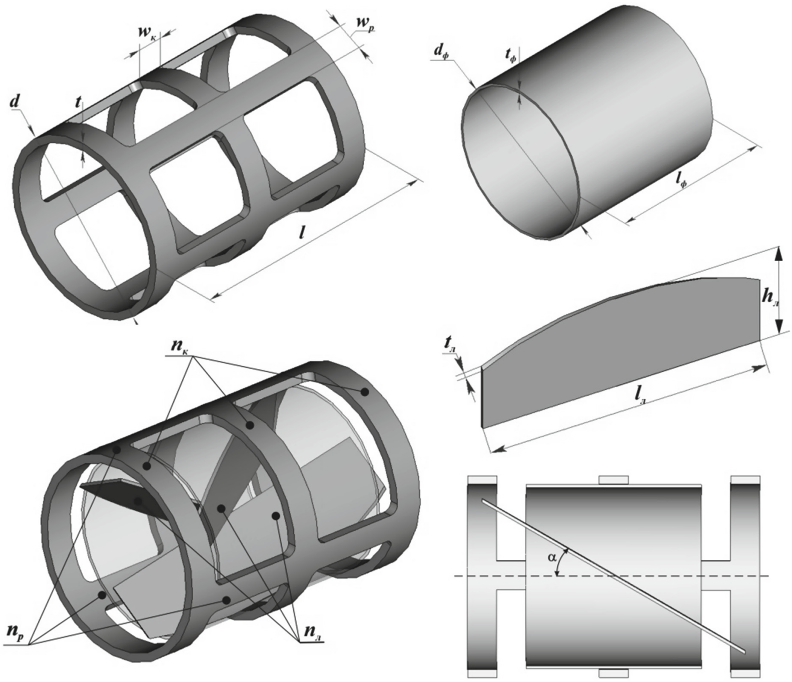

Fig. 2. To the choice of the design parameters of the EE of the CEC. *Source*: developed and compiled by the authors.

We took as the criteria of the choice of the parameters:

– the permissible current density. Here we take into account the conditions of heat exchange with the working liquid, the permissible value of induction in the parts of the magnetic circuit (for the electromagnetic calculations);
– providing the given values of the temperature of the working liquid at the EE output and the permissible thermal load of the CEC elements (for thermal calculations);
– the hydraulic resistance created by the pressure element of the CEC and the axial component of the speed of the working liquid (for hydraulic calculations).

The CEC feature of the solving problem is the simultaneous accounting of electromagnetic, thermal, and hydraulic processes in the CEC.

At the given electrical conductivity γ and magnetic permeability μ the electromagnetic calculation is made using the equation:

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu_y}\frac{\partial \boldsymbol{A}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\mu_x}\frac{\partial \boldsymbol{A}}{\partial y}\right)-i\omega\gamma\boldsymbol{A}=-\boldsymbol{J}_{\mathrm{TC}},$$

where **A** is the vector magnetic potential; $\boldsymbol{J}_{\mathrm{TC}}$ is the third-party current density, calculated by the formula:

$$J_{\mathrm{TC}} = I_m / S_k,$$

where S_c – is the coil cross-sectional area of the (White and Woodson 1959).

We accept the following values for the calculation CEC model: $\mathrm{I_m} = 1249$ A, where $\mathrm{I_m}$ is the amplitude value of the phase current taking into account the number of turns of phase; f = 59 Hz where f is the frequency.

The electromagnetic calculation was performed using the ELCUT software package. The result of solving the problem is presented as the distribution of magnetic induction along the length of the MHE in Fig. 3. We can see that the dimensions of the MHE are $\Delta_{\mathrm{MHE}} = 3.1$ mm, $\mathrm{L_{MHE}} = 43$ mm for the maximum induction B = 0.5 T. According to the known values of magnetic induction and the sizes of the MHE we calculate the heating temperature at different frequencies of the supply voltage (Fig. 4).

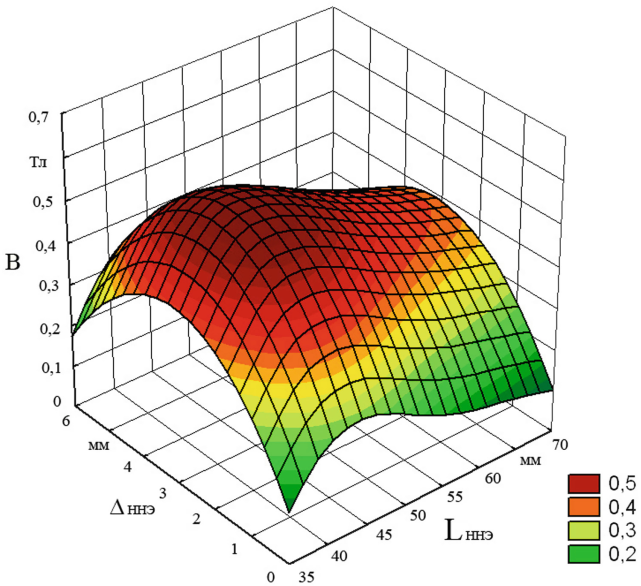

Fig. 3. The change of the magnetic induction. *Source*: developed and compiled by the authors.

The hydraulic calculation of the CEC is required to determine the main operating parameters: the output temperature depending on the axial velocity of the liquid v_x. The analysis of the hydraulic processes in the CEC requires taking the convective heat transfer into account at which the heat transfer at the movement of liquid is carried out simultaneously by the convection and thermal conduction. We make it using the equation (Schlichting 1974):

$$\vec{q} = \vec{q}_{cond} + \vec{q}_{conv} = -\lambda grad\Theta + \rho \upsilon i,$$

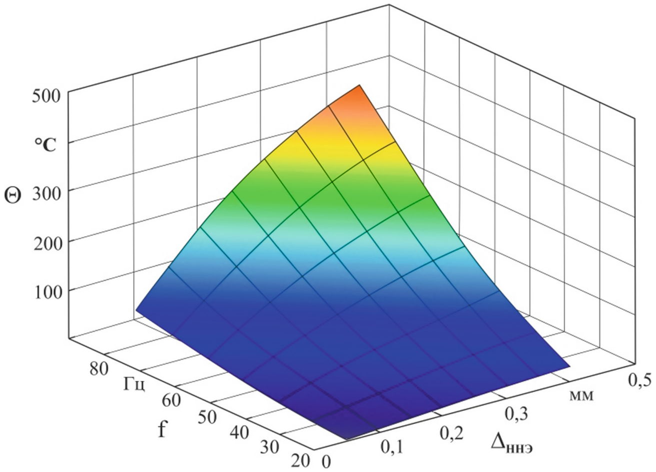

Fig. 4. The dependence of the MHE temperature on the voltage frequency. *Source*: developed and compiled by the authors.

where $\boldsymbol{q}$ is the local value (vector) of the heat flux density, W/m^2; λ is the coefficient of thermal conductivity, W/(m K); gradΘ is the temperature gradient, °C/m, ρ is the liquid density, kg/m^3; v is the liquid velocity, m/s, i the enthalpy, J/mole.

The solution of the problem of hydraulic calculation taking into account the heat transfer is related to the equations of energy, heat transfer, motion, continuity and the boundary and initial conditions (Schlichting 1974):

$$\frac{\partial \Theta}{\partial t} + \upsilon_x \frac{\partial \Theta}{\partial x} + \upsilon_y \frac{\partial \Theta}{\partial y} + \upsilon_z \frac{\partial \Theta}{\partial z} = \frac{\lambda}{c_p \rho}\left(\frac{\partial^2 \Theta}{\partial x^2} + \frac{\partial^2 \Theta}{\partial y^2} + \frac{\partial^2 \Theta}{\partial z^2}\right);$$

$$k_{term} = -\frac{\lambda}{\Theta_s - \Theta_{liq}}\left(\frac{\partial \Theta}{\partial n}\right);$$

$$\rho\left(\frac{\partial \upsilon_x}{\partial t} + \upsilon_x \frac{\partial \upsilon_x}{\partial x} + \upsilon_y \frac{\partial \upsilon_x}{\partial y} + \upsilon_z \frac{\partial \upsilon_x}{\partial z}\right) = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 \upsilon_x}{\partial x^2} + \frac{\partial^2 \upsilon_x}{\partial y^2} + \frac{\partial^2 \upsilon_x}{\partial z^2}\right);$$

$$\rho\left(\frac{\partial \upsilon_y}{\partial t} + \upsilon_x \frac{\partial \upsilon_y}{\partial x} + \upsilon_y \frac{\partial \upsilon_y}{\partial y} + \upsilon_z \frac{\partial \upsilon_y}{\partial z}\right) = \rho g_y - \frac{\partial p}{\partial y} + \mu\left(\frac{\partial^2 \upsilon_y}{\partial x^2} + \frac{\partial^2 \upsilon_y}{\partial y^2} + \frac{\partial^2 \upsilon_y}{\partial z^2}\right);$$

$$\rho\left(\frac{\partial \upsilon_z}{\partial t} + \upsilon_x \frac{\partial \upsilon_z}{\partial x} + \upsilon_y \frac{\partial \upsilon_z}{\partial y} + \upsilon_z \frac{\partial \upsilon_z}{\partial z}\right) = \rho g_z - \frac{\partial p}{\partial z} + \mu\left(\frac{\partial^2 \upsilon_z}{\partial x^2} + \frac{\partial^2 \upsilon_z}{\partial y^2} + \frac{\partial^2 \upsilon_z}{\partial z^2}\right);$$

$$\frac{\partial \rho}{\partial t} = \frac{\partial(\rho \upsilon_x)}{\partial x} + \frac{\partial(\rho \upsilon_y)}{\partial y} + \frac{\partial(\rho \upsilon_z)}{\partial z},$$

The boundary and initial and conditions for the working liquid flow in the boundary layer are:

– inside the boundary layer – $\frac{\partial \upsilon_x}{\partial y} \neq 0$,

– outside the boundary layer – $\upsilon_x = \upsilon_0$,
– on the outer border of the boundary layer – $\frac{\partial \upsilon_x}{\partial y} = 0$.

These conditions for heating the liquid in the boundary layer have form:

– inside the boundary layer – $\frac{\partial \Theta}{\partial y} \neq 0$,
– outside the boundary layer – $\Theta = \Theta_0$,
– on the external border of the boundary layer – $\frac{\partial \Theta}{\partial y} = 0$.

The calculation of the velocity in the gap between the MHE and the EE is complex due to the continuous volumetric movement of the EE liquid particles. In the first approximation we can describe the liquid movement by the Euler equation:

$$u_2 \upsilon_{2u} - u_1 \upsilon_{1u} = gH, \tag{1}$$

where u_2 is the tangential velocity at the blade output, m/s; v_{2u} is the tangential component of the output absolute velocity, m/s; u_1 is the tangential velocity at the blade input of, m/s; v_{1u} is the tangential component of the input absolute velocity, m/s; H is the pressure, Pascal; g is the gravitational acceleration, m/S^2.

In Fig. 5 we conventionally show the velocity direction for an arbitrary point of the blade is in Fig. 5. Here $\boldsymbol{v}$ is the vector of the absolute velocity; $\boldsymbol{v}_\mathrm{x}$, $\boldsymbol{v}_\mathrm{r}$ are the vectors axial and radial components of the absolute velocity; $\boldsymbol{v}_\mathrm{u}$ is the vector of the rotary component of the absolute velocity; $\boldsymbol{v}_\mathrm{m}$ is the vector of the meridional component of the absolute velocity; $\boldsymbol{u}$ is the vector of the rotary component of the velocity; $\boldsymbol{w}$ is the vector of the relative velocity; α_{wu} is the angle between the vectors of the rotary and relative velocities; $\alpha_{\upsilon u}$ is the angle between the vectors of the absolute and the relative velocities.

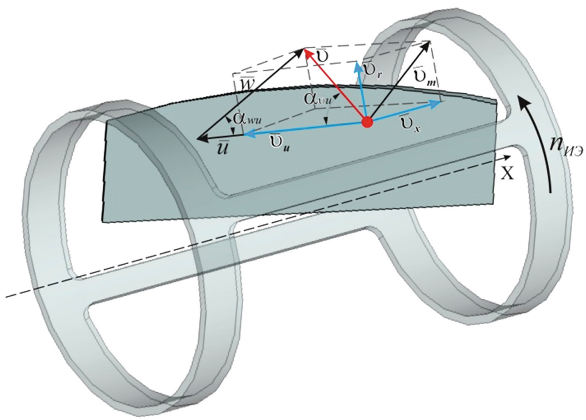

Fig. 5. The distribution of velocities on the blade. *Source*: developed and compiled by the authors.

We should use the values of volume, hydraulic and mechanical losses in the calculation equations to take into account the features of the CEC manufacturing.

After the transformation we get the Eq. (1) as the difference of the scalar product u and v:

$$gH = (u_2, v_2) - (u_1, v_1),$$

where v_1, v_2 are the liquid absolute velocities at the input and output respectively. After its solving we obtain the Eq. (1) written with respect to the blade:

$$\begin{aligned} gH &= (u_2 \sin\gamma_2 - u_1 \sin\gamma_1)(u_2 \sin\gamma_2 + u_1 \sin\gamma_1) \\ &- (u_2 \upsilon_{2R} \sin^2\gamma_2 ctg(\pi - \alpha_2) - u_1 \upsilon_{1R} \sin^2\gamma_1 ctg\alpha_1), \end{aligned} \tag{2}$$

Where γ_1 is the inner angle of the blade bevel; γ_2 is the external angle of the blade bevel; $v_{1\mathrm{R}}$, $v_{2\mathrm{R}}$are the radial components of the absolute velocity at the input and output respectively; α_1, α_2 are the angles of the blade installation at the input and output.

The components of the absolute velocity are found from the equations:

$$u_1 = \pi D_1 n_{EE};\ \ u_2 = \pi D_2 n_{EE};\ \ \nu_{2R} = \frac{Q}{\pi D_2 b_2};\ \ \nu_{1R} = \frac{Q}{\pi D_1 b_1}, \tag{3}$$

where D_1, D_2 – are the inner and external diameters; b_1, b_2 are the widths of the blade at the input and output, n_{EE} is the frequency of rotation.

The Eqs. (2) and (3) allow you to find the pressure at known geometric dimensions and frequency of the rotation:

$$\begin{aligned} &H = (\pi D_2 n_{ИЭ} g^{0,5} \sin\gamma_2)^2 - (\pi D_1 n_{ИЭ} g^{0,5} \sin\gamma_1)^2 + \\ &+ Q n_{ИЭ} g b_2^{-1} \sin^2\gamma_2 \cdot \mathrm{ctg}\,\alpha_2 - Q n_{ИЭ} g b_1^{-1} \sin^2\gamma_1 \cdot \mathrm{ctg}\,\alpha_1. \end{aligned}$$

The volume efficiency factor takes the volume losses into account (Kostyshin 2000):

$$\eta_{об} = \frac{1}{1 + 0,68 n_S^{-0,66}}, \tag{4}$$

where n_S is the calculated coefficient of rapidity found by the equation:

$$n_S = 3,65 n_{EE} \sqrt[4]{\frac{Q^2 N^3}{H^3}}. \tag{5}$$

The hydraulic losses are accounted by the coefficient equal to

$$\eta_h \approx 1 - \frac{0,42}{(lg(4500\sqrt[3]{\frac{Q}{n_{EE}\eta_v}}) - 0,172)^2}. \tag{6}$$

The mechanical losses take into account by the coefficient, in turn, found by the coefficient of rapidity (Kostyshin 2000):

$$\eta_m = \frac{1}{1 + 820 n_S^{-2}}. \tag{7}$$

The required power is determined by the formula:

$$P_{2m} = \frac{\rho g H_e Q_e}{\eta_v \eta_h \eta_m}, \tag{8}$$

where H_e, Q_e are the real pressure and flow rate at the finite quantity of pressure blades.

For the given power of the CEC only one of the values can be the deterministic design parameter: Q or H, the value of the second is determined by the Eq. (8).

The substituting (4)–(7) into (8) leads to the equation containing the nonlinear related values. This equation can only be researched by the simulation methods (Alyamovsky 2015).

4 Conclusions

1. The processes of power conversion determining the performance characteristics of the CEC at the given geometry and physical properties of the liquid depend on the design and size relationships of the executive element parameters.
2. The equation obtained with the help of the theory of hydrodynamics and establishing the relationship between the output and design parameters has an implicit form and it has no an unambiguous analytical solution.
3. The exact influence of the size relations of the EE on the output characteristics of the CEC can be researched on the parametric model using the special software.

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Modeling of Mass Transfer Processes in Special Applications Energy Devices

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Abstract. Purpose: the aim of the research is to model and analyze combined heat and mass transfer in special power devices based on an Electromechanical AC Converter.

Design/methodology/approach: the processes of converting electrical power into mechanical and thermal power, taking into account the main structural and operational parameters. The experiment planning theory is used to select significant parameters. The experiment plan is implemented in the Design of Experiments module of the Statistica software package. In the proposed approach, the experiment plan is selected; the number of factors; determining the center point; obtaining the matrix of the experiment plan. Visualization of the results is provided in the form of a Pareto chart.

Findings: the results of modeling electromagnetic, thermal and hydraulic characteristics in conditions of forced heat transfer using computational experiments in the SolidWorks Flow Simulation environment are obtained.

Originality/value: the simulation results of the mass transfer process under conditions of forced heat transfer using computational experiments in the SolidWorks Flow Simulation environment allow you to set the defining design parameters in special energy devices. Significant parameters for mass transfer processes are the installation angle and height of the blade, for heat transfer processes - the thickness of the body of the pressure element, the length and number of blades, the installation angle. Common significant parameters is the blade angle.

Keywords: Modeling · Significant parameters · Liquid flow · Pareto diagram · Velocity field

JEL Code: L94 · L95

1 Introduction

The electrical installations designed to transport the liquid or gaseous medium while simultaneously heating it are a group of the special energy devices (SED). The aria of SED application includes almost all the types of the pumping equipment and also the

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pneumatic and hydraulic drives for the various technological processes. The modeling of the mass transfer processes in such devices is based on the decomposition method. We select the most significant parameters for the specified target function from the general list of all the design parameters. The energy processes are divided into two types: the heat transfer and the movement of the working medium. We take the average value of the axial component of the absolute velocity of the liquid or the gas flow as a functional in the region of maximum heat exchange (the target zone I) and in the working channel (the target zone II). Finding the preliminary values of the target function allows excluding the minor design parameters. The results of modeling the mass transfer processes will be presented as the topological surfaces of the target function at the variation of the design parameters and (or) their significant combinations.

2 Materials and Method

The experiment planning theory is used to select the significant parameters (factors) and the account for their mutual influence in the absence of the priori information about the modeling object (Sidnyaev 2012).

The review of the SED designs shows that the output characteristics of the device significantly depend on the form factor of the pressure element (PE) (Ivanov and Kim 2019). The full-factor experiment with a center point is necessary to evaluate the influence of the PE geometry.

The experiment plan is implemented in the Design of Experiments module of the Statistica program complex in the following sequence: the type of the experiment plan; the quantity of factors; the procedure for performing the experiments; adding a central point; adding the name of factors, the lower and upper borders of factors; getting the matrix of the experiment plan; recording the experiment results; processing the experiment results; the visualization of the results (Pareto diagram, the response surface).

3 Results

The modeling of the hydrodynamic processes in the SED is based on the CFD (Computational fluid dynamics) technologies. This approach is based on the basic equations of flow processes: the continuity; the motion; the energy; the heat transfer; the state (for gases). The statement of the problem to be solved provides takes into account the turbulence of the mass transfer, the multiphase environment, the electromagnetic and thermal interactions. All these factors are mathematically described by the systems of nonlinear differential equations which have seldom an analytical solution, for example, at the small Reynolds number or the simple geometry (the Poiseuille flow).

For the problem under consideration we must replace the derivatives with finite differences in the equations. The SolidWorks Flow Simulation module of the SolidWorks system is used to model the mass transfer process in the SED take accounting the heat transfer. The calculated parametric model of the SED is imported into this module (Alyamovsky 2012).

While modeling the parameters of the geometric model of the PE of the SED are changed automatically using a specialized program. The parameter files are used when updating the PE geometric model created in NX or T-FLEX environments.

The result of the program work is the family of the calculated pressure element models imported in the "igs" format in SolidWorks Flow Simulation (Fig. 1).

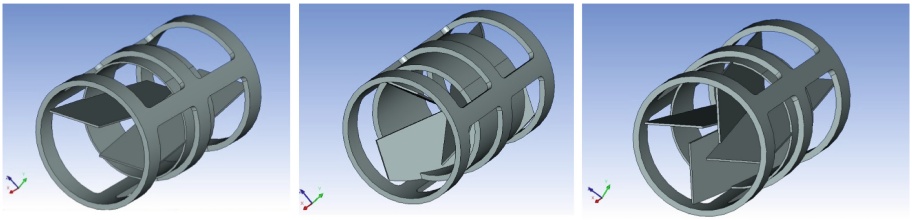


Fig. 1. The design models of the pressure element. *Source*: developed and compiled by the authors

The modeling in the SolidWorks Flow Simulation environment of the hydrodynamic process in the SED is performed using the "Wizard" in the several stages shown in Table 1:

Table 1. The sequence of modeling using the "Wizard"

	The stages of the "Wizard"	The selected conditions
1	Choice of temperature units	Degrees Celsius °C (Fig. 2a)
2	Determining the type of problem	Internal problem with global rotation around the X axis at the frequency of 3000 min-1 (Fig. 2b)
3	Assigning the medium type and the nature of the liquid flow	Water, laminar and turbulent nature of the liquid flow (Fig. 2c)
4	Assigning the wall parameters	Adiabatic wall, roughness 0 microns (Fig. 2d)
5	Setting the initial conditions	The default Value (Fig. 2e)
6	Setting the accuracy of the results and geometric of the model	Third level of resolution of the results and advanced splitting of the grid in the narrow channels (Fig. 2f)

The screen forms of choosing conditions using the "Wizard" is shown in Fig. 2.

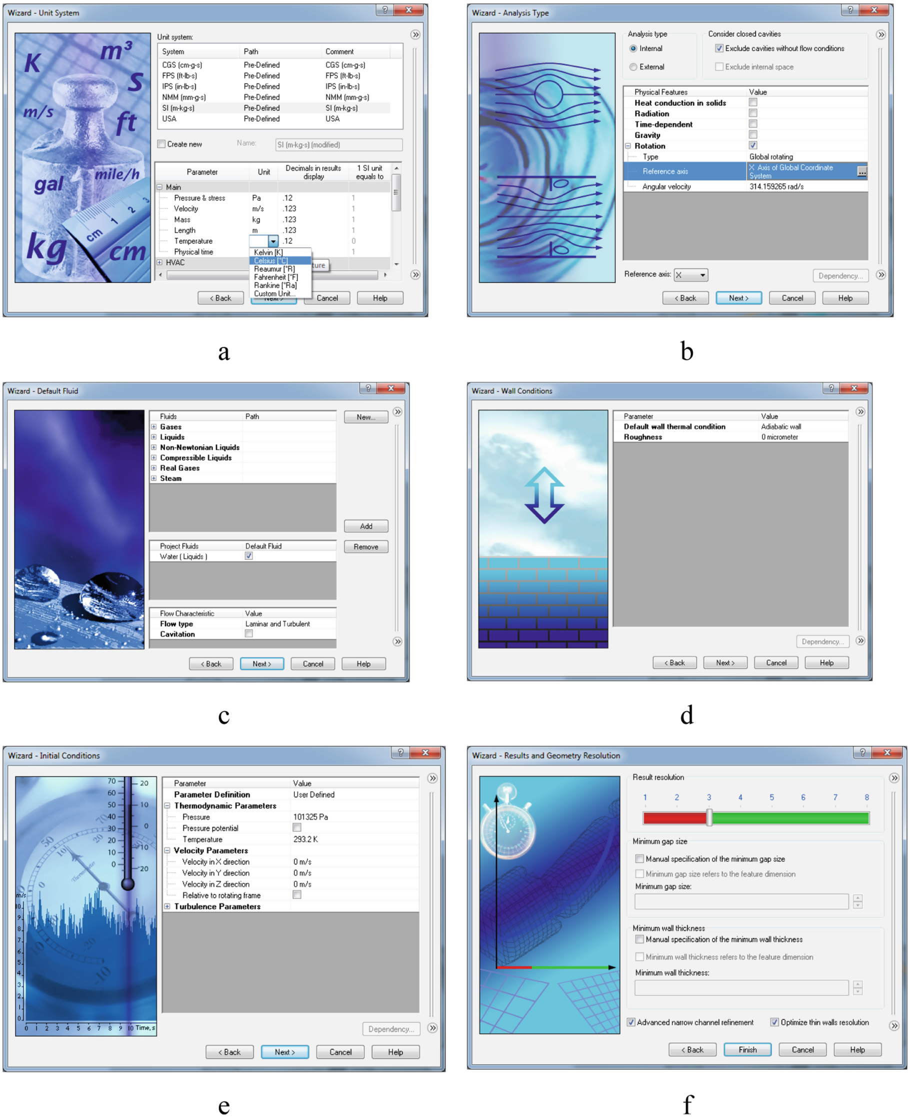


Fig. 2. The screen forms of choosing conditions using the "Wizard". *Source*: developed and compiled by the authors

After finishing the "Wizard" work we obtain the calculated area (Fig. 3) and generate the grid adapted to the model geometry (Fig. 4).

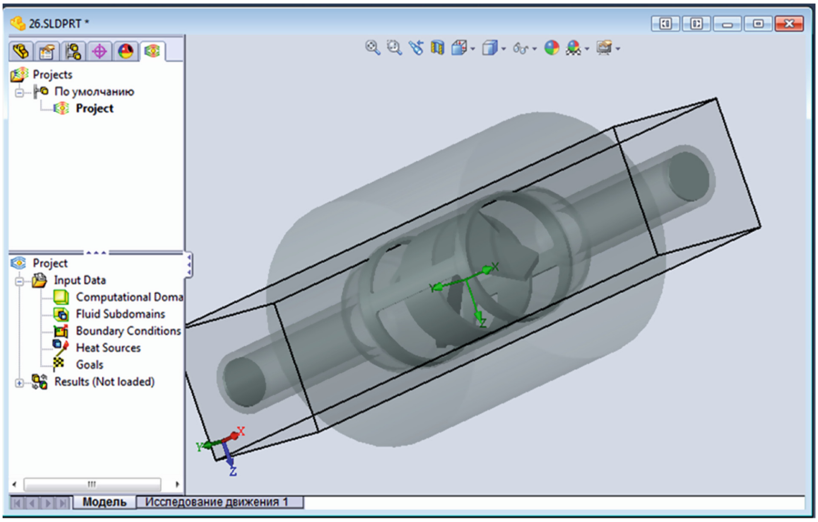
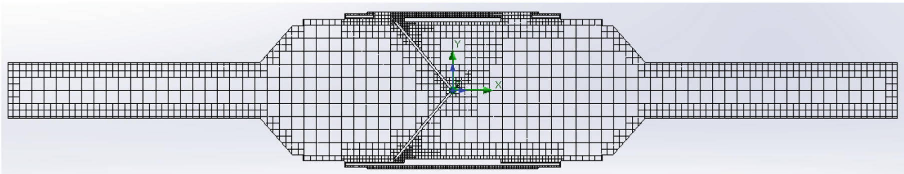
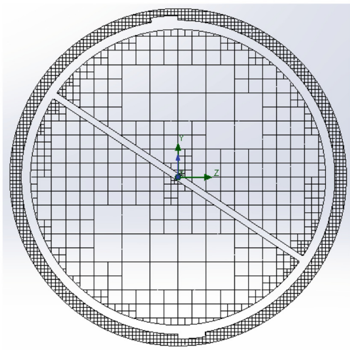


Fig. 3. The calculation area. *Source*: developed and compiled by the authors



a



b

Fig. 4. The calculation grid in the longitudinal section (a) and the cross-section (b). *Source*: developed and compiled by the authors

The input volume flow rate, m^3/s; the output pressure, PA; the real wall (for the SED stator) are set as the boundary conditions (Fig. 5).

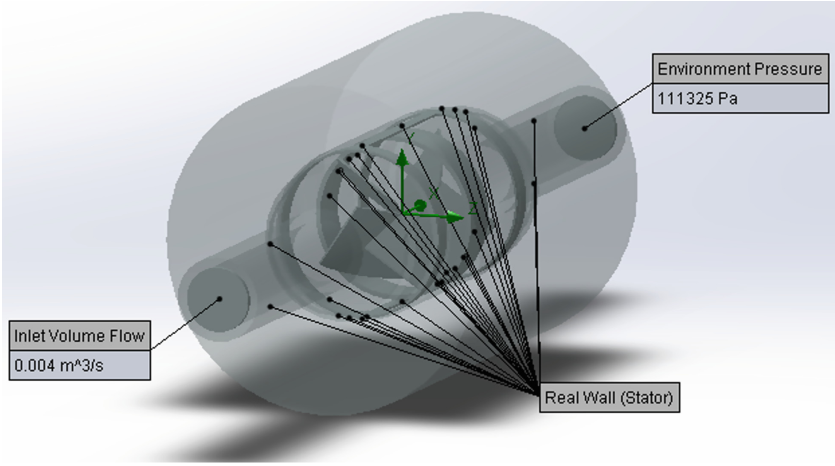


Fig. 5. The boundary conditions. *Source*: developed and compiled by the authors

To determine when the calculation stops it is necessary to control the convergence of the calculation process. The minimum and maximum values of the axial component of the flow velocity of the working medium are chosen as the convergence targets. The convergence control required to determine the end of the calculation process is performed according to the schedule shown in Fig. 6.

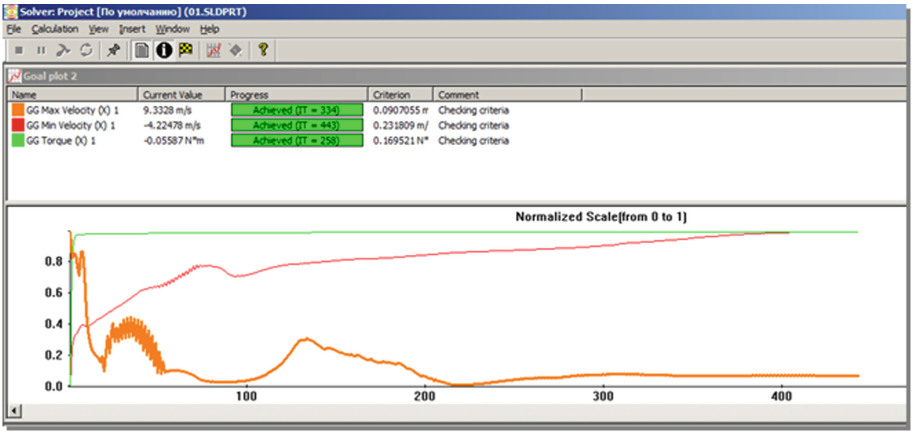


Fig. 6. The convergence graph. *Source*: developed and compiled by the authors

The result of the hydrodynamic calculation is the velocity field of the liquid. The visualization of the velocity field in the longitudinal section is shown in Fig. 7.

To improve the accuracy of the calculation results the average value of the axial component of the velocity is calculated by the volume of the working channel.

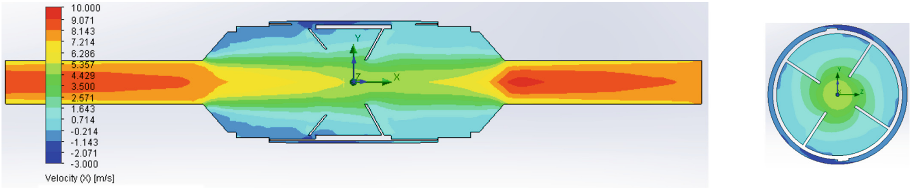


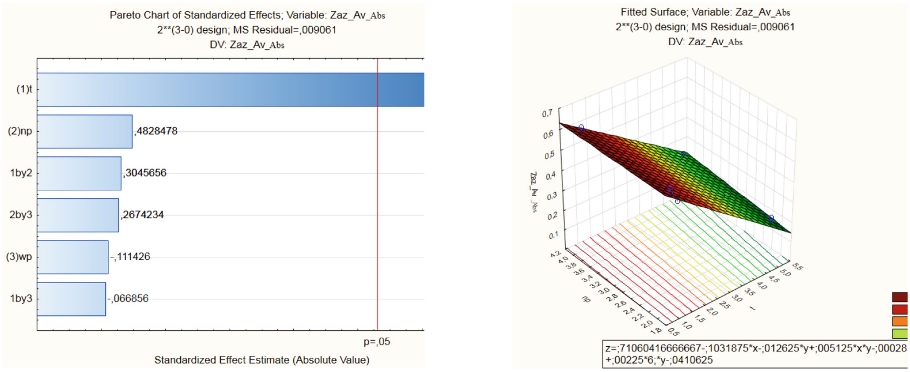
Fig. 7. The visualization of the velocity field. *Source*: developed and compiled by the authors

The analysis of the SED design shows that we should take 15 design parameters into account which theoretically can affect the efficiency of the device. Their quantity does not allow using the full-scale experiment since the quantity of experiments is 2^{15} (32768). For the effective formulation of the computational experiment we divide all the parameters into 3 groups with the attach to the assembly unit "Pressure element". Group 1 is parameters of the PE body (the external diameter d; the length l; the thickness t; the quantity of the rings n_r; the quantity of the edges n_e; the ring width w_r; the PE edge width – w_e). Group 2 is the parameters of the blade (the length h_b; the thickness t_b; the height h_b; the quantity n_b; the installation angle *alfa*). Group 3 is the parameters of the internal ferromagnetic core (the diameter d_f; the length l_f; the thickness – t_f).

In the experiment plan we use 3 parameters for the PE body: the thickness, the quantity and the width of edges. The external diameter and length of the PE don't be varying because they are limited by the stator parameters. The quantity of the rings is determined by the conditions of closing the secondary current and is chosen not less than 2. The width of the ring is associated with the permissible current density under the forced convection and it is determined from the electromagnetic calculation of the SED. The length, height, number and angle of the installation are taken into account for the blade in the experiment. The length and thickness are used for the inner ferromagnetic core in the experiment.

The average value of the axial component of the liquid velocity in the different target zones is an assessment of the influence of design parameters belonging to the different groups of elements.

The results of the experiment for the PE body (Zaz_Av_Abs is the average value of the axial component of the liquid velocity in the gap, Cent_Av is the average value of the axial component of the liquid velocity in the center of the working channel). The corresponding Pareto diagram and the response surface for a significant factor t (the PE body, the target zone 1) are shown in Fig. 8.



a b

Fig. 8. Pareto map and the response surface for significant factor *t*. *Source*: developed and compiled by the authors

The results of the experiment for the PE blade and the corresponding Pareto chart are shown in Fig. 9.

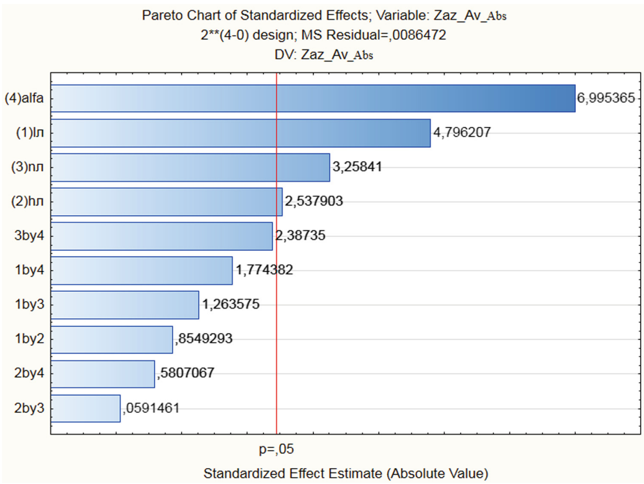
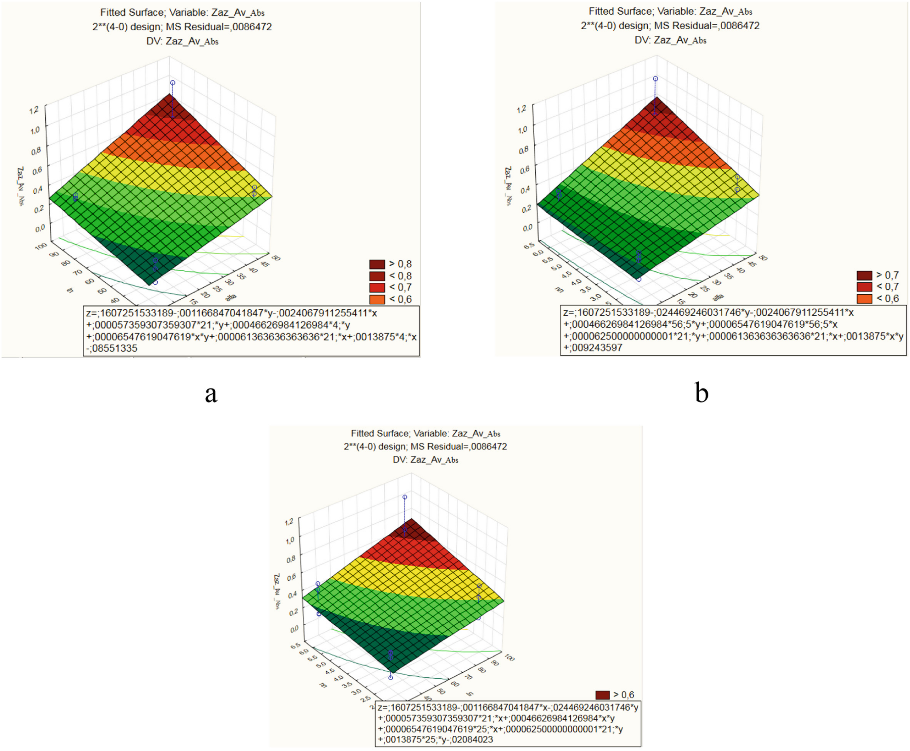


Fig. 9. The Pareto chart (the PE blade, target area 1). *Source*: developed and compiled by the authors

On the base of the Pareto chart we found the significant factors for the zone heat transfer: the blade height h_b and the blade length l_b, the quantity of the blades n_b, the installation angle of the blade α.

The response surfaces for the significant factors α, l_b, and n_b in target zone 1 while studying the blade parameters are shown in Fig. 10 a, b, c (the PE blade, target zone 1).

We similarly determine the significant factors for the center (target zone 2). There is an angle of the blade installation α and the joint influence of α and h_b (Fig. 11).



a b

c

Fig. 10. The response surfaces for the significant factors α, l_b, and n_b. *Source*: developed and compiled by the authors

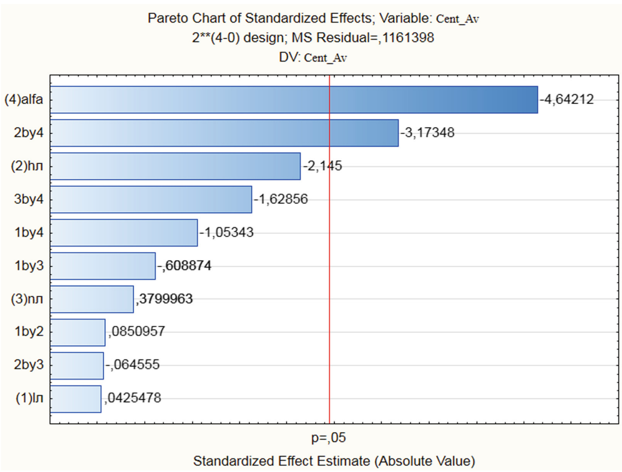


Fig. 11. The Pareto diagram (the blade, target zone 2). *Source*: developed and compiled by the authors

The response surface for the significant factors α and "α + h" in the center of the working channel (target zone 2) at studying the blade parameters is shown in Fig. 12.

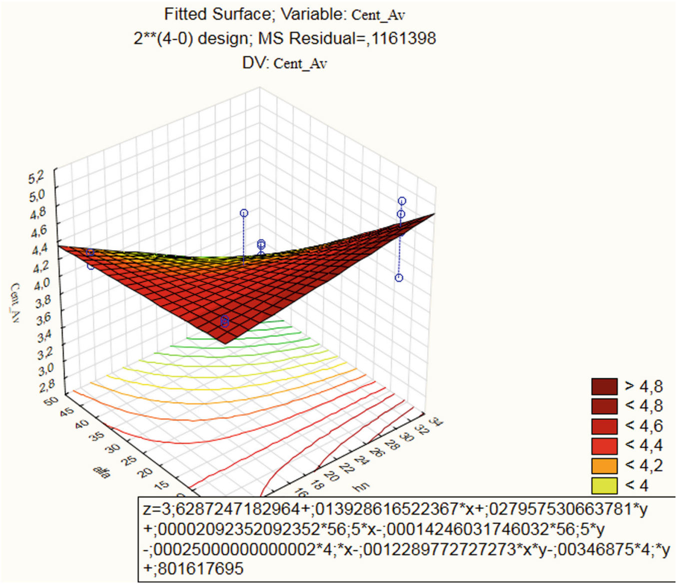


Fig. 12. The response surface for the significant factors α and h_b (the PE blade, target zone 2). *Source*: developed and compiled by the authors

The comparison of the significant factors found separately for the heat transfer region (t, α, l_b, "$t + \alpha$", "$\alpha + h_b$") and the mass transfer region (α, h_b, "$\alpha + h$") allows revealing the common defining parameters.

The general parameter is an angle of the blade installation. This eliminates to use it use for the separate controlling of the energy flows in the different target zones. We chose the velocity in the center of the mass transfer zone as the optimal angle of the blade installation. Previously the value α is assumed to be 45° for the plane blade. We specify the influence of the independent significant parameters at the discrete value of the angle.

The Pareto diagram allows finding the significant factors for the heat transfer zone (the thickness of the PE body t, the length of the blade l_b, the joint influence of t and l_b, the quantity of blades n_b. The Pareto diagram is shown in Fig. 13.

The resulting response surfaces from the parameters t, l_b, n_b for the heat transfer zone are shown in Fig. 14 a, b.

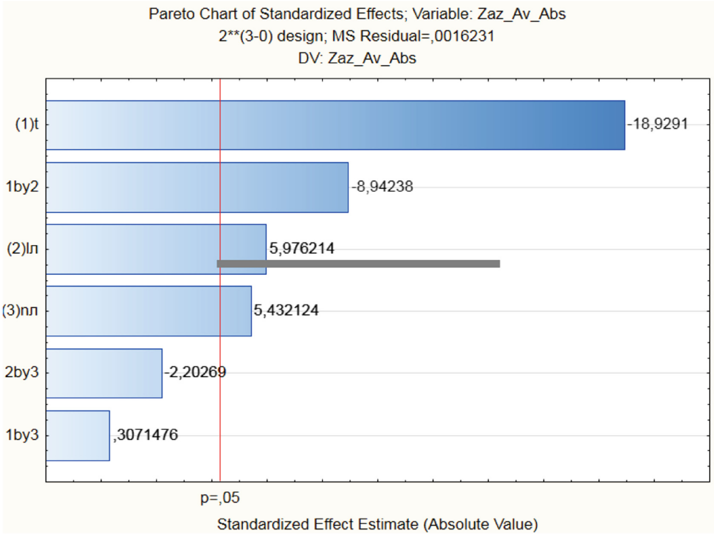
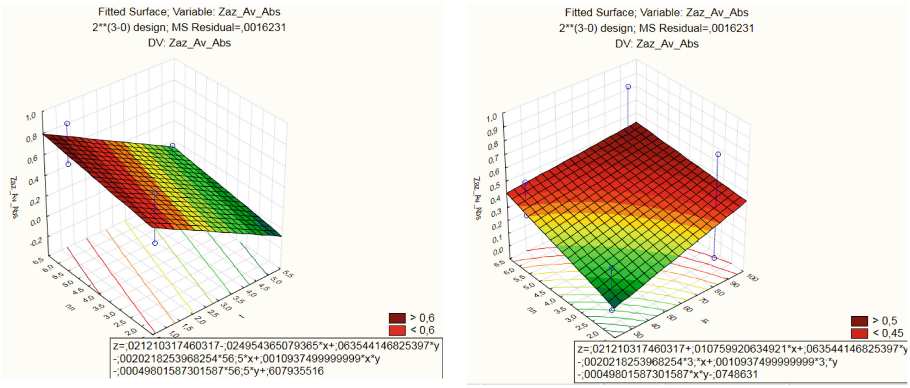


Fig. 13. The Pareto diagram for target zone 1. *Source*: developed and compiled by the authors.



a b

Fig. 14. The response surfaces for the significant factors t, l_b, n_b for target zone 1. *Source*: developed and compiled by the authors.

4 Conclusions

The results of modeling the mass transfer process under the forced heat transfer conditions with the help of the computational experiments in the SolidWorks Flow Simulation environment allow defining the significant design parameters in special power devices. The significant parameters are the installation angle and height of the blade for the mass transfer processes. The significant parameters are the thickness of the pressure element body, the blade length and the quantity of blades, the installation angle for heat transfer processes. The angle of the blade installation is the common significant parameter.

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Study of Numerical Vibrations of Open Thin-Walled Cylindrical Shells

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Abstract. Purpose: conducting a study of vibration analysis for a composite thin-walled cylindrical shell and compare the results with the data obtained from other sources

Design/methodology/approach: Closed or open thin-walled cylindrical shells are widely used in construction as an effective form of buildings and facilities and as load-bearing and enclosing structures. Utilization of a thin-walled shell for roofing has a number of advantages from an economic point of view when the shell can cover long spans without additional supports, thus providing plenty of space, and has an excellent relation between the enclosure surface (costs) and internal volume. However, this thin-walled structure is prone to resonance due to coalescence of the natural and forced vibration frequencies, which leads to its failure. Experience has proven that, as of today, shell oscillatory processes in construction are understudied, and a lot of accidents have occurred as a result of ignoring the dynamic impact of the forced loads at the design stage.

Findings: For this reason, further studies of oscillatory processes in thin-walled cylindrical shells are required as well as development of a mathematical model for taking the forced vibrations into account during design of shell structures for buildings and facilities.

Originality/value: the new verified mathematical model can be used for performing structural analysis, in design bureaus carrying out vibration analysis for cylindrical shells.

Keywords: Thin-walled open shell · Elastic modulus · Numerical vibrations · Concrete grade · Lira-SAPR software

JEL Code: C310

1 Introduction

Thin-walled cylindrical shells are currently made of metallic and composite materials. Reinforced concrete, which can be considered a multilayered structure, is frequently used as a composite material.

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Thin-walled cylindrical shells are important components of industrial facilities and machinery. They are used in such structures as liquid storage tanks, hoppers, etc. Shell bending usually poses a serious problem of failure of thin-walled shells when exposed to extreme loads, for example, an earthquake. As a rule, longitudinal and radial ribs are used to reduce thin-walled shell bending. Cylindrical shells can undergo a global shear or shear deformation during an earthquake. The majority of literature on shells deals with bending under simple loading conditions: uniform axial compression and uniform external pressure. The loading conditions in hoppers and tanks, on the contrary, require designing a stepped wall with pressures and frictions which vary over the entire body surface, leading to much more complex pre-buckling conditions. Strain as well as stress distribution for the external pressure are studied, and strain will be optimized by means of changing the wall thickness and the number of stiffeners.

Bending can cause structural failure if significant deformations occur. However, from a scientific and engineering standpoint, buckling phenomena usually occur before the deformations become really large, and it may seem that the structure is only slightly deformed or not deformed at all. As a rule, such phenomena take place in case of temperature condition changes. Structure bending is an important phenomenon in the structural theory, since it often (but not always) causes structural failure.

On January 30, 2001, a tank at the refinery located 10 km north of General Roca city (the province of Neuquén, Argentina) became deformed at moderate winds. The tank had the diameter of 31 m, and the design height of the completed structure was 9 m; however, the tank collapsed when the construction height reached 7.50 m above sea level. ASTM A-36 steel with the thickness of 0.48 cm was used as the construction material.

The construction schedule should be taken into account to understand the causes of failure. First, the circular bottom plate was completed, and then cylindrical rings (with the height of 8 ft.) were added and welded. Each ring was completed and welded on either side prior to being placed into the structure by means of a crane. The temporary connection between the shell and bottom plate was ensured by means of 20 mm spot welds spaced at the intervals of 0.50 m. This welding procedure is expressly adopted by API 650. Such scheduling of construction was required due to the short time necessary for using the cranes, so it was expected that the structural elements would be installed in place before all-around welding completion.

The traditional theoretical solution of the problem for analysis of the natural vibrations of a shell with asymmetric initial imperfection shows significant changes in the bending frequency spectrum even at a constant temperature, while local temperature variations of the shell cause significant changes in the stress-strain distribution, which is completely ignored during the analysis.

When studying numerical vibrations of open thin-walled cylindrical shells, let us use the theory of shallow shells described in papers by Vlasov (1949), Seregin (2019a, b), Sysoev et al. (2019), Seregin (2019a, b), in order to determine the vibration frequency of open thin-walled cylindrical shells.

Numerous studies of thin-walled cylindrical shell vibrations rarely consider a thin-walled cylindrical shell as a multilayered structure in which the importance of the effective elastic modulus for the thin-walled cylindrical shell oscillatory process can be determined as well as the mode of longitudinal half-wave vibrations taken into account for open thin-walled cylindrical shells, and circular frequency of the shell vibrations.

2 Materials and Method

Let us consider an open thin-walled reinforced-concrete shell with the length ***"l"*** and radius ***"R"*** (Fig. 1). We will take the ***(x, y, z)*** coordinate system and the shell middle surface as the reference point and draw a circular arc across the cross section ***(x, s)***. The structure consists of concrete and aggregate, with reinforcement fabric installed in the middle surface; thus, a sandwich structure is created.

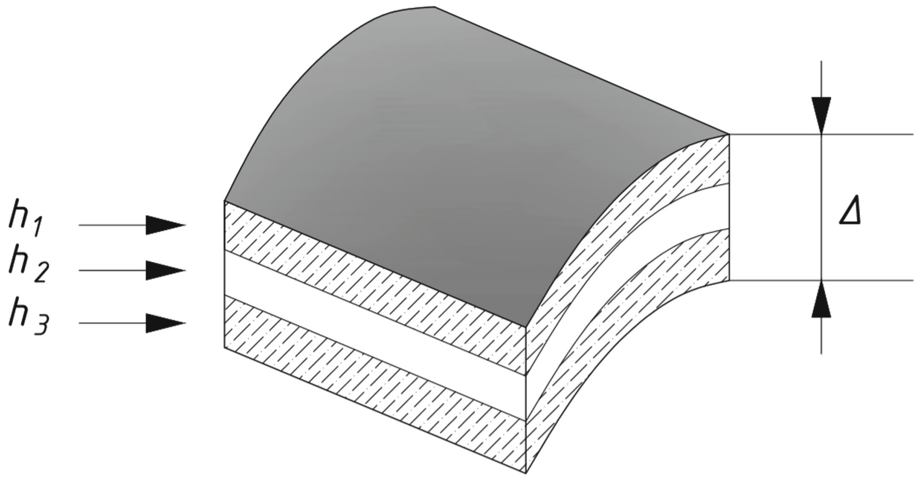


Fig. 1. Open Shell Segment with Layers. $h_{1,3}$ is concrete layer thickness. h_2 is connecting structure (reinforcement) thickness. *Source*: developed and compiled by the authors

Let us use the following, in order to take into account the effective elastic modulus:

$$E = \frac{1 - \upsilon^2}{\Delta} \sum_{k=1}^{3} \frac{E_k h_k}{1 - \upsilon_k^2}$$

The study was conducted using the variational method, and strain and vibration equations were obtained; the Kirchhoff-Love hypothesis and the main regularities of the elasticity theory were also applied.

In the absence of external influence, the transverse vibration equations for open thin-walled cylindrical shells will take on the following form:

$$\nabla^2\nabla^2 F = \frac{E\delta}{R}\frac{\partial^2}{\partial x^2}\left(1 - \frac{h^2}{\beta}\nabla^2\right)\chi, \tag{1}$$

$$D\left(1-\frac{\Theta\delta^2}{\beta}\nabla^2\right)\nabla^2\nabla^2\chi+\frac{1}{R}\frac{\partial^2 F}{\partial x^2}-\rho h\frac{\partial^2}{\partial t^2}\left(1-\frac{\delta^2}{\beta}\nabla^2\right)\chi=0 \tag{2}$$

The third summand of Eq. 2 represents the incoming load on the surface. The third summand ρh is assumed to be obtained by summation.

$$\rho h=\sum_{k=1}^{3}\rho_k\delta_k$$

The Laplacian $\nabla^2=\frac{\delta^2}{\partial x^2}+\frac{\delta^2}{\partial s^2}$, as well as relation between χ and ω are implemented by the following formula:

$$\omega=\left(1-\frac{\delta^2}{\beta}\nabla^2\right)\chi.$$

More details about the ***"β"*** coefficient value which is related to the lateral shear modulus can be found in papers by Sysoev et al. (2018), Wang et al. (2017), Seregin (2019a, b), Sysoev et al. (2019), Xing et al. (2013). Shell stiffness ***"D"*** is the sum of all shell layers, and ***"Θ"*** coefficient is determined using the following equations:

$$D=\frac{E\delta^3}{12\left(1-v^2\right)}\Theta,\quad \Theta=\frac{\Theta_1\Theta_3-\Theta_2^2}{\Theta_1\Theta}, \tag{3}$$

Poisson's ratio for a multilayered structure is determined using the following equation:

$$v=\sum_{i=3}^{3}\frac{E_k h_k v_k}{1-v_k^2}\left(\sum_{i=3}^{3}\frac{E_k h_k}{1-v_k^2}\right)^{-1};$$

As well as:

$$\begin{gathered}\Theta_1=t_3^2\left[1+2(\gamma_1+\gamma_2)-3(\gamma_1+\gamma_2)^2\right],\\ \Theta_2=3t_3\gamma_3(\gamma_1 t_1+\gamma_2 t_2)+6\gamma_1\gamma_2 t_3(t_1+t_2),\\ \Theta_3=4\left(\gamma_1 t_1^2+\gamma_2 t_2^2-3(\gamma_1+\gamma_2)^2\right),\\ \Theta=t_3^2+4\gamma_1\left(t_3^2+3t_1t_3+2t_1^2\right).\end{gathered}$$

In case of simple support, the boundary conditions for a cylindrical shell will take on the following form:

$$F=\nabla^2F=\chi=\nabla^2\chi=\nabla^2\nabla^2\chi=0\quad at\ x=0\,and\ =l \tag{4}$$

Introduction of the decision function ***"χ₁"*** *into the system of* Eqs. (1, 2) *enables reducing the latter to one equation; this has previously been described in papers by* Sysoev et al. (2017), Seregin (2019a, b)*:*

$$\chi=\nabla^2\nabla^2\chi_1,\quad F=\frac{Eh}{R}\frac{\partial^2}{\partial x^2}\left(1\frac{\delta^2}{\beta}\nabla^2\right)\chi_1 \tag{5}$$

$$D\left(1-\frac{\theta\delta^2}{\beta}\nabla^2\right)\nabla^2\nabla^2\nabla^2\nabla^2\chi_1+\frac{Eh}{R^2}\frac{\partial^4}{\partial x^4}\left(1-\frac{\delta^2}{\beta}\nabla^2\right)\chi_1=\rho h\frac{\partial^2}{\partial t^2}\left(1-\frac{\delta^2}{\beta}\nabla^2\right)\nabla^2\nabla^2\chi_1 \quad (6)$$

From now on, the boundary conditions of Eq. (4) relative to χ_1 function will take on the following form:

$$\chi_1=\nabla^2\chi_1=\nabla^2\nabla^2\chi_1=\nabla^2\nabla^2\nabla^2\chi_1=\nabla^2\nabla^2\nabla^2\nabla^2\chi_1=0 \quad \text{at } x=0 \text{ and } x=l \quad (7)$$

Solution of Eq. (6) may change if the support changes; the following formula is used for simple support:

$$\chi_1=\chi_0 e^{i\omega t} sin\frac{m\pi x}{l} cos\frac{ns}{R}, \quad (8)$$

Where m is the number of waves along the generator in the longitudinal direction of the thin-walled shell, n is the number of waves in the transverse direction, ω stands for circular frequency of transverse vibrations, χ_0 is constant.

By inserting Eq. (8) in (6), we will obtain equations for determining the circular frequency of vibrations:

$$\begin{gathered}\omega^2=\left[DB\left(1-\tfrac{\theta h^2}{\beta}B\right)+\tfrac{Eh}{R^2}\left(\tfrac{m\pi}{l}\right)^4\left(1-\tfrac{h^2}{\beta}B\right)\right]\cdot\left[\rho h\left(1-\tfrac{h^2}{\beta}B\right)\right]^{-1};\\ \text{where } B=-\left(\left(\tfrac{m\pi}{l}\right)^2+\left(\tfrac{n}{R}\right)^2\right);\end{gathered} \quad (9)$$

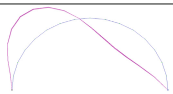
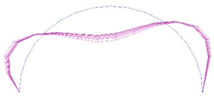
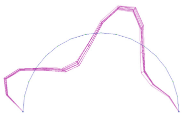
3 Results

Open thin-walled reinforced-concrete shells with the length l = 4 m and radius R = 2 m were used as an example, and the same input data were used for performing analysis in the Lira-SAPR software. Lira-SAPR is a well-known and widely-used software package.

The purpose was to compare the ultimate results of the analysis and computer-aided calculation, in order to determine the error. In the former case, the test was performed for an open thin-walled cylindrical shell made of B20 grade concrete, with the elastic (Young's) modulus E = 2.75 × 104 MPa, density $\rho = 2100\,\text{kg/m}^3$, thickness $\delta =$ 12 cm, and Poisson's ratio $v = 0.2$.

To determine vibration frequencies using the finite element method (FEM) in Lira-SAPR software, the shell under consideration was divided into elements: 50 along the length and 25 across the across. The calculation results are provided in Table 1, and an error from 8.44 to 1.6% has been identified based on these results (Fig. 2).

Table 1. The number of half-waves and vibration frequencies of the open reinforced-concrete shell

Sketch	Wave Number, n	Vibration Frequency, ω, Hz	Vibration Frequency, $Lira$, Hz	Relative Error, %
	2	68.22	62.48	8.4
	3	204.54	197.41	3.48
	4	380.33	374.2	1.6

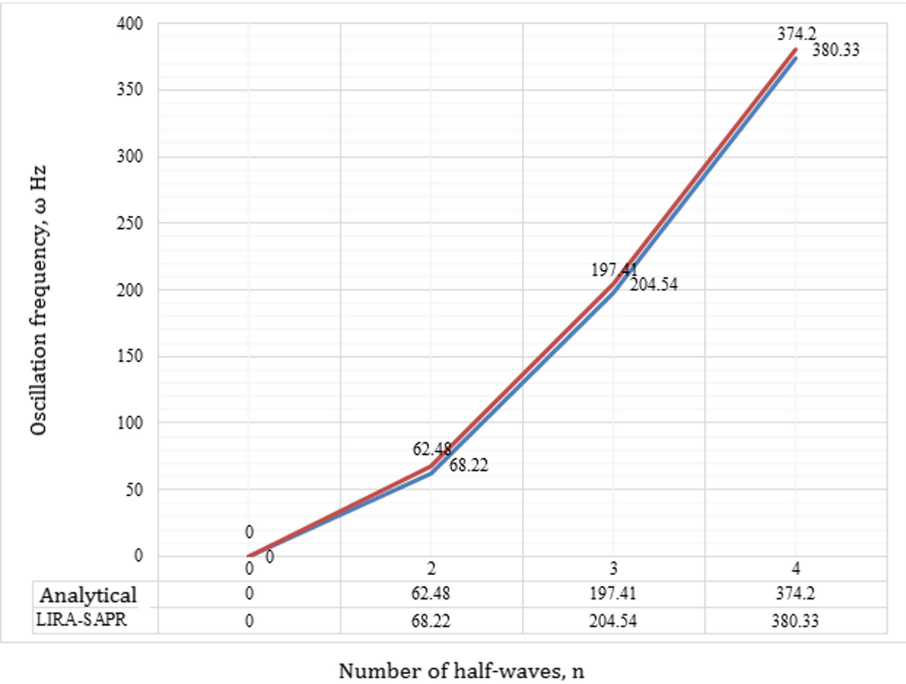


Fig. 2. Relation between the vibration frequency and half-wave number for a shell made of B20 grade concrete. *Source*: developed and compiled by the authors.

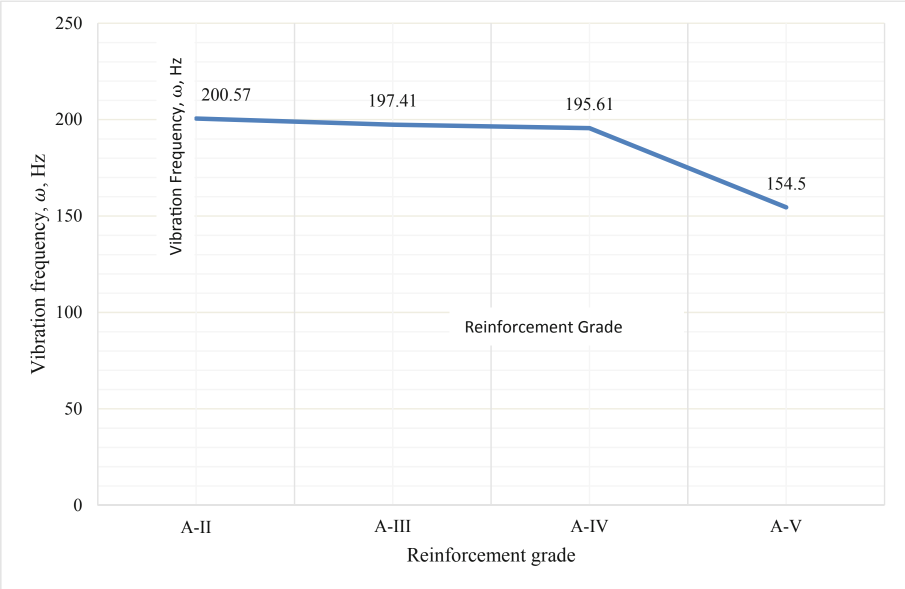


Fig. 3. Relation between the reinforcement grades and vibration half-wave number "n" equalling 3. *Source*: developed and compiled by the authors.

4 Conclusion

The purpose of this study is to determine the influence of physical and mechanical properties of a composite material on the dynamic processes in an open thin-walled cylindrical shell. It has been found that the accuracy of the circular vibration frequency for a shell increases, regardless of the concrete grade, with the increase in the number of longitudinal half-waves taken into account; however, the higher is the concrete grade, the lower is the numerical vibration value. The influence of reinforcement grade on the oscillatory process has also been studied. Note that it is only the reinforcement grade that increases, while the mesh retains its initial dimensions of 100×100 mm closer to the support area and 200×200 mm in other areas. The result is provided in Fig. 3. An ultimate conclusion can be made, based on the results that it is advisable that medium- and heavy-weight concrete be used as the material for manufacturing the item. Plain and ribbed reinforcement bars (AI $\div$ AIV) should be used for construction of shell structural forms, depending on the dimensions of the latter.

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Dissipative Structures of Laser-Hardened Structural Steels

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Abstract. Purpose: Study of structural changes in the surface layers of low-carbon alloy steel 25XM under the action of pulsed laser radiation using quantitative indicators of the structural organization of the material.

Methodology: Determination of quantitative indicators of the structural organization of the surface layer modified as a result of laser interaction with the material. Establishing a relationship between the specific energy of laser irradiation and the structural organization of the hardened surface layer.

Findings: The microstructure hardened by laser treatment of the surface layer has a layered structure and is characterized by increased nonequilibrium, while the distribution of quantitative indicators of the structural organization of the material over depth is gradient in nature. The density of the boundaries of microstructural objects characterizes the dissipative properties of the material, its ability to dissipate the absorbed energy of laser radiation due to thermal and atomic transfer. It was found that with increasing specific energy of a pulsed laser exposure, the density of the boundaries of the microstructural objects of the modified surface layer increases. Between the density of the boundaries of the microstructural objects of the modified surface layer is determinately associated with its microhardness.

Originality: Quantitative indicators of the structural organization of the material, characterizing its dissipative properties, are proposed. A methodology of their determination using digital images of microstructures is developed.

Keywords: Laser processing · Specific energy · Dissipative properties · Microstructure · Hardness · Density of boundaries · Hardening

JEL Code: L61

1 Introduction

Laser radiation refers to a highly concentrated energy flow. Structural changes as a result of the interaction of laser radiation with materials occur under nonequilibrium conditions against a background of high temperatures and their gradients, heating and cooling rates.

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Such thermal conditions are far from the conditions of standard heat treatment; therefore, the processes of structure formation during laser processing of materials are consistent, the development of which is carried out according to a synergistic algorithm. The result of this process is the formation of dissipative structures that create channels at the micro- and mesoscale levels of increased energy and mass transfer conductivity. The fundamental laws of this process are well studied and presented in the vast literature (Prokhorov et al. 1988). Nevertheless, there are a number of unsolved problems, the relevance of which remains. These include questions of a quantitative description of nonequilibrium dissipative surface structures arising under nonequilibrium conditions for the interaction of materials with highly concentrated flows of energy and matter, and the use of the obtained patterns for the selective control of laser technology processes.

Images of microstructures from a formal point of view represent a set of geometric figures, combined into sets with a certain ordering, by which visually it is possible to identify various structural components and their modifications. Modern image processing tools allow you to convert digital photographs of microstructures and color shades of their individual components into numerical arrays, using which you can create quantitative indicators and complexes characterizing the structural organization of the material and the dynamics of structural changes (Kim et al. 2014).

2 Materials and Method

The article presents the results of studies of structural changes in the surface layers of low-carbon alloy steel 25XM under the action of pulsed laser radiation using quantitative indicators of the structural organization of the material.

We studied the surface microstructures of samples of low-carbon alloy steel 25XM treated with pulsed laser radiation using the LRS-300 technological unit. The specific energy and radiation power density were calculated by the formulas

$$E = \frac{4Wft}{\pi d^2}$$

$$q = \frac{E}{t}$$

where E is the specific energy; q is the power density; t is the duration of the laser pulse; d is the diameter of the laser spot; W is the energy of a single pulse; f is the pulse frequency.

Modes of laser processing are presented in Table 1. The treated surface was a combination of single spots of laser action of a round shape with an overlap coefficient of 0.75.

Metallographic thin sections were etched with reagents corresponding to the composition and structure of the material (Brandon and Kaplan 2004). Images of microstructures in cross sections of the surface layers were obtained using Nikon 200A metallographic microscope at 400- and 1,000-times magnification. Micro-hardness was measured on a Vickers scale using an HMV micro-hardness meter (Shimadzu) with a diamond tip load of 0.49 N.

Table 1. Modes of laser processing of steel 25XM

Mode	*W, J*	*t, ms*	*d, cm*	*f, Hz*	*q, W/cm²*	*E, J/cm²*
1	*5.5*	*1.0*	*0.2*	*3*	$5.255.10^5$	*525*
2	*11.0*	*2.0*	*0.2*	*3*	$5.255.10^5$	*1051*
3	*3.6*	*1.0*	*0.2*	*3*	$3.439.10^5$	*343*
4	*8.1*	*2.0*	*0.2*	*3*	$3.869.10^5$	*773*
5	*2.1*	*1.0*	*0.2*	*3*	$2.006.10^4$	*200*
6	*5.0*	*2.0*	*0.2*	*3*	$2.389.10^4$	*477*

Image processing of microstructures was carried out by using the Image.Pro.Plus.5.1 program and included sharpening, removing a contrast mask, highlighting borders using the Laplace filter, and calibration to link the magnification of the image to the corresponding scale ruler. Then, quantitative indicators of the microstructural organization of the material were determined, in particular, the number of microstructural objects N, the total length of their perimeters P_i and the areas F_i fixed on a certain area of the metallographic section, and also the fractal dimension of the boundaries D_i (Kim et al. 2013). The latter characteristic was used as a measure of structural ordering. One image of microstructures included from 500 to 1,500 microstructural objects. This was sufficient to ensure acceptable statistical accuracy when using 2 to 3 microstructure photographs.

Based on the measurements, complex structural organization indicators were calculated, in particular, the average density of boundaries and the relative total area of dark microstructural objects.

$$p_{com} = \frac{\sum P_i}{F_p}$$

$$f_{rel} = \frac{\sum F_i}{F_p}$$

where F_p is the surface area of the metallographic thin section recorded in one photograph. With increase of 400 times, $F_{\text{ф}}$ equals to $240 \times 300\ \mu m^2$.

To determine the nature of the distribution of indicators of the structural organization of the surface layer in depth, the image of the microstructure was divided into strips 25 μm wide and 300 μm long, starting from the surface. In each selected area, quantitative indicators of the microstructures were determined and the average density of the boundaries was calculated, according to the results of which distribution curves along the depth were constructed.

Figure 1 shows the microstructures of surface layers formed by pulsed laser radiation. The initial structure of 25XM steel is an equilibrium ferrite-pearlite composition consisting of their grains close to equiaxial shape.

3 Results

The microstructure obtained as a result of the interaction of the material with laser radiation develops according to a synergetic algorithm far from equilibrium conditions.

The processes of structure formation occurring in a nonequilibrium system are nonlinear cooperative in nature, resulting in many unstable states associated with the transfer of charge, heat, defects in the crystal structure and matter. A structure formed under such conditions is characterized by a high content of free energy and can be classified as dissipative. Dissipative structures represent a set of structural formations that function according to a single algorithm designed to reduce free energy and restore the balance between external energy influences and heat drains.

The nature of the functioning of dissipative structures arising from the interaction of materials with concentrated energy flows differs fundamentally from those dissipative structures that are formed in nonequilibrium deformation systems. The dissipative structures formed during plastic deformation perform the function of converting the absorbed free energy into heat due to the work of internal friction and the generation of a stream of defects in the crystal structure. They initiate structural changes and create active channels for the removal and dissipation of heat into the environment (Balakhonov et al. 2006).

When a material interacts with a concentrated energy flow, dissipative structures create active channels of increased conductivity for diffusion and convective mass transfer initiated by ultrahigh temperature gradients, heating and cooling rates, and the propagation front of heat and shock waves. The implementation of these mechanisms requires certain energy inputs, which determine the efficiency of the dissipative process (Mirzoev et al. 1996).

One of the important components of dissipative structures is the internal boundary between grains and phases, which appear in the images of microstructures in the form of linear formations, combined into geometric sets with varying degrees of ordering. During crystallization of the melt, the interface transitions to the solid state in the last turn, remaining longer in the liquid phase form. The boundaries in the liquid phase state are effective channels for diffusion and convective mass transfer, which are an integral part of the dissipative process. After solidification of the melt, the internal boundaries represent a high-energy structure, including amorphous and crystalline phases with a high density of various structural defects. Such a structure is characterized by high diffusion activity, since the activation energy of boundary diffusion is several orders of magnitude lower than the activation energy of bulk intragranular diffusion. The greater is the total length of the internal boundaries, the higher the dissipative activity of the structure.

The surface microstructure is highly heterogeneous and has a layered structure typical of structures formed by laser irradiation (Libenson et al. 2008). The uppermost layer is subject to melting, and at high radiation power density - to evaporation. During the formation of the liquid phase, its active interaction with the environment occurs, associated with the absorption of gases, diffusion and convective mixing, and the formation of micropores.

The layer formed from the liquid-phase melt consists of dendrites of low-carbon martensite oriented perpendicular to the surface, small grains of residual austenite and ferrite. The nature of the orientation of the dendrites indicates a high degree of structural ordering of this layer. The presence of residual austenite is due to the uneven content of alloying elements, in particular chromium and molybdenum. The high cooling rate during crystallization of the melt often leads to the formation of hot and cold cracks.

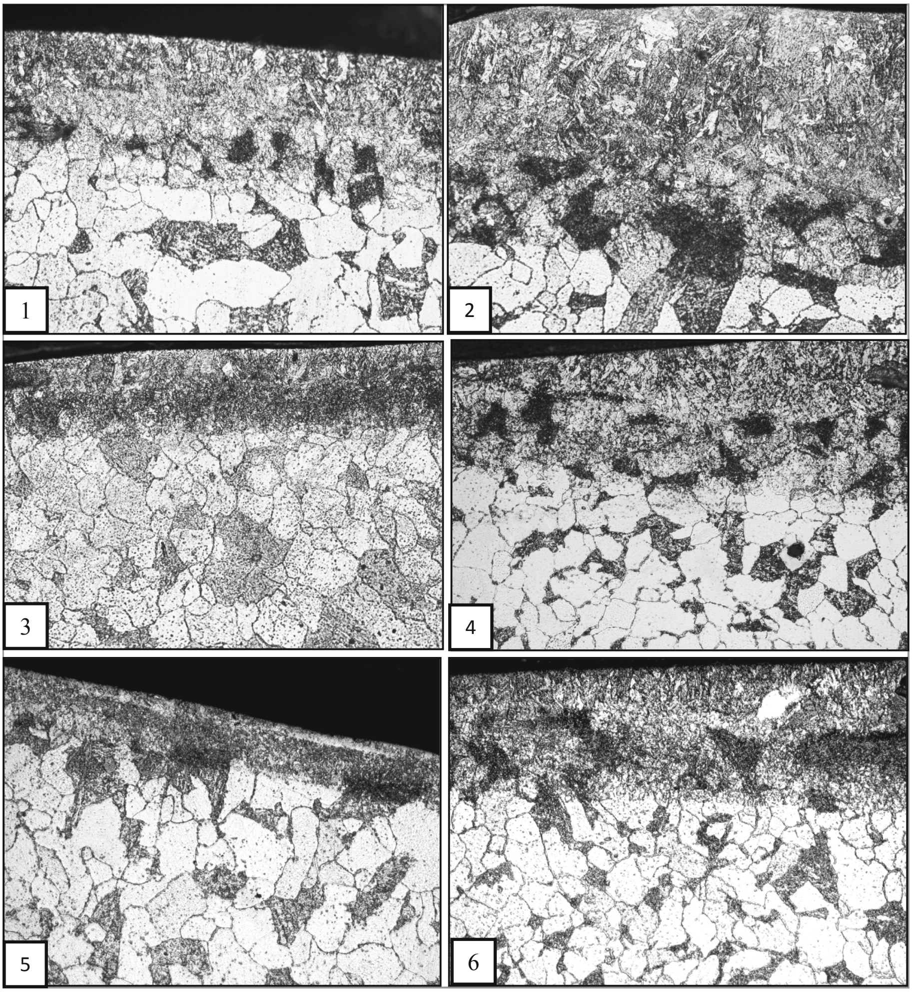

Fig. 1. The microstructure of the hardened layer. The image number corresponds to the laser processing modes given in the Table 1. *Source*: developed and compiled by the authors.

The heat-affected zone (HAZ) includes a layer with a hardened martensitic structure that smoothly passes into the region of the initial structure. The tempering zone is practically does not appear in the structure of the surface layer of 25XM steel. In the HAZ, a high density of point micro-objects is observed, the concentration of which is gradient in nature, corresponding to the distribution of temperature over depth. It can be assumed that the main cause of the formation of point microstructures identified by etching are vacancy colonies and dislocation exit to the surface of the metallographic thin section, which form nano- and micro-scale stress concentrators.

The depth of the altered layer and the dimensions of its individual regions formed by laser radiation take different values depending on the processing conditions. As the laser energy increases, the depth of the hardened layer tends to increase.

An analysis of images of surface microstructures obtained by laser processing shows that the maximum density of the boundaries takes place in the quenching region of the HAZ. A change in the average density of the boundaries along the depth hardened by laser radiation in some layer regimes is shown in Fig. 2.

Dark microstructural objects represent microstructures with high chemical potential, which can be identified by etching of a metallographic thin section. The higher the chemical potential of the microstructural component, the stronger its etching, which appears as a dark object in the image of microstructures (Bashkov et al. 2017). The total area of dark objects is the area of all cross sections of microstructural components in the plane of the section that have a high value of free energy. Such dark objects include the grain boundary, microvolumes with a high content of elastic energy arising around various micro- and meso-concentrators of stress, grains with an increased chemical potential in polycrystalline systems, etc.

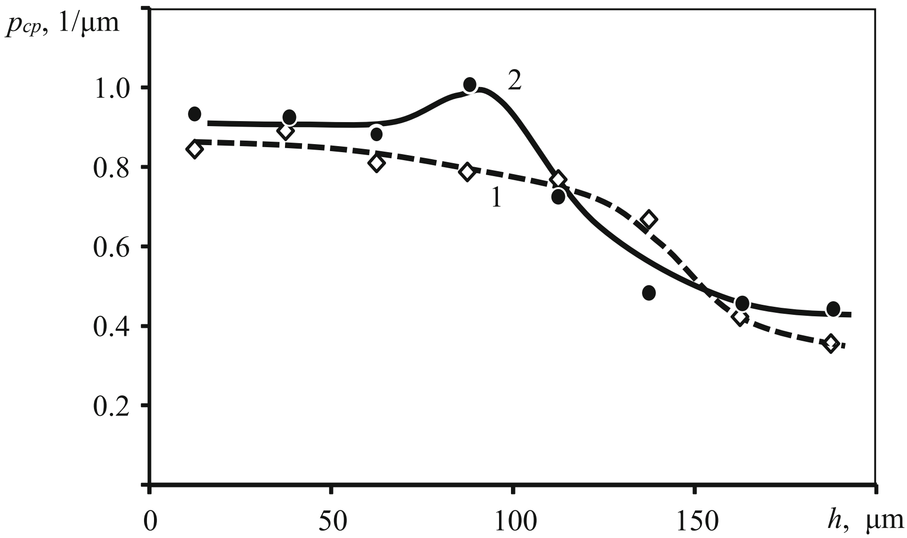

Fig. 2. The distribution of the average density of the boundaries along the depth of the hardened layer: 1) E = 1,051 J/cm^2;2) E = 773 J/cm^2. *Source*: developed and compiled by the authors

Figure 3 shows the distribution pattern of the total area of dark objects in the surface structures of the hardened layer, relative to the unit area of the metallographic thin section. The nature of the change in this indicator over depth is the result of the propagation of absorbed radiation and structural transformations initiated by this energy.

The absorbed energy of the laser action in metal systems shows itself mainly in the form of heat or a dynamic temperature field. In individual laser irradiation modes, a microstructure with a reduced chemical potential is formed in the uppermost layers. This is due to the processes of thermal annealing and tempering, which can occur in layers with high temperature. During laser processing of high alloy steels, the area of "bright" objects in the images of microstructures can be associated with the formation of residual austenite. It is difficult to etch even with a high value of its chemical potential. This must be taken into account in the structural-energy analysis of hardened and laser-modified surfaces.

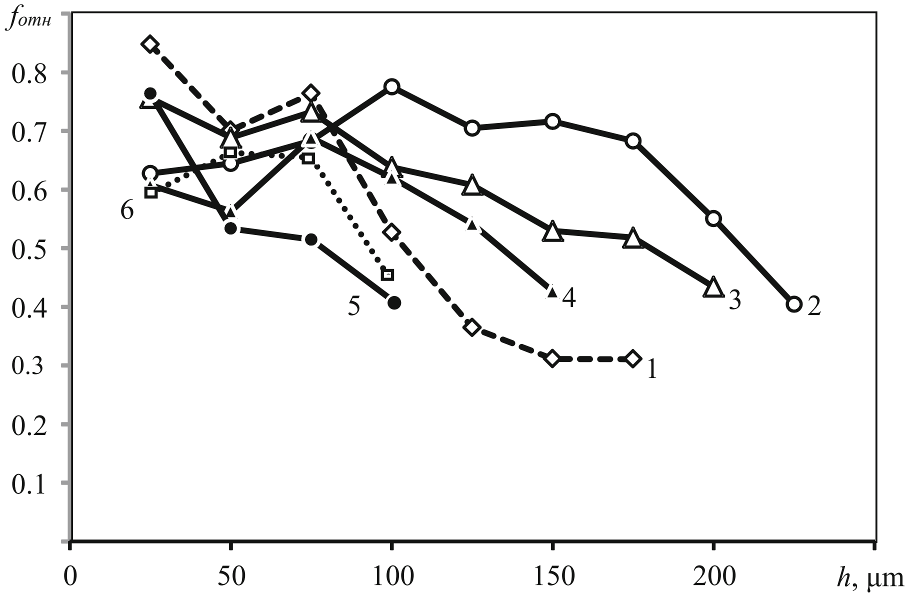

Fig. 3. Distribution of the relative area of dark microstructural objects along the depth of the hardened layer. The numbers of the curve correspond to the modes shown in Table 1. *Source*: developed and compiled by the authors

Hardening of the surface layer is gradient in nature. The depth distribution of microhardness is determined by the nature of the structural organization of the surface layer. Figure 4 presents the results of changes in microhardness in some laser treatment modes. Maximum microhardness takes place in the heat affected zone in the region of quenching structures. The uppermost region, which is formed from the liquid-phase state of the processed material, has a microhardness in most cases lower than in the hardened layer of HAZ.

The nature of the changeover depth of the average density of the boundaries, the relative area of the "dark" microstructural objects and microhardness clearly shows that there is a directly proportional relationship between these parameters. With an increase in the degree of disequilibrium of the microstructural state, the hardness increases.

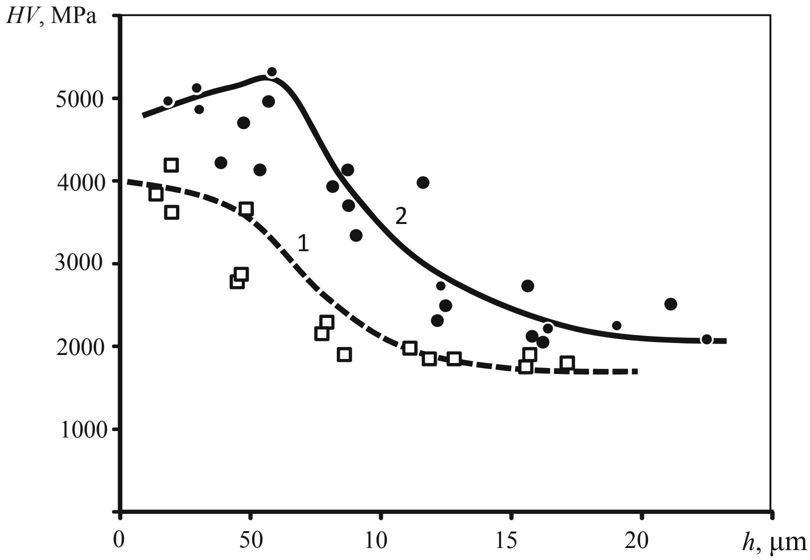

Fig. 4. The distribution of microhardness in the surface layer of steel 25XM after laser processing: 1) E = 1,051 J/cm^2; 2) E = 773 J/cm^2. *Source*: developed and compiled by the authors.

4 Conclusion

During laser processing, a surface microstructure is formed under nonequilibrium conditions for the interaction of a material with a highly concentrated energy flow and develops according to a synergetic algorithm, which by all indications belongs to the category of dissipative structures.

A quantitative evaluation of the nonequilibrium and dissipative activity of surface structures is the average density of the boundaries of microstructural objects, which characterizes the conductivity of diffusion mass transfer channels and potential barriers for braking deformation carriers under mechanical loading of the material.

Among the average density of the boundaries, the relative density of "dark" microstructural objects and the microhardness of the surface layer formed by laser hardening, a directly proportional dependence exist.

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Study of Nonequilibrium Structures by the Method of Multifractal Parametrization

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Abstract. Purpose: Investigation of the scale factor on the quantitative characteristics of the microstructure to quantify the structural organization of the material and determine quantitative indicators of microstructures, such as heterogeneity and degree of disorder.

Design/methodology/approach: The object of the investigation was microstructures of steel 45. Digital images of the microstructures were obtained using a metallographic microscope imaging processing that included sharpness adjustment, removing a contrast mask, highlighting borders and calibrating images.

Findings: Increasing magnification of microstructures images leads to a decrease in the surface area. The smaller objects are revealed, clearly visible the local curvature of the borders and the heterogeneity of the structural organization of the material are more clearly identified. The best information content of a multifractal spectrum is achieved if the area of microstructural objects is used as a measure for its calculation. The larger Δ_q, when $q >> 1$, the more ordered is the structure, and the periodic component is more manifested in it. The value of K_∞ is finite. It is a measure of disorder in the structural organization of the material, i.e. the larger K_∞, the more disorder.

Originality/value: The heterogeneity, orderliness, and periodicity of the microstructure of materials in a nonequilibrium state have long been analyzed only at a qualitative level. The use of fractal and multifractal formalism in the description of microstructures opens up wide opportunities for quantitative assessment of the structural organization of the material, clarifies and reveals new aspects of the known mechanisms of structural transformations.

Keywords: Microstructure · Structural heterogeneity · Ordering · Fractal and multifractal formalism · Structural state · Multifractal spectrum · Perimeter and area of microstructural objects

JEL Code: L61

1 Introduction

To obtain images of microstructures, metallographic thin sections were obtained, which were etched and examined using optical and/or electron microscopy. The resulting

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images can be characterized as a collection of geometric shapes with different colors. The structural organization of the material is volumetric, but in the images in the rectilinear plane, only its slice can be seen. Then all obtained three-dimensional images can be represented as two-dimensional objects, and images of two-dimensional and one-dimensional in the form of one-dimensional and points, respectively (Brandon and Kaplan 2004).

The image of a microstructure is a collection of geometric objects characterized by orderliness and similarity and belong to the category of fractal systems. Among the objects obtained, those that have the most important information are distinguished and assign them a single concept - "the interface of the structural state". In order to quantitatively describe structural objects, the following actions are taken: the boundaries of the structural state are selected, numerical indicators are determined and their change as a result of the impact on the material of energy flows is analyzed (Pratt 1982).

The boundaries of the structural states of the material consist of interphase and grain boundaries. In order to study the production technology, operating conditions, destruction mechanisms and the reasons for the exit of the part from the operating mode, an analysis of the shape, local curvature and ordering of the identified boundaries on a polycrystalline material is performed (Kim et al. 2013).

For a long time, for a material in a nonequilibrium state, it was possible to analyze the heterogeneity, ordering and periodicity of the microstructure only at a qualitative level. Fractal and multifractal description of microstructures makes it possible to assess the structural organization of a material from a quantitative point of view, as well as to refine the previously known mechanisms of structural transformations. Currently, multifractal spectra are the main method for identifying quantitative indicators of the microstructure. However, the multifractal spectra are dependent on the magnification of the microstructures image. As image magnification of microstructures increases, the surface area of the thin section recorded in the photograph decreases. In order to reveal smaller objects, the local curvature of their boundaries and structural heterogeneity in the images of the obtained microstructures, the visible surface area of the thin section is reduced by increasing the magnification of the image. As a result, the statistical sum is calculated over the increased range of the number set.

As a result of the study, the influence of the scale factor and quantitative characteristics of microstructures on the complex indicators of structural heterogeneity and order was shown.

2 Materials and Method

Multifractal formalism is based on the concept of a statistical sum, for the drafting of which any quantitative indicator of the structural organization of the material can be used as a measure. The technique for generating multifractal spectra with the mathematical apparatus describing this procedure are described in the scientific literature and are widely applied in material science research (Brandon and Kaplan 2004; Pratt 1982).

The image of a microstructure can be represented as a two-dimensional object in Euclidean space. A grid of identical rectangular cells is superimposed on the image. Further, in each cell, the value of the selected quantitative indicator of the structure is determined. As a result, we get a set of values $L(k) = \{M_1, M_2, M_3, \ldots, M_k\}$ that characterize the microstructure of the material in numerical terms.

The relative value of measure is calculated using the following formula:

$$p_i(\varepsilon) = \frac{M_i}{\sum\limits_{i=1}^{k} M_i}, \tag{1}$$

where $p_i(\varepsilon)$ - is the relative measure (density) of each cell;

M_i - the absolute value of the measure of each cell;

k - the number of cells.

Note that

$$\sum_{i=1}^{k} p_i(\varepsilon) = 1, \tag{2}$$

The statistical amount is defined as follows

$$Z(q, \varepsilon) = \sum_{i=1}^{k} p_i^q(\varepsilon), \tag{3}$$

where q - arbitrary real integers from $-\infty$ to $+\infty$.

The multifractal spectrum components are calculated using:

$$D_q = \left(\frac{1}{q-1}\right) \cdot \lim_{\varepsilon \to 0} \frac{ln[Z(q, \varepsilon)]}{ln\, \varepsilon}, \tag{4}$$

where $\varepsilon = \left(\frac{1}{k}\right)^{0,5}$ - characteristic linear cell size.

The multifractal value at q = 1 is determined by a separate formula:

$$D_1 = \frac{\sum\limits_{i=1}^{k} p_i \cdot ln(p_i)}{ln\, \varepsilon}. \tag{5}$$

At $q \to +\infty$(the multifractal spectrum positive branch), the cells with the highest density create the main contribution to the generalized statistical sum, and at $q \to -\infty$ (the multifractal spectrum negative branch) the lowest density. Therefore, the values of the component of the multifractal spectrum and the range of their variation shows the degree of heterogeneity of the number set L(k).

The components of the multifractal spectrum have different physical meanings. D0, which corresponds to q = 0, represents the Hausdorff dimension of the set L (k) and only allows one to estimate the dimension of the Euclidean space and the nature of the division of the image into rectangular cells.

The quantity D_1, is associated with the entropy of the fractal set, and used as a characteristic of the measure of disorder in the number set L(k).

For q = 2, the partition function represents the correlation integral, therefore, D_2 is called the correlation dimension. If the numerical set L(k) represented a set of points, then the quantity D_2 would represent a measure of the fact that at random 2 points would be located in one cell. With regard to the structural organization of the material, D_2 can be interpreted as a measure that at least one similar object is located near any microstructural element, i.e. a measure of the formation of ordered groups of the same type of microstructures. All other components of the set D_q represent the multifractal spectrum. Larger values of D_q for $q >> 1$ correspond to high entropy indices. In this regard, the value of D_q can be used to recognize microstructures visually impossible to differentiate or slightly distinguishable from each other.

The components of the multifractal spectrum are used to determine indicators of the structural organization of the material, such as (Vstovsky et al. 2001; Bozhokin and Parshin 2001):

$$\Delta_q = D_1 - D_q, \tag{6}$$

$$K_\infty = D_{-\infty} - D_{+\infty}. \tag{7}$$

As a result, the degree of disorder, orderliness and periodicity of the microstructure is estimated. For $q >> 1$, the larger Δ_q, the structure is more ordered, and the periodic component is more manifested in it. The value of K_∞ is finite and is a measure of disorder or chaos in the structural organization of the material, i.e. the more K_∞, the more disorder. In practice, $q = 40$ is sufficient to calculate complex multifractal indices. For more accurate studies, $q = 100$ or even $q = 200$ (Vstovsky et al. 2001; Bozhokin and Parshin 2001).

The object of the study was the microstructure of steel 45, obtained with an increase of 100, 200, 400 and 1000 times. A 4% solution of nitric acid in ethanol were used to etch sections. Nikon Eclipse 200 MA metallographic microscope was used to obtain digital images of the microstructures.

Image processing was done using Image.Pro.Plus.5.1 (USA) that included sharpening, removing a contrast mask, highlighting borders utilizing the Laplace filter, and calibrating images to fit the corresponding scale ruler. Image processing was performed only on the “dark” microstructural objects. When removing the contrast mask, “dark” objects included microstructures, in which the ratio of black and white colors was 128 pixels each (Pratt 1982; Kim et al. 2013). Then, quantitative indicators of microstructures were calculated, in particular, the area F_j, the perimeter P_j of each microstructural object, and the fractal dimension of the boundaries D_j. The algorithm for determining the fractal dimension of boundaries in the Image.Pro.Plus.5.1 program is based on the chord method (Godreche and Luck 1990; Manna and Vicsek 1991). As measures for calculating multifractal spectra, the same indicators were used.

When calculating the statistical sums and multifractal spectra, the q parameter varied in the range of integer values from −50 to +50.

3 Results

Figure 1 shows the microstructures of the studied steel 45 at various magnifications. The material consists of ferrite and pearlite grains with distinguishable section boundaries. The greatest information on the structural organization of the material is bordered by grain boundaries; therefore, they are called the interface of the structural state in materials science (Bashkov et al. 2019, 2017). Microstructures at a 100 and 200-fold increase do not reveal the development and local curvature of the boundaries, but they can determine with sufficient accuracy the percentage ratio of ferrite and pearlite grains and calculate the carbon content in steels from them.

At a 400-fold increase, the structural organization of the boundaries is well exposed and the pearlite phase structure starts to appear. With a magnification of 1000, it is possible to distinguish sections of boundaries with high and low coherence, and ferrite and cementite plates are clearly manifested in the structure of perlite. Borders with low coherence, having greater surface energy, are more etched and acquire a greater thickness and a darker shade. Starting with a 400-fold increase, ferritic and pearlite grains with higher free energy or chemical potential can be distinguished, which are more susceptible to chemical etching and acquire a darker shade.

The higher the magnification, the smaller the surface area of the thin section, fixed on the image of the microstructure. Therefore, microstructures obtained at 100- and 200-times magnification appear to be more homogeneous compared to 400- and 1000-times magnification. The heterogeneity of the microstructure with a magnification of 1000 is obvious; therefore, to ensure statistical accuracy, the number of images subjected to analysis is increased.

Figure 2, 3, and 4 show multifractal spectra calculated by various measures. Table 1 shows the complex indicators of multifractal spectra.

Multifractal spectra calculated along the perimeter and area of microstructural objects have much in common. In a comparative analysis of the areas of positive and negative q values, they are asymmetric. Smaller values of the range of changes in multifractal spectra in the positive region ($0 < q < +50$) compared with the negative region ($-50 < q < 0$) indicate that small microstructural objects predominate in the material microstructure. Increasing the multiplicity of the increase in the microstructure image, the scale of the components of the multifractal spectrum increases, but this regularity is strictly observed when using the area of micro objects as a measure. In multifractal spectra calculated along the perimeter of microstructural objects, there are violations of this regularity in the positive region q ($0 < q < 50$). So, with a magnification of 100, the values of multifractal spectra take on larger values than with a magnification of 400.

The components of the multifractal spectrum, calculated from the area of microstructural objects, are characterized by a wider range of variation and large values of the complex indices K_{∞} and Δ_{50}. Therefore, the preferred measure for calculating multifractals is the area of microstructural objects.

The nature of the change in the multifractal spectrum calculated from the fractal dimension of the boundaries (Fig. 4) is fundamentally different from previous multifractal spectra. The range of variation of the spectrum components and the values of complex indicators is an order of magnitude lower compared to the characteristics of

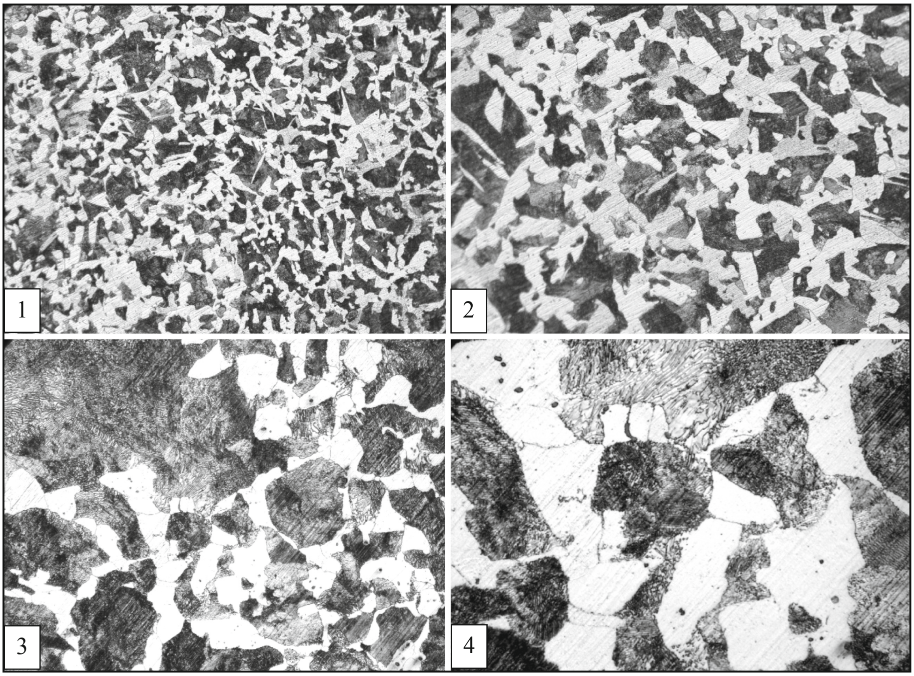

Fig. 1. The microstructure of steel 45 with an increase of: 1–100 times; 2–200 times; 3–400 times; 4–1000 times. *Source*: developed and compiled by the authors

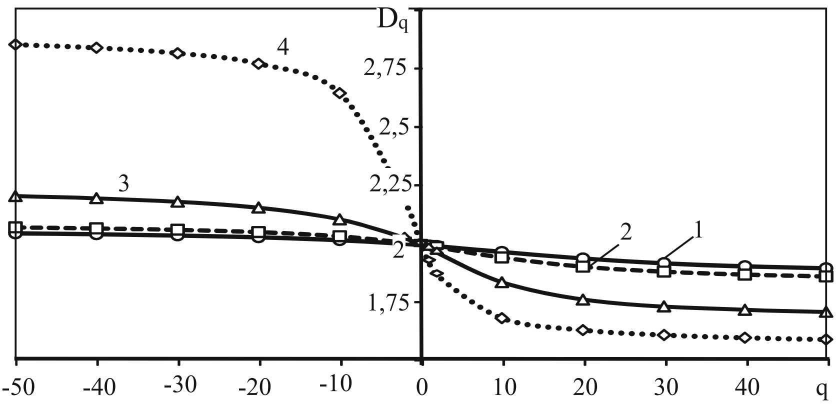

Fig. 2. Multifractal spectra calculated along the perimeters of microstructural objects: 1 - an increase of 100 times; 2 - 200 times; 3 - 400 times; 4 - 1000 times. *Source*: developed and compiled by the authors

multifractals calculated along the area and perimeter of microstructural objects. Moreover, the general pattern of increasing the range of multifractal spectra with increasing magnification is preserved.

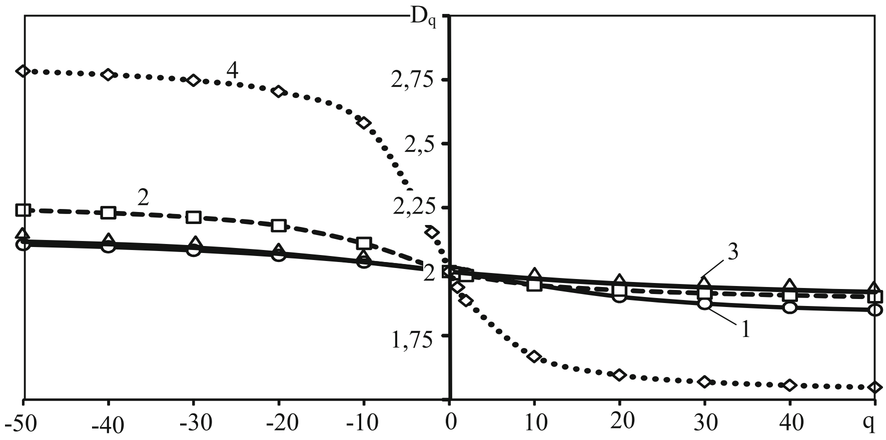

Fig. 3. Multifractal spectra calculated by the area of microstructural objects: 1 - an increase of 100 times; 2 - 200 times; 3 - 400 times; 4 -1000 times. *Source*: developed and compiled by the authors

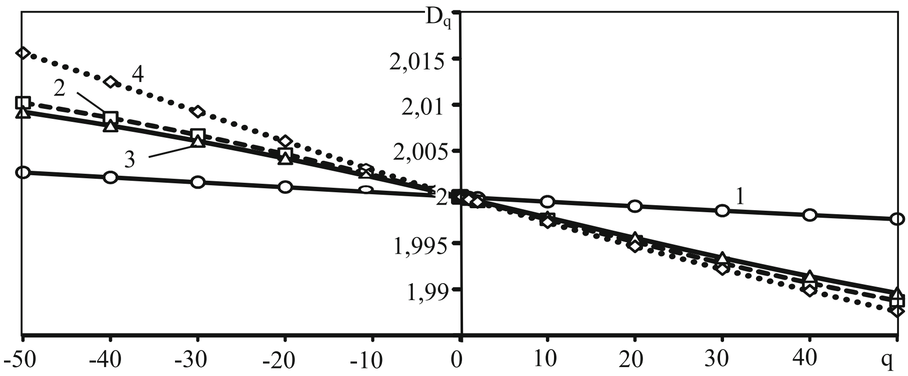

Fig. 4. Multifractal spectra calculated from the fractal dimension of the boundaries of microstructural objects: 1 - an increase of 100 times; 2 - 200 times; 3 - 400 times; 4 -1000 times. Source: developed and compiled by the authors

Table 1. Comprehensive indicators calculated from multifractal spectra

Image magnification ratio	Measure for calculating the multifractal spectrum					
	The perimeter of microobjects		The area of micro objects		Fractal dimension of borders	
	K_∞	Δ_{50}	K_∞	Δ_{50}	K_∞	Δ_{50}
100	0,1489	0,0966	0,2555	0,1451	0,0051	0,0023
200	0,2091	0,1292	0,3391	0,0903	0,0214	0,0112
400	0,4942	0,2694	0,1968	0,0766	0,0197	0,0102
1000	1,2568	0,3305	1,2360	0,3909	0,0197	0,0102

4 Conclusion

As the magnification of the images of microstructures increases, the surface area of the thin section captured in the image decreases. Thus, smaller objects are exposed; the local boundaries curvature and the structural organization heterogeneity of the material are more clearly apparent; leading to an increase in the range of the numerical set, by which the statistical sum is obtained, and the multifractal spectrum.

The best information content of the multifractal spectrum is achieved if the area of microstructural objects is used as a measure for its calculation.

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Investigation of the Processes of Transition of an Alloying Element into an Alloy During Electroslag Remelting of a Slag System Based on Multicomponent Raw Materials

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Abstract. Purpose: The article addresses the issues of obtaining highly alloyed alloys based on the integrated use of mineral concentrates on electroslag remelting.

Design/methodology/approach: The article discusses the processes of transition of alloying element from molten slag to metal under different operating modes of the system at different degrees of vibration impact. Mathematical model showing non-uniformity of distribution of alloying elements in metal melt is proposed and described. Composition and structure of obtained alloys are examined.

Conclusions: During the experiments, a slag system was formed based on multicomponent mineral raw materials, the degree of transition of tungsten to a molten metal in the range of modes from 5 to 15 Hz was analyzed. An electric slag remelting model was developed, considering the ESP process based on the theory of an open dynamic system. Experimental data help determine the nature and mechanism of the transition of the alloying element to liquid metal. These mechanisms help to regulate temperature zones, which reduces convection processes caused by temperature differences. And the transition of the alloying element depends on the direction and force of the electromagnetic field, both the electrode and the crystallizer.

Originality/value: On the basis of magnetic hydrodynamics (MHD) the issues of increase of alloying intensity and structure formation of alloyed alloys are considered. A promising method of solving the problem is the use of developed algorithms for the integrated use of mineral concentrates for the production of highly alloyed tungsten steels.

Keywords: Scheelite concentrate · Electroslag remelting · Magnetic hydrodynamics · Tungsten carbide · Alloyed alloy

JEL Code: C22 · C32 · L69 · L70 · L79 · O14 · O30 · O39 · Q29

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1 Introduction

The works Kuzmichev et al. (2016), Verkhoturov et al. (2003a, b), Verkhoturov et al. (2014), Babenko et al. (2008) consider methods for extracting alloying elements from concentrates by acting on them with intense energy flows. Such methods correspond to the theory of entropy reduction in the production of alloys without the stage of concentrate processing. The use of technologies that exclude the use of environmentally hazardous pyro- and hydrometallurgical processes leads to a reduction in production time. The use of such technologies will ensure a comprehensive and rational processing of concentrates, as well as compliance with environmental requirements.

One of these technologies is electroslag remelting (ESR), developed in the 50s at the Paton's Institute of Electric Welding and has a number of such advantages as: high productivity; obtaining pure refined metal; the ability to form seams of any shape and size.

When electroslag remelting occurs: a change in the composition of the slag, due to the reduction reactions of alloying elements and reversible reactions; hydrodynamic movement of slag due to changes in electrical, mechanical, thermal parameters of the slag bath.

It is not possible to analytically describe the processes occurring in the slag bath when alloying the deposited metal using multicomponent mineral concentrates using the existing methods of classical thermodynamics based on the analysis of quasi-equilibrium physicochemical processes (assuming the achievement of equilibrium).

To solve the set problems of the formation of alloyed metal, the authors used a dynamic approach. In this case the initial conditions (formation of the composition of the charge), the process parameters affecting the slag bath (current, voltage, diameter of the remelted steel, etc.) and the external effect on the slag bath in remelting process were set.

2 Materials and Method

A feature of the electroslag remelting process is the uneven distribution of the current density throughout the volume of the slag bath, which leads to an uneven distribution of temperatures in it. The temperature difference between the highest concentration of electric current and the cooled walls of the crystallizer leads to the occurrence of convection processes in the slag bath.

Due to the relatively low electrical conductivity of the slag, the current forms in it an intense Joule heat release, which ensures the melting of the consumable electrode. Due to the uneven distribution of the current density, the temperature in the slag bath is inhomogeneous, as a result of which thermal convection occurs in it. It should also be borne in mind that electric current is a origin of its own magnetic field, which leads to the appearance of an electromagnetic force, which can cause convection of liquid slag. Thus, the phenomena of heat and mass transfer in a slag bath must be considered using magnetohydrodynamics (Kuzmichev et al. 2017; Ya and Shcherbinin 1989).

Let us compose the basic equations for the transfer of momentum, heat and mass, depending on the electric current in the slag and liquid metal bath.

The Navier-Stokes equation of stationary motion of a viscous fluid contains an additional electromagnetic force $\vec{f}_e = \vec{J} \times \vec{B}$:

$$\rho(\vec{v}\nabla)\vec{v} = -\nabla p + \rho\nu\nabla^2\vec{v} + \rho\vec{g} + \vec{J} \times \vec{B}, \tag{1}$$

and the heat transfer equation contains the Joule heat release density $\left|\vec{J}\right|^2/\sigma$:

$$\rho\vec{v}\nabla T = \kappa\nabla^2 T + \left|\vec{J}\right|^2/\sigma. \tag{2}$$

Concentration transfer and continuity equations:

$$\vec{v}\nabla = D\nabla^2 C, \tag{3}$$

$$div\vec{v} = 0. \tag{4}$$

To these equations is added the equation of state of the medium:

$$\rho = \rho(T, C). \tag{5}$$

In addition, Maxwell's equations are needed:

$$div\vec{B} = 0, \tag{6}$$

$$\vec{J} = \frac{1}{\mu_0\mu} rot\vec{B}, \tag{7}$$

$$\partial\vec{B}\big/\partial t = -rot\vec{E}, \tag{8}$$

$$div\vec{E} = \rho_e\big/\varepsilon_0. \tag{9}$$

Here $\vec{J}$ is the electric current density, B is the magnetic field induction, ρ is the density, $\vec{v}$ is the velocity, p is the pressure, ν is the kinetic viscosity, $\vec{g}$ is the acceleration of gravity, σ is the specific electrical conductivity of the liquid, T is the temperature, κ is the thermal conductivity coefficient, C is the concentration, D is the diffusion coefficient, E is the electric field strength, μ is the relative magnetic permeability of the substance, μ_0 is the magnetic constant, ε_0 is the dielectric constant, ρ_e is the density of electric charges.

During electroslag remelting, the molten flux and liquid metal are in a closed volume of the slag bath on solid surfaces limiting this volume, the adhesion condition is satisfied $\vec{v} = 0$, and on a free surface $\partial\vec{v}_\tau\big/\partial\vec{n} = 0$ ($\vec{v}_\tau$ is tangential velocity, $\vec{n}$ is normal to the surface). That is, homogeneous boundary conditions are set at the boundaries of the liquid volume, and therefore an external source of melt associated with the action of surface forces does not exist at the boundary of the volume. In this case, the liquid can only be set in motion due to the action of internal volumetric forces, but the force must be vortex ($rot\vec{f} \neq 0$).

The source of movement of the melt is electric current, since only it is supplied from the outside. There are two mechanisms for this movement: the excitation of an electromagnetic force in the melt as a result of the interaction of an electric current with its own magnetic field and the appearance of thermal convection due to Joule heat release.

Let the bath have the shape of a round cylinder with an electrode coaxially immersed in the melt. The second electrode is the bottom of the cylinder. In a cylindrical coordinate system (z, r, φ), the welding current has z- and r-components. Under the condition of axial symmetry $\partial / \partial\varphi = 0$, taking into account the expression of the rotor in cylindrical coordinates ($\vec{i}_z$, $\vec{i}_r$, $\vec{i}_\varphi$ – unit vectors)

$$rot\vec{A} = \frac{1}{r}\begin{vmatrix} \vec{i}_z & \vec{i}_r & r\vec{i}_\varphi \\ \frac{\partial}{\partial z} & \frac{\partial}{\partial r} & 0 \\ A_z & A_r & rA_\varphi \end{vmatrix}, \tag{10}$$

as well as Maxwell's equations, we find that such a current causes only the azimuthal magnetic field B_φ, and the following relationship between B_φ and the components of the current density:

$$\vec{J}_z = \frac{1}{\mu_0}\frac{1}{r}\frac{\partial rB_\varphi}{\partial r}, \quad \vec{J}_r = -\frac{1}{\mu_0}\frac{1}{r}\frac{\partial rB_\varphi}{\partial z} = -\frac{1}{\mu_0}\frac{\partial B_\varphi}{\partial z}. \tag{11}$$

Then the electromagnetic force is calculated as

$$\vec{f}_e = J_r B_\varphi \vec{i}_z - J_z B_\varphi \vec{i}_r, \tag{12}$$

that is, like an electric current, it acts in the meridional planes $z - r$. We calculate the rotor of the force $\vec{f}_e$, then by the sign of the rotor we can find out the nature of the movement in the bath and equating the rotor $\vec{f}_e$ to zero, we can find out under which conditions the electric current does not cause the melt to move.

$$rot\vec{f}_e = -\vec{i}_\varphi \frac{1}{\mu_0 r}\frac{\partial B_\varphi^2}{\partial z}. \tag{13}$$

If a cylindrical surface of radius r_1 is selected inside the bath (shown by a dashed line in Fig. 1), then it can be seen that when the area of the immersed electrode is less than the cross-sectional area of the bath, the total current inside the selected cylinder will increase as it approaches the electrode. Consequently, B_φ will also increase on the surface of the cylinder, i.e. $\left.\frac{\partial B_\varphi}{\partial z}\right|_{r=const} > 0$ with increasing z.

The electromagnetic force should also twist the liquid in the meridial plane in the one shown in Fig. 1 direction. Therefore, the general movement of the melt is a vortex torus with movement along the axis of symmetry of the torus downward from the submerged electrode and upward along the side of walls of the bath.

Now consider the second mechanism. Let's apply the same technique as when considering the electromagnetic force, i.e. let's turn not to the force itself but to its rotor. Applying the *rot* operation to the Archimedean force $\rho\vec{g} = -\rho g\vec{i}_z = -\rho_0 g(1 - \beta T)\vec{i}_z$, in the axisymmetric (for simplicity) case, we obtain:

$$rot\,\rho\vec{g} = g\frac{\partial\rho}{\partial r}\vec{i}_\varphi = -g\rho_0\beta\frac{\partial T}{\partial r}\vec{i}_\varphi, \tag{14}$$

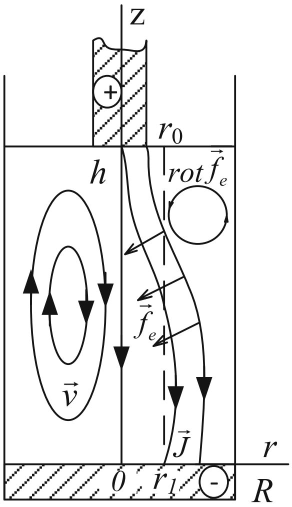

Fig. 1. Occurrence of motion in a slag bath: $\vec{J}$ – electric current lines, $\vec{f}_e$ – magnetic force distribution, $\vec{v}$ – melt movement, r_0 – electrode radius, R – bath radius, h – slag bath height. *Source*: designed and compiled by the authors

that is thermal convection is only possible with a radial temperature gradient. There is no other mechanism for the occurrence of thermal convection in a layer of liquid heating from above, in contrast to heating from below, when convective instability may be one of the causes of motion.

The obtained result makes it possible to predict the nature of thermal convection. First, it will occur in vertical (meridional) planes. Second, the direction of the melt movement, determined by the sign of $rot\, \rho\vec{g}$, depends on the nature of the temperature change along the radius (by the sign of $\partial T / \partial r$).

Thermal convection is directly opposite to electromagnetic one (Fig. 1). In this regard, the problem arises of assessing the relative role of thermal and electromagnetic convection, since, depending on the predominance of one or another convection mechanism, the conditions of heat and mass transfer in the bath radically change.

To compare the force rotors according to (13) and (14) is difficult because the first of them is determined by the derivative of the energy of the magnetic field along the axial direction, and the second by the derivative of the temperature along the radial direction. For example, take the following data: the radius of the slag bath $R = 2.5 \bullet 10^{-2}$ m, the electrode radius $r_0 = 2.5 \bullet 10^{-3}$ m, the height of the bath $h = R$, welding current $I_c = 1500$ A. The differentials of the quantities in (13, (14) are replaced by finite differences: $\partial z \rightarrow h$, $\partial r \rightarrow r_1$ (r_1 – arbitrary radius (see Fig. 1)), $\partial B_\varphi^2 \rightarrow B_\varphi^2\big|_{z=0} - B_\varphi^2\big|_{z=h} = \left(\frac{\mu_0}{2\pi r_1}\right)^2 \left(I^2 - k^2 I^2\right)$, where k is a coefficient that determines the fraction of the total current passing through a circle of radius r_1 at the bottom of the bath, $\partial T \rightarrow \Delta T = T|_{r=0} - T|_{r=r_1}$.

Then

$$\left|rot\vec{f_e}\right| = \frac{\mu_0 I^2}{4\pi^2 r_1^3 h}\left(1 - k^2\right), \quad |rot\,\rho\vec{g}| = \frac{g\rho_0\beta\Delta T}{r_1}. \tag{15}$$

The maximum value of the rotor of the electromagnetic force will take place at $r_1 = r_2$, the smallest at $r_1 = 0$ and at $r_1 = R$. The largest value of the rotor of the Archimedean force is determined by the maximum temperature difference. Naturally that $\Delta T_{\max} = T|_{r=0} - T|_{r=R}$, that is in the second expression (15) one should put $r_1 = R$. Taking data for slag and assuming $\Delta T_{\max} = 10^3 K$, we get $\left|rot\vec{f_e}\right|_{\max} \approx 2 \cdot 10^8\,\mathrm{H}/\mathrm{M}^4$, $|rot\,\rho\vec{g}|_{\max} \approx 1{,}2 \cdot 10^5\,\mathrm{H}/\mathrm{M}^4$.

Hence, we can conclude that in the selected conditions of the electroslag process, electromagnetic convection is decisive.

The process of melt movement in an electroslag bath belongs to magnetohydrodynamics (MHD). It depends on the direction and strength of the electric current passing through the melt and doesn't depend on the type of material of the electrode or flux (Podgaetsky and Kuzmenko 1988). Thus, the electromagnetic force f_e twists the liquid melt in a direction that coincides with the direction of the electromagnetic field (EMF). The general direction of movement of the molten slag is a vortex torus with the direction of movement of its axis of symmetry downward from the electrode and upward from the walls of the crystallizer. As a result of dissipation of energy from the electrode in the slag, a non-equilibrium stable system is formed, far from thermodynamic equilibrium.

Such a system is dissipative, which leads to the appearance of undamped oscillations or self-oscillations in it (Bezruchko et al. 2005). An example of such periodic self-oscillations is the Poincaré limit cycles described by Bezruchko et al. (2005) and Ivanova et al. (1994).

It can be assumed that similar toroidal trajectories, tending to other similar trajectories and representing in the aggregate a chaotic attractor, contain alloying elements.

Then the molten drop falling from the electrode and crossing these trajectories is not able to capture a sufficiently large amount of the alloying element.

The idea was put forward that during the oscillatory motion of the electrode in the slag bath, the toroidal movement of the slag breaks down and a drop of metal interacts with a large volume of slag, in comparison with the system at rest.

3 Results and Discussion

For experimental studies the important aspect of the work was to determine the composition of the experimental flux, consisting of a multicomponent oxide-containing mineral raw material and a reducing agent. Based on the experiments described in works Babenko et al. (2008), Kuzmichev et al. (2017), Babenko et al. (2004) and Verkhoturov et al. (2003a, b) a new composition of the flux was proposed, which included the following components: scheelite concentrate - $CaWO_4$, about 50%, fluorite concentrate - CaF_2, about 25%, and ferrosilicon - FeSi about 25% of the total share of the total batch volume. This composition of the charge was obtained in the course of optimization, based on ensuring the manufacturability of the process of reducing tungsten in a slag bath.

The experiments were carried out on a unit for electroslag remelting, low-carbon wire, was used as an electrode material. The remelting was carried out with a current in the range 400…500 A, and a voltage of 40…50 V.

Phase analysis and chemical composition of the obtained samples and slag were carried out on "VEGA 3 LMH" scanning electron microscope (TESCAN) equipped with "X-Max 80" energy dispersive spectrometer (Oxford Instruments). The microstructure images of the samples were taken in the backscattered electron mode.

To carry out experiments to verify the proposed idea, the installation (Drozdov et al. 2010) was designed and manufactured for oscillatory movement of the crystallizer relative to the electrode with an oscillation frequency of 5 to 15 Hz.

As a result of the movement of the crystallizer relative to the electrode during remelting, the crystallizer axis describes a virtual truncated cone with a base radius "*R*" at the level of the slag bath surface and a radius "*r*" at the base plate level (Fig. 2).

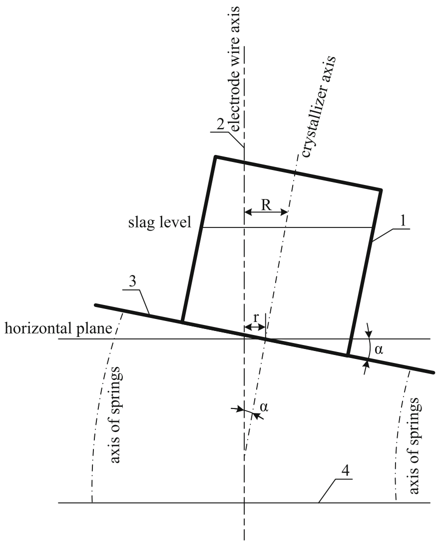

Fig. 2. Scheme of crystallizer movement in the ESR process on the experimental setup. *Source*: designed and compiled by the authors

In this case, the axis of the cone coincides with the vertical axis of the electrode wire. Under the action of the movement of the crystallizer, the liquid slag moves along circular orbits. As a result, the electrode wire crosses the entire volume of the slag bath, which leads to mixing of the entire volume of liquid slag and a uniform distribution of tungsten in it.

As a result of the experiments, samples were obtained that were cut lengthwise into two equal half-cylinders for research. The analysis of the obtained samples showed that the amount of tungsten, which passed from the slag to the metal, reaches 60…67 wt. % at a frequency of oscillations of the electroslag bath of the order of 15 Hz, and at a frequency of 5 Hz, the amount of the transferred tungsten fell to 12.6 wt. %. (Table 1).

Such inhomogeneities were clearly expressed in places located closer to the walls of the crystallizer (Fig. 3), and in places of layering as shown in the scheme (Fig. 2). In view of the inhomogeneity of the temperature distribution in the slag bath, the hottest zones of the metal, i.e. those located closer to the axis of the center of the electrode, had better indices for the homogeneity of the alloying element, but along with this, the proportion of the alloying element in the metal significantly decreased from 30 wt. % up to 3 wt. %. Also, the largest index of the transition of the alloying element W into the metal is concentrated along the tangent to the tori, the zone of which in the samples is concentrated at a distance from the electrode of about 5 mm, and at a distance from the walls of the crystallizer by 8 mm (zone B, Fig. 3).

Thus, the region of the metal located at a distance from the electrode, in the middle part of the microsection, about 14 mm in size, had the highest concentration of zones with the alloying element transferred into the metal, the proportion of which reached 60 wt% in relation to other elements. In the metal zone, located on the electrode axis (zone A, Fig. 3), the proportion of transferred W was 3… 13 wt. % in relation to other elements, in the studied mode.

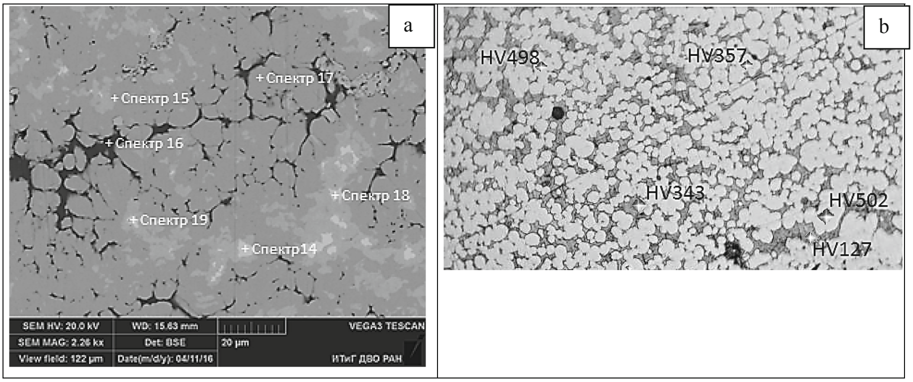

Fig. 3. Microstructure of the experimental alloy, where: a - phase microhardness (×700); b - image in reflected electrons – (“VEGA 3 LMH” scanning electron microscope (TESCAN)). *Source*: photos received by the authors

These anomalies can be the result of the outburst of the alloying element W due to its concentration at certain time intervals in the slag. Such areas were often located close to the walls of the crystallizer. The reason could be the covering with molten metal of the bunch adsorbed from the slag of the alloying element. In view of the inhomogeneity of temperatures, the metal approaching to colder zone, namely the wall of the crystallizer, did not allow W to dissolve in full.

At the end of remelting, the glassy slag on the cut had the following structure (Fig. 4a).

The tungsten phase in (Fig. 4) is represented by lighter areas, and has the character of cubic crystals elongated along the lines, forming the so-called “trajectories” (Table 2).

Table 1. The chemical composition of the metal after exposure to vibration

No. spectrum	Content of components in metal, wt. %				
	C	O	Fe	W	Si
14	2.97	26.4	1.83	68.80	–
15	3.04	27.93	22.34	41.61	0.97
16	2.87	26.25	57.43	13.24	0.21
17	2.96	26.98	20.85	47.33	–
18	2.90	27.18	17.50	48.84	0.72
19	2.95	26.72	19.23	51.10	–

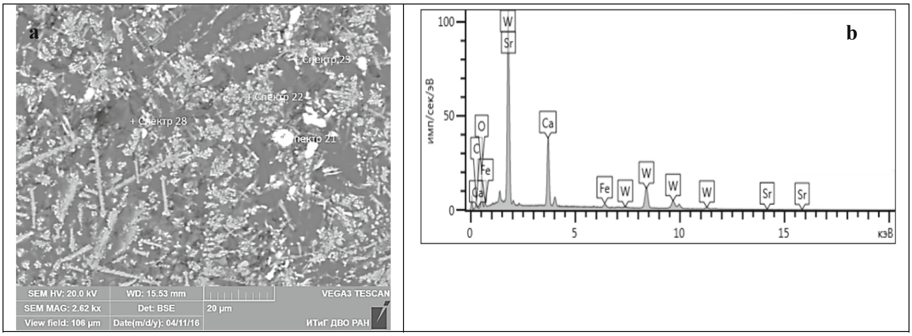

Fig. 4. a - slag microstructure; b - slag spectrogram. (“VEGA 3 LMH” scanning electron microscope (TESCAN)). *Source*: photo and diagram received by the authors

Table 2. The chemical composition of the slag after exposure to vibration

No. spectrum	Content of components in slag, wt. %						
	C	O	Fe	W	Si	Ca	F
21	4.04	29.56	1.38	48.15	–	12.67	–
22	3.02	27.22	2.01	47.9	0.1	14.96	4.5
23	2.87	26.25	57.43	13.24	0.21	14.34	3.96
28	3.96	37.79	26.13	9.24	4.15	15.35	3.38

If the vibration frequency of the slag bath increases up to 15 Hz it possible to observe a decrease in the total area of the areas saturated with tungsten throughout the section.

In the alloy, tungsten was in the composition of an intermetallic compound, doped ferrite and a chemical compound of tungsten and iron W_6Fe_7. It was possible to observe other compounds, for example, tungsten carbides W2C, formed by reduction of tungsten from WO_3.

4 Conclusion

1. The model of electroslag remelting was developed, considering the ESR process based on the theory of an open dynamic system. The degree of transition of tungsten to remelted metal in the range of modes from 5 to 15 Hz is analyzed.
2. Experimental data help to determine the nature and mechanism of the transition of the alloying element into the liquid metal. Changing the feed speed of the welding wire and reducing the heat removal from the working area of the crystallizer contributes to a more uniform distribution of W in the metal. These mechanisms help to regulate temperature zones, which reduces convection processes caused by temperature differences. And the transition of the alloying element depends on the direction and strength of the electromagnetic field, both the electrode and the crystallizer.
3. During experiments, alloys were obtained with a tungsten content up to 60… 67 wt. %, which can be further used as ferroalloys.
4. Chemical and phase analyzes showed that the alloy of the obtained samples contains compounds of intermetallic compounds Fe_7W_6, and carbides W_2C and WC, but the total proportion of carbides is insignificant due to the low carbon content in the welding wire and slag.

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High-Temperature Hydrogen Transfer Piping Element Repair in Oil Refinery: Case Study

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Abstract. Purpose: The purpose of this study is to improve the Manaurite 900 piping repair efficiency after a high-temperature operation in the hydrogen environment.

Design/methodology/approach: Manaurite 900 is an austenitic heat-resistant steel. A common feature of this alloy family is its high creep strength at high temperatures. A main reason for this is the fact that the diffusion coefficient of all elements is much lower in the side-centered cubic austenitic structure than in the body-centered cubic ferrite. This effect is enhanced by a large number of main alloying elements, such as nickel and chromium, along with other minor additions, specifically, heavy elements: molybdenum and tungsten. The repair was performed by manual metal arc welding. The issues of cracking and technological heredity manifesting themselves by carrying casting defects over into the weld are mentioned. The weld quality was checked both visually and by dye penetrant inspection (DP).

Findings: The main causes of cracking during repair were identified. The production sequence to repair the weld in the heavy-wall piping operating in the hydrogen environment at high temperatures was refined.

Originality/value: Recommendations are given to prevent cracking during the repair. A unique technology of defective edge restoration by a vertical buildup is proposed.

Keywords: Heat-resistant steel · Repair · Piping · Technology · Cracking · Manaurite 900

JEL Code: L61

1 Introduction

Preventive maintenance of the hydrogen production unit (HPU) at the Independent Petroleum Co. (NNK)-Khabarovsk Refinery in 2018 revealed cracking in the MANAURITE 900 (similar to the Russian KhN32T steel) weld connection between the header pipe and the header tee in the reformer (Fig. 1). The crack was located at the top of the weld and had a length of more than 200 mm.

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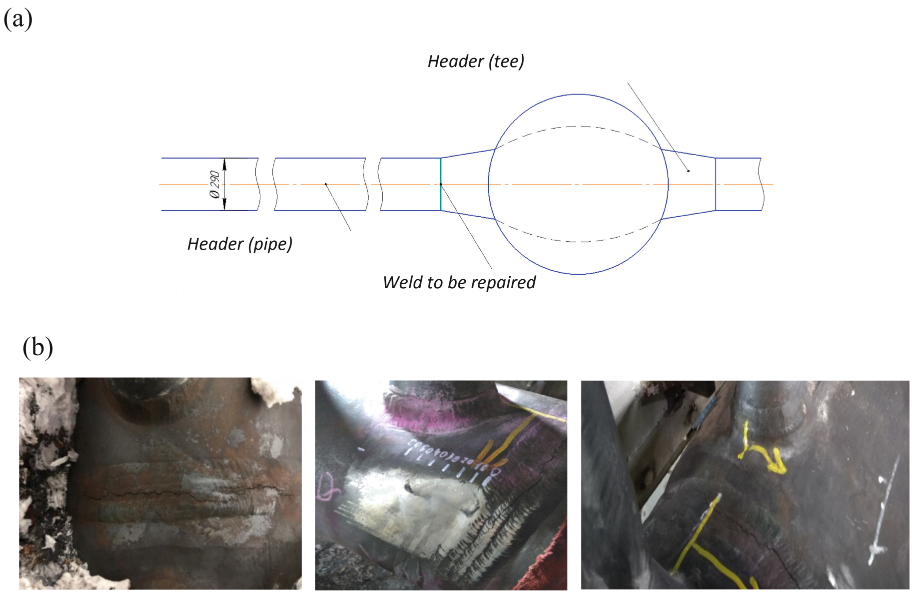

Fig. 1. Diagram of header to be repaired (a) and crack appearance (b). *Source:* Images made by the authors.

2 Materials and Method

Creep and tensile behavior of the candidate materials for high-temperature processes in nuclear power has been studied in the publications (Schubert et al. 1984; Shariat et al. 2003; Stevens and Trompetter 2004) that mention a comparison of the average Manaurite creep strength. The time to weld failure is at the lower range of the base metal scatter band. The properties defined in various simulated atmospheres are within the scatter band of the properties obtained for the air.

The publication (Jasiński and Zawada 2008) describes the study results for mechanical properties and microstructure of the Manaurite superalloy coupons cut from a catalytic centrifugally cast pipe in supply condition and after 1,000 h of aging. The process of catalytic pipe aging at a temperature between 750 °C and 900 °C causing deposition of intermediate phases in the alloyed austenitic matrix affecting the mechanical properties of the pipe material was studied.

The oxidizing properties of Manaurite were studied both in the air and in Ar - H2O at 950 °C (Mathieu et al. 2018). The alloy oxidation rate at 950 °C is higher in the atmosphere containing steam than in the air but the coupons are not evenly oxidized across the coupon surface. Internal aluminum oxidation related to a thick chromium buildup was regularly observed in this alloy. These findings show that the pre-oxidation conditions should be carefully studied and modified to achieve good heat treatment results.

The publication (Voorhees et al. 2011) discusses proportional similarity as a tool to evaluate a constant creep rate or time to failure at an early stage of the test. The remaining creep time obtained with a combination of four procedures is mentioned, that is, the Monkman-Grant relation, the proportional similarity method, the Larson-Miller parameter, and the curve fitting method, for the exposed reformed hydrogen tubes.

Successful electron-beam welding of the XW material and high weld properties are confirmed by the analysis of metallographic and mechanical properties (Verdier and Matesa 2007).

An update on the typical steel heat treatment efficiency is described in the publication (Gadalov et al. 2016), and the issues of extending conventional heat treatment are addressed in the publication (Murav'ev et al. 2019).

The repair technology was developed by the employees of NNK-Khabarovsk Refinery, JSC, and approved by the National Agency for Testing and Welding (NAKS). STO 38.17.003-2009, STO 00220368-008-2006, and OST 26.260.3-2001 were used as codes and standards with Thermanit 21/33So as the welding consumable. The thickness of the parts to be welded was 30 mm, and the diameter of the parts in the welding area was 300 mm. The edge preparation type was S3n as per STO 00220368-008-2006 (Fig. 2). Welding was done without heating. The design number of the beads was 28 to 36. Welding conditions: electrode diameter: Ø 3–4 mm; welding amperage at reverse polarity: 100 to 120 A. The bead layout is shown in Fig. 3. Power supply was the Caddy™ Arc 151i rectifier inverter; the ESAB KNM 351 YS welding machine with under carriage.

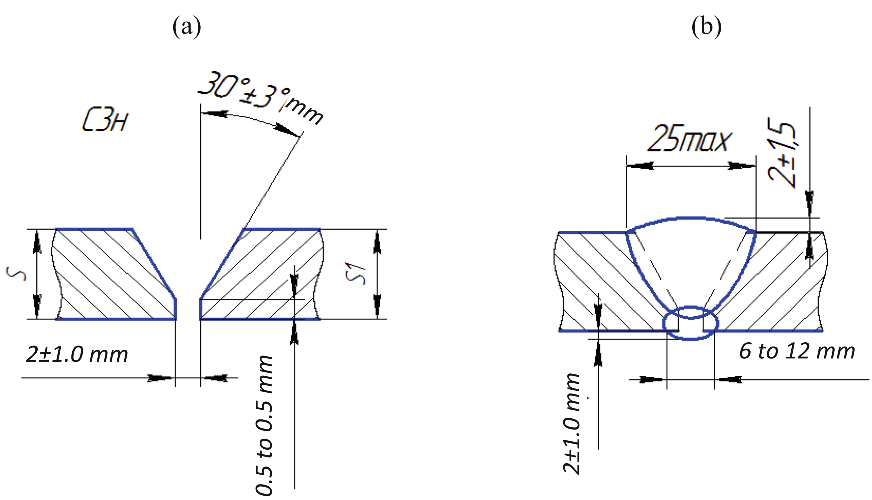

Fig. 2. Weld size before welding (a) and after welding (b). *Source:* STO 00220368 – 008 – 2006.

3 Results

Opening up the crack in the weld between the tee and the pipe in the H-220-101 reformer header of the hydrogen production unit (HPU) at NNK-Khabarovsk Refinery, JSC.

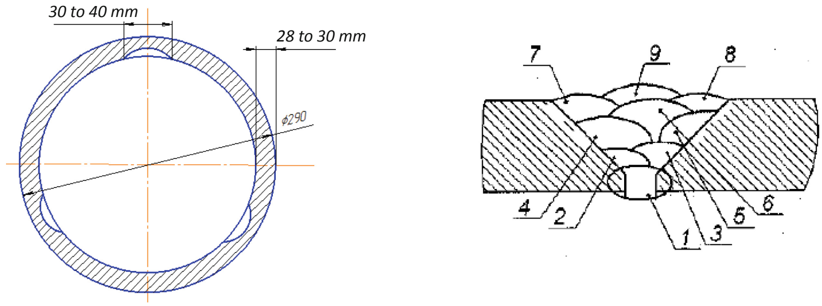

Fig. 3. Layout of tack welds and multi-pass weld beads. *Source:* National Agency for Testing and Welding (NAKS) approved technology

The crack was removed by arc gouging (with a graphite electrode); from experience, this technique is more efficient; the welder sees the crack through the welding shield/helmet and removes it completely; efficient performance of this operation mechanically is challenging (Fig. 4).

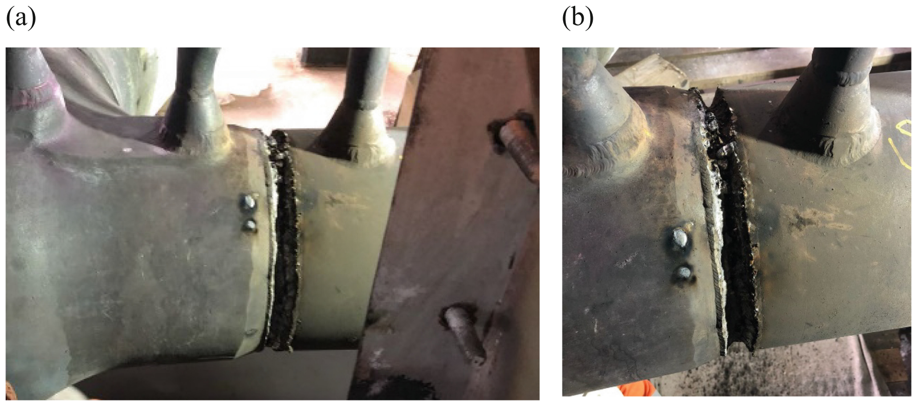

Fig. 4. Arc gouging results for defective weld. *Source:* Images made by the authors

After the crack removal, the markings from arc gouging were removed mechanically to a minimum depth of 5 mm from the deepest irregularity in the groove. The edges were machined to obtain a V-shaped weld groove (S3n); the edge preparation was dye penetrant inspected for defects (Fig. 5).

To avoid hydrogen pick-up and ingress of the oxygen and propane mixture burning products in the surface of the metal to be welded, the gas torch was used 100 to 150 mm off the edge for preheating up to 200–250 °C.

The edges were first built up radially but it caused cracking. The filler metal was ground down to 80 to 90% in the defective areas.

Attempts to build up from the inside of the edge across the pipe thickness with hand peening of each bead reduced the number of defects (Fig. 6).

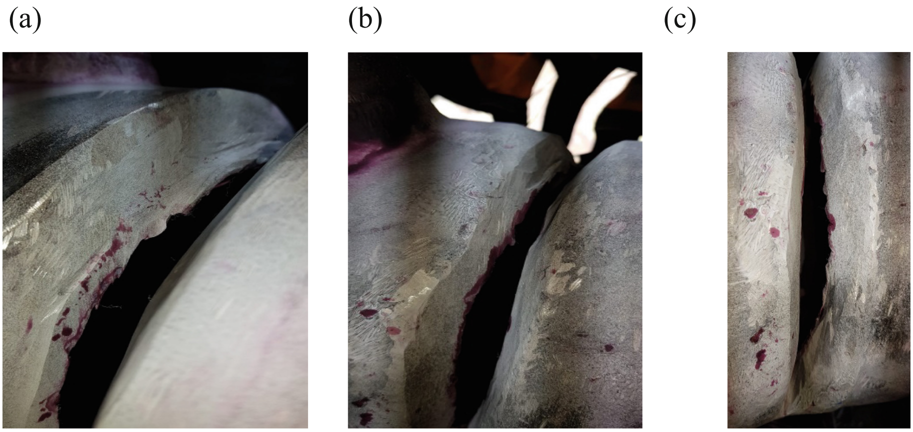

Fig. 5. Edges after machining. *Source:* Images made by the authors

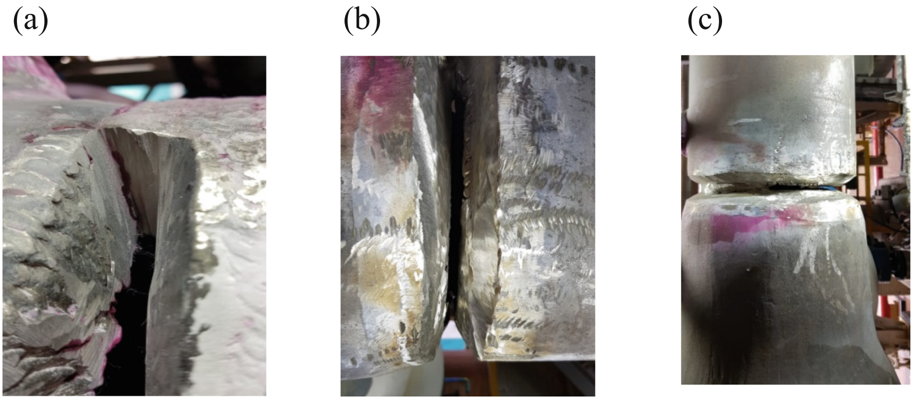

Fig. 6. Vertical edge buildup results. *Source:* Images made by the authors

After preparation and dye penetrant inspection of the built-up edges, checking for defects, and edge preheating up to 200–250 °C, the root pass was welded. The Thermanit 21/33Co electrodes were baked before welding, after baking they were placed into the quivers for cooling and drying (the manufacturer's recommendations for welding with the Thermanit 21/33Co electrodes are as follows: welding without heating or post-weld heat treatment; if necessary, stabilizing annealing at 875 °C for 3 h with air cooling). Welding of the root and subsequent beads was accompanied by defects such as microtearing, cracks, and porosity. The defects were completely removed mechanically, in some areas, cutting through the base metal at the weld root, grinding down about 85 to 90% of the weld (Fig. 7), and so forth with each subsequent pass maintaining an interpass temperature not more than 100 °C (the temperature was kept as per OST 26.260.3-2001 and STO 00220368-008-2006).

A temperature of 400–450 °C in the welding area failed to reduce porosity and cracks, and, by the same token, the header pipe shielding with argon did. Nitrogen supply to the

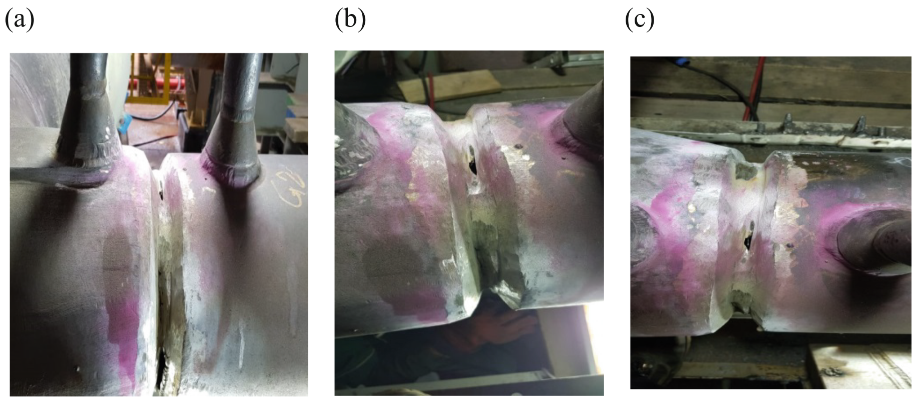

Fig. 7. Root bead of butt weld. *Source:* Images made by the authors

header through the reformer pipes to cool down the catalyst to avoid fire complicated welding and made it nearly infeasible (at the last stage of the weld repair0. However, it was efficient to peen each bead/layer/pass and carefully remove the slag mechanically with dye penetrant inspection of the result.

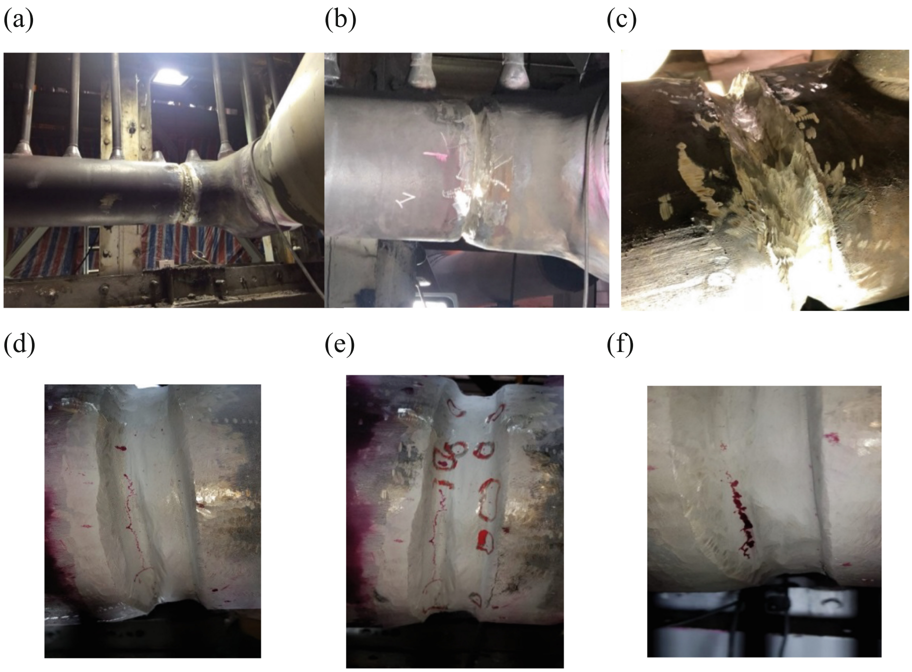

Fig. 8. Defects identified by dye penetrant inspection. *Source:* Images made by the authors

Grinding down the cracks in the welding layers (passes, beads) multiple times has led to an increase in the groove gap (Fig. 8) and also, due to a lack of uniform welding in the root and the subsequent beads, resulted in an unevenly deposited metal and an increase in the weld cross section, thus inducing internal stress, both in the main weld and the heat-affected zone.

Stabilizing Annealing. It was decided to relieve internal stress by heat treatment (Fig. 9) ** STO 00220368-019-2017, Item 5.1.26 in the stabilizing annealing conditions to remove the residual welding stress if it is necessary to keep the exact size. Annealing was performed in the following conditions: heating up to 870–900 °C, holding for 3 h, cooling with a heater down to 300 °C at a cooling rate between 50 and 100 °C/hr, and then in the air. (Fig. 7a, 7b, and 7c). Heat treatment was performed with the RT 75-6 machine (six circuits).

(a) (b) (c)

Fig. 9. Heat treatment facility (a) RT 75-6 machine panel (six circuits), (b) rear view of RT 75-6 machine (six circuits), (c) ceramic mats fixing for heat treatment. *Source:* Images made by the authors

After heat treatment, the welding proceeded with hand peening each welding bead/layer and thoroughly cleaning the weld and dye penetrant inspection. The metal was welded with minimum defects.

(a) (b)

Fig. 10. Dye penetrant inspection result. *Source:* Images made by the authors

After welding completion, the cap weld (reinforcement) surface was ground and prepared for dye penetrant inspection. There were no serious defects on the outer surface, however, a crack was identified in the fusion zone and the heat-affected zone (Fig. 10).

Defect removal had the following specifics: when lightly grinding through, a lot of defects were completely ground out, and then re-appeared in no particular order (Fig. 11).

(a) (b) (c)

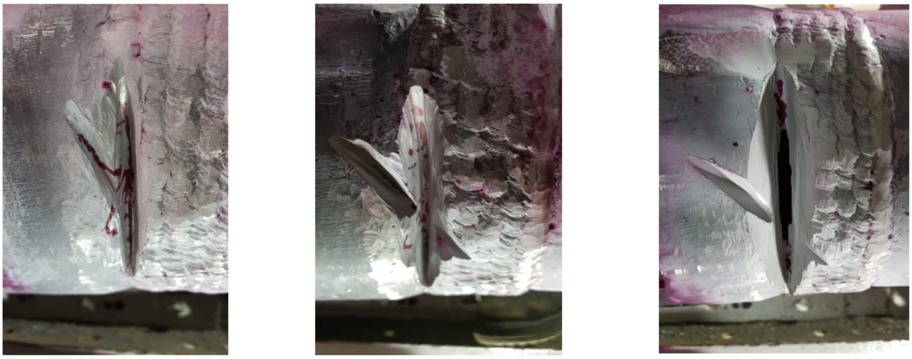

Fig. 11. Crack opening up. *Source:* Images made by the authors

The defects in the weld-affected zone were removed to clean metal; the main defects accumulated on the base metal side of the header tee (Fig. 12a); the weld side was relatively clean except for a burred cut edge at the weld root and isolated defects (Fig. 12b). The total size of the defect removed was about 80 mm (Fig. 12c).

(a) (b) (c)

Fig. 12. Crack preparation outcome. *Source:* Images made by the authors

Opening up the crack in the base metal of the header tee revealed a slag inclusion that most likely occurred when casting the tee (Fig. 13).

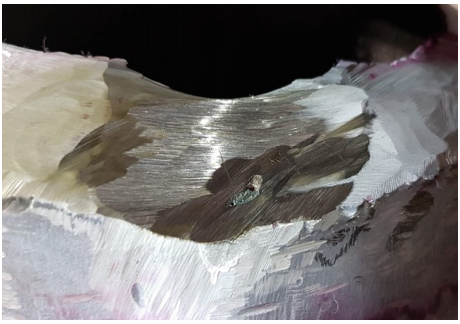

Fig. 13. Slag inclusion in base metal. *Source:* Images made by the authors

The defect was removed; the surface was dye penetrant inspected; then, the buildup started with the forming of the V-shaped weld groove (Fig. 14a and 14b).

When building up the left side of the lower header tee, there were no defects such as cracks. Slag inclusions from the electrodes on the left side of the tee in the lower part of the header were mainly detected (Fig. 14c). The lower header pipe side did not have any defects in the filler metal (Fig. 14c).

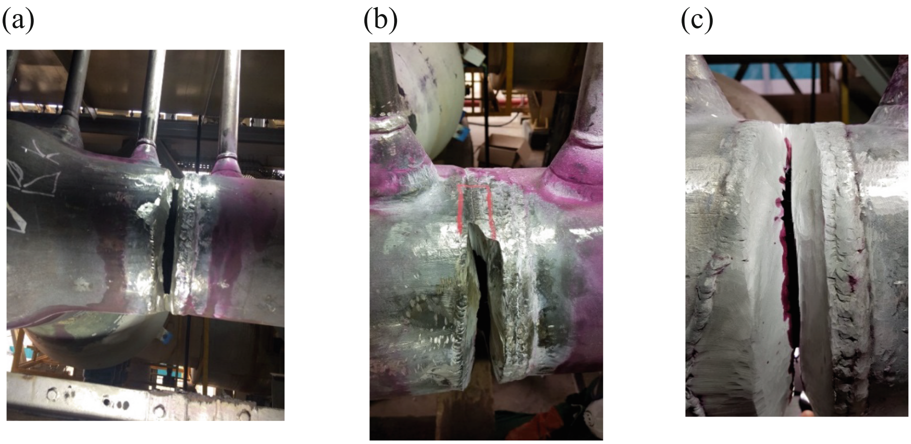

Fig. 14. Groove filling. *Source:* Images made by the authors

Having built up the edge on the lower header tee side, the weld root and all subsequent beads were welded (Fig. 15).

The weld after repair had operated normally for about eight months; any external defects on the surface of the weld and the heat-affected zone were not identified; further, when the unit was shut down for repair, the header was safely replaced with a new one.

(a) (b) (c) (d)

Fig. 15. Edge filling steps. *Source:* Images made by the authors

4 Conclusion

1. Extended weld operation at high temperatures in the hydrogen environment resulted in hydrogen pick-up by the metal, its embrittlement, and internal stress buildup. This phenomenon significantly reduces the weldability and leads to the risk of cracking.
2. When the welding procedure is applied to repair without preheating and subsequent heat treatment, which is recommended for new metal, cracking will occur even with a minimum arcing.
3. Heat treatment in the stabilizing annealing conditions: heating up to 870–900 °C, holding for 3 h, cooling with a heater down to 300 °C at a cooling rate between 50 and 100 °C/hr, and then in the air considerably reduces cracking and ensures good filler metal quality.
4. Peening the welding beads reduces both internal stress and cracking in the weld and the heat-affected zone.
5. Additional pipe shielding with gas (argon and nitrogen) during manual arc welding to reduce the weld defects does not yield favorable results.
6. The header tee has casting defects: slag inclusions that can cause both hereditary defects (slag inclusions in the welds) and cracking, as they do not have a spheroidal shape, and therefore are stress raisers.
7. Hydrogen pick-up analysis is recommended before welding and after stabilizing annealing using the available techniques.

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Change in Weld Metal Structure and Properties for Multi-pass Butt Welding of Stainless Steel Process Piping

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Abstract. Purpose: This project aims to identify the correlation between the conditions, materials, structure, and properties of multi-pass stainless steel pipe connections made by manual arc welding.

Design/methodology/approach: This project includes the following multicenter study: The patterns of the multi-pass heat cycle effects on the structure and properties of the weld metal and weld-affected zone of the permanent 12Kh18N10T austenitic steel connection made by manual arc welding with the different coated electrode classes (MMA, Procedure 111) caused by a highly concentrated heat source are analyzed. Microhardness and internal stress distribution across the weld cross section and weld-affected zone, and changes in alloying elements between the layers are studied, and static tensile tests are performed.

Findings: A consistent pattern between welding conditions and weld corrosion resistance has been identified; it is shown that the coupons welded in gentle conditions (lower welding amperage) have the highest percentage of weight loss while speed-up conditions substantially reduce this indicator. Changes in alloying elements in different zones have been determined: between the beads, along the fusion line, and in the heat-affected zone in different welding conditions and when using different electrode classes.

Originality/value: The completed multicenter study is often unavailable to the covered welding electrode manufacturers that define the combination of the wire, coating, and base metal, and welding conditions by trial and error. The study gives a complete picture of the processes occurring in the weld metal and the weld-affected zone and facilitates a reasonable selection of welding consumables and welding conditions for multi-pass austenitic steel connections.

Keywords: Austenitic steel · Microstructure · Weld connections · Stresses · Chemical element distribution · Properties

JEL code: L610 · L950

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1 Introduction

Austenitic steel as a material of process pipe systems is found in most sectors of the economy: nuclear power engineering, metallurgy, food and chemical industry, agriculture, oil production, transport and processing, aircraft and shipbuilding, etc. (Boillot and Peultier 2014). Each industry develops its own regulations for the design, fabrication, operation, and disposal of man-made facilities. Welding is the key process in the construction and repair of process piping (Bakhtizin et al. 2016).

The structure and properties of the filler metal depend on the transfer of alloying elements to the filler metal, for this reason, minimizing the burn-off of alloying elements during welding is highly topical (Verma and Taiwade 2017). The analysis of the alloying element transfer from the electrode rod and coating into the weld metal and comparison of welding results with different electrodes using different power sources for the welding arc has drawn great scientific interest.

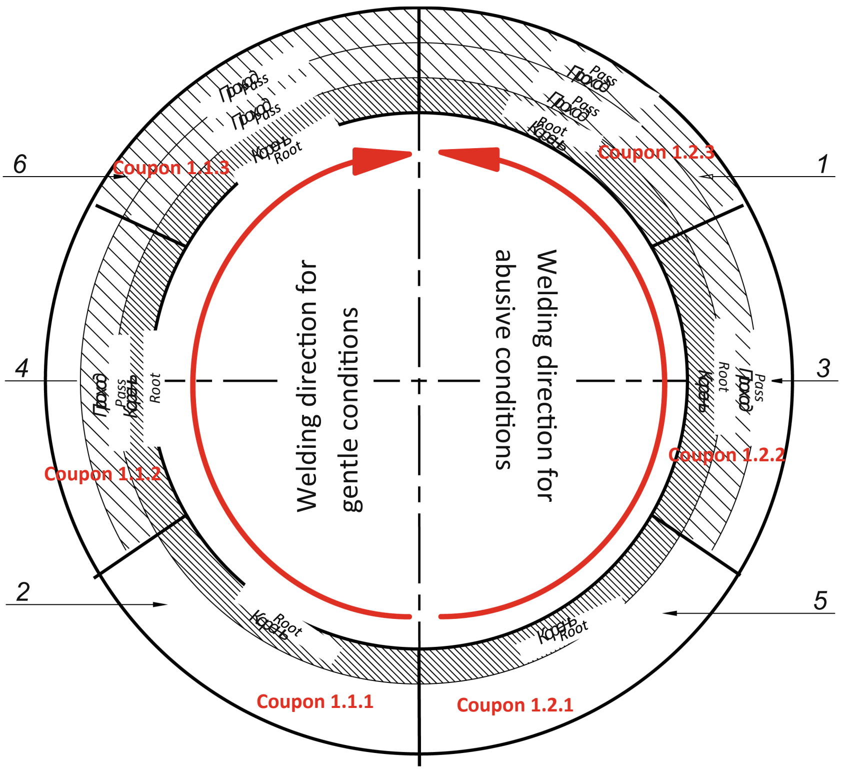
A change in background current and travel speed causes a simultaneous change in all region sizes (Wichan and Loeshpahn 2014). As the amperage increases, the transferred element percentage fluctuates with a change in the structure, which is obviously associated with an increase in the heat input of the arc (Taiwade et al. 2013; Vashishishtha et al. 2019).

Welding electrode formulation has been developed a long time ago and is designed for the use of welding transformers and rectifiers (Abson and Pargeter 1986). Inverters as AC/DC sources serve to change current pulse slope that consequently impacts the transfer of alloying elements from the welding electrode and the distribution of alloying elements in the weld, especially the multi-pass ones, and its resistance in a corrosive environment (Lu et al. 2005). This issue has not been sufficiently addressed.

2 Materials and Method

The metal structure in the welds made by manual arc welding with the TsL-11, TsT-15, OZL-8 covered electrodes in the 12Kh18N10T steel pipe spools (pipe workpieces) with a size of Ø159 × 6 × 100 mm is studied. The weld design is single-pass, double-pass, and triple-pass. Fixed welds were welded based on the S17 connection, GOST 16037-80, with direct current reverse polarity, unsupported, vertically uphill, in a continuous motion and a single direction, with the LORCH HandyTIG 180 AC/DC ControlPro welding inverter. The specified welding amperage corresponds to the minimum (gentle) and maximum (abusive, speed-up) values shown in the electrode data sheet for the relevant thickness. The perimeter of the weld was provisionally divided into 6 areas. The layout of the beads is shown in Fig. 1. When welding, the low thermal conductivity of the electrode metal results in an intense heating up of the rod and coating leading to the burn-off of alloying elements and coating degradation, therefore, one half of the electrode has been used up to produce the weld connection. After cooling, the remaining electrode was further used.

By doing so, 3 pipe spools were fabricated where the welds were made as follows: starting from the 6 o'clock position to the left (gentle conditions) and right (abusive conditions), the entire root pass was deposited, then from the 5 and 7 o'clock position



1 to 6: sector numbers

Fig. 1. Layout of beads and coupon identification for metallographic examination (sample for pipe spool 1). *Source*: Figure made by the authors

to the 12 o'clock position, the hot pass was deposited, and from the 10 and 3 o'clock position to the 12 o'clock position, the cap bead was deposited in the same welding conditions.

The microstructure of 18 cross-section coupons for the resulting welds is studied in the metallographic specimens with the following identification (refer to Table 1 and Fig. 1). The specimens were prepared with the Automet 250 (Buehler) honing machine. The structure of the weld metal and the weld-affected zone was analyzed using the Nikon MA200 metallographic microscope. Full-size weld microphotographs were combined from several microphotographs at 100x magnification with Photoshop CS6 with digital processing with ImagPro5 of the images at 400x magnification. The coupons were chemically etched in the following solution: glycerin: 4 parts, hydrochloric acid: 4 parts, nitric acid: 3 parts, and etching time was selected between 1 and 5 min.

The filler metal volume in each bead of the connection was measured using the microphotographs with the KOMPAS software by selecting specific beads within the image and digitally processing the data.

The Shimadzu HMV-2 microhardness tester with a load of 100 g and a scanning pitch of 0.5 mm was used for scanning measurement of the coupon microhardness. The INSTRON 3382 electromechanical tensile testing machine was used for static tensile testing. The tests were performed on the type XII coupons as per GOST 6996-66. The ferrite number was measured with the MF-51NC ferrite meter.

Changes in alloying element content in the multi-pass butt welds made by manual metal arc welding (MMA, Procedure 111) of the 8-mm 12Kh18N10T austenitic steel pipe with the TsL-11, TsT-15, and OZL-8 electrodes at different amperages were studied. Alloying element content (Cr, Ni, Si, Nb, etc.) was measured with the Carl Zeiss EVO LS 10 scanning electron microscope with Oxford Instruments X-Max 80 Detector (SDD) in the polished and etched coupons (metallographic specimens) of the connection cross section. The representative areas were used for this purpose: transitions between the weld metal and the base metal (for each bead) and transitions between the beads considering the overlap effect of the subsequent beads. Enclosed segments were measured (circles in Fig. 2), and the measurements (atomic percentage) in such area were averages for each point within the area.

Table 1. Coupon identification and welding conditions

Pipe spool number; electrode class	Condition description	Parameters	Coupon identification	Layer type
1, TsL-11	Gentle	Welding amperage: 70 A	1.1.1	R
			1.1.2	R+F
			1.1.3	R+F+C
	Abusive	Welding amperage: 90 A	1.2.1	R
			1.2.2	R+F
			1.2.3	R+F+C
2, TsT-15	Gentle	Welding amperage: 80 A	2.3.1	R
			2.3.2	R+F
			2.3.3	R+F+C
	Abusive	Welding amperage: 100 A	2.4.1	R
			2.4.2	R+F
			2.4.3	R+F+C
3, OZL-8	Gentle	Welding amperage: 50 A	3.5.1	R
			3.5.2	R+F
			3.5.3	R+F+C
	Abusive	Welding amperage: 70 A	3.6.1	R
			3.6.2	R+F
			3.6.3	R+F+C

Note: abbreviations for beads: R: root, F: fill, C: cap

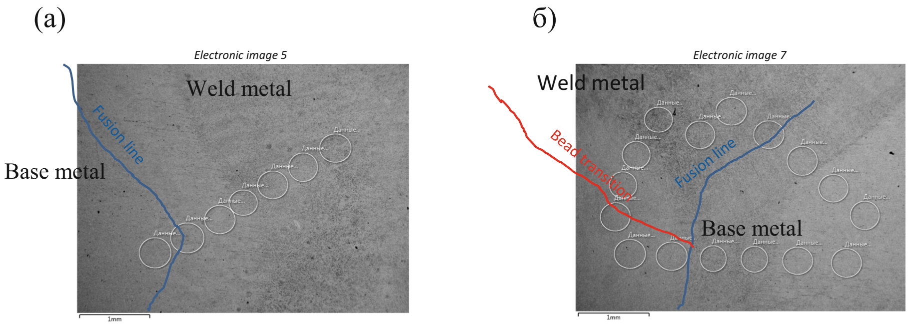


Fig. 2. Alloying element measuring areas. (a) single-pass weld, (b) double-pass weld. *Source*: The image was made with the Carl Zeiss EVO LS 10 scanning electron microscope with Oxford Instruments X-Max 80 Detector (SDD) and processed by the authors

As Fig. 2 shows, for a single-pass weld, measurements were performed in the spots aligned linearly from the base metal to the weld metal and crossing the fusion line. For the double-pass weld (Fig. 2b), the lines of the spots extend through both the bead overlap and the transition between each bead and the base metal. The measurements for triple-pass welds were performed similarly.

Elements such as Fe and C are ignored due to their high correlation and the impact of the cathode material that raises carbon. Based on the measurements, the alloying element distribution charts were plotted but without any quantitative parameter values. Accordingly, this article discusses a qualitative change in the alloying elements.

Corrosion testing of the welding coupons was performed in the Sea of Okhotsk between December 2018 and January 2020. Corrosion resistance was determined by weight loss through weighing with the ACCULAB ALC-110d4 balances.

3 Results

Based on the visual inspection results, all welding coupons were accepted.

The macrostructure of the resulting coupon cross section is shown in Table 2. Since the root bead of the fixed weld is welded uphill, the single-pass coupons (1.1.1, 1.2.1, 2.3.1, 2.4.1, 3.5.1, and 3.6.1) are characterized by an increase in the deposited bead volume up to the top of the groove. And vice versa, for the triple-pass coupons, the root bead has a minimum volume, and the groove is evenly filled with three beads with a good cap.

Scanning hardness testing (Table 3) shows the excess of weld metal hardness over that of the base metal in all the coupons. Hardness in the preceding bead decreases only slightly when the subsequent bead is deposited. Threshold microhardness is not observed in the coupons welded with the OZL-8 electrodes in the abusive conditions. Gentle welding conditions with the TsL-11 and TsT-15 electrodes ensure the minimum weld microhardness.

Ferrite number for the welding coupons is shown in Table 4.

As the table above shows, regardless of the welding conditions, the TsL-11 and TsT-15 electrodes cause high ferrite content in the weld metal averaging 1.0%. The TsT-15

Table 2. Coupon macrostructure

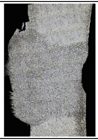
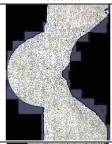
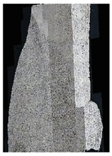
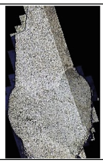
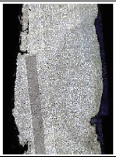
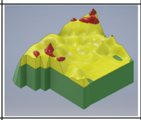
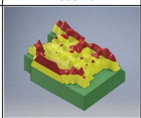
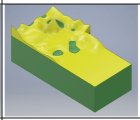
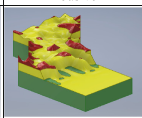
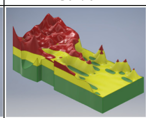
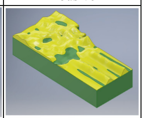
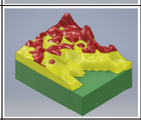
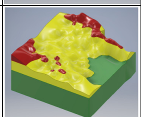
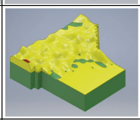
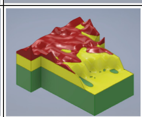
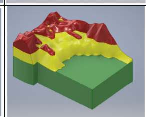
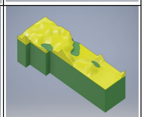
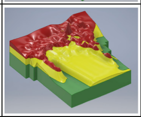
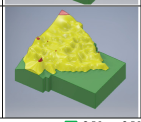
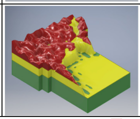
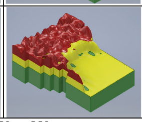
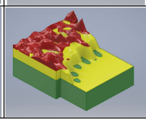
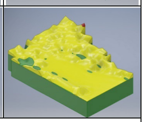
Pass	Electrode					
	TsL-11		TsT-15		OZL-8	
	Welding conditions					
	Gentle	Abusive	Gentle	Abusive	Gentle	Abusive
1st						
2nd						
3rd						

Table 3. Scanning hardness test results

Pass	Electrode					
	TsL-11		TsT-15		OZL-8	
	Welding conditions					
	Gentle	Abusive	Gentle	Abusive	Gentle	Abusive
1st						
2nd						
3rd						
Microhardness range:	■ 250 to 350	■ 350 to 450	■ 450 to 550			

electrode in the gentle conditions leads to a higher ferrite number. The OZL-8 electrode in the gentle conditions impacts the ferrite phase only slightly, while welding in the abusive conditions with this electrode leads to a ferrite number of 0.25%. At the same time, magnetism in the welds is experienced with an increase in ferrite number (Table 5).

Analysis results for changes in alloying elements in the single-pass, double-pass, and multi-pass welds versus the electrode class and welding conditions are summarized in the histogram (Fig. 3) where the upward pyramids represent an increase in element

Table 4. Ferrite number

Coupon	Electrode	Number of passes	Amperage, A	Ferrite number
1.1.1	TsL-11	1	70	0.8
1.1.2		2		1.41
1.1.3		3		1.14
1.2.1		1	90	1.28
1.2.2		2		1.13
1.2.3		3		1.77
2.3.1	TsT-15	1	80	0.69
2.3.2		2		1.62
2.3.3		3		1.82
2.4.1		1	100	0.27
2.4.2		2		1.42
2.4.3		3		1.44
3.5.1	OZL-8	1	50	–
3.5.2		2		–
3.5.3		3		–
3.6.1		1	70	0.23
3.6.2		2		0.27
3.6.3		3		0.24

Table 5. Stress measurements

Coupon	Stress, MPa	
	Weld	Base metal
1.1	−120.4	–
1.2	68.36	−145.2
2.3	149.46	0.59
2.4	−271.4	–
3.5	−79.54	–
3.6	−70.85	−148.72

content and the inverted pyramids represent a decrease in element content and a rectangle on the element axis means a stable content and no rectangle means that the element was not detected.

In static tensile testing, all the coupons failed at the base metal except for coupon 2.3.3 that failed in the weld-affected zone. When comparing ultimate strength and yield

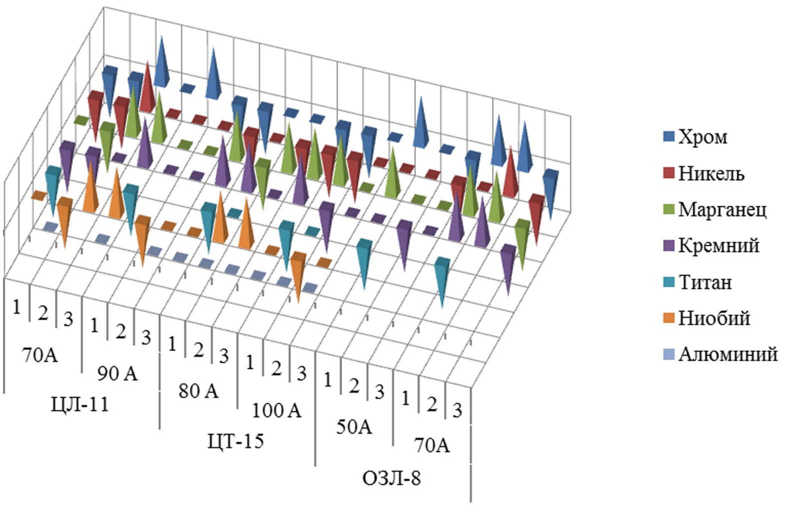


Fig. 3. Alloying element change histogram for single-pass, double-pass, and triple-pass welds made with TsL-11, TsT-15, and OZL-8 electrodes in gentle and abusive welding conditions. *Source*: Figure made by the authors.

strength with GOST 9941-81 for the 12Kh18N10T steel, we see that all the coupons subjected to static tensile tests have values exceeding the standard values except for coupon 1.2.3 with an ultimate strength meeting GOST but at the minimum limit allowed (Fig. 4).

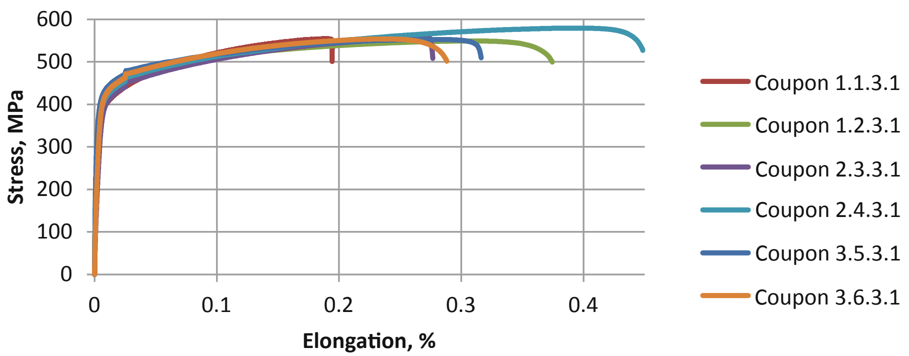


Fig. 4. General tensile test diagram for coupons. *Source*: Figure made by the authors.

Only coupon 1.2.3, 2.4.3, and 3.5.3 have an allowable elongation.

The seawater corrosion test's results are shown in Table 6.

As Table 6 shows, regardless of the electrode class, the welding conditions and the weight loss percentage correlate. The coupons welded in the gentle conditions (lower welding amperage) have the highest percentage (0.16 to 0.17), while the speed-up conditions significantly reduce weight loss (0.02 to 0.08).

Table 6. Weight measurements for coupons subjected to corrosion tests

Coupon number	Weighing results, g		Difference in weight, g	Loss percentage
	Before	After		
11	43.3158	43.2461	−0.0697	0.16
12	37.3087	37.294	−0.0147	0.04
23	43.7992	43.7227	−0.0765	0.17
24	39.56655	39.5359	−0.03065	0.08
35	45.0758	44.997	−0.0788	0.17
36	34.7873	34.7812	−0.0061	0.02

4 Conclusion

Manual arc welding with the TsL-11 electrodes of the single-pass and double-pass welds in the gentle conditions causes a reduction in all alloying elements, and the speed-up conditions are characterized by their stable content both for the single-pass and multi-pass design. That is, these electrodes can be recommended as the filling electrodes in the gentle conditions or multi-pass welds in the speed-up conditions.

The TsT-15 electrodes for single-pass welds reduce the main alloying element content (chromium and nickel). The double-pass and triple-pass beads in the gentle conditions mainly provide for the stabilization of all alloying elements. Abusive conditions for multi-pass welds show the best performance. These electrodes are not suitable for single-pass welding of light-gauge components and can be recommended for multi-pass welds in the gentle conditions.

The OZL-8 electrodes can be used for welding the single-pass welds in a wide range of conditions, well stabilize the element content in the double-pass welds, and show a decrease in the element content in the multi-pass beads regardless of the conditions. Therefore, these electrodes should be recommended for welding light gauges or the root and cap beads when welding heavy gauges.

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Combined Control in the System with Modal PI-Regulator

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Abstract. Purpose: The purpose of the work is to develop approaches to improving the accuracy indicators of the functioning of control systems for electric drives of technological equipment when performing trajectory movements of the working body.

Design/methodology/approach: The methodology of calculation, settings and research is based on state space methods, in particular, on the principles of modal control, which significantly expands the tool base for the formation of electric drive systems with specified target functions.

Findings: In this work, the methodological foundations of multifunctionality of control systems with modal regulators are formed by expanding the system with integration and forcing blocks that respond to various external challenges and requests to the systems. As a result of the combination of the principles of modal control, the principles of astatism and combined control, a model of the electric drive system has been developed that has the required dynamic characteristics, as well as high accuracy in steady-state and dynamic modes, both in terms of reference and disturbing influences.

Originality/value: The paper proposes a possible option for expanding the capabilities of modal control methods in the development of mechatronic modules, electrical complexes and systems of complex production equipment, taking into account the real conditions of their functioning in the technological process.

The area under consideration is included in the list of critical technologies of the Russian Federation - “Basic technologies of power electrical engineering”, and is also a priority in the development of science, technology and technic - “Energy efficiency, energy saving, nuclear energy”.

Keywords: Combined control · Modal control · Electric drive system · Dynamic characteristics · Accuracy · State regulator · Astatism

JEL Code: O31 · O33 · O39

1 Introduction

The development of robotics as one of the main elements of automation and improvement of production processes is largely determined by the efficiency of functioning of such elements of robotic systems as mechatronic modules. Their speed and accuracy under

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conditions of changing parameters and loads during the movement of manipulation mechanisms largely form the indicators of the effectiveness of robotic systems. Under the conditions of the action of uncontrolled loads of various configurations (up to parabolic) on individual mechatronic modules, including positioners, problems arise in maintaining the technological accuracy of both mechanical processing and the arc welding process, which is reflected in the works (Efimov et al. 2019; Gorkavyy et al. 2018).

Most of the design algorithms for regulators of electric drive systems of mechatronic modules, including service and instrumental ones, are based on the formation of separate loops with their subsequent step-by-step adjustment within the framework of subordinate regulation algorithms according to the works (Basharin et al. 1982; Petrovas and Rinkeviciene 2012). The presence of uncontrolled loads that the mechatronic modules overcome cannot always be compensated for, which significantly reduces the quality indicators of the functioning of mechatronic systems, and, therefore, negatively affects the implementation of technological processes by robotic systems (Berdonosov et al. 2018; Berdonosov et al. 2019).

Using modern tools for the development of regulators within the framework of the principles of modal control, indicated in the works (Qakernaak and Sivan 1977; Krasovsky Krasovsky 1987), the authors of this work managed to form the electric drive systems of mechatronic modules so as to minimize the influence of uncontrolled loads on their functioning, and, consequently, and on the implementation of algorithms for technological processes, which is reflected in the article (Melnichenko et al. 2019).

Attempts to increase the response speed for the reference action and, consequently, the accuracy for the reference input during trajectory movements, increasing the dynamics of the system expanded due to the block of integrators, lead to excessively large coefficients of the modal PI-regulator. In this article, the integration of the principles of combined and modal control is considered while maintaining a high order of astatism in the system, which, ultimately, will lead to the development of principles for constructing a multifunctional system of an electric drive of a mechatronic module of high accuracy, both in terms of reference and perturbing influences.

2 Methodology

Let a one-dimensional object described by the equations of state be given:

$$\begin{aligned} \dot{x}_0(t) &= A_0 x_0(t) + B_{u0} x_{in0}(t) + B_{m0} m_c(t); \\ y_0(t) &= C_0 x_0(t), \end{aligned} \tag{1}$$

where $x_0(t)$ – state vector of dimension n; A_0 – object matrix of dimension $n \times n$; B_{u0} – input matrix of dimension $n \times 1$; $x_{in0}(t)$ – object input vector of dimension 1; B_{m0} – perturbation matrix of dimension $n \times 1$; $m_c(t)$ – perturbation vector of dimension 1; $y_0(t)$ – output vector of dimension 1; C_0 – output matrix of dimension $1 \times n$.

It is required, in accordance with the principles of modal control, to synthesize an $n + m$ order system with m order astatism (with a modal PI-regulator) so that the expansion of the object due to integrators does not affect the desired response of the n order system with a modal regulator to the setting action. Moreover, it is required to improve this response (to increase the dynamic accuracy) due to direct connections in the reference action, and in fact, to implement in a system with a modal PI-regulator with combined control.

In fact, it is necessary to synthesize an $n + m$ order control system for an n-th order object (1), described by equations:

$$\begin{gathered}\dot{x}(t) = Ax(t) + B_u x_{in.\mathrm{c}}(t) + B_m m_c(t); \\ y(t) = Cx(t),\end{gathered} \tag{2}$$

and having the listed properties.

In the work Melnichenko et al. (2019), the corresponding reasoning was carried out and a block of integrators was developed that meets the requirements formulated above. This block contains m integrators, which will form the dynamic part of the regulator, thereby expanding the system to the dimension $n + m$. Integrator block transfer function

$$\frac{x_{out.r}(p)}{x_{in.}(p)} = \frac{p^m + k_{rm}p^{m-1} + \ldots k_{r2}p + k_{r1}}{p^m} \tag{3}$$

allows by choosing the coefficients of the numerator polynomial $k_{r1}, k_{r2}, \ldots k_{rm}$ to obtain the desired m zeros, compensating for the additional m poles of the transfer function of the synthesized system, thereby preserving the desired response of the n-th order system to the reference action feedback rates $\left[f_{n+1}, f_{n+2} \ldots f_{n+m}\right]$ «include» the block of integrators in the overall dynamics of the designed system based on the principles of modal control, and a single feedback on the output variable forms the system error.

Combined control presupposes the formation of direct links for the reference action, which actually force the passage of the reference signal to the internal structures of the object. In this case, direct connections affect the integrators of the regulator; thereby they can force its work, which in the final case will improve the work of the entire system in terms of the reference action. Figure 1 shows the block diagram of the integrator block together with the combined control structure.

The transfer function of the integrator block together with the combined control structure, for example, for $m = 3$, will have the form:

$$\frac{X_{out.r}(p)}{X_{in.}(p)} = \frac{p^3 + (k_{r1}d_1 + k_{r2}d_2 + k_{r3}(1 + d_3))p^2 + (k_{r1}d_2 + k_{r2}(1 + d_3))p + k_{r1}(1 + d_3)}{p^3}. \tag{4}$$

The polynomial of the numerator of the transfer function of the integrator block with the combined control structure includes the coefficients depending simultaneously on $k_{r1}, k_{r2}, \ldots k_{rm}$ and on $d_1, d_2, \ldots d_m$. The role of coefficients k_r and d of the polynomial is different. Coefficients $k_{r1}, k_{r2}, \ldots k_{rm}$ affect the dynamics of the system (they are in a closed loop of the system), and the coefficients $d_1, d_2, \ldots d_m$, combined by the matrix $D = \left[\, d_1 \; d_2 \; \ldots \; d_m \,\right]^T$, affect only the response to the setting action, that is for dynamic accuracy when working out trajectory movements. The inclusion of the composed block in the system being developed forms a combined control in a system with a modal PI-regulator.

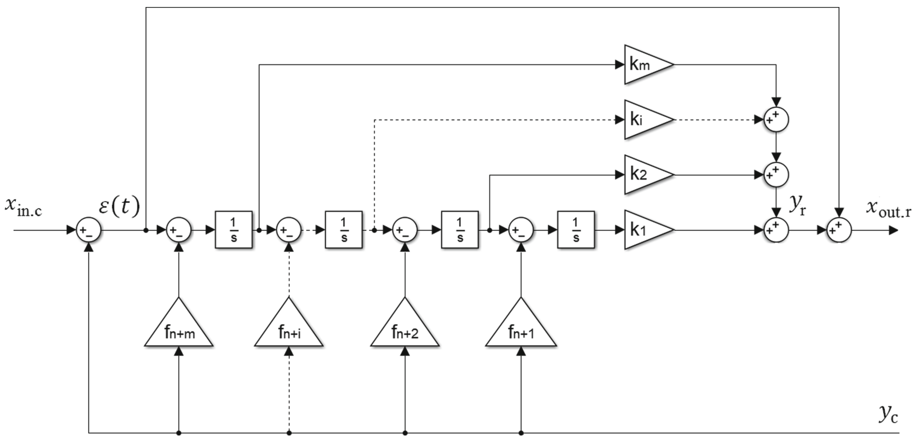

Fig. 1. Block diagram of the block of integrators with a combined control structure. *Source*: developed and compiled by the authors

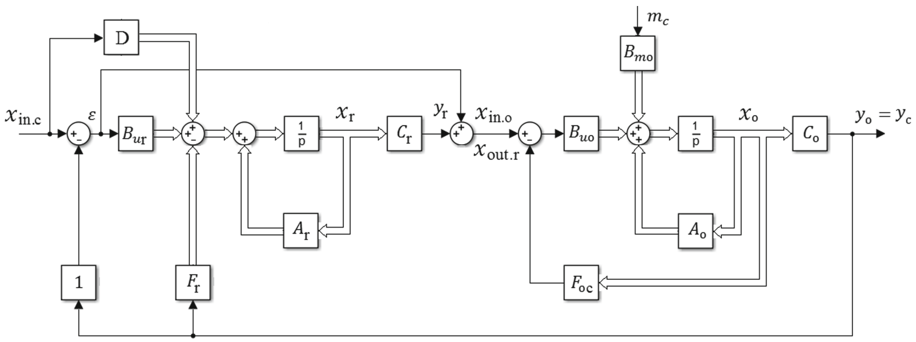

Fig. 2. Vector-matrix block diagram of the synthesized system. *Source*: developed and compiled by the authors.

The above reasoning and their analysis make it possible to form a mathematical model and, in particular, a vector-matrix structural diagram of the synthesized system (Fig. 2).

B_{ur} – input matrix of dynamic part of regulator of dimension $m \times 1$;
$x_r(t)$ – the state vector of the dynamic part of regulator of dimension m;
C_r – output matrix of the dynamic part of regulator of dimension $1 \times m$;
$y_r(t)$ – output variable of the dynamic part of regulator;
$x_{out.r}(t)$ – output variable of regulator;
A_r – state matrix of dynamic part of regulator of dimension $m \times m$;
D – matrix of coefficients of direct connections of dimension $m \times 1$ (combined control matrix);
F_r – matrix-column of coefficients fed from the system's output coordinate $y_c(t) = y_0(t)$ to the integrators of dynamic part of regulator;

F_{oc}– matrix-row of feedback coefficients for the state variables of the object of the synthesized system (calculated, as shown below, when synthesizing an $n + m$-th order system); scalar signals are indicated by lines, and vectors are indicated by stripes.

In accordance with the vector-matrix Eqs. (2) and the structural diagram (Fig. 2), the vectors and matrices of the mathematical description of the synthesized system have a block form and the corresponding dimension:

$$
\begin{gathered}
x_c^{\mathrm{T}}(t) = \left[x_1(t), x_2(t) \ldots x_n(t) \mid x_{n+1}(t) \ldots x_{n+m}(t)\right]; \\
A_c = \begin{bmatrix} A_0 - B_{u0}(F + C_0) & | & B_{u0}C_r \\ ----------- & | & --- \\ -(F_r + B_u) & | & A_r \end{bmatrix} - (n+m) \times (n+m); \\
B_{uc} = \begin{bmatrix} B_{u0} \\ -- \\ B_{ur} \end{bmatrix} - (n+m) \times 1; \qquad B_{mc} = \begin{bmatrix} B_{mc} \\ -- \\ 0 \end{bmatrix} - (n+m) \times 1; \\
C_c = \left[\, C_0 \; 0 \,\right] - 1 \times (n+m); \qquad C_r = [k_{r1}, k_{r2} \ldots k_{rm}] - 1 \times \mathrm{m}; \\
F_{oc} = \left[f_1, f_2 \ldots f_n\right] - 1 \times \mathrm{n}; \qquad F_r^{\mathrm{T}} = \left[f_{n+1} \ldots f_{n+m}\right] - 1 \times \mathrm{m}; \\
B_{ur}^{\mathrm{T}} = [d_1, d_2 \ldots d_m + 1] - 1 \times \mathrm{m}; \qquad y_c(t) = y_0(t); \\
[A_0 - B_{u0}(F + C_0)] - \mathrm{n} \times \mathrm{n}; \qquad -(F_r + B_{u0})C_0 - \mathrm{m} \times \mathrm{n}; \\
B_{u0}C_r - \mathrm{n} \times \mathrm{m}; \\
A_r = \begin{bmatrix} 0\;1\;0 & \cdot & 0 \\ 0\;0\;1 & \cdot & 0 \\ \cdots & \cdot & \cdot \\ 0\;0\;0 & \cdot & 1 \\ 0\;0\;0 & \cdot & 0 \end{bmatrix} - \mathrm{m} \times \mathrm{m}.
\end{gathered} \tag{5}
$$

Using the vector-matrix description (2), taking into account the dimension and values of matrices and vectors (5), a detailed structural diagram of the synthesized system with a modal PI-regulator and a combined control structure is drawn up. There is some multivariance when constructing a structural diagram using a vector-matrix description, and in fact, using differential equations. To exclude it, it is necessary to take into account that the error $\varepsilon(t) = x_{in}(t) = y_c(t)$ is fed via a direct channel directly to the input of the object (Fig. 2).

Let us calculate the coefficients of the modal PI-regulator without taking into account the structure of the combined control.

Let for a one-dimensional object of the n-th order (1) a detailed scheme is obtained and all vectors and matrices are defined in general form, taking into account the m-fold integration of the error $\varepsilon(t)$. In numerical form, uncertainties remain: the matrix is a row of coefficients $F_0 = \left[f_1, f_2 \ldots f_n\right]$, matrix-column $F = \left[f_{n+1} \ldots f_{n+m}\right]$ and coefficients of direct connections in the dynamic part of the regulator, united by the matrix $C_r = [k_{r1}, k_{r2} \ldots k_{rm}]$. A detailed method for calculating these matrices is presented in Melnichenko et al. (2019). It should be borne in mind that the procedure for calculating the coefficients is carried out without taking into account the combined control $D^T = \left[\,0\;0\;0\,\right]$.

3 Results

According to the developed method, we synthesize a system with a modal PI controller without taking into account the structure of combined control.

Let an object of the fourth order be given ($n = 4$) – electric drive thyristor converter - DC motor (Fig. 3). In accordance with Eqs. (1), its vectors and matrices have the form:

$$\left.\begin{aligned}
&x_o(t) = \begin{bmatrix} \varphi(t) \\ \omega(t) \\ i(t) \\ e(t) \end{bmatrix} = \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix}; \qquad A_o = \begin{bmatrix} 0 & k_p & 0 & 0 \\ 0 & 0 & \frac{C}{J_\Sigma} & 0 \\ 0 & \frac{-C}{R_я T_я} & \frac{-1}{T_я} & \frac{1}{R_я T_я} \\ 0 & 0 & 0 & \frac{-1}{T_{ум}} \end{bmatrix}; \\
&B_{uo} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{k_{ум}}{T_{ум}} \end{bmatrix}; \qquad B_{mo} = \begin{bmatrix} 0 \\ -\frac{1}{J_\Sigma} \\ 0 \\ 0 \end{bmatrix}; \qquad C_o = [1 \quad 0 \quad 0 \quad 0],
\end{aligned}\right\} \tag{6}$$

where $C = 1.13 \cdot \mathrm{m/A}$; ; ; $k = 100$; $T = 0.00125$ s; $J_\Sigma = 0.001\,\mathrm{kg} \cdot \mathrm{m}^2$; $k = 0.013$.

The electric drive can be acted upon by loads of various configurations determined by the technological process - step, linearly increasing, parabolic. It is required to synthesize an electric drive control system so that the desired response to the master (input) action is provided (for example, in accordance with the fourth-order binomial standard form at $\omega_0 = 100$) and steady-state errors from the action of disturbances of these configurations are excluded. The elimination of the steady-state error from the action of the parabolic disturbance leads to triple integration in the modal PI-regulator ($m = 3$). In accordance with the mathematical description (5), we determine the vectors and matrices of the regulator:

$$x_r(t) = \begin{bmatrix} u_{r1}(t) \\ u_{r2}(t) \\ u_{r3}(t) \end{bmatrix}; A_r = \begin{bmatrix} 0\,1\,0 \\ 0\,0\,1 \\ 0\,0\,0 \end{bmatrix}; B_{ur} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix};$$

$$B_m = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}; F_r = \begin{bmatrix} f_4 \\ f_5 \\ f_6 \end{bmatrix}; C_r = \left[k_{r1}\ k_{r2}\ k_{r3}\right]; F = \left[f_1\, f_2\, f_3\right]. \tag{7}$$

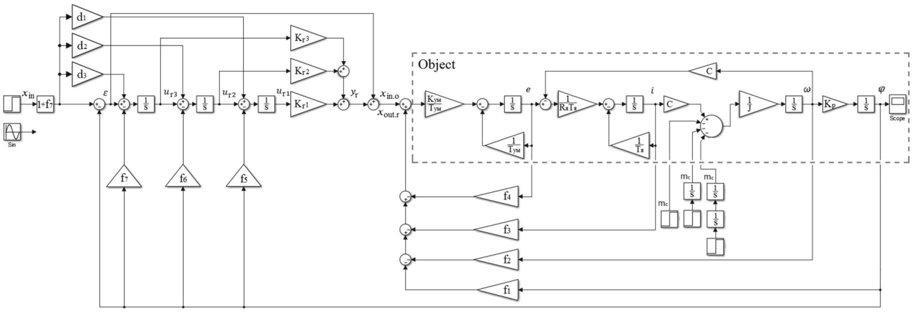

Fig. 3. Structured model of a synthesized electric drive system. *Source*: developed and compiled by the authors.

The vectors and matrices of system (2) in accordance with their block representation (5) have the form:

$$
\left.
\begin{array}{l}
x_{c}(t)=\begin{bmatrix}\varphi(t)\\ \omega(t)\\ I(t)\\ e(t)\\ \hline u_{r1}(t)\\ u_{r2}(t)\\ u_{r3}(t)\end{bmatrix}=\begin{bmatrix}x_1(t)\\ x_2(t)\\ x_3(t)\\ x_4(t)\\ \hline x_5(t)\\ x_6(t)\\ x_7(t)\end{bmatrix};\\[2ex]
A_{c}=\left[\begin{array}{cccc|ccc}
0 & k_{p} & 0 & 0 & 0 & 0 & 0\\
0 & 0 & \frac{C}{J_{\Sigma}} & 0 & 0 & 0 & 0\\
0 & -\frac{C}{R_{я}T_{я}} & -\frac{1}{T_{я}} & \frac{1}{R_{я}T_{я}} & 0 & 0 & 0\\
\frac{-(f_1+1)k_{ум}}{T_{ум}} & \frac{-f_2k_{ум}}{T_{ум}} & \frac{-f_3k_{ум}}{T_{ум}} & \frac{-1-f_4k_{ум}}{T_{ум}} & \frac{k_{p1}k_{ум}}{T_{ум}} & \frac{k_{p2}k_{ум}}{T_{ум}} & \frac{k_{p3}k_{ум}}{T_{ум}}\\
\hline
-f_5 & 0 & 0 & 0 & 0 & 1 & 0\\
-f_6 & 0 & 0 & 0 & 0 & 0 & 1\\
-f_7-1 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}\right];\\[2ex]
B_{uc}^{\mathrm{T}}=\left[\begin{array}{cccc|ccc}0 & 0 & 0 & \frac{k_{ум}}{T_{ум}} & 0 & 0 & 1\end{array}\right];\ B_{mc}^{\mathrm{T}}=\left[\begin{array}{cccc|ccc}0 & -\frac{1}{J_{\Sigma}} & 0 & 0 & 0 & 0 & 0\end{array}\right];\\[2ex]
C_{c}=\left[\begin{array}{cccc|ccc}1 & 0 & 0 & 0 & 0 & 0 & 0\end{array}\right].
\end{array}
\right\}
\quad (8)
$$

Suppose we choose the values of the three poles, due to the expansion of the system, in accordance with the binomial standard form of the third order with $\omega_{0r} = 100$. Then, to compensate them with zeros of the transfer function of the dynamic part of the regulator

(3), we calculate the coefficients of direct connections based on the equality:

$$p^3 + k_{r3}p^2 + k_{r2}p + k_{r1} = (p + \omega_{0r})^3 = p^3 + 3\omega_{0r}p^2 + 3\omega_{0r}^2 p + \omega_{0r}^3.$$

Thus, the matrix $C_r = \begin{bmatrix} k_{r1} \; k_{r2} \; k_{r3} \end{bmatrix} = \begin{bmatrix} 10^6 \; 3 \cdot 10^4 \; 300 \end{bmatrix}$ is defined.

In accordance with the chosen ω_0 and ω_{0r} for the synthesized electric drive system, the expression:

$$\det(pI - A) = (p + \omega_{0r})^3 \cdot (p + \omega_0)^4.$$

As a result of its solution, we determine the coefficients of feedbacks of the modal PI-regulator, grouped into matrices:

$$F = \begin{bmatrix} f_1 \; f_2 \; f_3 \; f_4 \end{bmatrix} = \begin{bmatrix} 1090.814 \; 0.136 \; 0.818 \; -0.00187 \end{bmatrix};$$

$$F_r = \begin{bmatrix} f_5 \; f_6 \; f_7 \end{bmatrix} = \begin{bmatrix} 0.0187 \; 1.248 \; 30.195 \end{bmatrix}.$$

We determine the transfer functions for the setting and disturbing influences:

$$\frac{y_{\text{c}}(p)}{x_{in.\text{c}}(p)} = C_{\text{c}}[pI - A_{\text{c}}]^{-1} B_{uc} = \frac{\frac{ck_{\text{ум}}}{R_{\text{я}}T_{\text{я}}T_{\text{ум}}J_{\Sigma}}(p^3 + k_{r3}p^2 + k_{r2}p + k_{r1})}{(p+\omega_0)^4 \cdot (p+\omega_{0r})^3} = \frac{\frac{ck_{\text{p}}k_{\text{ум}}}{R_{\text{я}}T_{\text{я}}T_{\text{ум}}J_{\Sigma}}}{(p+\omega_0)^4}; \tag{9}$$

$$\frac{y_{\text{c}}(p)}{m_c(p)} = C_{\text{c}}[pI - A_{\text{c}}]^{-1} B_{mc} = \frac{\frac{p^3 k_{\text{p}}}{R_{\text{я}}T_{\text{я}}T_{\text{ум}}J_{\Sigma}}(p^2 R_{\text{я}}T_{\text{я}}T_{\text{ум}} + pf_4 R_{\text{я}}T_{\text{я}}T_{\text{ум}} + pR_{\text{я}}T_{\text{я}} + pR_{\text{я}}T_{\text{ум}} + f_4 k_{\text{ум}} R_{\text{я}} + f_3 k_{\text{p}} k_{\text{ум}} + R_{\text{я}})}{(p+\omega_0)^4 (p+\omega_{0\text{p}})^3}. \tag{10}$$

As can be seen from expressions (9, 10), the system has third-order astatism with respect to the disturbance, and the response to the control action will correspond to the response of the fourth-order system with a modal P-regulator tuned to the binomial standard form.

The structured model of the synthesized system of the seventh order (Fig. 3) is compiled in accordance with the generalized structural diagram (Fig. 2), vectors and matrices (6), (7), (8). At the input of the system, a proportional link is added with a coefficient $\frac{1}{1+f_7}$ with the aim of forming a unit transmission coefficient of the system for the reference action. Figure 4 shows the response of the system to a master step signal with subsequent disturbances in the following order: step (1), linearly increasing (2), parabolic (3) (Fig. 5).

The response of the system to the reference action fully corresponds to the tuning of the system with a modal P-regulator to the binomial standard form of the third order with $\omega_0 = 100$, as follows from the transfer function (9). Responses to disturbing influences meet the stated requirements for eliminating steady-state errors.

The combined control in the structure of the modal PI-regulator allows changing the transient response towards increasing the speed (reducing the dynamic error in the reference action) without violating the tuning of the system dynamics to a given standard form, which is reflected in Vostrikov (2010). In the above example, all the coefficients of the modal PI-regulator are calculated, namely, the matrices C_r, F_{oc}, F_r.

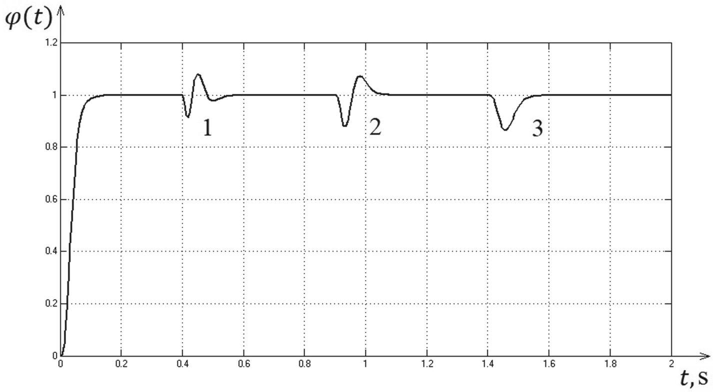

Fig. 4. The response of the system to the master and perturbing impact at $\omega_0 = 100$ and $\omega_{0p} = 100$. *Source*: developed and compiled by the authors

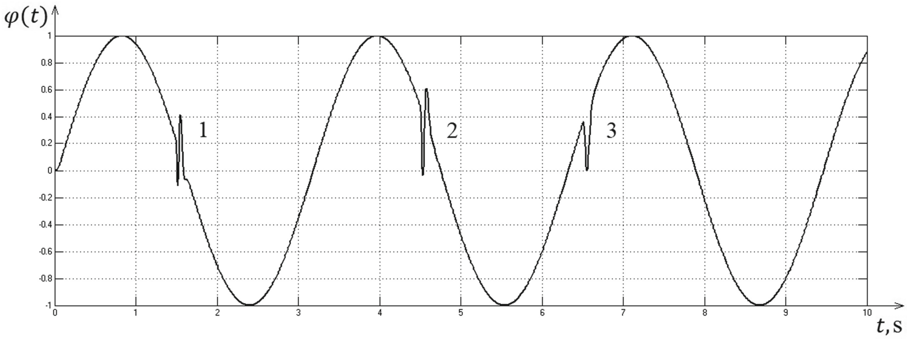

Fig. 5. The response of the system to disturbing influences when processing a si-nusoidal input signal with a frequency of $\omega = 2$ rad/s. *Source*: developed and compiled by the authors.

Let us introduce into the designed system the coefficients of the combined control structure united by the matrix $D = \begin{bmatrix} d_1 & d_2 & d_3 \end{bmatrix}$ (Figs. 2, 3). In this case, the polynomial of the numerator of the transfer function of the integrator block will correspond to expression (4), and the transfer function of system (9) is transformed to the form:

$$\frac{y_{\text{c}}(p)}{x_{in.\text{c}}(p)} = C_{\text{c}}[pI - A_{\text{c}}]^{-1}B_{u\text{c}} =$$

$$\frac{\frac{ck_{\text{ум}}}{R_{\text{я}}T_{\text{я}}T_{\text{ум}}J_{\Sigma}}\Big(p^3 + \big(k_{\text{p}1}d_1 + k_{\text{p}2}d_2 + k_{\text{p}3}(1+d_3)\big)p^2 + \big(k_{\text{p}1}d_2 + k_{\text{p}2}(1+d_3)\big)p + k_{\text{p}1}(1+d_3)\Big)}{(p+\omega_0)^4 \cdot \left(p+\omega_{0\text{p}}\right)^3} \tag{11}$$

by changing the input matrix of the system $B_u^{\text{T}} = \left[\begin{array}{cccc|cccc} 0 & 0 & 0 & \frac{k}{T} & d_1 & d_2 & d_3 + 1 \end{array}\right]$ in expressions (8). Consequently, the setting of the zeros of the transfer function (11) can be changed, thereby deforming the transient process in the system according to the reference action in the required direction. Indeed, if the polynomial of the numerator (11) is tuned to the binomial standard form, as before, but with a different value of ω_{0p}, then a different transient process (with high speed) can be obtained without changing the dynamics of the system (the characteristic equation remains the same). Suppose, if $\omega_0 = 100$, and $\omega_{0p} = 80$, then the system performance increases, as shown in the graph (Fig. 6), and the dynamic error during harmonic signal processing decreases (Fig. 7).

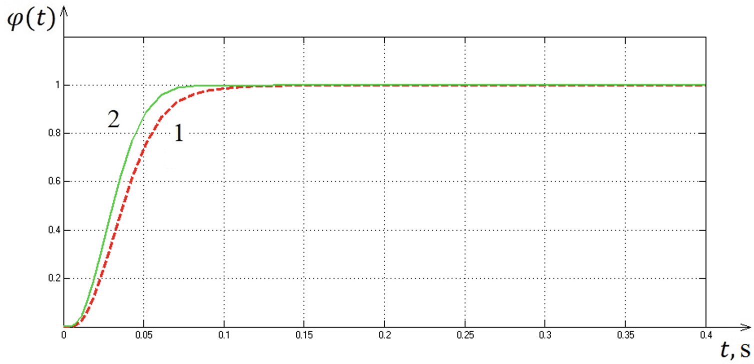

Fig. 6. Reactions to the setting action of systems: 1 – without structure of combined control, 2 - with the structure of combined control. *Source*: developed and compiled by the authors.

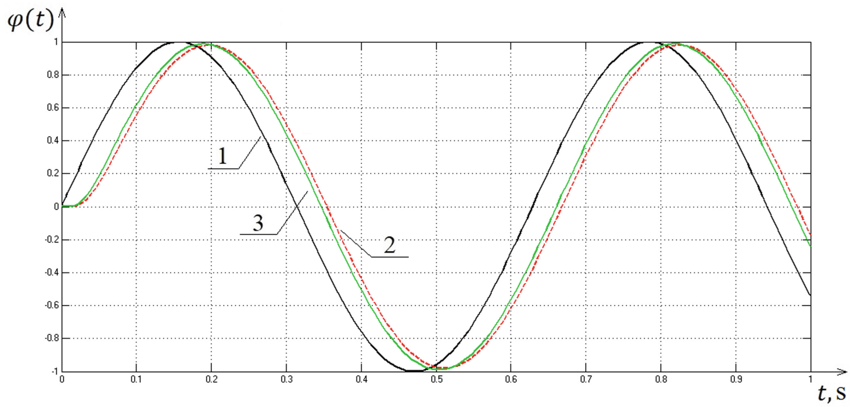

Fig. 7. Reactions to the setting sinusoidal action: 1 - input sinusoidal signal with a frequency of $\omega = 10$ rad/s; 2 - system without a combined control structure; 3 - system with a combined control structure. *Source*: developed and compiled by the authors.

The coefficients of the matrix D are determined from the equality:

$$p^3 + (k_{r1}d_1 + k_{r2}d_2 + k_{r3}(1 + d_3))p^2 + (k_{r1}d_2 + k_{r2}(1 + d_3))p + k_{r1}(1 + d_3) = p^3 + 3\omega_{0r}p^2 + 3\omega_{0r}^2 p + \omega_{0r}^3 \tag{15}$$

As a result of solving the system of equations

$$\begin{cases} k_{r1}(1+d_3) = \omega_{0r}^3; \\ k_{r1}d_2 + k_{r2}(1+d_3) = 3\omega_{0r}^2; \\ k_{r1}d_1 + k_{r2}d_2 + k_{r3}(1+d_3) = 3\omega_{0r}. \end{cases}$$

we define the coefficients d_1, d_2, d_3:

$$D^T = \left[-0.0000288\ 0.00384\ -0.488 \right].$$

Coefficients k_{r1}, k_{r2}, k_{r3} are defined when setting up system dynamics. The paper considers only one of the many options for setting up the combined control structure. Other settings make it possible to form other, including better, responses to control actions, depending on the requirements of the technological process.

4 Conclusion

Thus, the paper proposes one of the possible practical options for expanding the applicability of modal control methods in the development of mechatronic modules, electrical complexes and systems of complex technological equipment, taking into account the real conditions of their functioning.

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Research Methodology Based on the Idea of the Limiting Transition of Damping Properties of Structures Vibrating in the "Air" Medium Using a Laser Vibrometer

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Abstract. Purpose: This work is devoted to experimental studies of a cantilever beam, the development of a technique for measuring vibrations in a hydroelastic medium based on measurements in an "air" medium and the results of a comparative analysis of the amplitude-frequency characteristics of a cantilever obtained in an "air" medium.

Design/Methodology/Approach: The experimental installation was designed, developed and manufactured on the basis of the Far Eastern experimental basin of KnASU. It is designed to determine the parameters of free hydroelastic vibrations of a mechanical system with a point mass at the free end, it allows you to determine the amplitude-frequency characteristics. The work uses four models with different sail areas. To take readings in the experiments, we used the Polytec vibrometer software (Polytec High Speed Laser Vibrometer HSV2001). Experimental data processing and graphing were carried out using the Microsoft Excel program.

Findings: As a result of the experiments carried out, an assessment was made of the error of the obtained experimental data between the direct and mediated determination of the vibration parameters of the structure. The graphs for estimating periods with and without a flag have been obtained.

Originality/Value: The technique is original. Its originality lies in the use of a new idea of the passage to the limit and in performing experiments based on a vibrometer (Polytec High Speed Laser Vibrometer HSV2001). The results obtained on the basis of experimental studies are also original. The technique was created for practical use and allows one to determine the damping characteristics of systems vibrating in various liquids and consisting of various materials.

Keywords: Vibrometer · Experimental setup · Hydroelastic vibrations · Am-amplitude-frequency characteristics · Mechanical systems

JELCode: C02

1 Introduction

As the size and speed of the ship increases, the vibration of its sides increases. This becomes a big problem that needs to be solved in the design and construction of ships.

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https://doi.org/10.1007/978-3-030-69421-0_55

Excessive vibration of the ship should be avoided for the sake of passenger comfort and crew capacity (Iwer et al. 2001). In addition to undesirable effects on humans, excessive ship vibration can lead to fatigue failure of local structural elements or malfunction of machinery and equipment (American Bureau of Shipping 2006).

The experimental setup was developed on the basis of the far Eastern experimental pool of KnASU and is designed to determine the parameters of free hydroelastic vibrations of a mechanical system with a current mass at the free end. Figure 1 schematically shows an experimental setup.

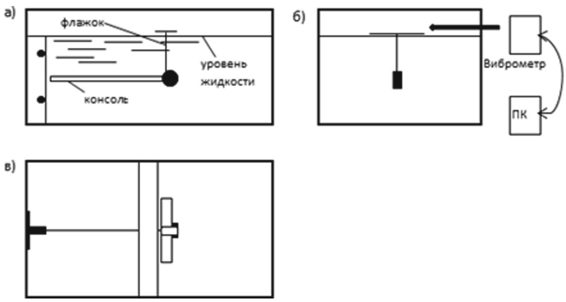


Fig. 1. Experimental setup diagram: (a) – side view; (б) – front view; (в) – top view *Source*: developed and compiled by the authors

Brief description of the installation: the left end of the beam is rigidly pinched, the right end is free and has a concentrated mass in the form of a load. The beam makes oscillatory movements in the direction of the y-axis.

Figure 2 shows a 3D view of the experimental setup.

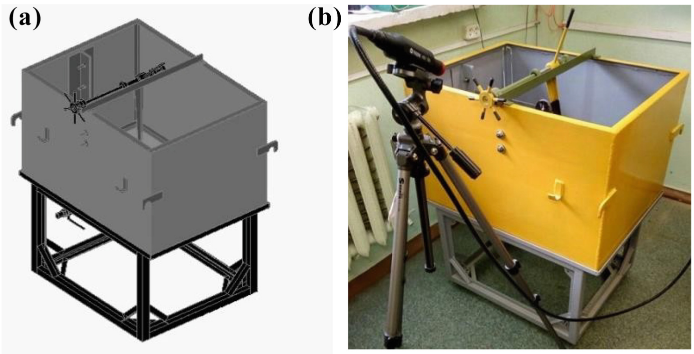


Fig. 2. Experimental setup (a) - 3D view; (b) – photo of the experimental setup. *Source*: developed and compiled by the authors

For convenience of consideration, the experimental setup was conditionally divided into four “separate sets of parts” such as:

– The bowl of the pool;
– Motor platoon of the maximum deflection of the beam;
– Stand for installation;
– Console.

Let's look at each "complex" separately in more detail.

The pool bowl (Fig. 3) is designed to create a working environment in which research will be performed.

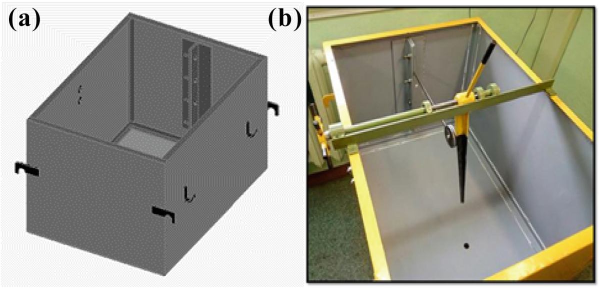


Fig. 3. Pool bowl: (a) - 3D view; (b) – take photos *Source*: developed and compiled by the authors

A pool bowl consists of individual parts such as:

– Welded steel sheets reinforced with corners;
– Pinching device that attaches the console;
– Stops for manual carrying;
– A drain device designed to remove "waste media" from the experimental installation.

The platoon drive (Fig. 4) of the maximum beam deflection is designed to deflect the system from the equilibrium position.

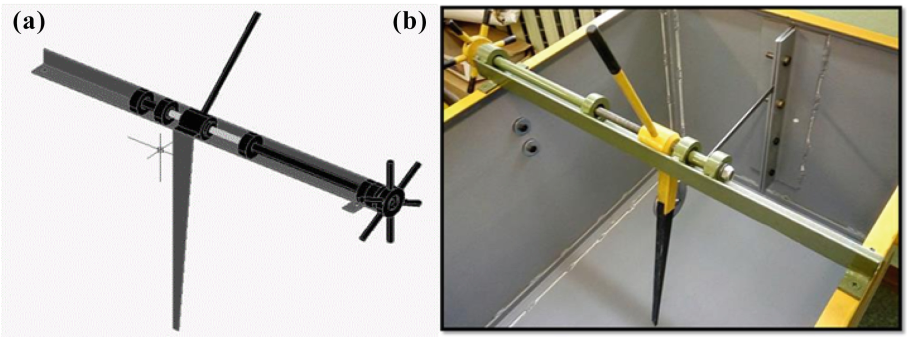


Fig. 4. Maximum beam deflection platoon drive (a) – 3D view; (b) photograph of the platoon actuator maximum deflection of the beam. *Source*: developed and compiled by the authors

This device consists of individual parts, such as:

- Support corner;
- Two thrust bearings;
- Three support bearings;
- Regulator of deviation of the beam;
- Shaft for the beam deflection regulator;
- Trigger.

The installation stand (Fig. 5) is designed to hold the entire experimental installation in place.

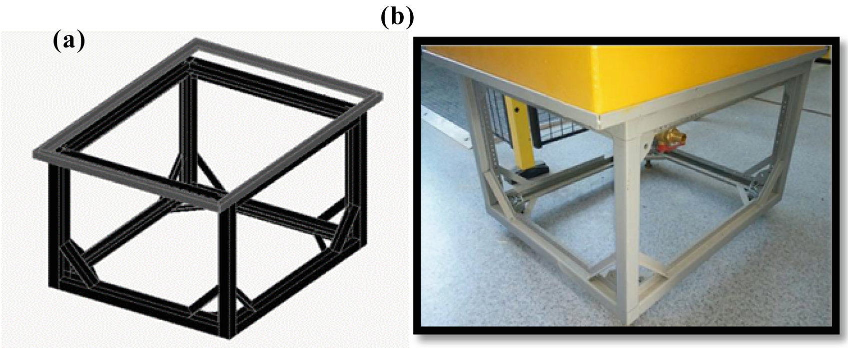


Fig. 5. Installation stand (a) – 3D view; (b) – photo of the installation stand *Source*: developed and compiled by the authors

It consists of the following details:

- Profile beams, welded together and reinforced with corners;
- Welded together in the corners to hold the pool in a stationary state during operation.

The console is necessary for determining the parameters of free hydroelastic vibrations of a mechanical system with a point mass at the free end (Fig. 6).

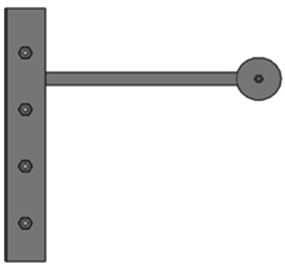


Fig. 6. 3D view of the cantilever beam. *Source*: developed and compiled by the authors

The console consists of:

– A beam rigidly secured by a pinching device;
– A model that gives the console a point mass.

2 Materials and Method

Performing measurements of the console's amplitude-frequency characteristics. Measurement of the amplitude-frequency characteristics on the model and on the flag is performed in the program "Polytec vibrometer software". We use four models with different windage areas (Fig. 7).

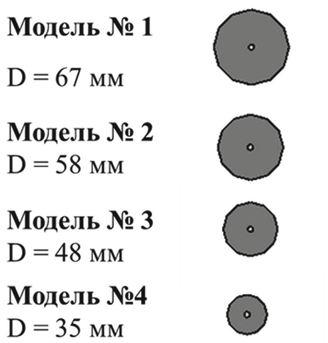


Fig. 7. Models with different windage areas. *Source*: developed and compiled by the authors

When the structure is located in environments such as water, diesel fuel, engine oil, and other liquids, it is difficult to perform vibration measurements using laser devices. The solution to this problem is to use a special marker-a flask placed at a certain distance from the object. In this case, measurements are made using the flag and the calculated coefficient of influence of the flag determines the actual values. To reduce the measurement error, the flag is attached to the structure under study using a rigid connection – a steel rod.

To determine the coefficient of influence of the flag in this work, studies were conducted on measuring vibration and on the design itself in the "air" environment and on the flag. Based on a comparison of the results obtained, we can conclude that the proposed method for measuring vibration of structures in liquid media is correct.

After taking readings of the amplitude-frequency characteristics on the model and on the checkbox, the received data is processed using the "Microsoft Excel" program. Based on the data obtained, graphs are plotted for comparing the amplitude-frequency characteristics of the model and the flag.

3 Results

Performing measurements of the amplitude-frequency characteristics on a console with a diameter of the attached mass of 67 mm. After performing measurements in the program "Polytec vibrometer software", we go to the averaging of data from ten graphs (console without a check box) and get the averaged data, which we use to build a graph. Figure 8 shows the graph of averaged data for the console's amplitude-frequency characteristics without the check box.

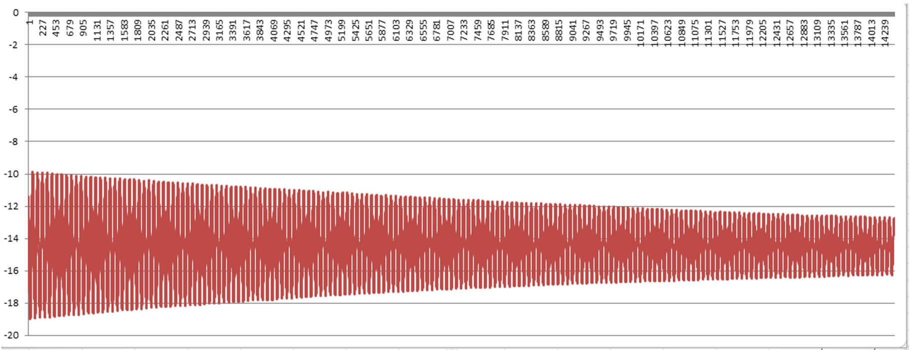


Fig. 8. Averaged amplitude-frequency data console characteristics without a check box (for the middle of the mass). *Source*: developed and compiled by the authors

A graph of the averaged data of the console's amplitude-frequency characteristics with a check box is shown in Fig. 9.

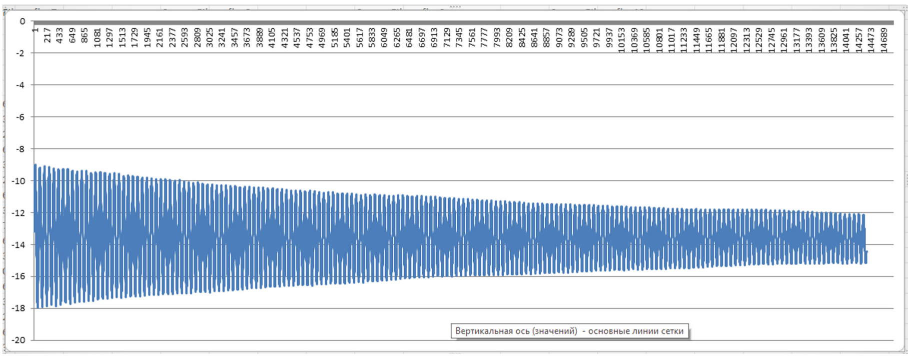


Fig. 9. Averaged amplitude-frequency data console properties with a flag (for the middle of the flag). *Source*: developed and compiled by the authors

The resulting graphs of the average values of the amplitude-frequency characteristics of the console with and without a flag are superimposed on each other to identify visually and in detail visible differences between the graphs.

For a clear view of the difference between measurements with or without a flag, select a separate part with a well-established oscillation period from the graph shown in Fig. 10. This part of the graph is shown in Fig. 11.

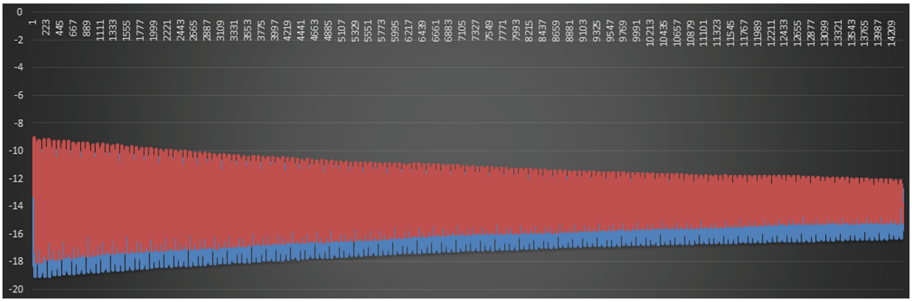


Fig. 10. Graphs of the average values of the amplitude-frequency console settings with a flag (red)

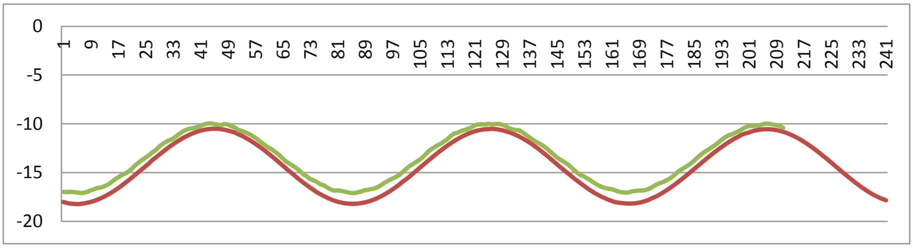
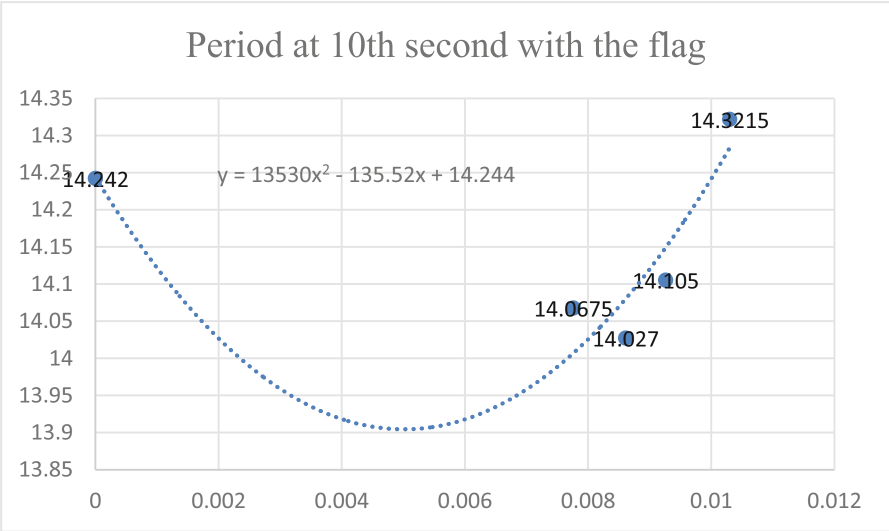


Fig. 11. Part of the chart with a well-established oscillation period: red – for the flag, green – for the mass (time interval from 9.5 s to 10.5 s). *Source*: developed and compiled by the authors

The resulting graph shows that changes in the amplitude-frequency characteristics when performing measurements (laser on the flag and on the mass) are insignificant and make up an error of less than 5%. As in the method described above, measurements of amplitude-frequency characteristics were performed on the console and with other diameters of the attached mass: 58 mm, 48 mm and 35 mm. According to the results obtained, as can be seen from the graphs obtained, it can be stated that the changes in the amplitude-frequency characteristics when performing measurements (laser on the flag and on the mass) are insignificant and make up an error of less than 5%.

Construction of calculated graphs of the beam oscillation period at the 10th, 20th, and 30th s. To get all the data we are interested in, we calculate the calculation of the beam oscillation periods for each second of the experiment and determine where the beam oscillations are stable.

Calculated graphs of the beam oscillation periods at the 10th, 20th, and 30th s of measurements are shown in Figs. 12, 13, and 14.



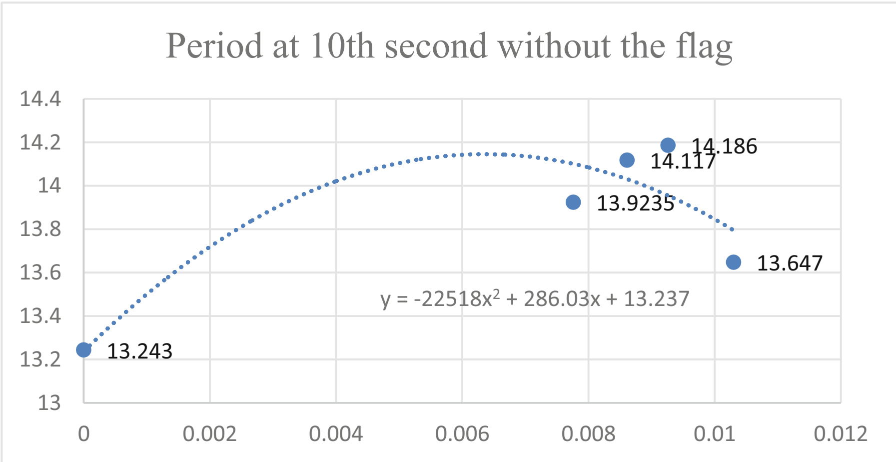
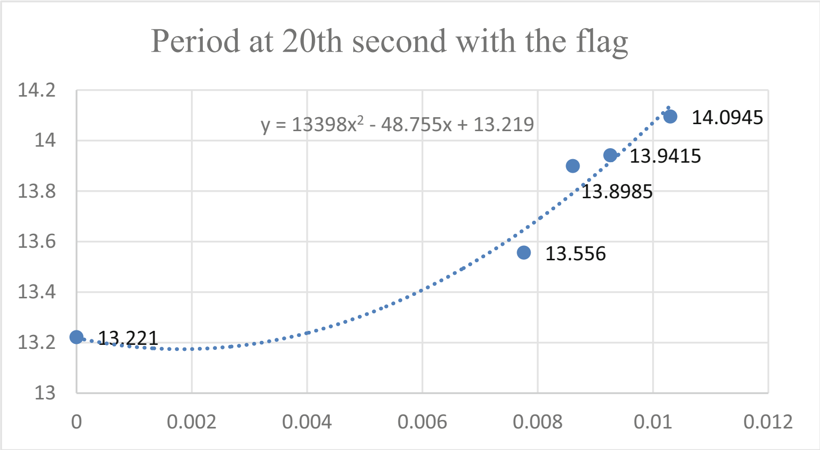


Fig. 12. Calculated graphs of the beam oscillation Period at the 10th s of measurement *Source*: developed and compiled by the authors



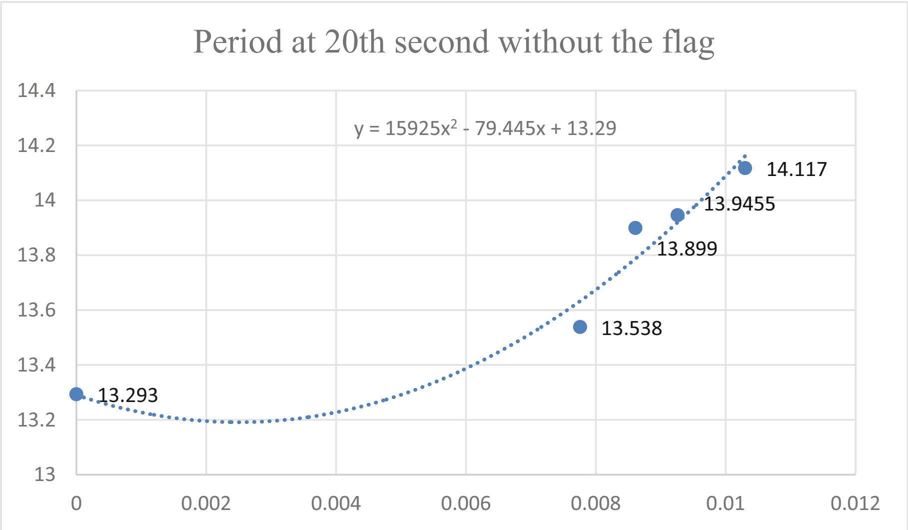
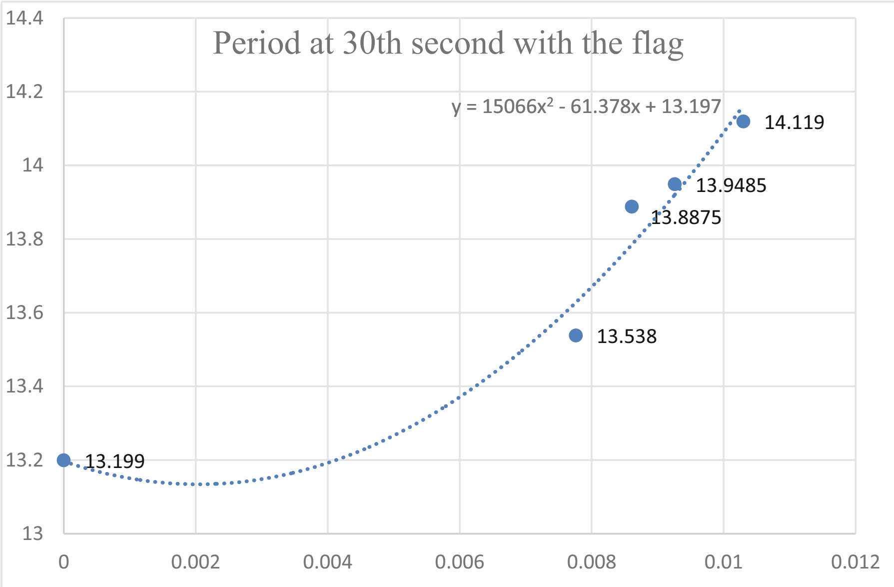


Fig. 13. Calculated graphs of the beam oscillation Period at the 20th s of measurement *Source*: developed and compiled by the authors



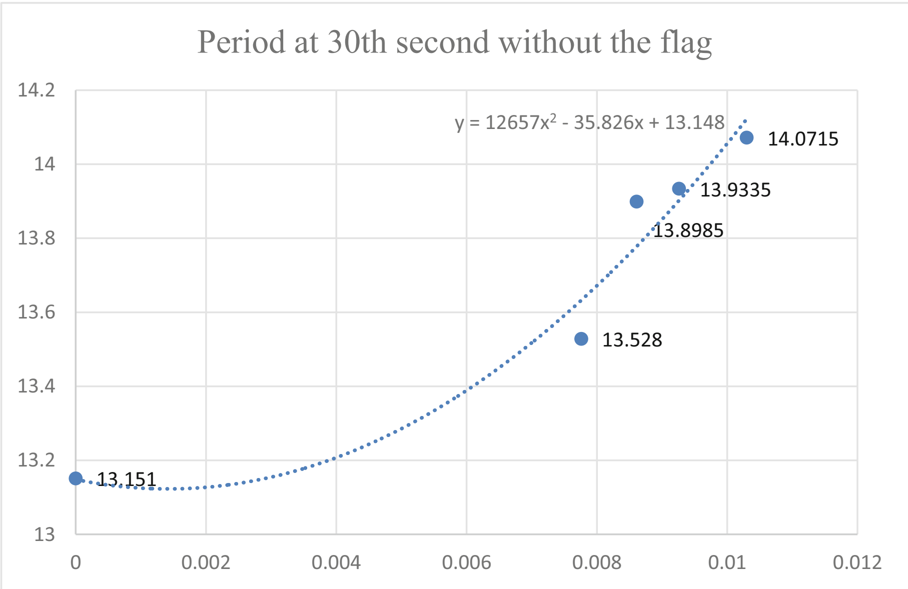


Fig. 14. Calculated graphs of the beam oscillation Period at the 10th s of measurement *Source*: developed and compiled by the authors

4 Conclusion

1. In this work, using experimental data obtained at the installation, graphs of the amplitude-frequency characteristics of the cantilever beam were constructed using the program “Polytec vibrometer software”. The results of comparison of graphs obtained on the basis of measurements for the model and for the flag are presented. A comparative analysis of all the amplitude-frequency characteristics of the cantilever beam obtained in the “air” medium is performed.
2. The transition point for the period (T) is 13.229 s.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use “New Materials and Technologies” on the basis of KnASU.

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Modeling of Hydraulic Structure Reliability Parameters During a Flood

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Abstract. Purpose: Consequences of floods have recently become disastrous. To reduce or prevent consequences, it is necessary to install protective structures. The purpose of the work is to develop mathematical and numerical models of the stability of the underwater cable system elements (UCS), to determine the pulling load at the point of attachment to the anchor.

Methodology: Studies of existing methods for calculating the stability of structures are not applicable to the calculation of underwater cable-stayed systems. The work includes studies of external forces on the UCS, study of the cable system and the strength of the anchor-soil system.

Findings: The article presents a mathematical model and methodology for taking into account the influence of external influences (waves of water, underwater currents) on the UCS. The work determines the loads that affect the stability of the topside, carries out the calculation, taking into account large displacements and significant sagging, and model experiments, develops a numerical model and calculation method, and compares results of determining the bearing capacity of pile anchors.

Originality/Value: The work developed:

- To determine the impact on the structure of loads from a water body, a mathematical model and a computer program have been developed.
- Theoretical modeling of the calculation of the cable system for reliability using the method of contour equations.
- Carrying out an experiment to substantiate the calculation of the reliability of the holding force of pile anchors from the effect of an external load.

Keywords: Numerical modeling · Finite elements · Pulling load · Cable-stayed system · Tension · Anchor

JEL Code: J81 · C51 · C53 · M54 · Z22

1 Introduction

Flooding is one of the disasters that people have been struggling with for millennia, but they have not been able to protect the population from this disaster. Every year the damage from floods increases, whole settlements suffer from flooding, and people die.

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Underwater cable systems (UCS) are used as a system for holding surface structures and obstacles.

The impact of waves and currents on a structure are the main destructive forces and account for about 95% of all loads (Pronkin and Stotsenko 1987).

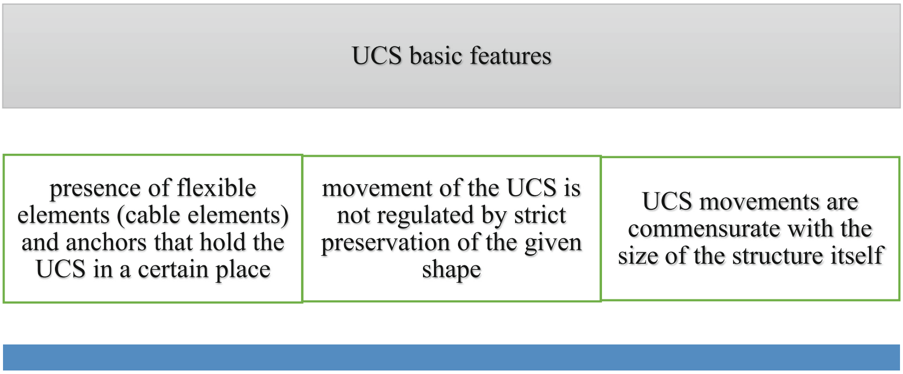

Fig. 1. UCS features. *Source*: developed and compiled by the author

Since the wave load on the structure causes large displacements of the topside, and the cable system allows significant displacements of the piles, therefore, the displacement constraint is not used in the calculations (Fig. 1). The anchor-soil system is in a stable state while ensuring the strength of the anchor material in the place of bending and the impossibility of deforming the soil or pulling out the pile (Taranukha et al. 2015).

2 Methodology

Mathematical model for determining parameters of currents and waves.

To calculate the reliability of hydraulic systems, a mathematical model is analyzed for determining the loads acting on a water body from waves and currents (Fig. 2).

To determine the forces from wave effects, we use the linear theory of waves, which does not take into account the interaction of waves with different frequencies, therefore, to calculate the PRF, we apply the principle of superposition of the parameters of the corresponding waves of different frequencies and directions (Danilov 1968) (Fig. 3).

We will conduct a study of the influence of external forces from a water body on the structure under the assumption that the modulus is constant, that is, in the first approximation (Taranukha et al. 2013).

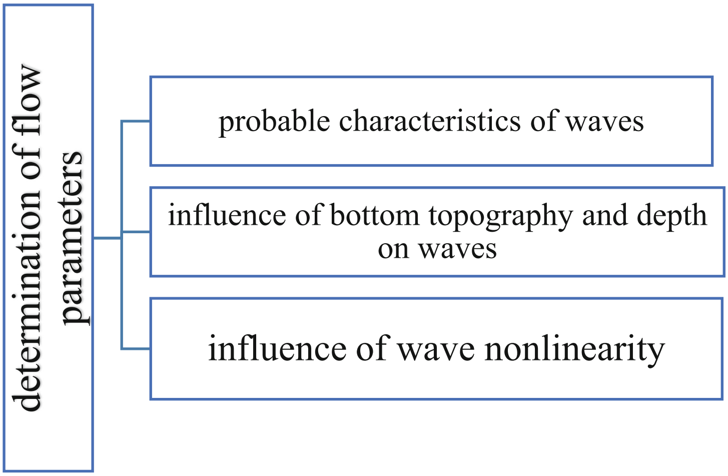

Fig. 2. Parameters from loads from a water body. *Source*: developed and compiled by the author

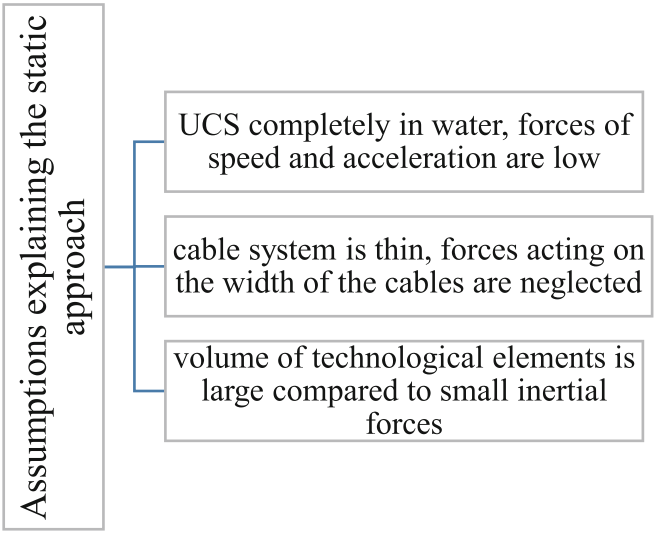

Fig. 3. Assumptions for calculating external loads. *Source*: developed and compiled by the author

For the calculation, the expressions are composed

$$\left.\begin{array}{l}
R_{1x} + R_{2x} + \int\limits_{S} q_p(S)\sin\alpha dS + \int\limits_{S} q_\tau(S)\cos\alpha dS = 0 \\
R_{y1} + R_{y2} + \int\limits_{S} q_p(S)\sin\beta dS + \int\limits_{S} q_\tau(S)\cos\beta dS = 0 \\
R_{Z1} + R_{Z2} + \int\limits_{S} q_p(S)\sin\gamma dS + \int\limits_{S} q_\tau(S)\cos\gamma dS + \int\limits_{S} P_g \cos\gamma dS - \int\limits_{S} P_w \cos\gamma dS = 0 \\
R_{Z2}\cdot L + \sum\limits_{i}\int\limits_{S} q_p dS\cdot a_i + \sum\limits_{i}\int\limits_{S} q_\tau dS\cdot b_i + \sum\limits_{i} P_g dS\cdot a_i - \sum\limits_{i} P_w dS\cdot a_{xi} = 0
\end{array}\right\} \quad (1)$$

Calculation results are shown (Fig. 4).

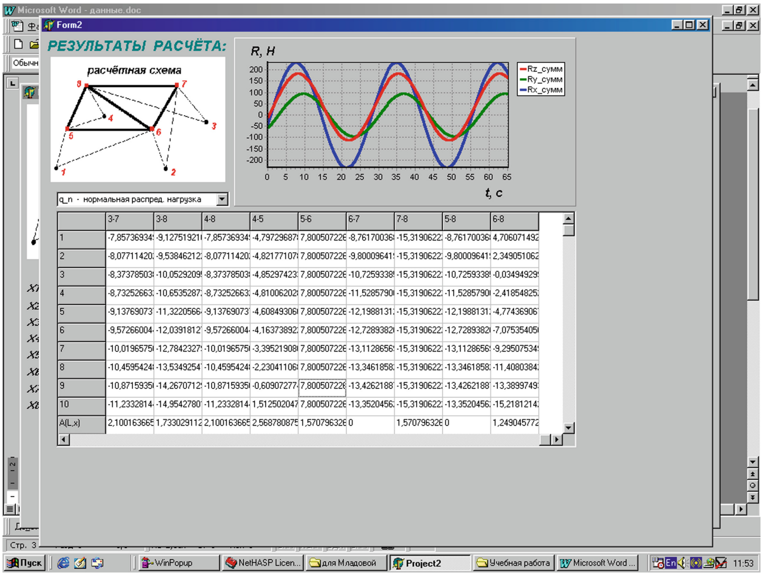

Fig. 4. Results of calculations of wave load *Source*: developed and compiled by the author

Mathematical model for calculating the cable system.

The method of contour equations was used to calculate the cable system. The calculation was made for the maximum forces in the cables and in the wires to the anchors.

Since the upper structure of the UCS is a cable-stayed system, there are design features. Based on this, a block design was proposed. Installation of this structure is carried out under water, and assembly in small blocks will be more technological and economical.

Two tasks are set - research of the horizontal retention system (anchors) and the superstructure (cables). Three models of cable structures, which have different geometric shapes, were selected as design schemes. UCSs belong to cable-stayed systems, since they consist of flexible rods that work only in tension (Bormotin et al. 2018).

In the method of contour equations, the system of equations in the general case is the following:

$$\begin{cases} [S]\ [\vec{k}]\{N\} = [\vec{k}_p]\{P\}, \\ [C]\ [\vec{k}](\{L\} + [B]\{N\}) = 0, \\ [D]\ [\vec{k}](\{L\} + [B]\{N\}) = [D]\ [\vec{k}^0]\{L\}, \\ [m^2] + [n^2] + [e^2] = [I]. \end{cases} \tag{2}$$

The solution of the equations is the coordinates of the nodes of the cable-stayed system in the deformed position. It is necessary to pay great attention to the behavior of the cables in the anchorage point.

With wave loads on a cable-stayed system, the most dangerous scenario is when 2 main cables connecting the base with the anchor are turned off from work, stability loss or structure collapse occurs (Taranukha et al. 2003).

The nodal displacements were found using the nodal coordinate method. In matrix notation, the equations of the method are as follows:

$$\begin{cases} SB^{-1}S^T X = -\vec{P}_m + SB^{-1}[m]\{L\} \\ SB^{-1}S^T Y = -\vec{P}_n + SB^{-1}[n]\{L\} \\ SB^{-1}S^T Z = -\vec{P}_d + SB^{-1}[n]\{L\} \end{cases} \tag{3}$$

To determine the depth of sagging of the cable-stayed system, an algorithm was developed and a program was compiled. This program is used as part of the general program for calculating the superstructure of a structure.

Physical modeling of the load bearing capacity of the pile (model experiments).

In the work, experiments were carried out on the pulling load of piles for comparison with the calculation method.

The tests were carried out in sandy dry and water-saturated soil. The piles used in the experiment had different geometric characteristics and materials (Fig. 5).

The critical pulling load was taken to pull the pile out of the ground.

An inclined pulling load was applied to the anchor, and characteristic cracks were formed at the moment of soil destruction (Gorbunov-Posadov 1973).

With an increase in the angle of inclination of the pulling force, the critical load increased significantly.

3 Results

The external forces acting on the pile are irregular; the period of load change is commensurate with the period of excitement. The existing methods of calculating the vertical pulling load are not applicable in these conditions. Based on the analysis of existing techniques, the paper presents the mechanism of pile operation for an inclined pull-out

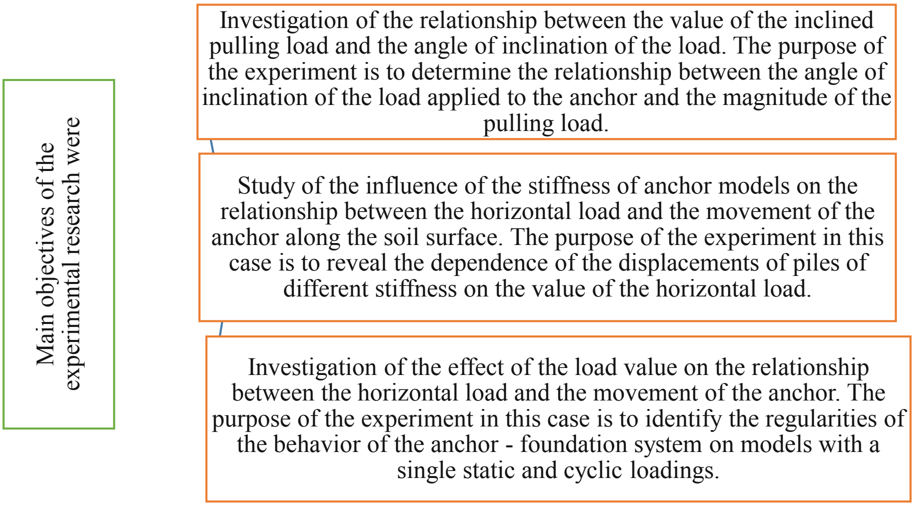

Fig. 5. Tasks of model experiments. *Source*: developed and compiled by the author

load (Abelev et al. 1983). The pile works in 3 stages: linearly deformed, plastic and elastic-plastic. Anchor breakout can occur at every stage (Taranukha et al. 1995).

The stresses arising at the boundary of the anchor-soil system were studied numerically based on the finite element method (Fig. 6).

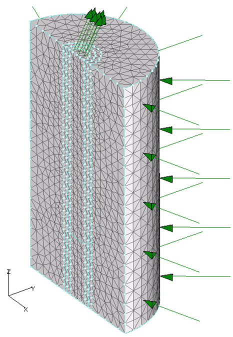

Fig. 6. Finite element diagram of a pile in the ground. *Source*: developed and compiled by the author

Active loads:

- Gravitational.
- Inclined pulling out.

The critical point is the pulling out of the pile from the ground. The retention of the pile in the ground depends on the properties of the base and the anchor. The stability of the underwater cable system is determined by:

- Normal and shear stresses.
- Change of coordinates when exposed to loads.
- Study of material strength.

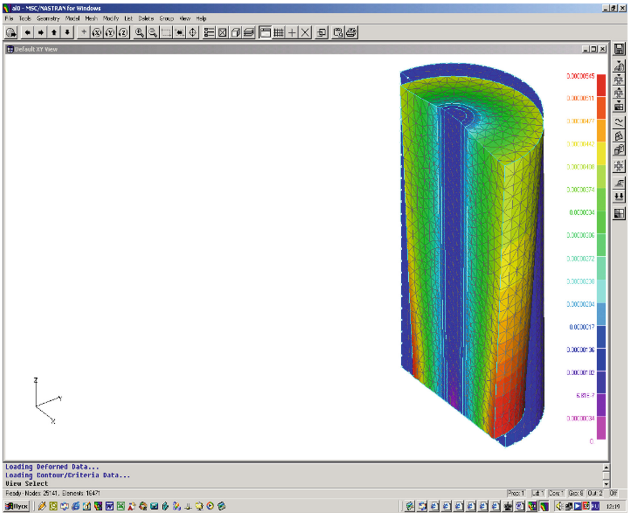

Fig. 7. Diagram of soil displacement distribution. *Source*: developed and compiled by the author

The determination of the critical pull-out load was carried out by the experimental and calculation method. The breakdown of the stability of the anchor-soil system occurs when the pile is pulled out of the soil (Taranukha et al. 1996). The critical pulling force is calculated by the numerical method based on the finite element method (Fig. 7). To determine the inclined load:

- Model experiment - determination of the critical pulling force at various angles of inclination.
- Determination of the forces occurring at the border of the pile and the soil at the moment of the pile breaking out, with an inclined load. The calculation is carried out by the finite element method.
- Studies have been conducted on the dependence of the definition stresses at the moment the pile is pulled out of the ground from the action of an inclined load (Fig. 8). An indicator of the dependence of the angle of inclination of the application of the pulling force and the destruction of the anchor-soil system is derived (Fig. 9).
- Calculation of the parameters of the critical pulling loads, individually, for each pile (depending on the properties of the soil and the pile) by the finite element method.

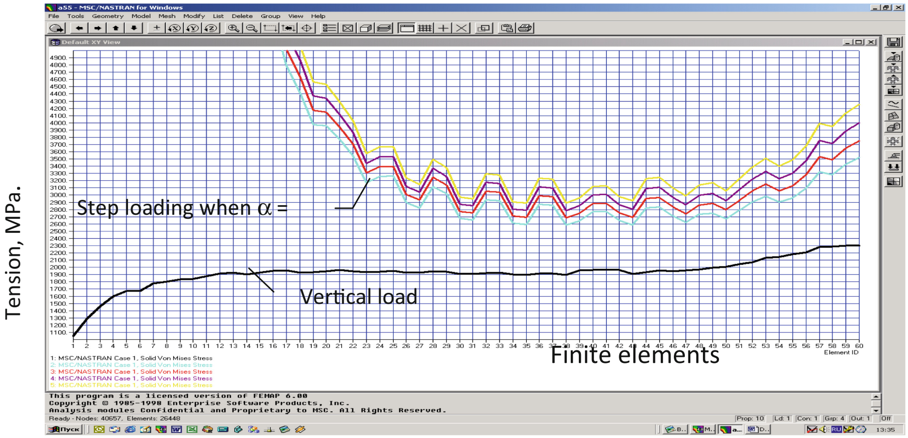

Fig. 8. Equivalent stresses $\sigma_{экв}$. *Source*: developed and compiled by the author

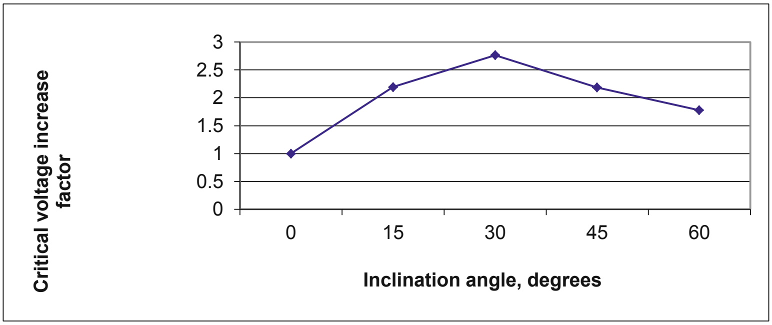

Fig. 9. Dependence of the coefficient on the angle of inclination. *Source*: developed and compiled by the author

- Determination of the critical force with a nonlinear relationship between stress and loads is calculated by the formula:

$$P_{кр}^{\alpha} = \frac{K_{\sigma} \cdot K_1}{K_0} \cdot P_{кр}^{0} \tag{4}$$

4 Conclusions

The article proposes a model for the construction of a UCS, which can be an underwater system for fastening structures that retain the flow of water. Water flows have tremendous power, they flood entire settlements and destroy everything in their path, and therefore, the reliability of the fastening system for barriers is very important.

The structure of the UCS has a number of features, so the model for calculating the stability of other structures cannot be used.

In this work, a calculation method has been developed for the model of accounting for the influence of external influences, which allows calculating the loads from the effects of waves and currents. The program has been developed. The impact of external loads gives large displacements and sagging of cable-stayed systems, which can lead to a violation of the integrity of the system. A mathematical model was developed to calculate the strength of the upper structure of the UCS. A program has been created to account for the sagging of cables (Taranukha et al. 1995, 1994).

External influences and deformation of cable-stayed systems will entail instability of the system, namely, breakage of wires in the attachment point to the anchor or pulling out the pile. Physical modeling and pulling out the pile, taking into account various materials and geometrical dimensions, were performed. A numerical model based on the FEM for determining the critical pulling force of the anchor from the base has been developed.

On the basis of model experiments and a numerical model, a comparison was made to determine the bearing capacity of pile anchors.

The mathematical and numerical models and techniques developed in this work allow calculating the external loads with sufficient accuracy, stresses in the cable-stayed system, and the critical pulling load of piles.

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Turning and Milling Conceptual Issues

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Abstract. Purpose: the objective is to create the simulation technique, allowing to predict tool life, to create models of new tools for new operating conditions, that will lead to a reduction in instrumental costs of metalworking industries.

Design/Methodology/Approach: experimental, theoretical studies and simulation modeling were used to achieve this purpose.

Received Data: the obtained results are focused on the development of recommendations for improving the process of processing product blanks with metal cutting tools using examples of milling and turning of hard-to-process materials. The results are obtained experimentally and by simulation.

New tool materials, new tool structures have been developed, optimal operating conditions have been identified. A 3-times reduction in tool costs has been achieved.

Findings: The obtained results allowed:

a) Identifying reasonable application areas for one-piece, assembled and compound cutters, taking into account cutter cost and machining precision.
b) Determining most reasonable tool materials for turning of corrosion-resistant stainless steel 09X17H7Ю.
c) Evaluating application possibilities for replaceable hard alloy plates for high performance machining on modern machines with CNC. Applying obtained results allows reducing tool costs share in total production cost without decreasing quality and machining efficiency. Most of the proposed solutions are based on creating new tool materials or improving the design of standard metal-cutting tools.

Originality/Value: Original tool materials and tool structures have been developed. Original methods for evaluation the tool quality are developed.

Keywords: New tool materials · Improving cutting tool design · Reducing tool costs · Compound end mill cutters · Replaceable turning plates

JEL Code: O330

1 Introduction

The paper considers the issues of tool material improvement which affect machining efficiency the most. The most important issues are the following:

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https://doi.org/10.1007/978-3-030-69421-0_57

1. The necessity of developing new tool materials for new structural materials. This includes adaptation of existing tool materials. This is due to the fact that the nomenclature of new structural materials is developing rapidly. Their physicomechanical and operating characteristics change so fast that their machining processes and equipment capabilities fall behind, tool working capacity is lacking.
2. The necessity of machining specialized structural materials, for example, corrosion-resistant specialized stainless steel 09X17H7Ю. It was created in the beginning of the previous century for manufacturing a number of submarine parts. Demand in it is growing rapidly due to the expansion of its application areas. However, the existing recommendations on its machining are seriously out of date. The machining equipment, for which the machining this specialized steel was considered, is long gone.
3. The necessity of satisfying the growing demand in the precision of manufacturing high-precision part workpiece surfaces. Requirements to precision (and roughness as well) are only going to grow. This will require higher precision and efficiency of metal-cutting tools respectively.

Certain obtained results related to these issues are given below.

2 Materials and Methods

The considered issues are related to Russian standard metal-cutting tools, namely, end mill cutters of hard alloy, replaceable turning cutter plates of hard alloy, tangential cutting plates used in reconstructive turning of railway car wheels.

The study used experimental approach and numerical simulation modelling. Using both of these methods led to expanding the existing view on the ways of improving metal-cutting tools.

3 Obtained Results and Discussion

The issues listed above are mostly related to the lack of the mathematical model of cutting. There have been attempts, (Shet et al. 2000), (Shatla et al. 2001), Vereschaka et al. (2016) to develop it, but they are intended for specific cases.

The lack of such model makes production engineers and researchers search for solutions using various software. Ansys and Deform software is most efficient for cutting. CAE software SolidWorks 2016 was used for virtual simulation modelling.

Modern machines with CNC require metal-cutting tools of new quality. This includes end mill cutters of hard alloy. Their high hardness and efficiency show good results. However, using such cutters has negative consequences as well. This includes high cutter cost and their failure due to shank chipping caused by tool's hard alloy inability to withstand alternating loads on the cutter's shank. Figure 1 shows the statistics on one-piece cutter shank chipping.

Designs of end mill cutters of hard alloy were suggested which exclude such shank chipping. For this, the cutting edge is made of hard alloy and the shank is made of structural material.

The analysis of the obtained results showed the following:

a **b**

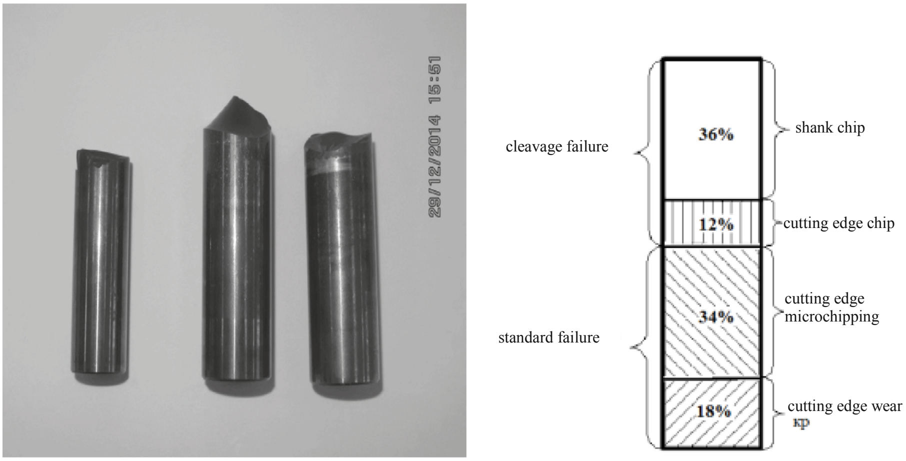

Fig. 1. Examples (a) of shank chipping and statistics (b) of one-piece cutter failure. *source*: developed and compiled by the authors

1. Error margin for the surface machined by the developed compound cutters is within general engineering precision for parts and a number of surfaces (recesses, grooves, pockets, chamfers, etc.) of high-precision aircraft parts. For example, tolerance grade 6 is ensured by a compound cutter with the cutting edge made of hard alloy ВК8 and the shank made of alloy Т30К4 not intended for tools. A cutter (length 90 mm, dia. 16 mm) with a shank made of Т30К4 may be used to manufacture slots with depth up to 5 mm in workpieces for high precision parts intended for aircrafts, for example.
2. Tolerance grade 9 allows for a cutter with a cutting edge made of hard alloy ВК8 and a shank made of structural steel 40X.
3. A cutter (length 120 mm, dia. 16 mm) with a cutting edge (length 40 mm) made of ВК8 and a shank made of P18 ensures tolerance degree 6 when machining a 5 mm deep slot wall even in sped-up cutting modes.
4. The required tolerance is ensured for general engineering parts at any of the considered cutter lengths (90, 120, 220 mm when cutting edge is 40 mm).

Figure 2 shows the information on the suggested solutions.

Figure 2 shows that the developed compound cutters can rival one-piece cutters in some areas without decreasing quality and machining efficiency and giving a significant (up to three times) reduction of tool cost). The paper (Mokritskii et al. 2018) gives more detailed information on compound end mill cutters.

Certain results were obtained with regard to increasing the efficiency of replaceable hard alloy turning cutter plates when machining stainless steels. The demand in them is related to the rapid growth of the need in highly corrosion-resistant steels. One of the examples is specialized steel 09X17H7Ю. Its physicomechanical and operational properties make it hard to machine due to the low wear-resistance of tools.

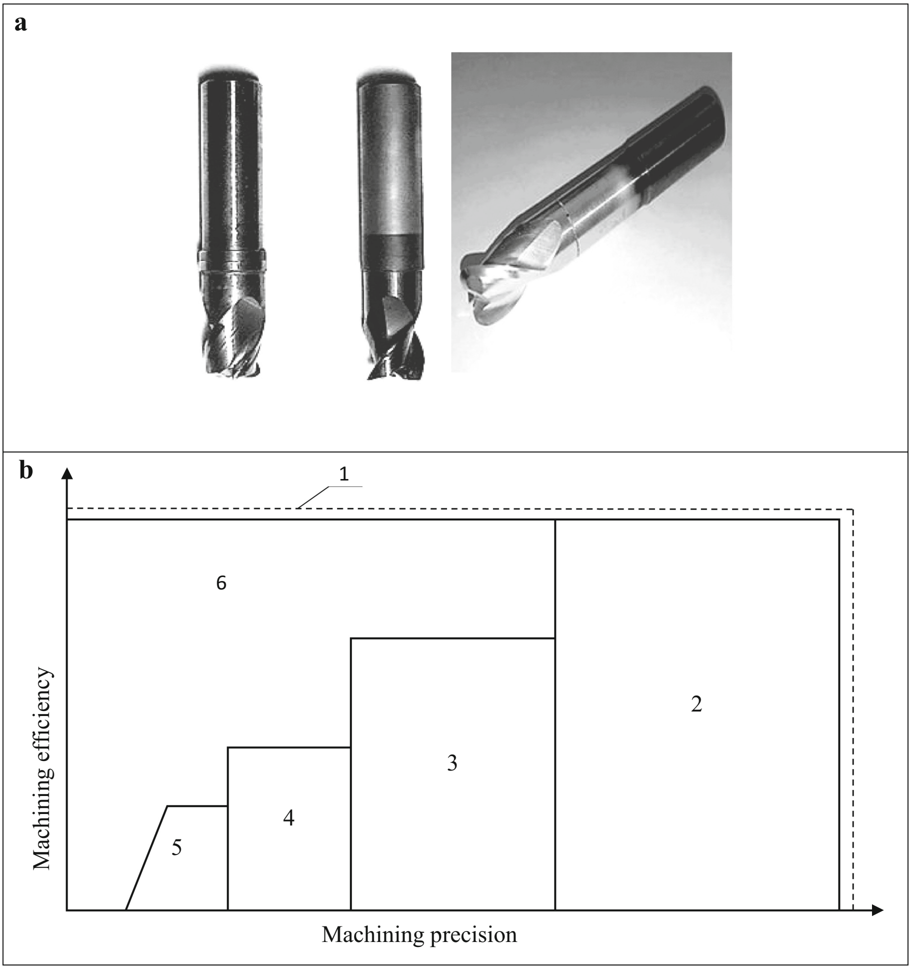

Fig. 2. Examples of developed compound end mill cutters (a) and reasonable application areas: 1 is a traditional one-piece cutter application area; 2, 3, 4, 5 are recommended areas for compound cutters; 6 is the recommended one-piece cutter application area (for a compound cutter with dia. 16 mm with cutting edge 40 mm and total cutter length: 2–90 mm; 3–120 mm; 4–220 mm; 5–over 220 mm). Source: developed and compiled by the authors

New tool materials were developed for standard hard alloy plates which allow increasing plate working capacity in over two times. This solution is applicable to Russian hard alloy BK8 for tools on account of using various coatings, depending on operating conditions. The solutions were obtained by simulation modelling and empirically proved. Short-time simulation modelling (first 5 min work time is enough) of plates operation was sufficient to solve the problem. This allowed approximating data and describing wear-time functional connection with the use of equations.

Figure 3 shows one such example.

Practical value of the obtained results comprises:

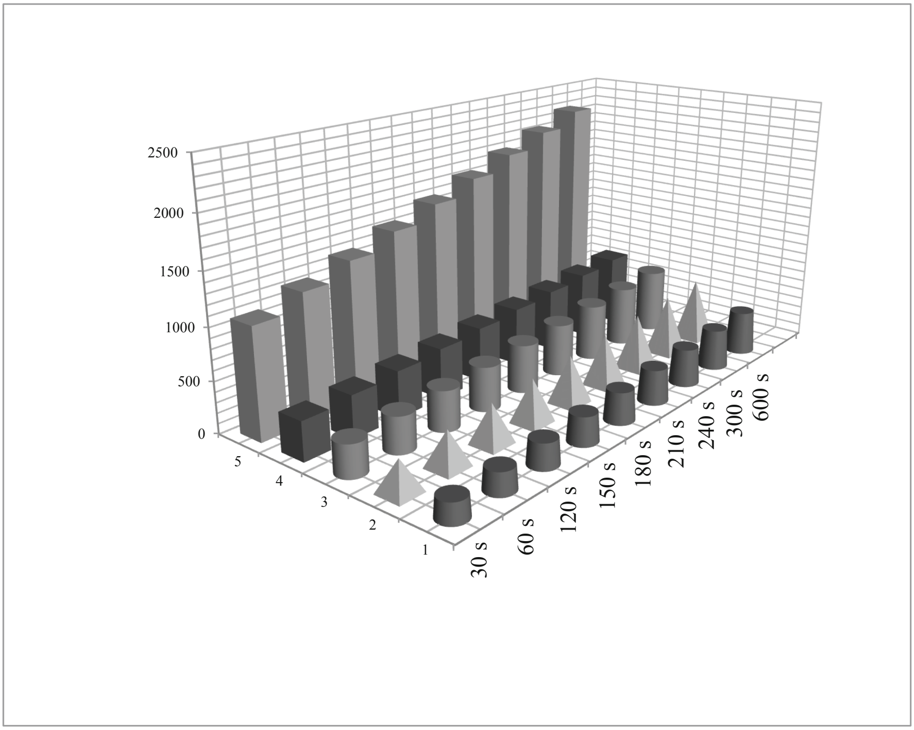

Fig. 3. Interconnection of tool wear (line 1, conditional wear value) with other parameters (temperature °C is line 2, tool material stress is line 3, tool material strain degree mm/mm is Line 4, maximum cutting force constituent value is line 5 (plotted in Newtons on the vertical axis) stress-strain state of tool material BK8 + Al2O3(2 μm) + (Ti)CN(5 μm) + (TiAl)N(3 μm) + TiN(3 μm). Source: developed and compiled by the authors

a) developed reasonable tool materials;
b) suggested design parameters of tool materials with the use of simulation modelling as well as cutting mode parameters;
c) suggested simulation modeling procedure for selecting viable tool materials and reasonable cutting mode parameters;
d) suggested recommendations on the use of reasonable cutting mode parameters and tool materials which can serve as the beginning of creating a bank of such recommendations for differing operating conditions

Obtained results and the accepted approach do not contradict known results (Grigoriev et al. 2011, Kharlamov et al. 2003, Parshin et al. 2010, Alekhin et al. 2015, Vasiliev et al. 2015, Vasin et al. 2001, Grigoriev et al. 2011, Evdokimov et al. 2015, Coromant 2003, Dalsky et al. 2001, Serebrennikova et al 2018, Bashkov et al. 2019, Thein et al. Odinokov et al. 2019). However, they develop them from the point of view of tool cost share reduction in production costs.

The results on the impact of manufacture precision of replaceable small diameter end mill cutter plates of hard alloy on the quality of the machined surface. The problem was solved in the reverse, i.e. a number of replaceable plates parameters was measured, their variation evaluated and the plates were sorted into conditional first grade, second grade and defective. Plate mass, length, width and thickness were the measured (determined) parameters. Plate mass was the most significant parameter. The data on this parameter predominantly is given below.

The plate shape and size were selected in compliance with the practices of standard Russian engineering facilities. The studies of plates of 15 different standard sizes (series, batches) were performed.

Plate mass control was performed using digital analytical balance ACCULAB Sartorius group in grams accurate to three decimal places. Mass control results were compared to those imposed by regulatory documents (GOST). A distinction between measured and regulatory plate mass values was discovered.

The plates in a series with mass difference within the second decimal place were referred to the first (premium) grade during plate mass control.

For example, the average value for series 1 plates was calculated as 8.893 g and the measured plate 4 mass of this series equals 8.927 g. The difference is 0.034 g. This is the difference in the second decimal place. Therefore, plate 4 refers to the first (premium) conditional grade. Plate 2 from the same series has a mass of 8.486 g. This allows referring it to the second grade. Plate 3 weighs 9.969 g. This means it refers to the third grade, i.e. defective (Table 1).

Table 1. Example of series 1 plates distribution into conditional quality grades by plate mass parameter

Series no.	Plate no.	Plate mass, g	Average plate mass value for series, g	Plate grade distribution in a series		
				Grade 1	Grade 2	Grade 3
1	1	8.516	8.893		1	
	2	8.486			1	
	3	9.969				1
	4	8.927		1		
	5	8.571			1	

Table 2 gives a more general view of plate mass variation in batches and grade shares. The following conclusions can be made:

1. Only four batches are without plate defects by mass. This means that plate manufacturer cannot ensure the required plate quality by mass using its technologies. Consumer incoming control is required.

Table 2. Distribution of studied plates by grade

Series no.	Q-ty of plates in a Series, ea	Grade 1		Grade 2		Grade 3 (conditionally defective)	
		Plate Q-ty, ea	Plate Q-ty share, %	Plate Q-ty, ea	Plate Q-ty share, %	Plate Q-ty, ea	Plate Q-ty share, %
1	5	1	20	3	60	1	20
2	8	2	25	1	12.5	5	62.5
3	4	1	25	3	75	0	0
4	8	3	37.5	5	62.5	0	0
5	14	0	0	7	50	**7**	50
6	15	9	60	5	33.3	1	6.7
7	17	2	11.7	15	88.3	0	0
8	16	0	0	7	43.7	9	56.3
9	25	0	0	18	72	7	28
10	24	1	4.1	16	66.6	7	29.3
11	19	0	0	7	36.8	12	63.2
12	13	0	0	5	38.4	8	61.6
13	23	0	0	4	17.4	19	82.6
14	19	0	0	7	36.8	12	63.2
15	54	20	37	34	66	0	0
Total	264	39	22.8	137	51.9	67	25.3

2. Seven batches have no premium grade by mass. This means that plates from these batches cannot be used in the conditions of high-speed machines with CNC due to possible tool imbalance. This also means that consumer incoming control is required.
3. Defective plates comprise 36.2% at average. There are batches with 82% defective plates.
4. In most batches, the plates' mass tolerance makes them applicable only in production which does not require high-precision of part machining. For example, at blank sections of general engineering production facilities.
5. The approach used herein may be the basis for diagnostics (determination of plate mass deviation value), reasons for defects and other process issues.

Table 3 gives data on the plate variation by plate length as an example. This parameter was evaluated when measuring plate length on a multi-sensor measuring center Sol 161 (digital count discretization 0.001 mm).

The analysis of results in Table 3 allows making the following conclusions:

Table 3. Quantity of plates distributed into conditional quality grades by plate length

Plate series no.	Plate Q-ty by grade, ea		
	Grade 1	Grade 2	Grade 3 (conditionally defective)
1	0	0	5
2	0	8	0
3	0	0	6
4	0	7	1
5	0	14	0
6	0	15	0
7	0	17	0
8	0	1	15
9	0	25	0
10	0	0	24
11	0	2	17
12	0	23	0
13	0	0	23
14	0	1	18
15	0	29	25

1. Plate series are radically different by plate length in first grade, second grade as well as by defective plates share.
2. A supply of plates in each series required for production activities of a standard engineering facility may vary. An averaged approach cannot be used. This can lead to an unexpected production facility shutdown due to the lack of plates in any of the series.

The difference in obtained conclusions (Tables 2 and 3) when studying plates by plate mass and length shown above is significant. Whereas only seven batches (5, 8, 9, 11, 12, 13, 14 of Table 2) have no premium grade by plate mass, all 15 batches (Table 3) have no premium grade by plate length.

Measurements of mass and length in replaceable cutting plates of hard alloy attest to a strange situation with regard to plate quality which emerged both on manufacturer's and consumer's side. The following conclusion can be made:

1. There is an issue with increasing metal-cutting tool quality. This was proved when taking into account only two parameters and many more should be considered.
2. The articulated results point at an insufficient level of manufacturer's plate quality control. They also show that consumer's plate incoming quality control is required. This requires additional time and money expenditures.

Summarizing information on the total impact of all controlled parameters allows making the following conclusions.

1. Only 38 of all plates (13%) correspond to the first grade. This is only taking into account plate mass. There is no plate corresponding to first grade by all 4 controlled parameters. This means that there are no plates which can be used at engineering facilities involved in high-precision part production.
2. The plates are mostly defective by plate length (48%) and width (40%). Plates defective by mass comprise 35%. The least number of defective plates (7%) is by plate thickness. 7 plates are defective by all four controlled parameters.
3. A share of the plates refers to the same grade by all controlled parameters. This mostly (13% of the total) refers to the second grade.
4. The instability of the second grade percentage by series means that plate manufacturing technology is poorly controlled and not oriented at high quality.
   The fact that there are a lot of plates referring to the second grade by all controlled parameters means that the considered plate nomenclature is mostly oriented at manufacturers involved in general engineering (not high) precision part manufacture.
5. The conclusion in para. 1 that there are first grade plates by mass does not mean that other plates are of good quality by this parameter. There are cases when plates are defective only by this parameter and show satisfactory results by all other controlled parameters.
   There are also cases when a plate refers to a certain grade by all parameters but mass. These facts may mean that plate mass is the worst controlled (and regulated) by plate manufacturer's parameter.
6. With such unstable plate quality, a consumer facility cannot buy precisely the required amount of plates for its production needs. The consumer facility is forced to:

a) buy a larger number of plates (with no guarantee of what defect percentage will be) which leads to the increase of tool costs;
b) introduce plate incoming control which leads to a significant increase of tool cost share in the part production costs.

4 Conclusion

The work outlines the principles of improving technological processes for machining hard-to-process materials. New instrumental materials and tools were created, based on them.

As a result of the work, a simulation technique was created, that allows predicting the tool life, to create models of new tools for new operating conditions.

The achieved result allows reducing tool consumption by 3 times, to expand the tool application area, to increase the machining efficiency without decreasing the quality.

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Production Process Impact on Permanent Electron-Beam Weld Connection Characteristics for Assembly of Large Titanium Aircraft Primary Structural Components

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Abstract. Purpose: This study aims to assess the impact of production processes on permanent connections in the titanium primary structural components made by electron-beam welding and their properties based on the specific welding defects.

Design/Methodology/Approach: Templates from the VT20 alloy and the VT23 alloy with their sizes corresponding to the maximum number of defects revealed analytically were studied. Electron-beam welding was performed with the KL-144 machine and the 30E3000 machine. The welds were inspected visually and dimensionally and radiographically with preliminary cutting with the Danobat machine with cutting oil. Conventional heat treatment in the UVN-1500 vacuum furnace and accelerated heat treatment in the Graficabro resistance furnace in different temperature ranges were performed. The mechanical properties of the permanent connections were evaluated with a static tensile test and an impact test using the Instron 3382, Shimadzu AG-X, and JB-300 W test machines.

Findings: Defective areas filled with capillary condensed moisture in the surface and near-surface layers lead to specific defects such as submicroporosity in the permanent electron-beam weld connections. Linear submicroporosity appears in the radiographic films as dark streaks. The detected defects lead to the deterioration of mechanical properties and generally to a complete lack of plasticity in the permanent connections.

Originality/Value: Accelerated heat treatment completed the phase change process within a certain time (90 to 120 s) and enhanced the mechanical properties of the permanent connections. Heat treatment has been found to remove specific defects due to the system's tendency to minimize energy while reducing the surface boundaries of submicroporosity.

Keywords: Titanium alloys · Heat treatment · Permanent connections · Mechanical properties · Electron-beam welding · Primary structural components · Phase changes

JELCode: L61 · L64 · Q33

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1 Introduction

The use of titanium and its alloys in aerospace engineering as a structural material is driven by their unique properties: high strength-to-weight ratio, corrosion resistance, heat resistance, etc. compared to steel and even aluminum alloys (Muravyov et al. 2009). The good weldability of titanium and its alloys holds a wide range of options for producing permanent connections by fusion welding structural aircraft components with a concentrated beam of high-energy (Gurevich et al. 1986).

A significant disadvantage of fusion welding for producing permanent connections is various defects, mainly, porosity, residual stress, warping, etc. due to chemical and physical heterogeneity of the connection area (Redchits et al. 2002, Gouret et al. 2004).

Researchers have different opinions about the causes and circumstances of porosity in the weld metal when welding titanium and its alloys. Nevertheless, the most reliable theory of porosity formation in the titanium alloy welds is the theory of a solid-phase bond at the edge connection outside of the liquid metal pool welding up any edge end defects and forming the gas-containing closed cavities that are introduced in the molten metal (Vilkhman et al. 2014). The reliability of the proposed theory is evidenced and clarified by hard evidence of the impact of the surface and near-surface defects in the welded blanks contributing to the condensation of capillary condensed impurities (moisture, cleaners, etc.) depending on the blank manufacturing conditions that are introduced into the liquid metal pool and split with the formation of porosity. An increase in the lifetime and enhanced agitation of the liquid metal pool leads to a complete removal of porosity in the permanent titanium alloy connections made by subsurface gas tungsten arc (GTA) welding (Dolotov 2004) while creating conditions for producing the permanent subsurface GTA weld connections in the structural elements untreated after cutting.

The article (Dolotov 2004) describing a method using a dual-tip electrode that provides the ability to change the lifetime of the liquid metal pool in a wide range and choose the time that will reduce porosity and maintain the permanent connection properties similar to the base metal properties is the most remarkable.

When producing the permanent titanium alloy connections by electron-beam welding (EBW) that has significant advantages over gas tungsten arc welding, along with the above defects, there are other defects inherent only in this welding type: root cavities, uneven weld root penetration, deep craters, and large blowholes (Vikhman et al. 2014; Vasilyev et al. 2015; Pupusha and Andreev 2017).

Defect formation due to an inadequate temperature of the permanent connection edges to be welded or edge “sticking” without diffusion interaction or porosity caused by different diffusion processes on the boundary surface inside the grain (Dolotov 2004) is less studied.

Given the complexity of the conventional heat treatment conditions (the size of the vacuum systems, thermal stabilization, temperature stabilization, and the subsequent cooling process), other more efficient and cost-effective heat treatment conditions for the permanent fusion weld connections should be explored. The heat treatment processes under the phase change conditions (Lyakhovitsky et al. 2009; Bashkov et al. 2016; Semashko et al. 2002) are prominent.

The purpose of this study is to assess the impact of production processes on the permanent electron-beam weld connection properties based on the specific defects inherent in this fusion welding type.

2 Materials and Method

For the study, templates from the VT20 and VT23 alloy with the sizes corresponding to the maximum defects revealed at a structural assembly during serial production (Table 2) were made. The EBW machines and conditions for producing the permanent connections during the structural assembly were selected following the same criteria as the template size for comparison with the conventional ones (Table 1).

The coupons were prepared and fitted up using a conventional technology including degreasing of the welded part surface and the startup and runoff tabs with industrial ethyl acetate and drying with alcohol and startup and runoff tab tack welding by gas tungsten arc welding.

After the preparatory operations, the coupon was secured in the fixture and pushed into the vacuum chamber of the electron-beam machine. After pushing in the coupon, the edges to be welded were cleaned and tack welded.

Table 1. EBW conditions for VT20 alloy (130 × 30 × 40) and VT23 alloy (130 × 50 × 40; 30 × 60 × 40) templates

Electron-beam machine	Alloy grade and thickness (h), mm	I_w, mA	I_f, mA	F, mm	V_{trav}, mm/sec	Welding conditions number
KL-144	VT20, h = 30	320	600	200	16	I
	VT20, h = 30	350	600	200	16	III
	VT20, h = 30	150	600	200	10	III
	VT23, h = 60	420	600	200	10	IV
	VT23, h = 60	470	600	200	10	V
30E3000	VT23, h = 50	415	600	200	7	VI

Note: I_w: welding amperage, I_f: focused current, F: distance between gun edge and workpiece, V_{trav}: travel speed

After welding, a visual and dimensional inspection for burn-throughs, craters, or lack of penetration was performed. The template welds were cut with the Danobat automatic band saw with cutting oil. The cut-out templates were radiographically inspected using the EXTRAVOLT-225 machine.

The VT23 alloy coupons were conventionally heat-treated in the UVN-1500 vacuum furnace, annealed at 750 °C for 30 min, aged for 10 h at 550 °C, and the VT20 alloy coupons at 750 °C for 30 min in the vacuum furnace and at 690 °C for 2 h in the electric furnace. Accelerated heat treatment was performed in the Graficabro resistance furnace;

the furnace was heated to 980 °C, then the coupons were placed, and each coupon was held for 15, 30, 60, 90, and 120 s.

The mechanical properties of the permanent connections were evaluated with a static tensile test using the Instron 3382 and Shimadzu AG-X test machines and an impact test with the JB-300 W impact machine. The microstructure and macrostructure were assessed using the Nikon MA200 metallographic microscope and the Hitachi S3400N scanning electron microscope. Microhardness was measured with the Shimadzu HMV2 microhardness tester.

3 Results

During EBW, vapor plasma forms due to fierce evaporation of the material when the metal is melted by an electron beam (Nazarenko et al. 1985, Trushnikov et al. 2013, Varushkin et al. 2015).

As Fig. 1 shows, the weld dimensions are acceptable, and any weld width deviations in the reinforcement area are not observed (Fig. 1a). The weld ends with an EBW typical crater (Fig. 1b). The weld root fracture (refer to Fig. 1d for the penetration end zone) has the EBW specific defects such as spiking.

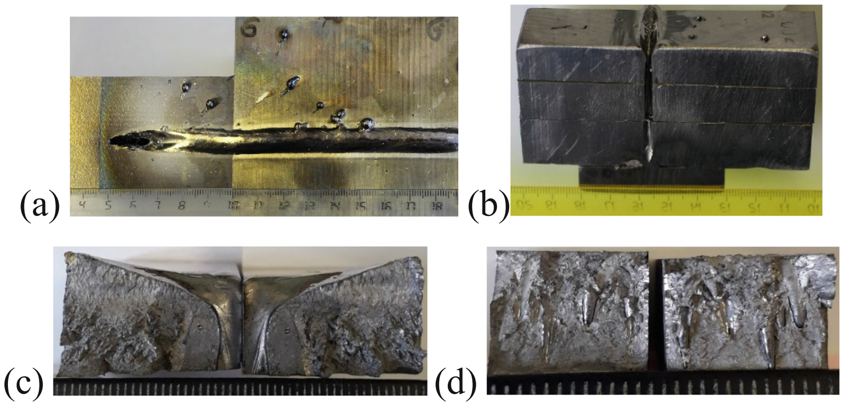

Fig. 1. Typical crater view at EBW end for 50-mm thick VT23 alloy template (Table 2) produced with 30E3000 machine: (a) weld surface view; (b) crater section and penetration view; (c) crater fracture view in reinforcement zone; (d) weld root fracture view. *Source*: prepared and compiled by the authors

The distribution of the defect types detected by a radiographic inspection is shown in Fig. 2.

Analysis of mechanical properties. Static tensile tests and dynamic impact tests have shown that the permanent EBW connections in the titanium alloy coupons failed mainly in the fusion zone between the liquid metal pool and the base metal of the heat-affected zone (Fig. 3).

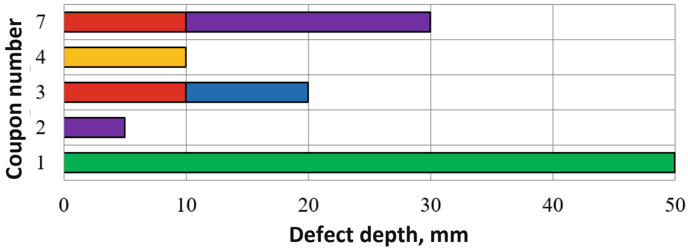

Fig. 2. Distribution of defect types for VT23 alloy template VI in Table 1: ■: dark streaks; ■: linear porosity; ■: lack of fusion; ■: crater; ■: clustered porosity. *Source*: prepared and compiled by the authors

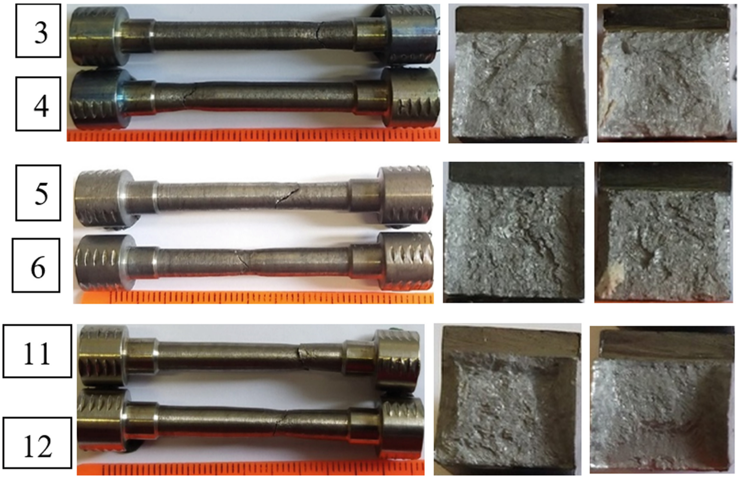

Fig. 3. Most typical failure types for permanent connection coupons from VT20 titanium alloy versus EBW conditions and post-weld heat treatment with numbers specified in Table 2. *Source*: prepared and compiled by the authors

In this case, the process of failure follows the basic concepts of physical mesomechanics for plastic strain and fracture of solids. The material is fragmented at mesolevel such as stretcher-strain marks (Chernov-Lüders bands) due to potential displacement of differently-sized structural elements (subgrains, grains, their conglomerates, elongated material blocks) (Zuev et al. 2008). The fragmentation is particularly pronounced in the localized neck areas of the coupons to be tested (Fig. 3).

Strain diagrams for the permanent connection materials during static tensile tests described by the following phases: elastic strain, uniform strain, and concentrated strain – have identified the impact of various factors on the process of failure in each phase and, finally, the weld connection properties (Fig. 4 and Table 2).

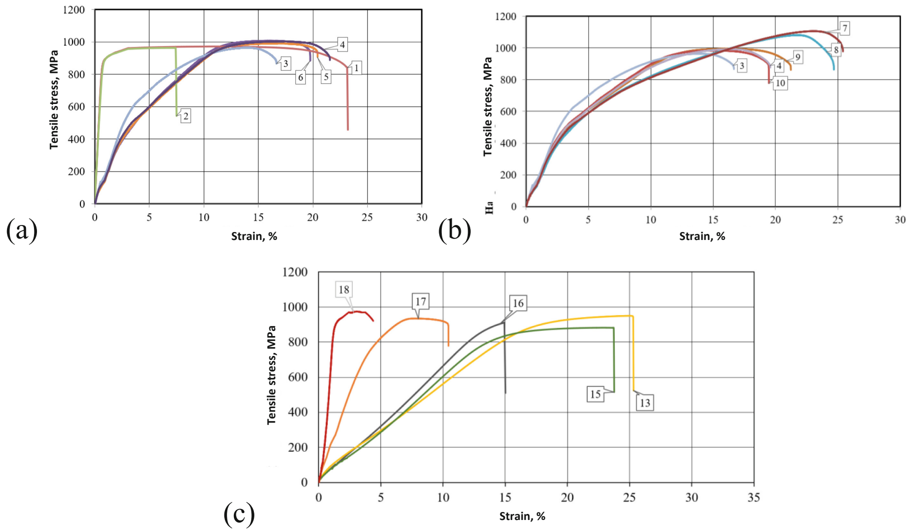

Fig. 4. Strain diagrams for EBW welding coupons from VT20 titanium alloy (a and b) and VT23 titanium alloy (c). *Source*: prepared and compiled by the authors

As Fig. 4 shows, there is also a correlation with the surface preparation conditions for the edges to be welded and the EBW conditions and the post-weld heat treatment conditions expressed through strain (between 0.01 and 30%) and stress fluctuation (between 963 MPa and 1,106 MPa for the VT20 alloy and between 888 MPa and 1,071 MPa for the VT23 alloy). At the uniform strain phase close the elastic strain phase, coupon 2, 5, 9, 13, 15, and 16 failed; at the uniform strain phase close to the concentrated distortion phase, coupon 14, 15, and 19 failed; and the remainder have survived all the phases.

It is well known (Zuev et al. 2008) that along with the dislocation theory of plastic strain by sliding and twinning, there is a process of plastic strain relaxation when stress is redistributed and its general level is reduced due to shear processes that activate adjacent volumes with the emergence of new zones defining, in general, its self-catalyzed nature when the final result returns the system to its initial condition with a subsequent repetition of similar cycles. Therefore, for the coupons that failed at the elastic strain phase or the uniform strain phase close to it (2, 5, 9, 13, 15, and 16), stress did not adequately relax, and the volume of accumulated energy did not return to its initial condition. At a certain stage, the distortion process reached the bifurcation point and changed due to the residual stress defects, porosity in the fusion zone, expulsion, and spiking that resulted in submicrocracks and failure caused by the Peierls-Nabarro force ($K = 2\sqrt{\frac{l}{r}}$) exceeding the interatomic bonding.

When examining the fractures in the surface layer of the crystallized liquid metal pool pressed against the back wall of the crater by vapor plasma, the clearly defined submicroporosity and porosity are detected (Fig. 5).

Table 2. Change in mechanical properties of permanent connections in VT20 and VT23 alloy templates versus EBW conditions and heat treatment

Material condition		Coupon number	Static tensile test				Impact test		
			σ_{ts}, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %	KC, J/cm^2	KCU, J/cm^2	Bending angle, α°.
VT20 template h = 30 mm	BM_{orig}	1	972	885	3.8	16.8	–	262	38
	Weld W/o HT	2 I	963	886	0.6	2.1	–	66	8
		3 II	967	530	8.4	17.3	65	–	–
		4 III	1,002	492	8.44	16.6	50	–	–
	Weld, HT	5 II	990	472	4.73	8.84	40	–	–
		6 III	1,006	481	8.2	15.7	61	–	–
	Weld, AHT	7 II, 30'	994	501	10.73	12.64	46	–	–
		8 III, 30'	984	512	8.8	13.12	56	–	–
		9 II, 60'	963	574	6.32	15.77	50	–	–
		10 III, 60'	992	506	5.77	11.83	69	–	–
		11 III, 90'	1,106	481	14.42	10.89	56	–	–
		12, II, 90'	1,081	465	10.54	16.2	58	–	–
VT23, h = 60, 50	BM_{orig}	13	951	779	0.31	2.7	–	132	20
	Weld, w/o HT	15 VI	888	754	0.3	2.8	–	37	6
		16 IV	912	837	0.1	2.6	–	68	9
	Weld, w/HT	17 V	935	651	16.3	6.6	–	17	4
		18 VI	1,071	300	29.2	8.5	–	39	5

Note: BM_{orig} is original base metal; weld, w/o HT is weld without heat treatment (welding conditions I to IV, Table 2); Weld, HT is after conventional heat treatment; Weld, AHT is accelerated heat treatment.

The analysis of the weld microstructure in a 50-mm thick VT23 alloy template welded by EBW with the 30E3000 machine has shown that along with submicroporosity caused by the capillary condensed contamination (Fig. 6b), it may also occur because of low electron beam energy to generate vapor plasma that is inadequate for the temperature of the edges to be welded. There is a partial penetration along the grain boundaries because of different diffusion processes on the boundary surface and inside the grain.

This is particularly clearly observed in the area where the boundaries of three grains meet as shown in Fig. 6a. The microstructure in the fusion zone has submicroporosity and the coalescence of small pores into larger pores in the weld area (Fig. 6a, 6b, and

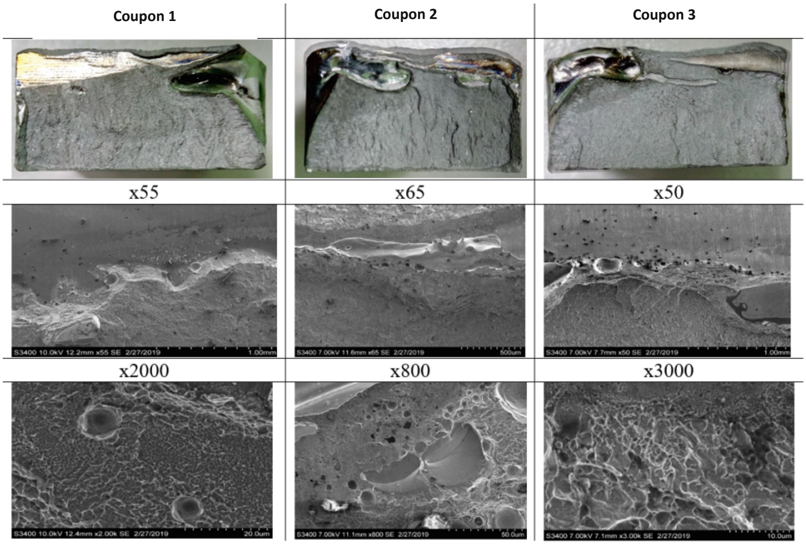

Fig. 5. Submicroporosity in fusion zone of liquid metal volume pressed against back wall of crater by electron beam vapor plasma. EBW of VT20 alloy templates with thickness of 30 mm. *Source*: prepared and compiled by the authors

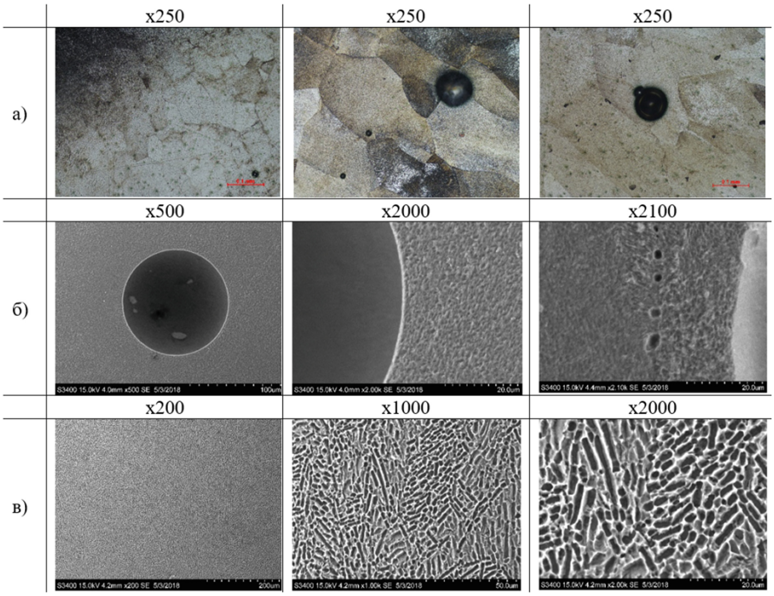

Fig. 6. Microstructure after electron-beam welding of 50-mm thick coupons from VT23 alloy templates obtained by optical (a) and electron microscopy (b and c). a and b: weld; c: base metal. *Source*: prepared and compiled by the authors

6c). The weld microstructure is coarse-grained with the clearly visible grain boundaries (Fig. 6a) and a fine mixture of the α and β phases inside the grain (Fig. 6b and 6c).

As Table 2 (coupons from 7 to 12) and Fig. 6 show, the process of phase change in the permanent VT20 and VT23 alloy connections electron-beam welded at the heating rate inside the temperature range of phase change occurs within a short period of time (90 to 120 s). The kinetics of phase change is characterized by a phased change in both mechanical properties and microhardness.

Initially, due to the removal of residual welding stress and reduction of structural heterogeneity, there is an increase in microhardness followed by a slight decrease essentially down to the microhardness caused by conventional heat treatment due to fast recrystallization. It should be highlighted that microhardness of the weld metal and the heat-affected zone significantly increases after EBW with a considerable difference that completely disappears during fast recrystallization (Fig. 7).

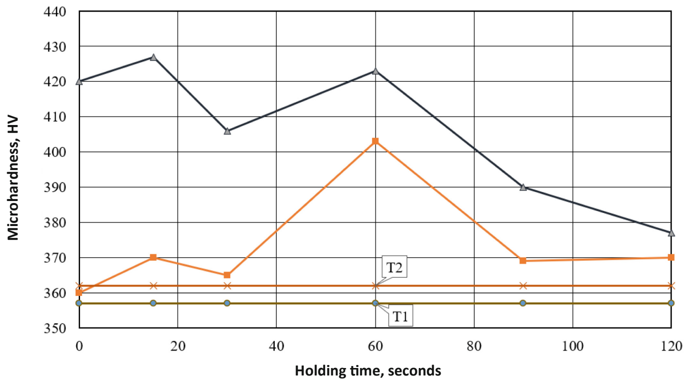

Fig. 7. Kinetics of weld microhardness change for VT20 alloy coupons versus EBW conditions and heat treatment: T1: heat treatment at 650 °C for 2 h in air atmosphere electric furnace; T2: heat treatment at 750 °C for 30 min in vacuum furnace. ▲: microhardness of metal weld; ■: metal microhardness in weld-affected zone. *Source*: prepared and compiled by the authors

4 Conclusion

The defective surface and near-surface layer at the edges of the blanks loaded with the capillary condensed impurities leads to the fusion zone submicroporosity in the weld metal of the permanent EBW connections from titanium alloys and porosity in the weld due to coalescence. Linear submicroporosity in the fusion zone appears in the radiographic films as dark streaks (Fig. 2) and leads to the deterioration of mechanical properties and nearly a complete lack of plasticity. Heat treatment prevents submicroporosity and submicrocavities; accelerated heat treatment enhances mechanical properties.

The low energy of the electron beam leads to submicrocavities due to partial penetration along the grain boundaries because of different diffusion processes on the boundary surface inside the grain. Typical submicrocavities occur where the boundaries of three grains meet (Fig. 6a).

The most viable method to prevent the specific defects of the permanent EBW connections in titanium alloys is to analyze the electron beam oscillation (Kar et al. 2019) and identify the life conditions of the liquid metal pool that stops defects and boosts properties.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Production Process Specifics for Permanent Fusion Weld Connections When Assembling Aircraft Titanium Ribbed Panels

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Abstract. Purpose: The purpose of this study is to ensure the stable production of permanent connections for the titanium ribbed panel assembly and improve the properties and reliability of aircraft titanium structural components.

Design/Methodology/Approach: The permanent connections were studied using the VT20 alloy workpieces made by gas tungsten arc welding. The radiographic inspection was performed with the RAP 150/300 machine with accelerated heat treatment in the Graficarbo resistance furnace and conventional heat treatment in the UVN-1500 vacuum furnace at different temperature bands. Mechanical properties were evaluated by static tensile tests and bending angle using the Amsler-10 test machine, microstructure and macrostructure with the Nikon MA200 metallographic microscope and Hitachi S3400N scanning electron microscope, and Vickers hardness with the Shimadzu HMV-2 microhardness tester.

Findings: A shorter lifetime of the molten metal pool has been found to form porosity and reduce the strength of permanent connections in static bend tests. Accelerated heat treatment and conventional heat treatment provide nearly complete alignment between the mechanical properties of the weld and the base material.

Originality/Value: The collected experimental evidence confirms that heat treatment can be performed directly during the welding of aircraft titanium ribbed panels with shielding gas.

Keywords: Titanium alloys · Heat treatment · Permanent connections · Mechanical properties · Gas tungsten arc welding

JEL Code: L61 · L64 · Q33

1 Introduction

Titanium alloy efficiency for aerospace engineering is ensured by high strength-to-weight ratio, heat resistance, and corrosion resistance compared not only to steel but also aluminum alloys (Muravyov et al. 2009; Bashkov et al. 2015). Therefore, titanium and

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titanium alloys are widely used for supersonic aircraft skin, wing leading edges, horizontal stabilizer, ailerons, and the major frame elements of the body, wing, and tail (Bratukhin et al. 1995).

As mentioned in the publications of Bratukhin (1995), Paton et al. (2014), and Barsky (2019), titanium alloys are useful in the assembly of large ribbed panels with both simple and complex spatial structure with permanent connections made by different fusion welding types with a concentrated beam of high-energy.

This is facilitated by a high surface tension coefficient (at 1600 °C $\sigma_{tens} = 1.7$ J/m^2) that contributes to an acceptable weld root of the permanent connection when assembling the unsupported titanium and titanium alloy panels (Muravyov et al. 2009).

Nevertheless, the use of these techniques for permanent connections in titanium panels is associated with some issues due to a high titanium reactivity when heated. The surface should be shielded from gas pick-up from the atmosphere (oxygen, nitrogen, hydrogen, and harmful impurities dramatically reduce the strength of the permanent connections) and porosity in the permanent connection area for all fusion welding types and, further, the defects specific to electron-beam welding in a vacuum (Kar et al. 2019).

The most common titanium arc welding process is gas tungsten arc welding. This process is the most versatile as it supports welding in various spatial positions, cramped conditions, and rapid equipment reconfiguration when changing the connection type and thickness of the metal to be welded. But welding permanent connections with this process when assembling light-wall structural components results in distortion and warping.

Parts in the main range of titanium alloy structural components in today's aircraft are workpieces with a complex spatial structure that are not virtually feasible to fabricate without such processes as stamping, heat treatment, and milling (Mokritskii et al. 2018), especially when welding permanent connections during structural assembly.

Historically, the ribbed panels are assembled with the permanent connections made by automatic gas tungsten arc welding (GTAW) with the USP-2,6 machine with the ADSV-6 automatic welder and the ASGV-4 head.

The welder or operator directly observes the production of the permanent connections, that is, the size of the molten metal pool, the resulting geometry, and if necessary, manually adjusts the welding conditions (I_{weld}, welding amperage, and the torch position relative to the weld vertical centerline). This leads to unstable welding due to the on-going parameter changes. It would not be correct to call such process automatic; it is actually semi-automatic.

For the pressing challenge of residual stress, the publication of Muravyov et al. (2009) suggests that it is removed from large structural components in an air atmosphere at lower temperatures using the existing electric furnaces due to the lack of suitable vacuum units. However, it will not completely remove residual stress.

Through analytical evaluation of the defects detected in the permanent connections made by GTAW, Muravyov et al. (2009), Redchits et al. (2002) have found that between 43 and 56% of the total identified defects was porosity. Porosity located near the surface poses particular risk since it drastically reduces the fatigue strength of the permanent connections not only as geometric stress raisers but mainly as a result of a lower metal ductility margin in the vicinity of the porosity boundaries due to a multi-fold increase in hydrogen content (Lukoyanov 2014).

Analytical evaluation of the porosity behavior suggests that the theory of Redchits, Frolov et al. (2002), which has been recognized by many researchers and continuously confirmed, is more reliable. When heated during the assembly, the permanent connection edges are displaced and a solid-phase bond is created in the connection at the outer edges of the liquid metal pool welding up any edge end defects, and the gas-containing closed cavities are generated that are introduced in the molten metal pool forming gas bubbles, that is, porosity.

The publications of Muravyov et al. (2009), Redchits et al. (2002), Huang et al. (2013) show that the major driving forces for porosity in the metal of the permanent titanium alloy connections made by fusion welding are microcracks, submicrocracks, and discontinuities filled with capillary condensed impurities caused by the processes of shaping the interface edges to be welded. Porosity in the permanent connections is known to occur when using a filler wire with capillary condensed impurities on its surface. Therefore, evaluating the surface quality of the edges to be welded based on the roughness parameters is, basically, inefficient (and incorrect). A general pre-assembly quantitative evaluation technique for the degree of the capillary condensed edge contamination has been proposed; it determines the efficiency criteria for using separating processes to shape the workpiece surface for welding the permanent connections and predicts the permanent connection defect level (between zero to unacceptable) based on the degree of the capillary condensed surface contamination. These permanent connection production processes increase labor intensity.

The publications of Paton et al. (2014) and Redchits et al. (2002) suggest that the flux is used for the permanent connections when assembling individual structural elements by GTAW, but it will increase the lifetime of the molten metal pool and decrease the mechanical properties such as strength and reliability of the permanent connections.

The method to reduce porosity in the permanent connections during assembly by GTAW with a W-shaped non-consumable electrode tip that helps manage the lifetime of the molten metal pool is prominent (Muravyov et al. 2009). A critical disadvantage of this method is the high consumption of the non-consumable electrode.

Stable production of permanent connections for titanium panel assembly by fusion welding, decrease in residual stress, prevention of porosity, reduction of labor intensity, and enhancement of properties and reliability of titanium structural components in the context of GTAW is the purpose of this study.

2 Materials and Method

Diversity of the concepts about the causes of porosity in the titanium alloy welds can be explained by the complex physical and chemical phenomena of porosity occurrence and an attempt to address the challenge in isolation without considering the multitude of the main contributing factors. This project is based on the theoretical and experimental mechanisms of porosity occurrence (Redchitz et al. 2002).

Production of permanent connections in the VT20 alloy workpieces ($200 \times 3 \times 700$) made by automatic gas tungsten arc welding (premium grade argon, GOST 1057-79) with the VT1-00 filler wire in the conditions listed in Table 1 has been studied.

The radiographic inspection was performed with the RAP 150/300 machine as per GOST 7512-82; mechanical properties were tested with the Amsler-10 testing machine

Table 1. Automatic gas tungsten arc welding conditions for USP-5000

Coupon number	I_{weld}, A	U_{arc}, V	V_{trav}, mm/sec	$V_{\Pi p}$, mm/sec	Argon flow rate, l/min		
					Torch	Trailing shield	Backup shield
1	280	16.5	2.2	7.0	7.0	6.0	5.0
2	280	16.5	2.5	7.2	7.0	6.0	5.0
3	280	16.5	2.5	7.2	7.0	6.0	5.0
4	280	16.5	2.5	7.2	7.0	6.0	5.0

Note: I_{weld}: welding amperage, A; U_{arc}: arc voltage, V; V_{trav}: travel speed, mm/sec; V_{feed}: wire feed speed, mm/sec

as per GOST 6996-66; conventional heat treatment was performed in the UVN-1500 vacuum furnace at a temperature of $750^{\pm 10}$ °C for 2 h.

The mechanism's specifics for the development of a new stable structure during heat treatment in the temperature conditions of pre-transformation include weakening bonds across the grain boundary causing fast diffusion that helps form a more perfect structure with higher mechanical properties in a much shorter period of time (Gorelik et al. 2005; Terentev 2007).

Based on the above theoretical data, short-term accelerated heat treatment was performed in the Graficarbo resistance furnace. Chemical analysis and electronic fractography of the fracture microstructure in the permanent connections were performed with the Hitachi S3400-N scanning electron microscope. Microhardness was measured with the Shimadzu HMV-2 microhardness tester. Microstructure and macrostructure were examined with the Nikon MA200 metallographic microscope.

3 Results

The surface and geometry of the weld metal in the permanent VT20 alloy connections made in different conditions with the USP-5000 automatic gas tungsten arc welding machine meet the codes and standards.

Radiographic inspection of permanent connection workpieces identified porosity correlated to welding conditions, that is, the higher the travel speed and the filler wire feed speed, the higher porosity per 100-mm weld length (Table 2 and Fig. 2). This pattern may be explained by the fact that when the lifetime of the molten metal pool decreases due to higher travel speed, the final nucleated porosity caught in the molten mass fails to disappear from the melt and remains in the weld metal of the permanent connections.

An increase in the number of pores per 100-mm weld length of the permanent VT20 alloy connections leads to a reduction in strength and bending angle (Table 2). All the coupons (tested after welding) of the permanent connections made by automatic GTAW with the USP-5000 automatic welder failed at the fusion line and the weld center (Fig. 1).

Fractographic study of the weld metal fracture features for the coupons of the permanent VT20 alloy connections made in different automatic GTAW conditions subjected

Table 2. Welding conditions versus porosity and mechanical properties of permanent VT20 alloy connections

Welding conditions number from Table 1	Number of pores per 100-mm weld length, pcs	Mechanical properties	
		Strength, σ_{str}, MPa	Bending angle, α°
1	8	$\frac{920-1030}{980}$	$\frac{39-44}{41}$
2	12	$\frac{1020-1060}{1040}$	$\frac{37-40}{980}$
3	19	$\frac{930-980}{960}$	$\frac{32-38}{37}$
4	23	$\frac{880-930}{900}$	$\frac{33-39}{36}$

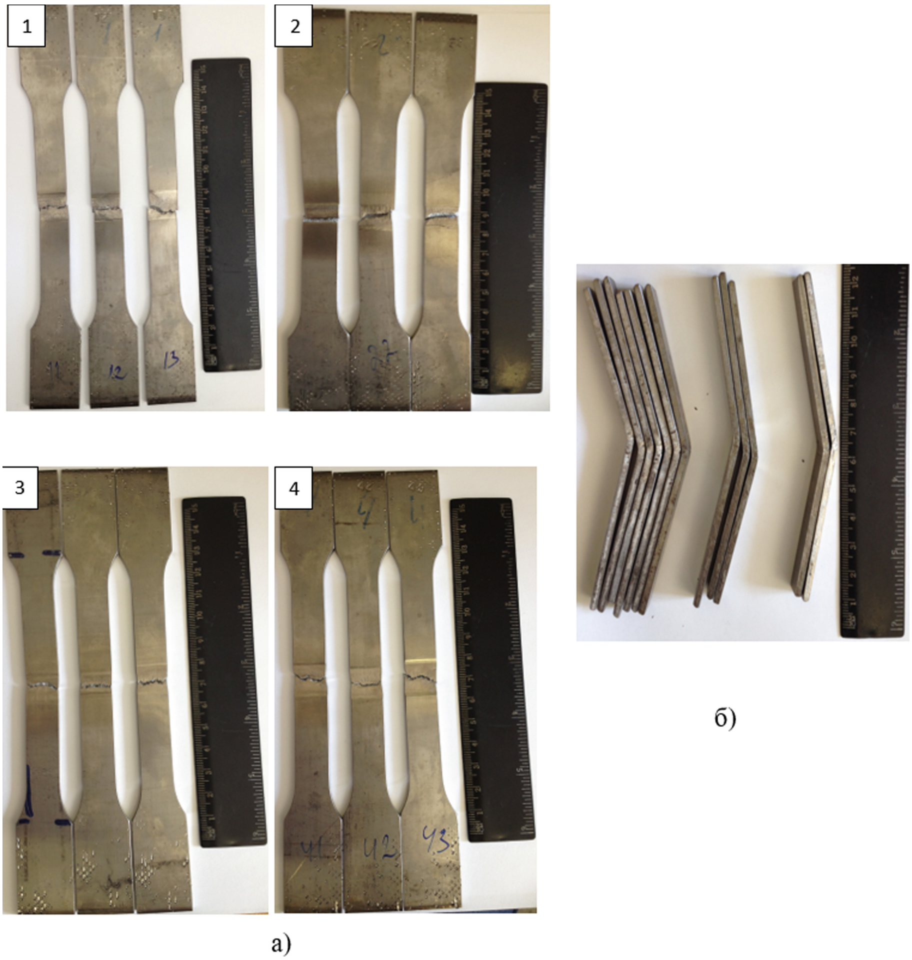


Fig. 1. Fracture type for automatic GTAW welding coupons after tensile strength tests (a, 1 to 4) and bend tests (b) *Source*: Images made by the authors

to static tensile tests have shown that for all the welding conditions, the fracture surface of the weld metal in the coupons is ductile as evidenced by the dimple structure on the fracture surface (Figs. 2-3 and 2-4). Moreover, the surface has been found to have large spherical cavities with a higher density at the edge that indicates failure in porosity (Figs. 2-1 and 2-2).

The conventional heat treatment conditions such as full annealing at 750 °C and under annealing at 650 °C have caused the properties of the permanent connections made by automatic GTAW with the USP-5000 machine to be almost fully identical to that of the base metal without any porosity.

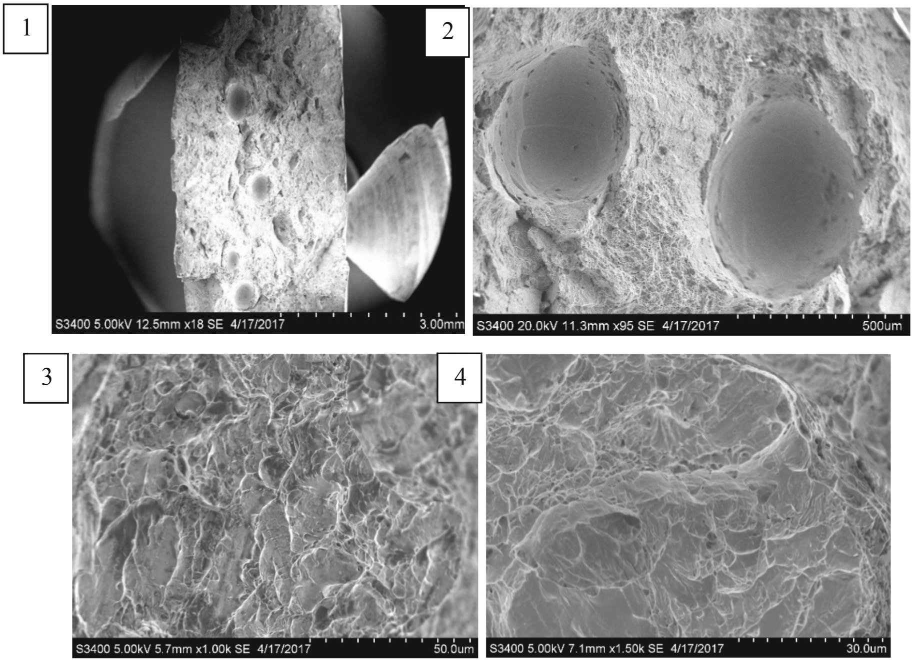
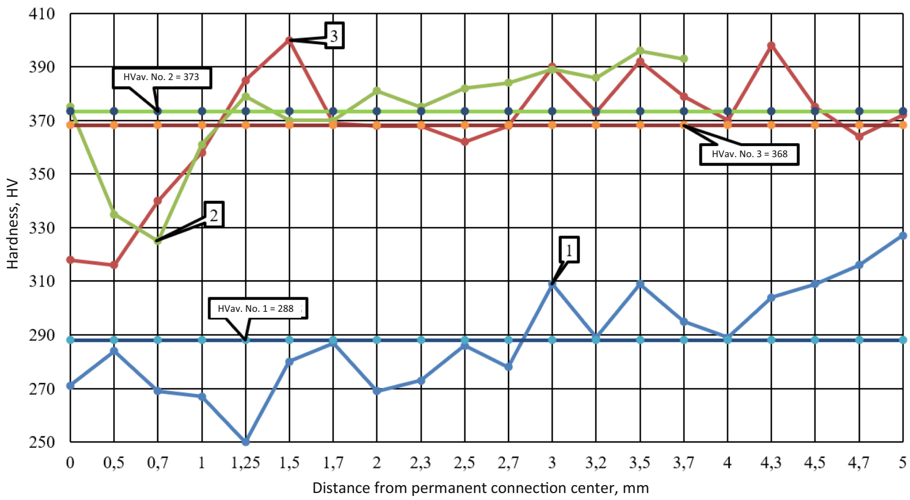


Fig. 2. Typical electronic photomicrograph for weld metal fracture surface of permanent VT20 alloy connection. *Source*: Images made by the authors

At the same time, there is a considerable difference between the microhardness of the weld metal and the base metal in the permanent connections made by automatic GTAW with the USP-5000 machine (Fig. 3) that is equalized by conventional heat treatment.

As Fig. 4 shows, phase change in the permanent VT20 alloy connections made by automatic GTAW with the USP-5000 machine with conventional heating at the phase change temperature band is completed within a short period of time. Kinetics of microhardness change is phased. In the initial phase, due to the removal of residual welding stress (reduction of structural heterogeneity), microhardness somewhat increases, then slightly decreases and increases again (due to fast recrystallization) up to the level equal to microhardness caused by conventional heat treatment (Fig. 4) (Fig. 5).



1: After welding; 2: After heat treatment at 650°C for 2 hours; 3: After heat treatment at 750°C for 0.5 hours

Fig. 3. Heat treatment conditions versus VT20 alloy weld and base metal microhardness for automatic GTAW with USP-5000 machine. *Source*: Prepared and compiled by the authors

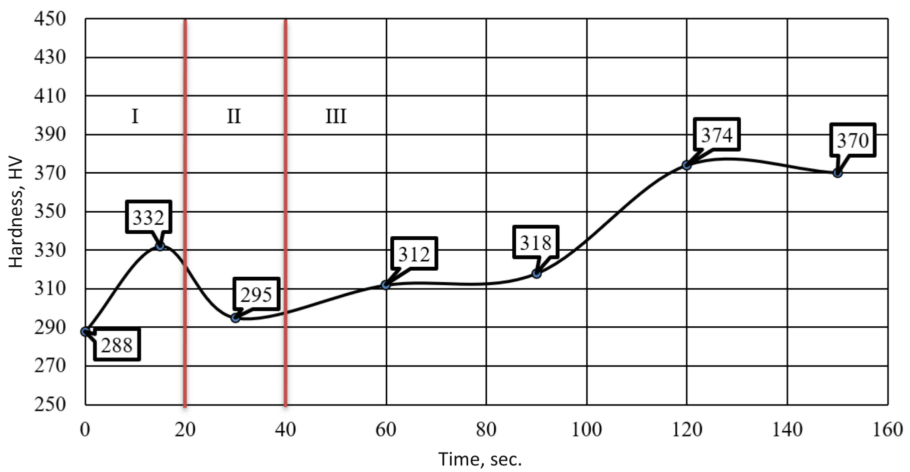


Fig. 4. Microhardness change in permanent VT20 alloy connections made by automatic GTAW with USP-5000 machine versus heat treatment by induction heating at phase change band (980 ± 50 °C. Phases: I: reduction of structural heterogeneity; II: recovery; III: grain growth. *Source*: Prepared and compiled by the authors

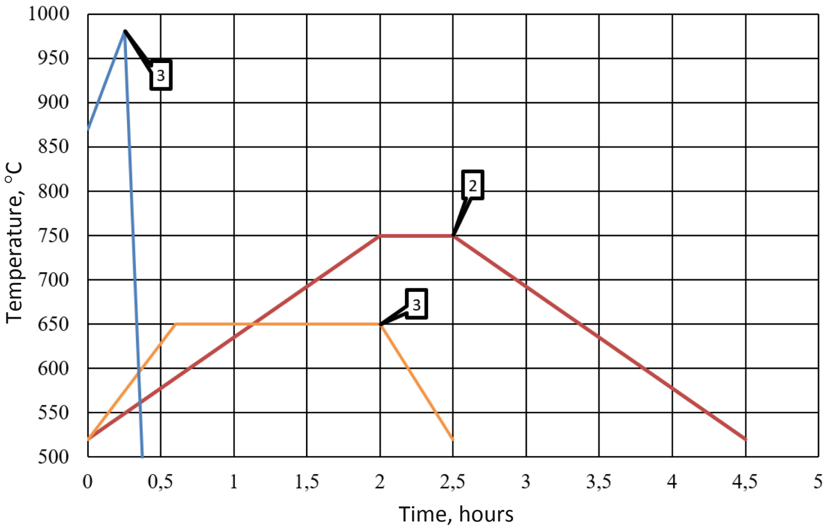


Fig. 5. Timing diagrams for heat treatment conditions of permanent titanium alloy connections welded with USP-5000 machine. 1: batch-type electric furnace; 2: UVN-1500 vacuum plant. 3: induction (or laser) heating directly in shielding atmosphere when producing permanent connections. *Source*:Prepared and compiled by the authors

4 Conclusion

Rapid crystallization of the molten metal pool leads to defects such as porosity and lower strength of permanent connections.

Conventional and accelerated heat treatment results in an acceptable strength of the permanent connection nearly equal to that of the base material.

The found evidence has shown that highly concentrated heat sources (induction, laser, electron-beam heating, etc.) may be used for heat treatment directly during the production of permanent connections in the same shielding gas as that is used for welding.

Acknowledgments. The study was carried out using the equipment of the Center for Collective Use "New Materials and Technologies" on the basis of KnASU.

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Power Transformer Electronic Starter

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Abstract. Purpose: The work is the development of a high-voltage power transformer electronic starter of the substation and the study of transients during start-up and transition to a stationary mode of operation.

Design/Methodology/Approach: The problem of starting power transformers with electric devices is considered, which is accompanied by current surges, voltage drops from consumers, electrodynamic shocks on transformer windings, DC components in magnetization currents and magnetic fluxes, additional starting losses in power transformers and in the network. It is proposed to change the situation for power transformers with simultaneous utility for both consumers and the network. This is achieved by adding an electronic part to the electric starter.

Results: The results of the study of physical processes in the Matlab software under starting a power transformer with the subsequent transition to a stationary mode of operation are presented.

Originality Value: The developed diode-reactor starter performs smoothly adjustable quasi-symmetric switching of the power transformer and has increased reliability. The transformer is controlled to be switched on with the leading phase of the first voltage harmonic, providing partial compensation of reactive power in the network during the start-up process. The originality of the technical solution is confirmed by the patent of the Russian Federation.

The soft switching of power transformers with the limitation of inrush currents in the power transmission is important both for the transformer structure and for the electric power industry.

Keywords: Starter · Power transformer · Electrical device · Electronic device · Diode rectifier · Reactor · Model in matlab software

JEL Code: C69 · Q40 · Q41 · Q49

1 Introduction

At existing transformer substations TS use uncontrolled switching on of power transformers PT with the help of electric devices (Sergeenkov et al. 1989), with simultaneous closing in all phases of mechanical contacts. With this method of switching on the PT, inrush currents and electrodynamic shocks occur on the transformer windings, voltage drops from consumers and additional losses in electrical equipment and in the network (Dan et al. 2007).

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To eliminate these disadvantages', a special method and algorithm for switching on RL-loads, in particular power transformers, is proposed, which can only be implemented using an electronic device, for example, a thyristor starter (Klimash and Tarakanov 2015).

However, thyristor starters during prolonged operation in power circuits themselves create additional losses of electricity, which in the form of heat are removed by radiators (Vashkelis et al. 1990).

Application of electronic-electric devices allows combining their advantages and eliminating disadvantages. The PT startup for parallel operation or under load by the electronic part of the device, and after its completion, the electronic part is shunted by the mechanical contacts of the electric device.

2 Materials and Method

A hybrid device specially designed for a power transformer (Liu et al. 2009) contains a circuit breaker, a thyristor switch and a contractor, which, after completion of the switching on process, shunts the thyristor switch with mechanical contacts. The known device, using a special control system for a three-phase thyristor switch, first connects two phases of the primary winding of the power transformer to the network at the moment of maximum line voltage from these two phases, and then connects the third. phase of the primary winding of the power transformer to the third phase of the network at the moment of transition of the same line voltage through zero.

Given the requirements for reliability of power supply systems, the disadvantages of the known starter with a thyristor controlled connection of a three-phase power transformer to the network include complexity and relatively low operational reliability.

Also known is an electronic-electric device for connecting a power transformer with an improved control algorithm (Klimash et al. 2012), which is more advanced. The electronic part of the devices operates in accordance with a special control algorithm and operations of the known method of switching on a three-phase power transformer, which complements the description of the electronic-electrical device, explaining the structure of its construction.

In the known device, after turning on the switch, a three-phase mains voltage is supplied to a valve converter made on thyristors (Klimash and Tarakanov 2014) and using a special synchronized and phased analog-to-digital converter - a digital control system with a network, connects the first of the two phase primary windings of the power transformer to the corresponding phases of the network at the moment when the phase voltage of the third phase of the network passes through zero, and then connects the primary winding of the third phase of the power transformer to the third phase of the network at the time of transition line voltage of the two previous phases of the network through zero.

After connecting the third phase primary winding of the power transformer to the network and the currents of the power transformer reach steady-state values, the valve converter is shunted by the mechanical contacts of the contactor. By this action, the electronic part of the device, together with losses on the thyristors, is cut off from the power supply system (Kholyavsky 1971).

However, this device also creates certain difficulties in the operation of power transformers of substations, which is associated with the presence of a microelectronic control system in the device and a decrease in the reliability of the power supply system as a whole. This disadvantage is especially evident in relation to high voltage power supply systems in the regions of the Far North with open-type transformer substations.

3 Results

A technical solution is proposed that greatly simplifies the operation and repair of the starter and increases its reliability, both of the electronic part of the device and of the power supply system as a whole. It consists in the fact that the electronic part of the device is made not on thyristors with a microelectronic control system, but on diodes (Bogomyakov et al. 2012). The design of the device is also simplified, which does not require special climatic design and protection from the effects of electromagnetic and electrostatic fields.

The essence of the proposed technical solution is illustrated by the following description and the accompanying drawings, where Fig. 1 shows a diagram of a device for switching on a power transformer.

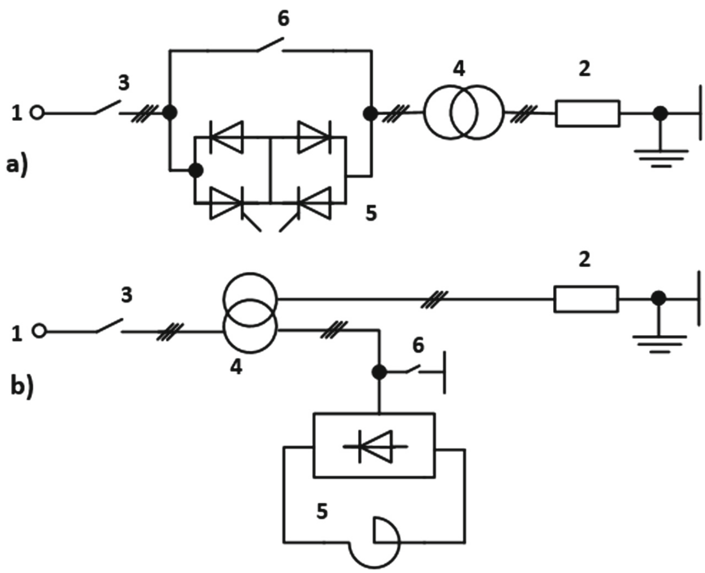

Fig. 1. Functional diagrams of devices for switching on power transformer with electronic starters: diode-thyristor (a); diode-reactor (b) *Source*: developed and compiled by the authors

The composition of the circuits with hybrid starters of the power transformer includes the following elements: 1 - three-phase network; 2 - RL-load of the transformer substation; 3 - network circuit breaker; 4 - power transformer; 5 - electronic part of the hybrid starter; 6 - electromechanical part of the hybrid starter.

In the circuit of the proposed starter (Fig. 1b), when the automatic switch 3 is switched on, the primary winding of the power transformer 4 is connected to a three-phase network 1 through a three-phase bridge diode rectifier 5 with a reactor in a DC circuit. In accordance with the laws of switching, the current through the reactor rises smoothly and in revenge with it the current and voltage of the primary winding of the power transformer change smoothly.

In Fig. 2 shows the waveforms of currents in relative units obtained on a block-modular model in MatLab software when the PT is switched on under load according to the standard transformer substation circuit (Fig. 2a), a circuit with a diode-thyristor starter (Fig. 2b) and a circuit with the proposed diode-reactor starter (Fig. 2c). Here, yellow, green and red colors respectively show phase A current, when the PT is switched on under load according to the standard transformer substation circuit (Fig. 2a), a circuit with a diode-thyristor starter (Fig. 2b) and a circuit with the proposed diode-reactor starter (Fig. 2c).

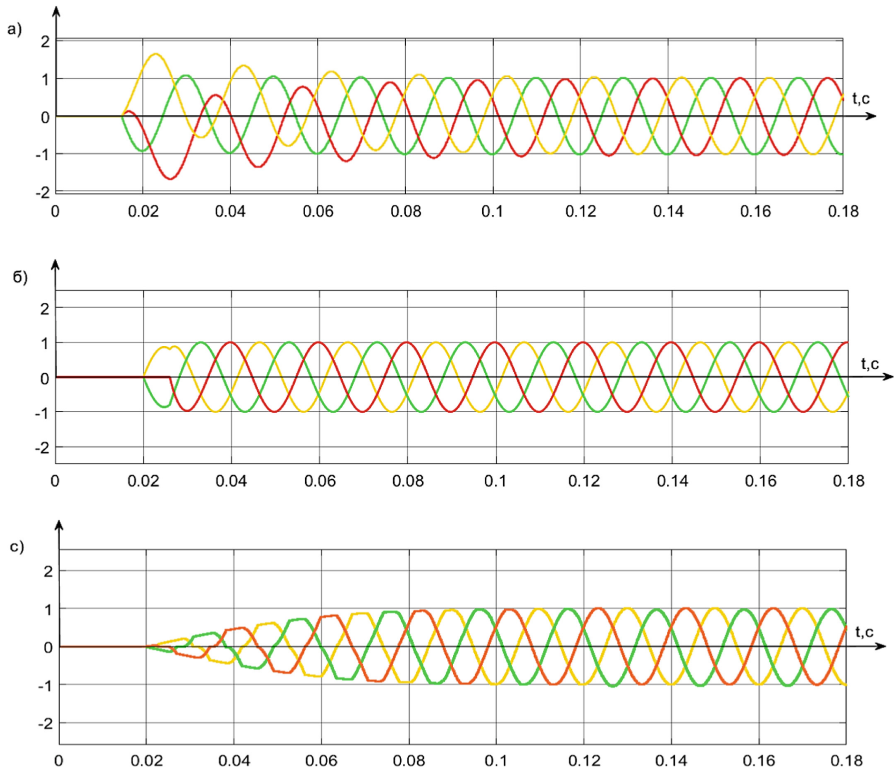

Fig. 2. Oscillograms of currents for three ways to switch on the power transformer under load: an electric device (a), a thyristor starter (b) and a starter on diodes with a reactor (c) *Source*: developed and compiled by the authors

From the oscillograms, the usefulness of using hybrid starters is seen both in the implementation of the second and third methods. They limit the starting current, and with it, the electrodynamic forces on the windings and starting losses in the network. During the start-up process, they remove the constant components in magnetization currents and magnetic fluxes, the voltage drops from consumers. At the same time, the advantage of the second method, implemented by diode-thyristor switches, is the possibility of applying the primary winding of the power transformer for any circuit and group and the high speed of the switching process (not more than 0.01 s). The advantage of the third proposed method, implemented by a diode-reactor device (diode rectifier with a reactor in a direct current circuit), is the high reliability of the hybrid starter (Klimash and Nimatov 2020).

Simulation in MatLab software of physical processes of diode-reactor starter of the power transformer of a substation In Fig. 3 shows a block-modular model of a transformer substation with a diode-reactor starter. The device model contains: three single-phase voltage sources (Ua, Ub, Uc); power line (PL); switches (Q1, Q2); diode-reactor starter module (DRS); power transformer (PT); three-phase active-inductive load (RL); current and voltage sensors (S_I, S_U) and other auxiliary elements. The module of the proposed DRS starter is included in the cut of the star of the primary winding of the power transformer.

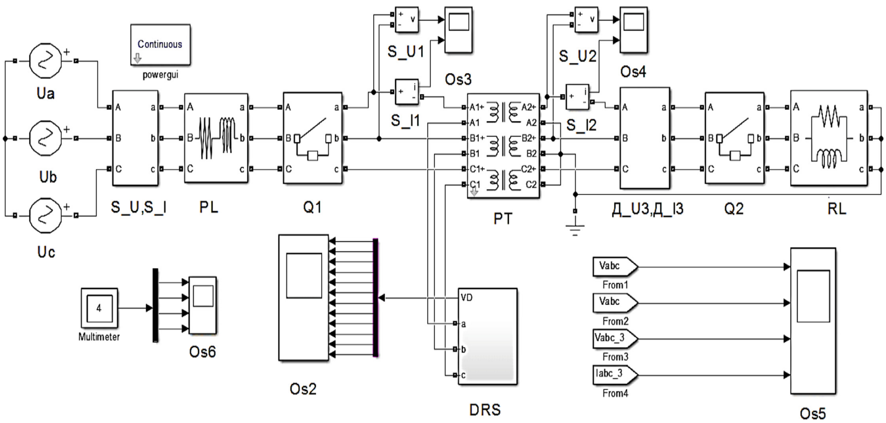

Fig. 3. TS model with electron-electric starter on the PT high side *Source*: developed and compiled by the authors

In Fig. 4 is a detailed diagram of a DRS module. It contains a 6VD three-phase diode bridge with an information output about the state of the VD valves, an SP smoothing reactor and a short-circuit contactor. The module of the proposed starter is included in the cut of the star of the primary winding of the power transformer.

It has been shown by numerical experiments in the MatLab software (German-Galkin 2013) that due to the natural switching properties of the diodes, the device makes a smooth symmetrical inclusion of power transformer 4 with the completion of the process of increasing phase currents and voltages on its primary winding (Fig. 5a-b) to steady-state values over several periods of mains voltage. The intensity of the start-up process of the power transformer 4 is set by the inductance of the reactor 6. Here, the oscillograms show the three-phase voltage systems u_a, u_b, u_c (a) and the currents i_a, i_b, i_c (b) of the primary winding of the power transformer, as well as the instantaneous values of the rectified voltage u_d and current i_d (c), in a circuit with a reactor obtained on

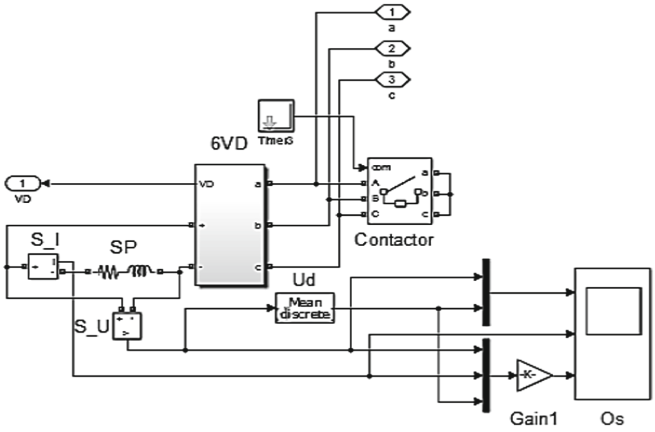

Fig. 4. Module diagram of the proposed starter *Source*: developed and compiled by the authors

a mathematical model in a MatLab environment when a power transformer is switched on under load.

It can be seen from the oscillograms (Fig. 5) that during the start-up of the PT there are no current surges causing a voltage drop. In addition, the starting transition process occurs with a smooth increase in voltage and a leading shift of its fundamental harmonic. The speed of the process of switching on the power transformer is about a tenth of a second (from 0.02 to 0.12). It is also seen that in the stationary mode of operation of the power transformer (at a specified time interval from 0.12 to 0.18 s during a numerical experiment), the network current has a sinusoidal shape.

In Fig. 6 in relative units shows the waveforms of voltages and currents at the input and output of the power transformer for one phase. It is seen that during the start-up of the PT there are no current surges and voltage drops. In addition, the start-up transient occurs with a smooth increase in voltage and a leading shift of the fundamental harmonic.

The mutual influence of physical processes in a direct current circuit with a reactor and a three-phase alternating current circuit with a power transformer gives rise to a new quality, which manifests itself in the start-up process by increasing the angle of natural switching of the diodes. This gives a diode bridge with a reactor in the rectified current circuit a regulating property similar to a thyristor voltage regulator with artificial switching (TRVA) (Rozanov et al. 2016). Due to this property, the starting device in the form of a diode-reactor starter with natural switching (DRPE) produces a smoothly regulated quasi-symmetrical switching of the power transformer with an increase in all phases of current and voltage according to the exposure law. It should be noted that the angle of natural switching of the diodes is equal to the angle of DRPE, resulting in controlled switching of the power transformer is produced with advanced phase of the first harmonic voltage, ensuring in the process of start-up partial compensation of reactive power in the network. After the phase currents of the power transformer reach the set values, the process of switching it on is completed using a short-circuit breaker that shuts the input terminals of the rectifier.

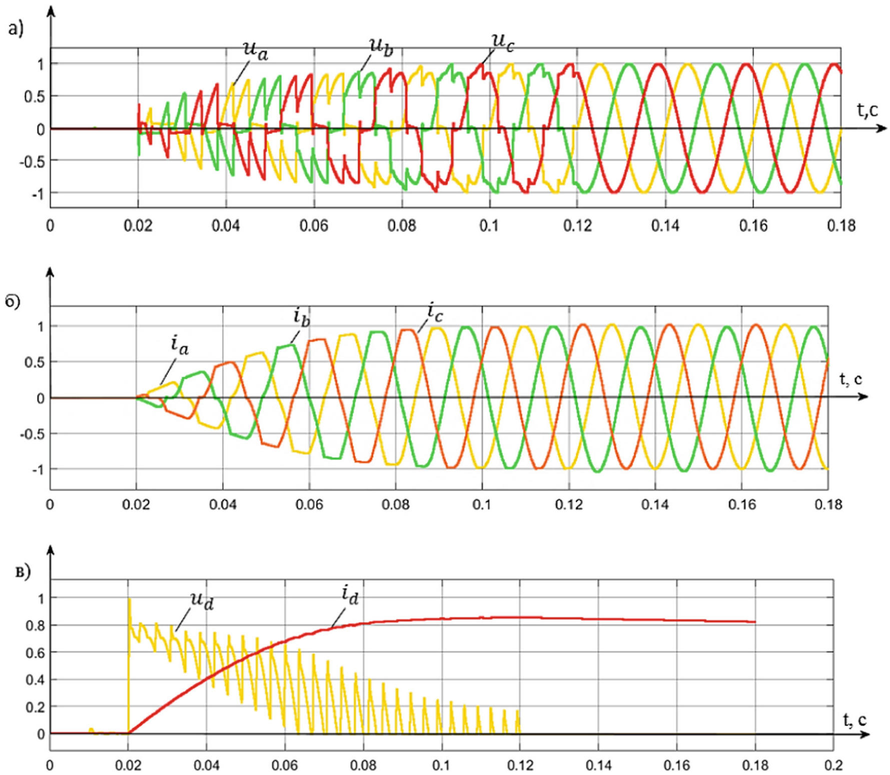

Fig. 5. Oscillograms of three-phase voltages (a) and currents (b) in the primary circuit PT and instantaneous values of the rectified voltage and current (c) in the circuit with the reactor *Source*: developed and compiled by the authors

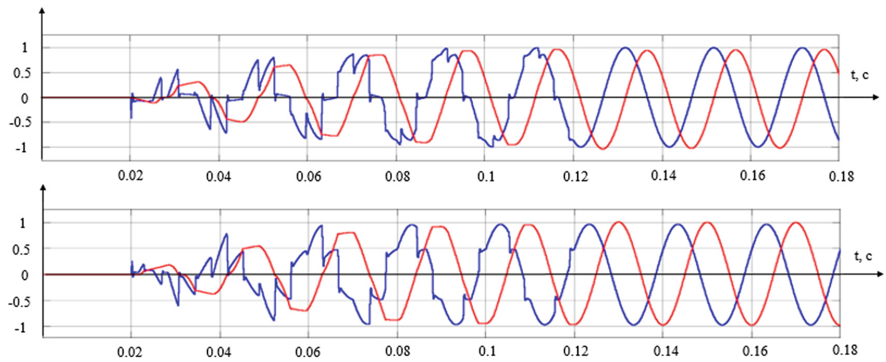

Fig. 6. Oscillograms of the voltage and current of one phase at the input (up) and output (down) of the power transformer when it is switched on by the diode-reactor starter *Source*: developed and compiled by the authors

Simultaneously with the voltage conversion, the currents in the primary and secondary phase windings of the power transformer 4 and in the network 1 change. First, the currents from a rectangular shape gradually acquire a trapezoidal shape, and then they also gradually take a sinusoidal shape (Fig. 5b).

After the currents of the power three-phase transformer 4 reach the steady values, the Electromechanical part of the hybrid starter 6 (three-phase short-circuit breaker) shunt the three-phase bridge diode rectifier 5 (Kopytov and Ulyanov 2018). With this operation, the device completes the process of shockless activation of the power transformer 4, providing a sinusoidal current in its windings and network.

The device for switching on a three-phase power transformer can be characterized as a hybrid electronic-electric device, which at the initial stage with relatively high speed forms the process of soft switching on the power transformer by an electronic device, and at the final stage an electric device shunts a three-phase bridge diode rectifier, cutting off the electronic part of the device from the system power supply.

4 Conclusion

As a result of the research conducted in the MatLab software, the following conclusions can be drawn:

1. The standard circuit of the transformer substation, equipped with electrical devices, does not provide controlled switching on of the power transformer. Starting under load with the simultaneous closure by mechanical contacts of all three phases occurs with inrush currents and voltage drops, large electrodynamic shocks on the transformer windings and starting losses.
2. The diode-thyristor starter provides controlled switching on of the power transformer with high speed, without exceeding the currents of their established values and without reducing the voltage. After switching on the diode-thyristor switches, it is shunted by an electric device. However, the microelectronic thyristor control system is vulnerable to large electromagnetic, electrostatic and thermal effects.
3. The proposed diode-reactor starter produces a quasi-symmetric controlled inclusion of the power transformer with a smooth increase in all phases of current and voltage. It lacks a microelectronic control system and therefore it is the simplest and reliable in operation.

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Operation Features Researching of Three-Phase Transformers Switched on to an Asymmetric Load

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Abstract. Purpose: The article is dedicated to the various parameters influence investigation on the transient currents inrushes, flowing at the three-phase transformer loading.

Methodology: The authors examined of the electrical power system components, analyzed the features of the electrical power system and the level of electricity losses in each element during its operation, depending on the load parameters. The paper outlines the main ways to control the elements of the electrical power system, their advantages and disadvantages. The basis of the methodology of this article is the concept of calculating the inrush currents that occur during transients of the three-phase transformer inclusion on the load, due to the analysis of the load and transformer parameters influence using a transformer substation computer model.

Findings: Using the transformer station model and the authors were calculated and obtained dependences according to the magnitude of the inrush current on each phase of the transformer by: moment's combinations of loads connection, load level changes and power factor of transformer loading, introducing a transformer asymmetric loading mode. The model calculation analysis data obtained follows that the value of the total minimum and maximum inrush currents when the load is connected to the transformer increases: proportional to the transformer load level rise; while reducing the load power factor; with an increase in the level of the transformer load asymmetry.

Conclusion: The findings may be used to create a control system, allowing to reduce energy losses when operating the elements of power supply system.

Keywords: Power supply system · Three-phase transformer · Load asymmetry · The load and the transition process

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1 Introduction

Power supply systems designed for the production and delivery of electricity to consumers consist of the following main elements:

1) Sources of electricity – power plants of various types, containing step-up transformers.
2) Distribution networks of high, medium and low voltage, including power lines, step-up and step-down transformers.

A feature of modern power supply systems is the limited ability to store electricity. Almost all of the generated electricity is instantly consumed in the form of useful energy and losses in power supply networks. Electricity consumption is substantially uneven (Pitolin and Scherbakov 2011). This is connected to the natural cycle (winter – summer) and the organization of production processes and human life (night – day, working days – weekends). And therefore, all the elements of the electrical power system operate in a changing load. The range of load changes in the elements of the electrical power system during the year is (0.2–1) of the maximum load (Novgorodov et al. 2016).

The electrical equipment used in power supply systems (In'kov et al. 2017) has fixed parameters, which values vary discretely (Sokolovsky and Klimash 2019). Energy losses in the electrical power systems elements depend on its parameters and transmitted power. For power lines, the amount of energy loss is nearly in proportion to the square of the transmitted power. For transformers, the dependence of energy loss on power is complex. This curve has a minimum equal to approximately (0.01–0.04) of the transmitted power, with a load power lying in the range (0.5–0.6) of the rated transformer power (P_{rat}) distributed over phases symmetrically. The energy loss in transformers increases with an increase in the load to P_{rat} by about 2–3 times. When the load decreases to zero, the efficiency (η) of the transformer tends to zero, and the relative losses ($1 - \eta$) tend to unity and multiply.

Another factor that greatly increases losses in power supply systems is the phase loads asymmetry (Masoum et al. 2008). Phase load imbalance leads to additional losses in transformers (Martynov 2009) and power lines (Serebryakov and Osokin 2017). Depending on the type of loads and the magnitude of the asymmetry, the amount of energy losses during asymmetric operating modes of the equipment is more than 3 times higher than the energy losses when operating at symmetric modes of power supply system elements (Njafi et al. 2014).

The concept involves the following main activities:

1) Stepwise power regulation of transformer substations. The substation consists of several (at least two) transformers of different capacities (Arsentiev and Gerasimov 2011). A lower power transformer operates at low load. When the load increases, it turns off and a larger power transformer is turned on. With a further load increase, a second transformer is turned on, and they both work on the load in parallel. Thus, in the entire range of load changes, the transformers operate in close to optimal modes and an overall losses reduction is achieved.

2) Usually, many loads, partially three-phase, partially single-phase, changing randomly, are attached to the substation lower-voltage transformer buses. The single-phase loads inequality causes a general load asymmetry of the lower-voltage transformer and the power line. It is possible to decrease the transformer loads asymmetry by reconnecting single-phase loads to other phases. To determine single-phase loads and connected phases, appropriate algorithms have been developed. Reducing the overall load asymmetry of the transformer reduces the loss of electricity in it and its power line.

The main problem in the implementation of these measures is the switching processes when the transformers are switched on to the load (Timonin 2011). In this case, transient's current inrushes occur, affecting the service life and reliability of the transformer (Novgorodov et al. 2013).

The value of the current inrush in the transient process of connecting the loads to the transformer phases depends on the following parameters:

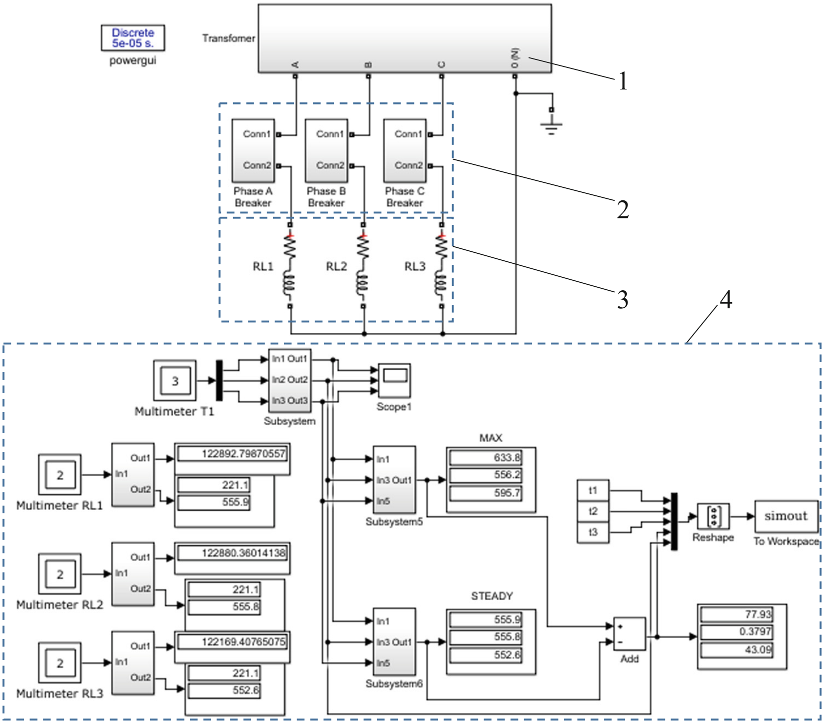
1) The moment of switching on the load commutators for each phase of the transformer, taking into account the different times of switching on the phase commutators;
2) The level of load currents asymmetry in the phases of a three-phase transformer;
3) The total power of the three-phase transformer and other parameters characterizing its windings;
4) Load power factor;
5) The magnitude of the connected load for each phase of the transformer.

2 Methodology

A team of authors investigated the load asymmetry effect on the operation of electric networks elements (Novgorodov et al. 2016). It pointed out that by choosing the moments of connecting the loads to the three-phase transformer phases, it is possible to reduce the transient currents inrushes, but the criteria for choosing such moments were not described. In addition, in this work, only the all transformer phases simultaneous inclusion is considered, which is practically impossible. The author researches were shown that the switch-on time of the load switch is a non-deterministic quantity even for modern switches and depends on environmental conditions, wear of the drive, etc. In the early works of the authors (Novgorodov et al. 2013), there is no data on the research of the various environmental parameters and load influence on the course of transients when the load switches are turned on.

This article investigates the effect of parameters 1, 2, 4, 5 on the inrush current of a transient process when a load is connected. The value of the inrush current ΔI is calculated from the steady-state value of the load current I_{st} to its maximum value I_{max} in the transient process: $\Delta I = I_{max} - I_{st}$. Further, the values of the inrush current for each phase of a three-phase transformer – ΔI_i are summarized: $\Delta I_{\Sigma} = \Sigma \Delta I_i$.

All researches were conducted on a virtual model of a transformer substation created in the MatLab software package. The model includes the following components: three-phase transformer with a delta-star winding circuit with a neutral wire; load switches for each phase of the line leaving the transformer; active-inductive loads of phases of the outgoing line; load control devices (Fig. 1).



1 – three-phase transformer; 2 – load switches;

3 – phase load of the outgoing line; 4 – control parameters instruments

Fig. 1. Transformer substation MatLab-model. *Source*: developed and compiled by the authors

The research examined the connection to the load of a transformer with a rated power of 400 kVA, which is most often used in urban power supply networks. The main parameters of the transformer are as follows: open circuit voltage (U_{oc}) and short circuit (U_{sc}), rated current (I_{rat}). In the design researches, the following parameters were used and changed:

1) The switching moment of the phase A load commutator: $t_A = 0{,}1$ s. This simulates the magnitude of time delay from the signal to turn on the load commutator to the direct switching of its contacts.

2) The simultaneous switching of the commutators is modeled by the delay at the moments of switching on the loads of phases B and C in comparison with phase A: $t_B = (0{,}1\ldots 0{,}11)$ s; $t_C = (0{,}1\ldots 0{,}11)$ s. The enumerating step of the moment's values t_B and t_C is equal to 0,001 s. In each case, 121 combinations of the phase switches (t_A, t_B, t_C) switching moments were considered.
3) The asymmetry level was set in the models by changing the parameters of the loads active and inductive power in phases using the calculated data of a computer program. The asymmetry of the load currents is characterized by the coefficient of load currents asymmetry:

$$\varepsilon_I = \frac{I_{max} - I_{mean}}{I_{mean}},$$

where I_{max} is the current value in the maximum loaded phase, A;

I_{mean} is the arithmetic mean value of all three phases current, A, equal to:

$$I_{mean} = \frac{I_A + I_B + I_C}{3},$$

The value of the current asymmetry coefficient lies in the range $\varepsilon_I = (0{,}1\ldots 1)$ with step of 0,05. Moreover, it is assumed that the load current in phase A has a maximum value, in phase B it is average, and in phase C it has a minimum value, respectively.

4) The load power factor lies in the range: $\cos\varphi = (0{,}5\ldots 0{,}9)$ in step of 0,05.
5) The transformer loading degree with respect to its rated power is determined by the load factor, the value of which lies in the range: $\beta = (0{,}1\ldots 1)$ in step of 0,1.

3 Results

Table 1 and Figs. 2, 3, 4, and 5 show the results of calculating the total inrush currents of transient processes when connecting loads, depending on the moment of their connection for a transformer substation with a capacity of 400 kVA at various levels of transformer loading ($\beta = 0{,}4\ldots 1$).

Table 1. Calculation results of a single-transformer substation model with a capacity of 400 kVA (tA = 0,1 s; tB = (0,1… 0,11) s; tC = (0,1… 0,11) s; cosφ = 0,5; β = 1)

Combination number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
t_A, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
t_B, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
t_C, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔI_Σ, A	117,5	133,2	147,1	154,8	151,6	133,9	102,4	81,34	91,71	105,2	121,3
№	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
t_A, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
t_B, c	0,101	0,101	0,101	0,101	0,101	0,101	0,101	0,101	0,101	0,101	0,101
t_C, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔI_Σ, A	125,8	141,5	155,4	163,1	159,9	142,2	110,7	89,6	100,0	113,5	129,6
№	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
t_A, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
t_B, c	0,102	0,102	0,102	0,102	0,102	0,102	0,102	0,102	0,102	0,102	0,102
t_C, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	137,0	152,7	166,6	174,3	171,1	153,4	121,9	100,9	111,2	124,7	140,8
№	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	150,9	166,7	180,5	188,2	185,0	167,4	135,8	114,8	125,1	138,7	154,8
№	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**	**55**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,104	0,104	0,104	0,104	0,104	0,104	0,104	0,104	0,104	0,104	0,104
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	166,4	182,2	196,0	203,7	200,5	182,9	151,3	130,3	140,6	154,2	170,2
№	**56**	**57**	**58**	**59**	**60**	**61**	**62**	**63**	**64**	**65**	**66**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,105	0,105	0,105	0,105	0,105	0,105	0,105	0,105	0,105	0,105	0,105
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	181,2	196,9	210,8	218,5	215,2	197,6	166,1	145,0	155,4	168,9	185,0
№	**67**	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**77**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,106	0,106
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	191,4	207,1	221,0	228,7	225,5	207,8	176,3	155,2	165,6	179,1	195,2
№	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,107	0,107	0,107	0,107	0,107	0,107	0,107	0,107	0,107	0,107	0,107
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	192,3	208,0	221,9	229,6	226,4	208,7	177,2	156,1	166,5	180,0	196,1

(*continued*)

Table 1. (*continued*)

№	**89**	**90**	**91**	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**99**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,108	0,108	0,108	0,108	0,108	0,108	0,108	0,108	0,108	0,108	0,108
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	179,8	195,5	209,3	217,1	213,8	196,2	164,7	143,6	154,0	167,5	183,6
№	**100**	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109	0,109
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	152,7	168,5	182,3	190,1	186,8	169,2	137,6	116,6	126,9	140,5	156,6
№	**111**	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**	**120**	**121**
tA, c	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
tB, c	0,11	0,11	0,11	0,11	0,11	0,11	0,11	0,11	0,11	0,11	0,11
tC, c	0,1	0,101	0,102	0,103	0,104	0,105	0,106	0,107	0,108	0,109	0,11
ΔIΣ, A	117,6	133,3	147,2	154,9	151,6	134,0	102,5	81,4	91,8	105,3	121,4

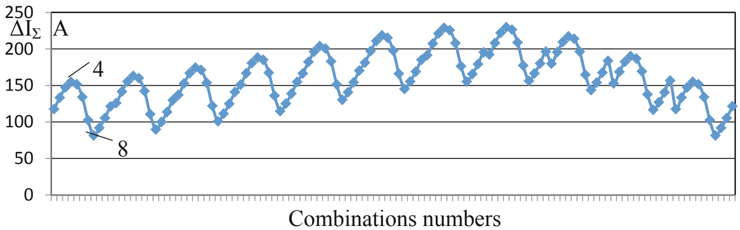


Fig. 2. Diagram of changes in ΔI_{Σ} value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots 0.11)$ s; $t_C = (0.1\ldots 0.11)$ s; cosφ = 0,5; β = 1) (numerals indicate the combinations numbers). *Source*: compiled by the authors

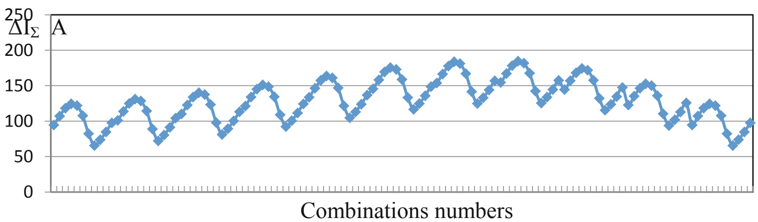


Fig. 3. Diagram of changes in ΔI_{Σ} value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots 0.11)$ s; $t_C = (0.1\ldots 0.11)$ s; cosφ = 0.5; β = 0.8) *Source*: compiled by the authors

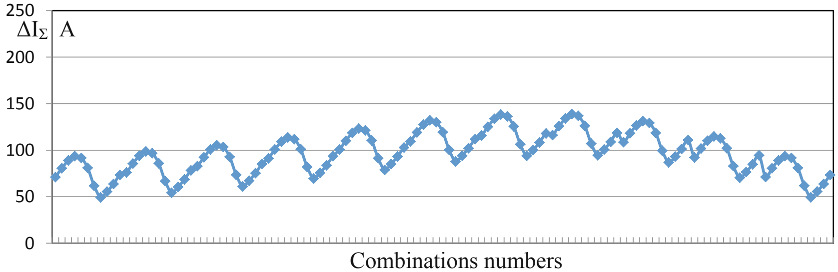


Fig. 4. Diagram of changes in ΔI_Σ value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots\ 0.11)$ s; $t_C = (0.1\ldots\ 0.11)$ s; $\cos\varphi = 0.5$; $\beta = 0.6$). *Source*: compiled by the authors

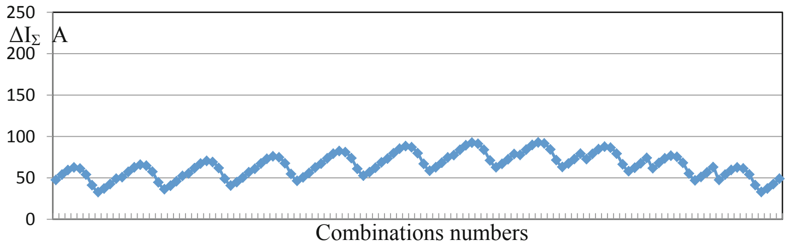


Fig. 5. Diagram of changes in ΔI_Σ value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots\ 0.11)$ s; $t_C = (0.1\ldots\ 0.11)$ s; $\cos\varphi = 0.5$; $\beta = 0.4$). *Source*: compiled by the authors

From the analysis of the diagrams presented in Figs. 2, 3, 4, and 5, it follows that the value of the total current inrush at the moment of load connection strongly depends on both the values of the circuit breakers delayed operation in phases and the connected power amount. The analysis is presented in Table 2 and in Fig. 6.

Table 2. Maximum $\Delta I_{\Sigma max}$ and minimum $\Delta I_{\Sigma min}$ value of the total current increase when the load on the transformer is turned on (power – 400 kVA, $\cos\varphi = 0.5$) at various loads β

β	$\Delta I_{\Sigma max}$, A	$\Delta I_{\Sigma min}$, A	$\alpha_1 = \Delta I_{\Sigma max}/I_{rat}$	$\alpha_2 = \Delta I_{\Sigma min}/I_{rat}$
1.0	229.61	81.34	0.41	0.15
0.8	184.42	65.38	0.33	0.12
0.6	138.86	49.26	0.25	0.09
0.4	92.93	32.99	0.17	0.06

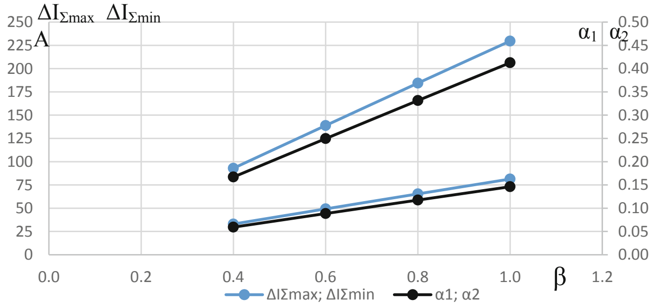


Fig. 6. Dependence graphs of the absolute ($\Delta I_{\Sigma max}$, $\Delta I_{\Sigma min}$) and relative ($\alpha 1$, $\alpha 2$) values of the total currents inrush when the transformer load is switched on from the load coefficient value β. *Source*: compiled by the authors

It was also investigated the influence of the connected load power factor on the total currents inrush value when the circuit breakers operate at different moments in time. The corresponding examples of diagrams obtained in the calculations (Figs. 7 and 8), and the total results – Table 3 and Fig. 9 (Fig. 10).

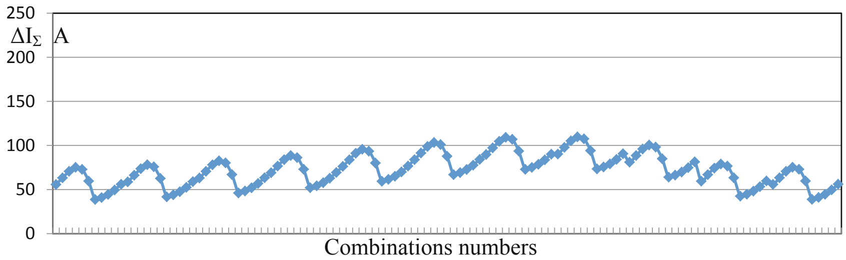


Fig. 7. Diagram of changes in ΔI_{Σ} value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots\ 0.11)$ s; $t_C = (0.1\ldots\ 0.11)$ s; $\cos\varphi = 0.7$; $\beta = 1$). *Source*: compiled by the authors

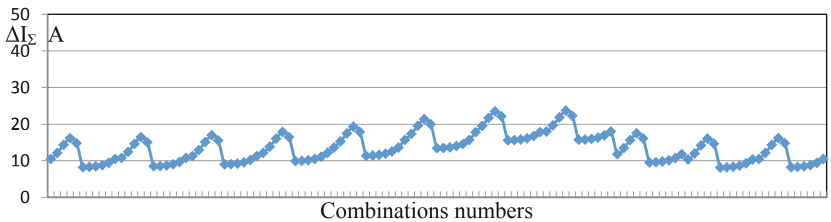


Fig. 8. Diagram of changes in ΔI_{Σ} value depending on combinations of connecting loads moments to phases of a power transformer 400 kVA ($t_A = 0.1$ s; $t_B = (0.1\ldots\ 0.11)$ s; $t_C = (0.1\ldots\ 0.11)$ s; $\cos\varphi = 0.9$; $\beta = 1$). *Source*: compiled by the authors

Table 3. The results of the current inrush calculation at various load power factors (power – 400 kVA, $\beta = 1$)

Cosφ	0,5	0,55	0,6	0,65	0,7	0,75	0,8	0,85	0,9
ΔI_A, A	77.929	66.618	55.960	46.080	36.940	28.535	20.879	14.025	8.070
ΔI_B, A	0.316	1.199	1.646	1.738	1.572	0.033	0.128	0.105	0.044
ΔI_C, A	3.100	3.465	3.396	1.929	0.241	0.361	0.316	0.195	0.007
$\Delta I_{\Sigma min}$, A	**81.344**	**71.282**	**61.001**	**49.748**	**38.753**	**28.929**	**21.324**	**14.325**	**8.121**

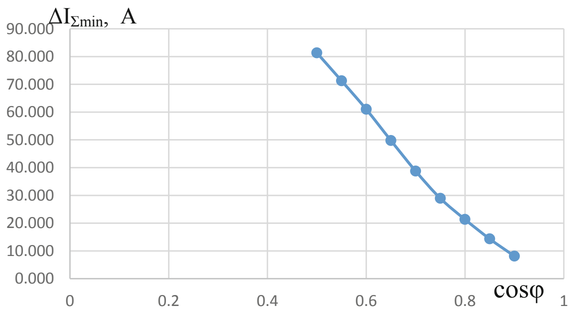


Fig. 9. A dependence graph of the $\Delta I_{\Sigma min}$ values on the change in the power factor cosφ under symmetric loading (400 kVA; $\beta = 1$). *Source*: compiled by the authors

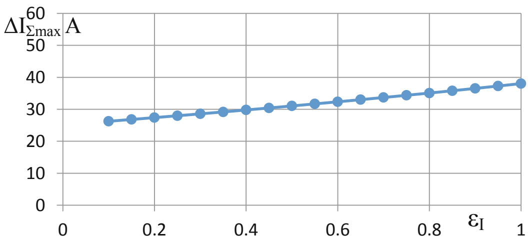


Fig. 10. A dependence graph of the ΔI_{Σ} values on changes in the values of the load currents asymmetry coefficient ε_I for case 3 of asymmetric loading (400 kVA; cosφ = 0.82; $\beta = 1$) *Source*: compiled by the authors

4 Conclusion

The inclusion of a transformer for a three-phase load is accompanied by non-stationary processes with current inrushes, which can exceed the rated values up to 1.5 times. The magnitude of the current's inrush depends on the magnitude of the connected load, the parameters of the transformer, the load power factor, its asymmetry and heterogeneity of the switch's contacts operation.

To reduce the current inrushes, it is advisable to choose the moment of switching on the load, taking into account the real delays in the inclusion of individual phases, which must be determined in advance. A 70–80% reduction in current inrushes can be achieved if, instead of three-phase circuit breakers, a separate controllable circuit breaker is installed on each phase, with the choice of a rational time of its switching on.

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Thermal Simulation in Transformer Type Heating Devices

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Abstract. Purpose: The purpose of the chapter it to develop and implement a mathematical model for examining a three-dimensional temperature field in a three-phase transformer-type heating element with a spatial magnetic system, to obtain recommendations for improving the design and checking the thermal state for such devices.

Methodology: For modeling, the finite element method has been used to provide a more accurate map of the temperature field and reveal local overheating zones in an electrotechnical device with complex paths of heat fluxes. In the proposed model, the heat transfer coefficient is specified individually for each boundary element by means of an iterative process. The model has been implemented in the Delphi programming environment, and visualization of the simulation results has been carried out using the MatLab software package.

Results: The analysis of the simulation results has been performed, the local overheating zones have been identified and the ways of improving the design of the 25 kW heating element has been proposed. The dependency of the maximum insulation temperature of the primary winding on the heat flux density from the surface adjacent to the tubes of the secondary winding has been obtained. It is convenient to estimate the thermal state of a transformer-type heating element by this dependency in engineering calculations for such devices.

Conclusions/value: The proposed method of modeling thermal processes allows to identify zones of local overheating more accurately, to determine the values of maximum temperatures in these zones, and to give recommendations on the choice of electromagnetic loads, improvement the design and engineer new heating elements.

Keywords: Transformer type heating element · Finite element method · Three-dimensional temperature field · Heat transfer coefficient · Heat flux density

JEL code: C6 · C8 · C9

1 Introduction

It is impossible to increase the reliability and durability of modern electrical devices without analyzing its thermal state. The heating level in various operating modes affects the service life of insulating materials of current conducting parts. During the exploitation

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of an electrical device, the insulation is subjected to various types of loads (thermal, mechanical, electrical, and others). Because of these reasons, aging and deterioration of the properties of insulating materials occurs. Aging rate is mainly influenced by the heating temperature.

Evaluation of the thermal state of electrical devices designed for technological heating of various media and objects is particularly important. Such devices include transformer-type electric heating elements for heating liquid and gaseous media in heating systems, hot water supply, as well as for other technological needs. The results of reseach of such devices are presented in the works of Elshin (2000), Kuzmin (2001), Zar Ni Nyein et al. (2018).

The temperature mode of operation depends not only on the electromagnetic loads in the active parts of the heating element (magnetic circuit, primary winding, secondary short-circuited heating circuit), but also on the mode of heat exchange with the heated medium, as well as on the required technological parameters of this medium (heat capacity, temperature, consumption). Therefore, the simulation of thermal processes in electrical devices, in a heating element of a transformer type particularly, is an urgent task.

2 Methodology

The issues of research and analysis of thermal processes of electrical devices are widely covered in the works of Filippov (1974), Borisenko et al. (1983), Krate and Black (1983). In the majority of works, the estimation of the thermal state of an object is based on a formal analogy between electrical and thermal processes by means of thermal equivalent circuits, or the thermal conductivity equation is used under certain assumptions.

The method of thermal equivalent circuits is based on the analysis of heat fluxes from sources of thermal energy in examining objects. Real paths of heat fluxes are replaced by equivalent electrical circuits with thermal resistances. Furthermore, electrical circuits, if necessary, can be converted and calculated using methods known in electrical engineering. This approach to estimate the thermal state of the objects is described in the works of Sipailov et al. (1989), Tikhomirov (2016), Bespalov et al. (1987), Meyers (1971), Kopylov et al. (2016), Serikov (2011), Litovets et al. (2017). Such approach is the simplest and most appropriate for engineering calculations, does not require usage of cumbersome mathematical model of the heat transfering process and leads to suitable for practice results. However, this method does not provide a result with the required accuracy when structures with complex paths of heat fluxes are being examining and local overheating zones and values of maximum temperatures in these zones are being identified.

Simulation of thermal processes using the numerical solution of the differential equation of heat conduction provides a more accurate map of the temperature distribution in complex structures under examination. Such approach allows to check the correctness of electromagnetic loads set (current density in the windings and induction in the magnetic circuit) and to propose ways to improve the design in order to exclude local overheating zones.

With the help of modern computer technology, it is possible to implement the solution of the field theory problem using the widespread universal finite element method. The theoretical foundations of this method are stated in the works of Zenkevich (1986), Norrie and de Vries (1981), Segerlind (1979). Method allows approximating a continuous value (temperature) by a discrete model based on a finite number of subdomains (elements). Nodes that belong to finite elements are freely located within the examined area. Finite elements themselves can have form of various geometric shapes, including those with curved sides, edges and faces for the best approximation of geometry of the examined area.

The examined desing of the transformer-type heating element with a planar spatial magnetic system (Fig. 1) consists of a rod 1, a toroidal yoke 2, a primary winding 3, which is connected to a three-phase power source, a body 4, pipes of a secondary winding 5 and short-circuiting disks 6. The internal cavity of the structure filled with compound. The heating element is installed in a tank with a heated liquid. Heat exchange with the heated liquid occurs through the inner surfaces of the pipes 5, the outer surface of the body 4 and the outer surfaces of the upper and lower disks 6. The research of the temperature field in the middle section, described in the article by Kuzmin and Serikov (2001), does not take into account the heat exchange between the primary winding 3 and discs 6, therefore, the modeling of a three-dimensional temperature field was performed in the work.

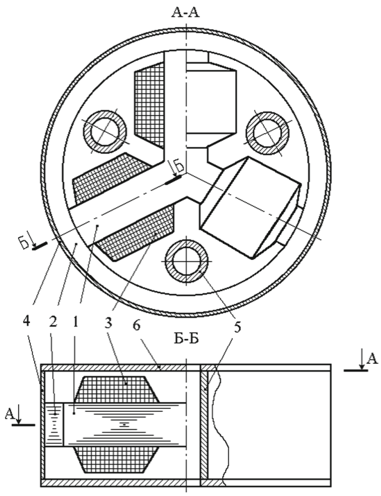

Fig. 1. Transformer type heating element with a spatial planar magnetic system. Source: developed and compiled by the authors

Simulation of the temperature field was carried out for the volume sector, which makes up 1/6 of the whole structure with taking into account the symmetry of the heating element (Fig. 2).

The temperature field inside the examining area is described by the three-dimensional heat conduction equation

$$\lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + \lambda_z \frac{\partial^2 T}{\partial z^2} + q_V = 0,$$

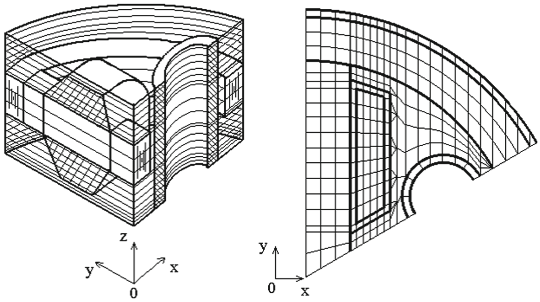

Fig. 2. Examining area. Source: developed and compiled by the authors.

where T – is the temperature; λ_x, λ_y, λ_z – are coefficients of thermal conductivity of the media along the x, y and z axes, respectively; q_V – specific power of heat sources.

On surfaces contacting the heated liquid, the boundary conditions of convective heat transfer are fulfilled

$$\lambda_{\mathrm{x}} \frac{\partial T}{\partial x} l_{\mathrm{x}} + \lambda_{\mathrm{y}} \frac{\partial T}{\partial y} l_{\mathrm{y}} + \lambda_{\mathrm{z}} \frac{\partial T}{\partial z} l_{\mathrm{z}} + \alpha (T - T_B) = 0,$$

where l_x, l_y, l_z - are direction cosines of the outer normal to the boundary surface; α – convection heat transfer coefficient; T_{B} – temperature of heated liquid.

Heat flux on the adjacent sides of the sector is absent; therefore, the thermal insulation condition is valid for these surfaces

$$\lambda \frac{\partial T}{\partial n} = 0,$$

where n – is the outer normal to the surface.

Tetrahedrons were used as the basic finite element in the work, which were previously combined into triangular prisms and parallelepipeds (Fig. 3) for the convenience of automatic construction of the examining area. The inner examining area constructed of 30267 tetrahedra. The examining area boundary is formed from 2202 triangular elements. The number of nodes in which the temperature value was determined is 6000.

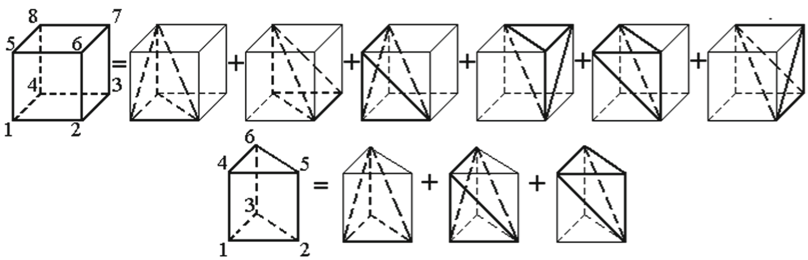

Fig. 3. Diagram of the formation of a parallelepiped and a triangular prism from tetrahedrons. *Source*: developed and compiled by the authors

The accuracy of determining the temperatures at the nodes of the finite element mesh depends not only on the accuracy of the geometric approximation of the examining area, but also on the correctness of setted conditions for heat transfer, including the heated liquid with the usage of the heat transfer coefficient α. The difficulty is that the temperature of the heat exchange surface is not the same over the entire area. Therefore, the heat transfer coefficients must be determined for each boundary finite element separately using the formula

$$\alpha = \frac{\lambda_{\text{B}}}{l} \cdot Nu,$$

where Nu – is the Nusselt number; l – is a determining size; λ_B – is the coefficient of thermal conductivity of the heated liquid.

In natural convection, the Nusselt number is determined by the formula proposed by Mikheev and Mikheeva (1977)

$$Nu = C(Gr \cdot Pr)^n \cdot \left(\frac{\text{Pr}_{\text{B}}}{\text{Pr}_{\Pi}}\right)^{0,25},$$

where C and n - are coefficients, the values of which are determined by the heat transfer mode; Gr – is the Grashof number; Pr, $Pr_{\text{B},}$ Pr_{Π} – Prandtl numbers at the average temperature of the boundary layer T_{cp}, liquid temperature T_{B} and the temperature of the heat-transfer surface T_{Π}, respectively.

To calculate the Grashof criterion, such formula was used

$$Gr = \left(\frac{g\beta}{\nu^2}\right) \cdot (T_{\Pi} - T_{\text{B}})\, l^3,$$

where $\frac{g\beta}{\nu^2}$ - is the coefficient of the Grashof criterion at the average temperature of the boundary layer T_{cp}.

The average temperature of the boundary layer is determined by the formula

$$T_{\text{cp}} = \frac{T_{\Pi} + T_{\text{B}}}{2}.$$

When water is used as a heated liquid, its physical properties, which strongly depend on temperature, are determined by the approximating expressions:

$$\lambda_{\mathrm{B}} = 0,551 \ + \ 0,00254 \cdot T_{\mathrm{cp}} - \ 0,0000123 \cdot T_{\mathrm{cp}}^2;$$

$$Pr = \frac{1}{0,071 + 0,00337 \cdot T + 0,0000168 \cdot T^2};$$

$$\frac{g\beta}{\nu^2} = \left(-3,57 + 0,8 \cdot T_{\mathrm{cp}} + 0,00725 \cdot T_{\mathrm{cp}}^2 + 0,0007 \cdot T_{\mathrm{cp}}^3\right) \cdot 10^8.$$

If the temperature of the heat exchange surface is higher than the boiling point of water, the heat transfer coefficient is specified by the formula

$$\alpha = \frac{44(T_{\Pi} - 100)^3}{T_{\Pi} - T_{\mathrm{B}}} + \alpha_{\kappa},$$

where $\alpha_{\text{к}}$ is the heat transfer coefficient for natural convection without boiling.

The value of the heat transfer coefficient depends on the temperature of the heat exchange surface and the temperature of the liquid (water), so, an iterative method was used to determine it. At each iteration, for a separate boundary element, the average mass water temperature, the surface temperature of the boundary element, and new thermophysical properties of water were calculated, which are used at the next iteration. At the end of the mentioned iterative process, the final values of temperatures in the grid nodes are determined. To increase the convergence rate, the heat transfer coefficients at (n + 1) iterations are calculated using the relaxation process

$$\alpha^{(n+1)} = \alpha^{(n)} + U_{\mathrm{p}}(\alpha^{\left(n+\frac{1}{2}\right)} - \alpha^{(n)}),$$

where $\alpha^{(n)}$, $\alpha^{(n + ½)}$ – are values of heat transfer coefficients at the previous step and updated, respectively; U_{p} = 0,2…0,6 – is the relaxation coefficient.

The iterative process ends if the specified accuracy is achieved

$$\left|T_i^{(n)} - T_i^{(n-1)}\right| \le \varepsilon,$$

where $T_i^{(n)}$, $T_i^{(n-1)}$ – are temperature values obtained at this and previous steps; ε – is specified accuracy of temperature calculation.

For the most loaded operating mode of the heating element, the maximum permissible temperature of heated water is 85 °C.

The differential equation of heat conduction in the finite element method is solved by finding a function that minimizes the functional described in Segerlind's work (1979)

$$J = \int_V f_V \, dV = \int_V \frac{1}{2}\left[\lambda_{\mathrm{x}}\left(\frac{\partial T}{\partial x}\right)^2 + \lambda_{\mathrm{y}}\left(\frac{\partial T}{\partial y}\right)^2 + \lambda_{\mathrm{z}}\left(\frac{\partial T}{\partial z}\right)^2 - 2q_V T\right] dV.$$

During the resolvement, a system of linear algebraic equations is formed, the order of which is equivalent to the number of nodes in the finite element mesh. The resulting large-order system (6,000 nodes) is solved by the iterative Gauss-Seidel method taking into account the strip structure of the coefficient matrix. The algorithm for the automatic construction of the examining area accorded to set geometric sizes using finite elements in the form of tetrahedrons and triangles, the formation and solution of a system of linear equations, as well as the refinement of the heat transfer coefficients for each boundary element are implemented in the Delphi programming environment. Figure 4 shows the interface of the developed temperature field for simulation program.

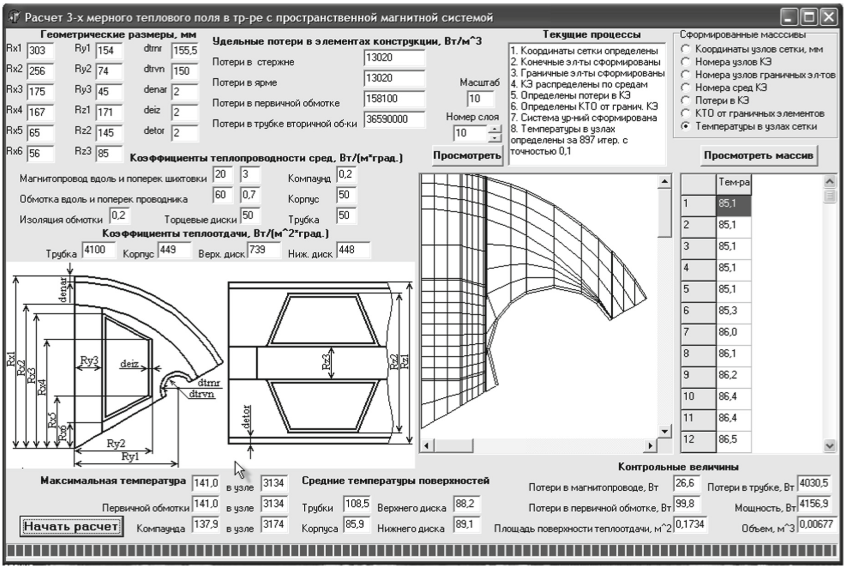

Fig. 4. Program interface. *Source*: developed and compiled by the authors

The result of the program is an array of numerical values of temperatures at the nodes of the finite element mesh. The graphical representation of the simulation results is implemented in the MatLab environment. Visualization of the temperature field in the examining area (Fig. 5) is performed by coloring the edges of the finite elements in accordance with the calculated values of temperatures at its tops using color gradation from white (more heated area) to black (less heated area).

In constrast to the existing software systems for modeling temperature fields, the developed program specifies the heat transfer coefficients for each boundary element individually, depending on local temperature conditions, which provides a more accurate identification of local overheating zones and maximum temperatures in them. This is necessary for making further decisions on improving the design of the heating element and evaluating the correctness of electromagnetic loads in its active parts.

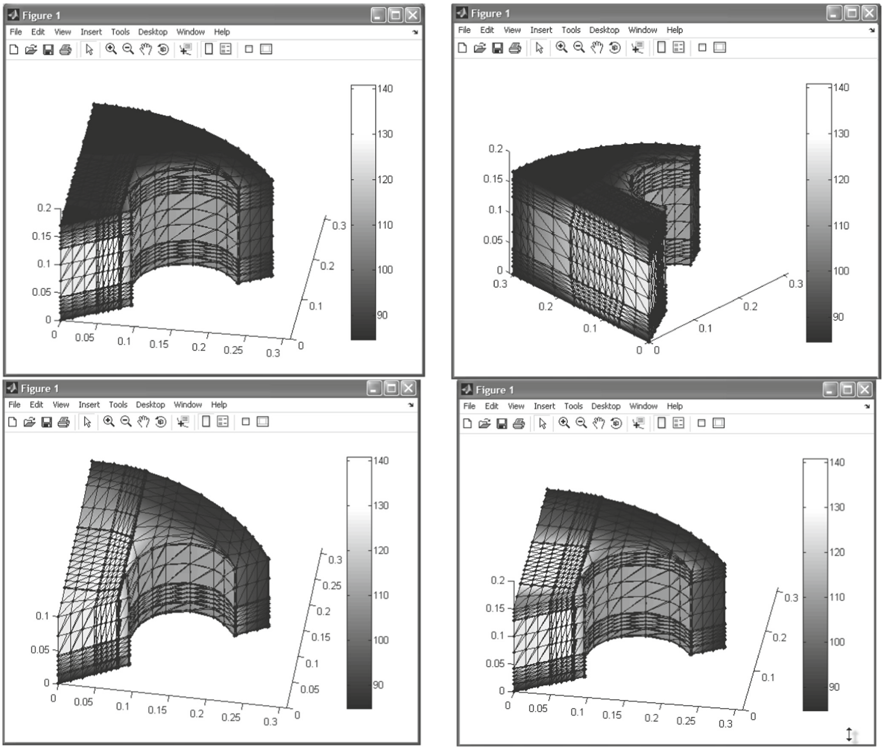

Fig. 5. Visualization of the temperature field. *Source*: developed and compiled by the authors

3 Results

Analysis of the simulation results for a 25 kW heating element confirms the correct choice of electromagnetic loads. The maximum temperature in the primary winding was 141 °C, which corresponds to the heat resistance class of insulating materials F. On the inner surfaces of the secondary winding pipes, which are in contact with heated water, there are local overheating zones with a temperature of 110 °C. In these places, conditions are created for water to boil, which leads to the formation of scale. To eliminate this drawback, it is necessary to increase the heat exchange surface of the secondary short-circuited loop by increasing the length of the pipes and the formation of protruding parts (Fig. 6, a). It is also possible to install fins for heat exchange on the inner surfaces of pipes or replace pipes with a more complex structure in the form of sectors (Fig. 6, b).

In the work the dependence of the maximum insulation temperature of the primary winding of T_{i} on the density of heat flux q from the surface adjacent to the secondary winding tubes has been revealed (Fig. 7). This dependence allows to estimate the thermal state of the primary winding at the designing stage during engineering calculations. Analyzing the obtained results, it is recommended to use insulating materials of heat resistance class *B* at a heat flux density q less than 650 W/m^2, heat resistance class *F* at q from 650 W/m^2 to 1150 W/m^2, and heat resistance class *H* at q more than 1150 W/m^2.

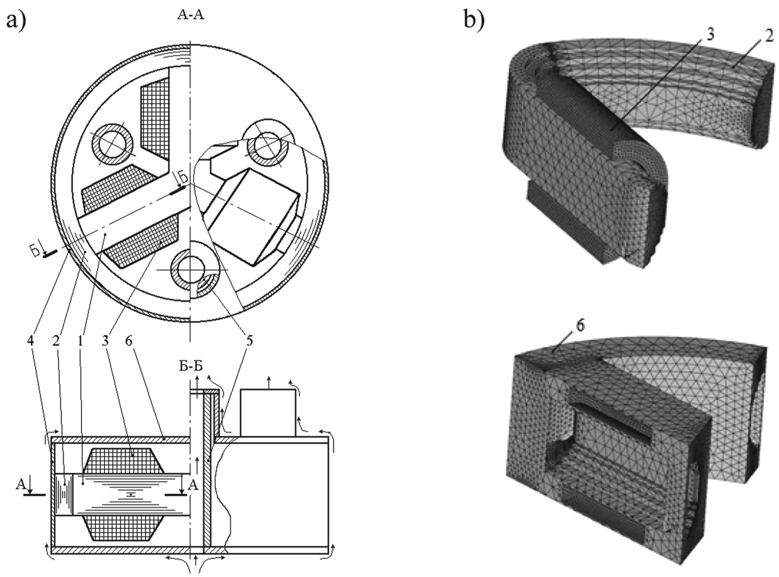

Fig. 6. Design improvement of the heating element. Source: developed and compiled by the authors

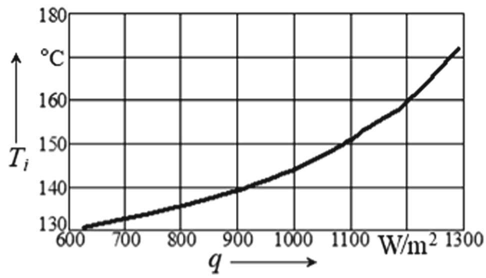

Fig. 7. Dependence of the maximum insulation temperature T_i on the heat flux density q. *Source*: developed and compiled by the authors

4 Conclusion

Therefore, the developed and implemented mathematical model makes it possible to produce a three-dimensional temperature field in a transformer-type heating element with a spatial planar magnetic system. The model has used an algorithm for the individual determination of heat transfer coefficients for each boundary finite element, which allows taking into account heterogeneity of heat transfer processes from different sections of the heating element surfaces. For a visual representation of the results, the temperature field was visualized using the graphic capabilities of the MatLab software environment. The temperature distribution in a three-phase transformer-type heating element with a spatial magnetic system has been estimated and its thermal state has been analyzed.

Recommendations for improving the design and measuring the heating of the primary winding insulation at the designing stage of new products have been made.

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Design of High-Speed Rotor Systems with Gas-Magnetic Bearings

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Abstract. Purpose: The purpose hereof is to develop a scientifically valid design procedure for high-speed rotor systems with gas-magnetic bearings.

Design/methodology/approach: The design procedure for gas-magnetic bearings is based on the design methods for gas-static bearings, taking into account magnetic forces. The calculation of air lubricating film is based on the original equation system classic in gas lubrication theory. It is performed by the numerical intergration of modified Reynolds equation from gas lubrication theory using finite difference method which is quite reliable as studies of various gas bearing designs show.

Findings: The design procedure for high-speed rotor systems with gas magnetic bearings is based on the results of extensive theoretical and experimental studies. The recommendations have been developed for determining or setting such characteristics of a rotor system with gas magnetic bearings as relative eccentricity, relative bearing elongation, design variable, number and size of feeders, average radial and electromagnetic gaps, relative bearing spacing, number of magnetic poles, spacing angle and magnetic circuit length, etc.

A unit, simulating the operation of a high-speed rotor with front gas-magnetic and rear gas-static bearings, was designed and manufactured to assess the accuracy of the developed method. Analysis of the obtained load characteristics shows satisfactory qualitative and quantitative correlation of theoretical and experimental functional connections.

Originality/value: The developed design procedure for high-speed rotor systems with gas-magnetic bearings allows determining bearing design variables, depending on load characteristics of a system.

Keywords: High-speed rotor system · Gas-magnetic bearing · Electromagnetic gap · Load · Stiffness

JELCode: O14 · O33

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1 Introduction

In modern mechanical engineering, increasing rotating speed of rotor systems is one of the ways to improve power and efficiency without increasing mass-dimensional parameters. Such equipment includes spindle assemblies of metal-working machinery, pumping and compressor equipment, generators, medical equipment and device components.

Rotation speed can exceed 800,000 min^{-1} and rotation accuracy is within 1 μm and less in the assemblies of such equipment. Rotor bearing must combine little wear with high reliability to prevent accidents, and if they do happen, there must be an option to stop the rotor without assembly design disfunction. This requirement is due to the fact that rotor system has an enormous moment of inertia margin at high rotation speeds, the power of which can destroy not only the assembly but the machine itself in case of an accident.

Nowadays high-speed rotor systems using roller bearings are prone to heat deformation and unstable rotor movement trajectory due to changing turn angle of a separator with a set of rolling bodies and ring manufacture error as well as limited rotation speed and lifetime (Lizogub 2007).

Using hydrostatic bearings for high-speed rotation systems allows for high rotation accuracy and damping capacity which significantly increases rotor vibration resistance. Such bearings have a practically unlimited lifetime and high load capacity at any rotation speed. The main drawbacks of hydrostatic bearings are a complex power supply system and limited speed due to liquid friction (Bushuev 1989).

A disruption of gas supply to the bearing leads to a pre-accident situation. Porous bearings, first mentioned in the paper (Montgomery and Sterry 1955), are of particular interest. Theoretical and experimental works of Donaldson and Patterson (1971) gave start to the use of partially porous inserts in gas bearings, meaning the appearance of partially porous bearings.

Electromagnetic bearings have a long lifetime, low power demand, relatively high stiffness when controlling pulling power of an electric magnet, insignificant rotation resistance factor. The lack of mechanical contact means such bearings can operate in extreme conditions. However, irrespective of these positive aspects, rotor systems with electromagnetic bearings are not widely used in mechanical engineering due to low bearing capacity and complexity of both bearings and electronic control systems (Guravlev 2003). What is more, a disruption of power supply to the bearing leads to a pre-accident situation.

There is special consideration paid to increasing quality and precision of metal working (Sarilov and Myl'nikov 2019; Erenkov and Otryaskina 2018; Mokritskii et al. 2018; Serebrennikova 2018). Using gas-magnetic bearings (GMB) in spindle assemblies of metal-cutting machinery is promising in this respect (Kosmynin et al. 2013).

Gas-magnetic bearings do not have the relatively low bearing capacity of gas bearings which magnetic forces fix in GMB. The unstable rotor position requiring complex control system which is the drawback of magnetic bearings is compensated by self-adjusting gas force field in the bearing (Shnaider and Sokol 1991). Such bearings will not be damaged in case of a pre-accident situation caused by cutout of compressed air pressurization or electrical solenoid control signal, which allows for emergency shutdown with no contact of bearing's shaft and box.

2 Materials and Method

The main advantages of GMB for high-speed rotors are increased bearing capacity, stiffness and reliability. All gas-static bearing advantages must be preserved during GMB design development which, together with magnetic suspension, will improve their operational characteristics.

It became possible to develop a design calculation method and give recommendations on GMB rotor assembly design based on the studies presented in the paper as well as output characteristics calculation method for rotor systems with GMB given in the paper (Kosmynin et al. 2013; 2014).

GMB design procedure is based on the gas-static bearing design method, taking into account magnetic forces, which is due to GMB ability to operate both with powered and unpowered magnetic suspension.

3 Results

Let us consider the design procedure for high-speed rotor with no-contact bearings which is illustrated in Fig. 1.

Based on experience with the operation of high-speed rotor with no-contact bearings, radial load should not be used to avoid the contact of gas bearing's rotor and box as radial load causes relative eccentricity $\varepsilon = e/c > 0.6$ where c is average radial gap; e is rotor's shifting on the bearing.

Due to the small difference of rotor and bearing box diameters (max. 1%) they are taken as equal for practical calculations. The front bearing design should have elongation $\bar{L} = L/D = 1.2\ldots1.4$ where L is bearing length, D is diameter. It should be noted that smaller elongation values refer to gas-static bearings and larger ones to gas-magnetic bearings. It should be taken into account that rotor system is prone to unstable operation if longer bearings are used as it increases load direction angle (Kosmynin et al. 2014). Gas-magnetic bearing is illustrated in Fig. 2.

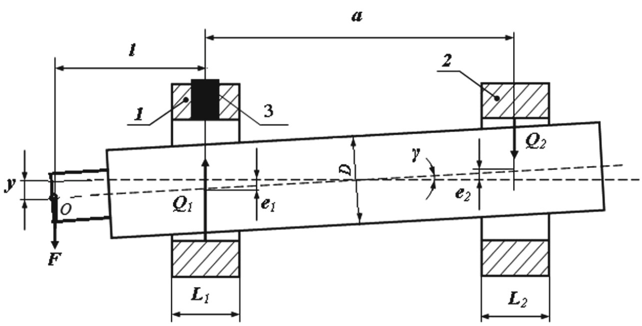

Fig. 1. High-speed rotor with no-contact bearings: 1 is front gas-magnetic bearing, 2 is rear gas-magnetic bearing, 3 is magnetic circuit. *Source*: developed and compiled by the authors.

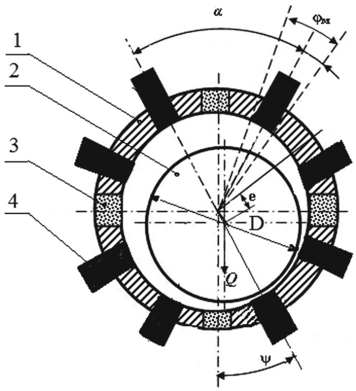

Fig. 2. Gas-magnetic bearing: 1 is bearing box, 2 is rotor, 3 is porous insert, 4 is magnetic circuit. *Source*: developed and compiled by the authors.

The studies described in the paper establish that output operational characteristics of a rotor system do not really depend on rear bearing length. Compared to the front bearing, rear bearing should be designed with smaller relative length ($\bar{L} = 1.0 \ldots 1.2$); thus, ensuring smaller load direction angle ψ. It should also be noted that shorter bearings with $\bar{L} < 1$ complicate the accommodation of porous inserts in the bearing box.

Based on multiple-option calculations, the design variable K_c preliminary value for GMB with round porous feeders at $\bar{L} = 1 \ldots 1.4$ can be determined using the following formula:

$$K_c = (0.55 \ldots 0.65) - 0.2\left(1.2 - \bar{L}\right).$$

Porous material permeability factor is found using the following design variable expression (Kosmynin et al. 2013):

$$k_p = \frac{\delta}{12\,R}\left(\frac{K_c}{c}\right)^{-1/3},$$

where δ is porous insert height, R is rotor radius.

The calculations of rotor system characteristics with variables $\bar{L} = 1.2$ and $\varepsilon_I = 0.6$ show that GMB with round porous feeders should be designed at design variable $K_c \approx 0.6$. A rotor system with this GMB design variable has high load characteristics and stiffness.

The value of average gas-static bearing radial gap should be taken as 20…90 μm, depending on the bearing diameter (Kosmynin et al. 2014). It should be noted that smaller gap leads to increased bearing stiffness, but the manufacture precision requirements to bearing rotor and boxes become stricter.

The paper (Kosmynin et al. 2013) presents the results of studies in which electromagnetic gap exceeded gas layer gap by more than three times. The findings show that at constant specific magnetic force $\bar{F}_m = F_m \big/ Q_{\max}$, increasing electromagnetic gap facilitates increased stiffness factor $k_J = d\bar{F}/d\bar{y}$ with simultaneous decreased bearing capacity factor $C_Q = Q/Q_{\max}$ (F_m is magnetic force; $\bar{y} = y/c$ is relative shift, y is axial shift of loaded cantilever, $Q_{\max}$ is maximum bearing capacity, Q is bearing load. Additionally, increasing electromagnetic gap h_{el} leads to the increased solenoid current strength required to create magnetic force, which demands noticeably larger size of solenoid and rotor system as a whole.

When selecting number and size of porous feeders, high operational characteristics of rotor system are ensured: rotor cantilever load; stiffness factor k_J; stable operation as well as bearing's ease of manufacturing. Taking into account these approaches to rotor system design six porous feeders evenly distributed around the pressurization row with relative diameter $\bar{d}_{ins}= 0.12$ ($\bar{d}_{ins} = d_{ins} \big/ D$ where d_{ins} is porous insert diameter) should be used.

Increased number of porous feeders results in insignificant increase of useful load (max. 6%). This complicates bearing manufacturing process. Increasing insert area to $\bar{d}_{ins} = 0.16$ facilitates system stiffness decrease by 35% (Kosmynin et al. 2013) in gas-magnetic mode and by 25% in hybrid mode. Smaller total area of porous matrix, for example, due to decreased number of feeders in the pressurization row or their diameter results in larger load direction angle ψ.

The paper (Kosmynin et al. 2014) also presents the study on gas-static bearings with porous key-like flow limiters. As studies show, this shape gives slightly better results compared to round inserts. However, using key-like feeders complicates magnetic circuit accommodation in GMB.

Insert height δ should be taken as equal to the thickness of a strong enough bearing insert wall. It should be noted that increasing insert height results in increased gas flow friction in porous material, but, on the other hand, minimal porous insert height is limited by only manufacturing technology.

Increasing bearing spacing leads to increased load on rotor cantilevers. The paper (Kosmynin et al. 2014) presents the results of the study on selecting reasonable bearing spacing which is within interval $\overline{a} = 3\ldots5$ where $\overline{a} = a/L$ is relative bearing spacing; a is bearing spacing. Relative bearing spacing must equal 4 to ensure high stiffness with high radial load capacity.

Decreased rotor overhang results increased maximum load measured at the cantilever. The overhang must ensure the machine performs its process tasks. On the other hand, minimum possible rotor overhang allows for higher stiffness and load characteristics.

Polar angle of magnetic circuit spacing, which affects only the load direction angle should be minimum possible. GMB design specifics must also be considered.

The number of magnetic poles is chosen, taking into account GMB design specifics. Porous limiters and magnetic poles should be alternated. The most reasonable number of porous limiters in a row $N_{ins} = 6$. The polar angle of magnetic circuit spacing is $\alpha = 60°$ or $120°$ (Kosmynin et al. 2013).

The studies showed that magnetic circuit elongation leads to increased stiffness and load on rotor cantilever. Load direction angle increases insignificantly. Longer magnetic circuits should be used in high-speed rotor systems (Kosmynin et al. 2014).

Based on the GMB rotor system design specifics given above, the following design procedure is proposed:

1) set: rotor diameter D, GMB elongation $\bar{L} = 1.2$ (gas-static bearing $\bar{L} = 1\ldots1.2$), rotor cantilever overhang l, relative gas bearing spacing $\overline{a} = 3\ldots4$;
2) determine: absolute bearing length $L = D \cdot \bar{L}$, bearing spacing $a = \overline{a} \cdot L$;
3) determine: design variable of gas-magnetic $K_c = (0,55\ldots0,65) - 0,\ 2\big(1,\ 2 - \overline{L}\big)$ and gas-static bearings $K_c = 0.4 + 0.25(\bar{L} - 1)$;
4) set: porous insert δ height equaling bearing box thickness;
5) set: relative radial gap c/D within the interval $(3\ldots8)\cdot10^{-4}$;
6) determine: absolute average radial gap $c = D\,(c/D)$;
7) calculate: porous insert permeability factor $k_p = \frac{\delta}{12\,R}\left(\frac{K_c}{c}\right)^{-1/3}$;
8) determine: the number of porous inserts in one pressurization row N_{ins} within interval $(4\ldots8)$;
9) set: relative porous insert diameter $\bar{d}_{ins} = 0.12\ldots0.14$ and relative pressurization line spacing $\overline{b} = (0,5\ldots0,7)$;
10) determine: absolute pressurization line spacing $b = \bar{b} \cdot L$;
11) set: the number of magnetic circuits N_P and polar angle φ_m, taking into account the number and size of porous limiters;
12) calculate: magnetic circuit width $\alpha_m = \varphi_m D$;
13) set: magnetic circuit elongation $\bar{T} = (0.5\ldots.0.95)$;
14) calculate: magnetic circuit length $T = \bar{T}\,L$;
15) set: minimal possible magnetic circuit spacing angle α, taking into account the number of porous inserts;
16) set: magnetic circuit material is chosen and specific magnetic force $\overline{F_M} = 0.02\ldots0.3$, depending on the purpose;
17) calculate: magnetic force $F_m = \bar{F}_m Q\mathrm{max}$;
18) determine: solenoid current equaling the number of coils per current in one coil $in_c = 1,414\sqrt{F_m/(\mu_0 T a_m)}$ where μ_0 is magnetic constant;
19) set: a number of solenoid coils n_c, taking into account rotor system design;
20) calculate: solenoid current strength i and cable diameter d_{cab};
21) verify: bearing geometric parameters $\pi\mathrm{D} \geq (N_{P*}\ (\alpha_m + \Delta) + N_{ins}(d_{ins} + 3))$, where Δ is jumper between magnetic circuit and porous gas flow limiter. If this condition is fulfilled, go to item 22; if not, go to item 9, changing the relative porous insert diameter;
22) Data output: D; c; L_1; L_2; a; l; θ; N_{ins}; d_{ins}; n_c; d_{cab}; φ_m; δ; b_1; b_2; N_P; α_m; T; μ.

A unit, simulating the operation of a high-speed rotor with a front gas-magnetic and rear gas-static bearings, was designed and manufactured to assess the accuracy of the developed method.

Elements and assemblies of the experimental unit had the following geometric characteristics: bearing length $L_1 = L_2 = 60$ mm; bearing diameter $D = 52$ mm; average radial gap $c = 45$ µm; bearing pressurization line spacing $b = 26$ mm; bearing spacing $a = 230$ mm; cantilever overhang $l = 65$ mm; magnetic circuit parameters: length 45 mm, width 14 mm, relative position angle 120°.

Six cylindrical porous inserts with diameter 6 mm and height 6 mm were positioned in one circular pressurization row of each bearing. Insert material had permeability factor $k_p = 3.57 \times 10^{-13} m^2$.

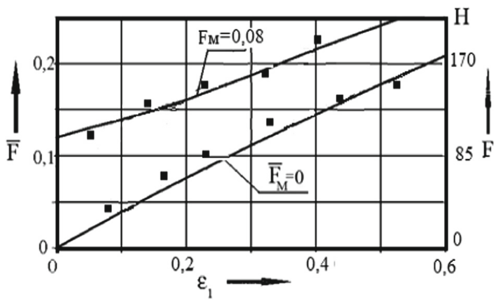

Fig. 3. Functional connection between relative load on shaft cantilever $\bar{F}$ (load F), relative eccentricity ε in GMB and relative magnetic force $\bar{F}_m$; is theory; is experiment. *Source*: developed and compiled by the authors.

As the result of the studies, a functional connection between relative load on shaft cantilever, relative eccentricity ε_1 and relative magnetic force $\bar{F}_m$ (Fig. 3) was obtained.

Analysis of the obtained load characteristics shows satisfactory qualitative and quantitative correlation of theoretical and experimental study results.

The relative error between experiment results and design values with regard to relative eccentricity $\varepsilon = 0.1\ldots0.6$ is under 10%. Therefore, the developed procedure allows designing high-speed rotor systems with allowable precision.

4 Conclusion

Further studies of high-speed GMB rotor systems conducted in Komsomolsk-on-Amur State University are focused on the studies and development of recommendations on GMB control systems (Kosmynin et al. 2014).

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Influence of the Shape and Support Type of Thin-Walled Cylindrical Shell on Its Forced Vibrations

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Abstract. Purpose: Identifying the patterns of influence of the shape and support type of thin-walled cylindrical shell on its forced vibrations.

Design/methodology/approach: The paper deals with the necessity to carry out structural analysis for shell-type buildings and structures in order to determine the action of loads which induce vibrations. An algorithm is provided for performing forced-vibration analysis of a thin-walled cylindrical shell, considering the influence of the shape and support type of the shell. An equation-coefficient-based matrix was used to solve the differential equations. A numerical experiment has been performed for X17 steel and relations between the vibration frequency of a thin-walled cylindrical shell and the number of half-waves have been obtained, with consideration for the shape and support type. The results show that when the frequency of thin-walled cylindrical shell vibrations is at its minimum (at the maximum value of the wave amplitude), it depends on the support type at the half-wave number n = 2..4, while at n ≥ 4, the vibration frequency is influenced by the shell shape.

Findings: The paper shows how vibrations of thin-walled cylindrical shells are affected by different methods of fastening. Comparison of the data obtained is provided.

Originality/value: The findings can be used for structural analysis, in design bureaus carrying out vibration analysis for cylindrical shells.

Keywords: Thin-walled cylindrical shell · Forced vibrations · Shapes · Support types · Analytic model · Variational formulation

JEL Code: C310

1 Introduction

Current architecture and construction trends are aimed at erecting long-span buildings and facilities without intermediate supports, lightweight and openwork structures. Combined shell structures are best suited for this purpose. If we consider the economic feasibility as well (relation between the internal (effective) volume and external surface area), the structures of choice are thin-walled cylindrical shells. However, such structures have

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seen a number of accidents the causes of which have not been clearly determined. For example: the tragedy in Transvaal Park (Moscow) claimed the lives of 25 people in 2004; in 2010, one of the roof sections collapsed at a stadium in Minnesota (USA) burying the underneath stand; in 2015, the accident at the tank under construction at an oil refinery (Komsomolsk-na-Amure), which occurred due to vibrations caused by wind loads; in 2015 (Verkh-Irmen settlement in the Novosibirsk Region), the roof of a covered ice rink collapsed under the combined wind and snow loads; in 2017, a school roof collapsed in Murino residential settlement; in 2018, catastrophic deformation of the roof occurred at the skating rink under construction in the town of Istra; the accident in the city of Balashikha in 2018 lead to collapse of the roof of an arc-shaped steel parking lot; the environmental accident due to diesel fuel spill near Norilsk occurred on May 29, 2020 as a result of an emergency tank rupture at CHPP-3 owned by JSC NTEK. Load-bearing structures of the above listed facilities were designed in full compliance with the construction norms and regulations, with due regard for the required factors of safety. However, the building structures are not designed for oscillatory processes which frequently occur in thin-walled shells and can cause resonance phenomena leading to structural failure, as described in papers by Vlasov (2020), Seregin (2019), Sysoev et al. (2019), Seregin (2019).

2 Materials and Method

To solve this problem and study the oscillatory mechanism of thin-walled shells in more detail to ensure early identification of causes of potential failures for structures, buildings, and facilities, a numerical experiment was conducted at Komsomolsk-na-Amure State University, as outlined in papers by Sysoev et al. (2018), Wang et al. (2017), Seregin (2019), Sysoev et al. (2019), Xing et al. (2013). The analysis was performed using the dimensions of thin-walled cylindrical shells with the diameter of 150 mm and 200 mm and the length of 400 mm; two types of support were provided for each shell: simple support and rigid fixing, Fig. 1. Forced vibrations of a thin-walled cylindrical shell are induced by the external force N.

The following assumptions are made when designing thin shells:

- The normal strain is small; therefore, the transverse normal is considered inextensible, as, for example, in papers by Sysoev et al. (2018), Wang et al. (2017), Seregin (2019), Sysoev et al. (2019), Xing et al. (2013): $\varepsilon_z = 0$.
- Shell deviations are small, and strains are infinitesimal.
- The shell is moderately thin; therefore, it can be assumed that the normal stress along the thickness direction is negligible, so the plane assumption may be applied: $\sigma_z = 0$
- Linear elastic behavior of materials is assumed.
- Rotational inertia is ignored.

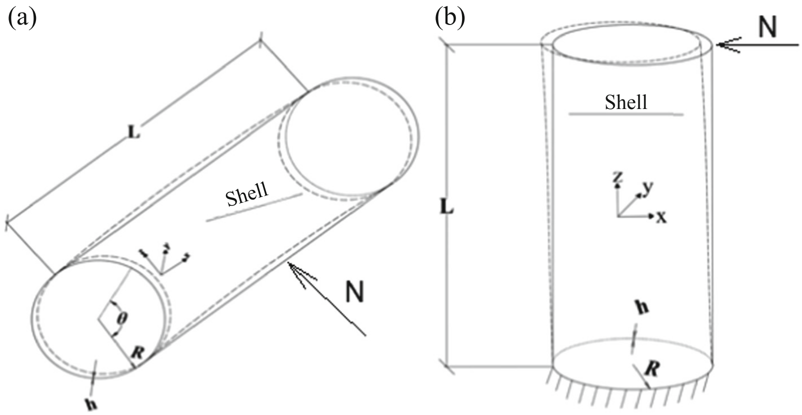

Fig. 1. a) Simply supported thin-walled cylindrical shell; b) rigidly fixed thin-walled cylindrical shell. *Source*: developed and compiled by the authors

The stress-strain relations for a thin-walled cylindrical shell which includes lateral shear strain effect may be represented as follows:

$$\begin{Bmatrix} \sigma_x \\ \sigma_\theta \\ \tau_{x\theta} \\ \tau_{xz} \\ \tau_{\theta z} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 & 0 & 0 \\ Q_{21} & Q_{22} & 0 & 0 & 0 \\ 0 & 0 & Q_{66} & 0 & 0 \\ 0 & 0 & 0 & Q_{55} & 0 \\ 0 & 0 & 0 & 0 & Q_{44} \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_\theta \\ \varepsilon_{x\theta} \\ \varepsilon_{xz} \\ \varepsilon_{\theta z} \end{Bmatrix}$$

where:

$$Q_{11} = \frac{E(z)}{1 - v(z)^2}, Q_{12} = \frac{E(z)}{1 - v(z)^2};$$

$$Q_{21} = \frac{v(z)E(z)}{1 - v(z)^2}, Q_{22} = \frac{E(z)}{A\left(1 - v(z)^2\right)};$$

$$Q_{66} = \frac{E(z)}{2A(1 - v(z))}, Q_{44} = K\frac{E(z)}{2(1 - v(z))};$$

$$Q_{55} = \frac{Q_{44}}{A}, \; A = 1 + \frac{z}{R},$$

K is the shear correction factor, $K = 5/6$ for first-order strain. Standard effective material properties P of functionally graded materials, such as *E (z)*, *υ (z)*, density *ρ (z)*, thermal expansion *α (z)*, or thermal conductivity *k (z)* can be expressed in terms of material properties.

Then the first-order-theory displacement field takes on the following form Sysoev (2019), Xing (2013):

$$u(x,\ \theta,\ z,\ t) = u_0(x,\ \theta,\ t) + z\psi_x(x,\ \theta,\ t);$$

$$v(x,\ \theta,\ z,\ t) = v_0(x,\ \theta,\ t) + z\psi_x(x,\ \theta,\ t);$$

$$w(x,\ \theta,\ z,\ t) = w_0(x,\ \theta,\ t).$$

where (u_0, v_0, w_0, ψ_x, ψ_θ) are the unknown functions which are to be determined. The shell deviations are small, and strains are infinitesimal, i.e. $w(x,\ \theta,\ t) < < h$.

The strain-displacement relation in cylindrical coordinate terms is written as follows:

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{\theta\theta} \\ \varepsilon_{x\theta} \\ \varepsilon_{xz} \\ \varepsilon_{\theta z} \end{Bmatrix} = \begin{vmatrix} \frac{\partial}{\partial x} & 0 & 0 \\ 0 & \frac{1}{R}\frac{\partial}{\partial \theta} & \frac{1}{R} \\ \frac{1}{R}\frac{\partial}{\partial \theta} & \frac{\partial}{\partial x} & 0 \\ \frac{\partial}{\partial z} & 0 & \frac{\partial}{\partial x} \\ 0 & \frac{\partial}{\partial z} & \frac{1}{R}\frac{\partial}{\partial \theta} \end{vmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

then:

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{\theta\theta} \\ \varepsilon_{x\theta} \\ \varepsilon_{xz} \\ \varepsilon_{\theta z} \end{Bmatrix} = \begin{Bmatrix} \varepsilon^0_{xx} \\ \varepsilon^0_{\theta\theta} \\ \varepsilon^0_{x\theta} \\ \varepsilon^0_{xz} \\ \varepsilon^0_{\theta z} \end{Bmatrix} + z \begin{Bmatrix} \varepsilon^1_{xx} \\ \varepsilon^1_{\theta\theta} \\ \varepsilon^1_{x\theta} \\ \varepsilon^1_{xz} \\ \varepsilon^1_{\theta z} \end{Bmatrix}$$

where:

$$\left\{\varepsilon^0\right\} = \begin{Bmatrix} \varepsilon^0_{xx} \\ \varepsilon^0_{\theta\theta} \\ \varepsilon^0_{x\theta} \\ \varepsilon^0_{xz} \\ \varepsilon^0_{\theta z} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial u_0}{\partial x} \\ \frac{w_0}{R} + \frac{\partial v_0}{R\partial \theta} \\ \frac{\partial v_0}{\partial x} + \frac{\partial u_0}{R\partial \theta} \\ \psi_x + \frac{\partial w_0}{\partial x} \\ \psi_\theta + \frac{\partial w_0}{R\partial \theta} \end{Bmatrix}$$

$$\left\{\varepsilon^1\right\} = \begin{Bmatrix} \varepsilon^1_{xx} \\ \varepsilon^1_{\theta\theta} \\ \varepsilon^1_{x\theta} \\ \varepsilon^1_{xz} \\ \varepsilon^1_{\theta z} \end{Bmatrix} = \begin{Bmatrix} \frac{\partial \psi_x}{\partial x} \\ \frac{\partial \psi_\theta}{R\partial \theta} \\ 0 \\ 0 \\ \frac{\partial \psi_\theta}{\partial x} + \frac{\partial \psi_x}{R\partial \theta} \end{Bmatrix}$$

Taking into account the Hamilton's principle, differential equations of motion change to the following form Seregin (2019), Qu et al. (2013):

$$\int_{t_1}^{t_2}\left(\delta T_{\text{shell}} - \delta U^{\varepsilon}_{\text{shell}} + \delta W\right)dt = 0$$

where δT_{shell} and $\delta U^{\varepsilon}_{\text{shell}}$ stand for changes in kinetic energy and shell strain energy respectively; δW stands for change in thermal performance; t stands for time.

The strain energy for a thin-walled cylindrical shell is expressed as follows:

$$U^{\varepsilon}_{\text{shell}} = \int_{-\frac{h}{2}}^{\frac{h}{2}} \int_0^L \int_0^{2\pi} \frac{1}{2}\{\varepsilon\}^T [Q] \{\varepsilon\}(R + z)d\theta dx dz$$

Kinetic energy for a rotating thin-walled cylindrical shell is expressed as follows:

$$T_{\text{shell}} = \frac{1}{2}\int_{-\frac{h}{2}}^{\frac{h}{2}} \int_0^{2\pi} \int_0^L \rho(z) \left\{ \begin{array}{c} (\dot{u}^2 + \dot{v}^2 + \dot{w}^2 + z^2\dot{\psi}_x^2 + z^2\dot{\psi}_\theta^2 \\ + 2z\dot{u}\dot{\psi}_x + 2z\dot{v}\dot{\psi}_\theta \\ (R + z)dx\, d\theta\, dz \end{array} \right\}.$$

For simplicity, when solving membrane equilibrium equations, we can determine that $N_x^T \neq 0$, $N_\theta^T = N_{x\theta}^T = M_x^T = M_\theta^T = M_{x\theta}^T = 0$. Works performed on the body due to heat load can be described as follows:

$$W = \frac{N_x^T}{2}\int_0^{2\pi} \int_0^L \left[\left(\frac{\partial w}{\partial x} \right)^2 \right] (R + z) dx d\theta.$$

where W is work performed on the shell, N^T is heat load, which is determined as follows:

$$N_x^T = \int_{-\frac{h}{2}}^{\frac{h}{2}} \beta \Delta T(z) dz,\ \ \beta = [Q_{11}(z) + Q_{12}(z)]\alpha(z),\ \ \Delta T(z) = T(z) - T_n$$

where $\Delta T(z)$ stands for temperature change, and T_M is the outside surface temperature.

It is assumed that the temperature will change along the thickness direction only; therefore, this change can be described in terms of solving a steady-state heat-transfer equation for a cylindrical shell Qu et al. (2013), Chen et al. (2015). The temperature field equation is written as follows:

$$-\frac{d}{dz}\left[k(z)\frac{dT}{dz} \right] = 0.$$

By making the appropriate substitutions and applying the Hamilton's principle to the energy functional, we obtain the following equations of motion:

$$\frac{\partial N_x}{\partial x} + \frac{\partial N_{x\theta}}{R\partial\theta} = I_0\frac{\partial^2 u_0}{\partial t^2} + I_1\frac{\partial^2 \psi_x}{\partial t^2};$$

$$\frac{\partial N_{x\theta}}{\partial x} + \frac{\partial N_\theta}{R\partial\theta} + \frac{1}{R}Q_\theta = I_0\frac{\partial^2 v_0}{\partial t^2} + I_1\frac{\partial^2 \psi_\theta}{\partial t^2};$$

$$\frac{\partial Q_x}{\partial x} + \frac{\partial Q_\theta}{R\partial\theta} + \frac{N_\theta}{R} + N^T\frac{\partial^2 w_0}{\partial x^2} = I_0\frac{\partial^2 w_0}{\partial t^2};$$

$$\frac{\partial M_x}{\partial x} + \frac{\partial M_{x\theta}}{R\partial\theta} - Q_x = I_1\frac{\partial^2 u_0}{\partial t^2} + I_2\frac{\partial^2 \psi_x}{\partial t^2};$$

$$\frac{\partial M_{x\theta}}{\partial x} + \frac{\partial M_\theta}{R\partial\theta} - Q_\theta = I_1\frac{\partial^2 v_0}{\partial t^2} + I_2\frac{\partial^2\psi_\theta}{\partial t^2};$$

where $(I_0, I_1, I_2) = \int_{-\frac{h}{2}}^{\frac{h}{2}}\left(1, z, z^2\right)\rho dZ$,

$$N_x = A_{11}\frac{\partial u_0}{\partial x} + A_{12}\left(\frac{w_0}{R} + \frac{\partial v_0}{R\partial\theta}\right) + \frac{B_{11}}{R}\frac{\partial\psi_x}{\partial x} + \frac{B_{12}}{R}\frac{\partial\psi_\theta}{R\partial\theta};$$

$$N_\theta = A_{12}\frac{\partial u_0}{\partial x} + A_{22}\left(\frac{w_0}{R} + \frac{\partial v_0}{R\partial\theta}\right) + \frac{B_{12}}{R}\frac{\partial\psi_x}{\partial X} + \frac{B_{22}}{R}\frac{\partial\psi_\theta}{R\partial\theta};$$

$$N_{x\theta} = A_{66}\left(\frac{\partial v_0}{\partial x} + \frac{\partial u_0}{R\partial\theta}\right) + \frac{B_{66}}{R}\left(\frac{\partial\psi_\theta}{\partial x} + \frac{\partial\psi_x}{R\partial\theta}\right);$$

$$M_x = B_{11}\frac{\partial u_0}{\partial x} + B_{12}\left(\frac{w_0}{R} + \frac{\partial v_0}{R\partial\theta}\right) + D_{11}\frac{\partial\psi_x}{\partial X} + D_{12}\frac{\partial\psi_\theta}{R\partial\theta};$$

$$M_\theta = B_{12}\frac{\partial u_0}{\partial x} + B_{22}\left(\frac{w_0}{R} + \frac{\partial v_0}{R\partial\theta}\right) + D_{11}\frac{\partial\psi_x}{\partial x} + D_{12}\frac{\partial\psi_\theta}{R\partial\theta};$$

$$M_{x\theta} = B_{66}\left(\frac{\partial v_0}{\partial x} + \frac{\partial u_0}{R\partial\theta}\right) + D_{66}\left(\frac{\partial\psi_\theta}{\partial x} + \frac{\partial\psi_x}{R\partial\theta}\right);$$

$$Q_x = K A_{44}\left(\psi_x + \frac{\partial w_0}{\partial x}\right);$$

$$Q_\theta = K A_{55}\left(\psi_\theta + \frac{\partial w_0}{R\partial\theta}\right).$$

where $\left(A_{ij}, B_{ij}, D_{ij}\right) = \int_{-\frac{h}{2}}^{\frac{h}{2}} Q_{ij}\left(1, z, z^2\right)dz$.

Taking into account the following boundary conditions:

$$v = w = N_x = M_x = N_{x\theta} = 0$$

The displacement fields which satisfy these boundary conditions can be written as follows:

$$\begin{aligned}
&u = \tilde{A}\ e^{i\,\omega t}Cos\left(\tfrac{m\pi x}{L}\right)Cos(n\theta);\\
&v = \tilde{B}\ \ e^{i\ \omega t}Sin\left(\tfrac{m\pi x}{L}\right)Sin(n\theta);\\
&w = \tilde{C}\ \ e^{i\ \ \omega t}Sin\left(\tfrac{m\pi x}{L}\right)Cos(n\theta);\\
&\psi_x = \tilde{D}\ \ e^{i\ \ \omega t}Cos\left(\tfrac{m\pi x}{L}\right)Cos(n\theta);\\
&\psi_\theta = \tilde{E}\ \ e^{i\ \omega t}Sin\left(\tfrac{m\pi x}{L}\right)Sin(n\theta).
\end{aligned}$$

At $v = w_x = w_\theta = \psi_x = \psi_\theta = 0$.

The displacement field which meets these boundary conditions can be written as follows:

$$
\begin{aligned}
u &= \tilde{A}\, H(x) Cos(n\theta) e^{i\ \omega t};\\
v &= \tilde{B}\, \phi(x) Sin(n\theta) e^{i\ \omega t};\\
w &= \tilde{C}\, \phi(x) Cos(n\theta) e^{i\ \omega t};\\
\psi_x &= \tilde{D}\, H(x) Cos(n\theta) e^{i\ \omega t};\\
v &= \tilde{E}\, \phi(x) Sin(n\theta) e^{i\ \omega t};\\
H(x) &= \tfrac{x}{L}\left(2\tfrac{x^2}{L^2} - 3\tfrac{x}{L} + 1\right);\\
\phi(x) &= \tfrac{x}{L}\left(\tfrac{x}{L} - 1\right)\left[\tfrac{x}{L}\left(\tfrac{x}{L} - 1\right)\right].
\end{aligned}
$$

Applying the Galerkin method, we obtain the following:

$$
\begin{aligned}
\int_0^{2\pi}\int_0^L F_1 u_0 dxRd\theta &= 0;\\
\int_0^{2\pi}\int_0^L F_2 v_0 dxRd\theta &= 0;\\
\int_0^{2\pi}\int_0^L F_3 w_0 dxRd\theta &= 0;\\
\int_0^{2\pi}\int_0^L F_3 \psi_x dxRd\theta &= 0;\\
\int_0^{2\pi}\int_0^L F_3 \psi_\theta dxRd\theta &= 0.
\end{aligned}
$$

After integration, we obtain a system of homogeneous linear algebraic equations with unknown coefficients $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, $\tilde{D}$ and $\tilde{E}$ as follows:

$$
\begin{aligned}
a_{11}\tilde{A} + a_{12}\tilde{B} + a_{13}\tilde{C} + a_{14}\tilde{D} + a_{15}\tilde{E} &= 0;\\
a_{21}\tilde{A} + a_{22}\tilde{B} + a_{23}\tilde{C} + a_{24}\tilde{D} + a_{25}\tilde{E} &= 0;\\
a_{31}\tilde{A} + a_{32}\tilde{B} + a_{33}\tilde{C} + a_{34}\tilde{D} + a_{35}\tilde{E} &= 0;\\
a_{41}\tilde{A} + a_{42}\tilde{B} + a_{43}\tilde{C} + a_{44}\tilde{D} + a_{45}\tilde{E} &= 0;\\
a_{51}\tilde{A} + a_{52}\tilde{B} + a_{53}\tilde{C} + a_{54}\tilde{D} + a_{55}\tilde{E} &= 0.
\end{aligned}
$$

For convenience, the equation can be written in the matrix form:

$$\left[M\omega^2 + K\right]d = 0.$$

Where: $d = \left[\tilde{A}\,\tilde{B}\,\tilde{C}\,\tilde{D}\,\tilde{E}\right]$. The equation can be solved by using common mathematical models based on the approaches developed by different scientists, for example, Vlasov, Donella, Mushtari, etc. The solution was found by applying a matrix based on the differential equation coefficients.

3 Results

Based on the results of the numerical experiment for shells made of X17 steel, relations between the vibration frequency and variations in the half-wave number n have been

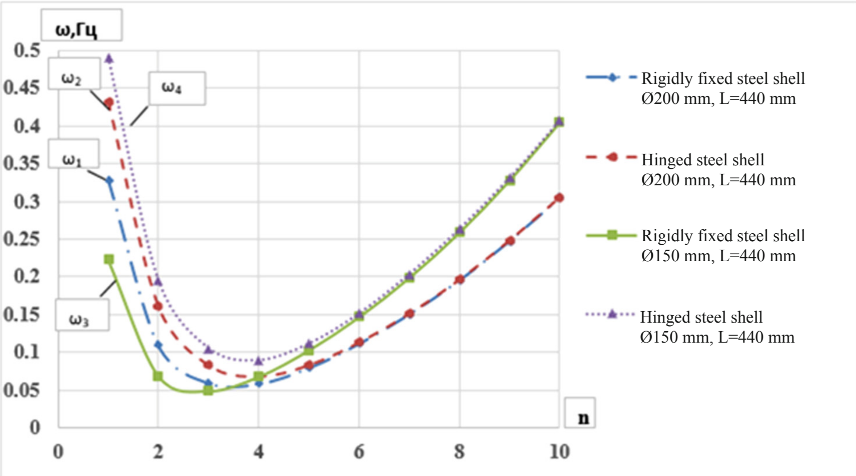

Fig. 2. Relation between the vibration frequency and the number of half-waves, with consideration for the thin-walled cylindrical shell shape and support type. *Source*: developed and compiled by the authors

identified, taking into account the shape of the thin-walled cylindrical shell and the support type, at the temperature of 18 °C (Fig. 2).

Figure 2 shows that the half-wave number (n) varies from 1 to 10, then ω_1 = from 0.328 to 0.304, ω_2 = from 0.432 to 0.305, ω_3 = from 0.223 to 0.405, and ω_4 = from 0.491 to 0.407. According to the diagram, the minimum vibration frequencies correspond to the half-wave number n = 2..4. Results of the numerical experiment show that the frequency depends on the support type at the half-wave number n = 2..4 and minimum vibration frequency of the thin-walled cylindrical shell, when the wave amplitude is at its maximum; however, the vibration frequency is influenced by the shell shape at $n \geq 4$.

4 Conclusion

At the first stage of the forced vibration onset on the thin-walled cylindrical shell, the support type remains critical before the fourth half-wave. After the fourth half-wave, the critical role is played by the shell shape — its diameter and, accordingly, curvature. The wave amplitude will be at its maximum when the vibration frequency of the thin-walled shell is at its minimum, i.e. the most detrimental deformations occur at the half-wave number n = 2..4.

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Application of a Reactor-Thyristor Device at a Transformer Substation

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Abstract. Purpose: The purpose of this work is to expand the functionality and improve the adjustment properties of thyristor switches in relation to a transformer substation, as well as to study the physical processes of a transformer substation with a dual-band reactor-thyristor device installed instead of the well-known mechanical voltage regulators called SWE and RUL.

Development/Methodology/Approach: The proposed a two-band reactor-thyristor device for voltage stabilization at consumers with simultaneous compensation of the reactive power of the network. The named device contains parallel connected to the network cosine capacitors and a two-band reactor-thyristor unit connected in series in the primary winding of the transformer substation from a parallel-connected reactor and a thyristor AC voltage regulator.

Results: The obtained results of the study of the physical processes of a transformer substation with a two-band reactor-thyristor device during voltage stabilization at consumers with simultaneous compensation of reactive power confirmed that the use of a two-band thyristor reactor device on the high side of the transformer substation leads to an improvement in the energy performance of the transformer substation and electricity consumers.

Originality/Value: The proposed new methods and devices for constructing a model of a two-band reactor-thyristor device - a power transformer, a mathematical model of a two-band reactor-thyristor device - a power transformer (R-TD – PT) has been developed, and also in the MatLab environment, systems of pulse-phase control of a two-band reactor-thyristor devices. The originality of the work is confirmed by the certificate for the program for ECM and patents of the Russian Federation for the invention and utility model.

Keywords: Thyristor switches · Dual reactor · Capacitor Bank · Transformer substation · Energy indicators · Power quality · Dynamics of switching on and off the power transformer

JEL Code: C69 · Q40 · Q41 · Q49

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1 Introduction

Known in domestic practice, three - phase voltage stabilizers have limited power (up to 100 kVA), high weight, low speed, and do not provide reactive energy compensation, but on the contrary, they consume additional reactive energy from the line.

The works of Rozhkov and Kozulin (1987), Porudominsky (1974), Nekliaev (1987), Chunikhin (1988), Rodstein (1981), Kukekov (1972), Vinogradov et al. (2014), Gerasimov and Merkuryev (1988), Venikov et al. (1985), and Sergeenkov et al. (1989) the issues of voltage regulation on the high side of the TS using mechanical voltage regulators such as SWE and RUL, which do not provide continuous voltage regulation with simultaneous reactive power compensation at the substation. Applied on TS a capacitor bank (CB) generates reactive power, which varies depending on deviations and fluctuations in the network voltage and creates additional losses from fluctuations in the phase of the network current. This issue is described in more detail in the paper in Solodukha (1981), Panfilov et al. (2016, 2017), Savelyev et al. (2019), Cherniy and Solovyev (2018, 2019), Pospelov et al. (1983), Headgear (2009), Zhezhelenko et al. (1981).

Exists a single-band reactor-thyristor device, which the authors propose to replace the device SWE and RUL for shock-free switching on, switching off without an electric arc and continuous voltage regulation of the TS. Famous a single-band reactor-thyristor device in addition to positive indicators it also has disadvantages associated with relatively large voltage distortions at the input of the power transformer and for consumers in the entire control range, at the rated voltage in the network, the greatest voltage distortions are created at the input of the power transformer and at consumers, as well as switching on and off of the power transformer is performed at an increased voltage at the input of the power transformer and at the load. The above disadvantages a single-band reactor-thyristor device negatively affect the energy performance of transformer substations.

Elimination of disadvantages of a single-band reactor-thyristor device, known devices such as SWE and RUL are discussed in this paper, in which proposed the method and device regulation of voltage and generating reactive power of a transformer substation and the device for its implementation.

2 Methodology

In this paper, the methodology used is methods of the theory of electric circuits, the theory of differential equations, the theory of automatic control and mathematical modeling.

The proposed dual-band reactor-thyristor device Klimash et al. (Klimash Tabarov 2018a, b), as well as the single-band R-TD – PT and known SWE and RUL devices, is switched between the network high-voltage switch (HV) Q1 and the primary winding of the substation power transformer in the star section. The scheme of the dual-band R – TD – PT as part of the TS is shown in Fig. 1. The scheme includes a three-phase network (G), power line (W), network HS (Q1), capacitor bank (CB), HS (Q2) in the circuit CB, the basic modules (VS–1) and secondary (VS–2) of the thyristor key (TK) with their system pulse-phase control (SPPC), which is synchronized with the network via measuring voltage transformers (MVT), contactor (AC), primary (L1) and second (L2) reactors, power transformer (PT) and active-inductive load (Z).

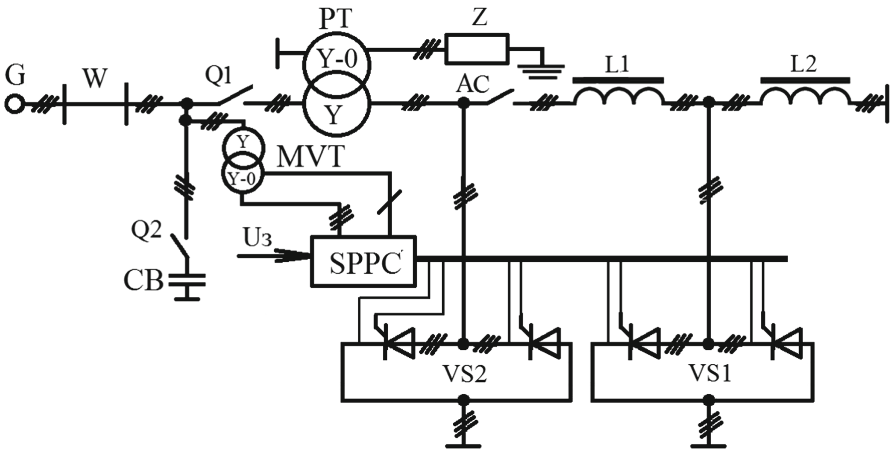

Fig. 1. Functional diagram of the transformer substation with dual-band reactor-thyristor device. *Source*: developed and received by the authors.

The prospect of developing automatic systems dual-band R-TD together with a capacitor installation as part of a TS with a power transformer according to the dual-band R-TD – PT scheme is characterized by the fact that it combines the functions of voltage stabilization and indirect reactive power compensation and provides voltage regulation at the input of the power transformer relative to the network voltage and for consumers between the set limits of regulation of the maximum and minimum separated by the nominal level. The proposed method provides for dividing the voltage control range into two sub-ranges: upper and lower.

To study the single-and dual-band R-TD – PT, Klimash and Tabarov (2018a, b developed a software package in the Matlab environment.

3 Results

The study of dynamic and quasi-stationary PT processes using single – band and two-band P-TD – PT was carried out on a mathematical model in the MatLab environment. The results of these studies are shown in the following oscillograms.

Let's consider the results of the study of TS at rated voltage in the network for single-band and dual – band R-TD – PT, which are shown in Fig. 2. The oscillograms labels indicate the following: 1 and 2 – phase voltages of the line and load; 3 and 4 – phase currents of the line and load; 5 and 6 – phase currents of the thyristor switch and reactor.

The following results of numerical experiments (Fig. 3) illustrate the operation of a two-band P-TD – PT when regulating the voltage at the input of the PT at different voltage levels network. Here the numbers indicate the following values: 1 and 2 – phase voltages of the line and load; 3, 4, 5 and 6- phase currents of lines, capacitors, PT, reactor, thyristor switch, and load.

As can be seen from the oscillograms shown in Fig. 3, the dual-band P-TD – PT at different levels voltage network supports voltage stabilization for consumers with

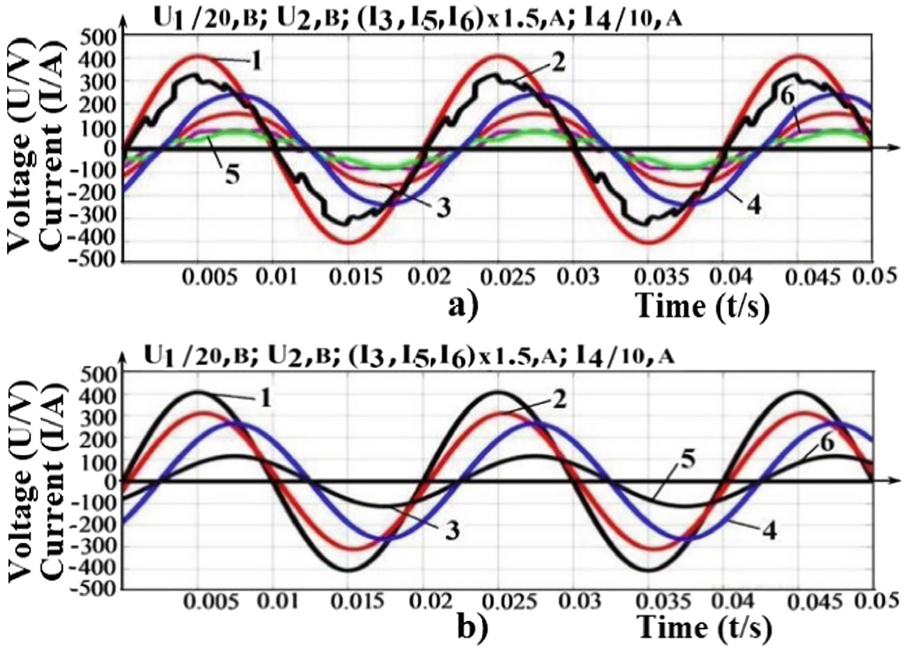

Fig. 2. Oscillograms of currents and voltages in the known (a) and new (b) scheme. *Source*: developed and received by the authors.

simultaneous reactive power compensation without distorting the current and voltage form at the input and output of the regulator. This characterizes another of the additional advantages of the proposed device.

Let's consider the results of numerical experiments of this physical process on a mathematical model for each of these ranges of voltage regulation. The results of these studies are shown in Fig. 4. The numbers in the figures indicate the phase voltage of the line 1 and load 2, the phase currents of the line 3, capacitor 4, power transformer 5, reactor 6, thyristor switch 7 and load 8.

From the result of the study of continuous voltage regulation with an intermediate sub-band, it is known that the proposed device distorts the shape of current and voltage in this sub-band. I want to note, that these distortions are within the International standard for the value of the non-sinusoidal voltage coefficient and the coefficient distortion current.

The following Figure shows the results of a study of the current at the input and output of a dual-band R-TD – PT at different control angles of thyristors. The results of this study are illustrated in Fig. 5, which introduces the following notation: 1, 2, and 3 – phase currents of the line, reactor, and thyristor switch.

The oscillograms in Fig. 5 shows, that the current on thyristors and reactors is distorted (Fig. 5a and b), and the resulting current, which is called the line current, has a sinusoidal shape at any control angles.

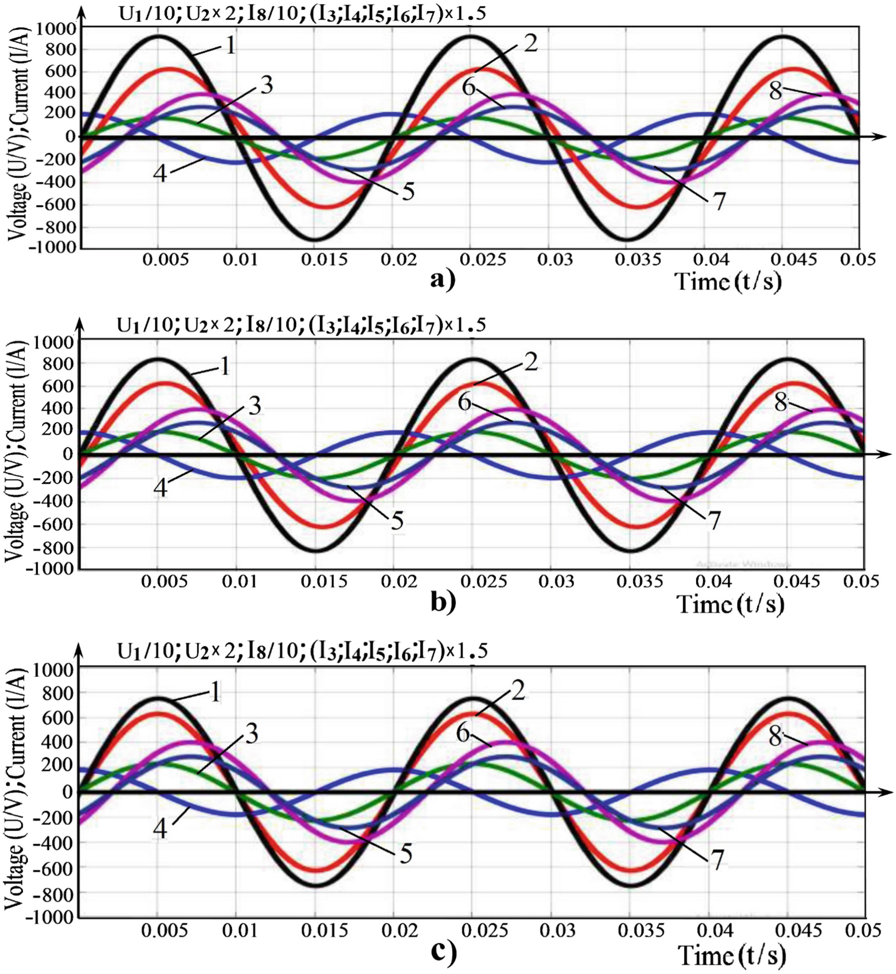

Fig. 3. Oscillograms of currents and voltages at different voltage levels of the line: maximum (a) nominal (b) and minimum (c). *Source*: developed and received by the authors.

The results showed that the two-band R-TD – PT fully stabilizes the voltage of consumers with simultaneous compensation of reactive power with good energy indicators and can be recommended for shop transformer substations of industrial and agro-industrial complex.

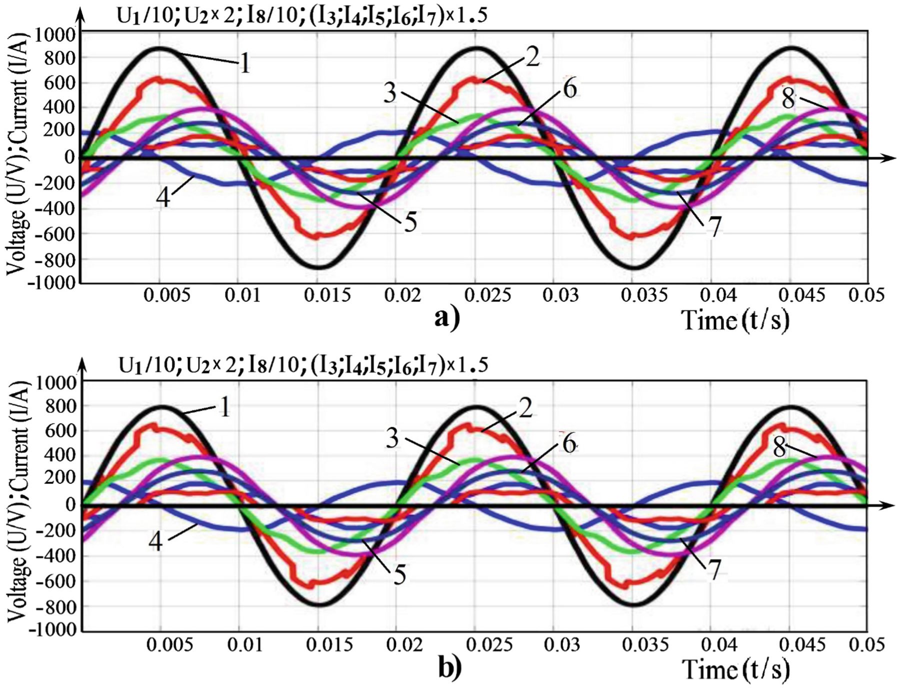

Fig. 4. Oscillograms of currents and voltages in the upper (a) and lower (b) voltage control sub-bands. *Source*: developed and received by the authors.

Consumers of the products of this article are substations of enterprises of all industries, agro-industrial and defense complexes, and urban electrified transport. Also of particular importance for this project are consumers who are far away from energy centers over long distances. These are 35/(10–6) kV and (10–6)/0.4 kV substations that have significant voltage deviations and losses in extended power lines.

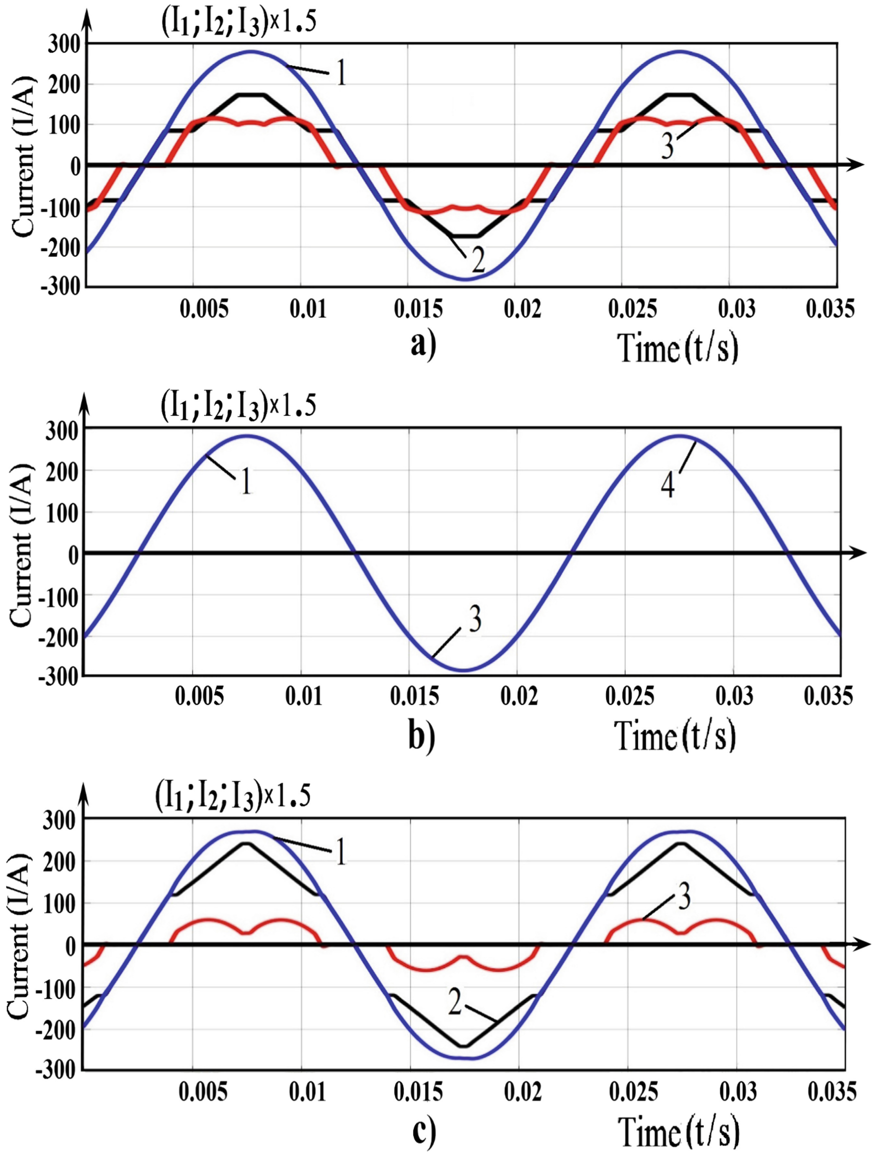

Fig. 5. Oscillograms of currents at overvoltage (a), nominal (b) and low (c) voltage in the line. *Source*: developed and received by the authors.

4 Conclusion

Taking into account the results obtained in the TS according to the dual-band R-TD – PT scheme with continuous voltage regulation for consumers at five voltage levels of the supply network, it can be concluded that the proposed device comprehensively improves the technical and economic indicators of the electric power system.

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The Experience of the Portal Machine Control System Modernizing for Automatic Arc Welding and Surfacing in a Shielded Gas

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Abstract. Purpose: modernize the portal machine control system for automatic arc welding and metal surfacing.

Design/methodology/approach: the plasma cutting machine was upgraded to a portal welding and surfacing machine. The machine used a mechanical control system for the welding torch, an electronic control system for electric drives, and "Mach3" software. A MIG/MAG welding head was installed instead of a plasma torch. The plasma cutter power source control outputs were connected to the welding power source control inputs. The welding torch trajectory control software was developed.

Findings: a hardware-software complex for welding with any types of welding electrode movement patterns, which are recommended for arc welding (linear, reciprocating, zigzag, crescent, eights, spiral, triangles, circles and other types) was manufactured.

Originality/value: the results allow to weld with high repeatability and quality. This allows to weld sheet structures with high quality, to use the developed machine to study the effect of welding modes on the welded joint quality, to use the machine to work out welding patterns. Results can be transferred to Kuka robotic welding lines and similar.

Keywords: Control program · Arc welding · Electrode movement pattern · G-code · Robotic welding · Automated welding · Software

JEL Code: C30 · L61 · L86 · M11 · M13 · M15 · O14 · Y80

1 Introduction

Currently, there is a trend towards automation and robotization of various technological processes. Thanks to this, productivity increases, rejects are reduced, the "human" factor is eliminated, the repeatability of operations is increased, etc. (Bolmsjo et al. 2002; Chen et al. 2014; Tao et al. 2019; Langdon et al. 1994). Automation and robotization of welding processes lags behind other types of technological processes.

Some types of thick-walled parts welding require simultaneous welding from the top and the bottom seam sides, or simultaneous welding from different seam sides. This

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requires maximum welding synchronization. But the technologist sets a small number of parameters (welding speed, welding current, electrode diameter, etc.) with large tolerances (up to $\pm$ 10%). In addition, each welder has his own “handwriting”. Therefore, it is difficult to achieve strictly specified welding parameters and synchronous welders work.

When working out welding modes, as well as when conducting research on welding parameters, it is necessary that the pattern of welds is the same. Violation of this condition leads to a significant error in the work results (Bakhmatov and Murav’ev 2017; Murav’ev et al. 2016).

Surfacing is very relevant and widely used in the repair of worn-out friction units, as well as in the additive manufacturing processes. These technologies can significantly reduce the cost of manufacturing and repairing parts. But to obtain high quality and the required properties of the deposited metal layer, a prerequisite is strict adherence to all the features of the technological process, which cannot be ensured by manual labor.

In connection with the high relevance of automation and robotization of welding and surfacing processes, work was carried out to automate the portal welding machine, the results of which are presented in the article.

2 Materials and Method

The literary search showed that when setting welding modes, the following parameters are set: welding current, welding speed, welding electrode type (filler wire type) and some others. But nowhere is specified the welded seams technique. In the educational literature there are only recommendations on the use of certain techniques for making seams for different joints (Losev and Yuxin 2000; Ovchinnikov 2016). Welding electrode trajectories (pitch, curvature radius, etc.) are not specified anywhere and are chosen by the welder independently based on his experience. Moreover, each welder has a limited set of seam patterns taught by his mentor. And these techniques differ significantly from the location of the welders school. The welding seam technique has a significant impact on the seam parameters. Krampit and Krampit (2015) showed that lateral electrode oscillations reduce the risk of burn-through and runoff when the weld pool is tilted, and also reduces weld bulge on the arc side. Metal heating and cooling can be controlled by electrode oscillating. Chernyshov (1970) wrote that the transverse electrode oscillations makes it possible to change the ratio of the length and width of the weld pool and more effectively keep the pool in a vertical and overhead position. It is recommended welding the seam root with the “crescent” oscillations and delay of the arc at the seam edges, or with longitudinal oscillations. Dolotov (2010), Fizulakov et al. (2016), Mamadaliyev et al. (2018), Murav’ev et al. (2015), Bakhmatov et al. (2016) shows that the electrode movement trajectory affects the duration of the weld pool and the mixing of the weld pool metal. And these factors have a significant impact on the weld edges fusion process and on pore formation. Kaidalov and Nazarenko (1986) showed that the beam affects hydrodynamic processes and changes the configuration of the weld pool, which leads to decrease root defects and decrease the tendency to crack formation. At the same time, it is possible to refine the seam structure, reduce the number of defects. But there is no technique for choosing the oscillation parameters, and the choice is made empirically after experiments on a large number of samples.

Analysis of technical documentation shows that the capabilities of automatic welding machines (welding tractors, orbital welding heads) are limited. Welding machines can perform the following paths: linear and zigzag. Robotic welding lines have more options (Madsen et al. 2002; Efimov et al. 2019; Egorov et al. 2018; Egorova et al. 2019). Kuka robots allow using ArcTech software to make welds with the following patterns: linear, triangular, trapezoidal, spiral, “double eight”. The software allows adjusting the pitch trajectory, seam width and the welding torch angle. But they cannot weld by the most common pattern types. The program settings number is small - it is not possible to regulate the “Double 8” seam circles diameters, it is impossible to perform asymmetrical paths, which are used when welding T-joints, etc.

For the experiments, a CNC plasma cutting machine was upgraded. This machine is controlled by the “Mach3” program using G-codes and M-codes. To control the welding current source, the outputs of the machine are connected to a semiautomatic welding power source “Svarog MIG 3500 (J93)”. Instead of a standard plasma cutting head, a welding head was installed.

To control the welding torch movement mechanisms, it was developed the software that generates G-codes based on weld data. Initial program data: weld intermediate point’s coordinates; welding speed of each trajectory section (linear seam speed); welding current; welding electrode trajectory pattern; pattern parameters. Data is entered either through the software interface or specified as a text file. The program output is an control program in G-codes. To ensure the maximum compatibility of the G-code program with various CNC systems, the developed software uses a minimum number of standard functions: M00; M03; M05; M30; Sxx (welding current value); G00; G01; G02; G03; Fxx (welding torch linear speed). To eliminate potential errors in trajectory calculations, circular interpolation is used in the “X Y Z R” format, where X, Y, Z are the coordinates of the end point, R is the radius of the circle.

Algorithmically, the trajectory creation consists in determining the tangency points of the approximating circles.To simplify the calculations, it was assumed that the starting point of the seam has coordinates (0; 0; 0) and the seam is located along the “0X” axis. After that, the coordinates are corrected using rotation matrices according by the formulas:

$$\begin{aligned}
X &= (X_0\cos(\gamma) - Y_0\sin(\gamma))\cos(\beta) + Z_0\sin(\beta)\\
Y &= (X_0\sin(\gamma) + Y_0\cos(\gamma))\cos(\alpha) - ((-X_0\cos(\gamma) + Y_0\sin(\gamma))\sin(\beta) + Z_0\cos(\beta))\sin(\alpha)\\
Z &= (X_0\sin(\gamma) + Y_0\cos(\gamma))\sin(\alpha) + ((-X_0\cos(\gamma) + Y_0\sin(\gamma))\sin(\beta) + Z_0\cos(\beta))\cos(\alpha)
\end{aligned}$$

where X, Y, Z are the current coordinates of the point; X_0, Y_0, Z_0 - initial point coordinates; α, β, γ - seam axis rotation angles relative to the coordinate system.

The seam axis rotation angles were calculated from the initial (X1, Y1, Z1) and final (X2, Y2, Z2) seam trajectory segment points using the vector multiplication formulas. The vectors were: axis 0X - vector $\vec{a}$ and vector $\vec{b} = ((X2 - X1), (Y2 - Y1), (Z2 - Z1))$. The calculations were performed as follows:

$$\cos(\gamma) = \frac{X_a X_b + Y_a Y_b}{|\vec{a}|\left|\vec{b}\right|} = \frac{X_b}{\left|\vec{b}\right|} \qquad \gamma = \begin{cases} \mathrm{a}\cos(\cos(\gamma)),\ \sin(\gamma) \geq 0 \\ 2\pi - \mathrm{a}\cos(\cos(\gamma)),\ \sin(\gamma) < 0 \end{cases}$$

$$\sin(\gamma) = \frac{X_a Y_b - Y_a X_b}{|\vec{a}|\left|\vec{b}\right|} = \frac{Y_b}{\left|\vec{b}\right|}$$

where X_a, Y_a, X_b, Y_b are the coordinates of the vectors; γ is the angle of rotation about the 0Z axis.

The angle of rotation about the 0Y axis was calculated in a similar way:

$$\cos(\beta) = \frac{X_a X_b + Z_a Z_b}{|\vec{a}|\left|\vec{b}\right|} = \frac{X_b}{\left|\vec{b}\right|} \qquad \gamma = \begin{cases} \mathrm{a}\cos(\cos(\beta)), \sin(\beta) \geq 0 \\ 2\pi - \mathrm{a}\cos(\cos(\beta)), \sin(\beta) < 0 \end{cases}$$

$$\sin(\beta) = \frac{X_a Z_b - Z_a X_b}{|\vec{a}|\left|\vec{b}\right|} = \frac{Z_b}{\left|\vec{b}\right|}$$

Using the cosines and sines of the rotation angles instead of the tangent has a clear advantage. Tangent is a periodic function with period π. Therefore, $tg(x) = tg(x + n \cdot \pi)$ (where n is an integer). At the same time, the maximum vector rotation angle is 2π. Therefore, using the tangent function is a source of errors in mathematical calculations.

The tangency points of circles and circles, circles and straight lines were calculated taking into account the fact that circles and lines must be tangent to each other. Analytical calculation of these points using the equations of circles and lines seems to be time consuming and often has several solutions. For example, when calculating a straight line tangent to two circles (Fig. 2g, h), 4 variants are possible. The geometrically solution makes it possible to simplify the calculation and ultimately obtain the following equations (for a seam in the 0XY plane):

$$X_a = \frac{X_0 + X_1}{2} + \left(\frac{b}{2} - r\right)\sin(\alpha 1) + r\cos\left(a\sin\left(\frac{2r}{l}\right) + \theta - \frac{\pi}{2}\right)$$

$$Y_a = \frac{Y_0 + Y_1}{2} - \left(\frac{b}{2} - r\right)\cos(\alpha 1) + r\sin\left(a\sin\left(\frac{2r}{l}\right) + \theta - \frac{\pi}{2}\right)$$

$$X_{11} = \frac{X_0 + X_1}{2} + \left(\frac{b}{2} - r\right)\sin(\alpha 1) \qquad Y_{11} = \frac{Y_0 + Y_1}{2} - \left(\frac{b}{2} - r\right)\cos(\alpha 1)$$

where X_a, Y_a are the coordinates of the tangency point of the first circle and the straight line; X_0, Y_0 are the weld fragment beginning coordinates; X_1, Y_1 are the weld fragment end coordinates; X_{10}, Y_{10} are the weld segment starting point coordinates; b is the seam width; r - circle radius; α1 - angle between the 0X axis and the vector $((X_1 - X_0); (Y_1 - Y_0))$; l - distance between points $(X_{10}; Y_{10})$ and $(X_{11}; Y_{11})$; θ - angle between vector 0X and $((X_{11} - X_{10}); (Y_{11} - Y_{10}))$;

$$X_b = \frac{X_0 + X_1}{2} + \left(\frac{b}{2} - r\right)\sin(\alpha 1) - r\sin\left(\theta - a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$

$$Y_b = \frac{Y_0 + Y_1}{2} - \left(\frac{b}{2} - r\right)\cos(\alpha 1) + r\cos\left(\theta - a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$

$$X_{12} = X_1 - \left(\frac{b}{2} - r\right)\sin(\alpha 1) \qquad Y_{12} = Y_1 + \left(\frac{b}{2} - r\right)\cos(\alpha 1)$$

$$X_c = X_1 - \left(\frac{b}{2} - r\right)\sin(\alpha 1) + r\sin\left(\theta - a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$
$$Y_c = Y_1 + \left(\frac{b}{2} - r\right)\cos(\alpha 1) - r\cos\left(\theta - a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$

where l is the distance between the points (X_{11}; Y_{11}) and (X_{12}; Y_{12}); θ is the angle between the vector 0X and (($X_{12} - X_{11}$); ($Y_{12} - Y_{11}$));

$$X_d = X_1 - \left(\frac{b}{2} - r\right)\sin(\alpha 1) - r\cos\left(\theta + a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$
$$Y_d = Y_1 + \left(\frac{b}{2} - r\right)\cos(\alpha 1) - r\sin\left(\theta + a\sin\left(\frac{2r}{l}\right) - \frac{\pi}{2}\right)$$
$$X_{13} = \frac{X_1 + X_2}{2} + \left(\frac{b}{2} - r\right)\sin(\alpha 2) \qquad Y_{13} = \frac{Y_1 + Y_2}{2} - \left(\frac{b}{2} - r\right)\cos(\alpha 2)$$

where l is the distance between points (X_{12}; Y_{12}) and (X_{13}; Y_{13}); θ is the angle between the vector 0X and (($X_{13} - X_{12}$); ($Y_{13} - Y_{12}$)); α2 is the angle between the 0X axis and the vector (($X_2 - X_1$); ($Y_2 - Y_1$)); X_2, Y_2 - coordinates of the seam path next segment end.

To ensure a smooth transition from the trajectory section last elementary step end to the trajectory next section first elementary step beginning, the elementary step last element end point was calculated taking into account the next step first point position, therefore, in the formulas, when calculating the tangent last point, the angle α2 is used instead of α1.

The spiral pattern deserves special attention. Ideally, moving along the 0X axis in a spiral should combine linear and circular motion:

$$X = X_0 + vt + r\cos(\omega t + \varphi) \qquad Y = Y_0 + r\sin(\omega t + \varphi)$$

where X, Y are the current trajectory coordinates; X_0, Y_0 are the initial coordinates; t - time; v - linear movement speed; ω - circular rotation speed; φ - initial angle.

But the G-codes command does not allow writing these equations. The G-codes allows using either linear or circular interpolations. It is possible to split the trajectory into a large number of elementary fragments, but this will increase the size of the control program and will require large computing power of the CNC unit. Therefore, the spiral trajectory is replaced by a two arc trajectory (Fig. 2b, c). The first method is used in the Kuka welding robot. The tangency points are described by the following equations:

$$X_a = X_1 + \frac{b}{2}\sin(\alpha 1) \quad X_b = X_1 - \frac{b}{2}\sin(\alpha 2) \quad r1 = \frac{l^2}{2b} \quad X_{10} = X_0 - \frac{b}{2}\sin(\alpha 1)$$
$$Y_a = Y_1 - \frac{b}{2}\cos(\alpha 1) \quad Y_b = Y_1 + \frac{b}{2}\cos(\alpha 2) \quad r2 = \frac{b}{2} \quad Y_{10} = Y_0 + \frac{b}{2}\cos(\alpha 1)$$

where X_a, Y_a, X_b, Y_b are the coordinates of the arcs tangency points; X_1, Y_1 are the seam trajectory section end point coordinates; b is the seam width; r_1, r_2 are the arcs radii; l is the distance between points (X_{10}, Y_{10}) and (X_a, Y_a); α1 is the angle between the 0X axis and the vector $((X_1 - X_0), (Y_1 - Y_0))$; α2 is the angle between the 0X axis and the vector $((X_2 - X_1), (Y_2 - Y_1))$.

This pattern has a significant drawback - the trajectory lines density at the seam top edge is higher than at the seam bottom edge. As a result, more metal is deposited at the top edge and the seam is asymmetrical. The second pattern does not have this disadvantage. Formulas for tangency points and for arc radii are:

$$X_a = X_1 + r2 \cdot \cos(\alpha 1) \qquad X_b = X_1 - r2 \cdot \cos(\alpha 2) \qquad r1 = \frac{b}{4} + \frac{\left(\frac{l}{2} + r2\right)^2}{b}$$

$$Y_a = Y_1 + r2 \cdot \sin(\alpha 1) \qquad Y_b = Y_1 - r2 \cdot \sin(\alpha 2) \qquad r2 = \frac{b}{2}$$

where l is the distance between points (X_1, Y_1) and (X_2, Y_2).

This seam has a more even metal distribution over the weld cross section.

Currently, the author is working on adapting the developed software for controlling the Kuka industrial robot using the KSS 8 (KRC4) command system - LIN and CIRC commands.

3 Results

The software was developed (Fig. 1), which allows to make the following welding torch movement patterns: linear (Fig. 2a); spiral (Fig. 2b, c); a crescent (Fig. 2d) with a bend in any direction; zigzag (Fig. 2e); triangle (Fig. 2f); figure eight (Fig. 2g); double eight (Fig. 2h); linear with return (Fig. 2i); a crescent moon (Fig. 2 j, k); snail (Fig. 2 l); seams with reinforcement along the seam axis and others. For all these patterns, the software allows to separately adjust the seam width, pitch size, fillet radii, seam root reinforcing circle diameters, and other parameters.

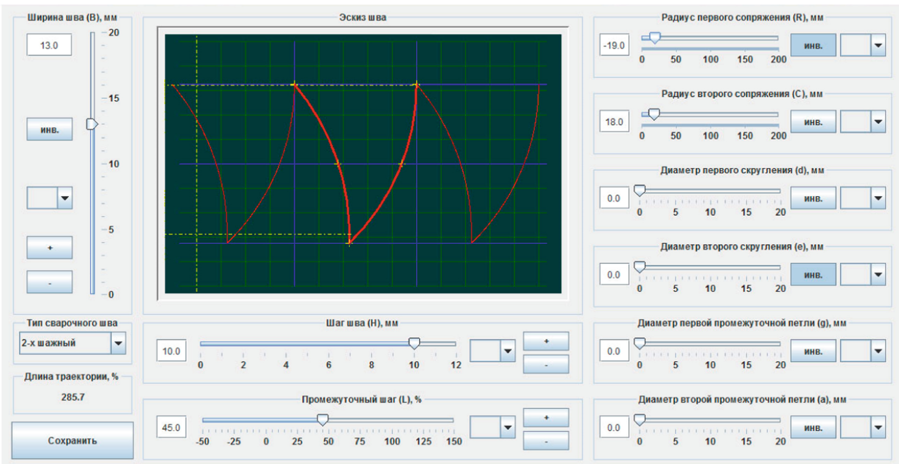

Fig. 1. Weld pattern setting window. *Source*: developed and compiled by the author

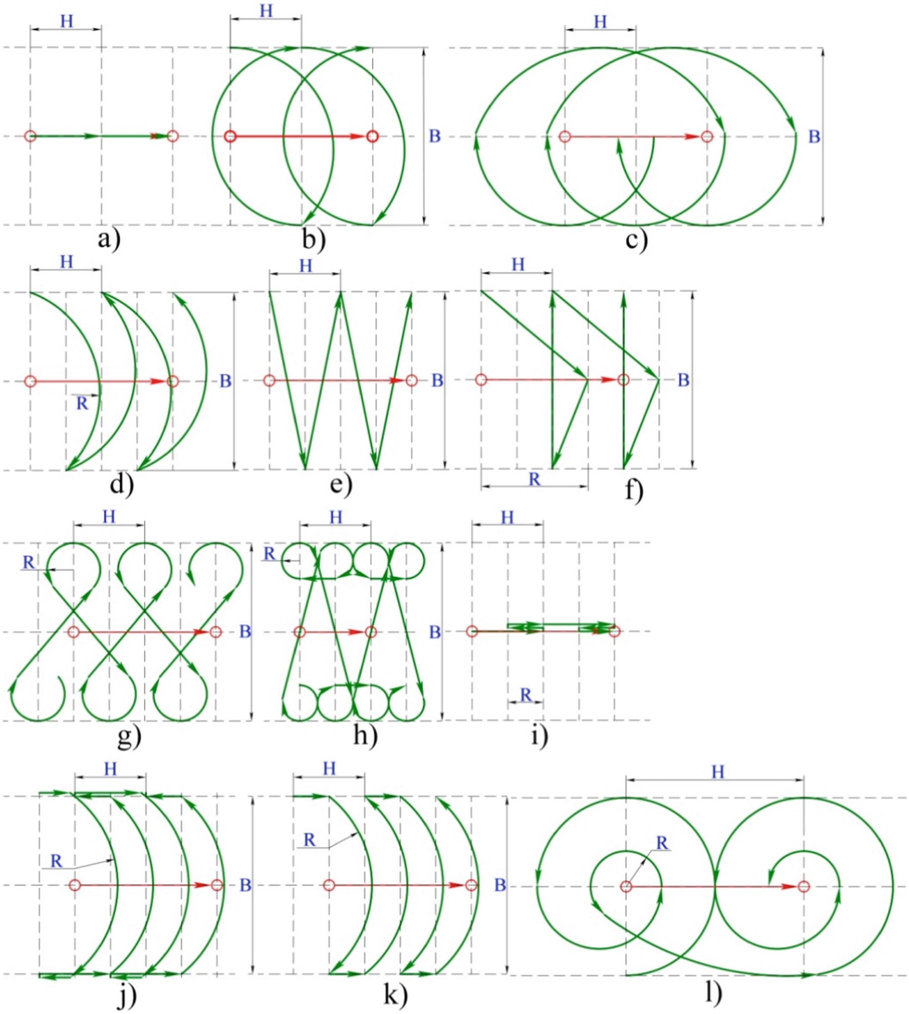

Fig. 2. Welding electrode motion patterns. *Source*: developed and compiled by the author

The results of the welding by developed machine are shown in Fig. 3.

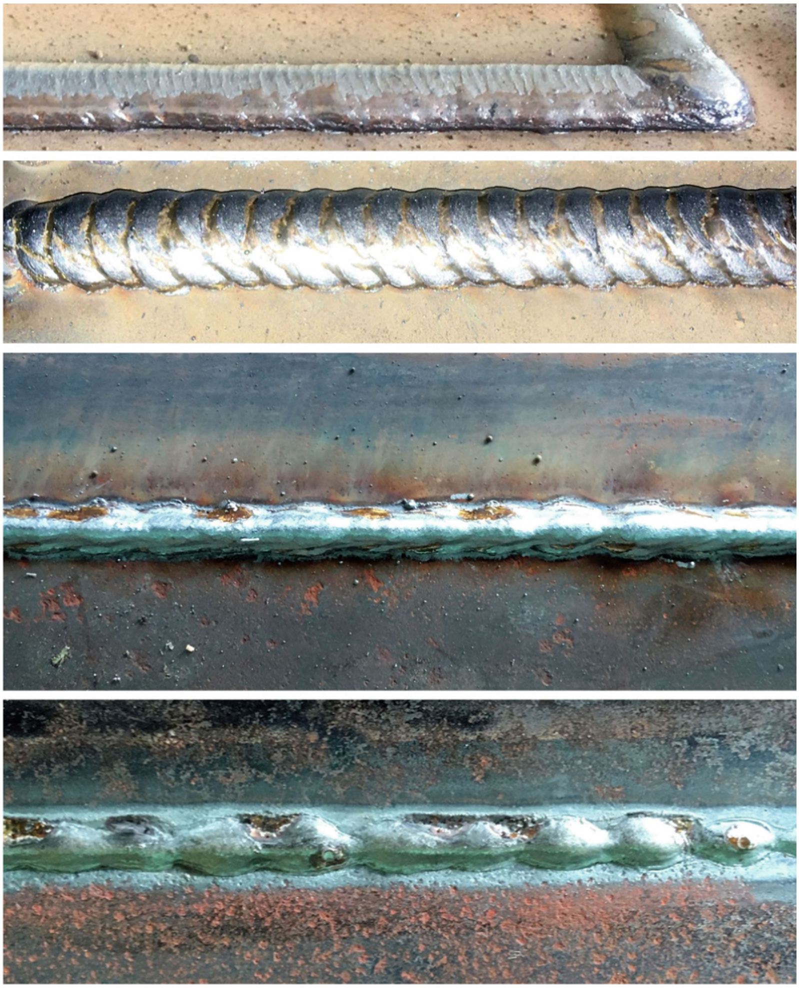

Fig. 3. The welds and surfacing samples. *Source*: developed and compiled by the author

4 Conclusion

The developed software for controlling the portal welding and surfacing machine provides a high degree of repeatability of the welding torch trajectory. The software allows welding with a large number of patterns that can be flexibly configured for different technological processes.

The software is planned to be upgraded so that it can import the control G-code (weld path) from CAM systems and convert it into commands to control the movement of the welding torch.

The author is working on the developed the optimal trajectories for the transition from one weld segment to another without changing the welding speed and ensuring the required penetration of metal edges at the tangent points. One solution to this problem is varying the welding torch movement speed during the welding process (for example, slowing down or accelerating it near the seam edge).

The author is working on adapting the developed software for controlling Kuka welding positioners.

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Models for Calculating Pipeline Performance with Data Hazards

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Abstract. Purpose: The purpose of this chapter is to describe the computer and analytical models developed by the author for calculating the performance of the computing pipeline with data hazards.

Design/Methodology/Approach: A uniform computing pipeline with data hazards is considered which can be used to accelerate the work of processors (CPUs), coprocessors, signal processors, as well as multi-threaded applications. We study random hazards by data. In order to minimize the loss of waiting time, we build an analytical model consisting of formulas for calculating the processing time for given hazard probabilities. To obtain this analytical model, we construct recurrence equations based on our table of increments in the average processing time of the input data array. To facilitate filling in the increment table, we apply the methods of the semiring theory. As a result, we obtain inhomogeneous linear recurrence equations. The problem of constructing an analytical model is reducing to solving these equations. To verify the obtained formulas, we use a computer model that is developed using methods of the theory of random variables.

Findings: Software has been developed to simulate the operation of the pipeline with conflicts. In case of hazards at a distance of no more than 2, formulas are obtained for the optimal pipeline depth.

Originality/Value: The obtained formulas for calculating the performance and optimal depth of the pipeline are new and belong to the author. The results are of great importance for the design of processors and multi-threaded applications.

Keywords: Computing pipeline · Processor performance · Random value · Simulation of hazards · Data hazards · Tropical semiring · Optimum depth

JEL Code: C63

1 Introduction

This chapter is devoted to building models for calculating the processing time of a given amount of data for a homogeneous computing pipeline having known probabilities of data hazards. These models are used to find formulas for calculating the optimal pipeline depth. A computer model is built, on the basis of which an application is developed that allows simulating the execution of the pipeline. The program is accompanied by the output of random graphs of the dependence of processing time on the depth of the

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pipeline. The analytical model consists of formulas for calculating the processing time of data obtained under the condition that the hazarding elements are at a distance of 1 or 2. They are obtained by solving recurrence equations and verified using a computer model.

In Dubey and Flynn (1990) the following formula was obtained for the optimal pipeline depth in the event of hazards at a distance of 1:

$$m_{opt} = \sqrt{\frac{(1-b_1)t_p}{b_1 t_o}} \tag{1}$$

Here m_{opt} is the number of pipeline stages at which the data processing time is minimal, b_1 is the probability of hazard between pairs of neighboring data elements, t_p is the processing time of one element by pipeline without taking into account the time for overhead, t_o is the overhead time for each stage. We follow the notation from the article Hartstein and Puzak (2002). Formula (1) does not take into account the amount of data. In Husainov and Titova (2018), this formula was refined for an arbitrary amount of data n

$$m_{opt}(n) = \sqrt{\frac{(1-b_1)t_p}{(b_1 + \frac{1}{n-1})t_o}} \tag{2}$$

This formula showed that the correction obtained could be significant. In this paper, we obtain a generalization of formula (2) for a pipeline with hazards at a distance of 1 and 2. This generalization, when passing to the limit as $n \to \infty$ gives one of the main results of our work

$$m_{opt} = \sqrt{\frac{(1-b_1)(1-b_2)t_p}{(1-(1-b_1)(1-b_2))t_o}} \tag{3}$$

strengthening formula (1) obtained by (Dubey and Flynn 1990).

2 Methodology

The method of recurrence relations is widely used to study computer systems. In particular, it provides an algorithm for calculating the performance for an acyclic wave processor, which is a generalization of the pipeline (Khusainov 2019).

We give preliminary information. We describe a method for constructing recurrence equations whose solutions allow us to construct formulas for finding the mathematical expectation of the processing time of n elements of the input data of a computing pipeline. The computing pipeline consists of several series-connected functional devices and is designed to process an array of input data elements. It works like a conveyor for assembling cars. Computing pipelines are used to accelerate the operation of processors, signal processors (Chowdhury et al. 2018; Belyaev et al. 2020; Singh et al. 2019) coprocessors (Merchant 2017; Woehrle and Kirchner 2018; Batra 2018), for processing big data (Costan 2019).

Input data elements can be numbers, machine instructions, database queries, arithmetic operations, etc. The processing of one element is divided into successive calculation steps. The number of steps is called the pipeline depth and is denoted by m. The total time of the calculation steps is called the total logical delay of the pipeline and is denoted by t_p. Each step must be assigned a functional device called a stage. This stage performs its step and conveys the results to the next stage. The data transfer session time between steps and other overheads is denoted by t_o. The last stage passes the result to the output. Stages can work in parallel. We will consider pipelines whose stages have the same runtime, which is called the pipeline cycle and is equal to $h = t_o + \frac{t_p}{m}$, where m is the depth of the conveyor. If there are no hazards, then the processing time of n elements in pipeline cycles is $T_n = n - m + 1$, or in nanoseconds $T_n h = (n - m + 1)h$.

Let $e_1, e_2, \cdots, e_n$ be the sequence of elements arriving at the input of the pipeline. Following Emma and Davidson (1987), we will call the distance between the elements e_i и $e_j, i \leq j$, the number $d = j-i$, and we will assume that for each $d \in \{1, 2, \cdots, m-1\}$, where m is the pipeline depth, the probability of hazard between the elements b_d, located at a distance d is given.

Our first problem is to find a formula for calculating the average processing time of n elements. We consider random variables whose values are equal to the processing time of the arrays of data elements. Probabilities b_d are given for input elements spaced d. The probability space consists of the set of triangular $(n \times n)$-matrices $\left(\varepsilon_{ij}\right)$, consisting of zeros and ones, such that $\varepsilon_{ij} = 0$ for all $i \geq j$. The element ε_{ij} for $i < j$ takes the value 1 with probability $p_{ij} = b_{j-i}$. The probability of an elementary event $\left(\varepsilon_{ij}\right)$ is equal to the product $\prod\limits_{(1 \leq i < j \leq n)} p_{ij}^{\varepsilon_{ij}} \left(1 - p_{ij}\right)^{1-\varepsilon_{ij}}$. For each $1 \leq k \leq n$, we introduce a random variable t_k assigning to each triangular matrix processing time of k elements. This representation of processing time justifies the possibility of compiling linear recurrence relations for finding formulas, because the mathematical expectation of a linear combination of random variables from one probability space is equal to the linear combination of mathematical expectations of these quantities.

In the computer model of the pipeline, a random event is constructed using a random number generator for the bits of the described matrix $\left(\varepsilon_{ij}\right)$. We take an enough large number M and for all $i < j$ generate random numbers $s \in \{0, 1, \cdots, M-1\}$. If $s < M \cdot b_{j-i}$, then set $\varepsilon_{ij} = 1$, otherwise $\varepsilon_{ij} = 0$. The numbers t_n are calculated by induction. Let n be the number of elements to be processed, m be the depth of the pipeline. For $n = 1$, we set $t_1 = m$. For $n > 1$ choose the smallest integer r from the range $1 \leq r \leq m-1$, such that $n - r \geq 1$ and $\varepsilon_{n-rn} = 1$. If such a number exists, then assign $t_n = \max(t_{n-1} + 1,\ t_{n-r} + m)$, otherwise $t_n = t_{n-1} + 1$. This allows us to create a recurrence equation for calculating the mathematical expectation T_n of a random variable t_n.

Consider, for example, the case when the probability b_1 of a hazard between neighboring elements is given, and $b_i = 0$ for all $i > 1$. In this case, the values of a random variable equal to the processing time of the n th element will be calculated using the recurrence relation $t_n = t_{n-1} + 1$ if $\varepsilon_{n-1n} = 0$ (no hazard), and $t_n = t_{n-1} + m$, in other cases. The first case occurs with probability $1 - b_1$, and the second with probability b_1.

Passing to mathematical expectations, we obtain a recurrence relation

$$T_n = (1 - b_1)(T_{n-1} + 1) + b_1(T_{n-1} + m) = T_{n-1} + 1 - b_1 + b_1 m,$$

provided $T_1 = m$. It is easy to see that his solution is given by the formula

$$T_n(m) = m + (n - 1)(1 - b_1 + b_1 m).$$

A graph of processing time versus depth is shown in Fig. 1. It closely approximates the obtained random graphs.

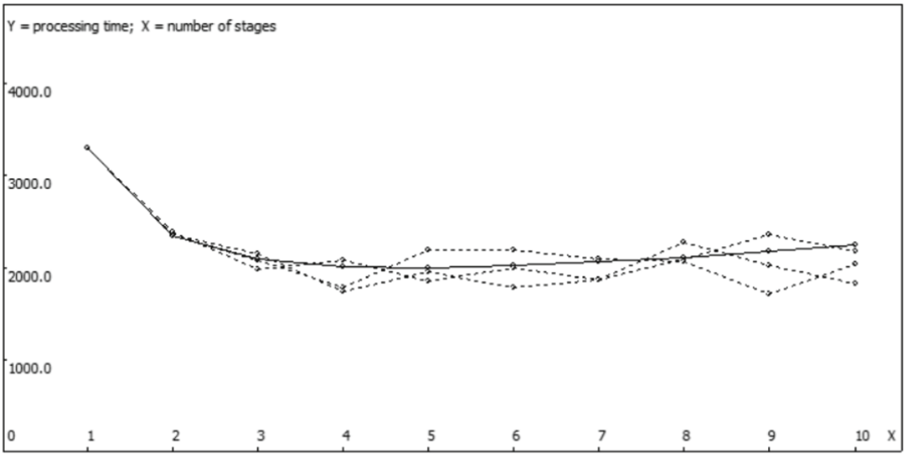

Fig. 1. The results of measuring the processing time in the case when random restart is possible. The graph drawn with a solid pen shows the theoretical values Y of the mathematical expectation of the processing time of n elements, depending on the number of conveyor steps (X). These values are calculated by the formula $Y = T_n(X) = (X + (n - 1)(1 + b_1(X - 1)))\left(t_o + \frac{t_p}{X}\right)$. The dashed broken lines show three graphs for the processing time of n elements obtained as a result of three experiments. The X axis represents the number of stages. The Y axis shows the processing time. *Source*: developed and compiled by the author

Consider the so-called simple analytical model

$$T_n(m) = \left(m + n - 1 + \sum_{i=1}^{m-1} b_i(m - i)\right)\left(t_o + \frac{t_p}{m}\right).$$

A similar formula was used in an article (Emma and Davidson 1987) to calculate the inverse bandwidth of a computing pipeline.

Figure 2 shows the results of experiments with the computer model described above. They show that this formula is not accurate even when the probabilities of all hazards are $b_i = 0$, except for the probability b_2 for a hazard at a distance of 2. Hence, this formula needs to be clarified.

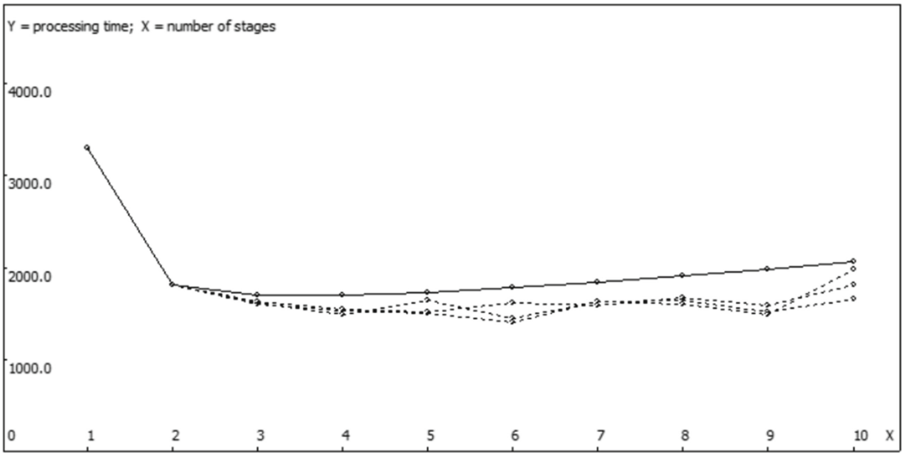

Fig. 2. The results of measuring the processing time in case hazards are possible at a distance of 2. Here X denotes the number of stages. Y is equal to the average processing time $n = 150$ elements. The solid pen draws a graph of the function $Y = T_n(X) = (X + (n-1)(1 + b_2(X-2)))\big(t_o + t_p/X\big)$. Dotted broken lines show graphs obtained as a result of experiments. *Source*: developed and compiled by the author

In this paper, we will construct a more accurate analytical model. When building, the values of the random value of the processing time are calculated using binary addition and maximum operations. To facilitate these calculations, we will use the so-called tropical semiring $\mathbb{N} \cup \{-\infty\}$, considered in (Pin 2017), where $\mathbb{N}$ is the set of non-negative integers in which the function of two variables $x \vee y := \max(x, y)$, and the role of the multiplicative operation is the addition of $x + y$. Operation $+$ has a higher priority than operation $\vee$. The zero element is $-\infty$. The resulting model gives the average processing time, depending on the depth of the pipeline. The optimum depth is calculated by standard methods.

3 Results

First, we consider pipelines that have hazards at a distance of 2, for a given probability b_2. The probability of no hazard is $b_0 = 1 - b_2$. All other probabilities are equal to 0. Then we will consider pipelines having non-zero hazards at a distance of no more than 2. We will build an analytical model for pipelines performance, which considers hazards at a distance of 1 and 2, and give formulas for finding the optimal depth - the number of steps at which greatest pipeline performance.

Consider a homogeneous conveyor having $m \geq 2$ stages, and some array consisting of $n \geq 1$ input elements $e_1, e_2, \cdots, e_n$. Suppose that we know the probability b_2 of a hazard according to data between elements with indices $i \geq 1$ and $i + 2 \leq n$. It is necessary to calculate the average processing time of n elements in cycles T_n. To this aim, we construct a recurrence relation for its calculation.

Time T_1 equals m. Since e_2 cannot have a hazard with e_1, than $T_2 = m + 1$. Element e_3 has hazard with e_1 with probability b_2. Therefore, $T_3 = b_2(T_1 + m \vee T_2 + 1) +$

$(1 - b_2)(T_1 + 1)$. Since $m \geq 2$, we obtain $T_3 = b_2 \cdot 2m + (1 - b_2)(m + 1) = 1 - b_2 + mb_2$.

Now let $n \geq 3$. According to the construction of the random variable t_n from Sect. 2, $t_n = \max(t_{n-1} + 1, t_{n-r} + m)$, where $r \in \{1, 2, \cdots, \min(m - 1, n - 1)\}$ is the smallest distance at which the hazard met with one of the preceding elements. It follows that in our case the following possibilities may occur that can be represented using the table, which we will call the increment table:

In the column e_n, the first row contains the symbol b_0, indicating that with probability b_0 the element e_n does not hazard with the previous ones, which implies that with probability $b_0 = 1 - b_2$ the time T_n will be equal to $T_{n-1} + 1$. In the next line, the symbols $b_0 b_2$ indicate that with a probability $b_0 b_2$ there was a hazard at a distance of 2, and e_{n-1} has no hazards. It follows that in this case the time T_n will be equal to

$$T_{n-2} + m \vee T_{n-1} + 1 = T_{n-2} + m \vee T_{n-1} + 1 + 1 = T_{n-2} + m.$$

The existence of empty columns e_{n-3} and e_{n-4} indicates that some of these rows should use these elements. For example, for the last row, with probability b_2 the time T_n equals $T_{n-2} + m \vee T_{n-1} + 1$, hence

$$\begin{aligned} T_n =& (T_{n-4} + m \vee T_{n-3} + 1) + m \vee (T_{n-3} + m \vee T_{n-2} + 1) \\ &= (T_{n-4} + m \vee T_{n-3} + 1) + m = T_{n-2} + m. \end{aligned}$$

Substituting $b_0 = 1 - b_2$ from Table 1, we arrive at the relation

Table 1. Values of the average processing time of n elements with various versions of previous hazards. Hazards at a distance of 2 are considered. In the case when there are no hazards, the time increment increases by 1 clock cycle. If there are hazards, then the time increases by m cycles

e_{n-4}	e_{n-3}	e_{n-2}	e_{n-1}	e_n	
				b_0	$T_{n-1} + 1$
			b_0	b_2	$T_{n-2} + m$
		b_0	b_2	b_2	$T_{n-2} + m$
		b_2	b_2	b_2	$T_{n-2} + m$

Source: invented, developed and compiled by the author

$$T_n = (1 - b_2)(T_{n-1} + 1) + \Big((1 - b_2)b_2 + (1 - b_2)b_2^2 + b_2^3\Big)(T_{n-2} + m).$$

We obtain the recurrence equation

$$T_{n+2} = (1 - b_2)T_{n+1} + b_2 T_n + 1 - b_2 + b_2 m \tag{4}$$

with known initial values $T_1 = m$, $T_2 = m + 1$.

Proposition 1. If the data array can have hazards between elements at a distance of 2, and has no other hazards, then the average processing time of $n \geq 1$ elements by a pipeline with a depth m equals

$$T_n(m) = m + \frac{1 - b_2 + b_2 m}{1 + b_2}(n-1) - \frac{b_2(m-2)}{(1+b_2)^2}\Big(1 - (-b_2)^{n-1}\Big). \tag{5}$$

Proof. If we take the initial value $T_0 = 0$, then this recurrence relation, for $n = 0$, will give $T_2 = m + 1 - b_2 \neq m + 1$. Therefore, we will consider the sequence $S_n = T_{n+1}$. We obtain the recurrence equation

$$S_{n+2} = (1 - b_2)S_{n+1} + b_2 S_n + 1 - b_2 + b_2 m$$

with initial values $S_0 = m, S_1 = m + 1$. Using standard methods for solving inhomogeneous linear equations, we obtain formula (5).

Corollary 2. Under the conditions of Proposition 1, with the total logical delay t_p and the overhead t_o of data transfer between stages, the optimal pipeline depth with hazard is equal to

$$m_{opt}(n) = \left(\frac{\big((n-1)\big(1-b_2^2\big) + 2b_2\big(1-(-b_2)^{n-1}\big)\big)t_p}{\big((1+b_2)^2 + (n-1)b_2(1+b_2) - b_2\big(1-(-b_2)^{n-1}\big)\big)t_o}\right)^{\frac{1}{2}}.$$

Proof. By formula (5), we have $T_n = Am + B$, for $A = 1 + \frac{(n-1)b_2}{1+b_2} - \frac{b_2}{(1+b_2)^2}\big(1-(-b_2)^{n-1}\big)$ and $B = \frac{(n-1)(1-b_2)}{1+b_2} + \frac{2b_2}{(1+b_2)^2}\big(1-(-b_2)^{n-1}\big)$. The average processing time in nanoseconds is $(Am + B)h$, где $h = t_o + \frac{t_p}{m}$.

The function $T_n(m)h = (Am + B)\Big(t_o + \frac{t_p}{m}\Big)$ depending at the depth m has the derivative $t_o - \frac{Bt_p}{m^2}$. Equating this derivative to zero, we obtain the optimal value of the depth, from which the desired formula follows.

Corollary 3. For a data array with hazards at a distance of 2, as $n \to \infty$, the optimal depth equals $m_{opt} = \sqrt{\frac{(1-b_2)t_p}{b_2 t_o}}$.

From this we can conclude that the formula (Dubey and Flynn 1990) for the pipeline with restarts coincides with the formula for the pipeline with hazards at a distance of 2.

Recall that the pipeline cycle or delay of a stage is called the response time of the stage. When obtaining formulas for calculating the processing time of a given amount of data, we will measure this time in pipelined clock cycles. To translate this time into nanoseconds, you need to multiply it by the pipeline cycle $h = t_o + \frac{t_p}{m}$.

For each $n \geq 0$ the values of the average processing time T_n of processing n elements of input data depend on the depth of the pipeline m, as well as on the probabilities of hazards b_d between elements located at a distance $d \in \{1, 2\}$. Processing the first element takes time $T_1 = m$. For $n = 2$, a restart is possible, whence the average processing time of two elements is $T_2 = (1 - b_1)(T_1 + 1) + b_1(T_1 + m) = 1 - b_1 + m + b_1 m$. Considering the increment table for calculating T_3, we get $T_3 = (1 - b_2)T_2 + (1 - b_1)(1 - b_2) + (b_1 + 2b_2)m$.

Table 2. Values of the average processing time of n elements for various variants of previous hazards, for the case of two hazards

e_{n-4}	e_{n-3}	e_{n-2}	e_{n-1}	e_n	
				b_0	$T_{n-1}+1$
				b_1	$T_{n-1}+m$
			b_0	b_2	$T_{n-2}+m$
			b_1	b_2	$T_{n-1}+1$
			b_2	b_2	$T_{n-2}+m$

Source: invented, developed and compiled by the author

Table 2 is intended to build a recurrence relation.

Analysis of Table 2 leads to a recurrence relation

$$T_n = (1-b_2+b_1b_2)T_{n-1} + (b_2-b_1b_2)T_{n-2} + (1-b_1)(1-b_2) + m(b_1+b_2-b_1b_2), \tag{6}$$

For all $n \geq 5$. This table (without the first column) is suitable for calculating T_4. Therefore, the obtained recurrence relation is true for all $n \geq 4$.

We introduce the notation

$$C(m) = \frac{m(b_1+b_2-b_1b_2)+(1-b_1)(1-2b_2)}{1+b_2-b_1b_2} - \frac{m(b_1+b_2-b_1b_2)+(1-b_1)(1-b_2)}{(1+b_2-b_1b_2)^2}$$

Theorem 4. For $n \geq 2$, the processing time on the pipeline with hazards according to data at a distance of 1 and 2 equals

$$\begin{aligned} T_n(m) = {} & 1-b_1+m(1+b_1)+C(m)\left(1-(-b_2+b_1b_2)^{n-2}\right) \\ & + \frac{m(b_1+b_2-b_1b_2)+(1-b_1)(1-b_2)}{1+b_2-b_1b_2}(n-2) \end{aligned} \tag{7}$$

Proof. Denote $S_n = T_{n+2}$. We found that for all $n \geq 0$ the recurrence equation holds

$$S_{n+2} = (1-b_2+b_1b_2)S_{n+1} + (b_2-b_1b_2)S_n + (1-b_1)(1-b_2) + m(b_1+b_2-b_1b_2),$$

under given initial conditions $S_0 = 1-b_1+m+b_1m$, $S_1 = 2(1-b_1)(1-b_2) + (1+2b_1+b_2-b_1b_2)m$. We introduce the notation $\nu = 1-b_2+b_1b_2$, $\alpha = b_1+b_2-b_1b_2$. We write the equation as

$$S_{n+2} = \nu S_{n+1} + (1-\nu)S_n + m\alpha + 1 - \alpha.$$

We solve the equation in the usual way. First we find a general solution to the homogeneous equation. It is equal to $C_1 + C_2(\nu-1)^n$. A particular solution of the heterogeneous is sought in the form of cn. It is equal to $\frac{m\alpha+1-\alpha}{2-\nu}n$. The general inhomogeneous solution is $S_n = C_1 + C_2(\nu-1)^n + \frac{m\alpha+1-\alpha}{2-\nu}n$. Using the initial values S_0 and S_1, we obtain

$$T_n(m) = S_0 - C_2\Big(1-(\nu-1)^{n-2}\Big) + \frac{m\alpha+1-\alpha}{2-\nu}(n-2).$$

Substituting the values of $\nu, S_0, S_1, \alpha,$ gives $C_2 = -C(m)$, which implies (7).

Figure 3 shows graphs of the average processing time in nanoseconds. It takes the values $T_n(m)h$, где $h = t_o + \frac{t_p}{m}$, and $T_n(m)$ is calculated by (7).

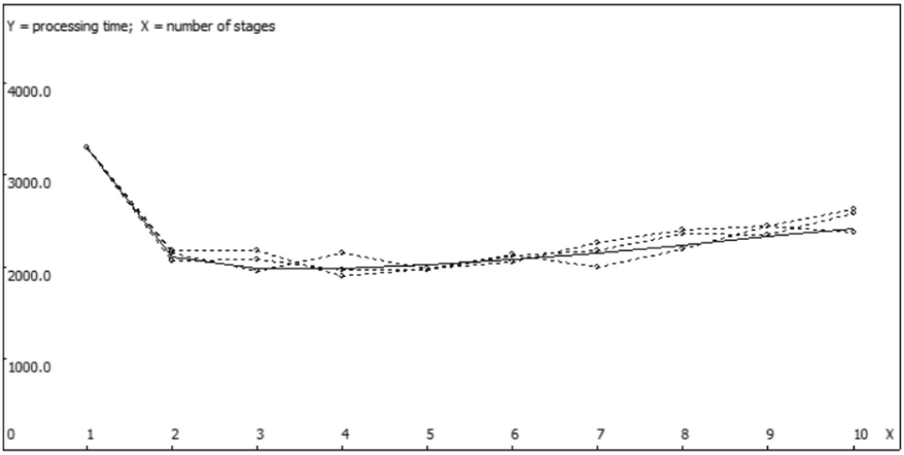

Fig. 3. A solid pen shows a graph constructed using an adjusted analytical model. The number of stages is plotted along the X axis, and the processing time along the Y axis. The probability of hazard at distance 1 is $b_1 = 0.2$, and at distance 2 it is $b_2 = 0.3$. The values of the formula (7) are close to experimental. *Source*: developed and compiled by the author

Equating the derivative in m of the function $T_n(m)$ defined by formula (7) to zero, we obtain the following generalization of formula (2).

Corollary 5. The optimal depth of the pipeline with hazards at a distance of 1 or 2 equals $m_{opt}(n) = \sqrt{\frac{B_n t_p}{A_n t_o}}$, where

$$A_n = -1 + b_1 + \left(\frac{b_1+b_2-b_1b_2}{1+b_2-b_1b_2} - \frac{b_1+b_2-b_1b_2}{(1+b_2-b_1b_2)^2}\right)\left(1-(b_1b_2-b_2)^{n-2}\right) + n,$$
$$B_n = 1 - b_1 + \left(\frac{(1-b_1)(1-2b_2)}{1+b_2-b_1b_2} - \frac{(1-b_1)(1-b_2)}{(1+b_2-b_1b_2)^2}\right)\left(1-(b_1b_2-b_2)^{n-2}\right) + \frac{(1-b_1)(1-b_2)}{1+b_2-b_1b_2}(n-2).$$

Corollary 6. For a data array in which all hazards belong to pairs of elements located at a distance of 1 or 2, as $n \to \infty$, the optimal depth is equal to $m_{opt} = \sqrt{\frac{(1-b_1)(1-b_2)t_p}{(1-(1-b_1)(1-b_2))t_o}}$.

4 Conclusion

In this work, recurrence Eq. (6) is obtained for calculating the average processing time for pipelines with random hazards from data at a distance of 1 and 2. This equation takes into account the number of input data elements entering the conveyor. The obtained formulas for the optimal conveyor depth can be used in the design of processors. For large amounts of data, we recommend the formula from Corollary 6. If small amounts of data are processed, it is better to apply Corollary 5. The results are consistent with experiments.

In the paper Khusainov (2020), a method for generalizing formulas for calculating processing time for a homogeneous pipeline to heterogeneous pipelines was proposed. In the future, obtaining some formulas for calculating the performance of the pipeline, the stages of which have different delays.

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Imperatives of the Digital Economy and Methodology Transformational Management

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Abstract. Purpose: The methodological origins of the concept of business transformation proposed by the authors are based on the concept of "transformation" - change and transformation, as a system-forming basis in the theory and practice of meinjment, which were laid down in the works of Ansoff, Weber, Mintzberg, Miller, Handwall, etc., It was they who at the end of the twentieth century formed the beginnings of a new methodological base for strategic decision-making - the school of "Configurations and Transformations." Sharing the views of supporters of this school, the authors have long been engaged in research in the field of this scientific direction. The results of these studies, as well as global trends in the digitalization and globalization of the economy, made the authors aware of the need to distinguish this field of research in an independent, focused direction with their own subject and object area, metatology and methodological tools, like production and music, innovation, investment and other areas in management. To identify this direction, the authors propose to name it "Transformation Management." At the same time, the authors formulate and submit to the general discussion of the scientific community the content of the subject and object area of this area, as well as the methodological foundations of transformational management developed by them, including the fundamental principles, forms and methods of business transformation.

Design/methodology/approach: systems and situational approaches, strategic and effective management methodology.

Findings: conceptual foundations of a new scientific direction in the economy, organization and management of entrepreneurship, called "Transformation Management," have been developed.

Originality/value: The problems of maintaining and developing entrepreneurial structures in the context of globalization and digitalization of the world and national economies are updated; Methodological foundations for the formation of transformational competencies of entrepreneurial structures have been developed; the content of the subject and object area of the scientific direction "Transformation Management" was determined, fundamental principles, methods and forms of business transformation were formed in the context of the development of the digital economy and the globalization of economic processes.

Keywords: Transformation of the business environment · Globalization of the economy · Digitalization of the economy · COVID-19 pandemic · Methodology for the formation of transfer programs and projects of entrepreneurial structures

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1 Introduction

At the present stage of society development, the most important values and achievements are information and communication technologies. Digitalization of the economy and governance is becoming the only possible tool for business survival and the general direction of management decisions in the face of global crises, such as, for example, the COVID pandemic - 19. According to a number of foreign scientists, in terms of the scale of losses, this crisis surpassed all earlier ones (Craighead et al. 2020).

Computer systems in the economy allow to process, analise and model a huge number of various parameters that determine the real state of market conditions and economic systems of international, national, territorial and municipal levels, as well as primary economic entities.

Currently, online platforms of banks and trading organizations provide a personalized relationship with each consumer of a product or service, allowing you to track changes in consumer preferences in real time, and brokers of commodity and foreign exchange, making management decisions, are guided in their activities by various events of international interaction.

At the same time, modern information technologies and widespread digitalization pose a threat of sharp changes in the structure of employment. The traditional model for the development of labor potential, primarily zones of accelerated economic development in Russia, risks a sharp change in the need of employers for professional competencies of workers. In part, the social tension that has arisen can be reduced by retraining people and developing their entrepreneurial competencies (Usanov et al. 2019). According to Ghobakhloo et al. (2020), "Social implications Manufacturing digitization can have deep social implications as it alters inter- and intra-organizational relationships, causes unemployment among low-skilled workforce, and raises data security and privacy concerns. Manufacturers should take responsibility for their digitization process and steer it in a direction that simultaneously safeguards economic, social and environmental sustainability".

2 Materials and Method

In modern management theory and practice, the concept of "transformation" is comprehensive, covering the entire variety of interconnected economic systems, including the global, national, territorial, municipal and primary market subject, as well as numerous areas, components and options, technologies and mechanisms for transforming economic activity. Transformational imperatives can arise both at the macro-level of public administration and at the micro-level of a particular actor.

The digitalization and globalization of the world economy is essentially the process of forming a single global production, financial, socio-cultural and information space. The result of those processes was the growing interdependence and even the "merger" of national economies. However, according to some authors, today whether small, local examples of digitalization are being formed (Culot et al. 2020).

At the macro level, digitalization and globalization affect national and regional economies, at the meso level - commodity, financial, foreign exchange and labor markets, at the micro level - individual organizations, enterprises and institutions (Usanov et al. 2019).

According to the International Telecommunication Union (ITU) and the World Bank, the level of development of information and communication technologies in Russia for 2017 corresponds to an index of 7.07, while in the USA and France it is 8.2, Germany and Japan - 8.5. Today, the Russian Federation ranks 45th out of 176 countries in the international ranking for the development of the digital economy, 35th in the index for the development of e-government and 10th in the index for global cybersecurity. The leaders in the development of information communication technologies are Iceland with an index catfish of 8.98, the Republic of Korea - 8.85 and Switzerland - 8.74 (Abdrakhmanova et al. 2018).

Digitalization and globalization, as methods of business transformation, are in practice implemented in two directions, differing in technological characteristics and their inherent mechanisms for the implementation of transformation programs and projects. The first is overcoming national barriers and entering international markets. The second is the integration of national market entities into the technological value chains of international companies - leaders of the global market.

Transformational programs and projects of the first direction are available only to companies - leaders of the national market. The second focus is on companies of all sizes and levels of competitiveness operating in both national and territorial and even municipal markets.

A global financial market has been practically formed, uniform standards for the quality of goods and services are being introduced, and the global consumer market is developing. Today, the share of e-commerce in the United States has reached 52%, while in Russia it is 18%. The World Trade Organization (WTO), established in 1995, today has 162 member states, including Russia. WCO defined the general rules of world trade and regulated the reduction of customs barriers and import duties.

Digitalization and globalization, on the one hand, facilitate economic interaction between economic entities of various States, create conditions for them to access the advanced achievements of scientific and technological progress, save resources, stimulate the formation and implementation of transformation programs and projects, ensuring the development and growth of the well-being of the whole humanity.

On the other hand, the negative consequences of digitalization and globalization are increased competition in national and national-territorial markets, which leads to the ruin of technologically backward and small-scale domestic business and, ultimately, to a decrease in the standard of living of the local population, which is also the motivation of socially responsible business to form appropriate transformational programs and projects.

Transnational corporations are the leading subjects in digitalization and globalization. It was they who, as a rule, were the initiators and developers of various programs and projects, which created organizational prerequisites for the transformation of market entities of the national economy. According to Reitzer (2010), today the share of transnational corporations in world industrial production is 40%, in foreign trade - 60%, in technological development - 80%.

The largest impact on the global economy is made by 500 largest transnational corporations, among which 130 belong to the United States, 65 to Japan, 60 to China, 35 to France, 34 to Germany, 30 to the United Kingdom, 10 each to India and Russia. Transnational corporations' activities cover all sectors of national economies, including mining, industry, agriculture, transport, communications and information communications.

The trend of increasing rates of globalization of socio-economic processes is a characteristic feature of modern economic conditions. The changes taking place in society lead to the emergence of new imperatives and the need for another adjustment of the management paradigm in management.

The imperative according to Kant is a requirement, order, law or a generally significant moral prescription. The management paradigm is the dominant system of fundamental scientific results of management theorists and practitioners at a particular time.

The essence of the management paradigm leading up to the end of the twenteeth century was that the market entity was seen by it as a primary economic system whose objectives and objectives had been adopted a priori by a given and stable for a long period of operation. At the same time, the main factors for efficient management were: increasing the scale of activities by deepening the specialization and rationalization of supply, production, marketing, labor and management processes, which reduced all kinds of costs and increased the quality of goods and services.

Nature adapts through evolution. Similar processes are taking place in business management. The comparison of the patterns of changes in nature and society was the motivation for the authors to form the concept of "transformational management," as well as a convincing argument for the fairness of the proposal to formalize it as an independent scientific direction in management at the modern stage of its development.

The main content of this direction of management, in our opinion, is the formation of methodological foundations for identifying transformational needs and the development of transformational compositions of market entities as the main factors in gaining competitiveness and ensuring life in dynamically changing economic conditions.

The imminent need of allocation of transformational management in the independent scientific direction, is caused by judgments and the data of the principal of management of the Sautgemtonsky university B. Ryan (1998) provided by him in work "Strategic account for the head": "The only position of balance for the enterprise is his crash. No organization can be in a position of sustainable equilibrium. If the enterprise does not develop, it crashes. "He cites the following statistics as arguments in favor of this point of view: "For every hundred firms created after the Second World War, there is less than one company that continues to operate today. Of all the newly established firms, less than a sixth of them survive after 5 years."

There are many reasons for this: changing consumer preferences, the power of resource suppliers, competitive pressures, global and local events, regulatory regulation of government activities, and so on. In general terms, they departed as a result of the increase in the number of contradictions (deformations) and the inability of the management system to ensure timely and systematic adaptation of elements of the internal environment, adequate for changes in management conditions.

3 Results

The Russian economy was still far from the world's leading economies and lagging behind global trends in terms of business sector development. The need to improve it required the search for new approaches and methods for managing change processes. The Government should focus on the socio-economic development of entrepreneurship as the basis of a market economy.

It should be noted, that the market model had many flaws, commonly referred to as "market failures." At present, the need to form, develop and introduce into economic practice the theory and methodology of transformational management as the only possible way to preserve and develop the socio-economic basis of society is becoming increasingly urgent.

The typology of alternative business transformation options in the fields of industry and outside the industry specialization is given in Figs. 1 and 2. In the process of its development, the results of mono-honeycomb studies of authors published in the works were used (Usanov 2012).

The branches of science have their own theoretical and methodological base. Each approach has its own conceptual idea. A concept is a set of ideas, principles and methods for solving a problem or problem.

The methodological foundations of the concept of "Transformation Management" proposed by the authors were laid down in the works of Ansof, Weber, Mintzberg, Miller, Handwall and others (2000), which in the end of the twenteeth century formed a new methodological base for the development of strategic solutions, called the school "Configurations and Transformations."

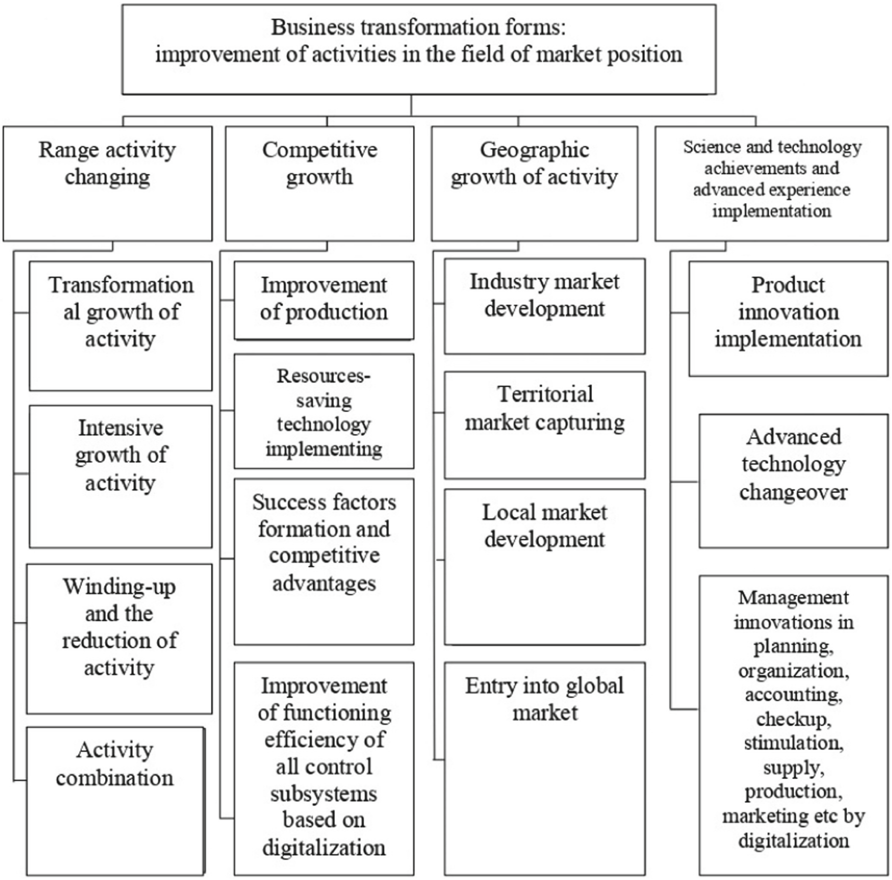

Fig. 1. Transformational management: typology of business transformation forms in industry specialization. *Source*: developed and compiled by the authors

The founders of strategic management schools focused on the identification, research and paired comparison of the relationships of variables between the internal and external environments of the organization. As a result of this comparison, a key success factor was chosen, which necessitated the use of appropriate strategy development technology.

The founders of the school of "configurations and transformations" are based on the application of an integration approach in management and propose to generalize everything in a row. With this approach, the development of an adaptation and development strategy acts as a planned transformation process, that is, the transformation of the configuration of elements of the internal environment of the organization for transformation - changes in the configuration of elements of the external environment of the business (Usanov et al. 2019).

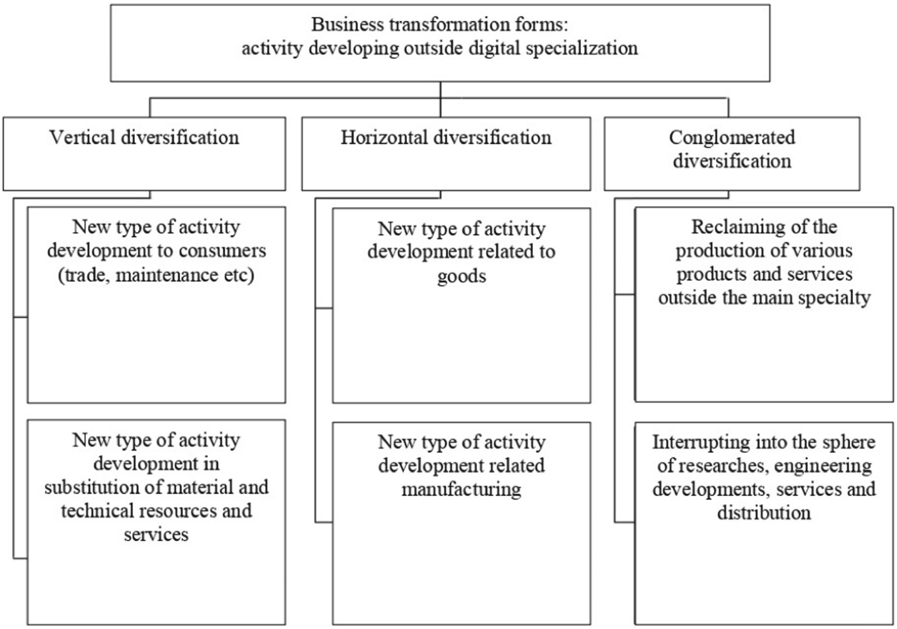

Fig. 2. Transformational management: a typology of business transformation forms outside the sphere of industry specialization. *Source*: developed and compiled by the authors

Sharing the views of supporters of the school of configurations and transformations, the authors for a long time were engaged in research in the field of this scientific direction, the result of which was the concept of transformational management proposed for discussion and the fundamental principles of the formation of trans-information programs and projects, which we have outlined in Fig. 3.

The conceptual idea of a new scientific direction “transformational management” is radically different from the already known scientific directions in topics, that it, using the capabilities of digital technologies and proven modern methods to improve the efficiency of economic systems, integrates the relationships of economic systems of all levels from a global to a primary business entity and is based on a key factor in ensuring the life of any organizational structure of a business in a regulated market - the need to form its transformational competencies.

The content (subject) and object of “Transformational Management,” as a new scientific direction in management, as usual, should be: forms, principles, methods, mechanisms, tools and technologies of transformations in the primary and aggregated links of entrepreneurial structures of both industrial and other spheres of economic activity.

The conceptual basis of the methodology of the proposed scientific direction of research “Transformational Management,” its structure and content are presented by the authors in the works (Usanov et al. 2012; Harchenko et al. 2012).

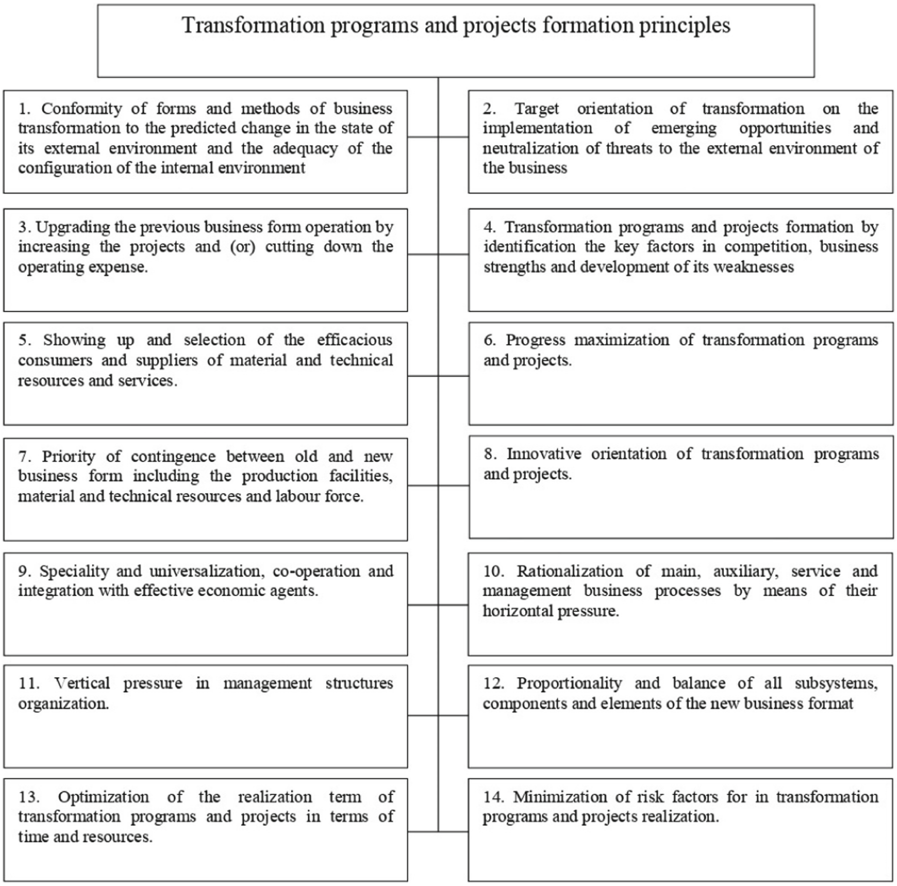

Fig. 3. Fundamental principles of transformational management. *Source*: developed and compiled by the authors

Without pretending to be exhaustive, we made an initial attempt to form a fundamental set of modern business transformation (transformation) methods, which is shown in Fig. 4.

Each of these methods of forming transformational programs and business projects has its own history of development, features of technology and implementation mechanisms, as well as areas of rational use. The cost-effectiveness of using these methods has been tested by the practice of advanced countries, including Russia.

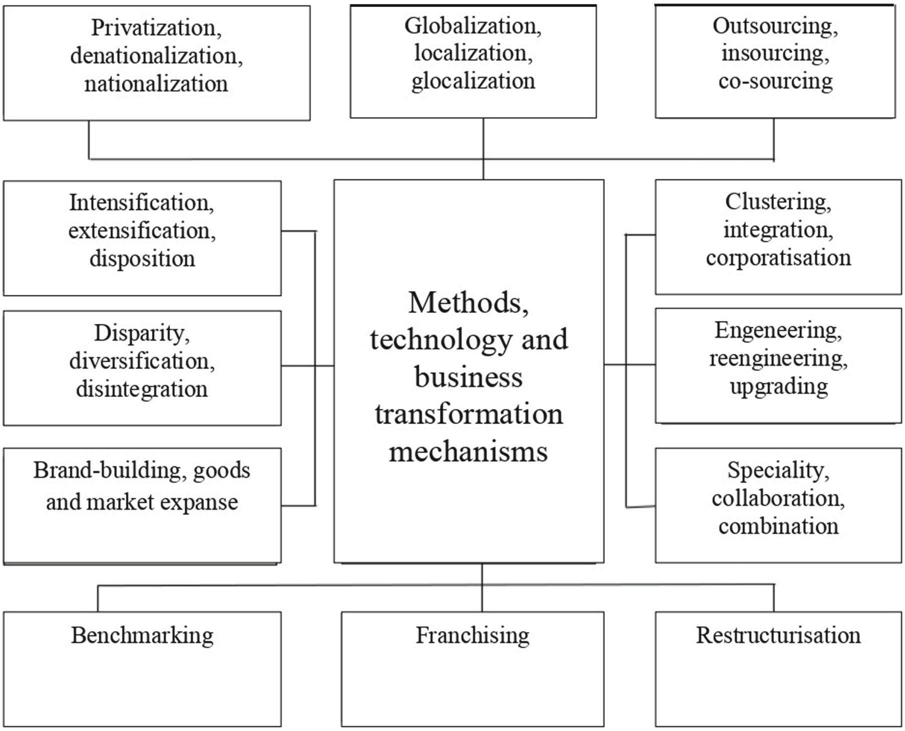

Fig. 4. Transformational management: methods, technologies and business transformation mechanisms. *Source*: developed and compiled by the authors

4 Conclusion

The analysis and updating of modern problems of the functioning of economic systems of the global, macro and micro levels allowed the authors to hypothesize the overdue need to form an independent scientific direction in the science "Economics and Management" called "Transformation Management."

The goal of transformational management is the formation of methodological foundations for the development of transformational competencies of entrepreneurial structures necessary for survival and successful functioning in the dynamic conditions of globalization and digitalization of the world economy.

Transformational management, like innovative -, investment - and other areas of management, is designed to provide a methodological base for entrepreneurial structures of various mas-headquarters and areas of activity to identify their transformational needs and form their transformational abilities.

Many years of research in the development of this area allowed the authors to form and propose to the scientific community the conceptual foundations of the transformation management methodology, including the definition of the subject and object area, the typology of forms of business transformation, the fundamental principles and methods of developing transformation programs and projects.

The authors will be very grateful to all those scientists and practitioners who, interested in this area of research, will participate in the discussion of this article, will express their own opinion and submit their comments and suggestions on its content.

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Innovative Development in the Regions of the Russian Federation: Features and Basic Digital Tools

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Abstract. Purpose: The aim of the work is, based on the analysis of the socio-economic indicators of the regions of the Russian Federation, to identify the factors that have a constraining effect on innovation processes for further building an effective state strategy for innovative regional development.

Design/methodology/approach: The conceptual methodological basis of the study was the theory of spatial distribution, the basic principles of which help to understand and comprehend the objective features of modern economic development at the meso-level of individual regions.

In the process of studying the specifics and tools of innovative development of regions, such general scientific methods are used as: comparative and logical system analysis; institutional and functional analysis; method of formal logic; positive and normative methods, etc.

Findings: The results of the study showed that the uneven development of Russian regions is determined by a combination of objective and subjective factors. Objective factors predetermine a significant gap between the levels of their economic and innovative development. A group of subjective factors is associated primarily with management competencies.

Regarding regions with a predominance of high-tech industries, measures of state support aimed at ensuring the creation of favorable conditions are appropriate: first, for expanded reproduction; secondly, for the development of fundamental science; thirdly, for the implementation of the achievements of applied sciences in the direction of the intensification of innovative industries.

Originality/value: The relevance of the work lies in the substantiation of the use of information and analytical systems in the construction of an innovative strategy for the development of Russian regions, taking into account their specific features and potential capabilities.

Keywords: Socio-economic development · Innovative development · Interregional differences · Information systems

JEL Code: R11 · R12 · O11 · O31 · O33

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1 Introduction

Effective socio-economic development of the Russian Federation is impossible without the sustainable development of its constituent entities, which involves the creation of a balanced regional economy based on the creation of modern production, housing and communal, transport and other infrastructure; improving the social sphere and ensuring favorable living conditions for the population; elimination of interregional imbalances. Moreover, following the main goals of the national economy for the long term, the vector of development of the Russian economy is becoming increasingly innovative. This determines the priority tasks for state institutions to ensure sustainable dynamics of innovation processes at the mesoscale of individual regions.

One of the tasks facing the state, science, and society and indicated in the Strategy for Scientific and Technological Development of the Russian Federation until 2035 is "the need for effective development and use of space, including by overcoming imbalances in the socio-economic development of the country. The main attention in this area is paid to solving the socio-economic problems of the regions through the implementation of the relevant scientific and technical areas in demand by the economy and contributing to the growth of technologies (Musterd el al. 2006).

At the same time, the modern task of the regions is to ensure not only sustainable development, but also innovative management of this process, taking into account the specifics of their socio-economic characteristics. At the same time, it is quite obvious that the features of the development of each territory are determined by a number of both objective and specific factors. It is logical to attribute the following to the first group of factors: the economic and geographical position and natural and resource potential of the region, demographic indicators, as well as the existing structure of industries and possible optimal output volumes. The second group includes a factor: business management methods and the stability of its conditions. It seems that it is precisely the factors associated with the regulation mechanism of the processes occurring in the regions that are decisive in creating an effective model of innovative management at the mesoscale of the national economy.

2 Methodology

The study is based on official data from open sources, state institutions at the macro- and meso-scales, as well as data from information and analytical agencies. The authors relied on regulatory documents governing innovation and the socio-economic development of the Russian Federation and its regions.

The conceptual methodological basis was the theory of spatial distribution, the basic principles of which help to understand and comprehend the objective features of modern economic development at the mesoscale of individual regions.

Special attention should be paid to the particularities of centers for creating single-industry towns as supporting centers for regional development, with spatial distribution on the mesoscale of individual territories. In addition to Krugman (2014), the work of Venables and Kanbur (2005) and Cooke (2010), Enright (2000), Leonard (2016), Nelson and Romer (1996), Venables and Fujita (2001), Hardin (1968) and other are devoted to the modeling of socio-economic processes in modern cities as strongholds of the “centripetal effects” of regional development.

In the researching the specifics and tools of innovative development of the regions, it is also planned to use general scientific methods, including: comparative and logical methods of system analysis to justify the provisions of the theoretical part of the study; institutional analysis to identify the impact of emerging institutions on the path of innovative development of regions; functional analysis in relation to the ratio of measures and methods for innovative development at the mesoscale, including financing from regional budgets; formal logic methods for constructing theoretical variable models of transformations based on the innovative development of regions; a positive method for studying and adapting basic digitalization tools at the regional level; comparative analysis to identify the conditions and characteristics of the socio-economic development of the regions; the normative method in developing recommendations for implementation on the implementation of the Russian Strategy for Scientific and Technological Development in the medium term (Skryl 2017).

A special place in solving the problem of innovative development of the regions is occupied by the method of index analysis of the relative quantitative and qualitative indicators of the innovative development of the Russian economy, including regional “sub-indicators”, which will reveal errors with the total national innovative index.

3 Results

Russia in the international innovation ranking

In 2018, Russia ranked 46th in the ranking of 126 countries in the Global Innovation Index (2017 - 45th place, 2016 - 43rd), yielding not only to Estonia and Lithuania, but also Ukraine, which rose from 50th to 43rd place.

Despite the fact that Russia’s position has deteriorated compared to previous years; experts noted fairly high results on such components of the index as education and the openness of business to innovation. In some components of the index, where the country’s strong positions are also noted, figures include ease of starting a business, access to information and communication technologies, and the creation of mobile applications.

In terms of the innovation quality Russia ranked 27th and 3rd among middle-income countries after China and India. Despite the decrease in the number of patents-analogues, Russia has achieved quite high results in the quality of scientific publications and high rates in the three largest state universities: Moscow, St. Petersburg, and Novosibirsk.

In addition, Russia is among the thirty leaders in terms of secondary and higher education, investments in science, the number of people engaged in mental work, the level of development of the IT sector, and also ranks first in the number of women with scientific degrees and engaged in scientific activities.

An aggravating factor is the fact that during the 1990s Russia has lost most of its critical technology. Machine building, being the key sector of the economy responsible for the technical and technological security of the country and being the basis of its production base, is in a critical position (Sorokina et al. 2018) The total depreciation of machine-tool equipment is about 80%, and the production of machine tools in the country over the past 20 years decreased by almost 20 times (from 70 to 3 thousand) with the annual decommissioning of about 50 thousand machines (Golova and Sukhovey 2015). Currently, Russian manufacturers of machine tools occupy less than 10% of the domestic market, and manufacturers of tools for machine tools about 40%.

In recent years, Switzerland has held first place in the innovation ranking, holding high rates both in the aggregate global competitiveness index and in such indicators as “institutions”, “infrastructure”, “health”, “education and professional development”, “innovation” (Golova and Sukhovey 2015). The top ten after Switzerland included the Netherlands, Sweden, the UK, Singapore, the USA, Finland, Denmark, Germany, and Ireland. The biggest breakthrough in 2018 was made by China, rising from 22nd place in 2017 to 17th.

Russia, however, lags significantly behind many countries, both in quantitative and qualitative indicators of innovation activity. For example, the share of innovative organizations in Russia in 2016 amounted to slightly more than 8%, decreasing by 2% compared to 2012, while in developed countries this figure is 6–8 times higher. Domestic organizations implementing technological innovations accounted for only 7.3% in 2016 of the total number of organizations. The indicators of innovation activity in the leading countries significantly exceed those of Russian enterprises. Thus, the share of new works and services for the market in Russia is several times lower than in Germany, Sweden, and the Czech Republic.

It is important to note that, given the importance of innovative resources as a key factor in modern socio-economic development, many countries continue to increase funding for science, technology, and innovation, even in times of global crisis. So, in China, the costs of basic research from 2010 to 2016 increased by 110%, in Germany - by 36%, in the USA - by 24%, in Russia this indicator grew by only 20% (Federal State Statistics Service 2019).

The specifics of the innovative development of the regions of the Russian Federation
Given the uneven territorial development within the national economy due to objective factors of geographical, natural-climatic, and historical-economic development, the key direction for all economically developed countries is to fill this unevenness by creating innovative models of regional development (Bondarenko et al. 2016).

This group of indices includes, first of all, the following: “Socio-economic conditions of innovative activity, “Scientific and technical potential”, “Innovative activity”, “Quality of innovation policy”. The aggregate performance of these indices by region shows that a fairly uniform development according to these indicators is observed only in the Saratov and Tomsk regions, as well as in the Krasnoyarsk Territory.

In the studied ranking, the regions are divided into four groups - strong, medium-strong, medium, medium-weak innovators. Among strong innovators, one can observe regions with a large gap in terms of the indicators under consideration. For example, the results of the study indicate that in the Republic of Mordovia this gap is more than 50 points between the minimum and maximum values: in terms of INI (innovation index), the region comes first, and in terms of index of socio-economic conditions of innovation (SECI), only 59. The indicators of INI and scientific and technical potential (STP) are four and fifty-eight, respectively. The situation is similar in the Chuvash Republic, where the discrepancies between the indicators, although smaller, are still significant: for example, the region ranks second according to the INI, according to QIP (quality index of innovation policy) - on the fifth; according to ISEU on the twenty-seventh, and on ITP - on the forty-ninth. Thus, there is a significant differentiation of the constituent entities of the Russian Federation not only by the rating of innovative development as a whole, but also by the sub-indices included in it.

An analysis of the constituent entities of the Russian Federation by the share of innovative products in the Gross Regional Product (GRP) revealed 15 leaders in this indicator, where the top ten included regions with a pronounced specialization in technological areas. Among such innovative leaders: the Vologda region, the Republic of Tatarstan, the Samara region, the Republic of Mordovia, etc.

At the same time, in terms of technological innovation costs, the first 10 regions are strong and medium-strong innovators. The group of medium-strong innovators includes regions with a high concentration of human and financial capital, as well as a good level of scientific infrastructure. These are such regions as the Moscow Region, Tyumen and Samara Regions, as well as such large Russian megalopolises as Moscow and St. Petersburg, and others. In turn, analysis of statistical indicators of innovative activity of the regions showed that only 12%. In the regions, the share of innovative products in GRP exceeded 10%, which is an extremely low indicator.

Fundamental differences with the composite innovation index (both positive and negative) are observed mainly in the socio-economic or scientific-technical block, as well as in their combination. So, STP has low values in five regions of the first and second groups. At the same time, outstripping rates for this indicator are observed in eight regions of the third and fourth groups. In turn, SEKI is an indicator of high potential for four constituent entities of the Russian Federation, which are among strong innovators. On the other hand, the SEKI indicator serves as a guide for nine weaker regions in the innovative development. Thus, in the Republic of Mordovia, the Lipetsk and Penza regions, the socio-economic conditions, and scientific and technical potential lag significantly behind the general level of development of innovations, despite their relatively small distance across the country from the megalopolis-innovator of Moscow. However, in the Sakhalin Oblast and Sevastopol, these areas are the most advanced.

The influence of information and analytical systems on the innovative development of regions

Currently, disputes continue regarding which factors affect the innovative development of the regional economy and how to stimulate it.

Many scientists noted that the innovative development of regions occurs, as a rule, due to their internal innovative potential, as well as effective management and support at the federal level. Internal innovation potential is determined by a number of factors that can have both a stimulating effect on the regional innovation system and a restraining effect, slowing down the pace of its innovative development, and the interaction of these factors can significantly affect innovation processes in the regions.

In the context of general processes of digitalization, attention to information-analytical systems (IAS) is increasing when making informed management decisions, both at the macro level of the entire economy, and at the mesoscale of individual regions and the micro level of an individual enterprise. IAS is becoming an integral part of the information structure of each enterprise, institutions of state and municipal government.

A feature of IAS from the point of view of determining the economic return on these systems is that, given the territorial scale of the country and the multilevel nature of regional development, it becomes difficult to assess the effectiveness of their use at the mesoscale of individual regions and digitalization processes in general. As conditions for the effective functioning of IAS at the regional level, the authors distinguish the following: elimination of restrictions by developing and developing the necessary regulatory framework; the introduction of uniform standards for documentation, which will be uniform both at the regional and macroeconomic levels; providing uninterrupted Internet connection in all regions; introduction of 5G communications in cities with population over one million people; allocation of funds from the budget for the training of qualified specialists and the acquisition of innovative equipment; providing continuing education in regions with developed AIS.

This list of conditions is due to the fact that at the regional level there is a shortage of qualified specialists at the stage of introduction of IAS, as well as a low level of general digital literacy at the stages of their operation and maintenance.

Based on the data from the open sources, the authors analyzed three large companies in the three leading regions (Moscow Oblast, Republic of Tatarstan, and Republic of Bashkortostan): SNS Group of Companies, Tatenergosbyt PLC, and Bashneft PLC. Capital spending on development of information systems and provision of information security were analyzed. The analysis of spending on innovative information systems and information security is directly proportional to net profit in these companies, in which the activities are automatized to a very large extent (Table 1).

Table 1. Cost ratio for information systems

Company	PLC Tatenergosbyt	SNS Group of Companies	Bashneft PLC
Costs of information systems and information security	≈7 million rubles	≈12 million rubles	≈15 million rubles
Net profit, RUB	647.86 million rubles	160 billion rubles	183,6 billion rubles
The ratio of costs and returns compared to PLC Tatenergosbyt	–	Costs of information systems and information security is 71% more than the cost of Tatenergosbyt. 140% more profit	Costs of information systems and information security is 114% more than the cost of Tatenergosbyt. 184% more profit

Source: compiled by the authors based on open sources

Based on open source data, the authors made a selection and analyzed in three leading regions (Moscow Region, the Republic of Tatarstan, and the Republic of Bashkortostan) three large companies: the SNS Group of Companies, Tatenergosbyt PLC, and Bashneft PLC for capital expenditures for the development of information systems in these companies and to ensure their information security. Cost analysis for innovative information systems and information security is directly proportional to the net profit indicators in these companies, where all activities are as automated as possible (Table 1).

At the same time, the costs of technical support from the budget of the regions under consideration differ from the used sample of large companies: for example, the amounts allocated for technical support of information systems in the Republic of Tatarstan exceed almost 4 times the costs in the Moscow region. From this point of view, one can explain the accelerated development, for example, in Tatarstan of many types of economic activity, including not only the industrial spheres of production, but also the agro-industrial sphere regarding the use of modern AIS. In addition, as noted above, Tatarstan is one of the leading regions in the subindex of innovative development. Special attention deserves the successful development of the Innopolis innovation center in Tatarstan, the economic activity of which is fully based on the use of the high-tech industry and is, to a certain extent, a regional innovation incubator.

The ratio of costs and returns to the development of information systems and information security at the level of large enterprises and at the regional level shows that the returns are quite uneven: if the introduction of IAS and information security techniques in business almost completely justifies itself, then the situation at the regional level does not always lead to positive effects. Moreover, as a rule, in some dynamically developing regions, IAS has a greater impact on the income of an economic entity. At the same time, in regions where the artificial barriers of sustainable bureaucratization institutions are higher in terms of using innovative management tools, the impact of information-automated systems is less on the total regional income.

Thus, the introduction of the use of information and analytical systems as one of the tools for the implementation of the Russian Strategy for Scientific and Technological Development testifies, on the one hand, to the direct proportionality of investing in IAS from regional budgets and adequate economic returns. On the other hand, it can be argued that, despite state guidelines for the development of the digital economy, along with technologies and natural geographical and natural-climatic advantages, the determining nature of the impact on the level of socio-economic development remains with the management models in the regions (Maksimova 2013).

4 Conclusions

The results of the study showed that the uneven development of the Russian regions is determined by a combination of objective and subjective factors. In particular, objective factors predetermine a significant gap between the levels of their economic and innovative development. The existing differentiation is characteristic not only by the rating of innovative development, but also by its sub-indices. A group of subjective factors is associated primarily with managerial competencies. This is clearly reflected, for example, in the effective economic return from the introduction of automatic information systems designed to optimize the relationship system at the mesoscale of individual regions in the process of innovative development.

In relation to regions with a predominance of high-tech industries, given the specifics of their potential, government support measures aimed at ensuring the creation of favorable conditions are appropriate: firstly, for expanded reproduction; secondly, for the development of fundamental science, which is fundamental in creating a fundamentally new high-tech products; thirdly, to implement the achievements of applied sciences in the direction of intensification of innovative industries.

From this point of view, considering the specifics of regions with the largest share of medium-tech industries, government support in the form of stimulating applied research and innovation, which are aimed primarily at solving the technological problems of the industrial complex of the territory, would be most appropriate. For resource-producing regions, state aid should be aimed at stimulating the introduction of innovations in combination with ensuring favorable conditions for socio-economic stability.

In matters of management at the regional level, it is important to adapt the successful experience of large businesses in the use of automatic information systems, removing subjective restrictions for using IAS and ensuring information security in all areas, including the introduction of innovative and digital technologies.

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Transformation of Financial Management Processes in the Digital Space

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Abstract. Purpose: Study of changes in financial management in the virtual space in the context of the struggle of developed countries for world leadership in the possession of information and communication technologies is necessary for the development of economic contacts between various business entities. The transnational nature of the digital space requires substantiation in the system of ensuring the security of the use of modern financial technologies.

Design/methodology/approach. The paper formulates the conditions for the emergence of financial risks at the macro level, identifies macro factors leading to the emergence of financial risks. The methodology of the point-weight method of risk assessment is proposed.

Originality/value: Developed measures to protect against the risks of business entities. The directions of using financial technologies in various types of economic activity are proposed.

Findings: Currently, the importance of digital capabilities of companies is increasing in comparison with the availability of production resources, it is concluded that modern financial technologies can cover a variety of financial services. The use of modern financial technologies is an important condition for business development.

Keywords: Financial technologies · Financial risks · Factors · Financial services

JEL Code: G14 · G17 · G32

1 Introduction

The globalization and integration of many processes are the characteristic features of the modern world, which entails the transformation of financial management. The contradictions between the national and international levels of government in the system of financial relations are intensifying. The rapid development of information and communication technologies leads to an increase in the influence of integration entities.

In the digital space, the rapid transfer and dissemination of information is ensured, which leads to both positive consequences and threats in the form of losses in violation of various conditions. The transnational nature of the digital space and promising development trends require international coordination, including in the security system using modern financial technologies. The mechanisms on the basis of which information

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and communication technologies are an important area of restructuring the development of the information society is to deepen integration, increase efficiency and introduce innovations in all types of economic activities. In the digital space, both positive and negative consequences for the sovereignty of the state are created, in connection with the emergence of macro-financial risks.

The use of big data and the development of information systems makes it possible to track the sequence, speed, quality of operations, both in the domestic market and in the system of international relations. A qualitatively different level of available information arises, on the basis of which accurate data on the movement of value, demand and supply can be obtained. Digitalization accelerates scientific and technological progress and the development of the need for continuous innovation and other major changes.

2 Methodology

The state's capabilities are diminished with the strengthening of international financial markets, global open information networks and other transformations of world economic relations. Virtualization of the financial market does not allow the state to fully control the operations carried out with increasing capital mobility and the dependence of national policies on operations in international financial markets.

With globalization, the global community becomes dependent on all actors. Dependence on the problems common to all countries and the problems of individual states is growing. Many authors consider these issues from different perspectives. The article (Gomber et al. 2017) discusses three key aspects of modern change: Digital Finance and FinTech, that is, the corresponding business functions, applied technologies and technological concepts, as well as the relevant institutions. The author (Ozili 2018) notes that digital financing and financial integration have several advantages for users of financial services, providers of digital finance, governments and the economy. The work (Sosa and Rocha 2019) analyzed the level of development of necessary skills, an online survey was conducted with managers, in which the final result of the study is to propose a skills development model for digital business managers. The study (Gabor and Broks 2017) notes that the FinTech-philanthropy development complex creates digital ecosystems that display expand and monetize digital marks. The authors (Alt et al. 2018) highlight the stages of the formation and development of FinTech in the financial industry. Economists (Wamer and Wäger 2019) emphasize that digital transformation is defined as the use of new digital technologies to provide significant business improvements, improve customer service, streamline operations or create new business models. Creating digital strategies opens up new possibilities for developing new strategies, noted in (Chanias et al. 2019).

A manifestation of globalization is the creation and effective functioning of transnational corporations, since large projects cannot be implemented within the framework of one nation state. Within the framework of transnational corporations, the globalization of production, capital, information and the world division of labor takes place, which entails the emergence of financial risks (Fig. 1).

At the present stage, financial risks are associated with the instability of public finances, accompanied by the depreciation of assets, at the same time the depreciation

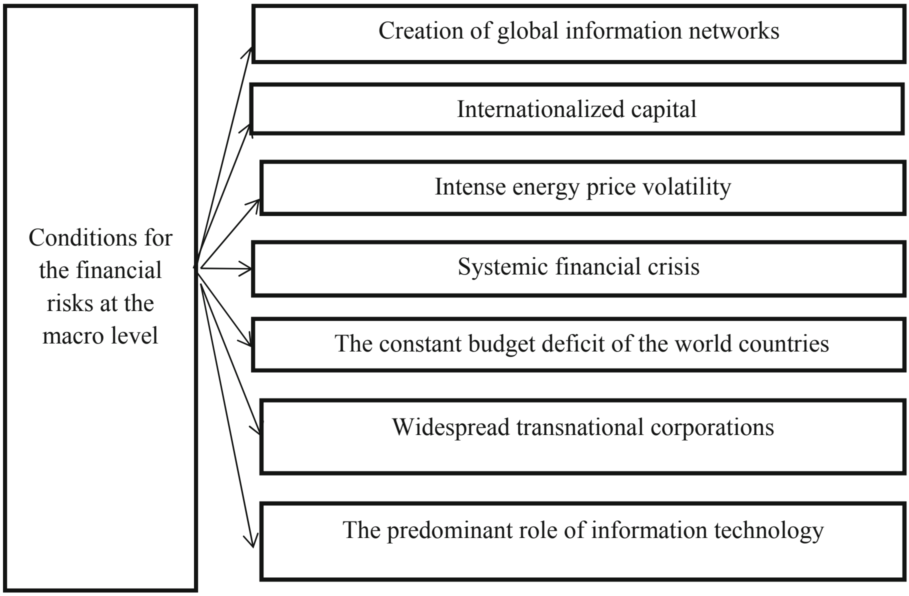

Fig. 1. Conditions for the financial risks at the macro level. Compiled by the authors based on research materials

of capital and the instability of financial markets. In many ways, this situation is determined by the renewal of traditional financial relations, the emergence of new forms of money, innovative virtual financial services. Financial globalization has led to a significant increase in the scale of the institution of the global payment system. The volume of transactions in national currencies is declining, while increasing the use of international means of payment.

Financial risks arise at all stages of financial flows in the system of global financial centers. The main parameters for the development of globalization are financial factors that are formed according to their own rules, which causes the many global risks.

Large-scale capital migration in the globalization of financial markets increases the vulnerability of market participants, which leads to increased financial risks. The main factors creating financial risks are: instability of the financial market, its segments and market participants, unfavorable market conditions and negative volatility of key indicators. The emergence of powerful new global financial centers and the weakening of existing centers also have a negative effect. Under the influence of macroeconomic conditions, the level of risk changes and certain components of financial risks can have a multidirectional effect.

The potential for interaction between the state and other countries and the economic state is characterized by an index of economic freedom (Cato Institute and Fraser Institute). The index includes the following indicators: "size of the state, legal environment and protection of property rights, access to "reliable" money, freedom of exchange with foreigners, regulation of credit policy, labor relations and entrepreneurial activity". The index is calculated based on the specific gravity of the influence, on the basis of which a composite index is formed by the country's rating. The index of economic freedom is used by transnational corporations to study the possibilities of penetration into the domestic market of a particular country.

3 Results

In the digitalization system of open assets, risks appear in sharing platforms, in financing local start-ups[1], at the same time there is an increase in financial services, which may favorably affect the development of innovative technological solutions in various types of economic activity.

In the context of the development of information and communication technologies, financial risks are modified and determined by the following:

– loss of the value of traditional assets not included in the digital transformation process;
– change of competencies in the digital space and the digital economy;
– the multiplication of the non-competitiveness of traditional models and the formation of strategies for the selection of models based on the processing of big data flows;
– the prevalence of global digital platforms (Fig. 2).

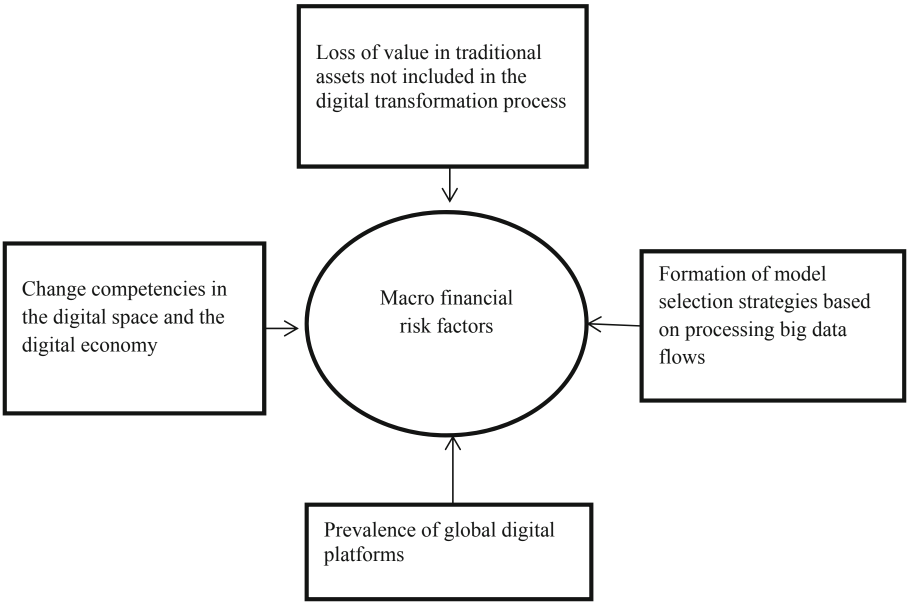

Fig. 2. Macro financial risk factors. Compiled by the authors based on research materials

[1] EAEU ECE as part of developing proposals for the formation of the digital space of the EAEU.

Diversification can be used as protection against risks, since losses in one type of activity can be compensated in full or in part by benefits in another form. When working with assets (tangible and intangible), intensive risk protection is often competent diversification. Financial flows flow to states with an effective system of protection against risks.

Based on the identification of risks, an assessment is made of the degree of risk exposure on the company's activities. The risk management system includes a set of methods and techniques aimed at predicting negative situations and developing a set of measures to prevent, neutralize, or reduce possible losses. In this case, it is necessary to carry out a risk analysis, including both a quantitative assessment and a qualitative analysis.

The results of a qualitative risk analysis are intended as initial information for conducting a quantitative analysis. At the stage of quantitative analysis, a quantitative assessment of individual types of risk and the decisions made as a whole is given, the permissible level of each type of risk is determined, depending on specific conditions.

Quantitative risk assessment can be carried out by various methods; in the practice of risk assessment the most commonly used method of expert assessments and statistical method.

The statistical method includes studying the statistics of losses that were at similar plants, the level and frequency of occurrence of a certain result is established, the most possible forecast of the development of events is compiled. In the statistical method, the following calculations are used: average value of the determined random variable, variance, standard deviation, coefficient of variation, probability distribution of the random variable. This method is based on the analysis of a large amount of data, the collection and processing of which is a laborious process.

The expert method is based on processing the opinions of experts, which may be specialists in a certain field.

In the point-weight method, a certain type of risk (R) can be interpreted by an appropriate number of factors, the values of which are determined by experts based on the probability of a risk. In addition, each factor is assigned a corresponding score (Bi) from 1.0 to 10.0. The specific gravities of the influence of factors on the total risk are established by expert means (Wi). In total, the specific gravities of the influence of factors are 1.0. The calculation is as follows:

$$R = \sum B_i W_i$$

The interpretation of the calculation is as follows: the risk increases with an R value approaching 10; the risk decreases with an R value approaching 1.

Risk management in the company is to reduce the risks of financial instability of the company. After conducting a comprehensive analysis of the financial condition of the company with a view to assessing the risks of activity, we can distinguish "problem areas" in which there is a high risk and safer areas where there is less or no risk.

The impact of the time factor must be taken into account due to the influence of the following items:

– the presence of inflationary effects, determined by the depreciation of money, while it should take into account the purchasing power of money, which changes over time with the same value of the nominal value;
– the circulation of funds in the form of capital and, accordingly, the removal of revenue from turnover, since at a higher speed of turnover, capital allows to get more profitability.

At the same time, the time factor increases the effect of the uncertainty factor. Business entities can use various risk protection measures (Fig. 3).

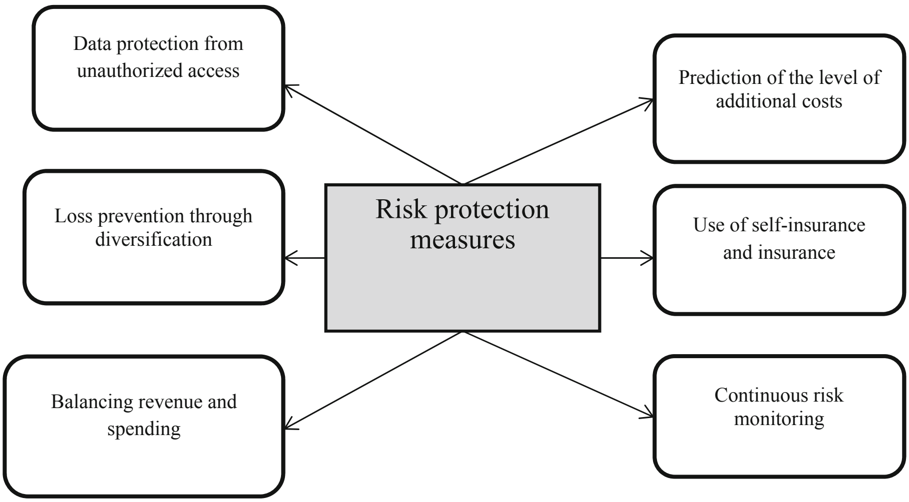

Fig. 3. Risk protection measures. Compiled by the authors based on research materials

Risk monitoring is necessary for the adequate functioning and development of the company. Identification of the risks of the company should be taken into account when developing the strategy and tactics of the company, which will allow maintaining balanced development. The organization's ability to self-finance is influenced by a rational credit policy, which is taken into account when using various types of financial technologies.

4 Conclusions/Recommendations

Modern financial technologies cover, by types and scales, various financial services: electronic payments and transfers, crowdfunding, asset management, financial market place, blockchain, etc. (Fig. 4).

The trend towards the organization of fully digital banks continues to be developed in the system of using online banking services. Financial technologies act as part of the macroeconomics, ensuring the movement of financial flows in the system of cross-border provision of financial services, and there are financial risks associated with

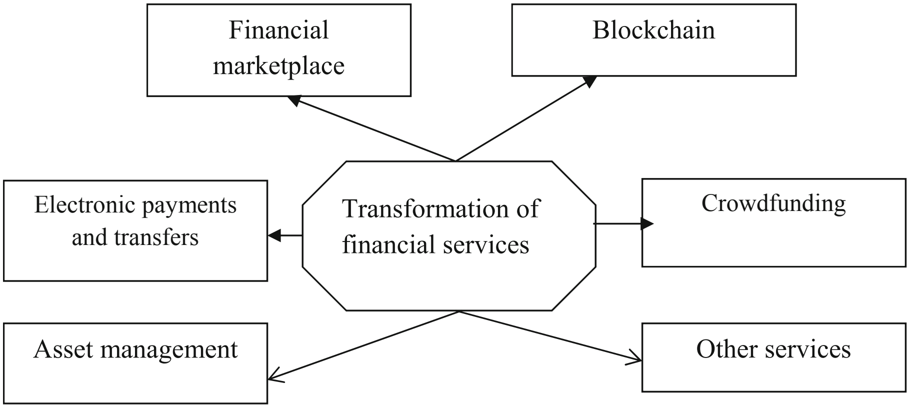

Fig. 4. Transformation of financial services. Compiled by the authors based on research materials

fraud in identifying users and ensuring information security of transactions. Cloud technologies provide more opportunities for the development of financial technologies and significant changes in the infrastructure of the financial sector of the economy. There is a multiplicity of reserve currencies with the use of the capabilities of the countries of macro-regions to free themselves from unnecessary derivatives, increasing the stability of world finances. The protection against financial risks may be operations involving the transfer of high-risk securities to more reliable low-risk securities; portfolio hedging, etc. Each state monitors financial risks to ensure the country's financial security in operations to finance investment projects abroad; borrowing in financial markets, etc. The severity of financial risks is manifested in the rapid development of information and communication technologies. The state of the global financial system affects financial risks, since at present a significant part of financial transactions is carried out using derivatives, there is a risk of not covering the relevant assets of these operations. Getting timely investments using modern financial technologies is an important condition for business development.

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Formation of a Power Supply System for Auto-Electric Transport in Russia

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Abstract. Purpose: The main purpose of the study is to form the infrastructure of the auto-electric transport market in Russia and to propose models of organizational interaction of market participants.

Design/methodology/approach: The article discusses the organizational aspect of managing the transformation process of energy markets. A hypothesis has been put forward that a new niche for the creation and development of the infrastructure of road electric transport can be occupied by companies from the oil and gas or electric power complex of Russia. For the purposes of the study, the authors have formulated three principles for choosing a model for the formation of an energy supply system for motor vehicles in Russia.

Conclusions: New technologies and modern global trends will inevitably change existing markets and lead to the creation of new markets. The rapid growth of the population of our planet, the requirements for the quality of life in the conditions of a shortage of natural resources and traditional types of fossil fuels and the tightening of requirements for environmental protection highlight the problem of the efficient using of energy. Taking into account the forecasts of world experts, the share of electric transport will reach 10–25% of the total number of cars in the world by 2035, it's necessary to prepare the corresponding infrastructure.

Originality/value: Three models of the formation of the power supply system of auto-electric transport in Russia were proposed and described. The authors have developed a mechanism for choosing a model for the development and construction of electric filling stations by potential market participants to assess the economic efficiency of the models. Testing on the example of one of the regions of Russia has shown the feasibility of using the model of creating a cooperative structure.

Keywords: Electric vehicles · Power engineering · Electric transport · Energy supply · Oil and gas complex

JEL Codes: F01 · L62 · L94

1 Introduction

The economic market of Russia, in particular, the electricity and power industry, will face great changes in the near future. The emergence of new markets and the development of

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smart grids lead to the need to identify new players and transform the roles of existing players in energy markets. Russia needs a modern energy system based on innovative developments and advanced scientific achievements, as well as the using of alternative energy sources, including renewable ones, especially in those regions where there is currently an energy shortage.

The emergence of electric vehicles is a phenomenon, which is associated with the emergence of a new solution to the centuries-old problem of mankind: the problem of movement in space. The development of the motor transport system correlates with the development of the country's economy as a whole due to its great influence on the development of the country's industry.

One of the indicators of the development of the economy is a high level of motorization. The highest value of this indicator falls on the developed countries of America, Europe and Australia. There are 306 vehicles per 1,000 inhabitants (as of July 1, 2019) in Russia. It ranks 54th place in the world in terms of the display of motorization. The number of vehicles increases by 1.5 million each year (Khorshid et al. 2007). At the same time, the level of motorization will grow even in the absence of growth in car production within the country. Experts predict that the level of motorization in Russia will approach the level of Eastern Europe and will reach 400–450 vehicles per 1,000 people by 2025 (Khripunova and Kopnina 2017).

The tendency of an increase in the level of motorization is superimposed on other global trends: the rapid growth of the planet's population, increasing requirements for the quality of life of people, tightening requirements for environmental protection (Baltrėnas et al. 2017; Dubovikova and Safoshina 2018; Lozhkin et al. 2016), exhaustion of fossil resources (Yu and Stuart 2017), the pursuit of development through innovation, etc. In this regard, electric vehicles seem to be a solution to the problems.

According to forecasts of world experts, the share of electric transport will reach 10–25% of the total number of cars in the world by 2035. In 2012, the number of sales in the global electric vehicle market was about 140,000 vehicles. Sooner or later, Russia will be affected by this trend. There are already 1,771 electric vehicles on the Russian market on the 1st, 2018. Experts predicted 200,000 electric vehicles in Russia by 2020. The country has developed state programs to support electric cars, provide benefits and tax cuts.

2 Materials and Methods

Certain aspects of the phenomenon of electric vehicles are studied by Russian and foreign scientists. Electric vehicles are analyzed in terms of environmental requirements (Efimova and Kotov 2015; Khripunova and Kopnina 2017; Wang et al. 2018; Baltrėnas et al. 2017; Dubovikova and Safoshina 2018; Lozhkin et al. 2016); from the perspective of fossil natural resources are considered in the work (Efimova and Kotov 2015); from the perspective of innovative development have been studied in works (Adnan et al. 2017; Li et al. 2017; Minak et al. 2017; Sassi and Oulamara 2017; Wang et al. 2018). Aspects of the development of technologies for the production of electric vehicles are considered in (Adnan et al. 2017; Lozhkin et al. 2016; Minak et al. 2017; Sassi and Oulamara 2017).

As a rule, the phenomenon of electric vehicles is considered from the standpoint of individual aspects and not as a complex. A distinctive feature of the study is the consideration of this phenomenon from a different position: the authors studied the organizational aspect of managing the transformation process of energy markets. A hypothesis has been put forward that a new niche for the creation and development of the infrastructure of road electric transport can be occupied by companies of the oil and gas or electric power complex.

The subject of the research is the organizational and economic relations that develop in the process of the development of the auto-electric transport market in Russia. The object of the research is the process of formation of the auto electric transport market in Russia.

The purpose of the article is to propose models of organizational interaction of market participants in order to form the infrastructure of the auto-electric transport market in Russia. Objectives of the article are:

(1) To formulate the principles of choosing a model for the formation of a power supply system for auto-electric transport in Russia;
(2) To propose models of organizational interaction of market participants in the creation of the infrastructure of auto-electric transport in Russia by the electric power complex, oil and gas complex and their joint efforts;
(3) To analyze the compliance of the models with the three principles.

The following methods were being used during the research:

(1) The method of comparing statistical series was used to analyze trends, which made it possible to substantiate the hypothesis about the growth of the global and Russian markets for electric vehicles;
(2) The method of scientific abstraction was used in the development of models for the formation of a power supply system for auto-electric transport in Russia, which made it possible to schematically display the interaction of participants in the new market.

3 Results

The following changes will inevitably occur with the further development of auto-electric transport in Russia. Firstly, the demand for electric mobiles will increase. Russia can manufacture them independently (there is a domestic electric car - Lada Ellada), import ready-made electric vehicles into the country, or assemble foreign electric vehicles on the territory of Russia. The first option seems to the authors to be insufficiently viable. Today, only 5.3% of all electric vehicles in Russia are domestically produced, they aren't in demand due to the high price and technical imperfection. Therefore, the second option is most likely at the first stage and the third option at the second stage of market development. Secondly, it will be necessary to create an infrastructure for refueling auto-electric transport (EAZS). Undoubtedly, this issue should be dealt with by Russian companies. The authors put forward a hypothesis that this role can be assumed by the country's oil and gas and electric power complexes.

The authors have compiled three principles that determine the choice of a model for the formation of a power supply system for auto-electric transport in Russia.

1. The maximum using of available resources and benefits.
   From the point of view of the socio-economic situation in the country, it would be better not to create the entire infrastructure from scratch, but to form it on the existing basis. This will allow not only creating new jobs but also not eliminating old ones. Another advantage of this approach is the using of the knowledge, experience and strengths of the companies. Thus, existing petrol stations can be converted into EAPs. It's better to use the experience of generating sales companies than to build the system anew, separately from them. Well-established relations between the oil and gas complex and the electric power complex can be simply scaled up.
2. Focus on maximizing performance.
   Electric transport, obviously, will be one of the activities of companies in the oil and gas and electric power complexes. Accordingly, this direction hasn't to interfere with all other activities of the company; it has to create a synergistic effect. In this case, the companies will be interested in carrying out the transformation of the market. The demand for petrochemicals will also grow (Burenina et al. 2017), which will allow companies not to lose money and also to increase their revenues. The volume of electricity generation by companies in the electric power complex will similarly increase. The companies will receive a large added value from the sale of electricity through the EAPs in addition to the growth in demand for electricity for domestic needs.
3. The need for integration and cooperation.
   The development of auto-electric transport in Russia affects several key industries; the impact of this trend will be large-scale and systemic. So, we should consider not the competition of industries for the right to create a new market but their cooperation and integration.

Three organizational models for the formation of the power supply market for auto electric transport have been formed: the introduction and development of the EAPs is carried out by the electric power complex (Fig. 1), the development and construction of the EAPs is carried out by the oil and gas complex (Fig. 2) and the creation of the Cooperative structure by the oil and gas and power complexes, which will deal with the development and implementation EAPs (Fig. 3). We should choose one development model to understand the further formation and development of the power supply market for auto electric transport. In the future, it will be necessary to describe the management model using it.

According to the first model, the development and implementation of infrastructure for electric vehicles will be carried out by the electric power complex. Companies need to create an appropriate department for doing this. In this scenario, the cost of charging electric vehicles will be relatively inexpensive and affordable for the consumer market. And a new energy monopoly may emerge on the market, which could significantly reduce the profits of oil and gas companies.

The second model assumes the creation in oil companies of an additional department or enterprise for the implementation of EAPs. Electricity generation is not the core

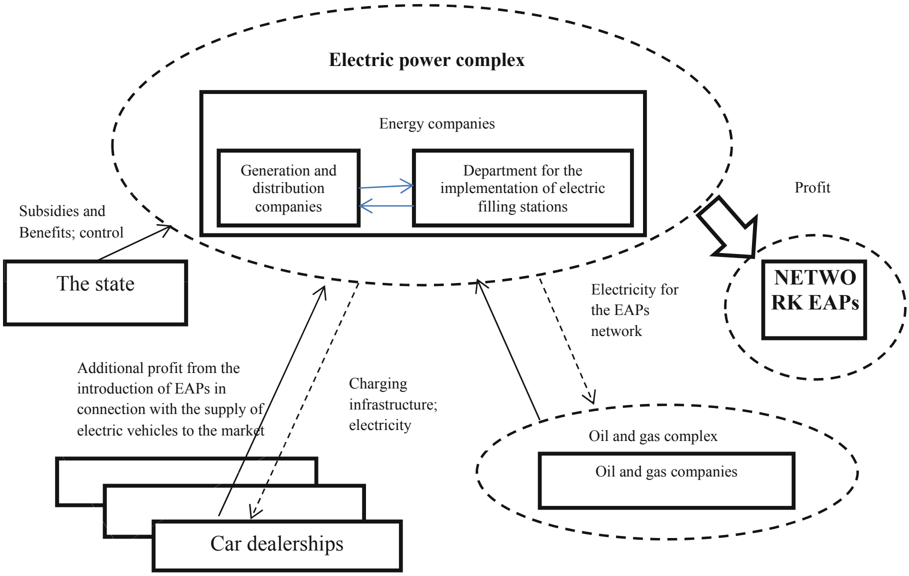

Fig. 1. Model for the development and construction of EAPs by the electric power complex

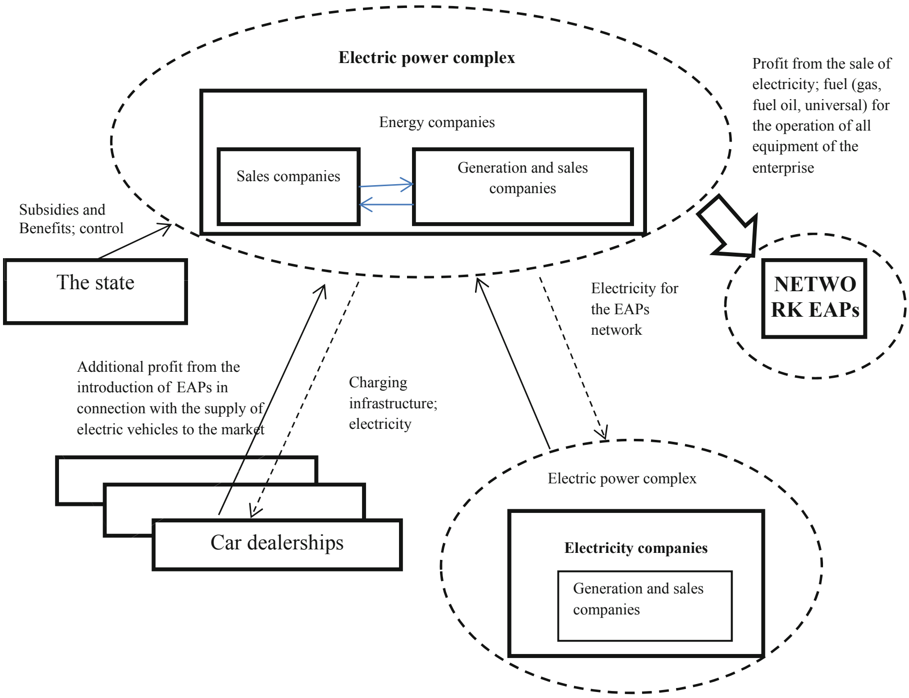

Fig. 2. Model of the development and construction of EAPs by the oil and gas complex

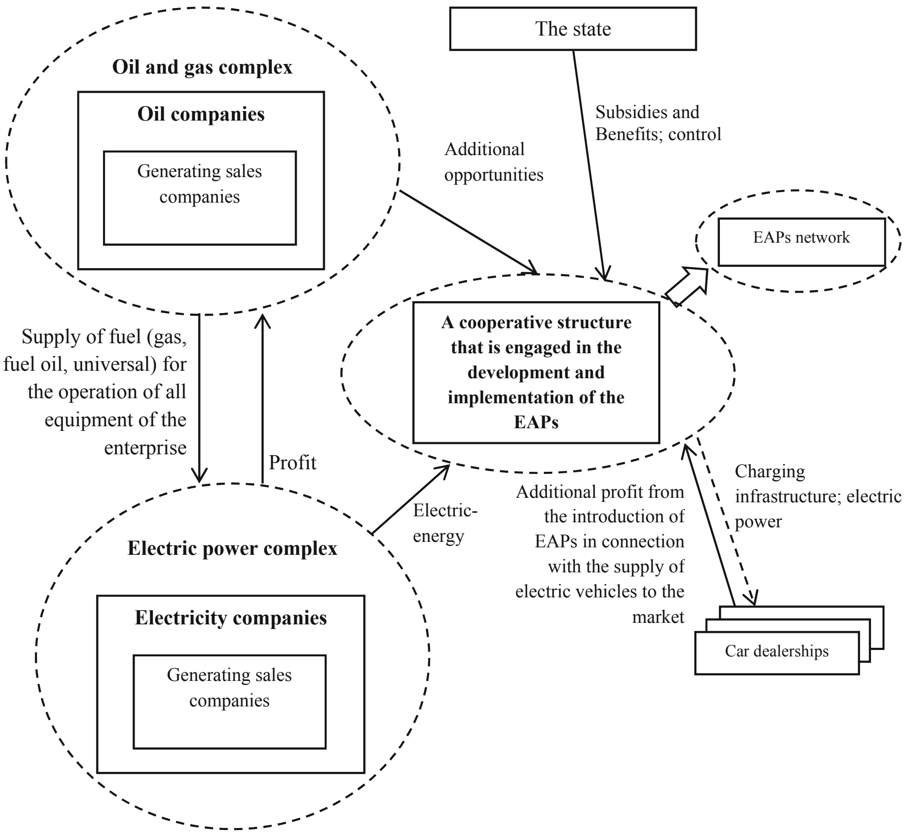

Fig. 3. Model for the development of a cooperative structure for oil and gas and electric power complexes

business of oil and gas companies. Accordingly, the price for charging electric vehicles will be significantly higher than for the first model.

In theory, the third model is optimal because it meets all three principles described earlier. The oil and gas and electric power complexes are creating a Cooperative structure that will develop and implement the EAPs. Generating sales companies will directly generate and supply electricity to the EAPs, thereby avoiding additional price hikes.

The generated models reflect the interaction and the role of the oil and gas and electric power complexes in the power supply market for motor vehicles (Table 1).

Based on this analysis, it was concluded that the third model is more applicable for the Russian market. At the same time, it's still necessary to assess the economic efficiency of the implementation of these models.

Table 1. Advantages and disadvantages of the models

Model	Advantages	Disadvantages
1. Oil and gas complex	There are no costs for the lease of land plots for the EAPs	Purchase of electricity on the wholesale market with a surcharge
2. Electric power complex	Generating own electricity	There are costs for leasing land plots for EAPs
3. Cooperative structure	There are no costs for the lease of land plots for the EAPs. They buy electricity not with a surcharge on the wholesale market, but at cost	–

4 Conclusion

New technologies and modern global trends will inevitably change existing markets and lead to the creation of new markets. The rapid growth of the population of our planet, the requirements for the quality of life in the conditions of a shortage of natural resources and traditional types of fossil fuels and the tightening of requirements for environmental protection highlight the problem of efficient using of energy. According to the forecasts of world experts, the share of electric transport will reach 10–25% of the total number of cars in the world by 2035.

The key factors in the development of the automotive electric transport market in Russia are the production of electric vehicles and the creation of infrastructure (EAPs). The development of the first factor is little determined by the domestic market and the development of infrastructure should be organized by Russian companies. The authors suggested that the oil and gas complex and/or the electric power complex of the country will be engaged in the development and construction of the EAPs.

The article describes three organizational models of the formation of the power supply market for road electric transport. Only the cooperative model satisfies all three principles. Existing filling stations can be gradually converted into EAPs. The experience of power supply companies can be used to reduce risks and improve the affordability of refueling electric vehicles. The well-established relationship between the oil and gas and power complex can be scaled up. Oil and gas companies can use part of the extracted raw materials not for the production of motor fuel but for the production of petrochemical products. The demand for petrochemicals will also grow, which will allow companies to increase their revenues. The volume of electricity generation by companies in the electric power complex will similarly increase. In addition to the growth in demand for electricity for domestic needs, companies will receive a large added value from the sale of electricity through the EAPs.

It's necessary to develop a mechanism for choosing a model for the construction of EAPs by potential market participants to assess economic efficiency of the implementation of the models. It must take into account the scenarios for the development of the electric vehicle market in Russia, the risks of an innovative project for the construction of an electric gas station and it also must economically justify the choice of one of the three models.

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Industry 4.0: Features of Development in Russia

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Abstract. Purpose: The purpose of the article is to analyze the changes generated by digital technologies and determine the degree of impact of Industry 4.0 on the work of Russian business.

Design/Methodology/Approach: The authors used a systematic approach in analyzing transformations generated by Industry 4.0. This led to the conclusion that a prerequisite for the successful use of digital technologies is the formation of a favorable institutional environment that can create effective incentives for successful work in the context of digitalization, and the creation of a regulatory framework in the field of digitalization.

Findings: The article shows how Industry 4.0 changes the model of interaction: producer - consumer, transforms the forms of business organization, changes the basic principles of formation of competitive advantages of companies. It was advisable for the manufacturer to use the open innovation model, which provides for an active search for promising ideas in the external environment for the company, conducting joint research, using the idea of customers in creating innovative products. In the context of digitalization, outsourcing processes have intensified. There is an acceleration in the development of franchising.

Originality/Value: The results of the research showed that in the conditions of digitalization a high degree of dependence of the efficiency of the main business processes on the quality of information, the speed of its processing and preservation is created. On the one hand, the use of information increases production efficiency and productivity. On the other hand, there are social risks and risks of loss of information, the leveling of which leads to the diversion of significant financial resources from the main activities of producers.

Keywords: Industry 4.0 · Open innovations · Transaction costs · System approach · Digitalization · Social risks of digitalization

JEL Codes: D 23 · L 26

1 Introduction

The modern economy is characterized by the rapid development of digital technology. Digital technologies fundamentally modify production processes, lead to the transformation of economic relations and the change of business models. Thanks to the innovative activities of industrial companies, it was possible to create a fundamentally new technology that allowed the transition to Industry 4.0.

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Industry 4.0 is characterized by the introduction of new technologies in all spheres of economic activity on the basis of the formation of a single digital ecosystem through the integration of all participants in the production process (Kaplinsky and Cooper 2005). The deep penetration of information technology into all business processes has ensured the revolutionary nature of Industry 4.0 (Schwab 2016).

2 Methodology

In modern economic literature there is no consensus on the methodology for studying the processes of Industry 4.0. This is determined by the features of the transformation of economic processes and economic relations, the emergence of new opportunities for the development of economic entities, their modification and transformation into new forms of interaction. The authors used a systemic approach to analyze the transformations generated by the processes of Industry 4.0. The application of a systemic approach, on the one hand, provides for the creation of special conditions for the introduction of digital technologies, on the other hand, it is determined by the transformation of the economic interests of all participants joining alliances, networks, and clusters. The study of digitalization processes from the perspective of a systematic approach allows us to identify the features of the implementation of Industry 4.0 technologies in the practical activities of Russian industrial enterprises.

3 Results

A prerequisite for the successful application of digital technologies is the formation of a favorable institutional environment that can create effective incentives for the successful work of economic agents. It is necessary to adopt a regulatory framework. In Russia, as in most countries of the world, a number of regulatory documents on digitalization have been adopted in recent years, the main of which is the state program "Digital economy of the Russian Federation".

Analyzing the data on the financing of digitalization processes in Russia, it should be noted that the main share in the amount of funding is the costs associated with the formation of information infrastructure (37.6%). The share of expenditures on digital technologies and projects is 21.9%. Expenses related to digitalization of public administration (25.1%) and expenses aimed at training personnel for the digital economy (11.4%) are comparable in terms of the share of expenditures (Table 1).

It should be noted that there is a steady increase in funding for the main areas of digitalization, which indicates the formation of favorable conditions for the introduction of Industry 4.0 technologies.

3.1 Industrial Internet of Things

The Industrial Internet of Things (IIoT), as an integral part of Industry 4.0, provides the opportunity to move to more efficient production management tools. IIoT allows to create "digital doubles" of physical products and production processes, simulate a

Table 1. Financing of the digital economy in Russia in 2019–2021, billion rubles

Directions of the program implementation	2019	2020	2021	Total	Share in the cost structure, %
Information infrastructure	41.7	48	62	151.7	37.6
Digitalization of public administration	29.2	31	41	101.2	25.1
Digital technologies and projects	21.5	25.5	41,6	88.6	21.9
Human resources for the digital economy	10.5	13.3	22.4	46.2	11.4
Information security	4.8	5.6	4.9	15.3	3.8
Regulatory regulation of the digital environment	0.265	0.265	0.265	0.795	0.2
Total amount of program funding	107,965	123,665	172,165	403,795	100.0

production management system, use virtual simulations long before establishing a real production process, create a fundamentally new system of control over the activities of all elements and mechanisms. Thanks to the use of the "digital double", it has become possible to simulate all business processes, forecast and prevent equipment breakdowns, generate more accurate forecasts of demand volume, and achieve the required level of energy efficiency. The introduction of IIoT technologies allows us to optimize the implementation of complex projects and reduce the development time for new products.

The successful implementation of IIoT is based on the use of information as the main resource. Work with large volumes of information generates an avalanche effect, which is manifested in the fact that data processing contributes to their further growth. A high dependence of the effectiveness of all the main business processes on the quality of information, the speed of its processing and safety is created (Elder-Vass 2016). Using information allows manufacturers to make optimal decisions and make the transition to a data-driven culture - a culture of decision-making based on data and achieving a "smart" result.

This hypothesis is confirmed by the successful activities of the Russian company Zifra, specializing in the export of digital solutions for a number of industries. According to the company, monitoring systems can increase production efficiency by an average of 20% and create a predictive analytics model that can predict equipment breakdowns (Zifra 2020). Digital has created digital technologies for enterprises operating in the mining industry, which allow to increase the productivity of the excavator-dumping complex by 5–15% and reduce the cost of operating equipment by 8% (Zifra 2020). The implementation of the IIoT project in the work of the United Engine Corporation allows to create "digital doubles" in the design, manufacture and operation of engines. For example, the introduction of IIoT by KamAZ allowed us to optimize the development of service documentation and reduce the time spent on complex design projects by 50%.

The activity of large Russian companies in the use of digital technologies is illustrated by the KPMG survey conducted among the 100 largest Russian companies in 2019. It was found that 70% of respondents have a digital transformation program developed by the company and expect to increase operational efficiency and reduce costs. The following technologies are the most popular among the largest Russian companies: big data analysis, predictive analytics, chat bots, office process robots. In order to increase the efficiency of using digital technologies, many manufacturers attract startups to implement pilot projects (Report KPMG 2019).

3.2 Transformation of Producer Behavior Patterns

The use of information as the main resource fundamentally influenced the change in the behavior of manufacturers. There has been a transition from a competition-based interaction model to a model based on cooperation. It became possible to use the model of open innovation, which significantly modifies the processes of competition. The model provides for the organization of the search for scientific ideas in an environment external to the company, conducting joint research, creating innovations with partners - "yesterday's" competitors, and further sharing intellectual property rights for strategic purposes (Chesbrough 2006).

Industry 4.0 has made it possible to actively use the ideas of customers in creating innovative products. Companies focusing on the open innovation model engage consumers as partners in the innovation process (Chesbrough 2006). Many international companies have successfully used the model of open innovation in their practice: Apple, Procter & Gamble, DuPoint, BASF (Hove 2008). Russian business is also involved in the processes of cooperation between producers and consumers.

3.3 Transformations in Producer – Consumer Relationship

Industry 4.0 has brought transformations to the interaction model: consumer - producer. The widespread use of information technology has allowed not only to determine consumer preferences, but also to turn consumers into "partners" in the innovation process.

Industry 4.0 has formed new relationships between producers and consumers based on the production of individual and highly customized goods (Schwab 2016). Elimination of intermediaries between producer and consumer leads to a significant reduction in transaction costs.

3.4 Network Form of Business Organization

The rapid nature of the changes, together with an increase in the instability of the external environment, has led to the need for manufacturers to reconsider traditional forms of business organization, which in the digital environment do not allow to quickly reorient the company to market demands. The most appropriate for modern challenges is the network form of business organization, which provides manufacturers with the ability to flexibly respond to changing working conditions.

A distinctive feature of a networked organization, according to M. Castells, is its ability to turn signals into products (Castell 1996). The development of information technologies allows modern enterprises to realize this advantage as efficiently as possible and get significant savings on transaction costs by reducing the cost of promoting products and analyzing the market, monitoring the activities of employees and the implementation of the management process, maintaining office space and organizing service services.

The introduction of digital technologies has contributed to the development of network forms of business organization based on outsourcing and franchising. Industry 4.0 allows enterprises under a franchise agreement to interact 24/7 using a single business concept with a detailed format. Thanks to this, inexperienced entrepreneurs get the opportunity to reduce risks and eliminate the likelihood of making wrong decisions.

The positive dynamics of the average annual growth rate of franchising in Russia and the increase in the number of franchises amid the stagnation of the national economy is clear evidence of the successful development of franchising as a network form of business organization. The increase in the average annual growth rate of franchising in Russia amounted to: 1999–2000. − 25%; 2010–2011 − 25%; 2014–2015 − 10%; 2017–2018 − 25%. There was an increase in the number of franchises: 2014 − 1280; 2015 − 1400; 2016 − 1515; 2017 − 1700; 2018 − 3,000 (Franchise Directory 2020).

3.5 The Risks and Threats of Digitalization

The "flip side" of the digitalization process is the presence of risks associated with Internet threats. The rapid increase in the number of cybercriminals, combined with information leakage and data loss, is causing serious harm, forcing manufacturers to make large-scale financial investments to ensure business information security, diverting funds from circulation. Businesses also have to invest in the development of measures to ensure their own information security. This leads to an increase in transaction costs.

Industry 4.0 poses social risks. The widespread adoption of information and communication technologies is changing the requirements for employees. A modern specialist must possess the skills of data analysis, be able to work with machine intelligence, or a computer scientist, have a high level of qualification. Industry 4.0 leads to a transformation of employment, which is reflected in the elimination of many traditional low-skilled specialties and their replacement with robots. Fear of losing a job provokes resistance to changes among company specialists and contributes to the development of neoludism as a new phenomenon.

Significant threats arise due to the lack of data protection mechanisms, which in the public domain become a "target" or "easy prey" for attackers, which inevitably leads to the loss of information. The inevitable risks of stopping all business processes in the event of errors or malfunctions in the operation of "smart devices" due to a power outage or problems caused by deliberate actions.

4 Conclusion

Industry 4.0. leads to significant changes in the business environment. There is a transformation of the fundamental principles of the manufacturers. The development of technologies of Industry 4.0 contributes to the rapid spread of the network format of business organization in the form of franchising. Digitalization has created the conditions for eliminating the intermediary link between producer and consumer, thereby allowing us to significantly reduce transaction costs. At the same time, there is an increase in transaction costs due to the need to finance activities aimed at ensuring business information security. In general, the development of Russian business is in the direction of introducing Industry 4.0 technologies.

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Training of Innovative Personnel in the Digital Economy

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Abstract. The purpose of writing a scientific article is to study the issue of training innovative personnel in the digital economy. The methodological basis includes the following tools, formulated in the form of methods: theoretical justification, definition, formulation of the features of the investigated object, evaluation, program comparison, selection, and grouping of general conditions. The results of the scientific article are the following aspects: the definition of "innovative personnel" was considered, the peculiarities of training of innovative personnel in the framework of the program "Digital Economy of the Russian Federation" were highlighted, milestones of the implementation of the federal project "Personnel for the digital economy for 2018–2024" have been identified, compared the priorities of the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013 years" and the federal project "Personnel for the digital economy for 2018–2024 years," Some recommendations on the training of innovative personnel in the digital economy were proposed. The author's recommendations for the training of innovative personnel regulated the importance of the development of the institutional environment and human capital in modern society. These proposals are not the only and final dogma that contributes to the training of innovative personnel in the digital economy. The recommendations are aimed at complementing the activities presented in government projects and programmes. In the future, this study can be supplemented by author's proposals in the field of introducing the definition of "digital frames" into the conceptual circulation.

Keywords: Innovative personnel · Digital economy · Program · Project · Indicators

JEL Codes: Z19 · Z18 · O39 · I25 · I26

1 Introduction

The change in the information foundations of the development of society led to the transformation of the system of training of innovative personnel. This condition made it necessary to develop new regulatory and declaratory norms in the field of training

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of innovative personnel in the digital economy. The digital economy contributes to the emergence of a new paradigm for the development of the national economy and changes related to human life. Regulation of these changes affects various areas and the subject environment of society. The emergence of negative consequences, formed on the basis of the transition from a post-industrial to a digital economy, determines the importance of revising approaches, primarily aimed at adapting the country's personnel potential. The production of this problem is related to the following grounds.

Firstly, the information space is being introduced into various branches of the national economy of the country, but at the same time, human capital does not have time to impress the skills and competencies corresponding to this environment (Maksimtsev and Gorbashko 2013). The formulated aspect notes the differentiation of the population in the field of transition to a digital economy. The technologization and informatization of the socio-economic environment led to the stratification of professional competencies of labor resources. This process will be strengthened in the short to medium term.

Secondly, the education system is being transformed towards distance learning (Mozhaev 2015). This condition was most clearly manifested during the advent of the coronavirus pandemic COVID-19, at the time of which in practice a remote education system for schoolchildren and students was tested. In addition, the appearance of a remote version of work on remote services contributed to a change in the labor relations between the employee and the employer.

Thirdly, the implementation of corporate education implies the introduction of a constant cycle of training within the framework of the concept of a "lifelong set of competencies" (Huseynova 2014). First of all, the system of corporate training is quite relevant for innovative companies interested in developing the skills of employees in accordance with the conditions of the digital economy.

The circumstances presented made it possible to conclude that it was important to study the issue of training innovative personnel in the digital economy. At the same time, this issue should be considered both from a theoretical point of view (revealing the necessary concepts) and as part of a practical analysis of the training of innovative personnel (based on the assessment of developed regulatory legal acts and programs). The purpose of writing a scientific article is to study the issue of training innovative personnel in the digital economy. The proposed goal regulates the implementation of the following tasks: consideration of the definition of "innovative personnel"; identification of features of training of innovative personnel of the digital economy in accordance with the program "Digital Economy of the Russian Federation"; identification of the main milestones of the federal project "Personnel for the digital economy for 2018–2024 years"; comparing the priorities of the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013 years" with the measures prescribed in the passport of the federal project "Personnel for the digital economy for 2018–2024 years"; offering recommendations for the training of innovative personnel in the digital economy (Lyapina et al. 2019).

2 Materials and Methods

The methodological basis for the study of the issue of training innovative personnel for the conditions of the digital economy is regulated by the methodological apparatus aimed at implementing the dual function: consideration of the theoretical basis of the conceptual apparatus and analysis of regulatory legal acts in this area. In accordance with the identified tools, to consider the theoretical aspect of the training of innovative personnel for the conditions of the digital economy, methods such as theoretical justification, definition, and formulation of the features of the object under study are used. Methods used to analyze regulations in the field of training of innovative personnel include assessment, programmatic comparison, identification, and grouping of general conditions.

3 Results

In the process of conducting a study on a given topic, we highlight some definition features and the essence of the concept of "innovative personnel". For the first time, the definition of "innovative personnel" appeared in the works of Schumpeter, aimed at studying the entrepreneurial class in the theory of innovative development. Innovative personnel are independent and confident people who have a fairly balanced attitude to money and rely on their own strength in solving problems (Frolov and Bosenko 2020). Today, it can be stated that this concept is more characteristic not of innovative personnel, but of entrepreneurial structures. Over the past 20 years, the concept of "innovative cadres" has been identified with various species actors in the economy. In simple terms, the classification of innovative personnel has a fairly wide typology. As an example, we can cite the following grouping of innovative personnel: within the fields and industries of innovation - employees of high-tech industries, in the field of science, in sectors of the modern economy, functioning on the basis of digital competencies (Cherevatova 2018); as part of the innovative process - innovators and innovators, workers providing the technological process, implementers (Lukyanova and Alekseeva 2010); innovative leaders - owners, entrepreneurs in the field of IT, innovative managers, managers-managers of technological processes (Makarova 2010), etc.

1. Differentiation of the characteristics of the structural element is characteristic of various definitions of the concept of "innovative personnel". Innovative personnel are subjects of innovative management that form and implement a process aimed at creating and subsequent marketing of unique products, goods and services (Bogomolova 2019). The highlighted concept more formulates the definition of "innovative manager" but at the same time gives a filled and general definition of the activities of the formulated subject. From the standpoint of innovation, innovative personnel are considered in a definition that reveals the conditions for giving these subjects certain functions. Innovative personnel are mediated innovative structures that implement the process of planning and organizing R&D based on business planning and the formation of a new unique product in the technological environment (Nazarova 2019). The presented definition basis regulates the initial stages of the innovation process in the context of which innovative personnel participate (Stroeva et al. 2019). Considering concepts from this position, some conclusions can be disputed. Firstly, innovative personnel cannot be limited to a certain stage of the innovation process (Lunkin 2014). Secondly, innovative personnel represent a broader concept of management

entities that both generate innovative ideas and receive income from the implementation of the formed innovative product (Kopteva 2018). Thirdly, innovative personnel are a collection of human resources endowed with innovative knowledge, competencies, and skills (Fey and Suetina 2019). In accordance with these conditions, innovative personnel are economic entities involved in the formation of an innovative process based on the competencies and skills obtained in the framework of educational and professional activities (Sanochkina 2019). This definition allows us to formulate the presented theoretical picture of the perception of the concept of "innovative personnel."

The obtained theoretical conclusion is declared in the context of the analysis of regulatory and legal activities on the issue of research of innovative personnel. Initially, the declaration of the aspect of training innovative personnel in the digital economy was reflected in the Order of the Government of the Russian Federation of 28.07.2017 No. 1632-r "On the approval of the program "Digital Economy of the Russian Federation" (Table 1). The system of training of innovative personnel reflected the gradual formation

Table 1. Training of innovative personnel of the digital economy in accordance with the program "Digital Economy of the Russian Federation"[1]

<table>
<tr><th rowspan="7">Training of innovative personnel</th><th>2018</th><th>2020</th><th>2024</th></tr>
<tr><td>Development of educational documents</td><td>Providing resources and mechanisms for general, vocational and complementary education for the digital economy</td><td rowspan="2">Updating the Human Resources of the Digital Economy</td></tr>
<tr><td>Creation of professional regulatory documents</td><td>Professional development trajectories for the digital economy</td></tr>
<tr><td>Preparation of competencies for the digital economy</td><td>Formation of a competency certification system for the digital economy</td><td rowspan="2">Ensuring the competence of citizens in the field of the digital economy</td></tr>
<tr><td>Launch Competency Pilot</td><td rowspan="3">Create at least one digital platform for research on end-to-end technologies (at least 5 participants and 2 partners)</td></tr>
<tr><td>Pilot Project Competency Testing</td><td>Create at least 10 digital platforms</td></tr>
<tr><td>Established system, mechanisms, communication platform for interaction of digital platform participants</td><td>At least 10 leading companies operate effectively</td></tr>
</table>

[1] Decree of the Government of the Russian Federation of 28.07.2017 No. 1632-r "On Approval of the Program" Digital Economy of the Russian Federation" https://www.garant.ru/products/ipo/prime/doc/71634878/#review Accessed: 28.08.2020.

of the foundations of digitalization in the professional and educational activities of these subjects.

The implementation of the Digital Economy of the Russian Federation program included three stages - milestones with concrete results and activities aimed at the formation and testing of the project in the context of the digital economy. The initial stage, limited to 2018, produced the need to implicate the regulatory framework in order to implement a pilot project to launch digital platforms and develop competencies for the work of innovative personnel. Subsequent milestones of the project included the process of providing resources and formulating professional trajectories in order to develop digital competencies of innovative personnel (until 2020), updating personnel potential, and switching to platform work of innovative enterprises (until 2024). However, after the adoption of the Decree of the President of the Russian Federation of 07.05.2018 No. 204 (ed. From 21.07.2020) “On National Goals and Strategic Objectives for the Development of the Russian Federation for the Period until 2024,” the Order of the Government of the Russian Federation of 28.07.2017 No. 1632-r was canceled.

The main indicators of personnel training for the digital economy, stated in the passport of the Federal Project, are presented in Fig. 1.

In general, under the conditions declared in the federal project “Personnel for the digital economy for 2018–2024”, measures for the functioning of the educational system in the medium and long term are described. The federal project “Personnel for the digital economy for 2018–2024” is essentially a forsyth tool that regulates the system of training innovative personnel. The training of innovative personnel in the digital economy in the context of a federal project is aimed at digitalizing society by means of introducing algorithms and mechanisms to provide a digital environment. The results of the project are obtaining 40% of the country’s population with digital skills by 2024, providing higher and secondary vocational education with at least 800 thousand people (while obtaining competencies in the field of information technology), producing 120 thousand people in the direction of information and telecommunications technologies by 2024.

The declared results of the federal project “Personnel for the digital economy for 2018–2024” are produced by obtaining specific indicators that allow you to establish parameters for the planned compliance of measures with their actual level. These indicators reflect the number of trained and retrained personnel in the digital economy; regulate the country’s place in the ratings of The Global Talent Competitiveness. By specifying these indicators on the basis of parameters, we will highlight the criteria for achieving results by 2024: the number of graduates with the competencies of the digital economy (3130 thousand people), the number accepted for the programs “information technology” and “mathematics” (546 thousand people), the number of trained people within the competencies of the digital economy (3900 thousand people), the country’s place in the ranking of The Global Talent Competitiveness (30th place), the share of digital resources used as part of the All-Russian verification work (100%).

In the context of the Federal Project “Personnel for the digital economy for 2018–2024”, two components are traced, which in essence identify both the positive and negative sides of the training of innovative personnel. On the one hand, high coordination of state actions is aimed at supporting schoolchildren and students in the field of professional education in mathematics, computer science, and digital economy technologies.

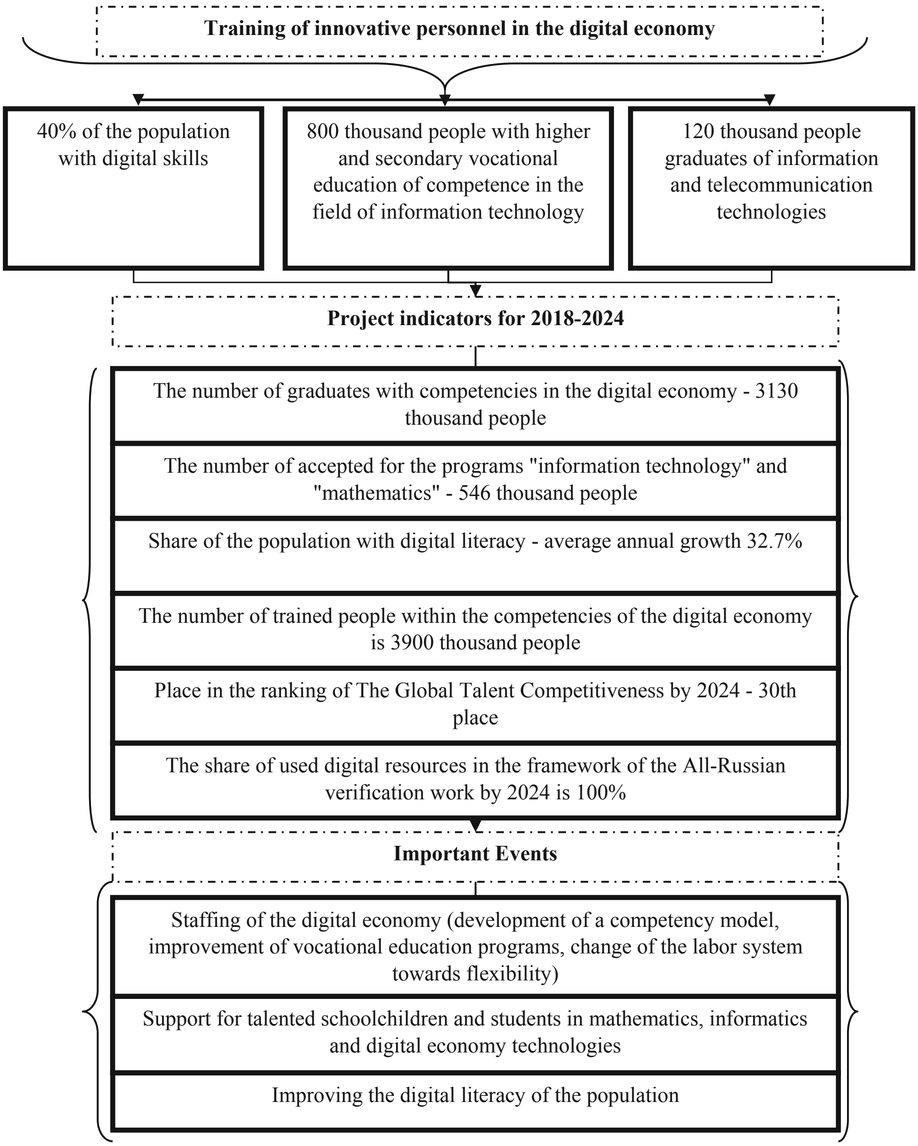

Fig. 1. Passport of the federal project "Personnel for the digital economy for 2018–2024 years"[2]

[2] Passport of the Federal Project "Personnel for the digital economy for 2018–2024 years". https://digital.gov.ru/ru/activity/directions/866/ Accessed: 28.08.2020.

On the other hand, the concept of "innovative personnel" is replaced by the definition of "frames of the digital economy," which also has a more formal and specific type of subject structure within the framework of the studied question.

Studying measures to train innovative personnel in the digital economy, it is quite interesting to shift the priority of aspects of the declared, but not implemented in the federal target program "Scientific and research personnel of the Russian innovative economy for 2009–2013 years". Table 2 compares the priorities of the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013 years" and the federal project "Personnel for the digital economy for 2018–2024 years". The production of the conditions declared in the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013" was based on the concept of "dominant" activity of human professional activity. As part of this priority, it was assumed that most of the professional activities of innovative personnel would be based on the process of self-education.

Table 2. Replacing the priorities of the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013 years" with events in the context of the passport of the federal project "Personnel for the digital economy for 2018–2024 years."

Priorities of the federal target program "Scientific and research personnel of the Russian innovative economy for 2009–2013 years"		Priority of the passport of the federal project "Personnel for the digital economy for 2018–2024 years"	
1.	Learning is the "dominant" activity of a person's professional activity	1.	Implementation of training activities in the areas of mathematics, informatics and digital economy technology
2.	Learning in the context of a lifelong rather than professional cycle	2.	Digital economy skills
3.	Training to address cross-border aspects of professional activities	3.	Implementation of the digital economy competency model
4.	Creating an individual trajectory of education	4.	Implementation of personal competency profile
High competition in the educational environment of innovative personnel			
Personal responsibility for the level of competence ownership			
Remote work and temporary contracts			

In fact, the selected aspect in the federal target program "Scientific and research personnel of the innovative economy of Russia for 2009–2013" was implemented only in the context of training scientific personnel, which is essentially part (type) of the personnel structure in the digital economy. This proposal in the federal project "Personnel for the digital economy for 2018–2024" was replaced by "the implementation of training activities in the field of mathematics, informatics, and digital economy technologies".

It can be noted that the training of innovative personnel in the digital economy is regulated by a fairly elaborate program and project document, which, on the one hand, contains a set of measures that allow focusing on the transformation of the educational environment, and on the other hand, forms a rather large gap between the priority and other areas of development of digital society. First of all, the training of innovative personnel in the digital economy does not affect the institutional approach and attitude to the development of human capital from the position of a leader in innovative personnel. The replacement of this item takes place on the basis of embedding the leaders of the IT industry in the context of the functioning of the digital economy. On the basis of this conclusion, some author's recommendations for the training of innovative personnel in the digital economy were formed (Fig. 2).

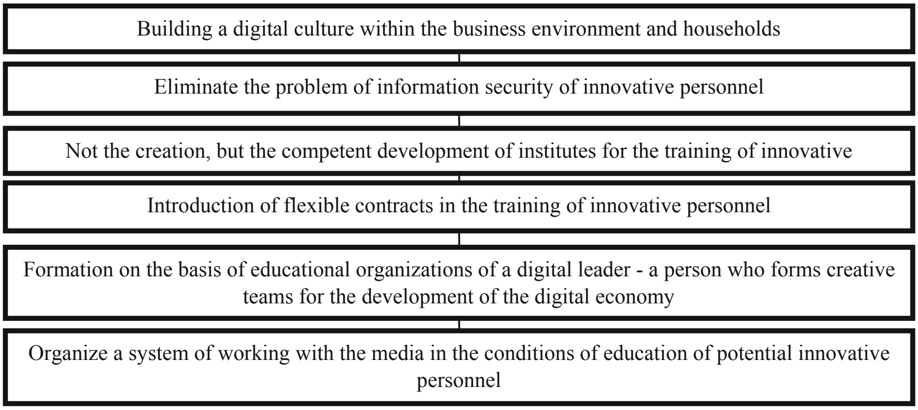

Fig. 2. Some recommendations for the training of innovative personnel in the digital economy

4 Conclusions

The above study on the training of innovative personnel has led to the following conclusions.

1. The definition basis for the definition of "innovative personnel" is quite extensive and has a large number of definitions. For the first time, the concept of innovative personnel was formulated by Schumpeter in the theory of innovative development, and subsequently underwent a change associated with the departure from the primacy of the entrepreneurial structure to the participants in the innovation process. The most common concept is the following definition: innovative personnel are economic entities involved in the formation of an innovative process based on the competencies and skills obtained in the framework of educational and professional activities.
2. According to the program "Digital Economy of the Russian Federation", the training of innovative personnel was based on a planned, gradual process of introducing measures into the practical activities of the country. Based on three key stages (2018, 2020, 2024), measures were planned to form new competencies and create digital platforms for the professional activities of innovative personnel. Subsequently, the program "Digital Economy of the Russian Federation" lost force in

accordance with the adoption of the Decree of the President of the Russian Federation of 07.05.2018 No. 204 (ed. 21.07.2020) "On national goals and strategic objectives of the development of the Russian Federation for the period up to 2024".
3. The Federal Project "Personnel for the digital economy for 2018–2024" has a shorter time frame for the implementation of measures and a more differentiated system of proposals in the field of training innovative personnel in the conditions of digitalization of society. Having conducted a brief regulation of these events, it is worth noting the high importance of training innovative personnel in the areas: mathematics, computer science, digital economy technologies. Other areas of social development do not have priority status in the context of the declared program.
4. The comparison of the priorities of the Federal Target Program "Scientific and research personnel of the innovative economy of Russia for 2009–2013" and the federal project "Personnel for the digital economy for 2018–2024" is associated with the elimination of previously declared measures in the field of training innovative personnel. The lifelong education system is gradually being replaced by the postulate "obtaining digital competencies". The form of competencies and skills is the main tool for the training of innovative personnel in the digital economy.

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Information Protection of Automated Systems Using Artificial Intelligence Methods

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Abstract. Purpose: Design of information protection system of automated systems using artificial intelligence methods.

Design/Methodology/Approach: This article deals with the use of artificial intelligence in the field of information security in accordance with the procedure established in GOST R 51275-2006 and the law on critical information technologies, as well as in connection with the expansion of the tasks of the state system for preventing hacker attacks on enterprises and organizations containing critical processes and technologies in their information infrastructures.

In this work, the structure of the software complex using artificial intelligence and the nature, volumes of necessary initial data that should be submitted to the input of the enterprise information security analysis program are considered.

It is shown that it is necessary to submit to the input of the software complex when modeling hacker attacks and creating a comprehensive information protection system in critical information technologies. It is noted that with the introduction of the law on critical infrastructures, a unique situation arises for the use of the GOsSOPKA database (State System for the Detection, Prevention and Elimination of the Consequences of Computer Attacks) to enter information for the use of artificial intelligence in the field of information protection. It also shows the prospect of using artificial intelligence in the field of information security, and it is indicated that such a direction of improving the integrated security of critical information infrastructures is almost uncontested.

Findings: The importance and possibilities of using an artificial Intel-object are shown taking into account the legislative framework for critical information infrastructures.

Keywords: Information security · Information protection system design · Neural networks · Hacker attacks · Machine learning methods · Scientific intelligence

JEL Codes: R01 · F22 · F63 · J15 · J61 · O15 · R11 · R23 · R58 · Z13 · Z18

1 Introduction

Today, in the age of information and computerization, technical and other objects and processes are increasingly managed through software and computer communication systems, networks and cloud technology (Chelukhin 2020). Moreover, such software and

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computer control is being introduced into technological processes that control objects of high importance, the violation of the mode of operation of which can lead to significant both economic and environmental damage, and sometimes irreparable consequences, as happened at the Chernobyl nuclear power plant.

Therefore, scientific developments in information security technology are now becoming increasingly important. One of the promising methods of such protection is methods with the use of artificial intelligence.

2 Materials and Methods

Today, machine learning methods are used to ensure reliable information security, when developing and modeling mechanisms for protecting against hacker attacks, analyzing the security of information systems, as well as predicting possible risks and assessing risks (Piletskaya 2020).

However, in order to create a reliable system for protecting information security by observing the requirements of the legislation and supporting it, a time-consuming primary analysis of possible information threats is necessary.

To do this, we propose the use of methods for auditing the state of information security.

The purpose of the study was to determine the order and nature of the data to be reported to the security system, which would process the information.

It is necessary at the beginning to analyze the main directions and opportunities for the implementation of artificial intelligence (AI) technology. Ideally, the management of the enterprise should decide on a preliminary audit of all information protection tools. The audit report data should be the basis for the development of the system and determine the array of initial data that should be entered into the system. This approach to designing information protection of automated systems using artificial intelligence methods will allow you to most accurately determine the threats of information of this nature of an organization or enterprise.

The hardware and software structure for information protection using AI can consist of several parts. As you know, the security of information is confidentiality, accessibility and integrity. Here, confidentiality (secrecy) access is allowed only to authorized persons. Integrity - Information changes only to authorized persons. Accessibility: Easily receive and use information by authorized persons.

The system should also record all attempts of hacker attacks.

Accordingly, it is necessary to have the following parts - this is the control of access, encryption of information, accounting and registration, ensuring integrity.

1. The access control module shall provide

   – access point analysis for authorized users:
   – to information on hard drives;
   – to servers;
   – to cloud information storages;
   – perform functions of the network screen of the intelligent level;

2. Registration and accounting module

   - logging the actions of all users.
   - registration of hacker attack attempts.

3. Encryption Module

   - application of all cryptographic protection methods in accordance with accepted standards;
   - Monitor the validity of software licenses and certificates;

4. Integrity Module

   - Selection of logging method.
   - Selection of software tools for integrity control.
   - Development of physical protection control.

At the same time, all these modules will have to work in conjunction with the rest of the protection of information security devices, including in conjunction with the devices of the access control system of the enterprise or organization, physical automated means of obstruction and detection of violators.

Personnel or staff time-keeping services with the help of this time-recording software will be able to document the effectiveness of their work to each employee.

The composition of the software complex performing the delivered data is shown in Fig. 1.

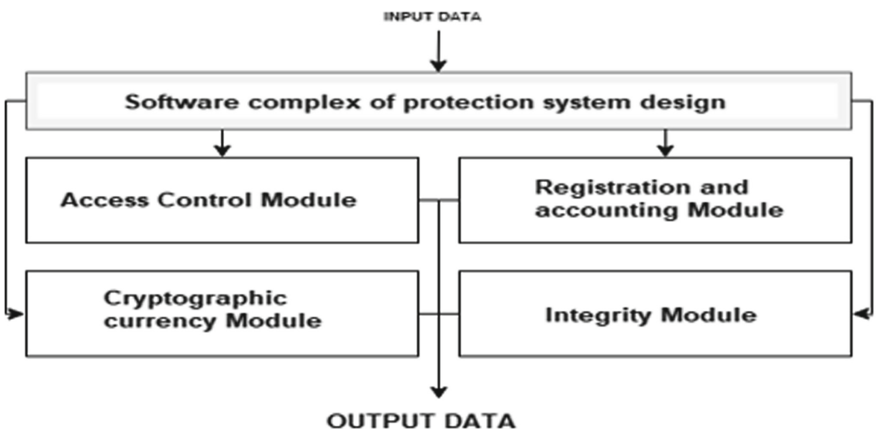

Fig. 1. Composition of the software system. *Source*: developed and compiled by the authors

In more detail, the input data will necessarily include the following components:

- list of equipment for information protection purposes;

- access control module;
- encryption module with application of all cryptographic protection;
- protection area diagram;
- network topology;
- diagram of systems to systems outside the controlled area;
- personnel monitoring and time recording system;
- basic provisions of the information security policy;
- basic internal guidance documents, guidelines for the protection of information;
- results of the last audit of auditors.

As a result of the software system operation at the output we will have:

- security class;
- developed draft terms of reference for the development of the information protection system;
- list of necessary technical protective equipment;
- list of required software;
- a set of personnel training measures for working with the complex.

The diagram of input and output data is shown in Fig. 2.

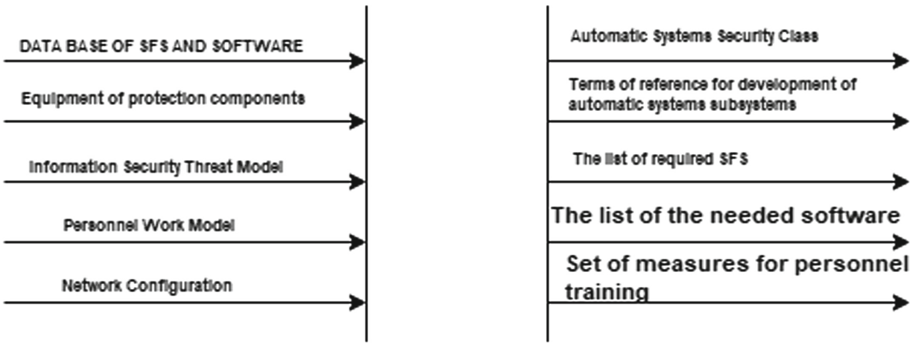

Fig. 2. Input and output data. *Source*: developed and compiled by the authors

The use of artificial intelligence technology will significantly accelerate the work on information protection. The possibility of mathematical modeling can also play a significant role here, as indicated by Cheluhin et al. (2019). A similar method of mathematical modeling is successfully used in many other branches of science, as for example, this was done in the work of mathematicians Grigorieva et al. (2020).

The ability to use AI technology to perform information security tasks is practically unlimited. But here, as mentioned above, the main difficulty will be the task of formulating input data to the system. Here it is necessary to recall that in the Russian Federation a state system is being created to detect, prevent and eliminate the consequences of computer attacks (GosSOPKA) for the exchange of information about cyber attacks. Back in January 2013, the FSB was instructed to create the structure of the state system for detecting, preventing and eliminating the consequences of computer attacks on information resources of the Russian Federation. GosSOPKA should ensure the prediction of the IS situation of all owners of information resources in the field of cybersecurity. Branches of GosSOPKA will be established throughout the Russian Federation, which will be in direct connection with it. Moreover, these branches will have to inform GosSOPKA about all cases of detection of hacker attacks, attempts to hack information resources Chelukhin (2020).

The main problem of information security systems using artificial intelligence in the field of information security is assumed to be a high level of its reliability, the ability to close all gaps in the system for the penetration of intruders. The uro-vein of such a protection system should be very high. The probability of penetration of the attacker should be no more than 1–3% according to the calculated data. In contrast to such a system, for example, a hacker, using artificial intelligence as well, can be content with the success of penetration by a very low percentage - from 5 to 15%. Because when you bulk send out a virus or zombie hundreds of computers, even a small amount received from one computer, multiplied by hundreds gives a very high "income" from such activities. A robot hacker with artificial intelligence can produce such mailings in thousands, which can also lead to inoperability of enterprise servers.

Protection against such a smart hacker attack can also be complicated by the actions of a hacker program that can analyze the protective actions of the enterprise or organization security system, and find opportunities to block or deceive such protective actions of the information security system. In addition, such smart hacker programs can successfully conduct network intelligence without much difficulty before an attack. Since there is a lot of information about the enterprise, its employees and management are freely available to the enterprise itself. Therefore, the enterprise information protection system should also be able to recognize such actions, and distinguishing them from the actions of legal users and their customers. In other words, if a computer is used to check the persistence of the enterprise security system, monitor its data completely, the enterprise information security system should be able to quickly collect information about the computer and assess the danger of its actions, and then block its access and even to legal information of the enterprise in the future. Or have a complete database of the most dangerous Internet users. Already today, such a practice of markers of the most dangerous sites takes place. In particular, even many banks today have a database of unscrupulous borrowers. Something should be implemented in the field of information security using artificial intelligence.

Experience and practical results are accumulated, and the theoretical potential of developments in the field of artificial in-tech and its use for information security systems is also accumulated. This is especially important today for the automation of information security systems of critical information infrastructures of production and technological processes. In addition, as is known, the law "On Information Security of Critical Information Structures" covers almost all areas of industry, medicine, science, aerospace and military. The implementation of this law in information protection systems in the not-so-distant future will be obligatory, since today all production processes and technologies are managed using computer technology, communication systems, and more recently using cloud technologies, distributed systems. This in turn complicates the tasks of protecting the information, as well as the development and design of automated protection systems against hacker attacks.

The world is growing trends in the use of “smart” materials (Chelukhin 2016), “smart” actuators, “smart” control systems.

Today, the use of artificial intelligence in the field of information protection takes only the first steps, but the existing legislative framework in this area, government decisions and FSTEC (Federal Service for Technical and Export Control) guidelines require an increasing amount of coverage in the field of information protection, and it is unlikely to be possible to create a modern system of such protection without the use of artificial intelligence.

It should be noted that this will significantly complicate the task for developers and it will require a higher developer qualification in the development of such information security systems using artificial intelligence.

It is also necessary to note the economic side of designing and using automated information protection systems using artificial intelligence. Of course, the use of artificial intelligence greatly increases the cost of developing such protection systems, since the level of technical literacy of development specialists will be quite high.

3 Results

The proposed article addressed the potential of AI techniques for designing an information protection system. The scientific literature describes many successful proposals that use machine and deep learning to detect attacks and monitor the state of security of the system, which indicates the relevance of these methods in the field of cybersecurity. This is especially important today, since the legislative activity of the authorities is forced to take legislative measures on modern challenges of the information era and on the destructive actions of criminal attempts in the field of information technology. It is the emergence of new legislation in the field of cybersecurity that significantly complicates the tasks of creating information security systems and programs. It is natural to assume that such a situation will lead to the use of artificial intelligence methods in the development of programs and information security systems.

Therefore, we can talk about the potential success of using artificial intelligence for designing an integrated system for protecting automated systems.

4 Conclusion

To date, the use of artificial intelligence in the field of information protection is taking only the first steps, but the existing legislative framework in this area, government decisions and FSTEK guidelines require an increasing amount of coverage in the field of information protection, and it is unlikely to be possible to create a modern system of such protection without the use of artificial intelligence.

It should be noted that this, in turn, in the design of such information security systems using artificial intelligence, will significantly complicate the task for designers and will require a higher qualification of developers and designers.

It is also necessary to note the economic side of designing and using automated information protection systems using artificial intelligence. Of course, the use of artificial intelligence significantly increases the cost of developing such protection systems, since the level of technical literacy of development specialists will be quite high.

In addition, as a result of the uniqueness of the tasks of each enterprise and rare hacker attacks, it is unlikely that it will be possible to apply the typical developments available to security system developers for these purposes.

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Concept of "Smart City" in the Framework of Scientific Discourse

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Abstract. The "smart city" concept as a potential center of population concentration in an era of growing urbanization is justified through the prism of not only technological and socio-cultural aspects, but also human capital with special qualities, adapted to the smart urban space.

The initial methodological premise and starting point of the study, which reveals the essence of the conceptual provision, is the understanding that smart city is an extremely complex technical and technological, socio-economic and cultural phenomenon, which is characterized by multi-purpose orientation, dynamism and multidimensionality, which can be understood by disclosing its own unique nature.

The aim of the study is to substantiate and evaluate the existing system of contradictory views and the tendency of theoretical thought development within the conceptual apparatus on the basis of generalization of different conceptual approaches.

The research logic of the stated problem is based on the conceptual apparatus, which forms the methodological basis of the research, reveals the semantic content and specific features of a smart city, and also allows the most complete disclosure of its nature, character and specific features.

The diversity of author's modifications has also served as a reason for scientific analysis, which characterizes the conceptual approaches related to the justification of technological, socio-economic and political processes of the future city, reveals potential opportunities, and provides an in-depth assessment of the basic conceptual provisions of the smart city.

The general conclusion of the study is that the conceptual design of a smart city within the framework of scientific discourse is still in its infancy and is constantly evolving. At the same time, certain scientific statements are not unequivocal in their essence and are characterized by controversial assessments due to the lack of a unified approach, especially in terms of the conceptual apparatus, which includes a wide range of definitions that contradict each other.

Keywords: Smart city · Terminology · Methodology · Concept · Digitalization · Discussion

JEL-codes: O 32 · O 33

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1 Introduction

Digitalization, computerization and the emergence of the Internet with access to unlimited databases radically changed the life of citizens in a modern city, their social interaction and communication, which contributed to the formation of a smart city. In the last decade, cities of the future (smart cities) as objects of scientific research have received increased attention. This is due to the special role of the smart city in the society and the presence of its specific features. In modern conditions, the urban reality is gradually emerging, that is a hybrid of a physical city and its virtual information-digital copy, in which a large array of data is formed within the network structure. This city is a kind of blood system made from roads, which has a digital nervous system in the form of devices communicating with each other – Internet of things, memory (cloud storage and Big data technologies), and a kind of brain (machine intelligence). All this together resembles a chip that transmits all the urban information generated by citizens and the devices that interact with each other and the environment (Potemkin 2018a, b).

A smart city is a high-tech city that has an impact on people's lives, which includes a complex system consisting of technological (hard) and social (soft) infrastructure. This is a fundamentally new strategy of urban infrastructure development, based on the joint use of ICT, intelligent management and clearly defined smart goals. In the era of rapid technology development, the scientific community thought about the consequences of introducing smart cities. This has led not only to a rethinking of the problem of urbanism, but also triggered the emergence of a scientific discourse related to the concept of "smart city". In this regard, there is a rethinking of values, the role of technology in the lives of citizens and ways of further development of mankind, which sets a constructive framework for research, suggests appropriate methods and techniques that contribute to the achievement of goals in the digitalization.

The concept of "smart city" acts as a complex component, substantial and descriptive model based on the interaction of technology providers, government agencies and civil society. Within the framework of this model, the formation of a smart citizen takes place, participating in the formation of democratic principles of the smart city, which reflect the trends and events of the past period, as well as reveal new aspects of this process.

2 Background and Methodology

The initial methodological premise of the scientific approach to identifying the nature of a smart city is to understand that it is a complex phenomenon. This gives a reason to consider it as a multifaceted and multifunctional process, the methodological basis of which lies in the following approaches:

Systemic approach that sees social systems as semantic, self-reproducing and self-organizing units, allowing us to see the features of the future organization from the perspective of an evolutionary approach;

Non-linear approach, allowing us to justify the features of the future organization and choose one of the most favorable structures – attractor of its evolution;

Evolutionary approach, developing under the influence of exponential growth of ICT, which has a non-linear character;

Sociotechnical approach, reflecting the relationship between social and technical systems.

The methodological level of research is based on the following theories. Firstly, the theory of techno-human balance, which justifies a natural connection between technological potential, quality of cultural and psychological regulation and sustainability of society. Secondly, these are the theories of digital society and network information society. Third, there are the theories of post-industrial society – "computopia", information society of the "third wave" and "knowledge society". The genealogy of the smart city and concepts reflected in the discourse about the cities of the future are also used (Potemkin 2018a, b).

3 Results

Within the framework of the conceptual approach, representatives of the scientific world express different points of view, advance arguments for various provisions and give all sorts of definitions of the "smart city" concept, reflecting the essential characteristics and its functions. A wide variety of author's modifications and their inconsistency served as a reason for discussion, which unfolded in the media, indicating the need of the modern world for smart organization of urban space. The polemics involve the scientific community, experts, specialists, as well as representatives of authorities, which have different positions in this matter. In this regard, it is extremely important to define the termbase and conceptual construct, which are fundamental and widely discussed conceptual issues of the smart city issue.

The word combination "smart city" was first used by Drucker (2006), which was included in the common vocabulary, has a wide range of meanings and is widely recognized in scientific use. The researchers never reached a consensus on what to consider "smart" because the meaning of the word "smart" has a large number of synonyms (receptive, perceptive, etc.). In Oxford and Merriam-Webster dictionaries, this term is defined not only as clever, but also as smart, intelligent, neat, elegant, well-organized, high-tech, etc.

In the mass media and literary sources, there is some word combinations related to the meaning "smart city". Digital city is a digital environment that creates an enabling environment for citizens to exchange information, work together, interact and share experiences seamlessly anywhere in the city. Ubiquitous city is a city of electronic globalization, which emphasizes the policy of unlimited access of all citizens to electronic space. Information city is a city engaged in trade, providing social services based on an array of data. Humane city is a city where favorable conditions are created for the formation and development of human capital. The presence of various definitions gives rise to the effect of terminological multivariance, differing in the subject matter and scope of application (Potemkin 2018a, b).

The semantics of the word combination "smart city" is extremely complex, which is a rather dynamic and ambiguously interpreted concept. It is one of the etymologically polysemous and difficult to interpret in contemporary academic space notions, which has lost a direct link with urbanism. A smart city is based on the theoretical basis of the concept of "smart city", based on the interaction of urban space, technologies that generate innovation, social learning and ICT in cities (Bazhenov 2012). The concept of smart city was introduced in the mid-90s and then was actively used in the public sphere (Soderstrom 2014). Research carried out under the concept of smart city is divided into 2 groups. The first group discloses the technocentric interpretation of these cities, while the second group describes a balanced combination of human, social, cultural, economic, environmental and technological aspects that form the basis of integrative models of a smart city. In doing so, an attempt is made to find a consensus between technological efficiency and the humane effect of a smart city.

As a reaction to the ongoing changes, "smart city" is a dynamic concept which includes 3 stages of progressive development, which are located in chronological sequence and differ from each other in form and content. At the first stage, technological determinism prevailed and social capital was ignored, which provoked strong criticism from the humanities. At this stage, an attempt was made to conceptualize this notion using ICT and an initial set of key concepts and performance criteria. *The initial stage* of formation and development of a smart city is characterized by the most important results that have not lost their meaning in modern conditions, which through the prism of different concepts and cumulative knowledge acquisition justified the formation of a smart city in a multifaceted process. In the process of its formation, the original smart city concepts gave way to more advanced, science-based concepts that reflect the achievements of science and technology in the field of production organization, urban management and human resource development.

The second stage is characterized by wide popularization of the term "smart city" in the public discourse, reflecting the view not only of economists, political scientists, sociologists, but also representatives of the administration, i.e. there is an interdisciplinary discourse covering economic, political, socio-cultural transformations within the technocentrist approach to "smart city". At this stage, the main actor and initiator was the municipal authority implementing projects that were aimed at increasing the efficiency of municipal functions.

At the third stage, a wide discussion of scientific reports is held, focusing on how to make the city comfortable and convenient for a community of smart people based on modern technologies. At this stage, the character of changes in the process of formation and development of a smart city is conceptually justified, significant adjustments are made to it, and scientifically sound methodological approaches are proposed. In addition to individual changes and the introduction of new forms of governance, citizens are empowered through ICT, which has radically changed the nature of interaction in urban space. At the same time, each subsequent step absorbs the best of the previous ones, which contributes to a more complete conceptual understanding of the smart city. During this period, there are scientific treatises that reflect the role of modern technology, the principles of democracy, social interaction in the life of society in the digitalization (Townsend 2013; Cohen 2018).

Over time, the concept of "smart city" had become so multi-dimensional and multifaceted that it is difficult to understand what should be referred to as "smart". Thus, for example, from the point of view of Komninos et al. (2013) and other co-authors, a smart city is urban space in which technological, human, social and cultural capital of the community is aimed at creating new knowledge on solving urban problems and increasing the ability to withstand them. At the same time, the concept of "smart city" should be combined with the concept of "intelligent city".

A well-known researcher Cohen (2018) believes that a smart city should be based on ICT for efficient use of resources and energy in order to improve the quality of public services, reduce negative impact on the environment and contribute to the development of the green economy.

The methodological premise of the European Commission's program (FP7, CIP ICT-PSP) is that this concept includes an open innovation system focused on meeting the needs of citizens. Unlike other theoretical and conceptual approaches, the city is seen as a platform that enhances citizens' participation and encourages them to create urban space together.

H. Schaffers claims that the concept of "smart city" should be based on a progressive approach, starting with creating the conditions for the formation of human capital, rather than on how ICT can improve the city. Hollands (2008) considers smart city from a narrow angle, giving priority to technology.

Kitchin (2016) presents a smart city as a result of a balanced combination of technological, social, economic and environmental aspects, including features of digital measurements, connected systems and flexible computing infrastructures, responding to the emergence of new interfaces of Internet technologies. The ultimate spatial and multiline definition of this concept is given in the UN policy document on promoting sustainable human settlements development.

Domestic authors refer to the smart city as a single system of urban management, combining energy-saving and energy-efficient technologies and objective information (Medvedeva et al. 2015). The simplest and most common opinion is that smart city is an association of communication and information technologies, which are aimed at managing urban property, transport, education, health care, etc. (Sabinina 2019). In addition, there are many modifications of the concept of smart city, due to the specifics, traditions, etc. of smart city. These examples, which can be continued considerably, give an idea of the essence of smart city and vary widely, reflecting a wide range of views on the role and meaning of smart city in the system of urban planning (Boykova et al. 2016).

The most relevant views are those of researchers who focus on a smart city with the sustainable development in the current period without negative impact on the development of future generations (Vidyasova 2017). Researchers who focus on technological, social and ICT aspects are faced with a wide range of ethical issues related to the inevitable collection and use of data by governments and companies that implement these technologies. As smart cities develop, the question of information directly related to the confidential data of city residents, their privacy and security becomes more and more acute. Since the total number of people lives in digital or digitally mediated urban spaces, the public should know how the authorities implement the code, content, control and urbanization of this information (Greenfield 2013).

The results of the study indicate that in modern conditions there is a wide variety of scientific approaches to the definition of "smart city", which differ in content and orientation, reflecting its deep essence. At the same time, the emphasis is placed not only on technical and technological, but also on cultural, social, political and other activities that benefit the residents of the city. A brief review of the ways of argumentation, proposed options and comparison of different points based on theoretical assumptions shows that the mass media and sources of scientific literature do not have a clear understanding of the essence of smart city.

Individual researchers disclosing the concept of this category pay less attention to the disclosure of its content than to the desire to clarify the role of a particular position in justifying the character of a smart city. Scientific approaches based on various key characteristics and methodological assumptions revealing the essential side of the object under study not only lack semantic unity on methodologically important issues, but also show serious disagreements in scientific approaches in substantiating the concept of "smart city". This is due to the fact that smart city is a complex phenomenon, so researchers strive to take into account its broad multidimensionality as far as possible and on this basis to reveal its complex structure.

The conducted research indicates that modern academic pursuits, theoretical developments, methodological assumptions of various scientists, on which the conceptual apparatus is based, do not give an in-depth view of this process. All this is the reason why a logically complete and systematic approach to understanding the essence and content of the smart city has not been developed. As a result, the problem under discussion not only remains methodologically and conceptually unsolved, but also becomes even more confusing.

4 Conclusions

Based on the analysis of theoretical concepts, it was concluded that the concept of "smart city" is a complex phenomenon, which is extremely difficult to give a common universal definition. For all the complexity and ambiguity of the problem under study, the approaches presented, which focus on different areas of research, do not allow sufficiently substantiating the nature of smart city, and make the whole variety of its manifestations possible. Acknowledging the important role and significance of the presented conceptual approaches, paying tribute to the merits of many concepts on which the views of this or that researcher are based, and positively assessing the substantive and methodological significance of the presented positions, it should be emphasized that none of them fully solves the problem. This is due to the fact that these studies conducted by individual authors are controversial, have different degrees of generalization, do not fully reflect the nature of the smart city and do not implement a wide range of varieties of its manifestations, which points to the obvious incompleteness of the scientific conceptual framework on this issue and the theoretical failure to solve this problem.

From the point of view of scientific argumentation, individual authors' opinions are too cumbersome, not sufficiently convincing and not completely objective. Their premises which demonstrate the claim to universality in the construction of the concept of smart city are quite controversial. Methodological approaches at substantiation of its essence are not sufficiently argued, conceptual approaches are not always consistent with the initial assumptions and conceptual orientation of this or that author, and also need more specificity achieved through transformation, which requires an expanded approach in its definition.

The logic of diversity suggests that the conceptual orientation of researchers (however deep it may be) cannot fully reveal the reality under study. Everything that is done in this direction means only a desire to get closer to the solution of this issue in the ways and means which are the basis of certain methodological approaches. At the same time, it is extremely important to set the right accents, determine the motives and understand what approaches to implement to build the theoretical basis of the concept of "smart city". All this points to the objective need for in-depth theoretical analysis and focus on approaches that take into account the rapidly changing realities of modern life in the smart city.

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Peculiarities of Organization of Financial and Accounting Processes in Digital Economy

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Abstract. Purpose: The purpose of the article is to use clustering and visualization methods to organize financial accounting processes in the digital economy by means of Tableau.

Design/methodology/approach: General scientific methods of cognition: comparative analysis, abstraction, classification, generalization, as well as analysis of documents.

Findings: When discussing the relevance of the peculiarities of the organization of financial and accounting processes in the context of digitalization, the relationship between the transformation of Russian accounting and the digital economy should be considered, which will allow us to see a new vector of impact on the escalation of the country's digital economy.

The trend towards digitalization of absolutely any financial services is obvious and is no longer a secret for anyone. Credit organizations are confidently reducing the staff of operationalists and office consultants, without fear of talking behind their backs about their rapidly falling reputation and attracting more and more technical and IT specialists. On the contrary, the departure of this segment into the "figure" is even welcomed and perceived positively by customers. In their work, the authors turn to such a question as the peculiarities of organizing financial and accounting processes in the digital economy. It has been identified that the Tableau Workbench can adapt and develop business process data mining best practices. Based on them, the authors investigated the dynamics of sales for each group of goods at the point of sale, determined the decline and increase in sales by seasons, as well as revealed non-profitable, profitable and such hours at which income is moderate. The system compares the sales hours for one of the item groups among the proposed sales points. The methods of clustering and visualization of data used in the work are discussed in detail. As a result of the study, the following were identified: seasonality of the product, revenue for each of the distribution points; a popular, moderate and unpopular hour-by-hour purchase time, and a recommendation for increasing sales of a particular product. In this way, modern tools allow you to maintain competitive advantages and quickly adapt to changing conditions.

Originality/value: The paper examined mining technologies, studied and selected the Tableau tool, specializing in data visualization.

Keywords: Financial transactions · Financial accounting process · Digital economy · Financial planning · Tableau · Clustering · Sales management

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1 Introduction

Over the past couple of decades, we have witnessed the widespread of the latest information technologies and their introduction into various fields of social and economic field. All this, coupled with the availability of free access to the Internet, has led to a huge increase in the volume of information produced by humans. Today, humanity produces as much information as was created during the entire existence of the Earth until the current millennium. According to research companies, now the amount of data on the planet doubles every couple of years. Due to the huge amount of existing information, only a small part of it will be seen by the human eye, and, as a result, significant amounts of practical and useful information will simply pass by. This leads us to understand the importance of the problems associated with analyzing the accumulated data to extract new knowledge.

Fierce competition arising from the transition from the "producer market" to the "consumer market" made the use of data mining in business relevant. We can say that modern financial management systems need to be constantly updated after the development stage, from the simplest calculation of reserves and production capacities manually to the latest computer automation methods. Since the modern economy advocates a completely different idea of managing industrial enterprises, it is necessary to review the scientific and practical strategic issues of improving the efficiency of financial stability management.

Object of research: methods and tools of data mining in financial accounting processes.

The scope of research is the process of organizing financial and accounting processes in the digital economy.

2 Materials and Method

The following were engaged in the study of problems to increase the efficiency of managing the financial stability of the enterprise based on financial accounting processes: Kokoreva and Makarov (2015), Friedman (2017), Chaya and Chupakhina (2017), Sheremet and Khori (2019), Sheshukova et al. (2014). Analytical platforms specializing in data visualization tools were Microsoft Power BI (BI CONSULT (2020a)), Tableau (BI CONSULT (2020b)), Tableau Desktop (2020).

At the same time, despite the high level of problem development at the theoretical level, they have not been sufficiently studied at the empirical economy level - in particular, practical solutions that allow for intelligent analysis, which reveals hidden patterns, as a result of the application of algorithms and bringing spatial data to a view that could be visualized. The authors proposed Tableau tools as a clustering and visualization tool for organizing financial and accounting processes in the digital economy.

The methods of research selected general scientific methods of cognition: comparative analysis, abstraction, classification, generalization, as well as analysis of documents.

3 Results

There is no noticeable research on information technologies in the financial system; it remains analog both in terms of limited functionality and in terms of manual control (Tea 2017). At the same time, in addition to the organizational and management segment, the financial system consists of an archaic accounting segment. As practice shows, those enterprises that have a complex production structure are in dire need of operational economic information. It is this information that helps company management make sound management decisions (Sheremet and Khorin 2019). The reality of the financial plans being developed is a major challenge in this area (Fig. 1).

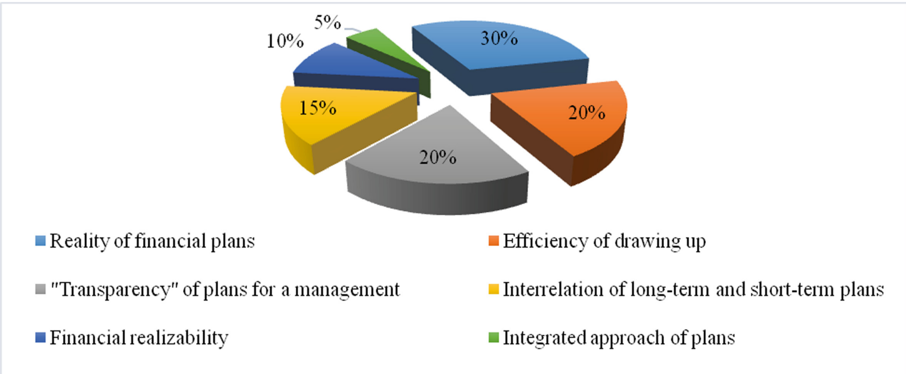

Fig. 1. Problems related to the organization of financial planning *Source*: compiled by authors

Typical management accounting problems of enterprises are shown in Fig. 2.

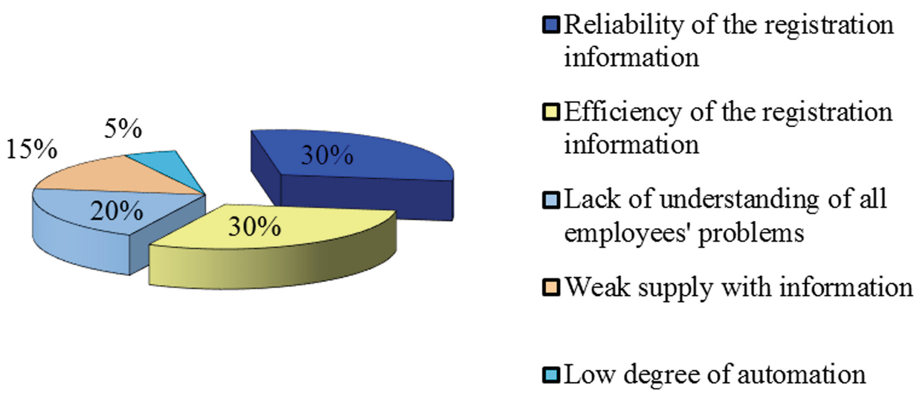

Fig. 2. Complex management accounting situations of enterprises *Source*: compiled by authors.

One of the prominent representatives of the emerging trend is, for example, crowdland (loan P2P). This relatively new financial product came to Russia several years ago and is a system of lending to business by individuals directly, without the participation of an intermediary. All operations take place online, investors and borrowers can independently track the movement of their own funds and monitor profitability. Borrowers are assigned a rating that is the main indicator of their activity and solvency, which, if the terms or conditions of payments are violated, can be lowered. However, this direction also has certain problems that cannot yet be solved. Firstly, in Russia there are not enough qualified specialists who offer services in the high-tech market in the field of finance. There are also no clear programs in educational institutions that would prepare such personnel. And this significantly inhibits the development of digitalization of the segment.

Automation of accounting operations using end-to-end technology is comparable to the replacement of manual switching on the PBX and works on the principle: “primary data is input, full-format financial statements are output that is generated in automatic mode.”

In the field of data analysis, clustering is one of the fundamental tasks and often acts as its first step. In practice, by studying the features of separating groups of similar clusters, you can build a separate model for each group. As a result, product groups, suppliers, customers are identified and separate strategies are developed for them. All characteristics of objects are divided into numerical and categorical. For example, the attribute “price” is numeric, “packaging” is categorical. As a measure of proximity for numerical attributes, the Euclidean distance calculated by formula (1) is often used (Kokoreva and Makarov 2015):

$$d(x, y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}, \tag{1}$$

Where d(x,y) is the shortest distance between points x and y.

The categorical attribute is characterized by a measure of the similarity of Chekanovsky-Serensen and Jacquard, which is given in formula 2:

$$\left(\frac{|t_1 \cap t_2|}{|t_1 \cup t_2|}\right). \tag{2}$$

Another difficulty arises when the measurements of our objects are mixed, that is, one part has a categorical type, and the other part - a numerical one. At the same time, categorical attributes are often more important than numerical attributes.

Let’s move on to visual analytics. The most important idea of digital analysis is the reflection of data in various visual forms. Which helps to better interpret the analyzed data and work with the visual image (BaseGroup Labs 2020).

Object size estimates are made available through the advancement of the latest digital technologies, which allows you to review the investigated data from all sides in real time and analyze perceptual skills in detecting undefined samples in visual space. This, of course, makes it possible to more clearly articulate the goals of our research. Working with noisy and heterogeneous data, using visual data and human participation, is easier and more accurate compared to automatic methods. Statistical and mathematical algorithms are also not required, since the displayed graphic data are intuitive. The above mentioned advantages make it possible to facilitate the user's work, and improve the quality of the received information during digital analysis (Fig. 3) (BI CONSULT (2020a, b)).

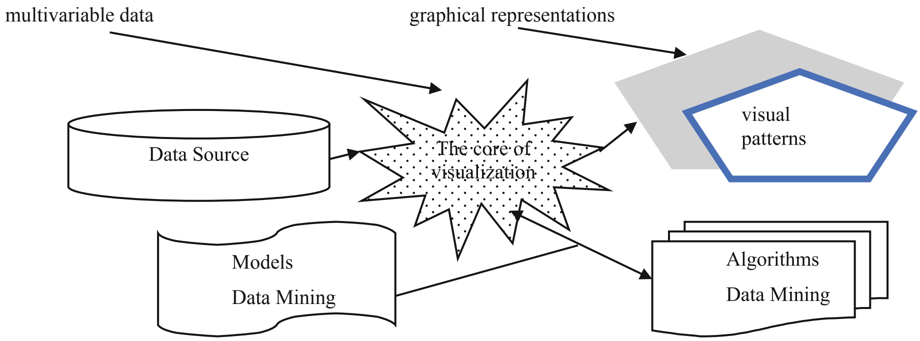

Fig. 3. Data presentation procedure *Source*: compiled by authors

Information is extracted from a source at the same time when analyzing data, for example, from files and a database. Hidden patterns are detected using the Data Mining algorithm. As a result of the application in the visualization core, the original data is processed. And the final task of processing is to visually represent multidimensional data on a computer.

One-dimensional data that consists of a single dimension is time. Two-dimensional data are already two separate attributes, for example, geographical data, which are characterized by the following indicators - longitude and latitude. Typically, these attributes are displayed as points in a 2D coordinate system. So it is impossible to display multidimensional data as two/three-dimensional points. Attributes are data columns. Special rendering methods, such as parallel coordinates, are required to display correctly.

But not all texts and hypertext can be reflected in the form of measurements and not all visualization methods for them can be used, so you need to create data for a view suitable for visualization methods. Tableau is an analytical platform specializing in data visualization tools, most data actions, in addition to connecting data sources, will be considered visualization (BI CONSULT (2020a, b).

We illustrate several visualization methods using Tableau. We add a date to the Columns shelf, indicate the sorting by months, to the Rows shelf, transfer revenue, to Filters we add a group and select a sorting, for example, "Energy Products" and choose the type of data presentation lines (Fig. 4) (Tableau (2020)).

The result was a linear sales schedule for the months, showing the revenue of the Energy Drinks product group. The clear leader in the number of sales, which are 1995 dollar equivalents, and in the income of 891542 dollar equivalents of money, is "Coca-Cola soft drink, strong-carbonated", which is the only one in cluster 5. In second place is the product "Sprite drink soft, strong-carbonated" the number of sales is 1743, revenue is 226905 dollar equivalents, owned by cluster 4, which includes two product items. The third place is taken by the Good Apple Juice product, the number of sales - 669, revenue - 158855 dollar equivalents, included in cluster 6, in which there are 5 commodity items.

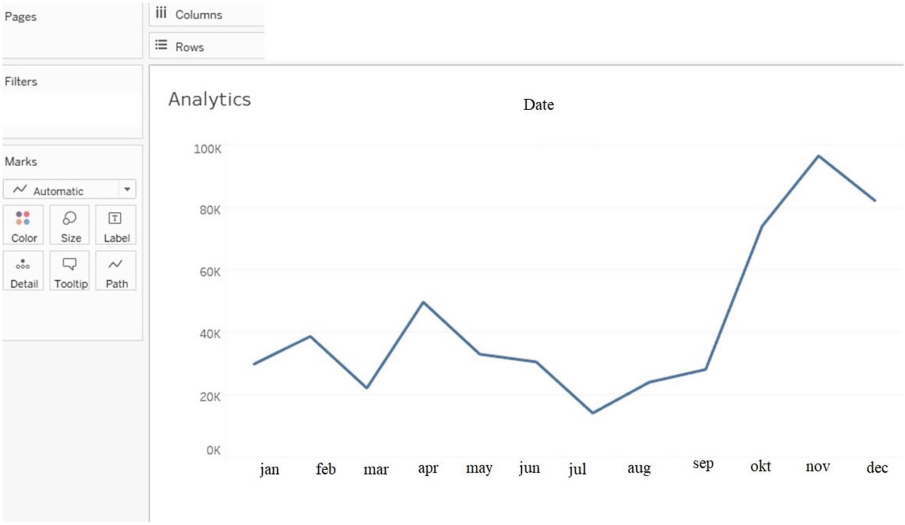

Fig. 4. Linear 2D Sales Chart by Month *Source*: data from Tableau software

The rest of the nomenclature is concentrated in the first, second and third cluster. Of the four product groups, consider the sales structure of three of them, which have the highest revenue indicators. In the first place is "Carbonated drinks" in the second "Juices and juice-containing drinks" in the third "Energy drinks." The performance of the four product groups can be considered in Fig. 5.

Let us consider the "Carbonated Drinks" product group. It includes five clusters. The leader is the fourth cluster with one commodity position – "Coca-Cola soft drink, strongly carbonated". High revenue, high popularity. The remaining clusters have moderate and low revenues with a wide variation in sales in quantitative terms. The data is shown in Fig. 6. Cluster 2 includes two products "Sprite, soft drink, strong-gassed" and "Schweppes, Beater Lemon (soft drink, strongly carbonated)" It is characterized by high popularity, moderate revenue.

Cluster 3 is characterized by moderate popularity and little revenue. Cluster 5 has 5 product items, characterized by moderate popularity and sales. Cluster 1 has a large number of product positions, but sales and popularity are low. When creating a purchasing policy for this product group as a whole across the network, you should take into account the characteristics of sales in all five clusters.

It is necessary to take into account the dynamics (seasonal features), interaction with other product groups (cross sales), variability of sales and other factors. Let's consider the product group "Juices and Juice-containing Drinks," the diagram is shown in Fig. 6. We observe four clusters. Among this group, the undisputed sales leader is "Dobriy" Apple Juice, which is part of cluster number three. The fourth cluster included two positions of the "Dobriy" juice with the tastes of multi fruit and pineapple. Both products show high popularity, but sales are higher in multi-fruit juice. Pineapple-flavored juice needs to raise the price. In the second cluster there are 9 products characterized by low sales

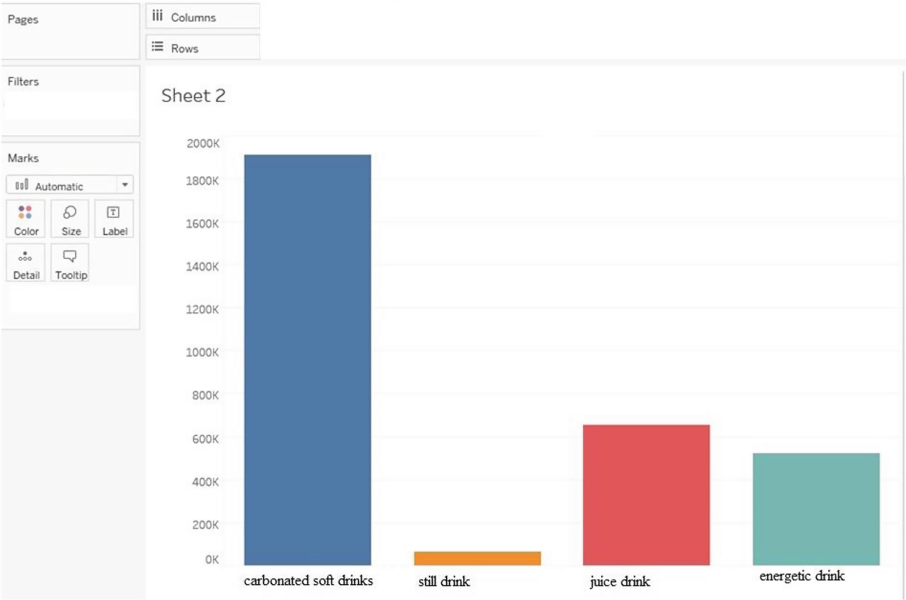

Fig. 5. Indicators of four product groups *Source*: data from Tableau software

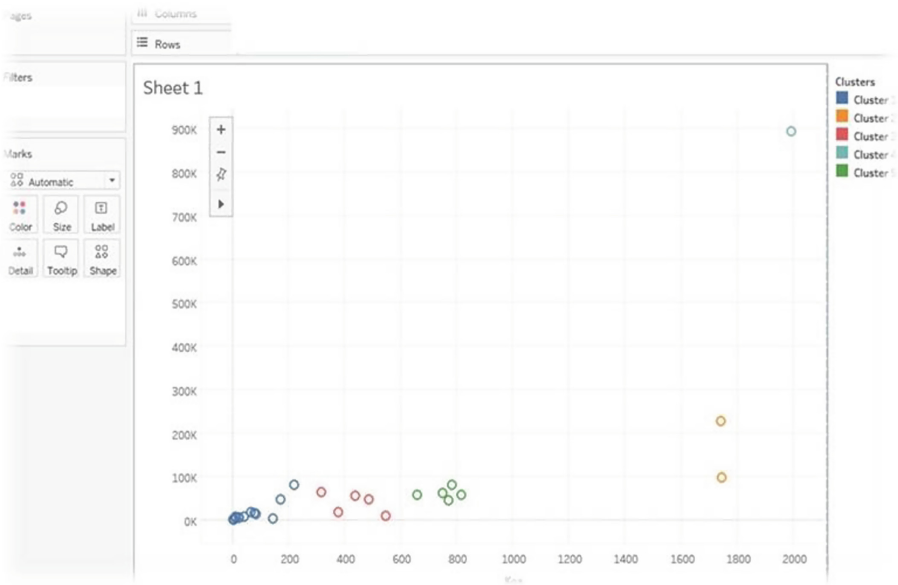

Fig. 6. Clustering by “Carbonated Drinks” group *Source*: data from Tableau software

with moderate popularity. It is most profitable to raise the price of those goods that have a higher number of sales, but a low price (Friedman 2017).

The first cluster has a rather low popularity and sales of goods in quantitative terms but its number brings 39.7% of all juice sales in the product group under consideration (Fig. 7).

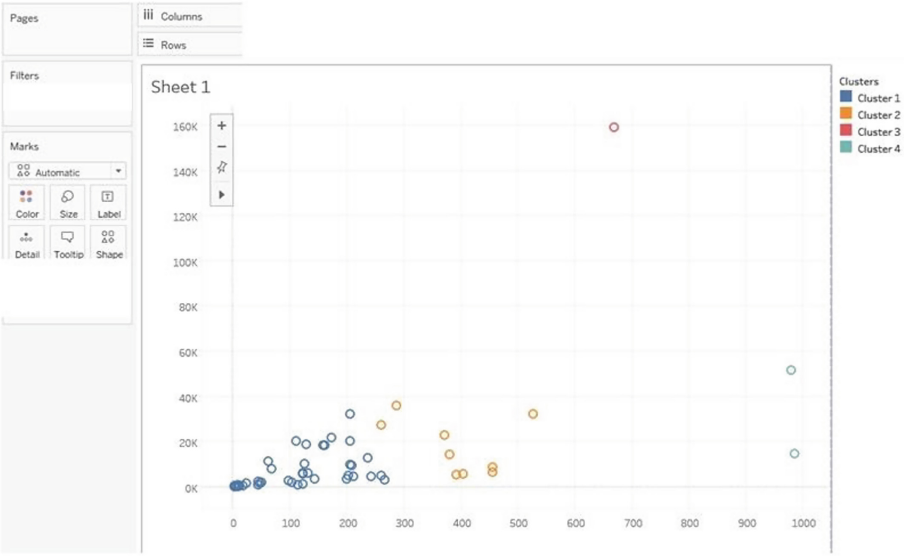

Fig. 7. Clustering by "Juices and Juice drinks" *Source*: data from Tableau software

Let's show the dependence of revenue on price. To do this, we transfer trend line to the rendered field presented by us in Fig. 8.

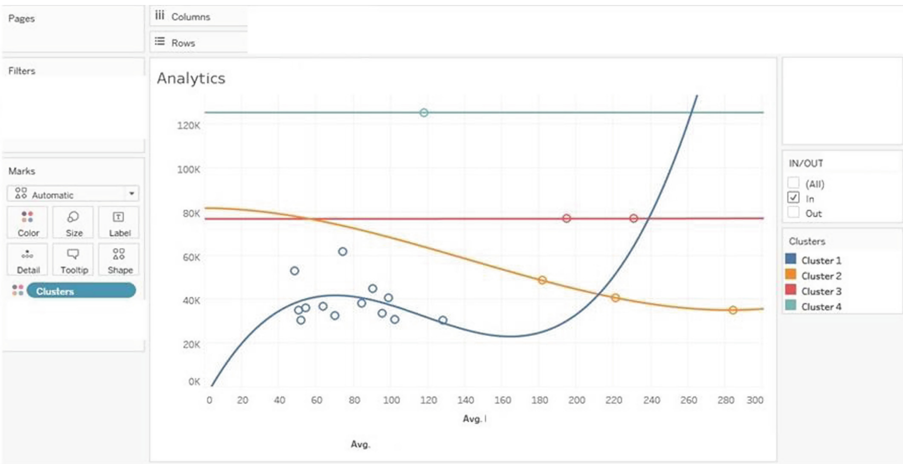

Fig. 8. Revenue-price dependence *Source*: data from Tableau software

Add average estimates for axes with 95% deviation. And switch the revenue to display average (Fig. 9).

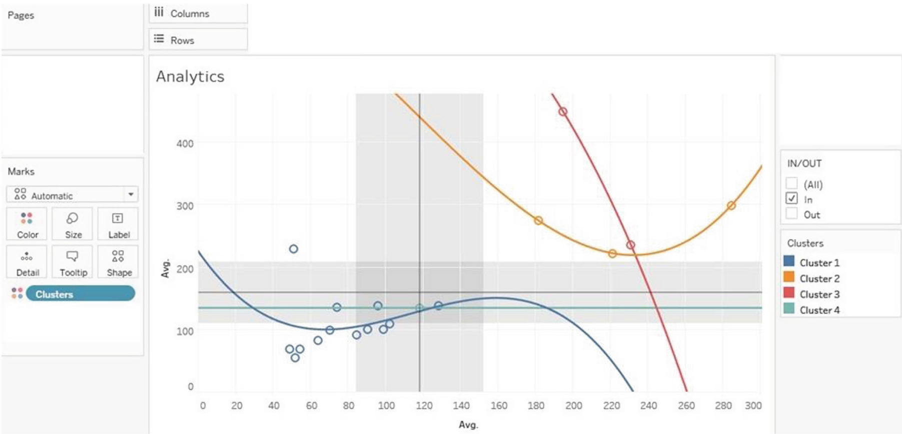

Fig. 9. Average Price and Revenue Determination *Source*: data from Tableau software

The average price at the first point of sale for highly profitable goods with a 95% interval is 118.5 rubles, revenue 158.9 rubles. As a result of data mining by clustering, each of the clusters of goods was investigated, thereby identifying highly profitable, medium-profitable and low-profitable goods. For each of the clusters, characterization and recommendation were given. In addition, a data set was created - highly profitable goods for the first point of sale and the dependence of revenue on price was displayed, and the average price and revenue for the new data group were determined (Sheshukova et al. 2014).

Using the trend line tool, as well as Median with 95% Cl, price trends and median income for each cluster of the Juices and Juice-containing Drinks product group were determined. The next step is to analyze the dynamics of sales, examining which you can determine the strengths and weaknesses of the goods sold depending on the season. Create a forecast for the Black Monster Assault item from the high-yield item group at the first point of sales. To do this, we will transfer to the Columns shelf: group, item, date (set by month). We'll add revenue to the Rows shelf. On the Filters shelf we add a group code, a sales point with sorting according to the first and highly profitable articles (Fig. 10).

Add forecast to the viz area and turn on Mark Level at all points (Fig. 11).

We will conduct similar actions for the product Powerade Snow Gold (Fig. 12). Here we can see the tendency to stop selling goods for three years at the same time, namely December, April and June.

Now we can see the forecast of the product "Powerade Snow Gold" for two years without failures, showing the permissible deviation from the forecast. When eliminating sales failures, revenue is expected to increase by about 7,103 dollar equivalents for the next year and by 8,298 dollar equivalents for 2021, respectively. Therefore, the authors considered the forecast for two products from one to two years in a month and determined

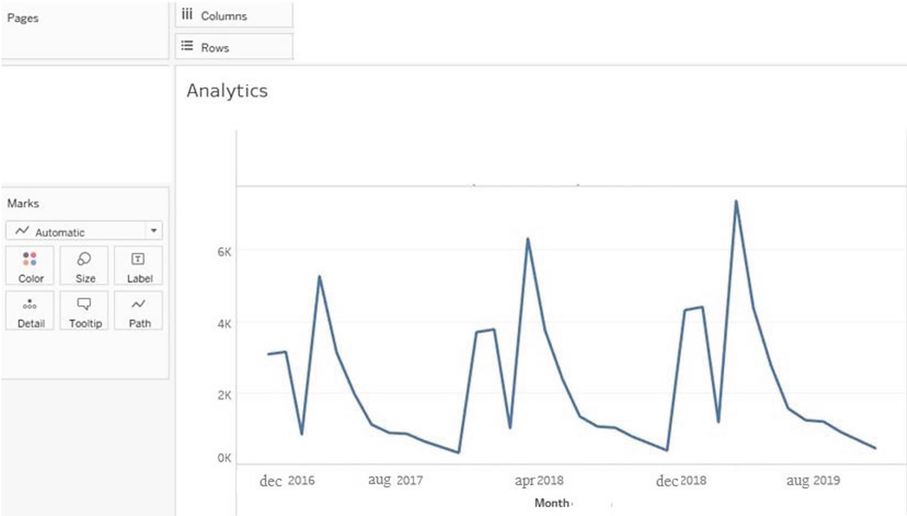

Fig. 10. Monthly revenue of the selected product for three years *Source*: data from Tableau software

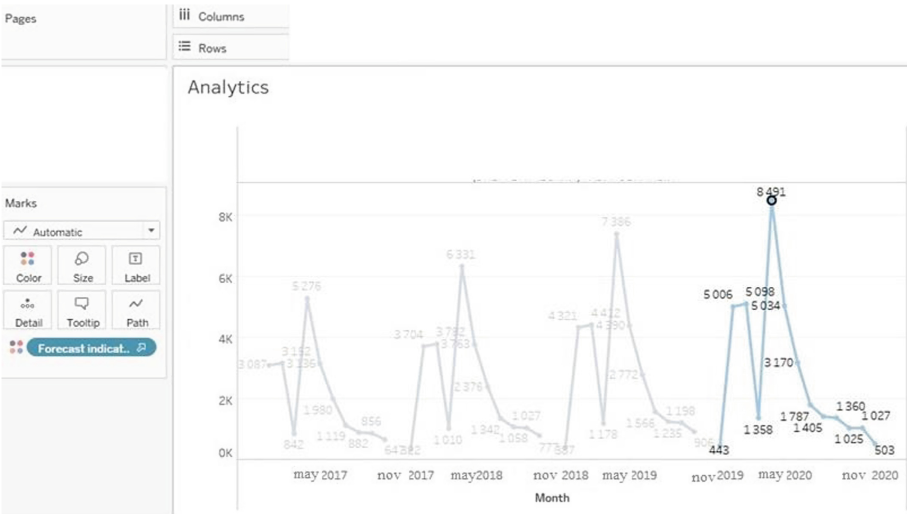

Fig. 11. Monthly revenue forecast for next year *Source*: data from Tableau software

a failure in sales in one of the products and calculated the likely revenue when fixing this problem. The situation is shown in Fig. 13.

To increase the popularity and revenue of this product, it is necessary to increase its fame by advertising and to make all kinds of discounts, promotions.

Fig. 12. Monthly revenue forecast of the selected item for the following year *Source*: data from Tableau software

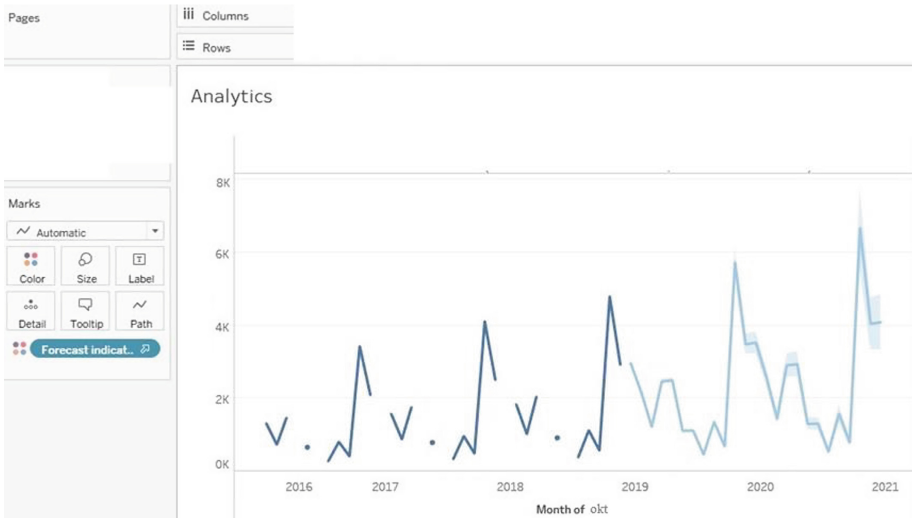

Fig. 13. Forecast for 2 years *Source*: Tableau Software Data

4 Conclusion

As a result of data mining by clustering, each of the clusters of goods was investigated, thereby identifying highly profitable, medium-profitable and low-profitable goods. For each of the clusters, characterization and recommendation were given. In addition, you created a data set - high-yield items for the first point of sale and displayed the dependence of revenue on price, as well as the average price and revenue for the new data group. Using the trend line tool, as well as Median with 95% Cl, price trends and median income for each cluster of one of the product groups were determined. We have compared sales hours for one of the groups among all sales points. The forecast for two products from one to two years in terms of months is considered, a failure in sales at one of the products is determined and the likely revenue is calculated when fixing this problem. Therefore, methods and tools for mining the data of financial accounting processes were investigated and, on the basis of this, clustering and visualization methods were proposed for organizing the above processes in the digital economy using Tableau tools.

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Impact of the Digital Economy on the Legal Regulation of Labor Relations and Protection of Labor Rights

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Abstract. Purpose: The main purpose of this article is to identify and study the problems of the impact of digitalization on the legal regulation of labor relations and the protection of labor rights.

Design/methodology/approach: The method of legal analysis, formally legal method and statistical method were used in the process of research.

Findings: The introduction of a figure into labor relations highlights not only the shortcomings of the legal regulation of labor of employees using the Internet in the implementation of their labor function and outside the employer's location, but also the low efficiency of protection of their labor rights due to this circumstance. The authors identify the positive and negative aspects of the introduction of digital technologies in labor relations and how they contribute to the protection of labor rights.

Originality/value: There is a decrease in the financial and time costs of those employers who use remote work. To replenish the legal regulation of the work of teleworkers abroad and from abroad, it's proposed to amend Chap. 49.1 of the Labor Code of the Russian Federation, regulating 100% teleworking without its stationary counterpart and also regulating the range of working hours of a teleworker, excluding their over-employment. It's important to establish the employee's obligation to pass a professional exam and oblige him to provide this document as mandatory in the process of hiring.

This will contribute to the emergence of healthy competition, overcoming labor opportunism of workers and balancing the wages of teleworkers. It was recommended to fix the quota for the availability of "stationary" and teleworkers for one employer in the ratio, for example, 2:10 for effectively protecting the labor rights of teleworkers with increased economic interest of employers in teleworking. The conducted research can serve as a basis for studying such a legal phenomenon as the robotization of labor and its impact on the preservation of labor relations and human intelligence and also the protection of labor rights.

Keywords: Digital economy · Remote work · Protection of labor rights · Labor relations · Digitalization

JEL-Codes: J21 · J41 · J81 · J83 · K24 · K31

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1 Introduction

In Russia, as in other countries, digital has begun to play a significant role in all areas of life: financial and banking, manufacturing, architecture, medicine, and now in servicing all these areas, including personnel and legal services. As a result, the category "digitalization of public relations" appeared, covering, among other things, the digitalization of labor relations, as a new legal phenomenon.

In Russia, the legal basis of the digital economy is constituted by the Strategy for the Development of the Information Society for 2017–2030 [1], in accordance with which the national program "Digital Economy" was developed [2]. The digital economy, according to the Strategy, is defined as an economic activity based on digital data, the processing of large volumes and the using of the analysis results of which, in comparison with traditional forms of management, can significantly increase the efficiency of production, technologies, equipment, storage, sale, delivery of goods and services [1]. The tasks of the national program consist of the tasks of federal projects, which in general form the national program: normative regulation of the digital environment; innovative infrastructure, human resources for the digital economy, information security, digital technologies and digital public administration. We are interested in the first of the listed federal projects for the purposes of this study - the regulation of the digital environment, one of the tasks of which is to create a system of legal regulation of the digital economy based on a flexible approach in each area. The legal framework, which was formed as a result of the implementation of this federal project, will make it possible to cover digitalization, including labor relations, and personnel workflow, and ensure their effective implementation. Due to the legislation on the digitalization of labor relations is currently only being formed, in this scientific study an attempt is made to study the influence of numbers on labor relations, or rather on the preservation of labor relations and protection of labor rights.

Let us emphasize that the draft Federal Law No. 922869-7 "On Experimental Legal Regimes in the Field of Digital Innovation in the Russian Federation" [3] has been developed, covering the listed areas of the economy. But the most remarkable thing consists in the explanatory note to this project, among the normative legal acts that will need to be amended and supplemented, the Labor Code of the Russian Federation isn't indicated, although it's labor relations that will ultimately undergo a significant transformation as a result of these experiments.

Perhaps the absence of an indication of the Labor Code of the Russian Federation will be made up for by the implementation of another draft Federal Law No. 859678-7 "On conducting an experiment on maintaining electronic documents by individual employers concerning labor relations with employees" [4], which has already been approved by the State Duma in three readings. Its validity period is calculated until March 31, 2021. Remote workers and workers temporarily sent to other employers under an agreement on the provision of workers (personnel) labor (Chaps. 49.1 and 53.1 of the Labor Code of the Russian Federation) are excluded from the list of participants. Based on the results of the introduction of electronic personnel document management, normative legal acts will be developed and adopted, changing and supplementing the current labor legislation.

The literature review was divided into 2 parts by us. The first is a study of traditional labor relations, the features of which were described in the fundamental works of [5, 6].

The second part of the study is related to the study of non-standard forms of employment, in particular those that use digital technologies in labor relations [7–9] et al.

2 Materials and Methods

In the course of researching the legal aspect of the impact of digitalization of the economy on labor relations and protection of labor rights, we used methods such as legal analysis (analysis of regulatory legal acts), formally legal method (formation of new legal structures) and statistical method (use of official statistics).

The study can further explore the digitalization of labor relations and the protection of labor rights, including labor robotics. These studies, which were made by Russian and foreign scientists, should be aimed not only at saving traditional forms of employment, but also at saving a person as an employee and a party in labor relations with the employer.

The conducted research can serve as a basis for the development of international normative acts on the robotization of labor and the introduction of amendments and additions to the current Russian and foreign legislation, including on the work of teleworkers.

3 Results

A study of the impact of digitalization of the economy on labor relations and protection of labor rights should be carried out, reflecting the positive and negative aspects of the introduction of digital technologies in labor relations and how they contribute to the protection of labor rights.

1. The using of digital technologies significantly saves the employer's financial resources: considerable costs are excluded for the maintenance of personnel and legal services in charge of supporting the work of employees. Personnel workflow is very significant in volume, because it regulates the work process step by step not only as a whole for the collective of employees, but in particular for each employee of the employer. This is the conclusion, amendment, addition of the collective agreement, local regulations, registration of the hiring of each employee, his transfers, moving and other changes in the terms of the employment contract, combination of professions (positions), vacations (annual and additional), material and disciplinary liability, registration of dismissal, etc. As a rule, the employee must be familiarized with the documents accompanying the entire labor process against signature. In the conditions of work of small or medium-sized businesses, there are fewer problems with familiarizing employees with personnel documentation than employers with more than 100 employees. However, the written familiarization of employees with the documents takes a significant amount of paid working time from the personnel services. The number of personnel workers and lawyers, who provide legal support to the personnel department, directly depends on the volume of work and on the total number of employees at the employer, if such support is installed by the employer.
2. In accordance with Article 64 of the Labor Code of the Russian Federation, a discriminatory element of hiring is a requirement from a potential employee of the place of registration. This means that the place of registration of the employee hired

shouldn't mean anything to the employer, and this, in turn, entails the erasure of geographical boundaries within the country and between countries. Perhaps the using of digital technologies will significantly expand the geography of their places of work for employees. Some of them would work well remotely if the employer uses these technologies. If we consider Russia geographically, then an employer located in Moscow can successfully use the services of employees located, for example, in Krasnodar or Omsk. If you give an example, expanding the geography of the using of digital technologies, then an employee living in Russia may well work in another country without traveling there. However, Russian labor and the Ministry of Labor of the Russian Federation speak out negatively about the conclusion of an agreement on remote work and admit only a civil-legal basis for cooperation of employers with such workers, explaining their position by the fact that the employer will not be able to guarantee the observance of the labor rights of a remote worker abroad, since Russian legislation applies only on the territory of the Russian Federation [10, 11].

The opposite situation, when a foreign citizen works remotely from another country in Russia, also causes rejection from the Russian government authorities. It's clear that the legislation of the Russian Federation on the labor of foreign citizens doesn't imply remote work, although the Labor Code of the Russian Federation doesn't contain restrictions on attracting such categories of workers to remote work. However, operating with the same arguments, the Ministry of Labor of the Russian Federation denies the possibility of concluding an employment contract on remote work with foreign workers from abroad [12].

We think that the active development of digital technologies will only increase the presence of this problem. Ultimately, Chap. 49.1 of the Labor Code of the Russian Federation will be amended to allow remote work abroad and from abroad, but with certain peculiarities. For example, only 100% remote work should be envisaged, excluding its stationary counterpart; it's necessary to regulate the range of working hours of a remote worker, etc.

It's obvious that teleworking contributes to the development of competition among workers and employers. On the one hand, this fictitiously increases the percentage of employment of the population, contributes to the mass coverage of the population with work, but on the other hand, it significantly increases the number of low-skilled workers in the labor market, reduces the quality of the work that they provide, affects the wages of skilled workers, which, in principle, helps to reduce demand among employers for remote employees. Therefore, the apparent increase in the percentage of employment of the population, in fact, only creates this appearance, due to the employer tries to conclude fixed-term employment contracts with low-skilled workers, and these workers again remain unemployed some time later. As a result, a skilled worker is pushed out of the sphere of remote work, which economists warn about, considering this a threat to the labor market [13].

This unhealthy competition is a form of labor opportunism, when a low-skilled worker actually hinders the career of a skilled worker. Russian legislation doesn't contain legal ways to overcome this form of labor opportunism of workers. Therefore, if an employer uses a remote form of work and wants to conclude an employment contract with a qualified employee, he needs to be helped in this within the legal framework. In particular, in the Labor Code of the Russian Federation, the obligation of an employee to undergo an independent qualification assessment (this is a kind of professional examination, which is currently conducted on a voluntary basis) [14], and oblige him to provide this document as mandatory applying for a new job. In this case, there will be a legal area for healthy competition between low-skilled and unskilled workers, which will allow the employer to calculate their capabilities, which are related to the amount of wages paid, thereby overcoming the labor opportunism of workers.

Thirdly, continuing to consider distance work as a positive product of the introduction of digital technologies, we note that in Russia and other foreign countries distance work began to be introduced into practice not so long ago. In this case, the employee performs a labor function outside the employer's place of work using information and communication technologies on the Internet (this type of work is called «telework» abroad). However, only 5% of employers used this type of atypical employment in our country, over 3 years of legal regulation of teleworking (Chap. 49.1 of the Labor Code of the Russian Federation), i.e. as of January 1, 2020, but although every second employee is ready to work remotely, according to the different surveys, 30% of employees can't do this due to lack of support from employers, and 18% of employees' profession doesn't allow them to work remotely [15]. It seems that one of the reasons for the low number of teleworkers is the unpreparedness of the current legislation and the employers for the rapidly changing digital technologies.

Taking into account the last months of work and the pandemic, which was declared by World Health Organization, employers have intensified the using of remote work all over the world: some employers use it voluntarily, others have to do it. Meanwhile, employers have already felt the benefits of its application: practically eliminated or significantly reduced rental costs and wages of personnel. Employees have also recognized the benefits for themselves associated with the absence of time costs for travel to and from work. For example, digital technologies began to be actively used, first of all, in the financial sphere, then in medicine, architecture, education and in other sectors of the economy.

At the same time, the end of the pandemic and quarantine in Russia and other countries may give rise to another problem - a decrease in demand for office space rental and, as a consequence, a decrease or absence of "stationary" employers. The question will inevitably arise of the return of tenant and there are many employers among them, for the previous course of work when they needed office space.

The introduction of digitalization of labor relations will reveal another important problem in a short time: labor robotization. Researchers believe that by 2030 the digitalization of labor relations will lead to the termination of the existence of 50% of specialties, and 20 million people may become unemployed. Let's note that one of the signs of labor relations - the monotony of work, its lasting nature, was taken by researchers as a basis. They counted repetitive operations at work and identified a pattern: those professions, in which the most part of monotonous operations occur, are greater and the risk of replacing these workers with robots (for example, 73% of such operations in the hotel business) [16].

Thus, two powerful threats to traditional forms of employment in general and to humans in particular appear on the labor market at once: remote work and robotic labor. And if mankind can still cope with the presence of remote work in terms of employment, because there are professions and specialties, which work is difficult to perform remotely and, accordingly, the need for their work will be constant. These professions are, for example, a cook, pastry chef, nurse, etc. Then it's pointless to argue with the undoubted economic benefit for the employer from labor robotization. A low-skilled labor force performing monotonous work may well be replaced by robots, but creative work, including creating programs for robots, will still remain with the "man of labor" [13].

4 Conclusion

This study allowed us to conclude that the economic interests of the employer shouldn't level out the traditional labor relations with employees that have been developing over the years. Modernization of such relations is possible, but not their complete exclusion. It seems to us that the socialization of the employer should be fixed at the level of the Labor Code of the Russian Federation or other national regulatory legal act of each country, which will contribute to the harmonious development of labor relations between workers and employers.

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The Problem of Preservation of Unique Biodiversity of Sarkent as a Source of Green Tourism

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Abstract. This paper presents the species of predators and mammals, preservation of biological diversity, as well as problems of the influence of anthropogenic activity on Sarkent National Park. The unique ecosystem of this national park will ensure ecological and biological balance and attract tourists in the future who wish to get acquainted with the wildlife of Sarkent. For Kyrgyzstan, the creation of such nature reserve will provide an additional destination of green tourism, ecotourism, and biotourism.

The development of tourism enables the state to form its own tourist base, provide additional financial injection in the budget at the expense of tourists, creates additional jobs and provides a certain level of living for the local community living in the territories of Sarkent.

The wildlife as the most important biological resource is a certain part of our national wealth. As creators of the environment, animals are of paramount importance in ensuring soil fertility and water purity, in pollination of flowering plants, and are involved in the transformation of organic matter in the ecosystem.

In particular, mammal species are the most common and ecologically flexible species in the wildlife. However, recently, various unreasonable economic actions have had a negative effect on the change in the fauna of many regions of the republic as a result of a powerful anthropogenic transformation in terms of natural complexes, which has resulted in a change in their life environment and to a rapid reduction of life spaces.

27 mammal species which belong to 6 orders were found in the territory of Sarkent National Park which is specially protected for the first time in the Batken Region of the Kyrgyz Republic, and they have been given a zoological and ecological environmental description.

Keywords: Fauna · Anthropogen · Resource · Ecosystem · Biodiversity

1 Introduction

The preservation of biological diversity of the fauna of territories of special protection of Kyrgyzstan seems to be problem on the national scale.

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The study of modern factorial, population, ecosystem states of mammals that can be found in various biotic communities in the territory of Sarkent National Park and the development of methods and principles for their protection and effective use during the period of increasing anthropogenic pressure.

Academic Novelty of Results Obtained. Specific landscape distributions of zoogeography of the southwestern part of Turkestan range have scrupulously analyzed. The state of vanishing, uncommon and endangered mammals has been assessed.

The scientific matter on the fauna of mammals has been collected from 2012 till 2016. The total length of the explored route through the park is 64 km.

Standard methods were used for zoological and environmental research (Bibikov 1956; Kucheruk 1952; Kucheruk and Korenberg 1964; Karaseva and Telitsyna 1996; Formozov 1932). But they were carried out with account of the taxon groups of animals and features of the life environment (Kulnazarov 1993; 1996).

As a result, in the collection of theoretical materials, visual observations were made on the reconnaissance route on foot, on horseback, with the use of binoculars; for small mammals – according to the trap-per-day number line; for ground mammals – researchers determined by their traces whether they live there or not; attention was paid to traces before haul-out and the excrements of mammals leading an active and hidden lifestyle. In addition, a survey of hunters, old poachers, old people, and other people constantly visiting jailoo was conducted.

When the researchers identified the species composition of mammals that can be found in the territory of the park, they used scholarly works of Sokolov (1963), Бобринского (1965), Kuznetsov (1975), Yanushevich and Aizin (1972), Toktosunov (1958), Kulnazarov (2003) and other researchers.

Scholarly works of Pavlinov and Rossolimo (1987) were used for the classification of mammals that can be found in the territory of the park.

In addition, the distribution of species of certain mammals by various landscapes has been established with the use of bird pellets and droppings of carnivorous mammals in the process of identification of the species composition of the food spectrum of wolves (Kulnazarov and Altybaev, “Instruction on the collection of bird pellets and droppings of carnivorous mammals for laboratory research” 1996).

Relying on former scientific efforts taken in the territory of Sarkent National Park in 2012–2016, the author has analyzed his own research materials and a vast number of literary sources, having managed to generalize them. The studies have made it possible to identify 27 mammal species that can be found in various landscapes in the territory of the park, which actually became the target of research.

Plant-feeders, their species composition, their numbers and distribution in various landscapes.

Double-toothed rodents – *(Lagomorpha).* Double-toothed rodents include hares *(Leporidae)* and red pika *(Lagomyridae).*

Hare (Lepus tolai Pallas, 1778). This species of hare can be found in all regions of Kyrgyzstan. Hare *(Lepus tolai Pallas, 1778)* can be found throughout the park, in underwoods and large-stone underbrushes, on rocky and shrubby hills, in juniper forests, in Gosh-Dzhailoo Gorge, Gadandyk Gorge, Kol Gorge, Zhakurut Gorge, Bek-Suu Gorge, Tenizbay Gorge, and Ai-Kol Gorge. The dynamics of their quantitative growth particularly increased in Gosh-Dzhailoo and Bek-Suu, where it increased by several times. In Gosh-Dzhailoo, the quantitative dynamics increased from 1.44 ± 0.48% to 7.21 ± 1.04%, in Bek-Suu – from 0.80 ± 0.36% to 5.61 ± 0.92%. At the same time, in such gorges as Gadandyk, Kol, Zhakurut, Tenizbay and Ai-Kol it has increased from 1.60 ± 0.50% to 3.85 ± 0.77%.

Such a fluctuation in the density of population of hares can be attributed to nutritive base, larger or smaller amount of snowfall, and exposure of hillsides.

Red pika *(Ochotona rutila Severtzov, 1873)*. Red pika can particularly often be found in the southwestern territory of Kyrgyzstan. Red pika *(Ochotona rutila Severtzov, 1873)* can often be found in stony areas that emerged from the stone ruins of the altitudinal belts zones of all gorges (Gadandyk, Zhumurut, Zhakurut, Kara-Sai, Bek-Suu) in the territory of the park.

Rodents – *(Rodentia)*. All rodents living in Ferghana, Chatkal and Pamir-Alay, and Turkestan range in the south of Kyrgyzstan, belong to terrestrial species, and only one species (oriental mole lemming - *Ellobius tancrei Blasius*, 1884) belong to subterranean species. According to Kulnazarov, B.K., it has been found that 20 species of rodents can be found in the southern region.

Porcupine – *(Hystrix indica Kerr, 1792)*. Porcupines are prevalent in South-Western Europe, North Africa, Central Asia and India.

At the same time, in Sarkent National Park, porcupines can be found in relatively limited territories. Porcupine feeds exclusively on plant food, it is a plant-feeder.

Mouse-like rodents *(Muridae)*. 14 species of mouse-like rodents were found in the south-west of Tien Shan range and in Pamir-Alay range (Kulnazarov 2008a). Overall, 23 species of mouse-like rodents were identified in the southern region of Kyrgyzstan (Toktosunov 1958; Aizin 1979; Yanushevich and Aizin 1972; Kulnazarov 1994).

To date, there is no information about the species composition of mouse-like rodents in the territory of Sarkent National Park, about the possibility of their occurrence in various landscapes and about the density of their population. Therefore, in our research we turned our attention to the species composition of mouse-like rodents in various landscapes, to the nature of their occurence, and to the density of population. In this regard, steel traps were mounted in all possible landscapes; as a result, 7 species of mouse-like rodents were identified, which include high-mountain vole (*Alticola argentatus*), juniper vole (*Microtus carruthersigalis* (Pallas, 1778)), common field mouse (*Apodemus sylvaticus*), house mouse (*Mus musculus*), Turkestan rat (*Rattus turkestanicus*), common vole (*Microtus (M.) arvalis*).

Common field mouse (*Apodemus sylvaticus*) has significant quantitative advantage of all mouse-like rodents that can be found in the territory of Sarkent National Park. Its quantitative indicator is 43,7 ± 2,18 per cent of the total number of animals caught in various landscapes, and is a dominant species. House mouse (*Mus musculus*), (18,2 ± 1,70), followed by high-mountain vole (15,9 ± 1,61) is considered as a subdominant.

As a consequence, it has been found that different species of mouse-like rodents have their own conventional biogroups and that they have non-uniform distribution and density of population.

Oriental mole lemming (*Ellobius (E.) tancrei*) can be widely found from foothill valleys to Chatkal valley, Ferghana valley, and valleys of Alay Mountains, Turkestan range, located at a height of 3500 meters above sea level (Kulnazarov 2008a; Yanushevich and Aizin 1972; Toktosunov 1958). Their adapted life environment consists of hayland, fields and neardeserts. The density of their population varies depending on the life environment.

Cloven-hoofed mammals – (*Artiodactyla*). As a consequence of our studies in the territory of the park, only 3 species of cloven-hoofed mammals were identified – Siberian ibex (*Capra (Ibex) sibirica*), wild boar (*Sus scrofa*) and roe (*Capreoluscapreolus*).

Siberian ibex (*Capra (Ibex) sibirica*) is wide-spread in the territories of Tien Shan and Pamir-Alay ranges of Kyrgyzstan (Bobrinsky, Kuznetsov, Kuzyakin 1965). Siberianibex are very prevalent in Turkestan range, particularly in the territory of Sarkent National Park. They can be found on the top belts of Gosh-Dzhailoo Gorge, Gadandyk Gorge, Kol Gorge, Zhakurut Gorge, Bek-Suu Gorge, Tenizbay Gorge, and Ai-Kol Gorge. Based on the studies that were conducted in these territories from 2012 till 2016, it has been found that there are 437 animal units of Siberian ibex there. Of these, 310 animal units are females, 127 are malesAt the present day, the density of population of Siberian ibices in Bek-Suu gorge is 14.1 $\pm$ 0.16 animal units per 1000 ha, whereas in Gadandyk Gorge and Zhakurut Gorge the density of population varies from 12.9 $\pm$ 0.13 animal units to 13.4 $\pm$ 0.15 animal units per 1000 ha. And the territories of Gosh-Dzhailoo Gorge and Kol Gorge are characterized by the lowest numbers, since the density of their population here is 9.37 $\pm$ 0.16–7.52 $\pm$ 0.11 animal units per 1000 ha. As for the total territory of the park, the density of population of Siberian ibices is 10.9 $\pm$ 0.05 animal units per 1000 ha. In the early years of the formation of the parkthe density of population of Siberian ibices was as little as 2.25 $\pm$ 0.02 animal units per 1000 ha. Hence, according to the results of studies in the territory of the park, a rather noticeable increase in the number of animal units of Siberian ibices can be observed.

Wild boar (*Sus scrofa*). Wild boar is one of the most common species of cloven-hoofed mammals in the territory of CIS. In the territory of Sarkent National Park, wild boars (Sus scrofa) can be found in juniper forests of Gosh-Dzhailoo Gorge, Gadandyk Gorge, Kol Gorge, Zhakurut Gorge, Bek-Suu Gorge, Tenizbay Gorge, and Ai-Kol Gorge. In the total territory of the park, the density of population of wild boars per 1000 ha is 2.72 $\pm$ 0.03 animal units. And during the analysis of the density of population of wild boars in each gorge in the territory of the park it has been found that they differ depending on the conditions of the region. For example, one of the gorges which are characterized by a rather high indicator of the density of population, are gorges Gosh-Dzhailoo and Ai-Kol. Whereas in gorge Gosh-Dzhailoo the number of wildlife boars is 3.12 $\pm$ 0.09; 4.94 $\pm$ 0.11 animal units per 1000 ha, then in gorge Ai-Kol it is equal to 2.74 $\pm$ 0.06; 3.96 $\pm$ 0.08 animal units per 1000 ha. At the same time, in such gorges as Gadandyk, Kol, Zhakurut, Bek-Suu and Tenizbay, the density of population of wild boars per 1000 ha varies from 0.80 $\pm$ 0.04 animal units to 3.44 $\pm$ 0.08 animal units. According to this information, you can see that the number of wild boars has decreased to the lowest point up to date compared to the previous century.

Roe - *Capreolus capreolus Linnaeus*, (1758). However, currently this species of cloven-hoofed mammals is one of the most uncommon animals. This is because roe can be found in a very limited number of places in the territory of Sarkent National Park. One roe was found in the juniper forest on a southern slope of Ai-Kol Gorge during our research.

Predators: species composition, their numbers and distribution in various landscapes

21 species from the group of insect-eating mammals (*Insectivora*), predators (*Carnivora*), characteristic of 5 breeds, were identified in the territory of Kyrgyzstan. Common Tien Shan shrew (*Sorex asper*) of characteristic species of insect-eating mammals, 2 species of chiropterous animals, and 10 species of predators were identified in the territory of Sarkent National Park. Therefore, this Chapter contains the information about the results of the species composition, numbers and distribution of mammals and predators in various landscapes.

Insect-eating mammals – (*Insectivora*). Insect-eating mammals belong to arguably rare animals, despite their wide-spread occurence in the territory of Kyrgyzstan. According to the results of our research, only one species of insect-eating mammals has been found in the territory of Sarkent National Park – common Tien Shan shrew (*Sorex asper*).

Common Tien Shan shrew (*Sorex asper*). Literary sources state that its range covers only the boundaries of the territory of Tien Shan range and cannot be found in other territories. Therefore, it was called an endemic form for the territory of Tien Shan range (Shniktnikov 1936; Ognev 1940; Yanushevich and Aizin 1972). During the expedition in the territory of Sarkent National Park, one animal unit of common Tien Shan shrew was caught in the juniper forest in the top part of Kara-Sai Gorge. Hence, there is no doubt about the fact that common Tien Shan shrew is an endemic form of not only Tien Shan range, but also Turkestan ranges.

The body length of common Tien Shan shrew is 51–104 mm (66.2 mm on the average), its tail length is 32–47 mm (38.4 mm on the average), its foot length is 10–14 mm (11.8 mm on the average), its ear height is 4–8 mm (5.6 mm on the average), its weight is 4.9–12.3 g (7.7 g on the average) (Stroganov 1957).

Chiropterous animals.

Chiropterous animals – *Chiroptera*

Grey long-eared bat - *Plecotus austriacus*. Grey long-eared bat can be found in various landscapes: in the forests, on the roofs of the houses, in cultural landscapes, in the caves, on the cliffs, etc. In 2012, 5 animal units were caught in Zhakurut Gorge in the territory of the National Park.

Common noctule - *Nyctalus noctula*. A representative of this species was caught in 2013 during the field practice in Semiz-Koyon Gorge organized by the academic department. Its biology and occurrence are still to be clarified.

Predators *(Carnivora)*. 21 species of predators were identified in the fauna of Kyrgyzstan. At the same time, 10 species were found in the territory of Sarkent National Park.

Wolf *(Canis lupus)*. According to literary sources, the wolf can be very widely found in all the mountains and mountain valleys of Kyrgyzstan. We have found that wolf population dynamics fluctuated in the territory of Sarkent National Park from 2012 till 2016 – it increased and decreased alternately. In the analysis of their quantitative indicator for the total territory of the park, researchers detected an increase from 0.37 ± 0.01 to 1.10 ± 0.02 animal units per 1000 ha, followed by the reduction to 0.35 ±

0.02 animal units. However, there is a large increase of the wolf population in some areas of the park. Thus, in the area of Gosh-Dzhailoo and Kol gorges, the quantitative indicator for wolves is 0,52 ± 0,04–3,12 ± 0,09 animal units and 0.61 ± 0.03–1.38 ± 0.05 animal units per 1000 ha respectively. Consequently, this shows that currently the number of wolves in Turkestan ranges has increased significantly compared with 2002. In our opinion, the reason for such an increase in the number of wolves, is, firstly, due an increase in the livestock number, and, secondly, due to the migration of cloven-hoofed mammals from the territory of Tajikistan.

Common fox *(Vulpes vulpes)*. Having analyzed the habitats and morpho-anatomical features of common foxes, Yanushevich, A.I. confirmed the existence of two species of common foxes – karaganka fox (V.v. Karagan Erxleben) and Tien Shan fox (V.v.Ochroxantha Ognev). In the territory of Sarkent National Park, the density of population of common fox (Vulpes (V.) vulpes) throughout the territory was 0.45 ± 0.01 animal units per 1000 ha in 2012, then by 2016 it was equal to 1.57 ± 0.04 animal units which means there is an increase in their quantitative dynamics from 0.65 ± 0.65% animal units to 9.9 ± 2.32% animal units. However, the density of the population of common foxes varies across the park. In some gorges, in Gosh-Dzhailoo for example, there are 1.04 ± 0.05 animal units to 3.64 ± 0.10 animal units, in Bek-Suu – от 0,72 ± 0,04 animal units to 2,53 ± 0,07 animal units per 1000 ha. The quantitative C 2.59 ± 1.18% to 8.44 ± 2.24–9.09 ± 2.32% in these territories. The lowest rate falls on gorges Kol and Zhakurut: the population per 1000 ha here is 0.46 ± 0.03–0.55 ± 0.03 animal units, which means it is equal to 1.95 ± 1.11%–2.59 ± 1.82% of the gross quantitative share of predators in the territory of the park.

Brown bear *(Ursus arctos)*. The researchers had different opinions as to the systematization of bears that can be found in the territory of Kyrgyzstan (Ognev 1931; Kuznetsov 1948; Novikov 1963). However, prior to that, in 1928, Flerov, K.K. analyzed the systematic location of brown bears, and concluded that Tien Shan brown bear belongs not to the species of Ursus pruinosus, but to the species of Ursus arctos L. The brown bear can be found in a limited number of places in the territory of Sarkent National Park, where there are no factors of disturbance, – in juniper forests inside the gorges, in alpine and subalpine belts.

Ursus arctos L. was noticed in Zhakurut Gorge, Bek-Suu Gorge and Ai-Kel Gorge. The density of population of this predator in the total territory of the park is 0.7 ± 0.01–0.12 ± 0.03 animal units per 1000 ha. And their quantitative dynamics for 2012–2016 increased from 4.76 ± 0.25% animal units to 14.3 ± 0.02% animal units. The density of population varies in different gorges: in Bek-Suu it is equal to 0,18 ± 0,03–0,54 ± 0,05 per 1000 ha, while in Zhakurut and Ai-Kol the density of population varies from 0.14 ± 0.03 to 0.15 ± 0.02 animal units. The dynamics of their quantitative growth is 4.76 ± 0.25%–14.3 ± 0.20%.

Ermine (Mustela erminea). According to some information sources on the systematics of ermine (Ognev 1935; Kuznetsov 1948; Novikovdun) 2 their subspecies are typical for the territory of Kyrgyzstan – *M. e. ferghanae* Thomas – Ferghana (M.E. Schnitnikov) Ognev – Semirechensk. In the All-Union collections "The fauna of mammals of the USSR" (1963) and "Mammals of the Soviet Union" (1967) it is specified that only one subspecies of ermines – *M. e. ferghanae* – is typical for Kyrgyzstan (Yanushevich and Aizin 1972).

The habitat of ermines is dense scrubs on the coast of the Ak-Suu River and stony, gentle mountain slopes and forest areas. During the research work on the coasts of the Ak-Suu River, only 4 animal units of ermine were identified.

Steppe polecat *(Mustela (P.) eversmanni)*. Steppe polecat lives in Alai Valley of southern Kyrgyzstan. Geptner (1867) in his works described the Tibetan steppe polecat – M. (P.) Eversmanni Larvota Hodgon (1849), as a huge animal. We failed to find the steppe polecats in the territory of Sarkent National Park. However, having inquired with the gamekeepers, we managed to obtain some information about the presence of steppe polecats in the open areas of the alpine and subalpine belts in the territory of the park. It is known from literary sources that the number of steppe polecats has extremely reduced recently (Abdisatarov 1913).

Stone marten *(Martes (M.) foina)*. Stone marten can be found throughout Tien Shan and Pamir-Alay ranges of Kyrgyzstan; they are particularly adapted to mountainous areas, as they prefer to inhabit the gorges with steep stony mountain slopes and rocks. In the territory of Sarkent National Park, they can be found in all gorges of the southwestern slope of Turkestan range at a height of 1500–3000 m above sea level. The density of their population in these territories has no special significance, since the density of population of stone marten in the territory of the park is as little as 0,22 ± 0,08 animal units to 0,62 ± 0,13 animal units per 1000 ha. From 2012 to 2016, their quantitative dynamics increased from 1.14 ± 1.13% animal units to 7.95 ± 2.88% animal units. The highest numbers of stone marten account for such gorges as Gosh-Dzhailoo, Bek-Suu, the density of population per 1000 ha is 0.78 ± 0.04–1.82 ± 0.07 animal units in Gosh-Dzhailoo, 0.54 ± 0.03–0.91 ± 0.05 animal units in Bek-Suu, and 0.32 ± 0.02–0.80 ± 0.04 animal units in Gadandyk.

One male of stone marten was caught in 2016 in the territory of the park in Agelek; its body size was measured, after which the animal was set free.

Badger *(Meles meles)*. According to Geptner (1967), 2 subspecies of badger are typical for the territory of Kyrgyzstan: Ferghana badger – M.m.severtzo vi Heptner (1940) and Tien Shan badger – M.m. tianschanensis (1910). Badger is one of the most common animals in Kyrgyzstan; its range extends from foothill valleys to mountain valleys to a height of 3500–4000 m above sea level.

As a consequence of our studies it has been found that the number of badgers in the territory of the park is extremely low. The badgers can only be found in a limited number of places in the territory of the park, and the density of their population per 1000 ha is 0.26 ± 0.03–0.52 ± 0.04 animal units in Gosh-Dzhailoo, whereas in Bek-Suu there are as little as 0.26 ± 0.03 animal units in Gosh-Dzhailoo. It is as little as 0.05 ± 0.03–0.07 ± 0.03 animal units per 1000 ha for the total area of the park.

Lynx *(Lynx (L.) lynx)*. Kuznetsov, B.A. (1948) [62] included lynx that can be found in Kyrgyzstan with subspecies F. l.isabellina Blyth (1874). The density of their population in the territory of Sarkent National Park is extremely low. The gorges where their quantitative indicator is much higher include Ai-Kol Gorge, Gosh-Dzhailoo Gorge, Gadandyk

Gorge, and Tenizbay Gorge. It has been found that the quantitative indicator of the density of their population per 1000 ha here reaches 0.74 ± 0.04 animal units to 1.22 ± 0.04 animal units.

Panther, or ounce *(Uncia uncia Schreber).* The subspecies of ounce Felis (Uncia) uncia Schreber) is typical for Kyrgyzstan. Ounce can be found in the territory of Sarkent National Park on the high cliffs of Gosh-Djailoo Gorge, Gadandyk Gorge, Zhakurut Gorge, Bek-Suu Gorge, Tenizbay Gorge, and Ai-Kol Gorge. In severe winters, ounce goes down to Agelek.Their quantitative indicator of the density of population (during 2012–2016) when calculaed for the total area of the park is 0.07 ± 0.15–0.30 ± 0.90 animal units per 1000 ha. The quantitative indicator of the density of population of ounce in Gosh-Dzhailoo (0.52 ± 0.28 animal units per 1000 ha), Gadandyk (0.64 ± 0.85 animal units per 1000 ha) and Zhakurut (0,55 ± 0,26 animal units) is the highest. At the same time, in other locations, for example, in Kol Gorge, Bek-Suu Gorge, Tenizbay Gorge, and Ai-Kol Gorge, it reaches 0.15 ± 0.18 animal units to 0.49 ± 0.27 animal units per 1000 ha.

According to our studies, wolf, common fox, and wild dog are distinguished by a high quantitative indicator from among carnivorous mammals. Currently, there are different opinions and polemics around the wolf among the population: we are talking about protection and reacclimatization of animals that was destroyed in the territories as a biologic species. Besides, there is an opinion that wolves should be preserved as a biologic species in small quantity.

2 Conclusions

1. 27 mammal species belonging to 6 orders were identified in the research that was carried out in natural and transformed biogeocenoses of Sarkent National Park.
2. 14 plant feeding mammal species which are characteristic of 3 orders *(Lagomorpha – 2; Rodentia – 6; Artiodactyla – 2)* and 13 species of predators belonging to 3 orders (Insectivora – 1; Chiroptera – 2; Carnivora – 10) were identified in the territory of Sarkent National Park. It has been found that different species of mouse-like rodents have their own conventional biogroups and that they have non-uniform distribution and density of population, and it was proved for the first time that common Tien Shan shrew is an endemic form of not only Tien Shan range, but also Turkestan range.
3. It has been found that the following species are dominant from the total number of mammals living in the territory if the park, per 1000 ha: from among plant-feeders – hare (4,57 ± 0,04), Siberian ibex (10,9 ± 0,05), common field mouse (43,7 ± 2,18), and from among predators: common fox (1.57 ± 0.04 animal units), wolf (1.10 ± 0.02 animal units).
4. The authors have identified the species composition, the number of predators and their distribution in various landscapes in the territory of Sarkent National Park as well as their role in the regulation of the number of plant-feeders in various ecosystems;
5. In order to protect and increase the population of Red-Book species (porcupine, ounce, lynx, brown bear, stone marten), the preserved area of the park should be expanded with the use of production and recreational territories; due to the absence

of preserved area in Turkestan range, it should be granted the status of a nature reserve in the long view.

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Optimal Strategy of Storage Unit Selection for Stand-Alone Hybrid Power Systems

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Abstract. Purpose: The purpose of the paper is to develop algorithms for strategies of storage unit selection for stand-alone hybrid power systems to be operated in the Khabarovsk Territory.

Design/methodology/approach: The authors define several approaches for the optimization analysis of the required quantity of batteries: initially we determine the quantity of solar and/or wind generators required as per the consumption and, accordingly, their total cost; then considering the monthly energy balance the required quantity of batteries and their cost are determined in case of separate or joint use of solar and wind generators. Total equipment cost is minimized by varying the number of single equipment parts.

Findings: It is shown that the existing selection strategies based on average monthly energy balances do not consider the peculiarities of the Khabarovsk Territory climate, as well as the changes in daily consumption associated with power consumers. Despite the proximity to the sea, many regions of the Khabarovsk Territory have a sharp continental climate characterized by hot summers (up to 40–45 °C) and cold winters (up to −35~−40 °C).

Originality/value: A promising method for solving the specified problem is the use of an information system module comprising a database of settlements with annual and monthly consumption schedules, information on annual and monthly flows of solar and wind energy as well as the characteristics of the selected equipment and an analytical block performing the calculations.

Keywords: Hybrid power systems · Optimization algorithm · Solar generators · Wind generators · Energy storage · Far North region

JEL Code: C61 · C63 · R19 · Q21 · Q42

1 Introduction

A huge number of researchers analyze the principles of hydroelectric power plants design with an increased focus on a variety of issues. The team of authors Binayak et al. (2017), Bao and Ying-Chih (2019), Ali et al. (2019), Sasan et al. (2019) researches the generation of electricity from wind generators and solar panels depending on weather conditions.

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https://doi.org/10.1007/978-3-030-69421-0_79

Both systems themselves are unreliable without sufficient capacity of storage units, such as batteries. When two systems use storage units, their reliability is increased, but even so, sufficient battery capacity is required to provide electricity during extended cloudy and/or non-windy days. The authors also consider the physical simulation of renewable energy systems as well as methodologies and criteria for optimizing stand-alone hybrid power systems.

Maurizio et al. (2018) conducted research to improve the efficiency of hybrid systems using a variety of optimization methods that help achieving the lowest expected total cost while meeting power demand and reliability requirements. Yu et al. (2010), Lucero et al. (2018) consider optimal models for designing hybrid systems including batteries to ensure optimal system configuration. Lin et al. (2016) discuss hybrid energy storage systems as well as chemical properties in different environments, taking ramp rate as one of the determining factors to be considered while calculating cost. Also, the author proposes a basic rule for the distribution of buffered power, while the minimum capacity of a battery and supercapacitor is simultaneously determined by integration. A probabilistic method is presented for analyzing how power and energy are compensated at a certain confidence level, two coefficients are set separately describing the state of energy storage and the limit.

The research by Weiping et al. (2019), Jihane and Mohamed (2018) proposes a prediction strategy for load-related parameters and also presents an efficient heuristic method (taboo search) for optimizing solar and wind hybrid power systems completed with a battery. When optimizing there are three main decision variables: quantity of batteries, surface area of a solar system, and sweep area of a wind turbine. The authors also take into account the net present cost as a target function for minimization.

Debao et al. (2019), Roshani et al. (2019), Muhammad and Tao (2019) considered a solar-wind-battery hybrid power generation system, the efficiency of which was determined for four weather conditions. In cases of strong wind/strong sun, strong wind/light sun, and light wind/strong sun, enough electricity is generated to meet the required load and provide some capacity to charge the batteries. Muthukumar and Balamurugan (2019), Omar et al. (2018), Olubayo et al. (2019) in their works propose an optimized hybrid solar-wind power generation system maximizing the generated power due to the use of neural architecture, bee colony algorithm and genetic algorithm. The research by Ranjay et al. (2018) presents a new methodology for waterfall analysis of modified electrical system or for optimizing a hybrid renewable energy system with a solar and wind energy conversion source, battery storage system, uninterruptible power supply, and the grid as system components.

Thus, a large number of researchers note that main problems of stand-alone hybrid power systems (SAHPS) are associated with storage units. The following can be used as storage units: electric batteries, supercapacitors, hydrogen storage devices, hydraulic storage devices, etc. Selection problems are related to the nature of these units. Let us consider the features of storage units for remote settlements of the Khabarovsk Territory. By the consumption all settlements can be divided into two large groups: settlements with central heating from boiler houses and settlements with individual stove heating. Table 1 shows monthly power consumption in remote settlements of the Khabarovsk Territory taking into account heating type: only stove or split (stove + central).

Table 1. Distribution of power consumption in remote settlements of the Khabarovsk Territory

Settlement/qty of inhabitants	Type of heating	Monthly consumption (thous. kWh)											
		01	02	03	04	05	06	07	08	09	10	11	12
Chilba/34		10	9	9	8	8	7	8	7	7	8	9	10
Savinskoe/321	Stove	55	62	53	48	58	58	57	59	88	71	70	72
Solontsy/446		80	83	64	70	68	60	61	72	72	72	72	73
Ukhta/141		15	13	12	10	12	12	13	12	12	13	12	14
Boctor/294		55	54	48	47	43	39	38	38	44	46	53	55
Bulava/1466		301	257	251	230	240	182	190	191	273	259	272	304
Verkhnetambovskoe/154		19	19	18	18	19	18	19	18	20	19	20	20
Ayan/920		395	367	352	316	309	305	341	305	328	400	342	369
Dudi/272	Split	80	65	67	61	47	50	38	40	53	57	68	60
Chumikan/1091		583	487	509	450	430	326	336	339	415	460	493	537
Udskoe/377		74	69	71	64	67	66	62	66	67	65	71	69
Tugur/355		100	94	89	57	55	65	53	53	65	73	65	91
Imeni Poliny Osipenko Village/1997		644	611	526	441	444	337	354	363	407	495	529	613

Diagrams of normalized average monthly power consumption per capita are shown in Fig. 1. Wide scatter of the normalized average monthly power consumption is associated with several reasons: increased consumption may be caused by industrial production except for households; split heating increases consumption in cold months due to the use of electric pumps for providing thermal medium circulation.

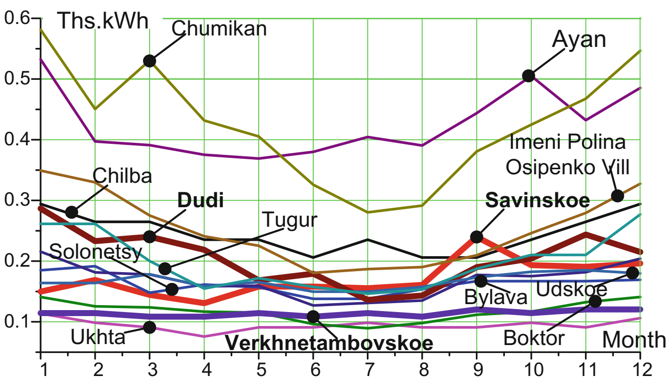

Fig. 1. Diagrams of normalized average monthly power consumption per capita. *Source*: developed and compiled by the authors

For more detailed analysis of annual consumption, let us select three typical settlements with similar number of inhabitants: Savinskoe: 321 inhabitants, stove heating; Dudi: 272 inhabitants; and Verkhnetambovskoe: 166 inhabitants, split heating.

The diagrams show that in the settlement with stove heating (Savinskoe), there is a pronounced seasonal increased consumption in autumn (September) which is most likely associated with procurement activities; in the settlement with split heating (Dudi) there is no such trend. Certainly, power consumption is higher in winter than in summer. And there is a third type of settlements (Verkhnetambovskoe), where the consumption is almost constant throughout the year.

Incoming energy flow (solar and wind) has the opposite tendency: more energy can be generated in summer than in winter. The information provided allows determining the characteristics required for storage units:

- storage duration;
- peak charge-discharge values;
- temperature range (arrangement in underground storage facilities).

2 Materials and Method

The calculation method for optimizing the quantity of batteries consists of three stages: preliminary calculations, evaluation of batteries demand, optimization of batteries quantity.

Stage 1. Preliminary Calculations

At this stage, annual and monthly output energies of N_{sun} solar generators and N_{wind} wind generators as well as users' annual and monthly power consumption are calculated.

Step 1.1. Calculate annual and monthly output energy of N_{sun} solar generators.

Sub-step 1.1.1. Calculate annual output energy of N_{sun} solar generators. For the calculation multiply total average normalized daily (kW • h/m^2 •day) solar radiation (Sun_In^{day}) by the number of days in a year N_day^{Year} (i.e. obtain annual normalized solar radiation); multiple it by total area of module elements (S(Mod$_{sun}$)); multiply it by the efficiency of a solar generator (module) (Mod_eff(Mod$_{sun}$)) and multiply it by the number of solar generators (modules) (N(Mod$_{sun}$)):

$$\begin{aligned} &\text{Sun\_Out}^{\text{year}}_{\text{year}}(\text{settl}, N_{\text{sun}}, \text{Mod}_{\text{sun}}) = \text{Sun\_In}^{\text{day}}(\text{settl})\text{N\_day}^{\text{year}}\text{S}(\text{Mod}_{\text{sun}}) \\ &\text{Mod\_eff}(\text{Mod}_{\text{sun}})\text{N}(\text{Mod}_{\text{sun}}) \end{aligned} \tag{1}$$

Sub-step 1.1.2. Calculate annual monthly output energy of N_{sun} solar generators. For the calculation:

- calculate solar energy by months using the formula taking into account latitude and longitude;
- for each month summarize cloud density data from the weather diary;
- multiply monthly data;

- multiply the result by the product of the number of solar generators (modules) ($N(Mod_{sun})$), total area of module elements ($S(Mod_{sun})$) and the efficiency of a solar generator (module) ($Mod\_eff(Mod_{sun})$);
- normalize the result to the value of annual output energy of N_{sun} solar generators.

Step 1.2. Calculate annual and monthly output energy of N_{wind} wind generators.
Sub-step 1.2.1. Calculate annual output energy of N_{wind} wind generators. For the calculation multiply average annual power density of a wind flow (at 30 m height) (W/m^2) by the number of wind generators $N(Mod_{wind})$; multiply it by the area covered by wind generator flow $S(Mod_{wind})$ and to calculate energy multiply it by hours per day N_hour^{Day} and the number of days in a year N_day^{Year}; then multiply it by the efficiency of a wind turbine $Mod\_effec(Mod_{wind})$ and divide it by 1000 to get energy in kWh:

$$\begin{aligned} &Wind\_Out^{Year}_{Year}(settl, N_{wind}, Mod_{wind}) = Wind\_In(settl)N(Mod_{wind})S(Mod_{wind}) \\ &Mod\_effec(Mod_{wind})N\_hour^{Day}N\_day^{Year} \Big/ 1000 \end{aligned} \tag{2}$$

Sub-step 1.2.2. Calculate annual monthly output energy of N_{wind} wind generators, taking that power dynamics of wind flow coincides with the dynamics of wind speed. For the calculation:

- for each month summarize wind speed data from the weather diary;
- multiply the result by the product of the number of wind generators ($N(Mod_{wind})$), area of a wind generator flow $S(Mod_{wind})$, wind generators efficiency $Mod\_eff(Mod_{wind})$;
- normalize the result to the value of annual output energy of N_{wind} wind generators.

Step 1.3. Calculate annual, monthly and daily energy consumption.
Sub-step 1.3.1. Annual energy consumption is taken from the corresponding table of the settlements database.
Sub-step 1.3.2. Annual monthly energy consumption is taken from the corresponding file attached to the settlements database.
Step 1.4. Basing on the energy balance, calculate the required quantity of solar and/or wind generators as well as equipment total cost.
Sub-step 1.4.1. By varying the number of solar generators $N(Mod_{sun})$ and wind generators $N(Mod_{wind})$ find the quantity providing for the total energy is greater than annual energy demanded by consumers. For each pair $N(Mod_{sun})$, $N(Mod_{wind})$ calculate generators total cost.
Stage 2. Estimation of Batteries Required Quantity
At this stage, basing on preliminary calculations, the required quantity of batteries is estimated to ensure uninterrupted supply of demanded energy based on monthly output energy balances of N_{sun} solar generators, N_{wind} wind generators and N_{bat} batteries and corresponding energy consumption; while varying the ratio of solar and wind generators quantity; while varying excess quantity of solar and wind generators to reduce the quantity of batteries.
Step 2.1. Basing on charge-discharge balance, calculate the required quantity of batteries using monthly data, while varying the ratio of solar and wind generators quantity; while varying excess quantity of solar and wind generators to reduce the quantity of batteries.

Stage 3. Optimization of Batteries Quantity.
At this stage, based on the previous calculations, an optimization algorithm is implemented to meet the criterion of minimum cost of the required quantity of batteries, solar and wind generators with an uninterrupted supply of energy demanded by consumers.

3 Results

Let us consistently present and analyze the results obtained for the settlements specified above: Savinskoe, Dudi and Verkhnetambovskoe. It is supposed to use solar generators SIM400-24-5BB-PERC, wind generators ALEN-10 kW and batteries SunStone Power MLG 200Ah 12 V.

Analysis of annual energy balance (Fig. 2) shows that the use of solar generators is economically more profitable, but this conclusion may change when analyzing monthly annual energy balance. It should be noted that Fig. 2 shows data per capita for convenience. Obviously, when considering the annual balance, the need for energy storage is not revealed; this balance is mainly needed to assess minimum quantity of solar and/or wind generators supplying demanded energy to consumers.

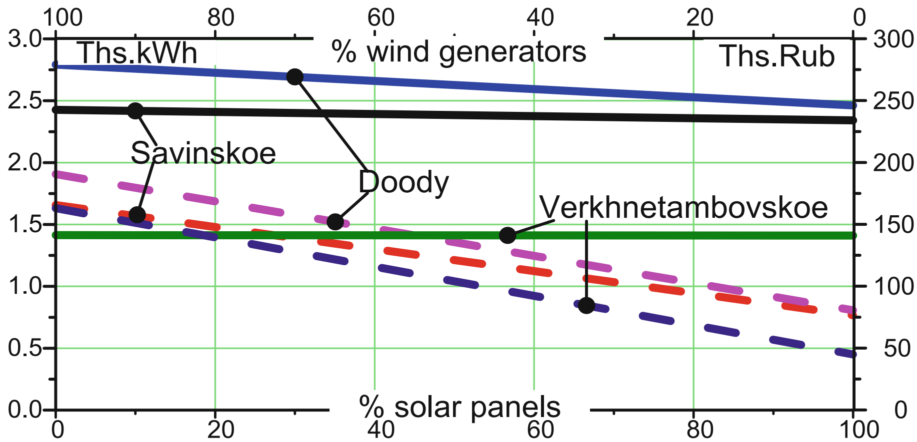

Fig. 2. Diagrams of the ratio of energy (solid line) and cost (dashed line) to solar panels and wind generators. *Source*: developed and compiled by the authors

The next stage is to analyze monthly energy balance. The dynamics of this balance for selected settlements is shown in Fig. 3, where Load is the energy consumption, Sun is output energy of solar generators, Wind is output energy of wind generators, Sun & Wind is total output energy of solar and wind generators, Battery is energy charging (green columns) and discharging (red columns) batteries.

The dynamics shows that all three settlements require storage units with energy conservation for at least six months; batteries can start storing energy from the second month (February); the most uniform accumulation mode for Verkhnetambovskoe settlement with the most uniform consumption.

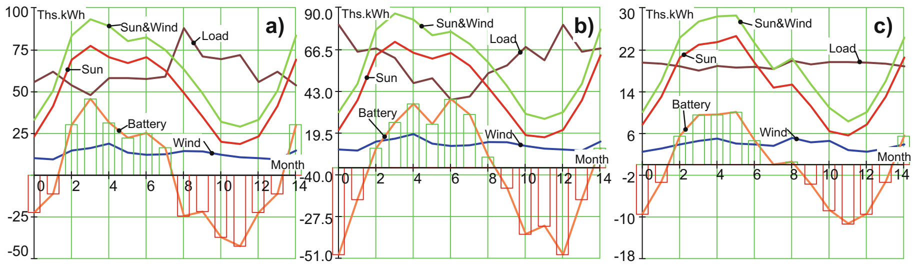

Fig. 3. Dynamics of monthly energy balance when using 80% solar and 20% wind generators: a) for savinskoe, b) for dudi and c) for verkhnetambovskoe

In addition, the dynamics of monthly energy balances allows determining the change in batteries state, required maximum charge, and consequently batteries required quantity. Changes in the state of batteries for three settlements are presented below (Fig. 4).

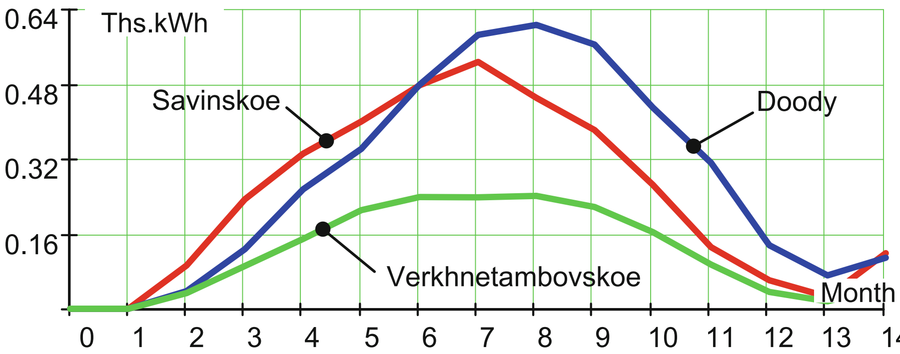

Fig. 4. Dynamics of monthly battery charge per capita *Source*: developed and compiled by the authors

When 80% of solar generators (1208 ea.) and 20% of wind generators (16 ea.) are used, Savinskoe settlement requires at least 77 thousand batteries. Cost of the equipment will make $2223 \cdot 10^3$ thousand rubles, at that 98.64% are batteries, 0.88% are solar generators and 0.48% are wind generators. Such result allows defining a strategy for reducing the equipment total cost: reduction of the batteries required quantity by increasing quantity of solar and wind generators providing for optimal percentage ratio. Optimization by the method of bee colony provided the following results: when using 1,746 solar generators, 44 wind generators and 942 batteries the total cost of equipment is $84.7 \cdot 10^3$ thousand rubles (31.82% is for batteries, 33.62% is for solar generators and 34.56% is for wind generators). Thus, the optimization of equipment quantity allowed reducing its cost by more than 20 times provided that cost proportion of each equipment type is almost equal. Upon this, the cost of equipment per capita is 230 thousand rubles (Table 2).

Table 2. Result of equipment optimization for Savinskoe settlement

Cost item	Basic option		Bee colony optimization result	
	Qty, ea.	Cost proportion	Qty, ea.	Cost proportion
Batteries	77,000	98.64%	1,746	31.82%
Solar generators	1,208	0.88%	44	33.62%
Wind generators	16	0.48%	942	34.56%
Total cost, thousand rubles	$2\,223 \cdot 10^3$		$84.7 \cdot 10^3$	

4 Conclusion

As a rule, with the same output energy, the cost of solar generators is minimum half less than the cost of wind generators.

Batteries (storage units) determine the cost of HPS equipment. The main way of reducing equipment cost is to increase output energy of solar and/or wind generators for the energy demanded by consumers to reduce batteries capacity and accordingly its quantity.

Optimization according to the criterion of minimum equipment cost while maintaining the uninterrupted power supply allows to significantly reduce equipment cost.

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Research and Modeling of Industrial and Social Processes to Improve the Safety of Human Life

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Abstract. Purpose: At present the development of computer technology and numerical methods makes it possible to solve voluminous computational problems and carry out multivariate analysis of complex non-stationary processes and phenomena by creating and applying mathematical models. The purpose is to develop a model based on a methodology for research and forecasting non-stationary processes and phenomena represented by time series based on wavelet analysis.

Methodology: The mathematical model proposed in the research work is based on multifactorial non-stationary input data. To solve such research problems, modern theoretical and numerical methods of working with nonlinear and non-stationary signals are used. The study is carried out on one of the most complex-conditioned phenomena, which is an industrial injury.

Findings: The article presents an analysis of injuries at 270 enterprises in various industries in Komsomolsk-na-Amure using wavelet analysis for various factors: the time interval, months, days of the week, gender, age, and other parameters.

The article offers an interpretation of results obtained in the form of wavelet - spectra with further recommendations for improving the safety of human life.

Originality/value: A mathematical model of the time series is proposed, which is unique because a chaotic component is introduced, that contributes to the reflection of a more real situation in identifying the time series for self-similarity in comparison with statistical methods of analysis. The reliability of the conclusions and recommendations is confirmed by the use of a modern method - wavelet analysis and the use of a large amount of information data provided by the social insurance department of Komsomolsk-na-Amure.

Keywords: Modeling · Wavelet analysis · Non-stationary signal · Injuries · Safety

JEL Code: J81 · C51 · C53 · M54 · Z22

1 Introduction

Industrial accident statistics are an example of a multifactorial, non-stationary and nonlinear process. The processing and analysis of such data is an urgent and significant task today which requires quantitative and qualitative research.

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A number of accidents and injuries is growing every year, and they are one of the main causes of death in most economically developed countries. Traumatism entails irreparable social losses and costs for enterprises and for the state, negatively affecting the quality of life of people. It should be noted that injury constantly accompanies human production activities. But the degree of such presence is variable. At the enterprises where much attention is paid to labor protection, where they try to predict the occurrence of accidents, and on the basis of the forecast - to eliminate the most likely causes of injury - the situation is improving.

Injury statistics reflect a continuous increase in injury cases. Work-related injury deaths are the third largest in the world, accounting for 220,000 work-related fatalities.

Speaking about Komsomolsk-on-Amur, Khabarovsk Territory, we can conclude that based on the data provided by the Social Insurance Fund, where work-related injuries are recorded, there are about 4 injuries per year for every 1,000 population. Based on information from the trauma center, there are about 144 injuries per year for every 1,000 population in a population of 246,000 people.

These data cannot be considered entirely correct, since there is a distortion of the fact that many employers do not record facts of accidents, as they bear responsibility and economic losses during the subsequent social insurance of employees.

Statistics on the contribution to industrial injuries by industry sectors in Komsomolsk-on-Amur are presented in Fig. 1.

Code OKVED (Russian National Classifier of Types of Economic Activity)	Industrial sphere	Cases, %
15100, 31100	Logging industry	25.1
14730	Defense industry	12.7
12130	Ferrous metallurgy	4,6
61124	Erection works of structures	3,9
61110	Civil and erection organizations	3,5
91511	Hospital facilities	2,9
90110	Housing maintenance	2,9
61129	Linear construction	2,9
92310	General education schools	2,4
51121	Automotive industry	2,2
18221	Butter, cheese and dairy	1,5
51111	Railway transport	1,5
21120	Vegetable growing	1,4
90211	Public improvements	1,4
14912	Repair of industrial production	1,3
91515	Ambulance and emergency care facilities	1,1
12221	Mining and processing of copper ore	1,1
12271	Extraction and processing of tin ore	0,9
Total		73,5
Other industries		26,7

Fig. 1. Industry contribution to occupational injuries. *Source*: developed and compiled by the author

Compared to the general background, fatal injuries at work are relatively low but compared with other countries submitting their data to the International Labor Organization, its level remains very high. This indicates that the social problem of occupational injuries is currently not well understood and requires further research.

Industrial injuries, as a non-stationary process, can be determined by a whole set of different factors that are difficult to study and analyze using traditional methods, for example, Fourier analysis or statistical analysis. The statistics of injuries and diseases are so multifactorial and non-stationary in time that the listed traditional methods of analysis do not give a general picture of the prerequisites and causes that led to the occurrence of injuries.

The occurrence of accidents in a single territory is random and stochastic in nature; the intensity of the process is due to numerous prerequisites and factors on which the level of injury directly or indirectly depends.

The degree of influence of one factor or another depends on parameters that cannot be predicted or mathematically described. Measurements of the statistical characteristics of processes and fields have become firmly established in the practice of modern research. In this case, we can consider the theory of random functions, the methodology of which is developed within the theory of statistical measurements.

The random process x(t) is represented with the help of certain functions - the results of experience, called realizations of the random process, the form of which cannot be proved in advance. Thus, an ensemble consisting of an infinite set of realizations is a probabilistic model of a random process (Astafieva 1996), (Afanasiev and Yuzbashev 2012).

The practice of describing stochastic processes includes a modern type of analysis of non-stationary signals - wavelet analysis.

The wavelet transform was originally used specifically for the analysis of non-stationary signals and is applicable in various fields in technical sciences, medicine, economics, and for the analysis of social processes.

When processing data, wavelet analysis spreads the frequency spectrum in time to accurately identify the moments of appearance and disappearance of various cycles in dynamics. Wavelet analysis reveals the frequency features of the investigated time series, which in time precede unexpected and single "bursts' in dynamics, etc. (Gribunin 1999).

Unlike spectral analysis, which records various cycles in the entire analyzed time series, wavelet analysis makes it possible to empirically check the occurrence and end of cycles at different time moments.

The purpose of the work is to develop a model, which is based on the technique of research and forecasting of non-stationary processes and phenomena, represented by time series based on wavelet analysis.

2 Materials and Methods

A time series is statistical information on the process under study, which is collected at different time intervals. Time series analysis is needed to determine the structure and predict the behavior of time series. The forecast assumes that information gained in the past helps to explain future values (Afanasiev and Yuzbashev 2012; Daubechies 2001).

The article presents a mathematical information model for the study of occupational injuries, where the collected information on injuries is used as input data in the form of time series. The result of time series analysis will be visualization based on computer methods of information processing. The visualized results make it possible to identify patterns in the behavior of the time series of the system under study (Amosov et al. 2018a, b), (Amosov and Baena 2017).

Based on the analysis of this time series, it is supposed to build forecasts of bursts of instability or instability of the phenomenon of the studied processes and phenomena.

2.1 Time Series Mathematical Model

A universal mathematical additive model is proposed for identifying and forecasting time series of the following form (Amosov et al. 2018a, b):

$$y_t = \chi_t = \eta_t + \varepsilon_t, \tag{1}$$

where χ_t – an indicator reflecting the scale of the chaos of the series, which determines the type of the time series, taking into account its trendiness;

η_t – trend component, with polynomial approximation of different degrees.

$t = t_0, t_1, \ldots, t_n$ – time moments;

ε_t – random noise.

2.2 Continuous Wavelet Transform

Continuous wavelet transform is similar in analogy to applying continuous scale transform and wavelet transfer $\psi(t)$ with a number of arbitrary values a and b:

$$\mathrm{W}(a, b) = \frac{1}{a} \int_{-\infty}^{\infty} \psi * \left(\frac{t-a}{b}\right) f(t) dt, \tag{2}$$

where a - scale factor;

b- shift parameter;

symbol (*) denotes a complex conjugation operation.

Two-parameter function $W(a, b)$ carries information about the dynamics of the contribution of components of different scales in time and will be called the spectrum of the wavelet transform coefficients.

The essence of multiscale analysis is that you can study the signal at different scales and study the scales of interest in details.

If we want to get the result in the necessary details or some details at different scales, in order to enlarge the image, or if we want to get rid of noise and neglect insignificant details, then this type of transformation is most ideal.

The calculation of the wavelet transform has the form (Yakovlev 2003a, b):

$$\mathrm{W_s}(a, \mathrm{b}) = (s(t), \psi_{ab}(t)) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} s(t) \psi * \left(\frac{t-b}{a}\right) dt, \tag{3}$$

where t – time axis;

b – time moment;

$\psi(t)$ – wavelet function;

$s(t)$ – frequency inverse parameter;

$(*)$ – means complex conjugate.

2.3 Modified Combined Processing Approach for Time Series Analysis

The first stage is the choice of statistics for the formation of the time series of interest by various factors: time intervals, years, months, days of the week, gender, age, etc.

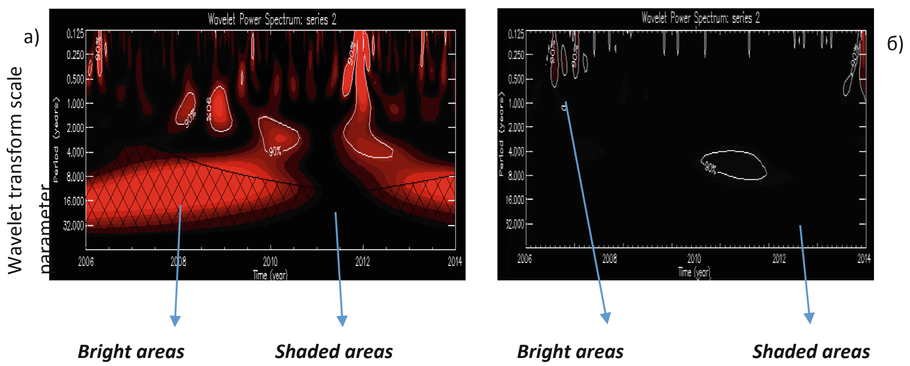
As a result of processing the time series of wavelet analysis, we will receive more complete information about the process under study in the form of wavelet spectra and will be able to identify patterns in the behavior of the system.

To obtain a complete time-frequency representation of the signal, it is necessary to calculate the wavelet transform, using the formula (3).

We have some function $\psi(t)$, time-dependent. The result of its wavelet analysis will be some function $W(a, b)$, which already depends on time and frequency (inversely proportional).

For each pair a and b wavelet transform calculation is the following: the wavelet function is stretched by b times horizontally and by $1/b$ times vertically, and then it is shifted to a point. The resulting wavelet is designated as $\psi(a, b)$. e perform averaging in the vicinity of the point b using $\psi(a, b)$.

As a result, we get wavelet spectra (Fig. 2) illustrating the time-frequency characteristics of the signal, where time is plotted along the abscissa axis, and frequency along the ordinate axis.



Bright areas are the accumulation of prerequisites for the occurrence of accidents. Shaded areas - a stable state of the process under study, the absence of precursors of accidents

Fig. 2. Wavelet spectrum of accident occurrence in men a) and women b). *Source*: developed and compiled by the author

The absolute value of the wavelet transforms for a particular pair *a* and *b* identifies the color that reflects the result. The absolute value of the wavelet transforms for a particular pair and identifies the color that reflects the result. The more volume of presence this or that frequency has in the signal at a particular moment in time, the darker the shade in the wavelet spectrum will be.

3 Results

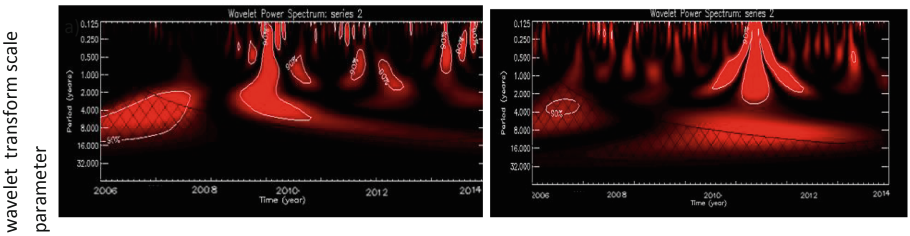
3.1 Time Series Analysis by Gender

Analysis of wavelet spectra by gender (Fig. 2) showed a cardinally opposite visualization in terms of the intensity of bursts at the same localization.

This indicates that men, unlike women, have a greater number of prerequisites for the occurrence of accidents, while the factors that affect the level of injuries in men and women are the same, with different reactions to these disturbances.

3.2 Time Series Analysis by Months

The wavelet spectra for all months have an approximately uniform distribution, with only a slight predominance of the chaotic nature of the analyzed process in February and more in October (Fig. 3).



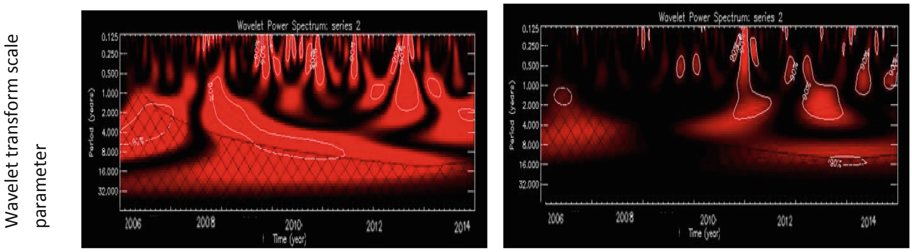
a) wavelet-analysis for February; б) wavelet-analysis for October

Fig. 3. Wavelet spectrum of the time series of injuries over time. *Source*: developed and compiled by the author

3.3 Time Series Analysis by Day of the Week

Wavelet spectra for Thursday with the highest randomness and Sunday with the lowest one are shown in Fig. 4.

The results indicate that on Monday and Thursday, the scenario of the situation tends to be chaotic. This differs from the classical statistical analysis, according to which most injuries occur on Friday 31% and Monday (in second place) - 19%, which may indicate that the prerequisites for the realization of accidents should be considered during this period.

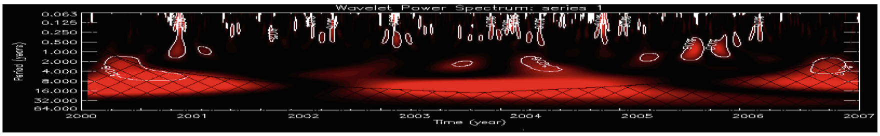


a) wavelet-analysis Thursday; б) wavelet-analysis Sunday

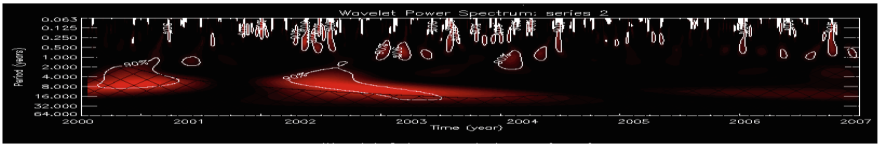
Fig. 4. Wavelet spectrum of injury time series by days of the week. *Source*: developed and compiled by the author

3.4 Time Series Study by Age

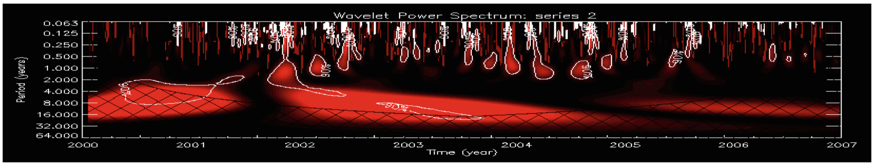
Figure 5 shows wavelet spectra by age criterion, which showed that 20-year-old workers have the least injuries than those over 50 for quite objective reasons - there are fewer of them, but the occurrence of injuries is usually associated with the absence of due attention and distraction. Employees aged 21–30 and 41–50 are among the most antipersistent time series.



a) initial wavelet spectrum at the age of 21-30



b) initial wavelet spectrum at the age of 31-40



c) initial wavelet spectrum at the age of 41-50

Fig. 5. Analysis of the time series of injuries by age. Source: developed and compiled by the author

4 Conclusions

The article presents the results of computer processing of statistical information of time series on injuries using wavelet analysis to obtain visualized results in the form of wavelet spectra.

The task was to identify the patterns of behavior of time series and to obtain as complete information as possible, which is not available in the original form about the process under study using the interpretation of wavelet spectra.

Based on the results obtained, it is possible to make predictions of the possible instability of the phenomenon of the studied processes, which tend to an unstable state, to identify the most risky groups (time period, month, gender, age, etc.) and, as a result, develop more appropriate recommendations and measures.

Firstly, it is recommended to increase control and attention to the work of personnel in the months with the highest probability of injury occurrence, where the wavelet spectra had bright areas, especially for men, and the age group where there was a similar dynamics on the wavelet spectra.

It is necessary to pay close attention to the forestry, ferrous metals, tin ore mining and processing industries, where additional analysis of the causes of injuries is required.

It is advisable to rationalize the work schedule in production on Monday and Thursday, as the most traumatic days, to introduce additional breaks on these days in order to restore the attention of workers and increase the accuracy of their operations.

This mathematical model of time series processing can be applied to process time series of any social processes and has a practical purpose.

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Economic and Institutional Aspects of Environmental Protection

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Abstract. Purpose: The purpose of the article is to analyze the effect of environmental protection made by government on economy and politics. As the environmental problems become more and more discussed nowadays, the theme is topical.

Methodology: The main method discovers the connection between growing environmental danger which is supported by statistics and current economy which is in stable contact with the nature itself.

Results: As it is explained, not only government can benefit from environmental protection. As business involves in its strategy environmentally friendly actions, it gains the support from the government with lower taxes or grants, and from ordinary people who take care of the nature. This mechanism is similar with business investment system – with some improvements the company can get profit.

Value: The topic is extremely relevant in Russia as in country with such large natural wealth. With economic problems it is becoming harder to invest money in environmental protection both for business and government – that is why this problem is necessary to solve.

1 Introduction

Aspects of environmental pollution are mainly regulated by administrative means, which, in our opinion, are ineffective. In the context of the development of the modern economy, it is advisable to talk about an environmental tax. The concept of environmental tax is the formation of tax revenues in both the federal and regional and local budgets. An environmental tax will replace current payments for various types of environmental impacts.

The function of nature has always been to provide natural resources for economic activity and absorb industrial and consumer waste. But for a long time we used the concept of "unlimited resources", of which there are many, and therefore they have no price. On the other hand, nature was attributed the ability to accept an unlimited amount of waste, and therefore there were no economic problems in using soil, water and air for waste disposal.

2 Methodology

After the report "The Limits to Growth" was presented for the Club of Rome, the world community realized that natural resources are limited, and if the level of consumption

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remains significant in most areas, all these resources will soon be exhausted. In 1992 this report was updated.

All over the world we see the destruction of nature. Every second we lose 3,000 km^2 of wood and 1,000 tons of natural soil (Laszlo 1991). Half of the total cut down forest died in 1950–1990. In almost all parts of the world, wood consumption exceeds several times its amount equal to annual natural growth. Forests have a beneficial effect on the climate, retaining water and restraining the effect of the greenhouse, and deforestation is dangerous because it causes air pollution and acid rain. Figure 1 shows data on the number of deforestation in hectares.

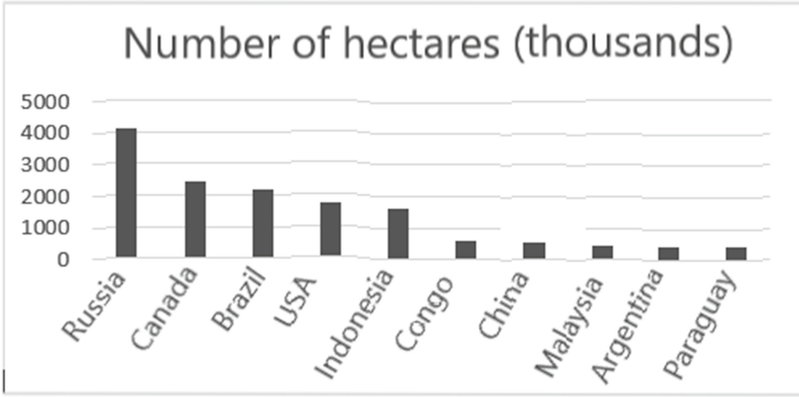

Fig. 1. Area of deforestation. *Source*: Statistics of forest clearance - https://cont.ws/@30091963/904956

From 1860 to 1985, energy consumption increased 60 times. Most of the energy is consumed by industrial countries. Europeans consume 10–30 times, North Americans consume 40 times more commercial energy than third world countries. Natural gas resources, which have a less harmful effect on the environment compared to other types of fossil fuels, will remain for 240 years if annual consumption remains at the same level as in 1990 (taking into account open gas fields). If consumption grows to 3.15% per year, as it was before, gas will last only until 2054. If coal and oil are replaced by gas faster than before, gas resources are expected to be exhausted within 50 years. All this can even happen if the exploration of new gas fields allows to increase the volume of known resources by 4 times (Third World Resurgence 1997). Figure 2 shows data on world energy consumption by sector.

At present, radioactive and chemical agents are the most difficult to produce among industrial wastes along with substances of global exposure, such as gases, which cause a “greenhouse effect”. There are very few natural organisms that can be processed into non-hazardous substances. Today, about 65,000 types of synthetic substances are sold, and only 1% of them are tested for toxicity. And only 20% of 3–5 newly created compounds are studied in terms of their possible toxicity, while the community is aware

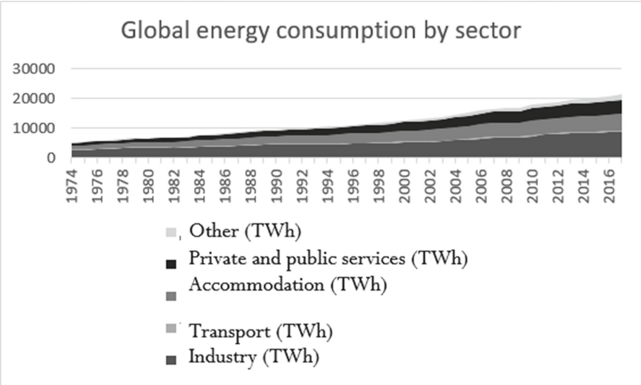

Fig. 2. World energy consumption by sector. *Source*: International energy agency, official site https://www.iea.org/statistics/electricity/

of environmental issues. 90% of such industrial waste comes from industrialized countries that transfer environmentally hazardous production to third world countries where industrial waste is also transported (Meadows and Randers 1992).

How can the economy counteract these trends? The answer lies in the current economic order. In a market economy based on numerous independent organizations and enterprises, the latter act on the basis of the need to obtain growing profits - as the difference between sales results and expenses.

Air pollution resulting from industrial activities and forest destruction is not considered the expense of one enterprise. Countermeasures are considered the task of the whole society; the state, as a rule, is forced to bear the necessary expenses. In this regard, the theory speaks of an external negative impact, social costs, which are not taken into account in the calculation of this enterprise.

The first answer to this fundamental problem associated with costing was to postulate the so-called compiler principle. Where possible, the perpetrator of social costs should be identified and held accountable.

The boundary of the application of this principle lies where it is technically impossible to identify the undeniable author. In this case, the principle of social responsibility is applied, that is, the entire community assumes responsibility for all consequences. Air and water pollution is usually cumulative, and the "fault" of a particular organization cannot be established. The border also lies in the economic zone, because if organizations are forced to finance environmental measures, they may be on the verge of economic inability.

3 Results

Environmental issues pose certain challenges to organizations with private property. On the one hand, state rules force entrepreneurs to take some measures or circumvent some steps aimed at protecting the environment. We can talk about the environmental goals of organizations when they, on their own initiative, declare that environmental protection is their goal, recognizing their environmental responsibility. The goals can be realized in special measures, such as: checking the composition of the material in the purchased raw materials; the use of environmentally harmful substances and their replacement with environmentally friendly materials; control and modernization of production processes in terms of energy consumption, harmful substances and industrial waste; the possibility of recycling products; refusal to use excessive packaging to reduce waste, etc.

Thus, the problem of environmental protection provides the basis for the introduction of environmental policy, the main criteria of which are formulated by the Swiss economist Frey (1985): efficiency, fair distribution, and consequences for public finances. Other criteria are the reliability of information about the causes and effects, the duration of the activity until the moment of exposure, moral aspects related to the willingness of the community to take environmental measures and, of course, the interests of all interested parties. Based on these criteria, the following environmental policy tools are recognized: 1. Convincing the need for voluntary action; 2. Public quantitative indicators; 3. Environmental taxes; 4. Grants; 5. Market relations in the implementation of environmental certificates.

Environmental standards exist in accordance with the law. This is a system of environmental standards. The main indicators used to control water and air quality are the maximum level of pollution (MCL), the concentration of a specific chemical that does not cause pathological changes or diseases in humans, and the degradation of natural ecosystems if exposure occurs every day for a long time. MCL in the Russian Federation is quite strict and can be compared with world ones. Although in many regions and waters they are not observed, which is an indicator of pollution and environmental degradation. At the same time, in 103 cities with a population of 50 billion people, MCL in the air exceeds more than 10 times.

Worldwide harmful emissions amount to 1 or 3 billion tons per year, most of which are in highly developed countries located in the central part of the northern hemisphere.

There are more than 24,000 enterprises in Russia that dispose of hazardous waste in air and water. 33% of emissions are from metallurgy enterprises, 29% - from energy enterprises, 7% - from the chemical industry and 8% - from coal mining. More than half of all air emissions are from transport.

Specialists have long considered the demographic situation in Russia "catastrophic." The pollution of air and water by industrial enterprises is so deep and harmful to the environment that it is one of the most powerful negative factors affecting humans. Studies prove that in Russia only 10% of school graduates are healthy. Over the past decade, the number of healthy girls graduating from schools has decreased from 28.3 to 6.3%, that is, more than 3 times. Life expectancy in Russia is 69 years; it is 8–10 years less than in 44 capitalist countries.

4 Conclusion

All these data on the nature and state of human health eloquently confirm the undeniable links between the destruction of ecological systems and negative changes in the human gene pool. Under the influence of harmful substances from birth to old age, most people lose their health and shorten their lives. This leads to a decrease in labor productivity and an annual increase in medical services. That is why economic measures along with administrative actions can become an effective means of protecting the environment.

It is believed that the unfavorable environmental situation in Russia is due to the following reasons: 1. Property monopoly on natural resources and means of production, which deprived producers of incentives to protect the environment and brought state control over environmental protection to formalities; 2. The predominance of the military industry, which squeezed the octopus throughout the country and consumed all the funds allocated for environmental protection, modernization of technologies and restoration of production assets, which are on average 40–60% worn out; 3. The prevalence of consumer psychology and the belief that Russia's natural resources are endless and inexhaustible, poor environmental culture of the society, and lack of environmental education (Legislation and Economics 1992).

But one cannot agree with such an explanation of environmental reasons. Even when the means of production were privately owned, acid rain destroyed everything in hundreds of Canadian lakes. When natural resources and means of production were state-owned, it was impossible to go unpunished for stopping or not fulfilling planned targets. At the same time, the state did not care about environmental protection.

The main reason for the destruction of the environment is the poor ecological culture of society, lack of awareness of the environmental consequences and neglect of the state towards nature, as well as legislative deficiencies. Although this was not enough, there were centralized capital investments in environmental measures. The draft State Ecological Program provides for the following measures to prevent environmental degradation and its improvement: reconstruction of worn-out facilities, introduction of the latest technologies and efficient designs of oil refineries, etc.

Aspects of environmental pollution are mainly regulated by administrative means, which, in our opinion, are ineffective. In the context of the development of the modern economy, it is advisable to talk about an environmental tax. The concept of environmental tax is the formation of tax revenues to the budgets of all levels of the budget classification. The environmental tax will replace current payments for various types of harmful environmental impacts, which will contribute to the implementation of the effectiveness of tax administration.

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The Model of Company Security in Crisis Conditions

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Abstract. Purpose: The article is devoted to the study of ensuring the security of companies in crisis conditions. In the conditions of market reality, when legal entities seek to maximize their profits, and the state tries to create conditions under which the benefit for society will be the maximum most important aspect is ensuring the security of the company, the most relevant issue arises in times of crisis and change i.e. in market conditions.

Design/Methodology/Approach: The authors consider the provision of economic security for companies in crisis conditions by means of a specially developed model, revealing its components with an emphasis on the interconnection of elements and the result.

Findings: In order to ensure the economic security of companies in crisis conditions, the authors propose a specially designed model that can level threats and risks with special emphasis on ensuring the stable development of the subject of legal relations.

Originality/Value: The model for ensuring the security of companies in crisis conditions developed by the authors allows taking into account changes in the external and internal environment, with an emphasis on the relevant formation, distribution and use of all resources of an institutional unit, maximizing the utility function of processes and ideas for capital appreciation, leveling threats and risks while ensuring stable development subject of legal relations, which in turn determines the effectiveness of economic security.

Keywords: Ensuring economic security · Threats and risks · Business · State · Crisis conditions · External and internal factors · Changing resources · Result

JEL Code: G3 · M1

1 Introduction

In the conditions of market reality, when legal entities seek to maximize their profits, and the state tries to create conditions under which the benefit for society will be the most important aspect, ensuring the safety of the company, the most urgent issue arises in times of crisis and change i.e. in market conditions.

So, initially all the activity of subjects of legal relations is determined by the desire for profit, which in turn generates competition through the desire for quick profit, and

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therefore involves the reverse side, i.e. threats, risks and dangers. Thus, the economic content of a company's security boils down to being able to get a stable development while mitigating threats and risks i.e. increase in capital (resources, profitability, etc.) with an emphasis on changing resources (in terms of rationality and justification) and efficiency (time interval and result), taking into account alternatives and external factors (inflation, etc.).

It is the nature and essence of the legal relationship laid in the economic content of security i.e. desire, aspiration, actions aimed at obtaining stable development while ensuring the leveling of threats and risks inherent in the subject of legal relations.

2 Materials and Method

The multifaceted nature of the problems of ensuring economic security is caused, firstly, by the desire of all legal entities to maximize their benefits, and secondly, by the direction of state activity, through the relevant management of creating conditions under which the implementation of legal relations in the process of life of legal entities and institutional units will maximize the benefits of both society and for the country. The most important element of the relevance of the economic security system is the congruence of goals with the national security strategy of the Russian Federation in the economic security system, which in turn will lead to a synergistic effect and greater usefulness for both society and the country, as well as through the prism of effective interaction with control supervisory authorities and for a particular subject of legal relations (Krokhicheva et al. 2017).

When planning their livelihoods, it is logical for any subject of legal relations to proceed from the strategic directions of the innovative development of socio-economic systems, which make it possible to effectively use all the technical and investment potential in their interests (Godina et al. 2019). When determining their competitive advantages, as well as monitoring the environment of an institutional unit, it is logical and expedient to proceed from an effective assessment of a particular region in which the legal entity carries out its activities, while the importance and significance of the used analytical approaches and methods for assessing economic security can hardly be overestimated (Tsvetkov et al. 2019). The importance and importance of ensuring the economic security of a business is also determined by the technologies used, namely the response speed and databases, the emphasis being made on the uneven development of regions, which leads to the fractality of ensuring economic security both in the country as a whole and in individual regions (Arkhipov et al. 2019). In determining the criteria and indicators for ensuring the safety of companies in crisis conditions, it is also advisable to proceed from the institutional support of the social and innovative activity of a large city that affects the vector of development of this company, so an institutional unit will certainly play a significant role in the center of its region, which means that the accumulation of funds will occur through the center i.e. a large city, it is logical to place emphasis on social and other consequences for its administration, as well as funds that can be used to increase the efficiency of formation, distribution and use of resources (Popov et al. 2019). The institutional characteristic of the region's economic security, in turn, allows identifying the responsibility points of both the institutional unit and counterparties with special emphasis on vulnerable areas and their relevant use (Kayukov et al. 2018). Modeling the assessment of the impact of industry factors on the level of socio-economic development and economic security of territories is necessary in order to relevance of the most private model of an institutional unit since the interconnection of all variables (both external and internal) allows, on the one hand (when used effectively), to achieve a competitive advantage, and, on the other hand, to mitigate dangers, threats and risks, which also allows to maximize capital gain and optimize the stable development of the subject of legal relations (Chichkanov et al. 2020). The polemic nature of scientific processes, schools, approaches and methods with an emphasis on concepts, methods, and tools is ensured by the versatility of scientific schools and areas, as well as the effectiveness of using theoretical ideas and conclusions in practice (Bochko 2019). It is also worth noting that when making any operational, tactical, and strategic decisions, as well as their implementation depends on subjective factors, namely the effectiveness of human resources expressed in the final analysis by labor productivity (Shlykova 2018). Important in the financial and economic activities of the institutional unit is also the territory of priority development since their effective use allows achieving tax asymmetries and increased innovation effect, which in turn also acts as a competitive advantage (Chichkanov et al. 2018). When monitoring the problems of economic security, it is logical and appropriate to proceed from special developments and developments of leading centers for studying economic security problems in Russia, which optimizes the efforts of the institutional unit and maximizes the hypothetical managerial effect of leveling threats and risks with a focus on the effective management of the company in crisis situations (Bersenev 2019). It is also worth noting that the resources are theoretically of equal importance, both material and non-material, and in practice, the bias towards specific resources is due to their influence on the subject of legal relations, as well as possible profitability (Mikhalkina et al. 2018). The study of global risks on the financial and economic activities of legal entities is also an important element in ensuring economic security, allowing us to understand the structural changes in economic processes with special emphasis on the hypothetical effect on institutional units and counterparties (thirteen). The vital activity of an institutional unit is unthinkable without reference to the specific region in which it carries out financial and economic activities, which is why Basel acts to determine the total resource potential of a region with an emphasis on the relevance of the methodology for determining and changing (Lomovtseva 2012). The competitive advantage is also often due to the resource potential of the immediate region and the effectiveness of its use, both short-term and long-term (Liu et al. 2020).

3 Results

In order to culminate in ensuring the safety of companies in crisis conditions, it is necessary and advisable to take relevant operational, tactical and strategic management decisions to mitigate threats and risks while ensuring the stable development of legal entities.

In consequence of the foregoing, it is advisable to propose a developed model for ensuring the security of companies in crisis conditions (Fig. 1).

The model consists of the following interconnected enlarged blocks:

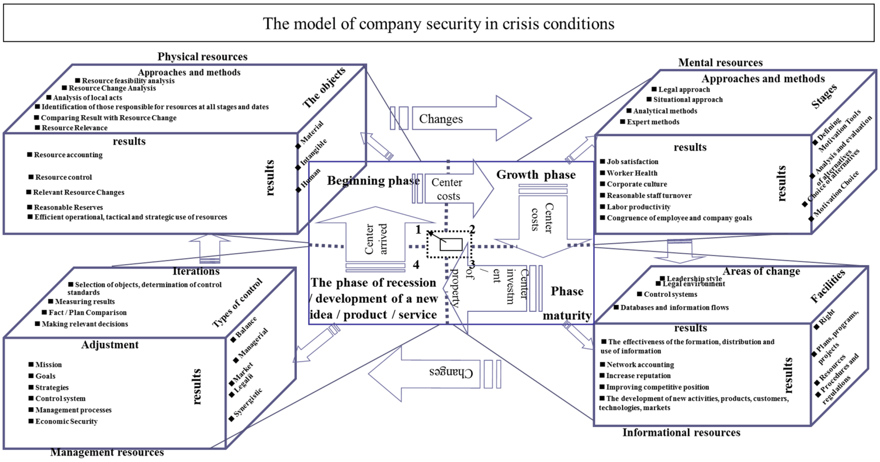

Fig. 1. The model of company security in crisis conditions. Source: developed and compiled by the authors.

The first block of the company's security model in crisis conditions are physical resources i.e. all those resources that ensure the functioning of the institutional unit, namely:

1) material, they are reflected on the balance sheet of the institutional unit and are evaluated in the accounting (financial) documentation, and also have two subspecies: a) financial i.e. cash and credit capacity (the amount of funds that an institutional unit can borrow in the financial market) and b) physical i.e. buildings and structures, production facilities, stocks and semi-finished products, finished products, etc.;
2) intangible resources, it is worth noting that directly any resources of an institutional unit are productive assets that the subject of legal relations has, so it is logical and appropriate to attribute to intangible resources: a) technologies used by the subject of legal relationship; b) intellectual property rights owned by an institutional unit; c) reputation i.e. the brand of the institutional unit itself among buyers, partners, the public, workers, etc., it has a cost estimate as defined as the difference between the market price and the value of all assets, thus there is "goodwill" and "badwill"; d) the corporate culture of the institutional unit, the right corporate culture is a very valuable intangible asset of the institutional unit, including due to the fact that it is very difficult to copy, and it takes a lot of time and effort to create the "necessary" corporate culture. A "proper" corporate culture can become a powerful tool for selecting, controlling, and motivating personnel, as well as a driving force in the business itself;
3) human resources, in turn, is the most important factor capable of developing an institutional unit, they are divided into: a) human capital, it represents knowledge, skills and know-how that cannot be formalized and which are thus inseparable from their carriers; b) social capital i.e. resources potentially available to the institutional unit that arise from the relations of employees with other people (including those outside the company) and their relationships.

Thus, objects of physical resources are determined, and therefore, after identifying objects, it is logical to switch to approaches and methods of working with them. Thus, the second sub-block of the first block of the model for ensuring the security of companies in crisis conditions is precisely "approaches and methods", such as: analysis of the appropriateness of resources determining which resources and when are deemed necessary and which are ballast; resource change analysis, those. Answers the questions of effective acceptance-transfer of resources and their adequate use; analysis of local acts, allows consolidating the formation, distribution and use of the resources of the subject of legal relations in local acts with special emphasis on the non-contradiction of normative legal acts; the determination of those responsible for resources at all stages with an emphasis on timelines allows solving issues with the final link of possible claims at the stages of formation, distribution and use of resources; comparing the result with changing resources answers the question of the justified and effective formation, distribution and use of resources, for example, having ten nails and five boards, it may be a task to nail boards I use two nails for each, the result should be expressed in the effective fastening of the boards t.e. nailed at once with two nails, and the use of resources should be effective i.e. if one nail in the process of work is spoiled, then there is no sense in arriving at one board with only one nail, because this will affect the final quality of the work, in this case it is necessary to establish the reason and use the reserve (eleventh) nail, the cause may be a marriage of the nail, in which case the question will be to who accepted them and the suppliers, or maybe in the inept work of the employee, respectively the question will be about his qualifications, which it is advisable to raise for the first time (having worked out the issue separately with the personnel department, namely, who is responsible for his hiring), and, in the second case, subject to disciplinary liability; the relevance of resources, in turn, determines their effective use, taking into account the above example, timing and responsibility.

The third sub-block of the first block of the company security model in crisis conditions is the results and are expressed in: accounting (accounting, tax, management) of resources; control of resources, through liability and storage efficiency; relevant change of resources expressed through their effective formation, distribution and use; the validity of stocks i.e. the availability of reserves sufficient for continuous operation, even in cases of force majeure, but at the same time, the reserves should not be excessive since this leads to an increase in the cost of their storage; effective operational, tactical and strategic use of resources, emphasizes the multifaceted approach to the processes of formation, distribution and use of resources i.e. takes into account congruence of goals and synergistic effect.

The second block of the company's security model in crisis conditions is mental resources; it also consists of three subunits:

1) stages: determination of instruments of motivation, analysis and evaluation of alternatives, possible choice of motivation, including alternative;
2) approaches and methods: legal (fixing in the local acts of an institutional unit not contradicting normative legal acts), situational ("floating" approach taking into account the behavioral peculiarity of individuals to rapidly changing and crisis conditions, that is, it allows you to adjust motivation with an emphasis on its performance currently), analytical (allows you to find an individual approach to each employee,

provide decent motivation, the emphasis is on non-monetary motivation), expert (determines which motivation is best for the subject of legal relations and why);

3) results: satisfaction with the place of work i.e. employees are satisfied with the ergonomics and microclimate of the workplace, i.e. health concern for the continuity of the work process, corporate culture i.e. microclimate with an emphasis on business reputation and business style, the validity of staff turnover i.e. minimization of layoffs and maximization of job satisfaction, labor productivity i.e. increasing the efficiency of the use of working time, congruence of the goals of the subject of legal relations and the institutional unit i.e. the desire to maximize the employee's utility functions at the same time should maximize the company's utility functions, for example, if a manager receives a bonus for the number of sales, he can sell goods to competitors, which will not be profitable for the company, which means that the manager must be stimulated in such a way that his efficiency is maximal for interests of the company, and therefore its own.

The third block of the model for ensuring the security of companies in crisis conditions is information resources has the following subunits:

a. means: law (regulatory instrument), plans, programs and projects i.e. directly how and how the work is carried out on the formation, distribution and use of information flows, resources i.e. IT-technologies necessary for the formation, distribution and use of information flows, procedures and regulations i.e. direct implementation of the formation, distribution and use of information flows;
b. areas of change: leadership style i.e. depending on the effectiveness of the leadership on the formation, distribution and use of information flows, the productivity of its subordinates, the legal environment i.e. change of local acts regulating the formation, distribution and use of information flows, management systems i.e. constructing relevant subordination, with an emphasis on personalization, unification and standardization of information flows, an important criterion in this case is the sufficiency of information i.e. there should be no unnecessary information, and the employee information should be exactly sufficient to fulfill his functions, which will also help protect commercial and other secrets, databases and information flows i.e. the formation of special databases that allow you to maximize response time to the search for important information.
c. results: the effectiveness of the formation, distribution and use of information by all subjects of legal relations in particular and the institutional unit as a whole, network accounting i.e. opportunities to use IT-technologies to increase work efficiency and all processes associated with the formation, distribution and use of information flows, increase reputation through goodwill and the media, as well as customer satisfaction, improve competitive positions through the above actions, mastering new types activities, products, customers, technologies, markets through relevant response to variables, taking into account information databases.

The fourth sub-block of the company security model in crisis conditions is management resources, it consists of three sub-blocks:

1) types of control: balance i.e. accounting of all resources, it is worth noting that ultimately everything on the institutional unit is reflected in the balance sheet and has a monetary value, i.e. management for the purposes of managers other methods and methods can be applied, for example, costs can be taken into account both by elements and by articles, market i.e. defines “goodwill” and “bedwill”, as well as the market value of all assets and liabilities, is calculated by hypothetical realization of all assets and hypothetical satisfaction of all obligations, legal i.e. correspondence of all actions to legal norms, i.e. synergetic i.e. emphasis is placed on the possibility of obtaining synergistic effects, processes and functions and the institutional unit should work in such a way as to maximize their utility functions.
2) iteration: selection of objects and determination of control standards, measurement of results, comparison of a fact with a plan, adoption of relevant operational, tactical and strategic management decisions.
3) adjustment and/or result: fulfillment of the mission of the subject of legal relations, fulfillment of goals, implementation of strategies, ensuring the effectiveness of the management system and management processes, as well as directly ensuring economic security.

The fifth block of the company’s security model in crisis conditions is the use of ideas, services, goods, responsibility centers in the phases of the life cycle, which makes it possible to attribute a specific project to a specific life cycle and, in accordance with it, identify weaknesses and strengths, and through the use of responsibility centers and their skillful use, to work effectively with them, therefore, in the formation of an idea, emphasis is placed on costs, with its initial implementation due to the fact that costs prevail over profit, costs are also priority, the maturity phase represents the greatest return, i.e. The profitability for which it is necessary and advisable to monitor, which means the center of ownership is the highest priority, it is also implacable that it is logical to use investments for development, both own (reinvestment) and borrowed, which means that the investment center is also important in the transition in the last phase, namely the decline phase, it is logical and appropriate to use the center of ownership, it is worth noting the fact that the decline in the effectiveness of one idea can only mean that it is advisable to modernize, which in turn will lead to the emergence (formation) of a new idea, such In this way, the cyclical nature of the life path of ideas, services, and goods is determined. All this is most relevant in a rapidly changing environment i.e. taking into account variables and crisis phenomena since the survival process of the institutional unit often depends on the response time.

4 Conclusion

Thus, the developed and proposed model for ensuring the security of companies in crisis conditions allows us to take into account changes in the external and internal environment, with an emphasis on the relevant formation, distribution and use of all resources of an institutional unit, maximizing the utility function of processes and ideas for capital appreciation, leveling threats and risks with while ensuring the stable development of the subject of legal relations, which in turn determines the effectiveness of economic security.

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Standard of Living of the Russian Population: Challenges and Alternative Solutions

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Abstract. The central economic theme adopted at the outset and held throughout the article is population incomes. This indicator calls predominantly not only for urgent actions on the part of the government in various fields of activity, but it is also considered an index of the welfare of the society. Income indicators: nominal and real incomes in particularly, the size of scholarships and pensions are crucial to determining the living standard of the population. Nevertheless, these indicators are not the only determinants of the standard of living. Some other economic factors, comprising the level of education and birth, are very important the welfare of the nation.

The subject covered in the article is especially pertinent to today's situation in Russia. The reason for this is that the country covers a large territory and is rich in natural resources, but it is faced with the thorny problem of unevenly distributed population, and consequently with the income differentiation in the country that in turn leads to social stratification and tension in the society.

Keywords: Government's proposals · Dynamics of the population incomes · Nominal and real disposable incomes · Composition of individual income · Social stratification

JEL Code: J24 · J18 · J38

1 Introduction

Income is, first of all, a source of satisfying the needs of people, but at the same time it is a revenue part of the federal budget (since it is generated from taxes on income of individuals and legal entities). Incomes of the population are divided into natural and money (Kovalenko et al. 2016).

Money income includes people's earnings and benefits in the form of wages, pensions, scholarships, allowances; as well as income from the use of property, the sale of shares and the provision of services, while natural income comes mainly from agricultural products from cottages or household plots, which are intended for personal consumption, and not for sale.

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There are several possible sources of income generation: salaries and wages (including bonuses and remunerations); income from business activity; from lending of private property; or selling of currency and some others (Poklonova et al. 2017). As a rule, salaries and wages account for the main part of the population income. The share of other sources is not significant, but it still exists.

Besides, we distinguish between nominal and real disposable incomes (Kovalenko et al. 2016):

- Nominal income is the amount of income excluding taxes and price levels.
- Real disposable income is the income that is available after you have made obligatory payments (taxes) and adjusted to consumer price index.

For the most complete analysis of the living standard of the population, indicators of real disposable income are used, since they are more objective and relevant, and reflect the current economic situation and the quality of people's life. Nevertheless, it should be borne in mind that the concept of' 'quality of life' differs in different countries. The quality of life is usually interpreted as a combination of several indicators: the level of economic well-being, demographic characteristics, health status, and the level of social well-being, such as living conditions, ecology, education, etc. (Repina 2017). For Russia, the main indicator is still the economic aspect, and we will consider it in this work.

All revenues received are mostly spent on meeting needs and wants, i.e. for the acquisition of material goods and services. The level of income determines the quality of consumed goods, as well as the amount that can be purchased with the given level of income (Kovalenko et al. 2016).

Another important component in determining the level of well-being of the population is the indicator of the total income: these are all means of the population, including benefits and free services. The growth of total income at stable prices and taxes is the evidence of an increase in purchasing power of population, i.e. the ability to satisfy their needs.

Further in this paper, we will consider changes in the incomes of the Russian population, their distribution over the territories, as well as the reasons for changes in income in certain periods of time.

The purpose of the article is to analyze the dynamics of the population incomes in Russia over the period of 2007–2017 and determine the sources and distribution of income. The paper aims to describe the role of the State and measures taken by the government to generate and allocate the income.

2 Materials and Methods

It should be noted that in researching the theme we studied articles published in the economic journals in which the measures taken by the government to generate incomes were described in detail. In the articles particular attention is paid to the government's proposals, the statistics from the official website of the Federal State Statistics Service and its analysis.

Thus, the research methodology is comprised of a thorough search for the scientific data, statistical analyses, systematization and generalizations of the research findings focused on identifying the current trends and their interpretation, supported by the data evaluation.

Unlike the majority of books and publications in the field of economics the paper is not a synoptic anthology of the writings of the current authors in the field. Instead, the article offers recommendations based on the authors' findings and alternative solutions to the existing difficulties and setbacks.

3 Research Results

3.1 The Dynamics of Russia Population Income

According to the Federal State Statistics Service, we compiled a table of per capita income within a period of ten years 2007–2017.

Table 1. The average per capita income of the population

Years	Rubles per month
2007	12,540.2
2008	14,863.6
2009	16,895.0
2010	18,958.4
2011	20,780.0
2012	23,221.1
2013	25,928.2
2014	27,766,6
2015	30,466.6
2016	30,747.0
2017	31,477.4

(From Federal State Statistics Service, 2019)

As it can be seen from Table 1, over the period of ten years, per capita income increased 2.5 times, but as noted earlier, you should not fully rely on this indicator. First of all, if you calculate the growth rate of this indicator, you can observe the downward trend as the growth of this indicator slows down every year that undoubtedly adversely affects the welfare of citizens; consequently, the most accurate indicator is the real disposable income of the population (Table 2).

After the 2008 crisis, the economy began to recover, there was a significant increase in real incomes of the population, but since 2014, due to falling oil prices, the imposition of sanctions against Russia, and the depreciation of the national currency (Kovalenko et al. 2016) the disposable incomes declined significantly.

Table 2. Real disposable income in Russia

Years	% to the previous year
2008	102.4
2009	103.0
2010	105.9
2011	100.5
2012	104.6
2013	104.0
2014	99.3
2015	96.8
2016	94.2
2017	98.3

(From Federal State Statistics Service, 2019)

However, in times of favorable economic situation, the country starts to undergo rapid stabilization, and then real incomes of the population go up, as it happened after the 2008 crisis. Besides, the government has taken certain social measures aimed at supporting the most vulnerable groups of the population. It subsequently has had a beneficial effect on their standard of living.

While speaking about the incomes of the population, one should also take into account their structure (Table 3).

Table 3. The composition of individual income

	2007	2008	2009	2010	2011	2012	2013	2014	2015	**2016**	**2017**
Total money income, billion rubles	21,311.5	25,244.0	28,697.5	32,498.3	35,648.7	39,903.7	44,650.4	47,920.6	53,525.9	54,117.7	55,466.6
Including (%)											
Wages, including hidden wages	67.5	68.4	67.3	65.2	65.6	65.1	65.3	65.8	65.6	64.6	65.1
Incomes from business activity	10.0	10.2	9.5	8.9	8.9	9.4	8.6	8.4	7.9	7.8	7.6
Social payments	11.6	13.2	14.8	17.7	18.3	18.4	18.6	18.0	18,3	19.1	19.7
Property incomes	8.9	6.2	6.4	6.2	5.2	5.1	5.5	5.8	6,2	6.5	5.6
Other incomes	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2,0	2.0	2.0

(From Federal State Statistics Service, 2019)

The predominant share in the income of the population comes from employment (more than 50%), followed by the income from entrepreneurial activity, the share of which declined after the crisis of 2008 and the events of 2014, since those were entrepreneurs who suffered most from sanctions. Over the period under review, there was an increase in the share of social payments, which indicates the practical implementation of the government social policy (Poklonova et al. 2016), as for other indicators, they show the downward trend in incomes.

As we have mentioned, real incomes of the population had a negative trend in 2015–2016, despite the fact that they nominally increased. What was the reason for it? This was due to the fact that during 2015 there was a decline in real wages and salaries, which, as we found out, made up about 50% of all incomes of the population. At the beginning of 2016 there was a decrease in real pensions, which was associated with a low level of their indexation (Fadina et al. 2016). Altogether, these factors led to a significant drop in real incomes of the population.

In determining the population standard of living, an important indicator to be considered is the differentiation of population incomes, i.e. classifying the population groups according to their income level. Table 4 shows what proportion of the population has one or another level of per capita income. (Kovalenko 2016).

Table 4. Distribution of the population by income level

Population with average per capita income per month, rubles	Year								
	2007	2008	2009	2010	2011	2012	2013	2014	2015
3,000–5,000	29.9	15.9	12.3	9.4	7.3	5.7	4.2	3.3	2.4
5,000.1–7,000	16,5	12.6	10.9	9,4	8,1	6,8	5.6	4,8	3.8
7,000.1–9,000	1.9	11.7	10.8	9.8	8.9	7.9	6.8	6.1	5.1
9,001.1–12,000	13.6	14.5	14.2	13.6	12.9	12.0	10,8	10,0	8.9
12,000.1–15,000	10.1	10.9	11,3	11.3	11.3	10,8	10,3	9,9	9.2
15,000.1–20,000	10.5	12.3	13.3	14.1	14,6	14,6	14.5	14.4	14.0
20,000.1–25,000	6,.0	7.5	8.6	9.5	10.2	10,2	11,2	11,4	11,6
25,000.1–30,000	3,5	4,7	5,6	6.4	7.1	7.8	8,4	8.8	9.2
30000.1–35,000	6,6	3,0	3,7	3.1	5.0	5.6	6.3	6.7	7.2
35,000.1–40,000	-	6.9	2.5	.8	3.6	4.1	4.7	5.1	5.6
40,000.1–50,000	-	-	6,8	5.2	4.5	5.4	6.3	7.0	7.9
50,000.1–60,000	-	-	-	-	6.5	3.1	3.8	4.2	4.9
Above 60,000	-	-	-	-	-	5.4	7.1	8.3	9.2

(From Federal State Statistics Service, 2019).

According to the data presented, it can be concluded that every year the number of people with the lowest incomes was declining while population with the highest income was growing. Besides, the share of the middle-income population was the largest. This indicated a positive trend, which has led to a rise in the general standard of living, but factually, the real level of income has fallen for most people.

In the analysis of income differentiation, a special Gini coefficient is used, which shows the degree of stratification of the society, and determines economic inequality: the higher this indicator, the higher the income inequality (Ahmedova et al. 2017).

Table 5. Gini coefficient.

Years	Gini coefficient
2007	0.422
2008	0.421
2009	0.421
2010	0.421
2011	0.417
2012	0.420
2013	0.419
2014	0.416
2015	0.413
2016	0.412
2017	0.410

(From Federal State Statistics Service, 2019)

According to the Gini index, we can conclude that the situation has not changed much over the past 10 years, and we can observe a moderate differentiation level. Nevertheless, the fact that coefficient makes up approximately a half is a negative feature for Russia, since the stratification of the society by the level of economic well-being is a symptom of social disease.

One cannot fail to consider such an indicator of the standard of living as subsistence level, since it is also important for determining the welfare of society (From Federal State Statistics Service, 2019). Every year the subsistence level rises, which is associated with both rising prices and growing needs of the society, but this does not mean that the rise leads to an increase in the standard of living of the population.

There is a direct correlation between the subsistence level and the average per capita income, so their ratio is calculated as a percentage - how much per capita income exceeds the subsistence level (Poklonova et al. 2016). As it can be seen from Table 5, this ratio over the past 10 years was in the range of 312–356%. However, as it was mentioned above, in connection with the events of 2014, this indicator fell, which also adversely affected the welfare of the society.

3.2 Differentiation of Incomes of the Population by Regions

The population of our country is extremely unevenly distributed throughout the territory, and consequently, the distribution of incomes is also uneven. Moreover, the size of salaries and wages for the same work in different regions is different, as well as the cost of living. All these factors lead to further differentiation in income. Conventionally, it is possible to classify the regions into 5 groups according to the money income of the population (Surkova et al. 2016):

The first group with an average per capita income of less than 15 thousand rubles per month. It mainly includes agrarian regions, and regions with a predominance of non-monetary incomes (Degtyareva et al. 2017), since their income is usually lower than that of industrial ones. These include: the Republic of Kalmykia, the Republic of Ingushetia, the Karachay-Cherkess Republic, the Republic of Mordovia, the Republic of Tuva and some others.

The second group with an average per capita income of 15–20 thousand rubles, is also characterized by mostly natural incomes, they include: 3 territories, 7 republics: Chechen Republic, Republic of Udmurtia, Republic of Adygea, etc., 19 regions: Vladimirskaya, Ivanovo, Volgograd, Tambov, Penza, Astrakhan, etc.

The third group with an average per capita income of 20–25 thousand rubles, is the largest, it includes 27 constituent entities of the Russian Federation, and is characterized by an average level of salaries and wages, an average density of population, and a low birth rate. These include: the Republic of Karelia, the Republic of Dagestan, Tula, Yaroslavl, Lipetsk regions and some others.

The fourth group with an average per capita income of 25–30 thousand rubles is comprised of only 7 constituent entities, and all its indicators are above the average. These include Krasnodarskaya, Permskaya and Khabarovskaya territories, the Republic of Komi and Tatarstan.

The fifth group consists of the regions with an average per capita income of more than 30 thousand rubles, and these are mainly the regions of the Central Federal district, cities of Federal status as well as Magadan Oblast, Nenetz Autonomous Okrug, Chukotka, and others.

As the analysis of these groups show, the largest number of the constituent entities of the Russian Federation has an average per capita income of 15−25 rubles, but there is a marked difference in incomes in different regions. As payment for work in industrial regions is higher than in agricultural areas (Arsakhanova et al. 2015) and the money form of incomes predominates the natural ones.

3.3 The Role of the Government Policy and the Ways to Prevent Real Incomes from Being Reduced

The government takes steps in creating opportunities for generating income for the population (Kabanov et al. 2017), besides social payments, the state provides salaries for civil servants (in the field of education, medicine, law and order, etc.). Moreover, the government succeeds in pursuing the policy of equalizing income differentiation between regions of the country by supporting low-income citizens, and small and medium-sized businesses. All these measures lead to an increase in economic well-being, which in turn has a positive effect on the average per capita income of the population.

However, the most promising and relevant methods of the government influence on population's income include the following (Kabanov et al. 2017):

- Development of the rural economy. As we discussed earlier, the first groups of regions with the lowest income include entities where the share of agriculture is large and the non-monetary form of income predominates.
- Reinforcement of taxation and pension reform. This issue has also become relevant recently, since there was an increase in the retirement age, which led to outbreaks of dissatisfaction among the citizens, and it is not known yet how this reform will manifest itself in the subsequent years.
- Elaboration of the government demographic policy, since population decline has become another problem of modern Russia, which must be focused on in order to restore the country's labor resources at the expense of natural population growth, but not at the expense labor migration.

The above problems are the reasons for the differentiation in incomes of the population, which leads to a higher social tension as the regions of the country with the highest incomes are overcrowded. To remedy this situation, the government should pursue an active policy in this area (Kostromina et al. 2017): for example, increase the minimum wage to fight poverty and unemployment; increase the percentage of revenue from the federal budget on salaries, wages and transfer payments.

4 Conclusion

Having examined the indicators of per capita income, real disposable income of the population, and the subsistence level income, as well as the differentiation of income among the population, we can conclude that the level of well-being of the population in this country is not sufficient yet, because there are problems such as a decline in real income, stratification of society by income level, low wages and unemployment. All these problems may result in a higher social tension in the society.

First and foremost, the government must be looking for ways to solve the analyzed problems. Their purpose is to stimulate economic growth, contribute to the improvement of living standard of the population and provide for the reduction in unemployment. Such effective government measures as social benefits, the program to support small and medium-sized businesses and others are aimed at achieving this goal.

The government policy should be targeted at closing the gap between the structure of incomes of the Russian population and a similar structure in the developed countries of the world.

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Special Aspects and Problems of Forest Utilization in the Legislation of Member States of the EEU

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Abstract. Purpose: The paper is concerned with the consideration of the problems of legislative regulation of the sustainable use of forest resources by the member states of the Treaty on the Eurasian Economic Union and cooperation in this field against the background of harmonization of national legislation proclaimed in the 2014 Treaty on the Eurasian Economic Union as one of the instruments that should be used to achieve goals set before the EEU.

Design/Methodology/Approach: The authors analyze the problems related to the need for digitalization and creation of an information resource that would contain information about quantitative and qualitative characteristics of natural resources and information about legal regulation of mechanisms for their provision.

Findings: The paper gives consideration to certain provisions of national forestry legislation and legislation on investment activities of the EEU member states, adopted both before and after the creation of a Union; the authors analyzed situations that, against the background of new legal realia which have already arisen and will continue to arise in the future due to the need to coordinate activities within a common economic area.

The authors study the provisions formalized in laws and regulations of the EEU member states, which regulate the access of foreign entities to forest resources of states, preventing the efficient economic cooperation of countries or promoting such cooperation.

Originality/value: The paper is focused on differences in approaches of national legislators both to the concept of forest utilization as such and to the subjective composition of participants in forestry relations. In this regard, the authors conclude about the need for further harmonization and unification of national policies of the member states of the EEU, as well as the adoption of supranational acts within the Union regulating the use of natural resources, including forest resources. Currently, there are only few treaties between individual states that designate the range of issues in our field of concern; however, they focus on cooperation in the field of environment protection, and do not establish any rules and provisions on the utilization of the natural potential that would be economically advantageous to all member states of the Union.

Keywords: Harmonization of legislation · Eurasian Economic Union · Investment · Forestry legislation · Environment protection

JEL Code: O17 · Q2

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1 Introduction

The issues related to access to information have been recently assuming critical strategic importance both for society and for the states. This particularly concerns the accessibility of information about natural resources and the possibility of using them. In many cases, legislation of most countries does not regulate the issues of access to information for foreign entities; their cooperation in this regard is deficient or lacks efficiency. All of the above, of course, also refers to the issues of interchange of information between the states included in the Eurasian Economic Union. It should be emphasized that the very essence of the economic union of states implies the possibility of access of foreign residents to natural resources; to this end, it is necessary to develop a common database that would contain information about quantitative and qualitative characteristics of natural objects, and above all information about legal regulation of mechanisms, providing the possibility of using them by business entities, investors, and other persons. It would seem that the Eurasian Economic Union cannot but follows the path of informatization, including as a political process aimed at building and developing an infrastructure that would combine geographically scattered information resources. A different picture can be observed in practice however. Access to information on possibilities of sustainable use of natural resources, including forest utilization that is of interest to us, is severely limited. This is primarily due to certain closeness of national legislation and the absence of uniform regulatory acts. The problem of harmonization of legislation is also related to the problem of informatization. There is no common database of laws and regulations of member states; there are no conditions for their approximation.

It appears that the principles and achievement of goals set before the Eurasian Economic Union must be effected through the very same harmonization of legislation of the EEU member states which is referred to in the Treaty on the Eurasian Economic Union which was signed in Astana on 29.05.2014. Based on the analysis of the text of this act, it clearly follows that harmonization as such is not a task which the members set themselves. It appears that harmonization, which is intrinsically an approximation of legislation which is mainly focused on the initiation of uniform regulation of similar public relations by legal provisions, and the harmonization of standards, which constitutes an approximation of national legislations with a view to establishing identical mechanisms for regulation of similar public relations – corresponds to the tools that should be used to implement these goals.

As can be seen from the provisions of the Treaty, the member states of the Eurasian Economic Union aim to liberalize service trade, institutions, and investment activities. Of course, the target goal can only be achieved through harmonization of legislation under mutually advantageous cooperation.

It is expected that this process must be based on a number of principles.

First of all, this is the principle of optimizing domestic regulation. It implies simplifying and reducing the provisions governing the issuance of all types of permits, and carrying out procedures for suppliers, service recipients, and entities that carry out operations or activities, as well as for investors.

Further, the authors refer to the pro rata principle; in other words, achieving such level of harmonization of national legal provisions and such level of cooperation that will enable effective functioning of the service market and institutions. We may also talk of the operating efficiency and investment activities.

Another principle is the win-win relationship principle. While complying with it, the member states of the EEU equally divide between themselves the benefits and liabilities, taking into account, of course, the individual specifics of the market, service sectors, and kinds of activity of each of them.

Last but not least is the principle of consistency. It is expected that the member states consistently operate, inter alia, at the level of activities and investing.

Accordingly, it may be concluded that the need for synchronization and harmonization of legal regulation of all areas of economic activity within the framework of the EEU must become a vital task of legislators of the member states of the Union, given the fact that the development and implementation of joint development programs are significantly complicated or even impossible due to non-conformities in legal framework and specifics of national regulation.

2 Materials and Method

The authors carried out the empirical analysis of international law acts of the Eurasian Economic Union passed both before and after the execution of the Treaty on the Eurasian Economic Union, and national legislation of its five members - Russia, the Republic of Armenia, the Republic of Belarus, the Republic of Kazakhstan, and the Kyrgyz Republic.

While analyzing the forest utilization policies of the member states of the EEU, we have observed and assessed legal, economic, and other factors related to the implementation of forest conservation. The research was based on the analysis and synthesis of new statutory provisions and the already ongoing process of formation of law enforcement practice (Smirnov 2020).

The analysis was aimed at identifying the factors contributing to international cooperation between the member states of the Eurasian Economic Union.

3 Results

It should be noted that there are no multilateral contracts or agreements concluded in the framework of the EEU, the purpose of which would be to regulate the management of natural resources. The Treaty on the EEU as such contains no special provisions that would regulate relations in the field of our interest. This does not mean however that there has been no need for such legal policies throughout the existence of the Union.

We can mention regulatory acts that were adopted by the EEU member states within the CIS, although they are mainly focused on environment protection in the region; nevertheless, they are also concerned with the regulation of relations in the field of natural resources in general and the use of forests in particular. For example, this is the 2013 Agreement on Cooperation of the Member States of the CIS in the Field of Environment Protection. There are also a number of bilateral treaties, which include the 2004 Agreement between the Government of the Russian Federation and the Government of the Republic of Kazakhstan on Cooperation in the Field of Environment Protection, and the 1994 Agreement between the Government of the Republic of Belarus and the

Government of the Russian Federation on Cooperation in the Field of Environment Protection.

The 2013 Agreement on Cooperation of the Member States of the CIS in the Field of Environment Protection also discussed harmonization of legislation and cooperation in forest utilization. In addition to the above, joint development and adoption of laws and regulations, provisions and standards in the field of management of natural resources, as well as harmonized methods for the monitoring of wild plants were proposed in the framework of cooperation in this area.

The Interstate Council on Ecology is entrusted with responsibility to facilitate in the elaboration of methodological approaches to solving economic issues of the use of natural resources and environmental protection, as well as to manage the development of various types of programs and projects in the field under consideration, both at the inter-State and regional levels.

Not that long ago, the countries of the former Soviet Union, which are currently independent states, were combined by the forestry management system, fully built on the principles of a planned, administrative business model. The literature sources point out that during the time since the collapse of the Soviet Union, each former Union Republic has formed its own unique management system in the field of forest utilization and conservation in proportion to its natural specifics and economic opportunities (Bagirov 2016).

Federal Law of June 9, 1999 No. 160-FZ "On Foreign Investment in the Russian Federation" in force in the territory of the Russian Federation defines in a similar way the conceptual framework in the field of foreign investment with laws regulating the investment activities of the member states of the Union, and come down to the possibility of investing in business ventures in the territory of the Russian Federation by foreign entities (though for some reason national legislator does not indicate the primary goal of investment - realization of profit - in the definition), Article 15 establishes guarantees of the provision of rights to the plots of land and other natural resources to the foreign investor.

It should be noted that Article 15 of the cited Law does not provide any guarantees for foreign investors, yet it merely establishes a general provision according to which foreign investors may acquire rights to natural objects, but only on the grounds that are directly stated in Federal and regional legislation, that is, in point of fact, it gives us a reference to the same Forestry Code of the Russian Federation, which would not regulate forest utilization by foreign entities (both legal entities and individuals). The Article, however, points out that commercial entities established with the involvement of foreign capital may be granted the right for the execution of a contract for the lease of a land plot through a public bidding process, unless otherwise provided for by legislation of the Russian Federation. However, the possibility of participation of a foreign-owned commercial entity in the bidding process by no means determines the guarantees of equal access to other natural resources to other foreign investors.

Hence, foreign legal entities, foreign nationals, persons without citizenship are still considered to be participants of forestry relations.

Pursuant to Article 22 of the Forestry Code of the Russian Federation and Federal Law No. 39-FZ of February 25, 1999 "Concerning Investment Activities Carried Out in the Russian Federation in the Form of Capital Investments", non-residents are entitled to invest in forestry. Further, it is recognized that facilities of both forestry and processing sectors that are created or upgraded shall be recognized as investment facilities. In addition, under Paragraph 2 in Article 5 of the Land Code of the Russian Federation, they are allowed to have rights (including to exercise ownership rights) to the plots of land that are occupied by forests. However, other federal legislation, including the Forestry Code of the Russian Federation, does not contain any provisions on the relevant prohibitions, thus foreign entities can be participants of property relations, including those where the parcels of forest land serve as the object of relations.

Hence, it may be concluded that though forestry legislation does not contain any express prohibition on forest utilization by foreign nationals (though they can only participate in these relations within the framework of investment activities), business entities of member states of the Eurasian Economic Union, despite the creation of a common economic space with the Russian Federation, have been equalized in rights (and duties) with any foreign investors, thus they have no preferences whatsoever.

It should be mentioned that legislation of other member states of the Treaty on the Eurasian Economic Union regulates these relations in absolutely different ways. Thus, nothing is mentioned about the possibility of forest utilization by foreign nationals and foreign legal entities forestry legislation of the Republic of Armenia, in a similar way to Russian Federation. The Forestry Code of the Republic of Armenia, adopted on October 2, 2005, defines forest user as an individual and legal entity who/which is entitled to benefit from forests and parcels of forest land, under a statutory procedure.

The Law of the Republic of Armenia "On Foreign Investment" designates four types of rights, which include, in particular, granting the right to utilization of land and concession rights for the use of natural resources in the territory of the Republic of Armenia. This means, in particular, the autonomous acquisition of these rights by foreign investors. However, Article 19 of the same Law states that these relations are governed by relevant legislative acts of the Republic of Armenia, which means it makes a reference to special legislation in the same manner as Russian legal acts. According to such authors as Belov, Gritsenko, and Zhmulina, there is no special regulation of concession agreements in the country, but the Law of the Republic of Armenia "On Foreign Investment" establishes a provision, according to which foreign investors can conclude contracts for the right to use both renewable and nonrenewable natural resources (Belov 2015).

According to Shakhrai (2019), concession agreements that are concluded with regard to the use of natural resources and primarily the use of sites of subsurface resources, are formalized in legislation in the member states of the Union. At the same time, the presence of legal provisions in legislation of these countries which are used to regulate concessional relations does not mean that they are in-demand. The literature sources point out that in actual fact they are sporadic. There are several reasons behind this situation – poor regulation of relations precisely in the field of natural resources (Bagdasarova 2009) and out-of-state balance of legal policies in the sector of investment and natural resources (Shingel 2017), third, law enforcement issues, since governments tend to grant a concession to those facilities the implementation of which is too complicated (Manenok 2017).

Kazakhstan lawmakers took it a step further, having formalized a binding express prohibition on the provision of land plots from the state forestry fund to foreign nationals in the Forestry Code of the Republic of Kazakhstan of July 8, 2003. Article 29 of the Forestry Code of the Republic of Kazakhstan establishes that only individuals and legal entities of the Republic of Kazakhstan shall be entitled to participate in public bidding for the procurement of the right for the long-term use of forests growing on parcels of forest land included in the state forestry fund. That said, there shouldn't be any foreign participation in the charter capitals of legal entities.

Further, Paragraph 2–1 of Article 31 of the Forestry Code of the Republic of Kazakhstan contains a provision, according to which the citizens of the Republic of Kazakhstan and legal entities of the Republic of Kazakhstan without foreign participation shall be entitled to participate in public bidding for the procurement of the right for the long-term use of forest resources for logging.

It is notable that the Law of the Republic of Kazakhstan "On foreign investment" of December 27, 1994 was declared to be no longer in force with the adoption of the Law of the Republic of Kazakhstan N 373 "On investment" on January 8, 2003.

Article 23 of the Business Code of the Republic of Kazakhstan, which lists business entities, does not contain any mention of foreign legal entities or individuals as business entities; however, they are referred to as market participants in Article 164.

We are falling under the impression that Kazakh legislators are not very consistent in the legal regulation of the area of relations that concerns the attraction of foreign investors in the national economy, which is not quite in line with the Resolution of the Government of the Republic of Kazakhstan No. 498 "On approval of the investment promotion program "National investment strategy"" adopted on August 22, 2017, and introduction of amendments in the Resolution of the Government of the Republic of Kazakhstan No. 1136 "On approval of the list of government programs and invalidation of certain Resolutions of the Government of the Republic of Kazakhstan" adopted on December 30, 2015.

The situation with legislation of the Kyrgyz Republic and the Republic of Belarus is absolutely different.

Article 14 of the Forestry Code of the Kyrgyz Republic states that "the parcels of forest land may be provided for the use to legal entities and individuals of the Kyrgyz Republic, foreign legal entities and individuals, as well as international organizations".

Article 7 of the Forestry Code of the Republic of Belarus of December 24, 2015 establishes that the parties to the relations in the area of use, conservation, protection and regeneration of forests are, inter alia, foreign legal entities and their representative offices, foreign nationals, and persons without citizenship.

Article 1 of the Law "On investments in the Kyrgyz Republic" refers to "concessions, including those for exploration, development, extraction or exploitation of natural resources" as a form of investment.

Concession agreements may be proposed as one of the forms of public-private partnership, as a one-stop shop for international cooperation among the member-states of the Union in the field of relations involving natural resources; however, as is pointed out in the literature, for example, the Republic of Armenia does not set any provisions that would regulate the models of public-private partnership in its traditional sense in its legislation. Instead, the legislator proposes other mechanisms: privatization, leasing, public procurement, investment contracts, public administration, etc. Concession agreements are either not mentioned at all or their detailed regulation is not spelled out (Belov 2015).

However, Russia and Belarus are tied by friendly relations, i.e. relations within the framework of a Union State. As concerns Belarus, Russia and Kazakhstan, they, among other things, are current members of the Customs Union, which implies the existence of a common economic area.

It is clear that such position does not contribute to the formation of a common legal framework, supranational legislation in this area of relations and requires at least harmonization, if not unification, of legislation, including the area of forestry relations. Therefore, it seems necessary to adjust the "residency" principle towards its expansion, which will be relevant not only in the context of the Customs Union, but also to the EEU.

Based on the analysis of Decree of the Supreme Eurasian Economic Council No. 112 of 23.12.2014 "On approval of individual national lists of restrictions, exemptions, additional requirements and conditions within the framework of the Eurasian Economic Union for the Republic of Armenia, the Republic of Belarus, the Republic of Kazakhstan, the Kyrgyz Republic, and the Russian Federation", it may be concluded that legislators of the member states of the Union are not aimed at elaborating a unified approach to regulating the overall status of foreign business entities and ensuring their equal access to forest utilization. On the contrary, the national legislation of these countries provides for various exceptions, limitations, additional requirements and conditions for foreign entities.

The provisions of the Treaty on the EEU formalize own legal policies of the member states in violation of the provision on harmonization of legislation, and encourage the member states of the Eurasian Economic Union to conduct such policies based on their own concepts of priorities and principles in relevant areas of relations, while restricting access of foreign partners to natural resources sectors.

4 Conclusion

Unfortunately, thus far, the execution of the Treaty on the EEU provides no guarantee of the implementation of principles of unification or harmonization of legal framework for the member states in the field of forest utilization and forest conservation.

There is not a single document of the Union that would directly formalize the rules of the use of natural resources in its territory.

The laws and regulations of the EEU member states in the field of forestry relations must be improved or amended by including in them clear policies regarding the legal status of foreign entities. They should directly establish preferences for economic entities registered in the EEU member states. This affects forestry legislation as such and legislation on investment activities.

In our opinion, there is an urgent need to improve national legislation concerning the legal status of non-residents from the member states of the Union, including the field of forest relations. A uniform procedure should be created for them that would guarantee equal access, along with residents, to the use of forest resources in the territory of these states (Navasardova 2016; Kolesnikova 2019).

Accordingly, the modification to create a homogeneous legal space of the Union for the natural resource-related types of activities of business entities from among member states may become a factor in accelerating integration processes, to contribute to the creation of conditions for the sustainable economic growth of the EEU member states.

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Main Trends and Directions of Innovative and Sustainable Development of Housing Construction

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Abstract. Purpose: The article analyses the main barriers and trends of innovative and sustainable development of housing construction in order to determine the key directions of housing strategy development at the regional level.

Methodology: The authors highlighted institutional-synergistic, systemic, integrated and integral approaches that allow us to form mechanisms for a flexible response to the system of managing innovations in housing construction, responding to the needs of the state, business and the population. The need for public administration through the establishment of a system of government by bridging over the contradictions between the economic and social efficiency of the region is justified.

Results: The scientific novelty consists in the development of theoretical provisions for improving the strategy for managing innovative and sustainable housing development at the regional level:

1. The authors identified the types of consumer properties of the residential environment, taking into account the differentiation of the consumer by income level and the possibility of changing the quality of the average apartment of mass development, which make it possible to determine the normative level of quality when designing innovative construction projects.

2. As a criterion for the level of sustainability of the development of the territory, the “socio-environmental-economic efficiency” of housing construction is justified and proposed, which is a system of quantitative and qualitative indicators characterizing the results of innovative and sustainable development of the region.

Based on the application of the institutional and synergistic approach, the authors formulated the goals, functions and elements of the management system for the innovative and sustainable development of housing, the implementation of which is carried out through the monitoring of indicators of sustainable development of the region.

Recommendation: The proposed types of consumer properties of the residential environment will determine the normative level of quality of the residential building and formulate minimum requirements for innovations in economy-class housing, which construction enterprises produce as a product of mass housing construction.

The goals, functions and elements of the system of management of innovative and sustainable development of regional housing construction formulated by the authors contribute to improving the efficiency of construction enterprises and the effectiveness of state authorities.

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1 Introduction

In recent years, housing construction has been developing at a rather high rate in Russia, but the speed of introducing innovative environmental-oriented processes leaves much to be desired. One of the reasons for the insufficient level of innovative activity of construction enterprises is the lack of a single center for making managerial decisions regarding construction production at the technical, technological and organizational levels (Ershov 2018).

The introduction of innovative technologies at the corporate level is a key factor in improving the competitiveness of the construction company. It is the application of knowledge-intensive advanced achievements aimed at solving environmental problems and shaping the sustainable development of individual regions and the country as a whole that will improve the quality of scientific and technological support for the housing sector and will contribute to the functioning of the construction enterprise on the basis of the principles of progressive development in order to improve its reliability and stability (Uskova 2009).

The analysis of Russian and foreign practices in the management of socio-economic systems showed that there is still no single methodological framework accepted by the scientific community that meets the requirements and features of the development of the Russian economy and includes modern economic, environmental and sociological parameters that will form mechanisms for a flexible response of the construction management system to the needs of the state, business and population (Shedko 2016).

Overcoming the contradictions between economic and social efficiency may be an option to address the above. The introduction of environmentally sustainable high-performance innovations in housing construction requires high-quality human potential, which ensures the social stability of society and affects the environment. This means that the achievement of social goals contributes to the growth of economic efficiency, therefore, it is necessary to create conditions for positive interaction and coherence between economic and social efficiency (Stiglitz 2016).

In this regard, a set of measures of public administration is needed, including regulatory impact, ensuring the innovative and sustainable development of the socio-economic system, including the stability of indicators of the functioning of housing construction in a particular region.

2 Methodology

The concept of "sustainable development" remains the subject of acute controversy among scientists, politicians and economists (Petrina 2017). The reasons for the ongoing discussions are due not only to different approaches to the interpretation of its essence and scope, but also to the complexity of describing the concept by generally accepted quantitative indicators (Uskova 2009). However, the analysis of the content of this concept as a separate category makes it possible to distinguish two main areas:

1) ecological stability of territories;
2) socio-economic stability of territories.

It should be noted that the category of "sustainable development" is considered by the levels of economic activity: international, national, regional, sectoral and level of the individual enterprise.

Due to the changes in internal and external factors affecting the sustainable development of the socio-economic system, the emergence of material and spiritual needs of the population, with new requirements for the quality of housing conditions of modern man, the search for strategic management methods and ways of socio-economic development in conditions of minimizing costs and ensuring the environmental safety of construction in the space-time continuum, becomes an urgent scientific task (Lazhentsev 2013).

3 Results

The main reasons that are barriers to the widespread spread of promising innovative trends in the Russian investment and construction complex include the following (Chernov 2015):

– insufficient investment resources;
– conservatism of consumers towards introduction of technologies of additive construction and digital technologies;
– constant growth of market value of 1 sq.m. of living space against the background of falling real incomes of the population;
– population collected many loans and has long-term mortgages;
– insufficient application of innovative technologies in the construction of construction facilities;
– Inadequate legislative and regulatory frameworks on environmental and energy conservation in construction and housing and communal services;
– dependence of construction enterprises on administrative bodies and public investment in the development of social infrastructure;
– high price for construction materials, as well as shortage and increase in the cost of qualified specialists, etc.

At the same time, there are a number of positive trends that are global drivers of innovative and sustainable development of construction at the international level:

– an increase in the proportion of urban dwellers in most regions, which contributes to the growth of high-rise buildings;
– development of legislative and regulatory documents regulating the construction of energy-efficient buildings;

– increase of labor productivity in construction due to digitalization of economy and formation of new profitable knowledge-intensive industries;
– improvement of transport-oriented and green development, as well as intersectoral interaction;
– reduction of construction time, creation of sustainable infrastructure of urban space due to industrialization, including fast-moving buildings;
– visualization of territorial information modeling of design, engineering solutions, construction works execution technologies;
– automation and robot based automation of construction technologies, including E-Plan programs, BIM technologies, 3D design and 3D printing;
– an increase in the population's demands for the quality of a residential building in terms of its environmental friendliness and energy efficiency;
– active use of building waste recycling, etc.

Achieving growth in the volume of new housing commissioning largely depends on the methods of financing any investment and construction project. The introduction of a housing financing scheme through escrow accounts (project financing) from July 1, 2019 allowed attracting borrowed funds from banks and reducing risks of misuse of equity holders' funds. At the same time, requirements for construction companies have tightened, which leads to the monopolization of the housing market by large players, the mass departure of most medium-sized companies and an increase in the cost of 1 sq.m. of housing being built. As a result, there is a need to develop state housing policy measures that will create equal market access conditions for large and small developers (Shvydenko 2018).

In designing innovative construction projects, the issue of determining the standard level of quality of a residential building remains the most important. In recent years, population requirements for safety, comfort, energy efficiency and environmental friendliness of housing have been increasing. In turn, the development of strategic directions for the development of housing construction should take into account a wide range of changed consumer preferences.

The main types of new apartments in high-rise new buildings can be classified according to the following characteristics:

1) by residential market segments;
2) on the consumer properties of apartments, taking into account the division of the consumer by income level.

In our opinion, it is most appropriate to determine the following types of consumer properties of housing taking into account the use of modern innovative technologies, which are presented in Fig. 1.

The application of the proposed segmentation, depending on the level of housing quality in each segment of the market, helps to identify the normative level of quality in the design of mass housing buildings based on the differentiation of the consumer by income level.

The main goals of innovative and sustainable development of construction include:

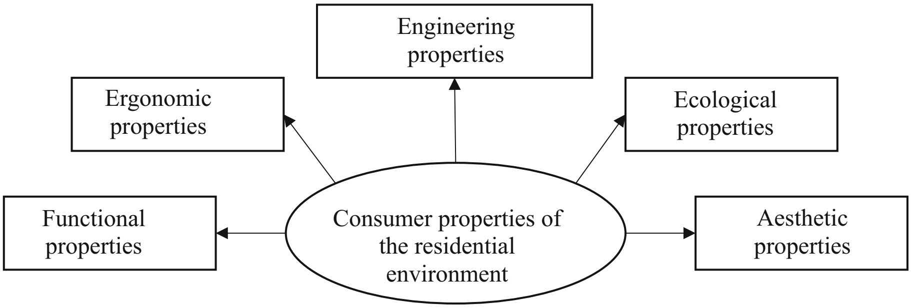

Fig. 1. Consumer properties of the residential environment, taking into account the use of modern innovative technologies

1. Increasing economic sustainability is achieved by optimizing the costs of construction enterprises and justifying the choice of the most economically promising ways to use construction facilities to attract investments in innovations that meet the general requirements of energy efficiency and environmental friendliness. Such an approach should ensure a transition to the sustainable functioning of the housing sector and create conditions for expanding the volume of construction of mass affordable, safe and comfortable housing based on integrated development of territories (Olatalo, 2017).
2. Increasing social sustainability can be ensured by a state guarantee to owners of construction facilities of their rights and interests if they undertake to comply with recommended social norms when using innovations.
3. The improvement of environmental sustainability is achieved by a large-scale transition from the construction of a separate construction facility with an adjacent land plot to entire "green" cities, the construction of which is regulated by the principles of sustainable development.
4. Improving spatial management stability is ensured by choosing the best location of various innovative communications in the development and application of information modeling technologies for spatial and territorial planning of the city.
5. The increasing promotion of environmental innovation in housing and the strengthening of the role of society can ensure the participation of non-profit organizations working on the principles of outsourcing and crowdsourcing in the process of territorial planning of the region.

The problem of improving the efficiency of innovative and sustainable development of the region, including housing construction, is a multidimensional and complex task, which consists in an unambiguous and unified assessment of its level and dynamics, which is very problematic (Uskova 2009). To develop such assessment methods, it is necessary to determine the requirements for selecting a criterion for sustainable development, which will include manifestations of economic and socio-environmental priorities for the development of the territory (Shvydenko 2019).

The theoretical analysis of the literature makes it possible to distinguish the following key requirements for selecting the criterion for the sustainable development of the economy of territories:

– evaluates the consistency of development of all subsystems of the society;
– promotes coordinated human and environmental development (a co-revolutionary approach);
– enables quantitative and qualitative measurement of the main directions of sustainable development of the Territory;
– takes into account the institutional, social, environmental, economic and financial aspects of sustainability;
– characterizes the objective relationship between extended reproduction and labour costs;
– reflects the patterns of development of productive relations in society, etc.

In our opinion, such a criterion can be the "socio-environmental-economic efficiency" of construction, since its economic content meets the above requirements and reflects the degree of dependence of sustainable development on the level of the scientific and technical base of production and on the quality of the labor force. In turn, improving the quality of the workforce depends on the state of health, level, lifestyle and life expectancy of a person.

The main advantage of socio-environmental-economic efficiency as a criterion for the level of sustainability of the territory's development, unlike GDP, is the assessment of the entire reproduction process and the ability to compare the results achieved with costs in order to assess the improvement (not deterioration) of environmental living conditions of the population and positive social consequences at a qualitative level (Stiglitz 2016).

The adoption of the proposed category in the economic practice of the strategic management of the region will allow the calculation of a qualitative measurable assessment of economic efficiency based on the consideration of environmental and social components, as well as its comparison with the quantitative economic results of production.

The following functions of managing the institutional sustainability of the region's economy can be distinguished:

1. The natural-technological function consists in the scientific justification of the use of high-tech innovative technologies, taking into account the environmental conditions for their implementation.
2. The forecasting and economic function is traditionally responsible for assessing the forecast state of factors and parameters of sustainable economic development at the regional level.
3. The infrastructure function is responsible for stabilization the system and assesstment of the possibility of balancing all elements that are part of the region's economic development infrastructure.
4. The protective and stabilizing function is due to the need to develop and implement actions that counteract negative external factors.

5. The control and information system performs the task of ensuring a system of regional regulation at the federal level and detecting contradictions in the economic activities of enterprises.
6. The socio-institutional function is responsible for the development of self-regulatory institutions of society, which will make it possible to form a single regional strategy of state, public and economic institutions based on the effective interaction of authorities at all levels of government in order to create a common economic policy for the sustainable development of the territories.

The proposed functional orientation will allow coordinating the management activities of territorial institutions of state power with the interests of society and preserving the general principles of state management, solving the problems of sustainable development with specific instruments of influence on the problems of individual regions. However, it should be noted that the practice of implementing sustainable development goals indicates that municipalities should play a proactive role as territories responsible for organizing the reproduction of resources and are minimal in area.

Targeted management of the development of the region involves the use of monitoring as one of the main tools for tracking changes in the economic situation that arise in the process of implementing the sustainable development of the territory (Shedko 2016).

Monitoring is carried out by analyzing the values of the sustainable development indicator system of the region, which simultaneously reflect the balance between the key components of sustainable development and the balance between the interests of stakeholders.

The main goals and objectives of monitoring the sustainable development of the region include:

– analytical studies of the obtained information on factors and indicators (indicators) reflecting the current state of the region's economy;
– identification of major positive and negative trends in the socio-economic impact of sustainable development in the region;
– development of short- and long-term development projections aimed at overcoming negative and supporting positive trends in the social, environmental and economic components of the region's development;
– exchange of final data between public authorities, local self-government, the population and other stakeholders in society;
– improvement of monitoring methods and procedures.

4 Conclusions/Recommendations

In conclusion, it should be noted that, forming a single economic space, the regions should create the conditions for the development of a strategy for the sustainable development of territories, which includes a mission, strategic development directions and strategic actions as complexes of policy measures developed on the basis of the coherence of interests of economic entities, the region, the state and society.

To overcome the contradictions between the economic and social efficiency of the territory, the authors substantiated and proposed the indicator "socio-environmental-economic efficiency" as a system of quantitative and qualitative parameters for the development of innovative and sustainable development of housing construction in the region.

The types of consumer properties of the residential environment identified by the authors will determine the normative level of the quality of the residential building and formulate minimum requirements for innovations regarding economy-class housing, which construction enterprises produce as a product of mass housing construction.

At the same time, the development of an innovative and sustainable housing management system at the regional level within the framework of the existing socio-economic conditions should include the achievement of high-quality construction production and final construction products. The subjects of such a management system are state authorities (regional and municipal entities), which carry out specific measures to introduce advanced technologies, as well as control during the implementation of innovative investment and construction projects. The objects of management are construction companies and business entities associated with the activities of these organizations: design companies, manufacturers of construction materials, house-building plants, transport companies, etc.

The findings complement the theoretical aspects related to the transition of socio-economic systems to the post-industrial type of reproduction in the context of globalization and the emergence of an innovative type of economy, in particular in the field of managing the regional housing policy of the state. The implementation of the proposed recommendations will increase the efficiency of construction enterprises and the efficiency of state authorities.

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Assessment of the Socio-Economic Situation of the Regions as a Tool for Realizing the National Development Goals of Russia

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Abstract. Purpose: The main purpose of this study is to develop a system for a comprehensive assessment of the comparative socio-economic situation of the regions of Russia for the supporting managerial decisions on the implementation of the national development goals of the country in the territorial context.

Methodology: The authors' methodological approach to a comparative assessment of the socio-economic situation of the regions of the Russian Federation has been developed due to the substantiation of a new system of interrelated indicators reflecting the most important social and economic aspects of regional development, which is associated with the implementation of Russia's national goals. A logically grounded methodology for the integral assessment of the current socio-economic situation of the regions is stated, criteria for the classification of the subjects of the Russian Federation is proposed for the entire set of factors of regional development.

Results: The article presents integral assessments of the comparative socio-economic situation of the constituent entities of the Russian Federation calculated with using the new methodology, including those characterizing the overall demographic situation in the regions, the state of the environment, the level of real incomes and employment of the population, the degree of development of key sectors of social infrastructure and also the general the level of economic activity in the regions, infrastructural provision of the territory, innovative potential, investment activity and the financial situation of the regions, respectively, for the IV quarter of 2019, I and II quarters of 2020. Trends in changes in the composition of groups of regions according to the degree of favorableness of the socio-economic situation in in the short term, forecast estimates are given for the IV quarter of 2020.

Value: The proposed methodological approach can be used to substantiate regional priorities for solving problems to implement the national development goals of Russia until 2024 in the context of the global crisis.

Keywords: Region · Socio-economic situation · National development goals · System of indicators · Comparative assessment

JEL Codes: R13 · R58 · R12 · R11

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1 Introduction

In modern conditions, increasing the effectiveness of policies, which is aimed at a widespread effective response to the pandemic and overcoming the global economic crisis, at strengthening the social sphere and an early restart of the economy, dictates the need to create a reliable information basis for constructive interaction between different levels of government, not only in the short term, but also at the stage returning to the trajectory of sustainable growth, in the process of achieving national development goals.

Linking the achievement of medium-term and long-term goals with the formation of a reliable metric basis for conducting inter-country and interregional comparisons is part of the current discourse, primarily in connection with the implementation of the UN Sustainable Development Agenda (United Nations 2015), which includes 17 goals, 169 tasks and more than 230 indicators. A general problem is maintaining a balance between conducting a comprehensive analysis of the situation, taking into account the peculiarities of national statistics in different countries, and ensuring the unification of estimates. It's noted, for example, that monitoring the achievement of sustainable development goals isn't an easy task due to the large number of indicators, individual countries prioritizing their goals, and their reporting based on voluntary national assessments, etc. (Dalby et al. 2019).

The Human Development Index is a generalized measurement of 3 key areas of human development (long and healthy life, knowledge and a decent standard of living) for 170 countries of the world (Human 2019) and also for individual regions (Permanyer and Smits 2018). Regional well-being assessments carried out by the OECD on the basis of a system of objective and subjective indicators in various areas characterizing the material conditions and quality of life of people in 393 regions of different countries (How's life 2020) and set of indicators for various aspects of well-being (for 362 regions), which serve as general guidelines when regions develop their own indicators of well-being, are used for a comparative analysis of the relative position of regions and to obtain public support from authorities in determining the directions for spending limited resources (Framework 2020).

The study of global competitiveness is appears to be complex carried out by the World Economic Forum, as a result of which the Global Competitiveness Index (Global 2019) is calculated, which integrates 12 groups of factors that determine the current and medium-term level of sustainable welfare and measures the impact of institutions, policies, etc. A similar index is also used for interregional comparisons: for 268 European regions, the Regional Competitiveness Index (The EU 2019) is calculated, covering 74 indicators grouped into 3 sub-indices - the base index, the efficiency index, and the index of innovative competitiveness factors.

In turn, the Inclusive Development Index, which also assessed by the World Economic Forum, is an integral index that assesses economic performance for more than 100 countries in three areas: growth and development; inclusiveness and equality between generations (sustainable management of natural and financial resources), highlighting 11 dimensions of economic performance in addition to GDP per capita (The Inclusive 2018). On its basis, Barinova and Zemtsov (2019) proposed a methodology for the integral assessment of the inclusive development of Russian regions using 10 economic and social indicators combined into 3 constituent blocks and in accordance with it the integral index is determined by preliminary normalization of each individual indicator, the subsequent calculation of the average for each group of particular indicators and the final calculation of the average of the group indices. Another method of development inclusiveness, which was proposed by Tokarev (2017) for resource regions, involves the using of 12 indicators, combined into 4 groups and the determination of a composite index of inclusiveness (as an average of group indices) based on a preliminary selection of pairs of component indicators with low collinearity and calculation intermediate group indices.

Thus, the rating agency “RIA Rating” (2019) regularly determines the rating assessments of the constituent entities of the Russian Federation according to their current socio-economic position using the rating methodology for 18 particular indicators, which are combined into 4 groups characterizing the scale and efficiency of the economy, the state of the budget and the social sphere of the regions.

At the same time, the Expert RA rating agency has developed a methodology for the integral assessment of the economic health of regions, including an assessment of its current level and the dynamics of its change based on 11 indicators combined into 3 groups that characterize the economic health of the population, regional business and the regional budget (Expert RA 2019). The integral indicator is determined by converting particular indicators into scores using linear functions and given benchmarks and their subsequent aggregation, taking into account expertly weighting factors.

Summarizing in general the experience of research accumulated to date in the area of a comprehensive assessment of the socio-economic situation of regions, it should be noted that there is still no approved methodology in Russia at the state level, that would become an information basis for monitoring the comparative socio-economic situation of regions and substantiating administrative solutions, the relevance of which has significantly increased in the context of the growing global economic crisis in 2020 caused by the coronavirus pandemic. The proposed methodological approach allows us to give a quick assessment of the current socio-economic situation of the regions (according to data for the 1st and 2nd quarters of 2020) and also to forecast its changes by the end of 2020.

2 Materials and Methods

The basis of the proposed methodological approach was formed by the author’s methodological provisions for conducting complex interregional comparisons (Grishina and Polynev 2012), concretized in terms of assessing regional competitive advantages in the preparation of the Spatial Development Strategy of Russia (Polynev and Grishina 2020). This are received a fundamentally new development in this study due to the linking of the proposed a system of indicators with the national development goals of Russia, which allows reflecting the degree of approach of each region to their achievement.

As part of a comprehensive description of the socio-economic situation of the region, key social indicators of the achieved level and quality of life of the population and the most important indicators of economic development, which make it possible to assess, among other things, the reproductive potential of the region, the current results of economic activity, the infrastructure equipment of the territory, are combined. The assessment of the current socio-economic situation in the region is carried out on the basis of the composite index, which synthesizes two indices, including the "static" one, which reflects its integral assessment for the last reporting year, and "dynamic", which us calculated using operational statistical reporting and characterizing the vector of current development this region.

The used particular indicators include, on the one hand, dynamic indicators, and on the other, characteristics that fix the stability of the situation, predetermining the relative stability of the final assessments of the socio-economic situation of the regions.

35 factor characteristics were used to calculate the static index, which were aggregated into 8 groups and 4 groups of them reflect the social aspects of regional development, including the demographic situation (life expectancy, mortality at working age and infant mortality, natural population growth), the state of the environment (discharge of polluted wastewater and emissions of pollutants into the air, provision of the population with high-quality drinking water), income and employment of the population (cash income (including wages), the share of the poor, the level of unemployment), the level of development of the social sphere (input of the total area of residential houses, the improvement of the housing stock, the level of development of health care and education, the quality of the urban environment).

The other 4 groups of indicators, in turn, reflect the economic aspects of regional development, including the innovative potential of the region (innovative activity, including technological innovation, research and development costs), infrastructure provision (the level of development of transport and information and communication infrastructure, provision of public transport, road accident rate), general characteristics of the reproductive process in the region (GRP production, labor productivity, activity of small enterprises, the state of the regional consumer market, the level of development of manufacturing industries, exports, including non-resource non-energy exports) and also the investment and financial potential of the region (investment activity, including private investment, aggregate financial results of activities and profitability of organizations, own budgetary provision of the region).

The integral static index is defined as the average of the composite group indices that combine particular indicators, which are normalized by the relative degree of deviation of the regional parameters of each indicator from its minimum among all regions of the level with a range of values from 0 to 1. In turn, the integral dynamic index of a region is calculated as a geometric mean of the following indices:

1) An index of economic activity that takes into account the structure of the region's gross value added, including the contribution of industrial production, agriculture, construction, wholesale and retail trade, paid services to the population, and Catering;
2) The real income index of the population;
3) The index of own incomes of the consolidated budget of the region (taking into account the price index);
4) The unemployment rate index.

These particular indices are included in the Integral Dynamic Index with equal weights, as well as 8 blocks of social and economic indicators, which are included in the Integral Static Index. At the same time, the actual duration of the impact of integral static and dynamic indices on the formation of the current socio-economic situation of the regions is taken into account while calculating the final composite index.

Based on the proposed methodological approach, an assessment of the current socio-economic situation of the regions was carried out, and a model extrapolation of regional development trends that formed in the first half of the year (Jan-Jun) 2020 made it possible to give a predictive assessment of their socio-economic situation at the end of 2020.

3 Results

According to the results of the comprehensive assessment, all the subjects of the Russian Federation were divided into 5 groups, depending on the degree of favorableness of their socio-economic situation, while the regions with a favorable position were attributed to group I, to group II - with a relatively favorable position, to group III - with an average, to the IV group - with a relatively unfavorable, to the V group - with an extremely unfavorable situation. For each region, four integral indices were calculated, reflecting four time slices, including the baseline (IV quarter, 2019), two operational estimates (for I quarter and II quarter 2020) and a forecast estimate (IV quarter, 2020). The regions, which are shown in Fig. 1, are ranked in descending order of the values of the Integral Index of Socio-Economic Situation in the base period - for the IV quarter of 2019.

Despite the sharp deterioration in the external economic situation that occurred in early March 2020 amid falling commodity prices (an almost landslide drop in oil prices), the announcement by the World Health Organization of a pandemic and the ensuing restrictions on economic activity for various sectors of the Russian economy, in the first quarter of 2020, the above shocks haven't had a noticeable lowering effect on statistical indicators reflecting various aspects of socio-economic development in most regions of Russia yet: the values of the calculated integral index for the first quarter are practically not inferior to those in the base period.

By the end of the 1st quarter of 2020, in the absolute majority of the country's macro-regions (Center and North-West of the European part of Russia, the Middle Volga region, the Urals, Siberia and the Far East), there were constituent entities of the Russian Federation belonging to at least four out of five groups depending on their current socio-economic status. At the same time, there were regions with a favorable and comparatively favorable position not represented only on the territory of the North Caucasus and the Lower Volga region. At the same time, there were subjects of the Russian Federation with opposite trends in its change in January-March 2020 in all macro-regions of the country.

By the end of the second quarter of 2020, the clearly manifested significant deterioration of the socio-economic situation haven't really affected only a few Russian regions belonging to the most different classification groups: the republics of Altai and Ingushetia, the Amur, Magadan and Smolensk regions, Khanty -Mansi and Chukotka Autonomous Districts. At the same time, the situation in the Tver, Kurgan, and Sakhalin regions remained practically unchanged compared to the beginning of the year. In turn, St. Petersburg (Group I), Krasnoyarsk and Perm Territories, Tomsk Region (Group II),

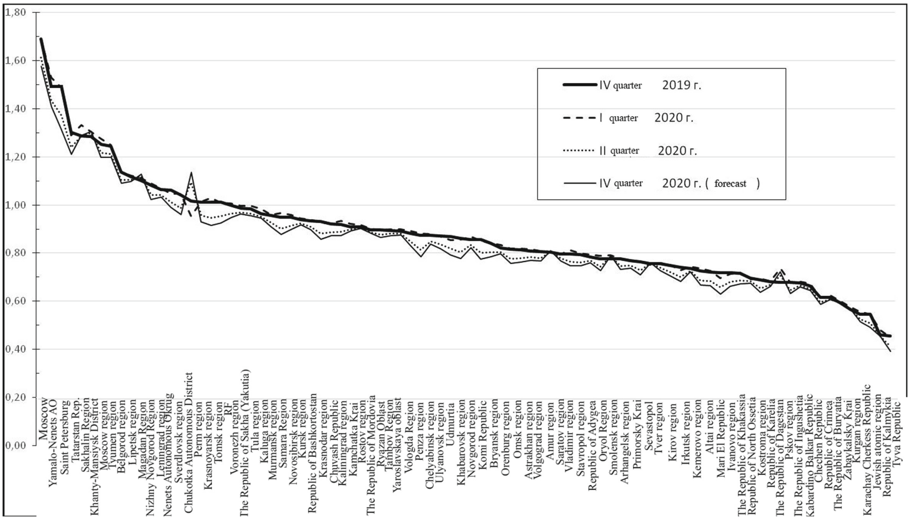

Fig. 1. Changes in the socio-economic situation of Russian regions in 2020. *Source*: compiled by the authors based on data from Rosstat and the Federal Treasury

Vologda, Novgorod and Ulyanovsk regions, the Udmurt Republic (III group), the Republic of Khakassia (IV group), the Republic of Tyva and the Jewish Autonomous Region (V group).

The preservation of the crisis trends, which were formed in the second quarter of 2020, may lead to a further decrease in the number of relatively prosperous regions and an increase in the number of disadvantaged regions of Russia at the end of the year: according to the forecast estimate, in the fourth quarter of 2020, the first group with the most favorable socioeconomic situation include only 5 regions; the second group - 9; in the third group - 28; the fourth group - 31; in the fifth group - 12 regions. Thus, in 2020, the total share of regions with an unfavorable socio-economic situation in Russia may increase from 36 to 50 percent, i.e., every second region will be forced to become the object of increased attention from the federal center.

4 Conclusion

In modern conditions, increasing the effectiveness of state regulation of regional development causes an operational comprehensive assessment of the socio-economic situation of the constituent entities of the Russian Federation, which can ensure effective interaction between federal and regional authorities in the process of achieving the national development goals of the country. A unified assessment of the comparative position of Russian regions, which was developed on the basis of a new original system of representative indicators, can become a metric basis for timely identification based on common criteria, in accordance with the proposed classification, of regions with a relatively favorable state of the economy and a relatively stable social sphere, and the most problem regions and territories of localization of crisis processes.

Anti-crisis measures taken by the federal authorities in an expeditious manner to the negative development of the situation in the regions, taking into account their current comparative socio-economic situation and the forecast of its changes, make it possible to prevent a further deepening of the crisis in the economy and social sphere, to ensure the return of the regions to solving problems sustainable development and joint achievement of Russia's national goals.

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Assessment of Changes in the Quality of Atmospheric Air on the Territory of Khabarovsk Krai

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Abstract. Purpose: The purpose of the autho's research is:

– to analyze the air environment in Khabarovsk Krai cities;
– to carry on comparative analysis of the results of air environment quality using traditional methods and bioindication methods;
– to select the most effective methods of monitoring the condition of the air environment in settlements.

Design/methodology/approach: Based on the methods of GOST 17.2.3.01-86 "Rules of air quality control in settlements", RD 52.04.186-89 "Guidelines for air pollution control" and RD 52.04.840-2015 "Application of the results of air quality monitoring obtained by continuous measurement methods", the assessment of the results of environmental monitoring of air quality in a number of settlements in the Khabarovsk Krai was made.

Findings: As a result of the analysis of air quality data of Khabarovsk Krai settlements, it was established that the environmental situation is rather complicated not so much in large industrial city centers, but in settlements where fuel and energy complex enterprises still use solid fuel (coal) as a raw material. The article notes that plants are more sensitive to poor quality of atmospheric air than humans. In order to improve the information of atmospheric air monitoring, it is proposed to include a stage in the program of air observation that would allow characterizing the impact of air quality not only on human health but also on the condition of urban vegetation.

Originality/value: The results of the research show that the creation of an effective monitoring system should consist of two stages that complement each other – monitoring of atmospheric air quality using bioindication and continuous measurement methods. The two-stage monitoring system allows for a comprehensive assessment of air quality in different areas of the population.

Keywords: Atmospheric air monitoring · Environmental monitoring · Pollutants · Anthropogenic pressure level · Bioindication method

JEL Codes: Q51 · Q53

1 Introduction

In accordance with the Constitution of the Russian Federation, every person has the right to a favorable environment. However, the right granted to a person by the Constitution

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imposes duties on them to preserve the natural environment and treat it with care for the benefit of the peoples living in Russia.

The most important component of the natural environment for all life on earth is the atmospheric air. The only creature on earth that can significantly change the quality of a natural object is a man of anthropogenic generation. Today, we are already standing at the critical point, when man causes a significant deterioration of its quality.

The Far East is considered to be one of the most urbanized regions of the Russian Federation, as from 70% to 80% of the population lives in cities due to natural conditions, a large part of which are small and medium-sized cities (Zaikanov and Minakova 2005). Cities have become not only centers of comprehensive residence of people, but also centers for the concentration of industrial enterprises for the production of goods, as well as intensive traffic flow centers. In particular, the impact air pollution of Khabarovsk Krai cities, which are territorially part of the Far Eastern Federal District, did not allow considering these territories as favorable for human residence (II category of hazard) (Denisova et al. 2011).

The activity of industrial enterprises, including enterprises of the fuel and industrial complex, and the branched out transport network lead to emission of a considerable quantity of various kinds of pollutants that weaken the resistance of the human body to various diseases in both children and adults.

Intensive development of industrial production and increasing intensity of traffic flows necessitated systematic control of the level of air pollution to obtain timely and reliable information.

2 Background and Methodology

The growth of technogenic load determines the need for regular monitoring of the level of air pollution in settlements in order to have reliable information to take timely and effective measures to reduce the environmental risk for the population. On the example of four cities of Khabarovsk Krai, in particular, Khabarovsk, Komsomolsk-on-Amur, Nikolayevsk-on-Amur and Chegdomyn, a retrospective analysis of the quality of the air environment for the period from 2009 to 2018 was conducted (State report, 2009; State report, 2017). The analysis was performed for the main four pollutants – suspended substances (RM10 and RM25), SO_2, NO_2 and CO. Processing, and generalization of data on air pollution and assessment of pollution levels are carried out in accordance with RD 52.04.667-2005 based on data from fixed observation stations. To assess the air quality, the main statistical indicators characterizing air pollution and calculated for different averages over time and space, as well as the main composite indicators of air quality are used (Nikiforova 2016) (Figs. 1, 2, 3 and 4).

According to regular observations by Roshydromet, over the period 2009–2018, gross annual emissions of suspended substances in Khabarovsk decreased by more than 35%, and in all other settlements there is a stable increase of 25–100%. Sulfur dioxide emissions have a clear downward trend from 15% (Komsomolsk-on-Amur) to 90% (Chegdomyn), and only in Nikolayevsk-on-Amur a twofold increase from 0.05 to 0.1 tons is recorded. The total emissions of carbon monoxide and nitrogen oxides decreased by 30–70% and 40–90%, respectively, and only in Chegdomyn there was a significant increase from 70% (carbon monoxide) to 350% (nitrogen oxide) for both substances.

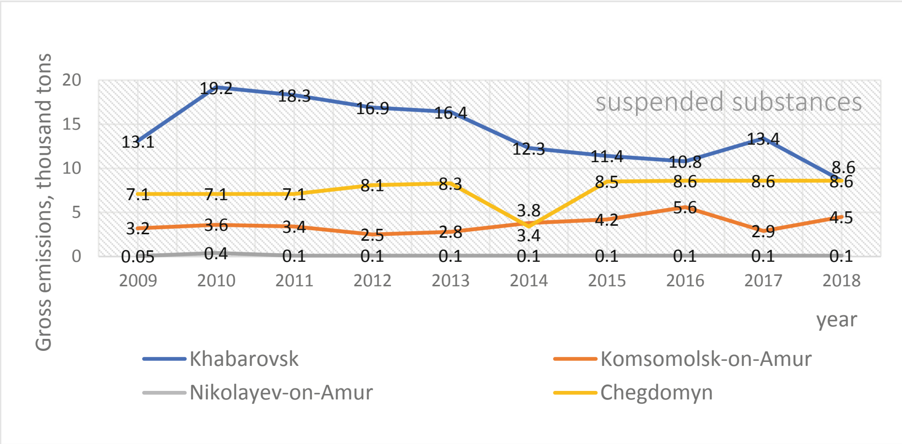

Fig. 1. Retrospective analysis of suspended substances in the cities of Khabarovsk Krai. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

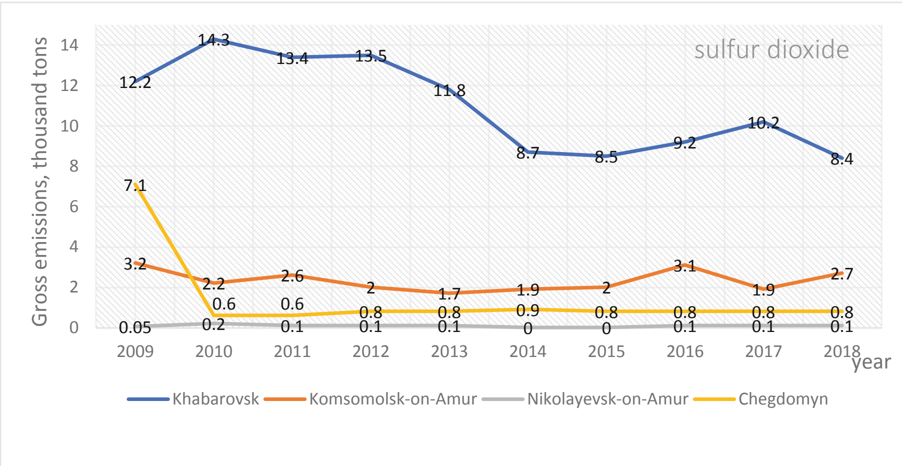

Fig. 2. Retrospective analysis of sulfur dioxide in the cities of Khabarovsk Krai. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

The results obtained allow us to draw a conclusion about a comparatively high degree of air pollution in Chegdomyn, due to the fact that emissions of three out of four air pollutants under consideration tend to increase. The high level of urban air pollution and, consequently, the high risk to public health is due both to the fact that industrial enterprises are located in the city centers (Kalmanova 2015), and the fact that solid (coal) or liquid (fuel oil) is clearly not "eco-friendly" fuel as a raw material for fuel and energy complex enterprises.

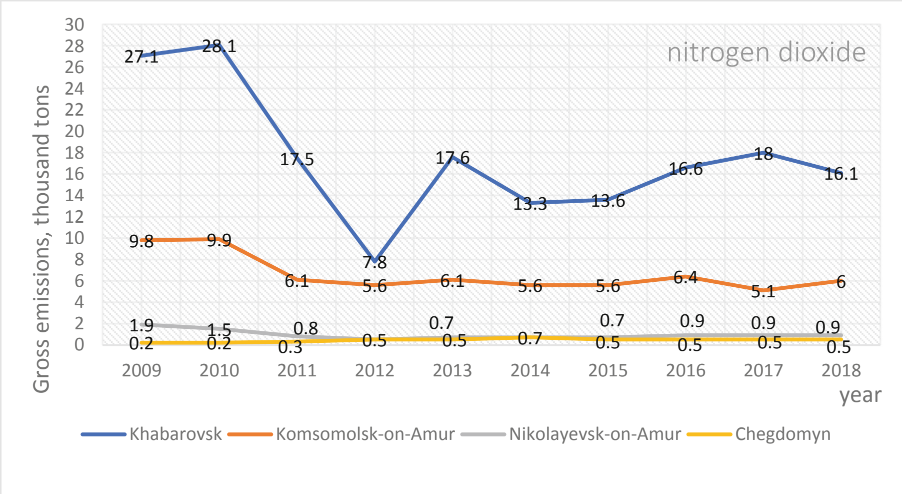

Fig. 3. Retrospective analysis of nitrogen dioxide in the cities of the Khabarovsk Territory. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

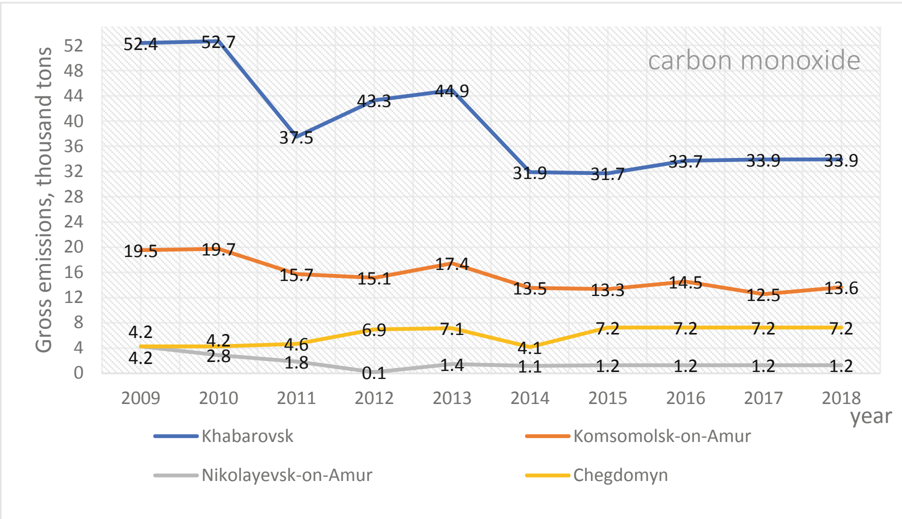

Fig. 4. Retrospective analysis of carbon monoxide in the cities of the Khabarovsk Territory. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

Reduced air quality seriously increases the risk of cardiovascular, respiratory, and acute and chronic respiratory diseases (Danilov et al. 2015; Tarasova and Kuznetsov 2008) (Figs. 5 and 6).

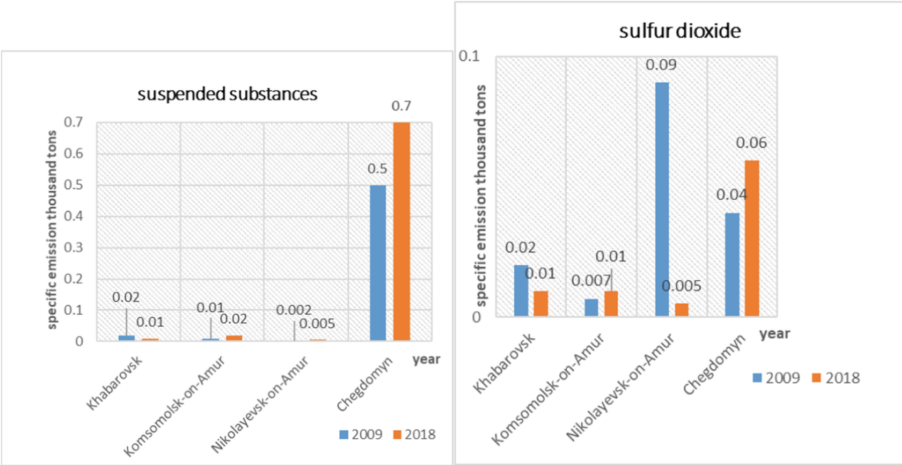

Fig. 5. Specific emissions of suspended solids and sulfur dioxide in the atmosphere of the cities of Khabarovsk Krai. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

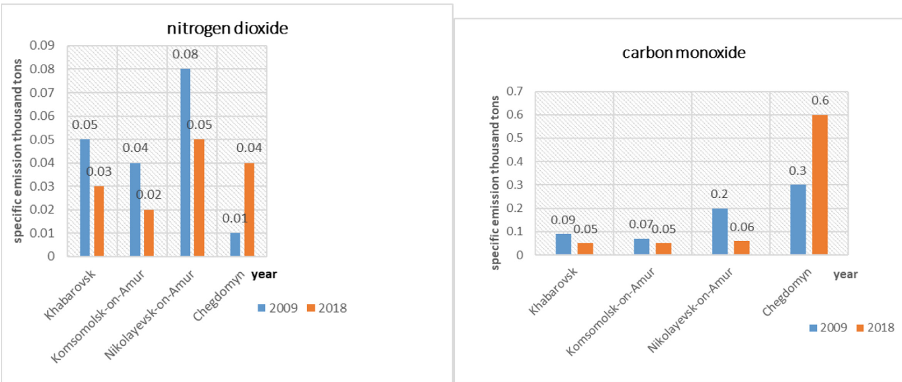

Fig. 6. Specific emissions of nitrogen dioxide and carbon monoxide in the atmosphere of the cities of Khabarovsk Krai. *Source*: compiled by the author on the basis of data from the Far Eastern Department of Hydrometeorology and Environmental Monitoring (2010–2019).

According to the analysis, there is a stable trend of reduction of specific emissions of pollutants in the air per person in three of the four cities studied – Khabarovsk, Komsomolsk-on-Amur and Nikolayevsk-on-Amur. The only exception is the city of Chegdomyn, where in 10 years, the risk to public health has not decreased, but on the contrary, increased by 1.5–4 times, due to the steady growth of pollutants entering the air. It should be noted that despite the high health risk for the population, there is no significant outflow of population from this city. At the beginning of the period under consideration, the city population decreased by 5–6%, but since 2017 it has been growing by 5% on average.

3 Results

Modern industrial development and intensive use of large volumes of vehicles do not allow completely excluding the negative impact on the atmospheric air. Every year, human needs, both domestic and industrial, are growing at an exorbitant pace.

Existing regulatory documents (GOST 17.2.3.01-86, 1987; RD 52.04.186-89, 1990) regulate the number of monitoring system posts depending on the number of population, area, and landscape, as well as the degree of industry development. With a wide variety of methods of environmental pollution control, it is possible to choose analytical equipment for environmental organizations to equip their laboratories.

Under the national project "Environment", a Federal Project "Clean Air" is being implemented to improve air quality in 12 industrial centers with a reduction of air pollution to the level of "increased", which is determined in accordance with recommendations (Guidance document 52.04.667-2005).

Methods based on the use of different devices allow determining not only the chemical composition, but also the concentration of individual chemical compounds and/or the presence of their traces in the environment. However, the integrated effect of the chemical compound on the natural environment, including humans, can only be determined by a bioindicator, because the natural environment, in contrast to hardware methods, reacts to very weak loads (traces), cumulating these substances. The results of the effect of cumulation of weak loads are observed not only in the form of death of the organism, but also in its various pathological reactions (Danilov et al. 2015).

To increase the informativity of the atmospheric air monitoring, it is proposed to include a stage in the program of observations of air condition that would allow characterizing the influence of air quality on the condition of urban vegetation.

On the example of an industrial center – the city of Komsomolsk-on-Amur – phytocoenoses (green plantings) were used as an indicator of the ecological state of atmospheric air.

SO_2, NO_2, and CH are among the pollutants that have a strong anthropogenic impact on green spaces, and SO_2 is the most characteristic one among the rest. Of the higher plants (trees), conifers (cedar, spruce, pine) are the most sensitive to SO_2, and among them, pine is the most sensitive to contamination. That is why pine trees were chosen as the "standard of indication method". This method produces a quick result from its application – a quick and accurate assessment of the environmental conditions. The research was conducted at several sites located in different parts of the city.

The results of the research show that site 1 – both on the scale of damage and on the scale of dehydration – belongs to class I (clean air zone), while site 2 belongs to class III (high air pollution zone). Therefore, we can conclude that the condition of green areas of coniferous trees is most affected not by traffic congestion of the streets, but the proximity of large industrial enterprises in the city, whose activities contribute significantly to air pollution. It should be noted that it is mature conifers, which react to the state of the atmospheric air (Table 1).

Table 1. Condition of pine needles

Types of damage and drying of the needles	Pad number	
	1	2
Total number of examined needles	262	166
Number of intact needles	212	0
Percentage of intact needles	80.9	0
Number of needles with spots	10	158
Percentage of needles with spots	3.8	95
Number of needles with drying	40	8
Percentage of needles with drying	15.3	5

The share of conifers in urban landscaping is small and does not exceed 20%; therefore, hardwoods, in particular, drooping birch, were also used as bioindicators (Zakharov et al. 2000). This method is based on the detection of symmetry disorders in the development of the leaf plate, which reflect the level of anthropogenic pressure on the ecosystem (Table 2).

Table 2. The values of asymmetry of birch leaves

Pad number	Values of leaf asymmetry in birch, X		
1	0.1	0.1	0.07
2	0.03	0.01	0.009
3	0.07	0.05	0.06

Comparing the results of site 1 research on coniferous and deciduous bioindicators, we can say that the influence of motor vehicles on the state of green spaces is most noticeable in deciduous trees (asymmetry values from 0.07 to 0.1, which corresponds to V points – extremely unfavorable conditions).

Summing up the results of the studies, we can say that deciduous trees are more affected by SO_2, which is confirmed by their changes (asymmetry value in the range from 0.009 to 0.1).

4 Conclusions

Bioindicators enable the detection of areas of high concentration of various pollutants, while their condition can be used to monitor the rate of change and the degree of harm that occurred in the environment. Application of this method has a number of advantages over chemical methods of environmental assessment, which gives an opportunity to speak about their effectiveness as the first stage of the environmental monitoring system. Introduction of this stage into the monitoring system will provide information on various effects (including even the weakest or, conversely, bulk emissions of toxicants), reduce the mandatory use of expensive and labor-intensive methods for measurement, and allow for normalization of the acceptable load on ecosystems taking into account their various natural and climatic characteristics.

The development of specific criteria for living organisms used as biological indicators is necessary to obtain fast and reliable data on bioindication method.

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Introduction of the Joint Value Creation Approach in the Region's Logistics Services Market

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Abstract. Purpose: The article examines the theory and practice of applying the joint value creation approach in the logistics activities of individual regions of Russia. The interaction of logistics companies with regional authorities, other business structures, scientific and educational centers within the network-like ecosystem is analyzed.

Design/Methodology/Approach: In most cases, scientists pay attention to the concept of joint value creation within individual organizations or corporations. In the logistics services market of the region, this concept brings to the fore trust, co-creation and partnership in the formation of supply chains.

Findings: It is shown that not only coordinated actions are required, but also partnership, trust, and constructive interaction of all participants in logistics supply chains. Coordination of actions and interests of partners is particularly in demand in the context of increasing complexity of logistics organizational forms and intellectualization of supply systems. In this regard, the symbiosis of the joint value creation and ecosystem approach can play a positive role. Its essence is to form a network of organizations united within a single digital platform, using its software and services to interact with each other and with customers in order to create value together. The world's largest ecosystems are already known: the American ones – Google, Amazon, Facebook, and the Chinese ones – Tencent and Alibaba.

Originality/Value: We offer an integrated communication approach to coordinating the interests and actions of logistics companies with regional authorities, other business structures, scientific and educational centers within the ecosystem of joint value creation.

Keywords: Logistics services · Partnership · Region · Joint value creation · Supply chain · Digital platforms · Ecosystem

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1 Introduction

The spread of joint value creation ideas has had a significant impact on the relationships between sellers, consumers, and managers in various industries and fields of activity

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(Prahalad 2004). The origins of the concept of joint value creation are found in works aimed at studying and improving business processes based on cooperation, partnership and trust (Zhukova 2018); in the theory of interaction marketing (Bagiev 2015).

The purpose of this research is to develop a methodology for joint value creation in the logistics services market of the region in terms of expanding the scope of interaction between logistics companies; combining them in joint activities with regional authorities, the business community, scientific and educational centers within the ecosystem.

The digital transformation of logistics activities taking place in Russia has an impact on the development of the logistics sector of the region's economy, involving all interested economic entities in the joint value creation. For logistics companies, the involvement of partners in joint value creation leads to the blurring of boundaries between participants in the supply chain and the formation of a network ecosystem. Logistics partnerships in the region are created in conditions of crisis and a high degree of uncertainty in the external environment. This complicates the problem of choosing optimal management solutions that should be implemented efficiently with minimal costs and within a given time frame.

The concept of joint value creation in the logistics services market is becoming a new milestone in the study of digital transformation of the region's infrastructure. The trend is that when implementing digital innovations, logistics companies are increasingly expanding the range of interactions with their partners, relying not only on their own strength, but also on external capabilities. The combination of internal and external capabilities increases the consumer value of logistics services that are realized not just for the consumer, but together with the consumer.

It should be noted at the outset, the term "joint value creation" is broader than the concept of "crowdsourcing" (Howe 2012). The essence of the idea of joint creation of value (benefits) is creating products, services, and performing work by joint efforts of developers, companies (managers and employees), their partners and clients.

A distinctive feature of crowdsourcing is the breakdown of work (functions, solutions) into components and the involvement on a voluntary basis of a wide range of participants (persons) and subcontracting much of the work. In our case, the joint value creation of logistics services involves not only their developers (managers and employees of logistics companies) but also government authorities, partners, clients, scientific and educational centers of the region (Afanasenko 2019).

In the modern market of logistics services in the region, there are already prerequisites for involving partners in joint value creation. This is a result of increased competition, reduced product (service) life cycle, individualization of customer needs, and rapid development of virtual logistics services (Borisova 2019). Another important driver of partnership in the supply chain is the prosumer, a professional consumer bridging the gap between producer and consumer (Toffler 1980). The re-emergence of this phenomenon the 1920s is associated with a new type of customers who are dissatisfied with the mass product offer and lack of individuality, which create innovative projects and services based on digital technologies.

The new prosumer affects the manufacturer's product range policy and related services; it is a competent user and a professional customer. It is the influence of prosumers that determines the development of a customer-oriented approach to the design of a logistics supply chain.

It seems that the joint value creation in the logistics services market is not limited to the involvement of some consumers, even professional ones. Now there is an objective need to combine the efforts of all participants in the supply chain: the interaction of logistics companies with regional authorities, other business structures, scientific and educational centers within the ecosystem. The following forms of involvement of partners in the ecosystem can be envisaged: focus on joint (taking into account the involvement of the consumer and all participants in the system) value creation; resource orientation (adaptation to existing products and services at the final stages of the value chain); interaction based on creating a unique experience.

Researchers differentiate the process of joint value creation by types of activities and spheres of influence of participants in the chain: joint production (providing services); joint idea generation; joint product promotion; joint marketing (Payne 2008). The digital marketing tools expand the possibilities of implementing the value orientation of the logistics supply system, when partners are involved in creating a product, generate new ideas, and draw the attention of the system coordinator (focus company) to important characteristics and functional features of the product (service).

Digital integration of supply chain participants is carried out in accordance with the management concepts: Supply Chain Management (SCM); Customer Relationship Management (CRM); Demand Chain Management (DCM). This combination of management concepts forms a customer-oriented digital matrix of partners' collaboration in the supply chain. We see the prerequisites for its practical implementation in the logistics sector of the region's economy in the coordination of actions of strategic participants in the supply chain. The theoretical basis for this is formed in the provisions of interaction marketing (Bagiev 2015) and digital logistics (Afanasenko 2019). These are not separate areas of scientific knowledge, but interrelated concepts that contribute to improving the competitiveness of supply chain participants in the market, adapting its strategies to changes in the external environment, and minimizing risk when making innovative decisions.

When designing an ecosystem of joint value creation in a region and developing a strategy for its development, it is necessary to understand the essence of the term "digital ecosystem". The term of "digital ecosystem" is based on a metaphor that suggests considering modern organizations as mixed communities and ecosystems in which people and digital agents interact. The digital ecosystem develops the theme of expanding the noosphere and human capabilities by building information repositories and creating digital assistant agents. It is in this context that we will consider the digital logistics ecosystem, which combines the virtual and real worlds into a hybrid system.

The digital logistics ecosystem can also be represented in a narrower sense, as a set of software devices, technologies, and IT services in which partners interact within a single digital infrastructure for data transmission, processing, and storage.

In this case, we are dealing with a qualitatively new level of use of information and telecommunications technologies in all functional areas of logistics. In other words, the creation of fundamentally new digital logistics systems requires an adequate digital infrastructure (Borisova 2018). This is evidenced by the experience of large ecosystems operating in our time. These ecosystems include American – Google, Facebook, Amazon, and Chinese - Alibaba, Tencent, and others.

According to expert estimates, such ecosystems will account for up to 30% of revenue and about 40% of profits of all global organizations in the world in the next 5–7 years. The practice of these ecosystems shows that the construction of super-complex systems of this scale is associated with the integration of intersectoral and interregional complexes that are different in nature and structure. First of all, this refers to the infrastructure that can unite seemingly unconnected industries and spheres of activity.

An analysis of the currently functioning ecosystems shows that most of them are based on a special, key service that is available to their extensive client base. For example, Uber – combines drivers and customers in its service; Facebook – users of the social network, Google – relies on search technologies, Airbnb – created a service for interaction between lessors and lessees in the real estate sector (Borisova 2018).

2 Materials and Method

In the process of researching different approaches to applying the ideas of joint value creation in the logistics services market of the region, the scientific arsenal of economic theory, management, integrated logistics concept and customer-oriented marketing paradigm, basic principles, and methods of digital logistics were used. To solve the problem of joint value creation in the logistics services market of the region, we turned to interdisciplinary knowledge that allows us to shed light on the solution of research tasks.

The strategic objectives of ecosystems of joint value creation in the region are associated with an increase in the balance of regional development, an increase in labor productivity in the economy, and an increase in the standard of living of the population. In the regions of Russia, ecosystem design is in the process of being developed. However, logistics operators are more or less involved in the practical implementation of the ideas of joint value creation, based on the use of well-established information systems: Supply Chain Management (SCM); Materials Resource Planning (MRP); Distribution Requirements Planning (DRP); Enterprise Resource Planning (ERP) (planning and distribution of resources in production, distribution and integrated management system); Quick Response Code (QR) (coding and rapid response system); supply systems Just-in-Time (JIT) and Just-in Sequence (JIS); Door-to-Door delivery (DTD); Effective customer response (ECR) (effective response to customer requests); Vendor Management Inventory (VMI) (supplier inventory management system) Warehouse management system (WMS); Transport management system (TMS), etc.

We believe that this information and communication base can be used to launch separate subsystems and elements of the logistics ecosystem in the region. This is proved by the appearance of innovative projects of various levels in the Russian regions on the logistics services market - from startups to digital industry leaders. These include enterprises from various industries and fields of activity: industrial, agricultural, investment, and banking structures. The digitization of financial flows is rapidly developed. In this regard, the logistics services market in the region is able to quickly provide services and solve the problem of integrating partners in an integrated ecosystem.

The obtained research conclusions and ideas about the essence of the ecosystem of joint value creation in the logistics sector of the region's economy are formed on the basis of aggregate knowledge about the problem under study. The above has determined our scientific position and its theoretical and applied justification.

3 Results

Joint value creation within the logistics ecosystem of the region brings the relationships of partners (system participants) to the level of trust. This indicates that the partnership has entered a higher stage of development, allowing participants to understand the essence of forthcoming changes in the social and economic life of the region and society caused by both the crisis and the pandemic. The combination of these two disasters showed the imperfection not only of the economy, but also of the social structure. This will require a shift to a new area of knowledge that leads to a different level of consciousness. In this context, a significant role should be assigned to influence marketing, since its scientific and practical arsenal forms personal relationships, subordinating them to certain rules. The systematic application of influence marketing is complicated by the processes of its digital transformation.

The following are some characteristics of digital marketing that can be used to study the problem of joint value creation in the logistics services market in the region:

– defining and shaping the needs of users of goods and services using an Internet intermediary in a virtual market environment;
– impact on the market using information and computer technologies to meet the demand for goods and services;
– the company's activities in the virtual market aimed at achieving commercial goals by meeting customer needs (customer-oriented activities);
– a system of information and communication methods used via the Internet to manage the demand for goods and services, ensuring the alignment of the economic and social interests of the company, consumers and society as a whole.

The key word in the definition of the concept of "digital marketing" is customer orientation, which takes into account the interests of the company and society. Customer focus is also an important component in the logistics practice of supply chain design. The integration of logistics and marketing allows participants in the value chain to focus on the final results of the activity, on the needs of the client.

The scientific community has developed an understanding of the need to integrate marketing and logistics in solving issues of joint value creation (Payne 2008). Good examples are well-established models of demand chain management, in which the consumer dominates the supply chain, and the interaction and co-creation of participants is aimed at meeting their needs.

The modern economy of the region and its logistics sector has changed significantly not only in the context of digital transformations of business processes, but also as a result of the socio-cultural crisis and the world-shaking coronavirus pandemic. According to experts, the decline in business activity as a result of such a disaster can slow down the growth of the world economy by a third.

The reality is that many logistics chains have already been disrupted in regional and interregional trade. Logistics companies try to minimize the negative consequences of forced downtime. It has become clear that this issue cannot be resolved without the trust of trading partners. The pandemic has reached almost all countries, and the scale of its impact on international logistics chains will be enormous. Although transport logistics chains are functioning, it is also obvious that their structure and configuration will change; there will be a redistribution of logistics flows; new routes and suppliers will appear which will lead to higher prices for goods. The coronavirus pandemic has already revealed the need to review approaches to interaction between trading partners and urgently adapt supply chains to the digital environment.

The concept of joint value creation within the logistics ecosystem of the region creates conditions for the formation of platforms for the joint use of transport and warehouse infrastructure. In the context of general quarantine, the role of digital platforms has increased dramatically. Within the framework of the platforms, remote electronic registration of documents for cargo transportation is being implemented without personal contact. For example, INTERTRAN technology integrates participants in the logistics supply chain for railway transport. The Russian Railways company has set the task of converting processes to electronic registration of all potential container transportations. Delivery services not only increase revenue at the moment (during the quarantine and isolation period), but also increase (expand) their customer audience through discounts or new users.

Digital technologies allow participants in the supply chain to adapt to new demand and new realities. A system of contactless delivery of goods is being implemented. Couriers are provided with masks and other protective equipment; cash payments are refused. Developers of new software products and services have expanded their field of activity. So, the Yandex-Food service is now available in 32 new cities. Together with a network of pharmacies, the drug delivery service “Samokat” and others. Online sellers are expanding their range of services to customers. For example, the website “Save yourself at home” advertises new Sberbank services available to customers in isolation.

Consumer trends indicate an increased interest in online trading. If earlier experts predicted that the volume of online sales will exceed traditional trade by 2036, in reality this moment may come much earlier. Online purchases were tested by those customers who had never made them before; they would remain loyal to digital purchases in the post-crisis period. Robotization of trade is gaining momentum. In the context of a pandemic, it is robots that can perform those operations (collect and deliver goods) that are dangerous for people. Robots are able to work faster and longer, perform more work, and thus optimize costs. The current volume of the world market for industrial robotics is about $ 20 billion. Experts believe that in the post-crisis situation, investments in robotization of logistics processes will continue.

According to forecast estimates, by 2030, most of all professions will be automated (60%). Services are already becoming the basic infrastructure for organizing work and implementing life communications. The work of company employees in remote mode gave an additional impetus to the development of cloud technologies. It is cloud technologies that permit to quickly implement new management solutions and act swiftly in the current crisis situation. According to analysts, the volume of the Russian cloud services market will approach one billion dollars by 2023.

Digital technologies are becoming a key asset of modern supply chains. They gave birth to a number of super giants working on the principles of information superiority: Apple, Google, Amazon, Alibaba, Facebook, Microsoft, Baidu, Tencent, etc. In fact, these companies are acquiring the status of virtual intermediaries that capture significant shares of the global market. As a result, competitive advantages are gained by supply chains that have access to a multi-million audience of mobile consumers and suppliers and influence the configuration of information flows.

A review of approaches to understanding the ideas of joint value creation (Prahalad 2004; Zhukova 2018) showed that their application in the logistics services market of the region is due to "the integration of social networks, industry, interdepartmental and international databases into a single digital space, and the formation of giant intermediary network-centric structures".

With the help of site information analytics, conditions are created for the development of collaborative innovations, where the latter are the result of interaction between partners, the exchange of new knowledge in the process of achieving common goals. As an example, the collaboration of the industrial giant Siemens, which invests about $4 billion annually in research and development, with Ayasdi, an innovative company founded at Stanford University in 2008 and engaged in machines with self-learning functions? This partnership gives Siemens the opportunity to work with a company that can solve the problem of generating ideas based on working with a large array of data, while Ayasdi can test their topological approach to data analysis based on real information, while expanding its market presence (Schwab 2017).

The partnership provides access to global digital platforms for joint research, development, marketing, sales, and distribution that increase competitive advantages by improving quality, flexibility, speed, and price of delivery. The role of cross-functional interaction of commerce, marketing and logistics is increasing (Afanasenko 2017).

In the system of joint value creation, modern breakthrough technologies of artificial intelligence and Big Data rely on integrated communications of partners. At the moment, disparate automated logistics systems remain predominant: transportation management and control; warehouse management; demand management and inventory replenishment. In other words, there is no single "picture" of logistics. The problem of rationalizing work with integrated data, updating their collection and processing has become more acute. There are other problems associated with the restructuring of key and supporting logistics functions in the supply chain. The new Data Laka technology is gaining popularity, which is innovative data storage of various formats, including a set of tools for processing them. The technology provides the ability to process a large amount of data when building various business models. This makes it possible to solve diverse tasks: from more detailed planning of the production program and sales volume, to modeling and testing the architecture of the integrated supply chain. One of the advantages of this technology is the ability to collect completely different data not only on the dynamics of internal logistics processes, but also on changes in the parameters of the external environment.

To improve the efficiency of integration of partners in the supply chain, they consolidate cloud applications and technology platforms related to determining the necessary number of resellers in the sales channel, developing pricing, and communication policies, and providing customer service (Afanasenko 2019).

4 Conclusion

Based on the results of the study, it can be concluded that the introduction of ideas of joint value creation, along with the effects on the logistics services market, also contributes to the formation of the digital infrastructure of the region. The range of innovations in the ecosystem of joint value creation is expanding: cloud technologies and artificial intelligence, neural network research methods and natural language processing. Some technologies have already gone beyond traditional algorithms and are able to create systems that can understand, learn, predict, adapt to a changing environment, and are potentially ready to function independently.

Such digital innovations lead to a change in the positive feedback loop between participants in the supply chain. On the one hand, "digital competencies are being consolidated: robotics, automation, in-depth analytics, information technology infrastructure software, etc.", on the other hand, a number of digital innovations, including the use of artificial intelligence, neural network research methods, and natural language processing, are accompanied not only by positive but also negative effects. Summing up, we note that the implementation of the ideas of joint value creation in the logistics services market of the region directly depends on the definition of the critical shared digital infrastructure; the formed security system and the rules of procedures for its joint use.

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Business Efficiency Strategies Based on Value Engineering (VE)

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Abstract. Purpose: Develop a strategy to increase the efficiency of Russian enterprises by introducing new and breakthrough technologies, as well as modern organizational and managerial methods based on the use of VE.

Design/Methodology/Approach: When developing this strategy, it is necessary: to define the critical functions of the enterprise - as systems; to analyze how these functions are affected and choose the best option using new and breakthrough technologies and develop the implementation process; and implement organizational and management methods to support the proposed strategy.

Findings: Critical functions of the system have been identified, strategies for improving critical functions and strategies for improving the quality of changes made. Critical functions. Methods of increasing the productivity of Russian enterprises by determining critical functions of systems and their improvement based on VE are proposed.

Originality/Value: To increase the efficiency of enterprises, an economic and technological concept of introducing new and breakthrough technologies has been developed by influencing the critical functions of the system with further improvement based on negative feedback control.

Keywords: Value engineering · Critical functions · Inventions · Breakthrough technologies · Strategy · Efficiency

JEL Codes: L20 · M11 · O12 · O11 · P11 · C52 · A20

1 Introduction

Currently, in order to improve the efficiency of the economy, the priority is to increase productivity based on new technologies (currently, productivity in our enterprises is on average 2.5 times lower than in the USA, Lenchuk (2016). Moreover, this process should be implemented in the presence of sanctions, a significant reduction in state income from the sale of hydrocarbons and the effects of the coronavirus pandemic. In these conditions, it is impossible to solve the problem using standard methods. For the solution, the economic and technological concept of introducing new and breakthrough technologies based on the use of the VE is proposed, which allows creating scientifically sound anti-crisis programs.

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Throughout the world, for a long period of time, the VE has been effectively used to improve the design parameters of various technical systems. For example, Lawrence Miles, the founder of the VE, was awarded the highest order of Japan by the Emperor of Japan "For the fact that he greatly helped Japan become a highly developed country in the world".

In Russia in the nineties, MУ was effectively used together with TIPS (Theory of Inventive Problem Solving) in TIPS-VE systems to improve various technological processes.

Currently, in world practice, the VE has also become widely used for economic calculations and solving strategic problems, Orlov (2014), Ryzhova (2012).

The article presents a strategic approach based on value engineering (VE), which allows searching optimal solutions to both simple and very complex problems at minimum cost.

Strategic plans and programs based on the VE can be effectively used both for enterprises and for departments, ministries and regions.

2 Materials and Method

The functional approach is used in the development of a strategy based on the VE, in which any system is considered as a set of functions. The strategy process itself consists of three stages:

1) Definition of critical functions of the system.

During the analysis, each function of an object is evaluated by three main criteria: the value of the function, the cost, and the degree of non-fulfillment of functional properties.

The value of a function is determined usually by an expert way or by the significance of the time and action of the implementation of the function. For organizational and management systems, the weight of profit from the implementation of functions.

The cost of the function is determined by the cost of implementing the function.

The degree of non-fulfillment of functional properties of technical systems can be estimated using the generally accepted reliability indicators: the probability of failure-free operation, the probability of failures or the parameter of the failure flow. These indicators for reliability analysis were developed for automation systems, and then began to be used for all technical devices.

The analysis showed that these indicators do not provide an objective assessment for complex systems to improve their efficiency. This is due to the fact that the standard indicators assume equality of significance of all failures, and only their number is taken into account.

For transport systems that work with different modes (combines, diesel locomotives, trucks, sea and river vessels), it is advisable to evaluate the modes as functions, and then develop ways to improve critical mode functions.

For organizational and management systems, the degree of non-fulfillment of functional properties of systems can be estimated by the weight of losses from poor-quality performance of functions or by the weight of the ratio of losses to profit, as well as by the probability of profit losses as a result of improper performance of functions.

The first critical function is defined in relation to the value of the function and the cost of providing it.

Indicators of consumer value P_i are determined by the formula:

$$P_i = F_i/C_i \tag{1}$$

Where F_i – function value;
C_i – The value of the own costs (prices) required to implement this function.
i – function number or type.

Sometimes the calculation of P_i is carried out not in relation, but in difference, that is,

$$P_i = F_i - C_i \tag{2}$$

The minimum positive value P_i or the maximum negative value (when calculated from the difference) will determine the first critical function.

The second critical function is determined by the maximum weight of the degree of non-fulfillment of functional properties.

2) Development of a strategy for improving critical functions.

At the same time, the process of improving the entire system at minimal cost occurs, since the innovation and investment impact is carried out only on the critical functions of the system.

In this process, various methods and techniques for finding ideas are used in world practice, among which the most effective are: brainstorming, morphological analysis, a list of control questions, Petrov (2018), the TIPS system (Theory of Inventive Problem Solving), Meerovich and Shragina (2016) and others. Moreover, it should be noted that the TIPS system developed under Altshuller in the USSR, although it is quite complex, it connects well with the VE and makes it possible to find original solutions in various areas of activity. The ideas obtained using these methods are usually very effective in solving relatively not very complex problems in small enterprises. To improve complex technologies based on the ideas obtained, patent analysis and special research must be carried out. Patented tested technology is easier to implement, but the maximum effect can be obtained when introducing breakthrough technologies. Typically, the introduction of such technologies requires significant initial costs for the implementation process and the improvement of the process technology, but in the future it is possible to achieve complete superiority in the market. Standard management and marketing methods when introducing breakthrough technologies do not have an effect. There is a need for a new perception of technological processes and prospects. These technologies can be conditionally divided into 2 types: A - technologists, according to which a reliable positive effect was obtained on the basis of research, on the implementation of which scientific teams in different areas of activity work in different countries of the world; B -

technologies by which the effect of the action is estimated by analogy, and the quantitative result can be determined during an experiment with the investment of significant capital funds.

3) Develop a strategy to improve the quality of critical function changes.

This strategy is implemented while improving the technological process of increasing the efficiency of critical functions based on new ideas obtained by various methods, patented inventions and breakthrough technologies.

Consider the feedback diagram of the critical function improvement process (Fig. 1).

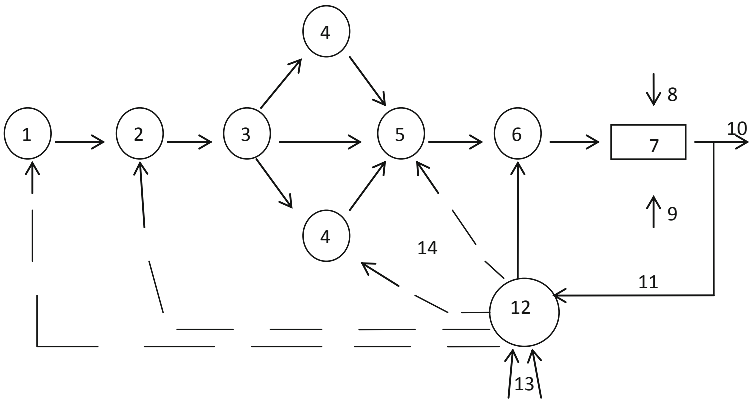

Fig. 1. Closed-loop critical function improvement process diagram

1 - definition of the problem and selection of the project objective;
2 - parameters that assess the level of achievement of the goal;
3 - criteria and norms for evaluation of selected parameters;
4 - development of separate units;
5 - development of a draft version of the design;
6 - development of working drawings;
7 - shows the manufacturing process of the article;
8 - disturbing effect of the environment;
9 - external scientific, technical and economic information;
10 is the resulting design-based product test;
11 - feedback channel, through which information on the test results of the manufactured article is received;
12 - shows the process of comparing and analyzing the resulting test data;
13- indicators of the best world samples of a similar purpose;
14 - corrective action.

According to this system, it can be seen that on the basis of the project goal, parameters are selected to evaluate this goal and the criteria for these parameters, on the basis of which nodes and the structure itself are designed. Based on the developed drawings and technologies, the design is manufactured and tested. Quantitative evaluation of test results through feedback is compared with the indicators of the best world samples of similar purpose and corrective effect is developed in order to reduce deviation of the resulting test data from the indicators of the best world samples of similar purpose. If these variances are very large, you must change the criteria, parameters, or purpose of the project.

As a result of multiple cycles of negative feedback, a new technology is created that has high competitiveness in the world market.

In the world practice of leading companies for complex projects, the process of refining a product on the basis of feedback is a significant part of the time and money from the entire project implementation process. For example, during the implementation of the Boeing aircraft engine project, 27% of the total costs were spent on design, production and demonstration, and 73% on quality improvements as a result of feedback adjustment.

When developing the priority of investing complex projects to increase the efficiency of the Russian economy, it is necessary to take into account international experience in creating competitive products by investing heavily in the third stage of strategy development according to the VE. Therefore, first of all, it is necessary to invest in projects that will improve the fundamentally developed technology, but have great potential to increase efficiency based on comparison with advanced foreign technologies. Such projects should first of all be the reconstruction of oil refineries and the construction of new ones based on modern technologies, as well as improving the transportation of oil and petroleum products. Large revenues derived from the implementation of these projects can be effectively used for the implementation of other projects, as well as the development of science and education.

3 Results

3.1 Implementation Options

As a first embodiment of this strategy, two breakthrough technologies of types A and B are proposed, which can be used separately in various technological processes, as well as in combination with obtaining a synergistic effect.

A) Production and introduction of nanocarbon structures into technological processes, which, when incorporated in a small amount, significantly change the physical properties of solid and liquid substances, while increasing the service life, resistance of materials, improving efficiency and other qualities, with the possibility of application in mechanical engineering, metallurgy, construction, energy, etc., Antsiferov and Oglezneva (2011), Mironenko et al. (2012).
B) Application of disintegrating technology using high-speed microturbines as a drive.

Disintegrator technology was developed by Hint, who theoretically substantiated and brilliantly proved in practice the feasibility of mechanical activation of sand and lime by the method of free impact and the production of artificial stones without the use of cement. As a result, a new building material called silicalcite appeared. Then this technology was successfully applied in chemical and technological processes of various fields of activity. To realize the synergistic effect, it is proposed to use Capstone microturbine as rotor drives, which has air bearings, due to which a shaft rotation speed of 96,000 rpm is achieved. Therefore, the effect is increased by 19 times.

The proposed strategy for improving the efficiency of disintegrator technologies is primarily advisable to use in the treatment of various liquids in biology, medicine, the chemical and oil and gas industries, Ivanov (2015).

3.2 Implementation Terms

Effective implementation of the proposed concept requires the following actions:

To change the state policy in the field of inventive activity and development of breakthrough technologies through significant tax incentives to enterprises that will introduce inventions and breakthrough technologies.

To determine in all competitions and grants the first priority right for patented inventions and KNOW-HOW for breakthrough technologies.

To include in the reporting indicators of governors, heads of ministries, departments, universities and institutes the number and effect of inventions and breakthrough technologies that are being introduced.

To organize training of production managers in universities who would effectively possess modern management methods and have modern technical knowledge in order to introduce new technologies and use modern equipment. Such specialists began to be trained only for energy, Golov, etc. (2016), Ivanov and Persiyanov (2018).

4 Conclusion

To increase the efficiency of the Russian economy, the first task is to increase productivity through the introduction of advanced organizational and managerial methods and new technologies. The solution proposes an economic and technological concept of introducing new and breakthrough technologies using VE by influencing the critical functions of the system and further improving them based on a negative feedback control system.

To effectively implement the proposed concept, it is necessary to provide significant tax incentives to enterprises that will implement the VE with the improvement of critical functions based on inventions and breakthrough technologies, as well as include in the reporting indicators of governors, heads of ministries, departments, universities and institutions the number and effect of inventions and breakthrough technologies introduced.

To provide specialists of enterprises that will implement this concept, it is necessary in universities to organize training of production organizers and analytical managers who could, on the basis of the VE, determine the critical functions of systems and develop their improvement through the use of new and breakthrough technologies, as well as modern organizational and managerial methods.

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Managing the Organizational Culture of an Enterprise is One Way to Improve Its Efficiency

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Abstract. Purpose: Consider organizational culture management as one of the factors that improve the efficiency of the enterprise. Particular attention is paid to trends in the economy and socio-economic structure of society, as well as the use and implementation of these trends in the formation of the management system of the organizational culture of the enterprise.

Design/Methodology/Approach: The modern conditions for the development of economic systems and the deepening integration and globalization of various spheres of society require companies to find effective methods of management and increase their productivity. An internal growth resource is a controlled organizational culture that helps unite the team into a single ecosystem to achieve the overall mission and goals of the company. The main problems for many economic entities in Russia are the low level of innovation, the outflow of the able-bodied population, and the high level of migration of employees between companies.

Findings: the development of an organizational culture, or rather the use of a new approach to its management, could increase the innovative activity of employees and the company as a whole, reduce staff turnover and, thereby, increase the effectiveness of the organization.

Originality/Value: in such a way, the purpose of the work is to demonstrate a new approach to managing organizational culture using local social networks. This tool will make the system more mobile, flexible and efficient.

Keywords: Management system · Organizational culture · Efficiency · Management · Local social network

JEL Code: D21 · E22 · J11 · J62

1 Introduction

At present, under the current conditions of fairly fierce competition in both domestic and world markets, the basis for the successful functioning of any organization or enterprise in Russia is the need and/or expediency to increase the efficiency of management and, as a result, increase the efficiency of production. There are a significant number of approaches and methods for achieving management efficiency, the objects of which

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can be the heads of the company, professional and personal qualities of managers, as well as individual elements of activity that implement certain management processes. To create and implement innovative measures aimed at improving the effectiveness of the enterprise management system, any element of the enterprise management system could be considered, which in a particular situation was the most relevant within the framework of the problem or task being solved. The relationship between all or most of the elements that make up the overall management system must be taken into account.

Among the ways to improve the efficiency of economic entity management are the following main areas or groups:

- modernization of the management system (structure) implemented, for example, through its optimization, restructuring and/or decentralization;
- development strategy planning based on analysis, research and evaluation of the innovative strategic position of the business entity, mission formation, policy and development trajectory of the organization;
- development and implementation of digital intelligent systems in the enterprise, which are aimed at providing automation of production processes and effective communication between employees, departments and other various components of the host entity;
- development and integration of effective tools and automated management decision-making systems, incentive and motivation systems for the productive performance of the tasks;
- use of a continuous staff development approach, in the process of training, retraining, development of creative potential and improvement of innovation perception;
- application of individual algorithms and programs for training, testing and/or evaluation of the organization's management, design of managers' career strategy, and selection of management style for effective influence on the personnel;
- application of modern methods of selection of highly qualified employees, their analysis and evaluation, formation of an attractive brand of the company as an employer, creation of favorable social and psychological climate in the working environment;
- work on formation and development of organizational culture of the company or any other organization.

Almost all the presented areas of improving the efficiency of enterprise management are related to one degree or another to the organizational culture, or, more precisely, to the need to manage the organizational culture of the economic entity (Slinkova and Grudistova 2009).

Organizational culture, its components greatly influence the innovative susceptibility and innovative activity of employees and the company as a whole, determine the success and efficiency of the enterprise. In modern conditions, for the effectiveness of the company's management, it is necessary to use a huge amount of personnel data, constantly update it in order to correct the activities, motivation and behavior of employees of the enterprise. This is a very complex process, requiring the appropriate professional skills of personnel resources, the use of the so-called HR management. Therefore, it is necessary to form new approaches that can form (and simplify) and implement all processes, systems and ways of managing personnel activities aimed at the effective functioning of the enterprise (Osovitskaya 2019).

As a result of the effective management of staff activities and organizational culture in general, we can highlight the increase in labor productivity, which must be considered in the socio-economic aspect - for example, as an innovative asset (as well as innovative susceptibility), the desire of each individual employee and team as a whole to realize their ambitions and potential.

Figure 1 shows, as an example, a corresponding tree of goals focused on solving the problem of increasing labor productivity for a virtual business entity.

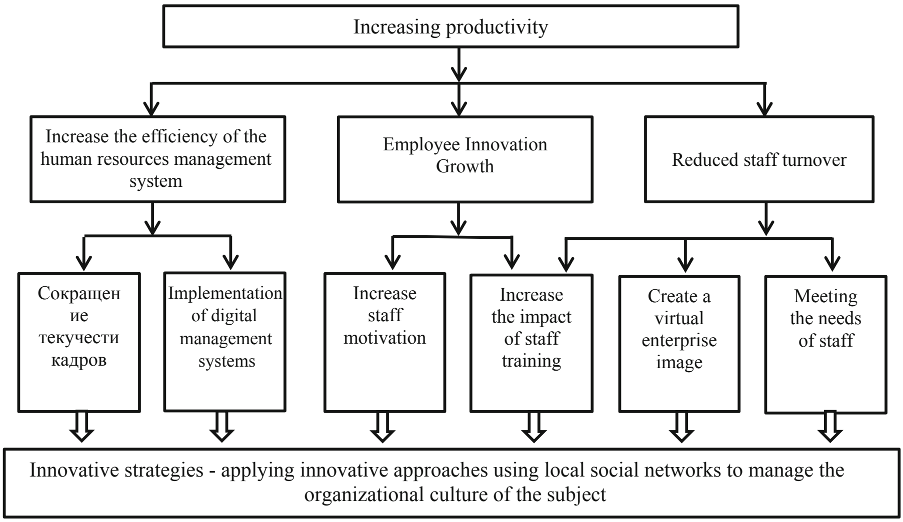

Fig. 1. Business entity goal tree. *Source*: developed and compiled by the authors

It should be noted that at present the management of organizational culture is associated with certain difficulties due to the fact that the personnel of enterprises is replenished by representatives of the new younger generation of Zetas (Bakanov 2014). They are radically different from their predecessors. Young employees are complex as a management object, they need interest to work, they perceive information in a compact form, they have a relatively short time of concentration, so traditional management methods become ineffective. If they don't like something, they quickly leave the company. But the effective functioning and development of the organization always requires new personnel with modern knowledge. It is here that the task of developing and implementing relevant means and methods of influencing the audience - means and methods of managing organizational culture.

2 Materials and Method

As already noted, the organizational culture has a significant impact on the efficiency of the enterprise. A modern and popular strategy, which is based on the requirements of various markets and is suitable for a dynamically changing external environment, implies a culture based on: high integration, individual initiative, risk, creativity, globalization processes, a high level of the communicative environment in the labor team. Such a strategy focuses on efficiency, labor productivity, ethical attitude to the consumer in a constantly changing environment. It is more successful when the culture of the organization has good innovation responsiveness, mobility and flexibility of management.

Companies or enterprises will always achieve high performance and stability of growth, but provided that their organizational culture is consistent with the strategy used. Linear processes maintain stability if culture is focused on centralized decision-making and constrains individual initiative. Unsystematic technologies result if they are formed on the basis of an innovative corporate culture, which stimulates and encourages individual initiative, manifestations of creativity and reduces the importance of formalizing processes. Particularly popular and effective, advanced companies recognize the strategy of decentralization of knowledge and management (Bezlepkin 2014).

The control of a strong organizational culture determines the behavior of employees. Staff knows what type of behavior they should adhere to. The systematization and predictability of activities in the company are formed by maintaining a high level of formalization of the workflow. The stronger the culture of the company, the less managers and management staff need to pay attention to the development and development of formal rules for managing the behavior of the team.

The impact of organizational culture on performance is determined by its ability to integrate with the overall strategy of the enterprise. In the case of cultural and policy divergence, the following main four approaches are taken:

- culture is ignored, but then it becomes a negative factor that prevents the effective implementation of the planned strategy;
- The management and decision-making process is adapted to a functioning organizational culture. This approach is based on the adoption of the barriers created by culture to implement the desired strategy and the development of alternative options for avoiding obstacles without the use of elements that radically change the strategy;
- attempts are made to change the culture so that it meets the conditions for the successful implementation of the used strategy. This is the most complex
- approach, as it requires considerable resources;
- the strategy adapts to a functioning culture, but here you need to take into account that the climate in the team may not be too good-pleasant to implement this
- approach.

Organizational culture, as shown in Fig. 2, has a strong connection with all the system-forming components of the system (business entity). The organizational culture is a kind of link and directly affects the efficiency of the operation or activities of the enterprise.

Research on the impact of organizational culture on the company is mainly carried out through questionnaires and/or questionnaires. The results of the studies reflect the general picture of satisfaction and/or dissatisfaction of the labor team. Such a way in a dynamically changing world is losing its relevance, as many employers see a positive, neutral or negative attitude towards the organization in the profile of the employee's social networks, where he constantly shares his opinion with others.

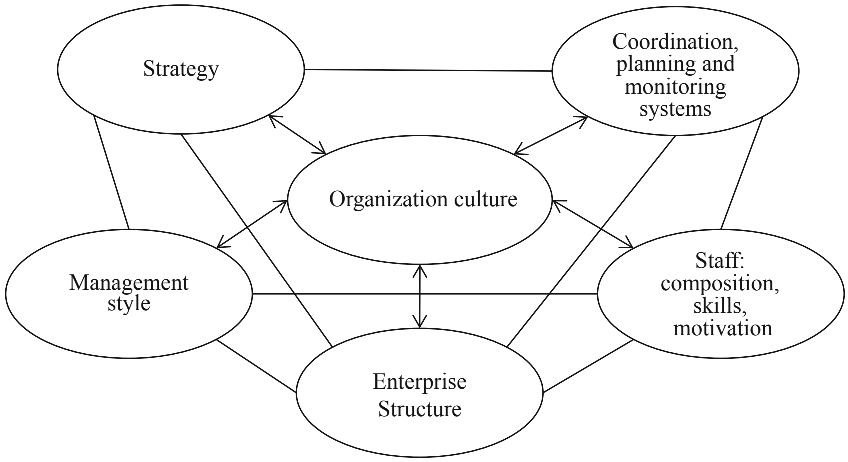

Fig. 2. Relationship of the management system to the organizational culture. *Source*: Solomanidina (2011). Organizational culture in tables, tests, diagrams

Culture has a significant impact on decision-making through available guidance and values that shape the professional behaviour of staff. The most important task of the organizational culture is to unite the team, which makes the decision-making process more effective, since it contributes to the development of communication. In some companies, openness of communication is appreciated, and in others, vice versa. An employee feels part of an organization when he has a kind of emotional connection and involvement in it. At the same time, its effectiveness can be measured through employee satisfaction (Holmes 2006).

The relationship between the results of the activity of the economic subject and the organizational culture in a generalized form is recorded in the model of Parsons (American sociologist). This model is based on the specification of specified functions that any social or socio-economic system must implement for its survival and the formation of conditions for achieving success. The model developed by Parsons was called AGIL (abbreiturva is co-placed by the letters of the names of functions: adaptation; goal-seeking; integration и legacy).

The essence of the described model is as follows. For survival and development, an organization or company must adapt to constantly changing conditions on the part of the external environment, strive to realize its mission and goals, ensure the integrity of a single structure, and gain recognition of society.

This model is gradually gaining great popularity among representatives of new business and various startups; it is characterized by a convenient form and meets almost all the needs of modern society.

When considering this topic, it is also necessary to take into account changes in the current state of the economy and the socio-psychological climate in society. In connection with recent events, it can be seen that the global crisis of 2020 (with the prerequisites of a structural species) is accompanied by a pandemic of coronavirus infection. This phenomenon encourages the Governments of most countries to introduce a strategy of social distancing and separation into the socio-economic structure of society. These measures lead to the expansion of markets such as distance education, remote work, virtual world, and artistic culture and many other areas of human life.

As a result, the modern world is in a state of peculiar explosive technological transformation. Throughout the history of the development of society, revolutionary and breakthrough technologies have always accumulated long and gradually. And such a state sooner or later conditionally exploded, launching an instant restructuring of both the economy and public relations. True, these tremors were accompanied by military operations: the formation of the philosophy of universal equality required a huge number of casualties in the First World War, and the idea that proclaimed the highest value of human life was established as a result of World War II.

The current situation with the crisis and the new virus in terms of the scale of losses and destruction, of course, is not comparable to previous stages of development, this is an unprecedented case, but the effect on the economy and politics, the consciousness of society, can be considered quite comparable.

This transformation has led to the transition of millions of people to remote work. Now the employee shows the effective use of working time at home, the time of distraction from the work process has been significantly reduced. A positive trend towards an increase in the traffic of corporate instant messengers and online education sites is also noticeable. Many employers note that remote work is a third more efficient than office work and much cheaper than it. But distance is a negative factor for successful communication in the team, the atmosphere of corporate culture is gradually losing its relevance, which can affect the activities of the organization. In this regard, the main task is to find approaches to the formation of an organizational culture in the digital environment.

3 Results

Currently, the social network is a virtual environment of communications, connections, opportunities that are necessary for the formation and management of organizational culture. This tool is used by all employees of various enterprises of any level, that is, modern society lives as if in two worlds, real and digital.

In this regard, it is proposed to use local social networks for each individual business entity as a system-forming factor. This can be considered as a ready-made proven mass method for the formation of various cultures, subcultures, philosophy, values and interests (Groshev et al 2019).

According to statistics, each representative of generations of "igreks" and "zetas" according to available analytical data goes to various social networks at least 5 times an hour. For that reason, that fact could be used to create a virtual communication environment for the organization. It is here that an employee will be able to express himself, achieve status, maintain a working profile, receive recognition from colleagues, as well as expand business ties and show activity in the life of the company for only one reason - for him this is a familiar habitat. A local social network can become the main tool for building community and team integrity, even if the enterprise operates in a remote format. With it, you can set both the pace of work and form an organizational culture, more precisely; it will be able to form itself, through interested and/or ambitious employees.

In this network, just like anyone else, it will be possible to register a personal account with limited access for students of various educational institutions of the professional education system.

Table 1 shows the option of forming the organizational culture of the enterprise using the local social network.

Table 1. Formation of organizational culture of the management entity

Method	Purpose	Method (local social network)	Result
Using Organization History Clarification of "heroic" examples	Formation of a sense of importance of the company in the history of the territory	Maintain Organization Profile Maintain Company Event News Feed	Holistic organizational culture
Leadership and Role Models Transfer of norms and values	Forming a sense of unity	Create an employee's virtual profile Maintain an employee's own blog	
Remuneration System Career management and job security Socialization of new team members Staff training and development	Developing a sense of involvement in the affairs of the company, membership in the team	System of "subscriptions, likes, reposts" Controlled and flexible rank system Increasing speed of adaptation Maintenance of online seminars	
Contacts between employees Participation in decision-making Inter-group coordination Individual exchange	Developing a sense of involvement in the affairs of the company Improving Worker-to-Worker Relationships	Use of collaborative conversations Instant online surveys and testing Formation of thematic groups Personal chats	

To represent and characterize the process of using the approach to organizational culture management in question, aimed at improving the performance of the business entity, use the context diagram shown in Fig. 3.

Using the new approach gives us additional opportunities and allows us to: form a register of promising employees; In connection with increased productivity, generate additional profits; make organizational culture a flexible and mobile system.

In today's circumstances, under the current conditions in the world, all these advantages are becoming relevant and in demand by the economic sector.

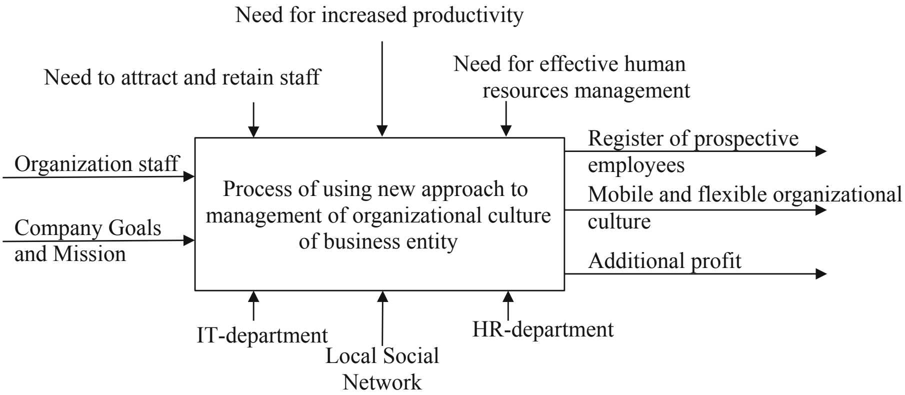

Fig. 3. Context chart. *Source*: developed and compiled by the authors

4 Conclusion

Indicators of financial and social effects can be used to characterize the results, which are determined by the following set of indicators of the enterprise:

- Financial effect is expressed in increase of the organization's income and/or decrease of expenses;
- The social effect is determined by the number of new employees or the decrease in staff turnover and training costs, as well as an increase in the number of
- innovative projects by staff.

When assessing the socio-economic consequences of using a new approach to organizational culture management, it is proposed to take indicators of the current effect. As a result of the use of the local social network, it is supposed to provide:

- stabilization and growth of the company's human capital;
- maintaining existing rules and regulations and creating a new virtual organizational culture;
- reduction of stress level in the team;
- Increase productivity, efficiency and quality of work by increasing employee motivation;
- Increase the efficiency of the employee management system;
- Introduction of new methods of work for professional orientation of future potential employees of the company and creation of a virtual attractive image of the company.

If we talk about economic efficiency, then, for example, according to the American consulting firm Bersin & Associates, companies using talent management strategies and organizational culture as a whole generate 26% more profits than competitors.

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Transformations of the Modern Russian Economy: Causes, Trends, Possible Alternatives

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Abstract. Purpose: The purpose of the chapter is to underline through the historical analysis of public debt relations the main changes in the economic system of the Russian Federation.

Design/methodology/approach: In this chapter the authors pay attention to the cyclical nature of economic relations. In particular, we are talking about the impact on the modern economic structure of centuries-old historical problems in the field of public debt relations. Besides we devoted special attention to the processes of capital's globalization, which can act as a problem, and, in the same time, can provide unique alternatives for modern Russian economy.

Findings: Centuries-old debt problems and the effect of capital globalization identified new development trend. In this chapter it was named as institutional and mechanical transformation in the financial sector of the economy. Besides, in the context of this transformation, possible alternatives for the future development of monetary circulation were identified in the chapter.

Originality/value: The institutional and mechanical transformation and the trends in the development of monetary circulation are united by a common goal - to speed up operations and to provide a high-quality reflection of current information. Perhaps these innovations will allow to optimize the procedure of state debt relations in its problem segments.

Keywords: Cyclical government debt relations · Globalization of capital · Institutional and mechanical transformations · XBRL (eXtensible Business Reporting Language) · Cryptocurrency and gold standard

JEL Code: E32 · H63 · E69 · E58 · E42

1 Introduction

Historically, finance was one of the most problematic areas of the Russian economy. It determined the specifics of economic development. Using the historical-system approach in this research, we identify and analyze the cyclical development of state debt relations. Although such development can be considered as the general form and tendency of state debt relations, it is still relevant to study the special factors that modify the modern cycles. It is necessary to develop ideas about financial policy alternatives and problems

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that must be resolved in this area. Moreover, the causes of these cycles can be quite contradictory.

Besides, we devoted special attention to the processes of capital's globalization, which, on the one hand, can act as a catalyst for cyclical problems, and, on the other hand, can provide unique alternatives for overcoming the negative aspects of cycles.

We also examined the main trends in the Russian economy, occurring in parallel with the cyclical development crisis of state debt relations. In this case, we are talking about a kind of institutional and mechanical transformation in the financial sector of the economy. As part of this transformation, a number of new institutional regulations (not yet specific to Russian conditions) are being applied. The main idea of our research is an analysis of transformational factors and alternatives that are typical for the development of the Russian economy.

2 Materials and Method

More than four centuries, since the re-establishment of independent Russian statehood, the economy has been affected by such circumstances as the state debt (Bozheryanov and Romanov 2013). A relatively favorable situation sooner or later turns into a crisis due to external or internal reasons. As a result, there is an increase in the debt burden, then the state implements some of the measures to regulate the situation, and finally this process ends with a reduction in the debt burden (Moiseev 2017). Moreover, this process has a certain periodicity, which allows us to conclude that there is a cycle.

The reasons of this cyclical nature may seem external political factors rather than exogenous economic factors. These circumstances have a real, deeper reason - ineffective norms for the implementation of economic relations (institutional, organizational, and economic norms).

Cyclical debt development in Russia cannot be eliminated for several reasons. Firstly, because the personal interest of the ruling elite prevails over the interests of social and economic development. It leads to the adoption of ineffective norms, aimed at the formal reduction of debt. Secondly, public debt funds are not aimed at economic development, and sources of debt repayment, on the contrary, are withdrawn from the economy, it clearly shows us double damage to the sectors of the socio-economic structure. Thirdly, there is still no good mechanism for co-financing within the country, and procedures of intergovernmental relations are poorly developed. As an example, we can consider budget regulation through intergovernmental transfers. This regional co-financing mechanism operates in accordance with a certain method, aimed at applying a new approach to the allocation of subsidies for equalizing the budgetary provision level. This approach is called "the model budget". The purpose of this innovation is to encourage regional authorities to apply responsible social and economic policies (Mokhnatkina 2015). Among the obvious disadvantages of the method, we can emphasize the high probability of funds concentration in the Federal center, which will cause damage to other regions and, of course, will contribute to inefficient use of funds by Federal ministries. And, therefore, this method is exclusively financial in nature. It will not be able to quickly solve the problem of insufficient funds. Its essence is to support already developed regions, but we are not talking about them now.

In addition, the influence of the capital's globalization is strong. It manifests itself as a kind of catalyst for most processes in the Russian economy, which may lead to the dominance of certain segments of it or, on the contrary, may lead to decline of various sectors (Buzgalin and Kolganov 2015).

The increasing cyclical nature of state debt relations and the impact of the phenomenon "capital's globalization" have led to the introduction of new social and economic elements into the financial system of the Russian Federation. Due to the weakening influence of the public sector, the situation of financial sector (institutional and mechanical transformation) was strengthened. Besides, cases of using capital with elements of a non-standard monetary circulation system began to appear more clearly.

3 Results

The transition of the financial sector to a Single chart of accounts, International financial reporting standards (IAS, IFRS), and a new mechanism for submitting reports in XBRL format, at the initiative of the Bank of Russia, has strengthened the integration of the financial market into the global economic system. The positions of financial players have been brought to the fore, and their role in the economy has been strengthened in comparison with those of public sector entities. In parallel, mechanical transformations are taking place, based on the introduction of new standards for accounting and reporting. There was a pronounced institutional and mechanical transformation of the country's financial system, which was able to compensate for the shortcomings of exclusively monetary state measures (Nesterova 2018).

It is important to note here, that the transition to XBRL has a number of advantages for the company: automation, cost reduction, speed, reliability, and more accurate data processing. There is an improvement in the analysis and quality of information for decision-making (XBRL - a new reporting format, 2013, Autonomous non-profit organization "Center for the implementation and development of the XBRL format" (XBRL Center), 2019). Implementation of IFRS and XBRL is a technologically and methodologically complex task, especially for financial market entities, and is also capital-intensive. The standards are based on a conceptual framework that implies the predominance of professional judgment in the decision-making process for providing information (Morozova et al. 2018). As practice shows, these innovations, in the case of inefficient implementation in Russian conditions, lead to an increase in the costs of company, for example, in the selection of personnel or in the acquisition of the necessary software (Fomina and Fomin 2016).

However, the introduction of new forms and methods of submission and reporting is not sufficient, because in this case it is necessary that all subjects and institutions of the financial market are able to interact with each other more effectively.

A conscious need is to turn to qualitatively new solutions. An alternative could be a return to the gold standard, which prevents states from issuing money without control. But, comparing the current global gold reserves with the amount of money in circulation, the measure seems poorly implemented.

Modern economists see the introduction of a virtual currency as a second alternative to solving these problems. For example, electronic coins – so-called cryptocurrencies. However, despite the legalization of this decision by some countries (Australia, New Zealand, Japan, Tunisia, South Africa, USA, Germany, etc.)., the probability of speculative use of this asset remains.

4 Conclusion

What kind of transformations and alternatives to the modern economy, which were caused by the instability of the public sector and, in particular, the debt problem, do we see? First of all, this is the most pronounced transformation towards the financial sector, and the transformation is two – level-additional financing of the financial sector by the state (although not fully effective) and regulation by the Central Bank of the Russian Federation of the processes of globalization of capital in terms of integration into the system of new standards and technologies. In addition, this is the emergence of new, extremely pronounced alternatives to the development of monetary circulation, which are also the results of the globalization of capital, but have not been regulated by the state yet.

Indeed, at this stage of development, we can talk about the existence of a dual or mixed type of financial system in Russia. The public sector, weakening, but still exerting a huge influence, sets and directs the main economic flows. A growing and every year strengthening financial sector, the organization of which is based on the results of the institutional and mechanical transformation and on the impacts of globalized capital. Besides, there is a growing system of money circulation, based on the use of new cryptocurrency mechanisms with the ability of reinforcing the gold standard. This mechanism will be able to influence both of these economic segments.

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Possible Medium-Term Scenarios of Dynamics of Russia's Energy Resource Exports After the Economic Crisis of 2020

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Abstract. Purpose: the purpose of the research is to define the minimum and maximum volume of decline in Russia's energy resource exports during and after the pandemic crisis, to forecast and analyze the physical and value amounts of exports of crude oil, petroleum products, pipeline natural gas, LNG and coal from Russia during the period of 2020–2024.

Design/methodology/approach: based on Russian Federal statistics, international statistical bases of organizations specialized in energy, business analytics and its forecasts the author predicts the physical volumes and prices of different energy goods exported form Russia for the medium-term period of 2020–2024.

Findings: The proposed scenarios reflect 3 possible ways of recovery from the pandemic crisis: negative, baseline and optimistic. The L-shaped, U-shaped and V-shaped graphs respectively represent the phases of recovery after the crisis caused by industrial break and lockdown in a certain sphere of fuel and energy economics. The decline in total amount of energy goods exports from Russia is estimated as 8–15% in negative scenario, 6–15% in baseline scenario and 4–10% in optimistic scenario in 2020. All the figures appearing in the article are justified by certain processes, governmental actions or counter actions of the principal external partners.

Originality/value: the results of the author's research presented in this article are new, consider the latest information and statistics about the global and regional economy during the pandemic crisis and can be used for planning the external economic interaction with Russia, as well as modifying European energy policy due to newly adopted Green Deal, modifying external energy policies of the Middle Eastern countries, China, US, JKT and other Asian countries and EAEU countries due to the actions of their principal competitor and partner - Russia. The results are also of use not only to governments, but also to business intermediaries and industrial producers as the article concerns the area of international energy supply.

Keywords: Energy exports · Energy supply · Russian exports · Fuel prices · Pandemic crisis · Regional economy · COVID-19 economic influence

JEL codes: F14 · F17 · G01 · G17 · O13 · P28

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1 Introduction

The economic crisis caused by the pandemic of the COVID-19 coronavirus has brought the entire world economy into a state of deep recession. It manifested itself in the decline of the industrial production caused by the quarantine measures, in a sharp drop in the purchasing power of the population, and in lowering of energy prices.

Industrial production represented 37% of total global energy demand in 2019. Fossil fuels account for 70% of all consumed energy resources. (IEA 2019) These facts largely determine the volume of Russia's energy resource exports. The value of energy exports amounted to 59.8% of the total value of Russian exports in 2019. (Federal Customs Service 2020) That is why forecasting the dynamics of Russia's energy resource exports is extremely relevant for both governmental bodies and energy consuming businesses within the country.

The critical importance of energy export planning in creating and adjusting strategies for domestic economic policy and participation in the global economy is highlighted in the works of Baran (2005), Frisch (1989), Kuznetsov (2019), Seredina and Cherkasov (2018), Tebekin (2019), Ulanov and Ulanova (2019).

The diversification of importers of Russia's energy resources as part of the energy security policy was noted in the works of Rodionova et al. (2017), Shkvarya (2017). It will become a key link in the chain of actions needed to maintain Russia's position in the global energy arena in the event of a significant drop in energy exports as a result of the COVID-19 pandemic and subsequent economic crisis.

2 Materials and Methodology

In this work, export of energy resources is understood as the export of crude oil, natural gas, liquefied natural gas (LNG) and coal, as well as the export of petroleum products.

The calculations of the volume of Russia's energy exports are based on the 2019 values provided by the Federal Customs Service of the Russian Federation (Table 1).

Table 1. Russia's energy exports in 2019

	Crude oil	Petroleum products	Natural gas	Liquefied natural gas	Coal	Total energy exports
Export volume in 2019, millions of tons	267.47	142.80	219.9 billion m^3	65.4 million m^3	205.39	-

(*continued*)

Table 1. (*continued*)

	Crude oil	Petroleum products	Natural gas	Liquefied natural gas	Coal	Total energy exports
Export volume in 2019, billions of USD	121.44	66.89	41.63	7.92	15.99	253.87
Average annual export price of a resource, USD / unit	454 USD/t	468.4 USD/t	0.19 USD/m^3	121.1 USD/m^3	77.9 USD/t	-

Source: developed and compiled by the author based on Russian Federal Customs Service (2020)

Three scenarios of the development of Russia's energy export dynamics are proposed: negative, baseline and optimistic. The names of the scenarios and their essence are determined by the state of the world economy.

The negative scenario implies an L-shaped graph of the development of the global economy with a protracted phase of depression crisis. It presupposes ineffectiveness of measures to counteract the spread of the COVID-19 virus and devastating consequences of the decline in world production and consumption.

The baseline scenario is characterized by a long-lasting phase of depression crisis followed by a rapid entry into the recovery phase of both the Russian and global economies, the suspension of the spread of the virus and the reduction of the burden on the health and financial systems, the well-coordinated policy of the OPEC+group in regulating oil production and, as a result, oil prices. The global economic development graph is U-shaped. The dynamics of Russia's energy exports will show a similar trajectory with the difference in trend in the phase of depression and recovery.

The optimistic scenario implies a V-shaped graph of relatively quick recovery from the crisis and a return to the amounts of world production and GDP of pre-crisis years in the time horizon of 1.5–2 years. The dynamics of Russia's energy exports will show a significant decline in the II-III quarter of 2020 and II quarter of 2021, given the seasonality of demand for energy resources. The decline will not be as dramatic as in other scenarios.

The forecast amounts of Russia's energy exports are presented in the scenarios based on a number of factors and existing development scenarios: forecasts of the dynamics of global economy and industrial production, the prevailing trend of a slowdown in global economic growth, the structure of energy consumption by industries, the dynamics of Russia's energy exports for the period of 2015–2019, oil, natural gas and coal price forecasts, trends in the ratio of use of energy resource types in the world economy and author's calculations of Russia's export opportunities, taking into account existing governmental export support.

The study was carried out in the II quarter of 2020 at the very beginning of the crisis; therefore, it includes a significant share of approximation. However, considering the fact that the calculations of the amounts are based on early forecasts of IMF (2020), IEA (2019), US EIA, OECD, UNCTAD, Deloitte (2020), Dediu et al. (2020) and Russian Ministry of Energy (2020), the study can be considered reliable and practically applicable for planning economic activity by both governmental bodies and businesses.

3 Results

The dynamics of energy exports are visually presented in Fig. 1.

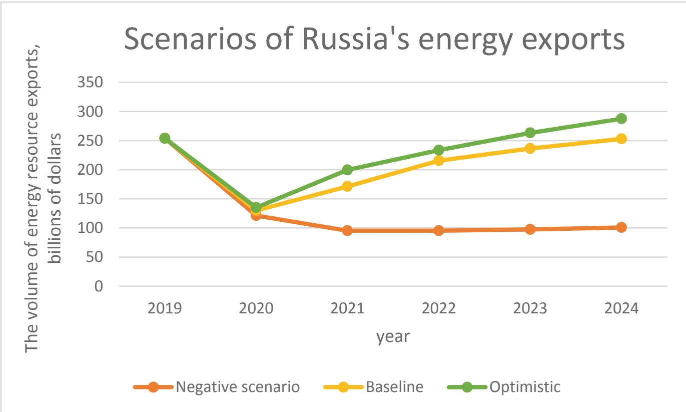

Fig. 1. Graphs of the dynamics of Russia's energy resource exports under the three scenarios of development of the economic crisis of 2020–2024. *Source*: developed and compiled by the author

Value indicators of the scenarios are set out in Tables 2, 3, 4.

3.1 Negative Scenario of Export Dynamics Development

Energy export amounts are predicted in groups of energy export goods for the period of 2020–2024 (Table 2).

Table 2. Forecast of amounts of Russia's energy resource exports for the period of 2020–2024 in a negative scenario

	2020	2021	2022	2023	2024
Crude oil export volume, millions of tons	235.37	208.63	213.98	215.3	220.5
Crude oil price, USD/t	236.39	172.26	153.93	153.93	153.93

(*continued*)

Table 2. (*continued*)

	2020	2021	2022	2023	2024
Crude oil export volume, billions USD	55.64	35.94	32.94	33.14	33.94
Petroleum product export volume, millions of tons	121.38	109.24	111.97	114.21	117.64
Petroleum product price, USD/t	250.57	180.87	158.55	158.55	158.55
Petroleum product export volume, billions USD	30.41	19.76	17.75	18.11	18.65
Natural gas export volume, billions of m^3	197.91	193.95	197.83	203.7	209.87
Natural gas price, USD/m^3	0.11	0.13	0.14	0.14	0.14
Natural gas export volume, billions USD	21.77	25.21	27.70	28.52	29.38
LNG export volume, millions of m^3	58.86	57.68	59.23	71.08	85.29
LNG price, USD/m^3	71.24	76.50	79.50	79.50	79.50
LNG export volume, billions USD	4.19	4.41	4.71	5.65	6.78
Coal export volume, millions of tons	188.96	183.29	201.12	203.64	205.67
Coal price, USD/t	49.00	53.90	60.00	59.00	58.00
Coal export volume, billions USD	9.25904	9.879331	12.0672	12.01476	11.92886
Total energy resource exports, billions USD	121.28	95.20	95.16	97.43	100.68

Source: developed and compiled by the author

A reduction in real export volumes in 2020 was planned at the level of 12% for crude oil, 15% for petroleum products, 10% for pipeline gas and LNG, 8% for coal. The dynamics after 2020, under a negative scenario, will show recovery only by 2023–24. Export of petroleum products, in contrast to other indicators, will show weaker dynamics of recovery due to the forecast for a decrease in the growth rate of oil refining.

Petroleum product prices in all three scenarios are tied to the price of crude oil and fluctuate between 103–110% of its price, the fluctuation corridor is set by the characteristics of the production of petroleum products and dependence on the price of the main raw material - crude oil.

3.2 Baseline Scenario of Export Dynamics Development

Under a baseline development scenario, the volume of oil exports from Russia will return to the pre-crisis level by the end of 2021, primarily due to the rapid recovery of the Chinese economy, which purchased about 30% of all oil exports from Russia in 2019. A longer recession in the EU economy (about 40% of oil exports, 85% of gas from Russia) compared with China will spur an increase in exports of both oil and pipeline gas at the turn of 2021–22.

The decline in real crude oil exports is estimated at 10%, petroleum products - 15%, natural gas - 6%, LNG - 10%, coal - 8% in 2020. Planned volumes of energy exports are predicted based on the baseline scenario outlined in the Forecast of Russia's Socio-Economic Development until 2024 (Ministry of Economic Development of RF, 2019).

Prices in the baseline scenario are predicted based on expert estimates for 2020–21, prevailing trends in oil production at maximum volumes and a relatively quick recovery in the level of demand for crude oil and petroleum products. Thus, the Deloitte report predicts a steady excess of gas and oil supply, which was outlined at the end of 2019, over the demand for these energy resources until the onset of winter of 2020 and multidirectional dynamics of supply and demand with surges in demand in May, July and November 2021 (Deloitte 2020) In 2020, LNG prices declined the most of all energy

Table 3. Forecast of amounts of Russia's energy resource exports for the period of 2020–2024 in a baseline scenario

	2020	2021	2022	2023	2024
Crude oil export volume, millions of tons	240.72	262.12	267.0	268.3	269.2
Crude oil price, USD/t	254.72	317.39	395.82	409.75	426.61
Crude oil export volume, billions USD	61.32	83.19	105.68	109.94	114.84
Crude oil export volume, millions of tons	121.38	128.66	131.23	134.50	140.50
Petroleum product export volume, millions of tons	267.45	333.35	407.70	422.05	439.4
Petroleum product price, USD/t	32.46	42.89	53.50	56.77	61.74
Petroleum product export volume, billions USD	206.71	212.90	233.50	244.00	250.40
Natural gas export volume, billions of m^3	0.11	0.14	0.16	0.19	0.20
Natural gas price, USD/m^3	22.74	29.81	37.36	46,36	50.08
Natural gas export volume, billions USD	58.86	60.2	66.75	85.28	108.07
LNG export volume, millions of m^3	71.24	74.80	78.50	81.68	86.58
LNG price, USD/m^3	4.19	4.50	5.24	6.97	9.36
LNG export volume, billions USD	188.96	201.30	205.00	209.10	211.19
Coal export volume, millions of tons	49.00	53.90	67.00	78.00	80.1
Coal price, USD/t	9.26	10.85	13.74	16.31	16.92
Coal export volume, billions USD	129.97	171.24	215.52	236.34	252.93

Source: developed and compiled by the author resources, as the production of this type of fuel is the most labor- and capital-intensive, the recovery trend of these prices is the smoothest due to the lack of published intentions of producers to open closed and develop new deposits.

3.3 Optimistic Scenario of Export Dynamics Development

Table 4. Forecast of amounts of Russia's energy resource exports for the period of 2020–2024 in an optimistic scenario

	2020	2021	2022	2023	2024
Crude oil export volume, millions of tons	240.72	267.12	268.0	268.3	272.2
Crude oil price, USD/t	267.55	359.17	403.15	443.47	465.46
Crude oil export volume, billions USD	64.40	95.94	108.04	118.98	126.70
Crude oil export volume, millions of tons	121.38	132.00	141.50	142.50	144.50
Petroleum product export volume, millions of tons	283.60	369.95	415.24	456.77	479.42
Petroleum product price, USD/t	34.42	48.83	58.76	65.09	69.28
Petroleum product export volume, billions USD	206.71	214.90	235.40	248.00	252.64
Natural gas export volume, billions of m^3	0.11	0.17	0.19	0.21	0.24
Natural gas price, USD/m^3	22.74	36.53	44.73	52.08	60.63
Natural gas export volume, billions USD	58.86	60.62	68.75	87.50	110.00
LNG export volume, millions of m^3	71.24	85.5	94.00	120.0	124.00
LNG price, USD/m^3	4.19	5.18	6.46	10.50	13.64
LNG export volume, billions USD	188.96	203.40	206.00	210.20	213.02
Coal export volume, millions of tons	49.00	63.70	76.00	78.30	80.62
Coal price, USD/t	9.26	12.96	15.66	16.46	17.17
Coal export volume, billions USD	135.02	199.45	233.65	263.11	287.42

Source: developed and compiled by the author

The 2020 decline in real export volume is predicted at the level of the baseline scenario, the recovery and achievement of values of an optimistic growth scenario for the world economy will occur faster.

Prices in an optimistic scenario are based on the presumption that the world economy will recover from the crisis and enter the recovery period rather quickly, stimulating a recovery in energy demand with a price increase of 5–10% annually. However, crude oil prices, for example, will not be much higher than the prices of the pre-crisis period due to consumer caution, the formation of significant reserves at the onset of the crisis, and the general trend towards a transition to cleaner energy resources, primarily pipeline gas. The price of coal will not significantly exceed the price level of 2019, as total coal demand will decline for the same reasons as crude oil.

4 Conclusions

The volumes of export decline both in physical and in value terms are significant in all scenarios, at least in 2020–21. Based on the prevailing trend of the weakening of the Russian ruble against the US dollar (energy exports provide a large share of Russia's foreign exchange earnings), this decline will be compensated, among others by tax revenue increases. This fact will prevent the Russian budget from suffering as significantly as, for example, the budgets of the United States or EU countries.

The depth of the current crisis is certainly comparable with the biggest shocks to the global economy, like the Great Depression of the 1930s. And the consequences of this crisis will have an impact on the entire geo-economic picture of the world, including the distribution of energy resources.

The author does not undertake to judge the likelihood of the occurrence of a particular scenario with a high degree of certainty, but is more inclined to a baseline scenario that reflects consolidated forecasts. At the same time, one must not exclude the possibility of synthesis of, for example, a baseline and negative scenario, which is a possibility mentioned in the main report of World Economic Outlook IMF (2020).

Of course, the presented scenarios for the development of Russian energy exports are subject to a large number of exogenous factors that can influence them, beginning with the outcome of the situation with the COVID-19 pandemic all the way to fluctuations in weather conditions in all regions of the world. However, the given trends, based on a deep synthetic analysis of statistics, opinions of business experts, forecasts of governmental bodies, international organizations and the personal vision of the author, give an understanding of the processes that will take place in the field of Russia's energy exports in the coming years.

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Accounting and Economic Aspects of Client Management at Service Enterprises

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Abstract. Purpose: Development of client management of service industry enterprises by systematizing the accounting and economic aspects of customer focus management and developing proposals for implementing measures aimed at forming client capital.

Design/Methodology/Approach: We find it practical to apply accounting methods and principles for assessing the effectiveness of client management, based on a comparison of the estimated economic benefits, the inflow of assets from regular customers, to which the criterion of loyalty fits, with the costs of creating and maintaining loyalty. Strategic accounting involves the formation, evaluation and registration of client capital based on a number of factors that will be proposed in this article.

Findings: In the process of preparing the article, the following results were achieved: the feasibility of accounting for client capital for the implementation of the principle of customer focus in managing a service enterprise was substantiated; factors for evaluating client capital have been identified; systematized accounting and economic aspects of client capital of service industry enterprises; recommendations on the development of client management are formulated with the aim of implementing the principle of customer focus and the formation of client capital in the management of a service enterprise.

Originality/Value: Consist in the fact that the results of this article make a theoretical contribution to the interpretation of the concept of client capital, enriching it with accounting and economic aspects, it shows the feasibility of registering client capital as a variety of intangible assets of a service enterprise, practical recommendations are made on the development of a client -management of service industry enterprises.

Keywords: Client capital · Service industry · Valuation · Accounting

JEL Code : D81 · M41

1 Introduction

The specificity of the service business lies in the fact that the main focus of his activities is the client and the satisfaction of his needs for obtaining high-quality services. There

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are also many hidden needs that the client wants to realize along the way with the main service, for example, a desire to communicate, obtain information, gain new experience, enjoy a comfortable environment, a sense of belonging to a consumer society. The principle of customer focus involves a deep study of customer motivation, constant improvement of the possibilities of its implementation. "The customer is always right" - this common phrase should become the main imperative of the company if it wants to form a stable, constantly expanding customer base, which is certainly the most important condition for survival in a modern highly competitive environment. A customer-oriented approach to managing a service enterprise involves the development of customer management aimed at creating and managing a database of regular customers.

It is necessary to conduct a comparative assessment of how much the client costs the service industry enterprise, that is, the costs of its maintenance with what income it brings in order to identify the financial result of the service and determine a fair motivating staff fee.

The implementation of this task of managing a service business enterprise in terms of client management is accomplished through research and systematization of the accounting and economic aspects of customer focus.

This article implements the following tasks:

- justification of the need to consider client capital in order to implement the principle of customer focus in the management of a service enterprise;
- determination of factors for evaluating client capital;
- systematization of aspects of accounting for client capital of service industry enterprises;
- formulated recommendations for the development of client management in order to implement the principle of customer focus in the management of a service enterprise.

2 Materials and Methods

Based on the research methodology, we used the following theories: supply and demand, transaction costs, capital theory, and the international concept of integrated reporting, strategic accounting, and valuation of client capital. The customer-oriented approach of service enterprises involves the formation of a database of loyal customers and systematic work with it. We consider it appropriate to apply accounting methods and principles for assessing the effectiveness of client management, based on a comparison of the estimated economic benefits, the inflow of assets from regular customers, to which the loyalty criterion is suitable, with the costs of creating and maintaining loyalty. Strategic accounting involves the formation, evaluation and registration of client capital based on a number of factors that will be considered in this article.

The objects of the study were enterprises of the Rostov Region service industry.

3 Results

Capital is a multifaceted economic category, affecting various general economic, legal, accounting aspects in its interpretation. As part of our study, we did not touch on a detailed consideration of them, since the subject of our research has certain boundaries and coincides with the subject of client management—client capital. Accounting and economic approaches to its interpretation are important for us, so they allow us to express this economic concept in a money meter and take it into account with the definition of management efficiency. There are no generally accepted methods of accounting and valuation of client capital, since the regulatory regulation on accounting does not provide for such an object of accounting, it is also not a legal category. For the correct assessment of the value of the service business, it is necessary to take into account all aspects of its functioning and the presence of regular loyal customers is one of them. In our opinion, customer capital is nothing more than a database of regular customers whose loyalty is time-tested.

Assessment of client capital is expert in nature and its methodology may have various amendments depending on the specifics of the enterprise. We empirically selected the factors that are taken into account in the process of evaluating the client capital of a service business enterprise, as reflected in Fig. 1.

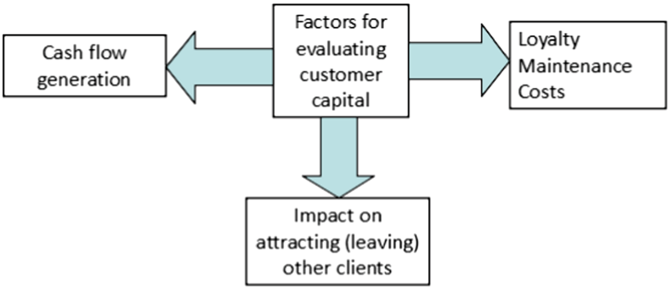

Fig. 1. Factors in assessing client capital. *Source* proposed by the authors

In our opinion, the main factor affecting the assessment is the estimated cash flow generation in the form of revenue, carried out by the client. To assess, we apply the discounted cash flow method, determined by the formula:

$$DCF = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i}.$$

Where:

DCF (discounted cash flow) - discounted cash flow;
CF (cash flow) - cash flow in period i;
r - the discount rate (rate of return);
n - the number of time periods for which cash flows are generated.

The next evaluation factor is the cost of attracting and retaining a client. These include the costs of personal work with him, including the costs of working time for telephone calls, the implementation of loyalty programs, the provision of personal discounts and special offers.

There is an expert assessment that a satisfied customer brings two new ones, and a dissatisfied customer leads ten. In our opinion, these parameters need empirical verification on the materials of individual enterprises in the service industry. Nevertheless, the factor of possible attraction or, on the contrary, withdrawal of clients seems to be important for assessing client capital. After all, as mentioned above, a client is, first of all, a cash flow, a company's revenue.

Customer capital is a database of regular customers whose loyalty is time-tested.

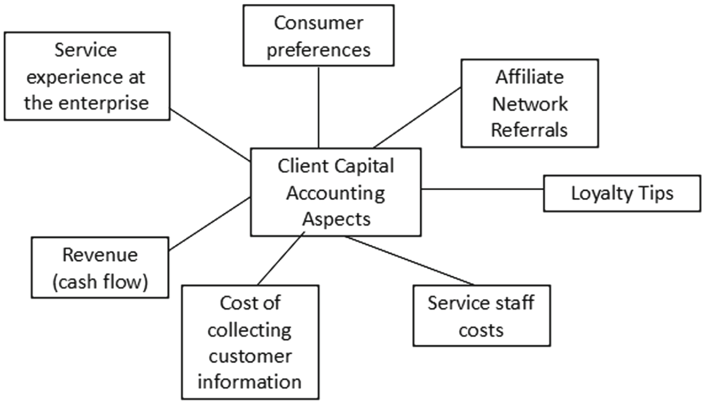

Fig. 2. Aspects of accounting for client capital. *Source* Proposed by the authors.

In the process of the study, we proposed seven accounting aspects of the database of loyal customers that form client capital, which can be seen in Fig. 2.

The first aspect we propose to consider the experience of interaction with the company, that is, the period of time during which the client is served at the service enterprise, acquires its services. This criterion for classifying a client as permanent or loyal is established in each company depending on the internal accepted model of client management, but the recommended period should be at least one year. Its size should be affected by the frequency of service.

As a second aspect, it is advisable to consider customer preferences of the client, which must be studied by analyzing the services, actually acquired by him, as well as various survey options, for example, in the form of questionnaires. Taking into account consumer preferences helps to evaluate the expected revenue of the client, opens up areas of work regarding the stimulation of demand by expanding consumer preferences, informing the client about new opportunities in purchasing a service or after-sales service.

The third accounting aspect is related to the possibility of attracting new customers, especially for affiliate programs, which include the construction of referral networks and the payment of a percentage of the proceeds to a higher partner as a reward.

The fourth aspect reflects the conditions of service and, in particular, the presence of a personal manager for a particular client. A customer-oriented approach to management in the service industry should be based on a careful selection of a network of personal managers and assigning clients to them, depending on business, personal qualities. Conflicts between a personal manager and a client are unacceptable; their relationship should be diagnosed and strengths and weaknesses identified.

The fifth accounting aspect allocated by us is the revenue or the wider cash flow expected from the client and also from his referral network, which he influences. Forecasting revenue is an important element in predicting the financial condition of a company, and in particular indicators such as profitability and solvency. Intensive interaction with loyal customers is an important methodological basis for forecasting company income.

Loyalty maintenance costs are the sixth accounting aspect that we offer to manage client capital. The activities of forming the client network include the costs of advertising campaigns, calling and consulting clients, the formation of special offers, and the payment of time spent on personal managers.

The seventh accounting aspect is the collection of any information characterizing the client. Obviously, a service company, to count on success, must know its customer.

Figure 3 presents a set of methods for the development of a customer-oriented approach of a service enterprise. The first method is aimed at stimulating the re-recommendation of the company brand to other customers by regular customers of the company.

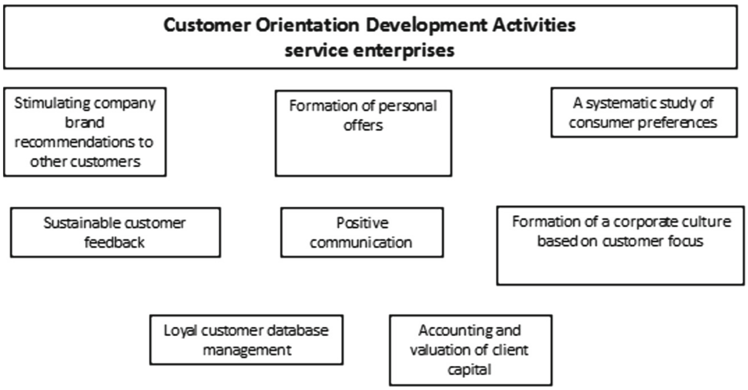

Fig. 3. A set of measures to develop a customer-oriented approach of a service enterprise. *Source* developed by the authors

Customer focus in sales implies a large selection of personal offers for each segment or group of consumers, as well as a high level of service - responsive consultants, managers. As a rule, employees are divided into two categories: the first - attract new leads, the second - work with regular customers, increasing the customer focus of the brand.

A systematic study of consumer preferences is the third proposed method. The basis of marketing in a service company is built on the interests of customers in the first place. The algorithm is to determine what customers want most and provide them with this. For example, most users of online services need fast technical support from specialists, so by giving this to customers, you can significantly increase the customer focus of your business.

Consumer feedback is the fourth method. It is difficult to consciously improve something when there is no response from customers about the quality of service. In addition, customers like it when their questions are quickly answered. The fact of the absence of complaints can speak of a poor connection with the "outside world". There are always consumers dissatisfied with something, and they should be able to convey the subject of their discontent to management.

The development of a positive communicative approach is the essence of the fifth method. Staff should be constantly trained in customer communications. Communications should be positive and reflect the positive emotional background of the service industry company. For example, it is advisable to introduce "three yes rules" in working with clients.

All of the above methods lead us to the application of the sixth method - the development of customer-oriented corporate culture of the company. The relations in the team should be on top, and the salaries of employees should correspond to the efforts expended. Highly motivated employees can maintain a corporate culture and engage loyal customers in it.

The seventh method is the management of a database of loyal customers, the attributes of which are customer experience, consumer preferences, affiliate programs and the presence of a referral network, conditions of service, cash flow, costs of maintaining loyalty, and information collection.

The eighth method is accounting and valuation of client capital. Client capital is certainly a form of human capital and the capital of the company as a whole. The presence of a methodology for assessing client capital is an important component in evaluating an enterprise.

4 Conclusion

In conclusion, it should be noted that the accounting and economic aspects considered in this article are the basis for developing a methodology for assessing the client capital of a service enterprise. Approaches to the development of the methodology may vary depending on the characteristics of a particular enterprise, accounting information system, style of client management.

The measures we offer to develop the customer focus of the service enterprise, such as encouraging the brand of the company to be recommended to other customers by the company's regular customers, formulating personal offers, systematically studying customer preferences, establishing customer feedback, developing a positive communicative approach, developing a customer-oriented corporate culture of the service company, managing a database of loyal customers, accounting and evaluating client capital lead to an increase in sales at service enterprises, an increase in revenue, and an increase in business value.

Increasing the value of the business is the most important goal of management and one of the factors directly affecting the cost is the availability and evaluation of client capital. In the formation of client capital, it is appropriate to use such accounting aspects as the experience of interacting with the service enterprise, customer preferences of the client, the structure of the affiliate network, the costs of the personal manager belt, the generated cash flow, the costs of maintaining loyalty, the costs of collecting information.

This article make a theoretical contribution to the interpretation of the concept of client capital, enriching it with accounting and economic aspects, it shows the feasibility of registering client capital as a variety of intangible assets of a service enterprise.

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Accounting and Analytical Indicators of a Decision Support System at Service Industry Enterprises

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Abstract. Purpose: The purpose of this article is to develop the main directions and principles for the formation of accounting and analytical indicators of the decision-making support system of service enterprises.

Design/Methodology/Approach: The following methods were applied: accounting modeling, systematization, algorithmization. The formation of the digital economy opens up new horizons for the development of accounting as a function of management and basic management science. Current trends demonstrate, on the one hand, the "dissolution" of accounting and economic analysis in corporate management systems, on the other hand, the methods of accounting and economic sciences for generating financial and economic information remain relevant and gain a new dimension in decision support systems (DSS).

Findings: In the process of working on the article, the following results were achieved:

- a classification model of accounting and analytical indicators is proposed;
- Improved presentation of the credentials of service enterprises based on the introduction of visualization tools for key indicators;
- proposed structural elements of the method of express audit of management decisions at service enterprises;
- improving the methodology for predicting the activities of service enterprises through the use of accounting and analytical indicators of decision support systems;
- the classification of signals of accounting and analytical indicators is proposed.

Originality/Value: lies in the fact, that the results of this paper make vkalad the development of decision support systems for service enterprises in terms of formation and improvement of accounting and analytical indicators that allow for eksress audit receive are solutions, predict deyatelnot on the basic of our proposed directions and thereby increase the effectiveness of management decisions.

Keywords: Accounting and analytical indicators · Decision support system · Service industry

JEL Code: D81 · M41

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1 Introduction

The relevance of the article is due to the fact that enterprises in the service industry have largely suffered from the COVID-19 pandemic and many have gone bankrupt. This phenomenon affects not only the domestic economy, but is a global trend. Of course, in the recovery period after a pandemic in the service industry, new methods of organizing business management are needed to help the industry out of the crisis in the shortest possible time.

As the subject of the study, we selected accounting and policy indicators, which are modern methods for generating management information based on the use of management information technologies, which are decision support systems (DSS). We are considering a classification model of accounting and analytical indicators, proposed for service industry enterprises, offering four enlarged groups of indicators: cost. Growth, performance, protection. It should be noted that the accounting and analytical indicator effectively implements its information function provided that the interface of the decision support system is successfully implemented. For these purposes, it is planned to use a wide range of credential visualization tools that allow generating a large-scale vision of the processes occurring at the enterprise.

This article identifies forecasting directions that allow management systems to be sensitive to changing conditions and anticipate new points of value creation. Among the areas of forecasting, the synergistic effect, immunization, risks and financial protection tools, the client base, and the range of services are highlighted. This article examines the management signals of accounting and analytical indicators from the point of view of the impact on the management decision: signals of a positive decision, positive decision with protective measures, changes in decision, signals of negative decision.

This article undertakes research and development of the main directions and principles of the formation of accounting and analytical indicators of the decision support system of service enterprises. In the process of working on the article, the following tasks were solved:

- a classification model of accounting and analytical indicators is proposed;
- Improved presentation of the financial statements of service enterprises based on the implementation of visualization tools for key indicators;
- proposed structural elements of an express audit of management decisions at service enterprises;
- improving the methodology for predicting the activities of service enterprises through the use of accounting and analytical indicators of decision support systems;
- the classification of signals of accounting and analytical indicators is proposed.

2 Materials and Methods

In the present study, the following methods were applied: accounting modeling, systematization, and algorithmization. Considering these methods separately, it should be noted that accounting models have long been known and are used in the economy. The balance sheet is one of the primary accounting models of the enterprise, double entry can be considered as an accounting model of a business transaction. With the development of economic relations and information technology, the method of accounting modeling has become increasingly complicated, allowing us to describe current phenomena and processes. Accounting methods, which include the collection, registration and synthesis of data on financial and economic activities, the construction of balance sheets and reports, the formation of a code of indicators, costing, etc. continue to be relevant and gain new dimensions through the use of digital technology.

Systematization is also a general scientific method applied by us, consisting in the formation of a logical construction of the whole based on selected elements, guided by certain principles. Regarding accounting and economic knowledge, the systematization method has its expression in a hierarchically built chart of accounts and structured reporting.

Algorithmization is the formation of an accurate set of instructions and prescriptions, logically and sequentially built and aimed at achieving a certain result through their execution. Calculation of scientific and analytical indicators occurs according to a specific predetermined algorithm in the decision-making support system.

In our opinion, the actual management method for enterprises in the service industry is the introduction of a decision support system (DSS) based on the use of wide accounting capabilities. Decision Support Systems (DSS) are flexible, dynamically developing corporate governance systems, the functional tasks of which are to provide information on the financial and economic activities of the company, which allows to "test" the management decision, conduct its express audit, and provide information on the consequences of making this or that decisions and predict its impact on key performance indicators of the enterprise.

The decision support system is aimed at optimizing the managerial decision by expressing its content in physical and value meters and reflect its premises and possible consequences through accounting and analytical indicators.

The study was conducted on the basis of materials from the enterprises of the service industry of the Rostov region.

3 Results

Based on the results of the study, a classification model of accounting and analytical indicators of the decision support system of service industry enterprises was proposed.

Accounting and analytical indicators are elements of the interface of a decision support system that allows the management subject to signal about certain phenomena and processes occurring on a company, as well as about various aspects of business development, which can be expressed in the language of accounting (Table 1).

It should be noted the differences in the accounting and analytical indicator and the notion of "indicator" customary in accounting science in the form of a coefficient or line of balance. The accounting and analytical indicator can be implemented on the basis of information technology and the use of visualization tools, allowing you to consider its change in time and with respect to specified restrictive parameters.

Credential visualization tools allow generating different types of reporting: financial, managerial, statistical, not just in tabular form, but using digital visualization methods

Table 1. Classification model of accounting and analytical indicators of decision support systems

Cost indicators	Growth indicators	Performance indicators	Security indicators
Show the market value of the business as a whole, as well as its individual elements. They are aimed at protecting the interests of owners in the area of preserving capital	They signal about types of activity, segments of activity, individual employees, clients, which are growth drivers, in the direction of which it is advisable to develop a business	Demonstrate the effectiveness of individual business segments by comparing costs and revenues	Signals about financial situation and the possibility of bankruptcy
Net asset value Net Liabilities Cost Cost of capital	Segment Revenue Employee revenue Customer cash flow	Economic Value Added Profit by segment Profitability	Immunization Risk Forecasting and Financial Protection Financial condition

Source: developed by the authors

that allow observing in a more visual form the impact of management decisions on reporting indicators, their dynamics and, accordingly, determine the managerial effect, and also see various analytical indicators in time dynamics and relative to borderline values.

The decision-making support system of service enterprises allows using the various capabilities of the interface that allows quickly generating report information by the utility criterion and present it in a form convenient for making an adequate effective decision.

Credential visualization tools are shown in Fig. 1.

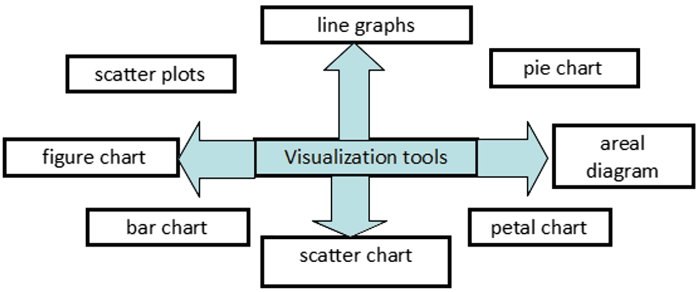

Fig. 1. Credential visualization tools. *Source*: compiled by the authors

Express audit of a management decision is an important and necessary component of decision support, which consists in assessing the impact of a management decision on the cost, growth, and productivity of service industry enterprises. Concerning the studied industry, in particular, the service industry, it is necessary to note such necessary elements of express audit as tax, legal examination, SWOT analysis.

A tax review of a management decision must be made at the planning stage to determine the estimated tax base and the amount of tax liabilities arising. Tax examination is carried out through the use of an indicator of the tax burden of service enterprises.

Legal expertise is an integral part of decision support. It includes the planning of legally significant actions, identification of rights and obligations arising as a result of the implementation of a management decision, determination of legally related parties - participants in business processes.

SWOT is a method of identifying the strengths and weaknesses of an economic situation under the influence of the considered management decision, emerging threats and emerging opportunities (Fig. 2).

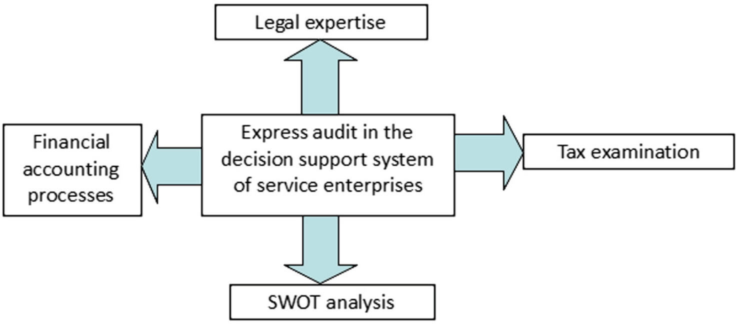

Fig. 2. Structural elements of express audit at service enterprises. *Source*: compiled by the authors

The management decision, the adoption of which is supported by the considered model, makes various changes to the business processes of the company, which affects the accounting and analytical indicators, the forecast and modeling of which is carried out (Fig. 3).

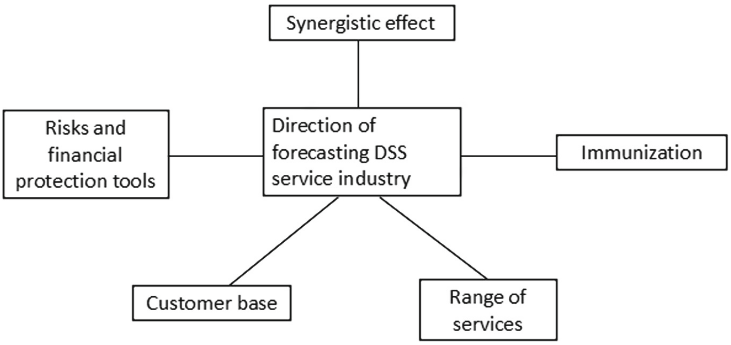

Fig. 3. Directions of forecasting a decision support system for service industry enterprises. *Source*: proposed by the authors

So, synergy forecasting is associated with registration and modeling of changes associated with the occurrence of a synergistic effect, which consists in the emergence of additional efficiency as a result of successful combinations of individual elements of the business system of the service enterprise. The decision support system at service industry enterprises should be armed with indicators of synergistic assets.

Immunization indicators arise in the process of solvency management and are designed to identify the ratio of the estimated receipt of financial flows and liabilities of the company. Immunization indicators should signal an increase in the solvency of the enterprise or its possible loss due to anticipated business processes.

Prediction of risks and the availability of financial protection instruments is carried out through the use of appropriate accounting and analytical indicators that demonstrate the risk of asset retirement as a result of sanctions or shortfalls due to the insolvency of counterparties.

The customer base is the most important direction of forecasting at service enterprises due to the characteristics of this industry. The client is the most important goal of the activity and the source of revenue. Customer satisfaction is a prerequisite for sustainable development of service enterprises.

The range of services offered in the market is constantly changing, new features appear in the offer and service. The decision support system should have information on the changing assortment and demand statistics for various elements of the service.

Accounting and analytical indicators are generated in real time and show the size and trend or other parameters of the service enterprise's activity within specified boundaries. The boundaries of indicative values are formed on the basis of the specified parameters. It is important that the indicator does not go beyond the limited value, the so-called "red line", signaling an undesirable size of its value.

The accounting and analytical indicators considered in this article are of an auxiliary nature for the manager and are the result of the generation of economically useful information by the decision support system of the service enterprise.

We can distinguish the following types of signals generated by accounting and analytical indicators regarding management decisions (Fig. 4).

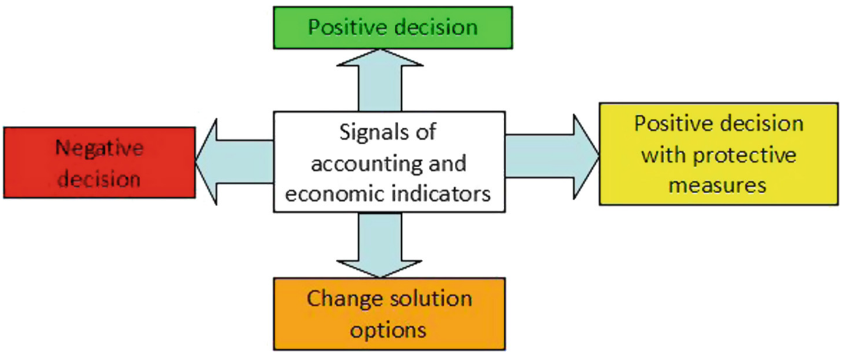

Fig. 4. Classification of signals of accounting and analytical indicators. *Source*: Developed by the authors

1. Signals of an unconditionally positive decision are formed by accounting and analytical indicators, the total value of which is in the “green zone”, that is, it is positive for the enterprise.
2. Signals positive decisions with protection are issued relative to the economic situation when the risk value exceeds the maximum permissible value, and for its implementation it is necessary to take a set of protective measures through risk insurance or the formation of a reserve.
3. Signals of the changed decision, accounting and analytical indicators indicate a high degree of risk relative to the economic situation, and DSS proposes to change the direction of its implementation, allowing to reduce the negative impact.
4. Negative signals are recommended in the case when the risk of a business transaction is high, the adoption of protective measures is unreasonable, since the costs of their implementation will significantly exceed the economic effect of a committed business transaction, and there are no alternative options for the implementation of the proposed business transaction.

4 Conclusion

The scientific and practical results of this article contribute to the development of decision support systems for service enterprises in terms of the formation and improvement of accounting and analytical indicators that allow for rapid audit of the decision made, to forecast activities in the main areas we offer and thereby increase the effectiveness of management decisions.

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Implementing an Integrated Approach to Ensure the Economic Security of an Enterprise

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Abstract. Purpose: We initiated this research to develop methodological recommendations to facilitate the application of the major provisions of an integrated approach to ensure the economic security system of an enterprise, taking into account its system characteristics, content, and directions of development.

Methodology: The key idea of implementing the integrated approach to ensure the economic security of an enterprise lies in the completeness and comprehensive coverage, identification, and assessment of internal and external factors, challenges and threats to the enterprise functioning, as well as in a consistent and coordinated analysis of their impact on the enterprise secure state and development based on the calculation of system-forming engineering indicators of property and security.

Results: The results offer compelling evidence that the enterprise protection mechanism includes a number of factor-determining components. In the context of using modern engineering tools, they allow evaluating the effectiveness of protective measures with access to engineering indicators of property as basic indicators of economic security.

Conclusions and Recommendations: The evidence from this study suggests that the application of the integrated organizational and economic mechanism of engineering tools focuses on making sound management decisions in the context of sustainable, secure and competitive development of an enterprise. We have found a cutting-edge solution for ensuring the economic security of an enterprise by developing unique software based on the integrated model and engineering tools presented in the study.

Keywords: Integrated approach · Economic security · Engineering tools · Property · Basic indicators of economic security

JEL Code: D81 · K11 · M41

1 Introduction

These days many organizations are sensitive to the need to defend against diverse threats originating from outside and inside the enterprise. From the perspective of an integrated approach, the effective use of all types of resources available is the core of the economic protection mechanism of any enterprise.

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As specified by (Krokhicheva et al. 2018), the emergence of newly discovered external challenges and threats, growth of risks and toughening competition at all levels of management questions the demand for exploiting up-to-date accounting and management tools, methods, and mechanisms to adequately reflect these evolving processes and assess their impact on the enterprise security level.

A comprehensive study of the enterprise economic security as the information and management category is increasingly becoming a vital problem since the need for economic security affects all industries and organizations. Besides, it poses the task to implement the integrated approach to justify the methods, tools, and technologies for ensuring the enterprise secure state and development in correlation with the categories of risks and conflicts, to identify the major threats to economic security, as well as to give grounds for the main strategies and a set of tactical tools and mechanisms for their implementation.

The application of the integrated approach to security management processes is based on the study of the accounting and analytical category of property that is viewed as the main indicator of the enterprise secure functioning, taking into consideration the managerial stuff and owners' interests and concerns.

The above-listed aspects prove the relevance of the research topic and the range of issues to be examined. The study addresses the economic relations arising due to the formation and functioning of the integrated system of ensuring and managing the economic security at the micro-level.

2 Materials and Methodology

What is known about the issues related to management and information-analytical support of economic security at the micro-level is largely based on the studies of Russian and Western scholars, proceedings of international and national conferences and other publications.

In recent years there has been considerable interest in theoretical and practical aspects of ensuring and managing economic security at the micro-level (Daft 2015; Korolev 2011; Krokhicheva et al. 2018; Lesnyak 2020; Lesnyak and Selezneva 2020; etc.). There is a vast amount of literature on the approach to the development of the integrated information and management systems (Elliott and Herbert 2002; Partridge 2000; Percy 2008; Shaw 2002; Taylor and Raden 2007; etc.).

We believe the integrated approach should be used considering the groundbreaking achievements not only in economics but in other areas of science that are critical in modern society – philosophy, sociology, law, mathematics, computer science, history, etc. At the same time, it is required to cover a maximum of essential factors, give a multidimensional assessment of the events and facts of economic life, and contemplate the alternatives of the developing situation, their possible outcomes, and probable consequences.

A comprehensive study of threat emergence and neutralization provides the basis for secure, sustainable and competitive development of an enterprise under the conditions of extreme dynamism of its external micro- and macro-environment factors, and specifies the content and directions of implementing the integrated approach to the processes that ensure and manage economic security (Korolev 2011).

Economic security as a safe condition of any enterprise implies the effective implementation of its vital economic interests in the face of emerging risk and conflict situations to solve strategic development issues.

As for the conflict theory, it focuses on the analysis of internal and external environmental factors that lead to conflict situations. Moreover, it examines shadow economic relations and criminalization of the economy, the conflict impact on the economic security of an enterprise, and the security of property relations.

3 Results

It is fundamental to note that the maximum coverage of diverse factors and threats, their identification, analysis, and forecasting, assessment of the degree of impact on the initial, current, and prospective level of economic security serve as the basis to implement the major provisions of the integrated approach.

The integrated approach to the content of the structural elements, which the protective mechanism of an enterprise consists of, and to the directions of its development involves taking into account multiple constituents. Among them are the variability and multifactor, completeness and comprehensiveness of management processes, the presence of a specific goal, the manifold ways to achieve the goal (channels of influence, methods, measures, and actions), consistency and the step-by-step use of methodological methods of control, analysis, and management, methods of making managerial multi-level decisions. Managerial decision-making is preceded by profound analytical work. Furthermore, the integrated approach must combine traditional and engineering analysis methods, formal and informal managerial decision-making procedures, the required variability in the forms and content of the information to be prepared.

The implementation of the integrated approach to assessing the enterprise security potential is based on the corresponding information and analytical support that brings to a focus the goal factor achievement – the current state and prospects for improving security, as presented in Table 1. The integrated approach to the processes of ensuring and managing enterprise security is related to the main factors of the formation and functioning of the enterprise protection mechanism, its structural elements, subject matter, and object of study. Table 1 illustrates that the procedures of assessing the level and potential of enterprise economic security are grounded on the calculation of certain system-forming indicators.

As was mentioned in (Korolev 2011), these indicators are exploited to evaluate the effectiveness of the course and the results of the implementation of protective measures based on the cost method. The cost method of assessing the level of the enterprise economic security allows widening the use of property indicators.

Property and its dynamics in absolute and (or) relative terms are the main indicators that manifest the effectiveness of the enterprise protective processes. The security of property relations in general and the interests of the enterprise owners in particular is the basis of its sustainable and competitive development. The assessment of changes in ownership during security goal-achieving is established by the enterprise value, considering all its assets and liabilities, and by obtaining the final cost indicators – engineering indices of ownership (Lesnyak and Selezneva 2020).

Table 1. Information and analytical support for implementing the integrated approach to assessing the security potential of an enterprise

Stage	Functions of management	System characteristic
1	2	3
Data collection and processing	Analysis and diagnostics	Information support for ensuring economic security of an enterprise
Building theoretical and econometric models, analysis, and interpretation of results	Monitoring the results obtained	Modeling the initial, current and prospective level of enterprise security (permissible or zero hazard level); assessing the reduction of danger to an acceptable level or exceeding an acceptable level of danger; evaluating the effectiveness of the core business activities of an enterprise
Assessment of socio-economic processes	Monitoring the results obtained	Predicting, identifying, scrutinizing, and assessing threats; specifying selective or complex sources of threats; signifying major threats
Identification, evaluation, analysis, and forecasting of security threats and risks related to these threats	Goal-achieving factor support	Risk identification, the variability of prognostic assessment of the main security threats, risk value assessment; threat monitoring, determining forms and methods of their neutralization
Interpretation of results	Analysis and diagnostics	Measures to neutralize threats, continuous diagnosis of crises
Analysis of the current state and development prospects of enterprise economic relations and their impact on economic security	Analysis and diagnostics	Analysis of the content, structure, and directions of development of enterprise economic activity in the context of the current security state and the possibilities of its improvement

(*continued*)

Table 1. (*continued*)

Stage	Functions of management	System characteristic
Predicting the dynamics of the key economic indicators of an enterprise	Assessment of the current state and prospects for improving economic security	Prognostic, scenario, factorial, structural analysis, evaluation of development alternatives within multivariate decisions; situational modeling and forecasting security indicators
Developing a strategy to ensure the economic security of an enterprise, as well as programs for its implementation	Methods of implementing protective measures Corrective actions	Development, analytic justification, implementation, monitoring, and evaluation of effectiveness, alteration of a strategy
Making operational, tactical, and strategic decisions to ensure the economic security	Specific protective tools Corrective actions	Process of developing and making decisions within the selected options, taking into account the selected basic analytical criterion – the growth of the enterprise value

Absolute and relative indicators of ownership, as well as established standards of enterprise resources, can be used to quantify the crucial system-forming indices of the economic security zone and margin: active, passive or neutral (normative); the zone of danger, the zone of constant attention, the normal zone, the zone of expansion (development); the zone of break-up (changes), as shown in Fig. 1.

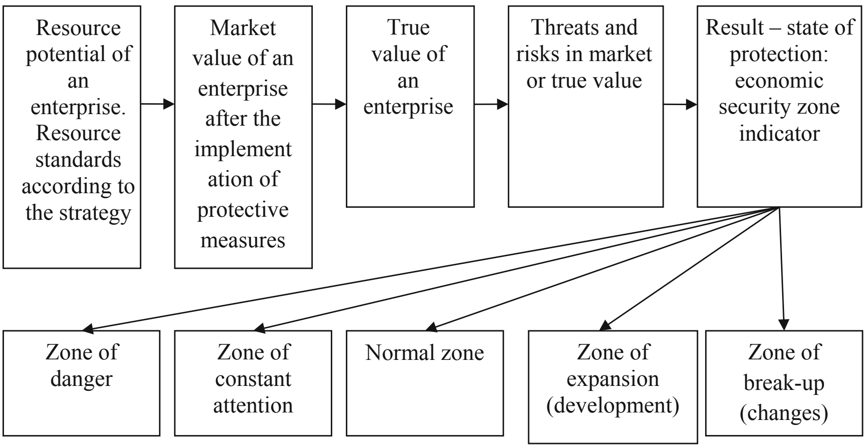

Fig. 1. Methodology for calculating the system-forming indicators of the economic security zone

The need for changes relies upon comparing actual results of business activities with some predetermined desired results and taking corrective actions in case actual results do not match the desired ones (Daft 2015).

Hence, while applying modern engineering tools and technologies, the set of measures aimed at ensuring the enterprise economic security also involves the search for new and better ways to improve the efficiency of the factor components of the protective mechanism in compliance with the data presented in Table 2.

Table 2. Improving the enterprise protection mechanism based on engineering tools

Area and specifics of the research	Functions of management	System characteristic
1	2	3
Studying the conditions for system functioning; justifying the relevance and practical significance of security-providing measures, methods, and means of analysis, and evaluating their effectiveness	Specific protection tools	Applying engineering tools to analyze, control, and manage economic security of an enterprise
	Assessment of the current state and prospects for improving economic security	System of initial and final operators, integrated use of traditional and engineering methods and models, informed decision-making based on the results obtained
	Corrective actions	Engineering methods for integrated accounting, analytical, control and management procedures as part of an iterative mechanism
	Initial level of the enterprise security	Using monitoring, scenario, control and other derivative balances; calculation of engineering indicators of property and security zone on their basis

Engineering tools are a system of derivative balances containing data on the state and dynamics of the enterprise resources and sources of their formation in diverse economic situations of the initial, current, or prospective security level. It serves as a basis for modeling the integrated economic security system of an enterprise, demonstrated in Fig. 2.

The use of engineering tools to manage the economic security is targeted at preventing crises and bankruptcies, achieving the goals and desired protection results, registering these processes by engineering records in the appropriate derivative balances, and reaching the final indicators of property, zone and margin of economic security that are relevant to the current economic situation. As expected, it provides the positive dynamics of the enterprise value, maintenance, and further development of property (Lesnyak 2020).

We are of the opinion that the integrated system of ensuring economic security of an enterprise based on the compilation and use of the proposed engineering tools makes it possible to implement the basic imperatives of a secure state and progress of an enterprise (security, stability, and competitiveness). Moreover, by establishing the net assets value and liabilities, as well as the zone and security margin indicators derived from them, one can evaluate the results of protective mechanism functioning, external effects defined in terms of its interactions with the external environment, the effectiveness

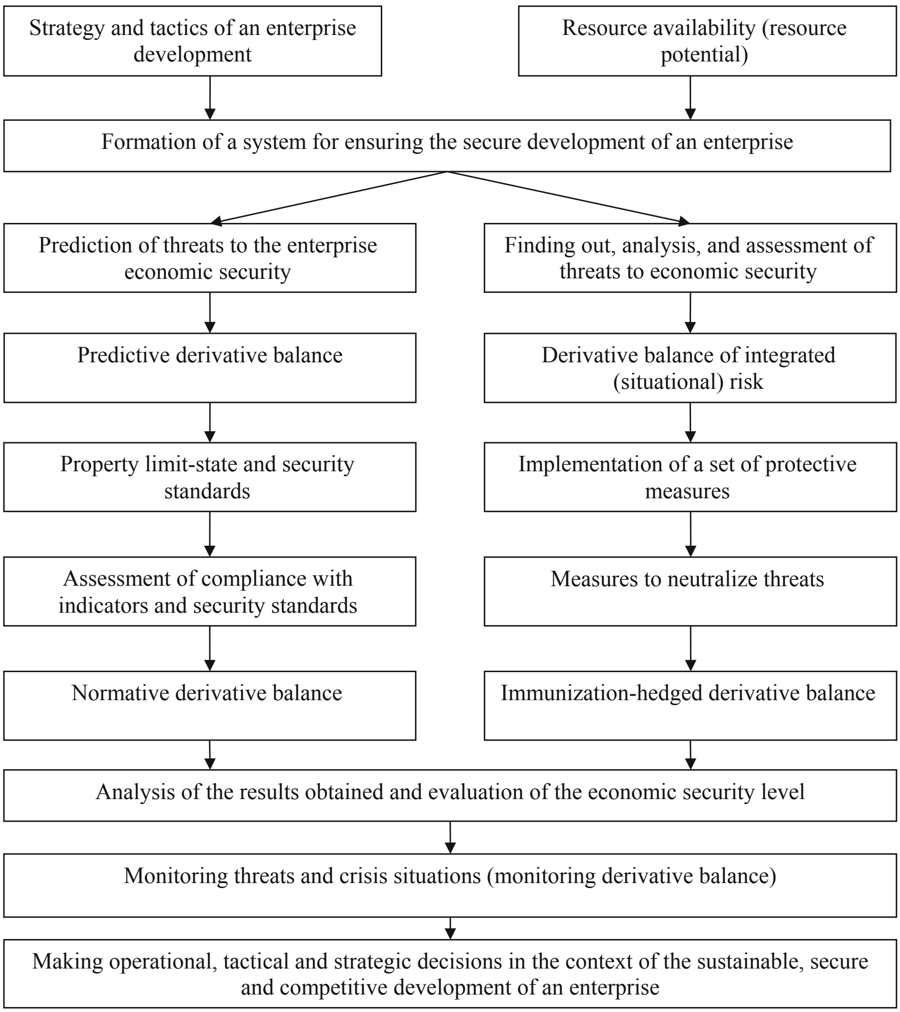

Fig. 2. The model of the integrated economic security system of an enterprise based on engineering tools

of the implementation of protective measures and impacts regarding the major indicator of the enterprise economic security.

The proposed model is the fundamental point of the integrated information support for enterprise economic security. In addition, the implementation of the security system following the integration requirements implies taking into consideration plenty of factors, including organizational, managerial, structural, production, administrative, industrial, technological, and informational ones.

4 Conclusions and Recommendations

To sum up, our work presented the major provisions for the implementation of the integrated approach to the formation and functioning of the enterprise economic security system regarding its characteristics, content, and directions of development. The given approach is based on the application of up-to-date engineering tools in the form of computer software, which is also outlined in the paper.

We have provided further evidence that the integrity of the proposed approach to ensure and manage security is grounded on immunization, hedged, guarantee, and other processes combined within the framework of a single accounting and management mechanism to implement adaptive and protective measures, impacts, and measures to neutralize threats. It is based on the complied engineering tools that provide information and analytical support for data processes and procedures represented by a system of derivative balances and their interpretations. Engineering tools have many valuable applications. First, they are used to conduct a critical, yet relevant assessment of the enterprise resource efficiency. Second, they allow evaluating the overall effectiveness of processes and procedures to achieve a certain security level (permissible or zero hazard level). Finally, engineering tools assist in working out the prospects of increasing the level of economic security in relation to the enterprise value, i.e. the basic indicator of the enterprise economic security.

Taking advantage of the integrated approach, we have also exploited the cost method to calculate the economic security indicators of an enterprise. Together they form an engineering approach to ensure and manage enterprise economic security.

Since the computerized accounting and management systems are vital to the business, we have developed software "Implementing accounting and analytical engineering tools for integrated management of adaptive-protective processes in an enterprise" (Authors: Lesnyak V.V. & Arakelyants E.S., Patent No. 2019610786).

It was designed to account and algorithmize the set of accounting, analytical, and control procedures to implement the adaptive capabilities of the integrated accounting and analytical system of an enterprise. Besides, it allows calculating the dynamics of changes in its value during the implementation of adaptive-protective processes to form an information field to manage and control these processes. The software contains algorithms for generating amounts from aggregated security records, which makes it possible to evaluate the altered structural components (protective, situational, price, etc.) of property dynamics.

The single organizational and economic mechanism of derivative balances, as well as the possibility of designing an integrated managing system regarding the distinguished managed objects as imperatives of a secure state and development of an enterprise, brought into being software "Implementing adaptive engineering tools for integrated management of enterprise property and solvency" (Authors: Lesnyak V.V. & Selezneva E.M., Patent No. 2020611945), whose testing confirmed our findings.

The given software has several interesting features. It is aimed at generating relevant information in the form of derivative balance sheets and statements about the current state and dynamics of aggregated and disaggregated indicators of enterprise equity and solvency. Moreover, it can spot the efficiency of employing enterprise property and payment resources at diverse stages (at the beginning and the end) of implementing adaptive measures and procedures in various economic situations. The effectiveness of adaptation processes is estimated considering the correlation between the enterprise economic and property relations. Finally, it analyzes the causal relations between adaptive, immunization, hedged, risk processes, and operations with access to engineering indicators of the enterprise value as a property complex.

For these purposes, it is reasonable to use engineering tools in the form of adaptive and immunization derivative balances and statements, summary and situational statements that allow specifying the financial risk and solvency zones taking into account both incoming and outgoing resources.

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Risk Engineering in Investment and Construction Activities

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Abstract. Purpose: The purpose of the research is to substantiate the methodological approach to the analysis of the feasibility of investing in investment and construction projects based on risk factors.

Design/Methodology/Approach: In the course of the research, the authors analyze several methodological approaches to assessing the level of risks of investment and construction projects, for the adequacy and objectivity of decision-making regarding the feasibility of investments. As a result of the enlarged comparison of methods of nominal groups, diagrams, analogies, Delphi, brainstorming, Crawford, checklists, analysis of strengths and weaknesses of the project, the authors justify preference for the investment and construction sphere, taking into account the criteria of simplicity, universality and compliance with project management tasks.

Findings: Part of the results of the research illustrates the adaptation mechanism of applying the method of expert assessments for quantitative identification and assessment of risks of an investment and construction project, which allows making comparisons to justify the appropriateness of investments. Based on the results of the risk analysis of a specific project, it is possible to objectively formulate recommendations for the construction organization for the project.

Originality/Value: A promising method of solving the problems of assessing the risks of investments in construction projects is the method of expert assessments, which is characterized by simplicity, versatility and flexibility. The adapted application scheme and proposed criteria for assessing various risk groups of investment and construction projects will allow design, construction and investment companies to objectively justify investments.

Keywords: Risk engineering · Risk management methods · Expert assessment · Project risks · Investment and construction activities

JEL Code: D81 · L74 · M11

1 Introduction

The justification of management decisions on the feasibility of financing investment and construction projects requires an objective assessment of forecasted economic indicators. An important criterion for the successful implementation of projects in the construction

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sector, which differs in the long-term nature of the production process, is the value of the aggregate risk. In this regard, it is important for the investor to reflect in the documents of the feasibility study of investments information on the options for the implementation of the investment and construction project, the proposed financing schemes and preventive measures aimed at preventing unfavorable developments to compare alternative projects.

The choice of the most promising alternative development options should take into account not only space planning, technical and architectural solutions, but also the cost of the project, its financial support, as well as profitability indicators and payback periods for projects. All planned indicators are taken into account in each case individually, based on the investor's experience and preferences for the consolidated parameters of the projects. The latter circumstance is especially important, since the main value of the project should not be exceeded at all stages of the life cycle of the project.

These circumstances make it necessary to methodically search for approaches to formalization, reduce labor intensity and increase the objectivity of investment decisions on the level of risk. Only methods of quantitative analysis of project risk can give the greatest objectivity. However, the large differentiation of construction projects, the unique features of construction, the long-term nature of the production cycle, the high dynamics of demand and supply in the construction market do not always allow the use of direct statistical methods of risk analysis and assessment. An extensive risk management toolkit requires careful analysis for efficiency in the investment and construction sector.

In our opinion, to assess the risks of investment and construction projects and in order to substantiate the option of investment solutions, it is necessary to use a combined toolkit that allows overcoming the shortcomings of incomplete and inaccurate economic parameters of investment and construction projects but, at the same time, objectively take into account the uncertainties and dynamics of the external environment of projects.

The ultimate goal of objective assessment and risk management of the project is interlinked with the objective function of entrepreneurship, which is to maximize profits with a minimum level of risk of non-receipt. Hence, the main task of risk management in the investment and construction sector to build an effective system for permanent monitoring and analysis of the level of risks of investment and construction projects.

2 Materials and Method

On the problem of improving certain elements of methodological approaches to risk assessment of investment and construction projects, many domestic and foreign scientists worked: Creemers et al. (2014), Hanna et al. (2013), Hosein and Ray (2020), Iqbal et al. (2015), Jepson et al. (2018), Ke et al. (2012), Serpell et al. (2017), Tsai and Yang (2010), Yakubu and Ming (2015).

Among the methods of research are methods of comparative analysis, qualitative and quantitative assessment of risks, risk management in construction (Murzin and Osadchaya 2013). The leading stage of risk management in the project is the risk analysis procedure (risk engineering), which is a separate procedure (Murzin and Osadchaya 2018), which can be presented in the form of a diagram (Fig. 1).

With regard to possible aspects of risk analysis and assessment, the following methods of information collection can be assumed (Murzin 2016):

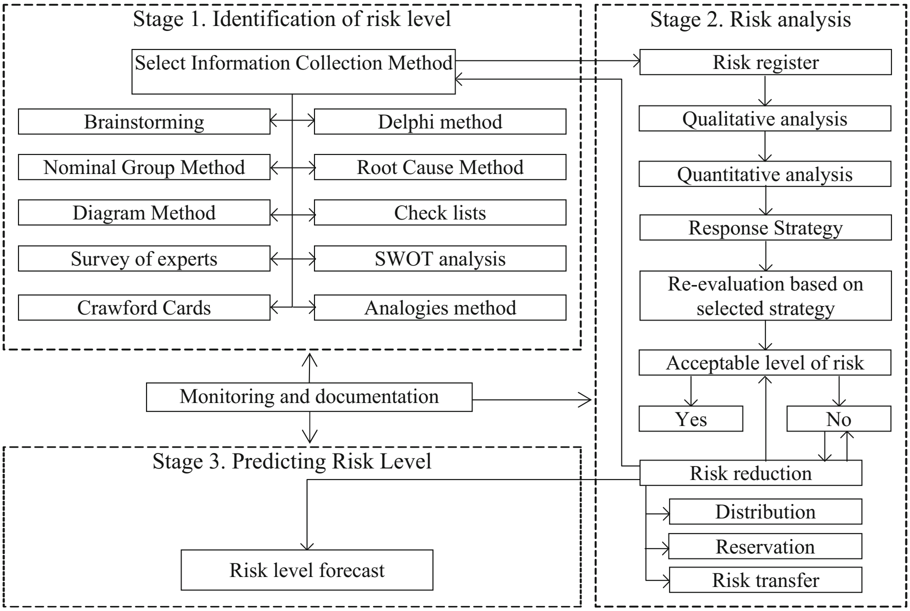

Fig. 1. Main stages and methods of risk engineering (Compiled based on the results of a review of literary sources)

1) the method of nominal groups, thanks to which a group of experts and specialists is organized (up to 10 people), and each of these specialists lists the risks that he sees in this project;
2) the method of using charts, where they are used to establish the causes and consequences of certain processes and their relationship of the chart. All the process is displayed in a flowchart, which allows tracing the sequence of events in chronological order;
3) analogy method, due to which it is possible to establish causal relations and process diagrams that will help to identify the order of events;
4) the Delphi method, which has the feature that participants do not know each other, and when using questions regarding project risks, the answers of specialists are selected. After that, all the answers undergo a detailed analysis, they are distributed and returned to specialists;
5) brainstorming method, where the main task is to create a list of project risks, where 10–15 people participate;
6) the method of the Crawford card, for which ten professional experts in the field of risks are required, they are asked ten questions, each of which the expert answers independently in shift form - in such a way each expert is obliged to discuss all ten questions;
7) search and identification of the main cause of risk, where the fundamental goal becomes to identify important causes that can provoke the project risk, to sort all risks by classification groups;

8) analysis of checklists is a method in which it is necessary to indicate a list of risks that are compiled on the basis of information and knowledge, which were found in projects of the same type already implemented;
9) analysis of the strengths and weaknesses of the project (possibility of success, threats of project failure), where it becomes an important task to identify the project perspective, all this will make it possible to find favorable opportunities and suggest possible threats from the environment for the implemented project.

Risk analysis can be divided into three distinct interrelated phases (Murzin 2016):

1) risk identification;
2) risk assessment;
3) risk prediction.

The identification of risks that may affect the project being implemented, their analysis and reflection on ways of responding to them become key aspects in the qualitative analysis of the feasibility of the project and the possibility of its implementation. The methods under investigation are mutually related to the characteristics of risk classification and the degree of their influence on the project results.

The classification of risks according to the system of three characteristics includes (Osadchaya 2017):

1. Project risks include: financial risks, market risks, risks of relationships with counterparties, risks of changes in the regulatory framework, technical risks, as well as construction risks.
2. Periodic or systematic risks.
3. Risks of force majeure situations.

The overall project risk can be determined by formula 1:

$$R = 0.7 * Rp + 0.2 * Rs + 0.1 * Rfm \tag{1}$$

where R - is the overall risk of the investment and construction project; Rs systematic risks; Rfm - force majeure risks.

Design risks are determined by formula 2:

$$R_n = 0{,}2 * R_1 + 0{,}25 * R_2 + 0{,}1 * R_3 + 0{,}1 * R_4 + 0{,}35 * R_5 \tag{2}$$

where R_n - project risk; $\mathrm{R}_1 R_1$ - technological risks; R_2 - The market position of the project R_a; - risks brought to the project by counterparties; R_4 - legal structure of the project; R_5 - financial risks.

Therefore, risk engineering generally aims to account for all possible risks of a particular project using quantitative tools (Puchkov 2018).

3 Results

To visualize the results of the risk analysis, a real investment project for the construction of a residential complex, which consists of 11 residential sections and 4 attached parking lots, was considered. Residential sections 1–11 are a technical underground, 1 floor with built-in public space, 23 residential floors and a technical attic. The maximum height of 25-story sections (from the elevation of the flat roof to the daily surface of the earth) is 71.07 m and 73.95 m (from the elevation of the flat roof of the elevator machine room to the surface of the earth).

The diagram of the residential complex is shown in Fig. 2.

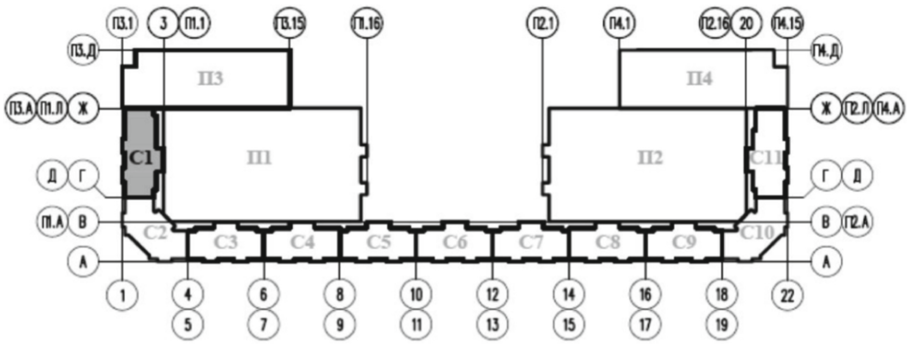

Fig. 2. Scheme of residential project of residential complex

Table 1 shows the main technical and economic indicators of the investment and construction project.

Table 1. Technical and economic indicators of the project

No.	Name	Unit of measure	Number
1	Land area		32,851
2	Building area		19,572.52
	– development area of residential sections		6,678.65
	– parking area		12,893.87
3	Total Object Area		157,602.7
	– total area of residential sections		126,664.81
	– the total parking area		30.937.89
4	Total area of apartments		88,125.72
5	Number of apartments		1482
6	Area of built-in premises		4,470.42
7	Storey of sections	Floor	25
8	Floor of parking lots	Floor	1–7
9	Total parking capacity	sq. m	925
10	Total parking area		40.850.2

Risk research is conducted by the method of expert assessments, which is often used to obtain a generalized opinion of qualified specialists on the feasibility of investing in an investment and construction project. It is due to this method that the degree of impact of risks on the construction project can be calculated.

To carry out the study, it is necessary to select experts in the specialized field who have extensive experience in working with investment and construction projects. The evaluation procedure then includes several steps.

First, each of the experts is provided with full information about the project and the questionnaire they are required to complete. The questionnaire includes estimates of possible risk losses. Experts, if possible risks are identified, assess the situations of their occurrence during the implementation of the construction project.

The first phase included the distribution of the impact of risks on groups and the investment and construction project as a whole. Risks are accepted to be divided into the following groups:

1) design risks;
2) systematic risks;
3) force majeure risks.

Table 2 presents the generalized results of an expert survey on the structure of investment and construction project risks.

Table 2. Expert assessment of project risk structure

	Expert assessment									
	1	2	3	4	5	6	7	8	9	10
Project risks	0.6	0.65	0.65	0.65	0.6	0.65	0.6	0.65	0.65	0.6
Systematic risks	0.25	0.3	0.3	0.25	0.3	0.25	0.25	0.25	0.25	0.25
Force majeure risks	0.15	0.05	0.05	0.1	0.1	0.1	0.15	0.1	0.1	0.15
Object of examination	11	12	13	14	15	16	17	18	19	20
Project risks	0.65	0.65	0.55	0.6	0.65	0.7	0.65	0.7	0.6	0.65
Systematic risks	0.25	0.3	0.3	0.3	0.3	0.2	0.2	0.25	0.3	0.3
Force majeure risks	0.1	0.05	0.15	0.1	0.05	0.1	0.15	0.05	0.1	0.05

Based on expert assessments, risks are grouped and the impact of each group on the project as a whole is determined:

1) design risks (63%);
2) systematic risks (27%);
3) force majeure risks (10%).

It follows that the overall project risk is defined as:

$$R = 0{,}63 * R_p + 0{,}27 * R_s * 0{,}10 * R_{fm} \tag{3}$$

where R_p - project risks; R_s - systematic risks; R_{fm} - force majeure risks.

Further, the risks included in each of the previously considered groups are expert assessed. Based on expert survey data, the degree of influence of each risk is determined:

1) construction risks (26%);
2) market position of the project (29%);
3) risks brought by counterparties (6%);
4) legal structure of the project (6%);
5) financial risks (33%).

Therefore, based on the information received, the overall risk can be determined:

$$R_n = 0,26 * R_1 + 0{,}29 * R_2 * 0{,}06 * R_2 + 0{,}06 * R_4 + 0{,}33 * R_5 \tag{4}$$

where R_1 - construction risks; R_2 - project market position; R_3 - risks brought by counterparties; R_4 - legal structure of the project; R_5 - financial risks.

Further, experts are invited to assess the likelihood of risk. The probability of risk was assessed according to the following criteria:

1) low risk potential - 15%;
2) the risk of manifesting itself - 99%;
3) risk probability is absent (practically) - 1%;
4) high risk level - 85%;
5) there may be a risk of 75%.

It is proposed to assess losses according to the following criteria:

– if the risk occurs, then the losses will be as high as possible - 99%;
– if risk occurs, losses will be high - 80%
– if the risk occurs, then the loss will be at the average level - 45%;
– if the risk occurs, then the losses will be minimal - 20%;
– If this happens, the loss will not happen - 0%.

In addition to the above aspects, it is necessary to note the assessment of technical and construction risks. Experts are invited to follow the following additional criteria:

The first evaluation criterion is 0%. According to this criterion, there is a state guarantee, or cash security: in other words, in a situation where investments are unsuccessful, the investor will fully return his spent money for an investment and construction project.

The second evaluation criterion is 20%. There is an approved estimate supported by a positive expert opinion. It is important that the expert who prepared the examination has sufficient qualifications. It is important that contracts with contractors and general contractors are already concluded, which is in itself evidence of the implementation of the project in the future, and, at least one of the stages should have a bank or state guarantee.

The third evaluation criterion is 40%. In this situation, a positive expert opinion is also needed, but in this opinion there may be conditions that something needs to be corrected or completed. Note that the date of delivery of the facility should be determined and the estimate should be approved. There are concluded agreements with contractors and the general contractor, which will allow the implementation of the construction project. Note that for at least one year there is a bank or state guarantee of the project.

The fourth evaluation criterion is 60%. The construction project has not yet passed examination, but it has already been prepared for its implementation. The estimated plan has not been finally approved, the date of delivery of the facility has not yet been determined. It should be noted that contracts have already been concluded between contractors and general contractors who have sufficient and proven experience in implementing construction projects.

The fifth evaluation criterion is 80%. The project was prepared for examination, but the estimated cost was not finally approved. The estimated cost has not been approved, the construction schedule has been drawn up, but the date of delivery of the facility is approximately determined. Contracts have been concluded, but not all contractors have experience in implementing construction projects.

The sixth evaluation criterion is 100%. The project will still be prepared for examination, but it is immediately worth noting that the estimate has not been determined, and the schedule has been drawn up, but it has not been approved. The date of delivery of the object is sufficiently approximate. Contracts are concluded only preliminary with contractors, general contractors, while not all of them have experience in the implementation of investment and construction projects. It is possible to use the latest technologies. No party implementing the project has proven successful application experience.

Therefore, for the model projects under consideration, the method of peer review, taking into account all the above-mentioned criteria and risk classification, should be noted that this method is the most functional in this area of activity. Table 3 summarizes the total risk calculation.

Table 3. Expert assessment of project risk levels

Project risks	Expert evaluation
Technological and construction risks	30
Project Market Risks	45
Counterparty risks	40
Risks of the legal structure of the project	50
Project Financial Risks	25
Systematic risks	25
Force majeure risks	10

The total project risk is:

$$R_p = 0.26 * 0.30 + 0.29 * 0.45 + 0.06 * 0.40 + 0.06 * 0.50 + 0.33 * 0.25 = 0.345$$

The total project risk is defined at:

$$R = 0.63 * 0.345 + 0.27 * 0.25 + 0.1 * 0.1 = 0.2949$$

It follows that the total project risk obtained through the expert evaluation method is 29.49%.

To optimize the work of the construction organization on the project, it is necessary to identify the following structural components that can reduce the risk of its activities and positively affect its profit:

1) forecasting cash flow to compare the project and optimal programs for production in this organization;
2) carrying out analytical work to identify the demand for specific products of the company and performing a comparative analysis of all products among themselves according to the demand criterion;
3) it is necessary to identify and indicate all restrictions that may arise with the market's need for specific products;
4) choose optimal and competent combinations of price and sales volumes taking into account market demand.

4 Conclusion

To adequately take into account the impact of risks on the investment and construction project, it is necessary to build an effective management risk system in the organization, which allows timely identification of likely unfavorable situations and make timely decisions aimed at reducing their possible impact on the project to an acceptable level.

The construction of an effective risk management system is necessary for organizations engaged only in investment activities, since at the stage of selecting an investment project, it is possible to evaluate the risks of various projects, compare them with each other and make a choice in favor of the project that best meets all the requirements of the organization.

The results of the analysis of the theory and practice of risk management in the design, construction, reconstruction, repair and operation of construction facilities show the viability and effectiveness of the approach to assessing investment risks in the construction sector, as well as make it possible to justify decisions on the feasibility of investment in construction based on the forecast level of risks, which contributes to increased efficiency of investments and management of construction projects.

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Artificial Intelligence as a Result of Intellectual Activity: Accounting and Tax Aspects

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Abstract. **Purpose:** The purpose of this research is to systematize approaches to accounting and taxation of software underlying artificial intelligence as a result of intellectual activity protected in copyright mode, and to consider modern approaches to the commercialization of intellectual rights in accordance with the current legislation and regulatory documentation.

Methodology: The theoretical and methodological basis of the work was the normative documents and materials of research in the field of civil law, accounting and taxation of the results of intellectual activity.

Results: The work analyzed the current legislative and regulatory documents in the field of protection, accounting and tax accounting for the results of intellectual activity. The analysis of these documents highlighted several options for recording the results of R&D, including as intangible assets. The issues of accounting and tax accounting of income and expenses related to the involvement of software and hardware for applied artificial intelligence systems were identified and systematized. The issues of the ratio of intellectual right and ownership of the material medium in which the software product is embodied are disclosed.

Findings: Currently, software and hardware for artificial intelligence applications is and will be considered in the near future exclusively as objects of civil law, accounting and taxation. Relevant and systematic knowledge of the relevant accounting procedures is needed to obtain economic benefits from the use and correct reflection in the accounting of these objects.

Keywords: Artificial intelligence · Software · Intellectual results · Material media · Accounting and taxation

JEL Code: K11 · M41 · O31 · O32 · O34

1 Introduction

Artificial intelligence (AI) technologies are one of the key areas of technological development that determine and will determine the future of the whole world (Decree of the President of the Russian Federation of October 10, 2019 No. 490).

Most developed and developing countries have adopted strategies for the development of artificial intelligence.

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There is no clear definition of the term "Artificial Intelligence" today. AI is a computer program created by a person and capable of creating new information (Alexeeva 2018).

AI - machines (robots) and/or programs that are aimed at solving intellectual problems, as if such problems were solved by a person (Gurko 2017).

AI is the ability of systems to correctly interpret data, learn from them, and use the knowledge gained to achieve goals, including independently (Analytical overview of the global robotics market 2019).

Most researchers divide AI into two types:

Weak (applied, narrow) AI are technologies programmed to solve narrow special problems: computer vision, decision-making, natural language processing, speech analytics, expert systems, chess programs, image recognition, speech, making a decision to issue or not issue a bank loan, and so on.

Weak AI is realized by successfully fulfilling the tasks laid down in the program, processing huge flows of information, and often surpassing human capabilities.

The market of software robots, rather limited in its functionality and in use, is growing faster than any other segments of the software market with varying degrees of independence, to automate routine business processes in the food industry, automotive and mechanical engineering, service sector, logistics.

Strong AI is able to independently solve any intellectual problems, understanding the meaning of what is happening on an equal basis with the human mind; it is based on an attempt to model calculations at the neural network level, that is, on the principles on which the human brain works: to independently learn and act on the basis of previous experience, each time making fewer errors.

Intelligent robots controlled by information-computing systems including AI elements (android robots, game and household robots, military, marine robots, unmanned vehicles, aircraft, space and medical robots, etc.) are designed not only for performing physical functions, but also for solving more complex intelligent tasks (Kamyshansky and Koretsky 2019).

Today, analysts at Sberbank write, there is no strong AI in nature, and in general there are reasonable doubts about the possibility of its implementation. Many researchers say that the creation of strong AI is possible by 2029. Therefore, AI now and in the near future is a weak AI, dealing with certain problems and tasks; this is no more than a suite of advanced software (software) that solves applications.

To properly reflect software transactions, knowledge of the rules of civil law in the field of intellectual property regulation, peculiarities of accounting and taxation of such transactions is required.

2 Methodology

At present, the methodological basis of accounting for the development of computer programs and their involvement in economic turnover is factored in the Civil Code of the Russian Federation (Part Four), Tax Code of the Russian Federation (Part Two), Accounting Regulations "Company Revenues" (RAS 9/99), Accounting Regulations "Organization Expenses" (RAS 10/99), Accounting Regulations "Accounting for Research, Development and Technological Expenses" (RAS 17/02), Accounting Regulation "Intangible

Assets Accounting" (RAS 14/2007), International Financial Reporting Standard (IAS) 38 "Intangible Assets," currently in force in the territory of the Russian Federation in accordance with Order of the Ministry of Finance of Russia dated 28.12.2015 No. 217n.

3 Results

According to Article 1261 of the Civil Code of the Russian Federation, a program for computers is "a set of data and commands presented in an objective form intended for the operation of computers and other computer devices in order to obtain a certain result, including preparatory materials obtained during the development of the program for computers and the audiovisual displays generated by it."

According to sub-item 2, paragraph 1 of Art. 1225 of the Civil Code of the Russian Federation) programs for computers are protected results of human intellectual activity (intellectual property). In order to correctly reflect the operations with RIA in accounting and taxation, which allows to use the object and all its competitive advantages, to profit from it, special knowledge in the field of intellectual property regulation, knowledge of the features of accounting and taxation of software registration operations and its further use is required.

The main and most developed institute for the protection of computer programs in most countries, including the Russian Federation, is copyright (exclusive, property), the main principles of which are factored in the Berne Convention "On the Protection of Literary and Artistic Works" (Berne Convention for the Protection of Literary and Artistic Works from 09.09.1886). This means that such objects are internationally protected as literary works.

Exclusive copyright arises automatically upon the creation of a program for computers and does not require mandatory state registration or other formalities of recognition of the program. Nevertheless, in Russia and the world it is customary to confirm copyright of works by depositing and registering them in order to better protect. In Russia, state registration of software is carried out at the initiative of the copyright holder by the Federal Service for Intellectual Property (Rospatent). During registration by the Rospatent subordinate organization, the Federal Institute of Industrial Property (FIIP) issues a certificate securing the exclusive right to software.

The existence of effective legal protection of intellectual property is recognized as an important condition for increasing the market value of companies, as it contributes to increasing their competitiveness, and is a stimulating factor for increasing the efficiency of their intellectual activities.

In some countries of the world, computer programs can be protected by patents. For example, in the United States, national patent law officially permits the protection of software as an invention, provided that such objects are necessarily associated with a material medium.

In the Russian Federation, countries of the European Union and Japan, the current legislation does not provide for patenting computer programs.

A significant number of computer programs are registered annually in the Russian Federation: for example, in 2018 registration certificates for 17007 programs were issued, which is 18.5% more than in 2017 and 21.6% more than in 2016 (Rospatent Activity

Report 2018). Software is inferior in terms of registration volumes only to trademarks and inventions.

Copyrights to the Software protect the result of intellectual activity, but do not apply to the material medium in which this RIA is embodied (Clause 1 of article 1227 of the Civil Code of the Russian Federation). Material media of AI (hardware, computer and network equipment, graphic editors, equipment with digital control, etc., including those embodied in the form of android robots created in the image and likeness of a person), as well as the software embedded in this media, can be alienated taking into account the features established by the legislation of the Russian Federation and relevant regulatory documents.

The research and development (R&D) phase is an essential part of the software lifecycle: R&D (independent generation and implementation of own ideas on optimization of existing and development of a new product, technologies that are absent from competitors) - introduction of RIA into the company's business turnover (use of RIA in own production or management) or/and commercialization (introduction of software products to the intellectual property market, support, financing and support) - profit and investment in R&D, etc.

Actual R&D expenses (material costs, salaries of employees with accrued insurance premiums, depreciation deductions and others) are recognized as investments in non-current assets under conditions (item 7 of RAS 17/02 (Russian Accounting Standards)): R&D performance is documented; the amount of expenditure has been determined and confirmed; the deliverable can be used for production or management purposes. Use of the result can be demonstrated.

The analysis of regulatory legal acts allows distinguishing several options for reflecting expenses and R&D results in the accounting of organizations performing the specified works on their own, or as customers (Yarichina 2010):

1. R&D expenses are included in other expenses in case the specified conditions are not met or there are no positive results of works; these conditions have been met, the results have been obtained, but the organization has decided not to use these results for production or management needs for economic reasons.
2. R&D expenses are reflected in the current expenses of the organization for the production of products (works, services) if the specified conditions are met, but the results obtained are either not safe or not properly executed. The accounting policy establishes the way and time frame for writing off such expenses for the current expenses of the organization based on the expected useful life of the R&D results, but not more than 5 years.
3. R & D expenses form the initial cost of an intangible asset (IA), if these conditions are met and the organization has issued exclusive rights to the results of intellectual activity.

According to the Tax Code of the Russian Federation, R&D expenses for tax purposes may be:

– capitalized and accounted for in IA with subsequent amortization of the object;
– included in other costs related to production and sale within two years.

The presence of intengible assets on the balance increases or consolidates the competitive position of the organization in the market, contributes to increasing the cost of business and attracting investments in its development, improving the business reputation of the company.

Intangible assets account for up to 90% of the capitalization of large Western companies.

The conditions for recognition of intangible assets in tax accounting are listed in paragraph 3 of Art. 257 of the Tax Code of the Russian Federation and are in many ways similar to the conditions for recognition in accounting: the existence of the intangible asset itself and (or) the exclusive right to it is confirmed by the relevant documents; the facility is expected to generate economic benefits in the future; the initial cost of the object exceeds 100,000 rubles, the object can be used for a period exceeding 12 months. The cost of acquiring an object worth less than 100,000 rubles is referred to material expenses.

Tangible media on which IAs are located and are an integral part of the corresponding physical object are not included in intangible assets. For example, paragraph 4 of IFRS 38 states that if the software is an integral part of a digitally controlled machine that cannot operate without this software, the cost of the software product is included in the cost of the asset and is accounted for in accordance with IFRS 16 "Fixed Assets" (Rozhkova 2019). In this case, the costs incurred in the R & D process are directed to the creation of the fixed asset and form its original cost.

The Civil Code of the Russian Federation provides for two possible ways to commercialize developments, involve their results in economic turnover: alienation of exclusive rights to the results of intellectual activity on the basis of alienation agreements and transfer of rights to RAI for use under license agreements. The latter option does not entail a change of copyright holder.

In accounting, in accordance with RAS 14/2007 and RAS 9/99, the organization's income from the transfer of the exclusive right to software under the alienation agreement is reflected as other income, in tax accounting - as income from sales.

In both accounting and tax accounting, with the transfer of exclusive rights for such an object, depreciation is stopped.

In accordance with paragraph 2 of Article 149 of the Tax Code of the Russian Federation, the sale of exclusive rights to program products in the territory of the Russian Federation is not subject to value added tax, while the sale of a material carrier is subject to VAT (paragraph 1 of article 146 of the Tax Code of the Russian Federation).

Revenues from the transfer of rights of use under the license agreement in accounting are reflected:

– as part of income for ordinary activities, if the granting of rights to intellectual property objects for a fee is a regular activity of the organization;
– as part of other income, when the granting of rights is not a regular type of activity (item 5, 7 of RAS 9/99).

In tax accounting, income from the transfer of rights of use to RES under the license agreement is reflected (Article 249, 250 of the Tax Code of the Russian Federation).

– as revenues from sales, if this form of alienation is carried out systematically;
– as extrarealizational income.

The choice must be enshrined in the organization's accounting policy.

The transfer of rights to use the Software on the basis of license agreements is not subject to value added tax on the basis of Clause 2 of Article 149 of the Tax Code of the Russian Federation.

According to paragraph 5 of Article 1235 of the Civil Code of the Russian Federation, income under a license agreement can be in the form of lump-sum payments (in the form of a firm amount paid, as a rule, at a time), or in the form of royalties - periodic payments.

In the absence of appropriateness and the possibility of financing their own R&D, organizations use technology from external developers. Acquisition of exclusive rights or rights to use the Software for its subsequent involvement in the economic circulation is carried out under the agreement of alienation of exclusive right or under the license agreement. These contracts are registered without fail if the rights to the registered software are acquired (transferred) (clause 5 of Article 1262 of the Civil Code of the Russian Federation).

The exclusive right to a software product worth more than RUB 100,000 and a useful life of more than 12 months, acquired under the law alienation agreement, is taken into account as intangible assets, with subsequent amortization during the useful life. If payment under the contract is made by periodic payments during its validity period, such intangible asset is not amortized, and royalties are taken into account as part of other expenses related to production and sale. Expenses for the purchase of an exclusive right to a software product with a value not exceeding RUB 100,000 are also taken into account.

Most organizations acquire rights to use software products under license agreements.

In accounting, the expenses associated with the acquisition of such rights reflect, depending on the type of license payments provided for by the contract (item 39 of RAS 14/2007):

– as expenses of the reporting period, if periodic payments (royalties) are established for the use of the Software;
– as future expenses to be written off during the term of the contract, if a fixed one-time (lump sum) payment is set for the use of the Software. If the term of the contract is not established, then it is accepted as equal to five years.

In tax accounting, such expenses are attributed to other taxpayer expenses related to production and sale (paragraph 1 of article 264 of the Tax Code of the Russian Federation).

4 Conclusion

In the near future, artificial intelligence carriers (such as, for example, intelligent robots) will still be considered exclusively as objects of civil law, accounting and taxation. In order to obtain economic benefits from the use and correct reflection in the accounting of these objects, specialists need relevant and systematic knowledge of the relevant accounting procedures.

However, in the future carriers of artificial intelligence will be able to act as subjects of law. In this case, it will be necessary to develop or update accounting and tax procedures for their performance.

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Optimization of Herd Structure as an Important Reserve for Increasing the Efficiency of Horse Breeding

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Abstract. According to the Strategy for horse breeding development up to 2025, one of the priorities is to increase the breeding stock of producing horses, which is caused by the negative tendencies of the past period (from 1991 to 2005) in horse breeding, which led to a steady reduction of the stock by more than two times.

Since 2006, the number of horses in the country has stabilized and even begun to increase somewhat. The main increase in livestock was in households, as well as in peasant (private) farms and individual entrepreneurs. The breeding stock increased from 570,800 to 612,800 heads or 7.4% from 2017 to 2019.

The most intensive growth rates are observed in horse breeding for meat production, the development of which is achieved by a significant increase in the number of horses in agricultural organizations.

When increasing the number of horses, special attention should be paid to optimizing the structure of the herd. This circumstance provides for the realization of the main mass of the young stock for meat in the most profitable terms.

Studies show that the weight of foals aged half a year and one and a half or two years, as well as that of foals aged two and a half and three years practically is practically the same, but the cost of keeping the latter is much higher. It is more expedient to sell young stock for meat in conditions of year-round grazing in autumn at the age of 6–9 months, 1.5 and 2.5 years. The authors propose three schemes for the optimal structure of the herd in the production of horse meat. Optimization of the structure of the herd in all directions of economic use of horses is an important reserve in increasing the efficiency of the horse breeding industry. In the future, by 2025, with an increase in the number of horses up to 1,480 thousand heads, the number of producing mares will reach 742 thousand heads.

Keywords: Horse use · Horse livestock · Herd structure · Optimization and efficiency of horse breeding

JEL Code: Q 16

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1 Introduction

The horse breeding industry is one of the most versatile in terms of consumer products and services. Its development is determined by a number of objective economic and social factors. During the years of transition to a market economy, the main areas of horse breeding have been preserved and developed, differing greatly in terms of horse resources, types of end products, technology and management: commercial, productive (horse meat and milk), sports and leisure and pedigree (stud farm) horse breeding.

The breeding stock, which ultimately determines all the production and economic indicators of the industry, is of particular importance in the development of all areas, along with the overall horse resources (Vatutin et al. 1985; Kalashnikov et al. 2007).

2 Background and Methodology

The main materials for the research were:

statistical data on the number of horses by sex and age groups, categories of farms and regions; literary sources, which address the optimization of the herd structure.

The following methods were used in the research: economic-statistical method, method of grouping, computational-constructive method.

3 Results

During the period of market reforms the horse breeding industry in Russia saw a significant reduction in the number of horses, which lasted for 15 years (from 1991 to 2005). The number of horses reduced by more than half from 2,618 thousand to 1,304 thousand heads. Only since 2006 there has been a slight upward trend in the number of horses (Koveshnikov 2002; 2018; Strategy for horse breeding development in the Russian Federation for the period up to 2025, 2020; 14].

Regional statistical agencies conducted a census of the total number of horses in 2017, which resulted in a 2.1-fold decrease in the number of horses (1,239,600 heads). Nevertheless, there was an increase in the number of horses from 2017 to 2019 (Table 1).

Table 1. Dynamics of the number of horses in 2017 and 2019

Categories of households	Number of horses, thousands of heads (at the end of the year)					
	total		including mares		2019 as % of 2 017	
	2017	2019	2017	2019	total	including mares
Households of all categories	1,239	1,311	570.8	612.8	105.8	107.4
Agricultural organizations	288.3	262.4	109.8	101.8	91.0	92.7

(*continued*)

Table 1. (*continued*)

Categories of households	Number of horses, thousands of heads (at the end of the year)					
	total		including mares		2019 as % of 2 017	
	2017	2019	2017	2019	total	including mares
Households of the population	588.4	658.3	298.7	332.8	111.5	111.4
Peasant (farmer) households and individual entrepreneurs	361.9	390.2	162.3	178.2	111.9	109.8

Analyzing indicators of the number of horses we can conclude that while the number of horses in agricultural organizations reduced by 25.9 thousand heads or by 9%, there was an increase in the number of horses in households of the population by 69.9 thousand heads (4.4%), and in peasant (private) farms by 28.3 thousand heads or by 7.8%.

Mare stock during this period increased from 570.8 to 612.8 thousand heads (7.4%). It is important to note that, if, during the whole period of market transformations, the total number of horses decreased from 2,618,400 to 1,310,900 heads, by 49.9%, the number of mares aged 3 years and above decreased only by 20.9% from 774.5 to 612.8 thousand heads. These data indicate a more intensive horse breeding industry in a market economy.

At present the main massif of horse livestock (782.5 thousand or 59.7%) is concentrated in two federal districts – Siberian and Far Eastern, while in 1990 they accounted for only 40.3% (Table 2).

Table 2. Horse population by areas of horse use (at the end of 2019)

Leading areas of horse use	ths. of heads	%
Commercial	570.0	42.2
Production of horse meat – total:	620.0	48.5
including: - in agricultural organizations and peasant farms	435.0	33.2
- in households of the population of the eastern regions	185.0	15.3
Dairy production	24.9	1.9
Sports and leisure	14.0	1.1
Livestock in mass horse breeding	1,229	93.7
Pedigree horse breeding	82.0	6.3
Total number of horses	1,311	100.0

Among the leading areas of horse use, production of horse meat is at the forefront with a herd of 620 thousand heads (48.5%), while the number of working horses at the beginning of 2020 decreased to 570 thousand heads (42.2%). The development of meat production in the industry, first of all, is achieved by a significant increase in the number of horses in agricultural organizations of all forms of ownership, as well as by further increasing the breeding stock.

In market conditions, it is advisable to achieve the main increase in the number of herd horses for meat production through the creation of a wide network of peasant (farmer) horse breeding farms, which are, as practice and regulatory calculations show, one of the most efficient types of enterprises in which high production and economic indicators of the industry are provided. However, on a mass scale, we should focus on the creation of family farms.

When increasing the number of horses, special attention is paid to optimizing the structure of the herd.

The basis of research on the justification of effective options for the herd structure herd is the calculation of the standard cost of live weight of young horses when growing them to different ages.

According to the research, it is more expedient to sell young stock for meat in conditions of year-round grazing in autumn at the age of 6–9 months, 1.5 and 2.5 years. This is due to the fact that in the grazing period the youngsters gain weight significantly and quickly, and in the winter period, on the contrary, the weight of horses either does not change or decreases. Studies show that the weight of foals aged half a year and one and a half or two years, as well as that of foals aged two and a half and three years practically does not differ, and the costs of keeping the latter are much higher.

Rational schemes of the herd structure, which are formed on the basis of optimal age groups of young stock for to sell it for meat and acceptable for most regions of Russia with herd horse breeding, are presented in Table 3.

Table 3. Recommended herd structure schemes for horse meat production

Indicators	Variants		
	I	II	III
Age of horses sold for meat	6–9 months	1.5 year	2.5 years
Livestock structure at the beginning of the year, %:			
- stallions	4.0	2.8	2.3
- mares	6.2	47.4	37.0
- young stock	29.8	49.8	60.7
Production of meat in live weight per 1 head, kg	112.6	106.2	100.5

The first variant of herd structure is most suitable for farms with insufficient resources and possibilities for keeping young stock in harsh climatic conditions or with insufficient availability of natural pastures. It can be recommended for the northern regions of Eastern Siberia where herd horse breeding is most developed. The most rational is the second variant of herd structure, which is based on rearing horses for two summer and only one winter month. The implementation of the above technological methods will help to increase the profitability of horse meat production.

Practical evaluation of the implementation of different herd structure schemes in the desert zone of the Astrakhan region showed that the sale of young animals at 1.5 years (47% of mares) provides 104 kg of meat – horse meat in live weight per horse, while the sale at 6–9 months and 2.5 years gives 99 and 97 kg, respectively (Kalashnikov et al. 2007).

The draft strategy for the development of horse breeding in the Russian Federation for the period to 2025 worked out by the Ministry of Agriculture of the Russian Federation together with the All-Russian Research Institute of Horse Breeding states that the number of beef herd horses in the public sector should amount to 500 thousand heads, including 298 thousand heads of beef herd mares. In the medium term it is planned to increase the number of beef horses in farms of the population, mainly in the eastern regions of the country from 185 to 225 thousand heads (21%) with the number of producing mares amounting to 128 thousand heads. Thus, the total number of beef horses in 2025 will be 725 thousand heads, including 426 thousand mares aged 3 years and above.

One of the priority areas of productive horse breeding development is dairy farming, which has a decisive social significance. The therapeutic qualities of koumiss and its nutritional value have been known to people since ancient times. It is proved that koumiss production can become an economically justified direction of horse breeding business. By 2025 there are all possibilities to increase the number of dairy horses up to 50 thousand heads with a herd of forage mares up to 25 thousand (Koveshnikov 2002).

Working horse breeding is a complex area of horse use. In addition to the main purpose – the use of horses as live draught, working mares produce foals, some of which are sold for meat. Working horses are also used for riding and in amateur sports. The rational and efficient management of working horse breeding is ensured, above all, by an increase in the output of horse days and the amount of work performed on the horses in certain periods.

To maximize the use of the reserves of working horse breeding, as well as to reduce the cost of work, it is necessary to increase the number of foals obtained from mares in the working horse stock.

The increase in the share of mares in the structure of the workhorse herd and in the structure of the herd determines a significant reserve of horse meat production. This is evidenced by the indicators of the survey of farms in the West Siberian region (Table 4).

By 2025 it is advisable to switch to the third variant of the structure in breeding of workhorses, where the number of working horses is 60% of mares, and where, along with work, the production of 73 kg of meat is ensured. In the future, with the stabilization of the horse population (570 thousand heads), the number of mares aged 3 years and older will be 246 thousand heads.

In pedigree horse breeding the number of horses will amount to 90 thousand heads, of which 36 thousand heads are mares of producing stock.

Summary project indicators of the number of horses at the end of the medium term are shown in Table 5.

Table 4. Meat production reserves for different livestock structures of working horses

Varinat	In the working stock, %		Structure of the total number of horses, %				Meat production per one structural head, kg
	geldings	mares	stallions	mares	geldings	herd replacements	
I	60	40	1.4	29.0	43.5	26.1	56
II	50	50	2.2	36.0	36.0	25.8	65
III	40	60	2.2	43.2	28.8	25.8	73
IV	30	70	2.8	50.0	21.4	25.8	81

Table 5. The number of horses by areas of use (project, thousands of heads at the end of 2025)

Areas of horse use	Total number of horses	including mares aged 3 and above
Commercial	570	246
Production of horse meat – total:	725	426
including: - in agricultural organizations and peasant farms	500	298
- in households of the population	225	128
Dairy production	50	25
Sports and leisure	45	9
Total mass horse breeding	1,390	706
Pedigree horse breeding	90	36
Total number of horses	1,480	742

4 Conclusions

Considering the prospective options for the development of horse breeding in terms of the use of horses, we can conclude that the total number of horses in the country will increase to 1,480 thousand heads, or by 12.8%. The main increase in the herd will be provided by the expanded development of productive and sporting leisure areas, while stabilizing the working herd.

Optimizing the structure of the herd will ensure an increase in the number of mares aged 3 years and older from 612.8 to 742 thousand heads, an increase of 21%.

The horse livestock projected for the medium term will meet the production and social needs for working, sports and recreational and breeding horses. In addition, the annual production of about 65 thousand tons of horse meat and 30 thousand tons of koumiss will make it possible to completely eliminate the import of these products.

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Multivariability of the Design Approach to the Concept of Restructuring in Construction

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Abstract. Purpose: The purpose of the research is to formulate an approach to the development and selection of business strategies for the operational areas of the construction enterprise based on the project approach.

Design/methodology/approach: The authors rely on a project approach in the development of an entrepreneurial strategy as part of the formation of a methodology and the restructuring of the enterprise. As a research methodology, a toolkit of a descriptive-analytical, comparative, matrix method, a method of semantic and structural analysis, a method of monitoring the content of terminology of theoretical and applied works in the sphere chosen for research is used.

Findings: It is determined that the strategic organizational reform of the construction enterprise is determined by the methodological and criterion aspects of the analysis by determining the vector of reform of the business direction and prioritization from the point of view of resource supply. A selection matrix for choosing entrepreneurial strategies for functioning business areas has been developed.

Originality/value: The originality of the proposed approach to the development and selection of a strategy for restructuring the construction enterprise consists in the synthesis of design and resource approaches. The main methodological problems of the enterprise restructuring are described, two basic approaches to the organization of transformation management are proposed: on the basis of the transformation of existing processes and on the basis of the strategic approach to the restructuring of the troubled enterprise or business sector. The proposed methodology for choosing business strategies for restructuring is due to the assessment of the strategic importance of the enterprise's areas of activity on the one hand and the potential for effective resource supply on the other.

Keywords: Restructuring · Project · Strategy · Strategic significance assessment

JEL Code: L21 · L23 · L25 · L74 · M11 · M21

1 Introduction

Modern economic conditions, with signs of classical stagnation of the economy, make it possible to talk about low efficiency and mobility of enterprise management systems. The restructuring procedure of the construction organization can be used as a tool to remove

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the organization from the state of crisis or to increase its current indicators and improve its current state, achieve certain goals and levels in this direction, and implement the strategy. An interesting approach is when the restructuring procedure is used both to solve current problems and to realize the existing potential simultaneously (Watanabe et al. 2009). A necessary prerequisite for the wide application of the restructuring mechanism in the construction industry is the existence of a fairly developed competitive environment, which dictates incentives for constantly improving the quality of products (Kamianetsky and Yaskova 2018). Otherwise, it becomes impossible to stay in a transforming market where other companies invest in their development.

In this case, restructuring becomes one of the important strategies for improving technology. Another important condition should be considered a sufficient development of the corporate governance system, since otherwise it is impossible to implement the restructuring mechanism itself.

Very few educational programs in leading business schools implement a restructuring course. Business leaders often do not have the basics, methodology and tools for organizational design or even conceptual understanding of it (Recardo and Heather 2013).

2 Materials and Method

The authors believe that at the present stage a single idea of restructuring has been formed, which is based on the concept of general project management (another widely used name is project management). This is evidenced by the results of the analysis of the works of Russian and foreign authors, in particular: Wernerfelt (1984), Bertrand and Betschinger (2012), Chukunova and Taranukha (2017), Besstremyannaya et al. (2017), Ahuja and Novelli (2014) Phillips and Zhdanov (2013) Gukasova and Brikoshina (2017), Troshkin and Kovtunenko (2018).

These and a number of other researchers believe that the essential characteristic of the project can be represented as follows: this is a single enterprise with given time boundaries. In some works, the definition of "project" is emphasized against "operation," which can be repeated many times. Evaluating the project approach from the point of view of its application to the formation of the methodology and the restructuring of the enterprise, the authors of the work note four problems arising in this regard.

The first is conceptual. It is due to the wide variety of reactions and ways of interaction of subsystems, on the one hand, and the need to develop a single action plan - on the other.

The second is theoretical. This complexity is connected simultaneously with the multi-variability and individuality of external and internal subsystems that determine the organizational state of the enterprise.

The third is the problem of dimensionality - it partly meaningfully develops the second, theoretical. We are talking about a complex and not always unambiguously clear hierarchy that determines the structure of the enterprise.

Finally, the fourth is the complexity of implementation. It naturally arises from the natural external and individual obstacles faced by restructuring participants who intend to create a new structure.

3 Results

We believe that it is sufficient to list six of its basic elements: 1) setting the goal, 2) description of the final result, 3) sequence of implementation (life cycle) of the project, 4) decomposition, 5) structuring, 6) communication and interaction of project participants.

At the first stage, a concept is formed, in particular: goals are indicated, the current situation is analyzed and evaluated, the necessary information base is formed and maintained, tactical and strategic implementation issues are coordinated, risks are identified and alternative action plans are developed, a feasibility study is drawn up and tested.

Then preliminary works (for example: design and survey) are carried out, project participants are designated, financing issues are resolved. As a result, a detailed project plan is drawn up and agreed upon, which serves as an indicator of readiness for the start of its implementation.

The third element of the system in question includes a number of its own substructures. These are separate sequential processes (phases) that should be described in more detail. It should be noted that there is no universal scheme for the development of the project, but the tasks of planning, budgeting, calculating resources, etc., require a focus on a certain model. To this end, developers usually identify four stages of the project life cycle: 1) start (or preliminary work), 2) creation (development) itself, 3) implementation, 4) completion.

Execution (implementation) of the project should begin with the preparation of internal and official documentation regulating issues of subordination and interaction. At this stage, the procedure and methods of work are worked out and communicated to the participants (Marisa and Yusof 2020). In particular, all team members and partners should know:

- peculiarities of communications and information support,
- specifics of document flow,
- interaction coordination schemes,
- conditions and forms of adjustment of work plans and results.

After that, the participants begin to carry out the planned activities, that is, the actual implementation of the project.

The next - the final stage involves in-house checking, as well as official external testing of the results of the work performed. Within the framework of construction projects, at this stage, specialists in the operation of facilities are selected and trained, work acceptance documents are drawn up, and, if necessary, the end of contractual relations with participants and partners is drawn up.

Modern management practice has developed two main approaches that determine the actions of management that oversees organizational changes. In the first case, we are talking about an analytical assessment of the implementation of functions. In general, this implies the orientation of the steps taken to transform existing business processes. It is determined mainly the inconsistency of the analyzed elements with the established economic and economic practices, existing norms and installations. This involves quite simple management tools, which can be used sporadically.

The second approach involves the development of an entrepreneurial strategy, which should become the basis for the formation and implementation of plans related to a problematic enterprise or business sector (division, direction). Such a base allows developing or, conversely, eliminates management objects, create new ones, or adjust the strategy. In this case, we are talking about more complex administrative tools that are used comprehensively and systematically. This approach implements not only current but also strategic objectives. Given the universality of the strategic approach, we believe that it is advisable to dwell on it in more detail.

1. Strategic organizational reform should begin with a review of the company's activities (Minnullin and Larkina 2019). In the case of construction enterprises, the following can be decomposed:

   – by the geography of the business unit;
   – in the direction of activity (design and survey, architectural, estimate and contract, supply and sales, construction, etc.);
   – by type of construction (industrial, civil, infrastructure, road, etc.);
   – by the nature of the customer (municipalities, regions, federal center, legal entities, individuals).

A list should be formed, which will become the basis for further analysis from areas structured according to the above principles: similar research objects need to be grouped. The main criteria for such systematization may be:

– specific financial and economic "weight" in the general organizational system (share of generated revenue, profit, volume of work performed, amount of attracted investments, etc.);
– degree of isolation (regional or foreign representative office, branch, division, subsidiary, organization - member of the holding, etc.).

Based on this analysis, a strategy can be developed and implemented. Management authors typically talk about four types of corporate strategies that focus on the following processes:

– development of existing business areas;
– diversification (i.e. creation of new directions);
– Identification of investment priorities, providing resources primarily for promising areas of activity;
– providing synergy from the interaction of several departments of the organization.

The next step is to determine the methodological and criterion aspects of the analysis. It should be noted that the authors of works on this issue focus on various evaluation criteria, put forward various objects of study as the basis. When choosing the methodology and criteria for analysis, the goals of developing an entrepreneurial strategy should be based on:

– determination of the vector of business direction reform;
– prioritization in terms of resource provision.

Qualitative work in this direction involves visualization of the results. For this purpose, two-dimensional matrices can be used, built, for example, according to the principles proposed by Ansoff (2009) and Porter (2016). The elements of the matrix can be separate, private, and integrated, complex indicators. This is determined by the state of the organization and the specifics of its activities.

In such cases, it is advisable to follow the strategy selection matrix of the current business lines (Fig. 1). The abscissa axis reflects the complex indicator "state - prospects for business development," the ordinate axis indicates the level of significance of the direction for the organization's activities.

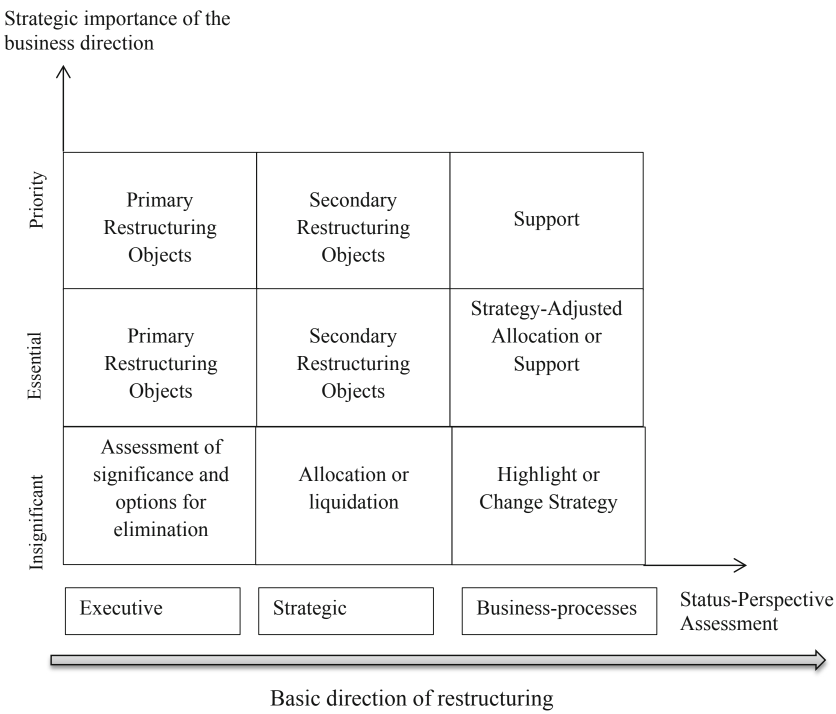

Fig. 1. Business restructuring strategy selection matrix for functioning business lines

When starting to develop the matrix, it is necessary to take into account that one of its most important application functions is the visualization of the state and prospects of business development, which in a vector coincides with the basic direction of structural reform. Therefore, you should first select the indicators that most closely characterize this axis. To this end, a list of the main criteria used for such an analysis is formed. In this case, Table 1 is an example.

Table 1. Some indicators characterizing the state and prospects of the business direction

No	Indicator name	Calculation principle
Investment uptake efficiency		
1	Net discounted income	The indicators obtained during the estimated period of the investment project are summed up, and the total is given to the initial indicator recorded during planning
2	Internal rate of return	Monetary discount rate at which discounted inflows and outflows are equal
3	Balance of accumulated funds	Arithmetic difference between inflow and outflow of money from investment, operating and financial activities
4	Cash flow from operating activities	Arithmetic difference between cash inflow and cash outflow from operations
5	Direct capitalization	Ratio of average annual net income to capitalization level (coefficient)
Business Outlook Indicators		
5	Market Performance	Ratio of the volume of products sold in the current year to the same indicator of the previous year
6	Relative Business Development Indicator	Ratio of segment growth rate to market growth rate as a whole
7	Average profitability of the market segment	Ratio of average profitability of segment assets to average market profitability of assets by market as a whole
Profitability (profit margin)		
8	Productions	Ratio of net profit to production costs
9	Sales	Operating Profit to Revenue Ratio
10	Holdings	Ratio of operating profit to annual average balance sheet

(*continued*)

Table 1. (*continued*)

No	Indicator name	Calculation principle
11	Fixed assets	Ratio of gross profit to year-average value of fixed assets
12	Capital	Ratio of net profit to annual average balance sheet
13	Fixed Costs	Ratio of operating profit to total fixed costs
14	Variable Costs	Ratio of gross profit to variable cost
Resource Efficiency		
15	Productivity	Ratio of cost of spent resources to value of manufactured products
16	Capital productivity	Part of revenue per unit of asset value
17	Capital intensity	Amount of fixed assets attributable to the rouble of finished products
18	Turnover of funds	Rate of use by the organization of the average working capital balance (during the period under review)
19	Material productivity	Volume of products produced per ruble of material resources consumed
20	Material capacity	Sum of material costs attributable to the RUB of manufactured products

The axis of the ordinates of the matrix conventionally shows the strategic significance (synergy) of business areas for the construction organization as a whole. In this case, the purpose of visualization and analysis is to determine how much the element in question (division, business direction) corresponds to the company's mission and its strategic goals. In general, it is important to find out whether current processes correlate with the priorities of the organization. The assessment of these facts can be approached in different ways:

– fixing the number of strategic goals and top-priority types of activities;
– heuristically generalize the estimate by applying a conditional scale.

In most cases, it is advisable to use the first mentioned option when analyzing the situation in companies with a complex subordination scheme in management - such a hierarchy determines the need to regularly reassess the relevance of existing strategies and identified priorities.

At the final stage, the examined elements are placed within the matrix (Fig. 1) and the direction of further actions is determined.

4 Conclusion

Therefore, the information summarized in the matrix will help to characterize the elements considered and justify the appropriateness of certain management actions.

1. Primary restructuring objects. You define the business processes or subdivisions that management should focus on first. This implies a particularly careful administration and priority of resources.
2. Secondary restructuring objects. They are taken into account and are considered in planning, but they are actively managed only if this does not divert resources from the restructuring of primary facilities.
3. Objects to select. We are talking about effective, promising, while administratively and organizationally to a certain extent independent elements of the system. Their own potential is sufficient for relatively autonomous development.
4. Objects to be liquidated. Elements that have received an unsatisfactory rating in analysis and decomposition should be excluded from the system.
5. Support for a unit or activity. No radical management action is taken against the supported facility. As a rule, we are talking about new elements of the system that need time to form and achieve a given efficiency, or about elements whose productivity is calculated to increase in connection with the upcoming transformations of the external environment.
6. Strategy adjustment. In some cases, decomposition and analysis indicate that there have been deficiencies or errors in strategic planning. Accordingly, management actions are required not by the elements of the system, but by its development strategy.

The tools discussed above are intended primarily for the management of existing construction enterprises.

The methodological approach to choosing an entrepreneurial strategy for restructuring a construction enterprise based on a matrix is justified. A feature of the matrix is the visualization of the state and prospects of business development, determined by the vector of the basic direction of structural reform. In order to characterize this direction, a list of indicators applicable for determining the state and prospects for the development of the business direction under consideration is formed. When comparing the prospects for structural reform with the strategic significance of individual areas, management approaches to change are identified. The peculiarities of the transformations revealed allow you to determine the peculiarities of individual stages of structural changes of the construction company.

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General Provisions of the Mediation Institution in Criminal Proceedings of European States

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Abstract. Purpose: Russia is interested in active integration into the international legal boundaries and in respect of thereof it is highly important to investigate and take into consideration international norms and standards devoted to restorative justice. The goal of a research is to study international legal references and provisions of the European states' national legislation concerning restorative justice programs, as well as already established practical application of such programs in these countries; to identify positive experience and draw conclusions from the practicability of taking into account certain provisions when mediation will be introduced in Russian sources of criminal procedure law.

Design/Methodology/Approach: During the course of the study the authors applied the dialectical method, general scientific methods (such as the method of analysis, the method of synthesis and the method of abstraction), as well as special methods of scientific knowledge (historical-legal and comparative-legal).

Findings: As a result of the research authors came to the conclusion that the legislative consolidation of mediation in criminal proceedings would make sense taking into account those thesis conclusions that were formulated in the findings of the research: the advisability of modifications in Russian Criminal Procedure Code and a special law of mediation, which would regulate the mediation in criminal proceedings, establishment of principles and definition of the parties and their legal status; the formation of a management body.

Keywords: Mediation · Criminal proceeding · European states · Conciliation of the parties · Restorative justice

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1 Introduction

The experience of the European states testifies to the advisability of introducing conciliatory restorative justice programs into the criminal proceedings. Conciliation between a person who committed a crime and a person who has suffered from it is a natural form

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of conflict resolution which replaced blood feud (Ser 2002), since in a society that consisted of small communities, maintaining a non-hostile relationship it became especially important and for this purpose negotiations and compensations are more effective than violence (Filatova et al. 2011).

Those particular restorative justice programs, which are recommended by the international legal documents, are the sources of European law for outspreading and development in criminal proceedings, especially in juvenile cases.

2 Materials and Method

In the course of the research authors studied the national legislation of the European states (when determining the list of the countries for the research authors were guided by the position of the European International Committees relating the countries with a border geographic location both to European. It is worth mentioning that for achieving the objectives of a research the standards belonging not only to the criminal procedure codes of these states were taken into consideration.

During the study the authors used a dialectical research method that made it possible to see the main patterns of the mediation development in criminal proceedings and their manifestation specificity in different national legislations.

The authors applied such general scientific methods as: the method of analysis which was used for the isolation and research of particular elements of the mediation institution as well as for comparing these elements in different national legislations; synthesis method was used for reuniting into a single system knowledge received as a result of the research that shows the features of using restorative program; method of abstraction made it possible to analyze the mediation development which is not same in different countries focusing on certain key features and elements. The authors also used special methods of scientific knowledge such as historical-legal (to systematize information about the origin and evolution of the mediation institution), comparative-legal (to identify individual features of the conciliation programs used in different countries, and for the further knowledge systematization taking into account the identified differences and similarities).

3 Results

In the criminal procedure of France, mediation was enshrined in Law No. 93-2 of January 4, 1993 on the criminal proceeding reform, according to which the prosecutor, before deciding upon whether to initiate criminal proceedings, may refer the parties (non-bindingly negotiated) to the mediation, if in his opinion, such measure would contribute to compensation for the victim and the mending of the offender (Andreeva 2012). Currently, French conciliation programs work for criminals regardless of their age.

In Finland, mediation has been developing only de facto for a long time, starting with the first programs conducted in 1983 and 1984 in the city of Vantaa gradually spreading within municipalities (for example, by 1990 mediation had been carried out on the basis of 25 municipalities, and in 1991 on the basis of 40 ones). Mediation in criminal proceedings of today's Finland is regulated by the Law on Criminal and Certain Civil Conciliation and is permissible at any stage of the proceeding (Borisova 2011).

In Austria, the mediation has been developing since 1985 exclusively as a way of responding to juvenile crimes (Pelikan 2009; Biryukov and Pronin 2011). Studies have shown that 90% of cases aimed at the mediation end up with a successful conciliation, and 80% of the conciliations are based on a pecuniary compensation agreement. Crime victims refused to participate in mediation in only 5% of cases (Haidar et al. 1988; Pelikan and Pilgram 1988). After receiving recognition from practitioners, it began to be used as a way of response to the crimes committed by adults, as a trial project at first, but eventually it was legislatively enshrined in the Austrian Federal Law on Mediation of 2003 (Groenheisen 2003). Later studies showed the positive impact of the use of mediation in criminal proceedings entailing legislative changes to improve the status of victims in criminal proceedings and expand the possibilities for out-of-court settlement (Hofinger and Neumann 2008).

In Portugal, the mediation in criminal proceeding has been regulated since 2007 by Law No. 21/2007 "On Mediation". Although its application is limited to crime cases in which imprisonment is imposed for no more than 5 years (Bolsova 2008). Restrictions are also provided: for crime cases committed against juvenile or during simplified legal proceedings (Arutyunyan and Dobrolyubov 2012). The successful settlement of a conciliation agreement by the parties presupposes the renunciation of criminal proceedings, however, the law entrusts the right of the victim to initiate the resumption of proceedings if the defendant does not fulfill the terms of the concluded agreement (Yelchaninov 2013).

In Germany, individuals must be informed and encouraged by the prosecutor's office and the court to participate in reconciliation programs at every stage of the proceeding. Restorative juvenile justice programs have been specifically developed. Thus, juveniles may be "forced" to act to reconcile with the victim and effect restitution. In fact, even if real reconciliation is impossible to achieve, and the court is made sure of clear offender's efforts to achieve this reconciliation (Ostendorf 2007), the order of the court is considered to be fulfilled (Yurkov 2009). At the same time, according to the judicial practice, reconciliation should occur between the victim and the offender directly (irreplaceably by the representatives or relatives either in matters of participation or in matters of compensation; damage must be compensated directly by the person who have committed the act, and not paid by the parents), thus putting an end to the dispute over the possibility of compensation (Amos 2018).

In Spain, mediation against adult criminals is still not regulated by the law but with regard to juvenile it has been used for a long time and successfully from 15 to 20% of criminal cases against juvenile ended up with a successful mediation (Schwartz 2018).

In the Czech Republic, after years of research, there was made a conclusion that the programs implemented by the probation and mediation service (especially for juvenile) need further strategic planning. They have gradually become an integral part of the criminal procedure in the Czech Republic and are actively used nowadays to resolve early parole issues in courts (Rozum et al. 2011).

Interest in restorative justice programs gradually became evident and at the end of 2002, initiated by of the European Justice Ministers, an innovative body was created to improve the quality and efficiency of European judicial systems – the European Committee for the Efficiency of Justice (hereinafter referred to as the "European Committee"). The European Committee analyses the functioning of the judicial systems of the European states and is summoned to guide the state policy in the field of justice, develops specific measures and devices aimed at quality improvement of the public justice service, the formation, and dissemination of the European justice standards, and support of the member states in their judicial reforms.

To ensure consistency between national mediation laws, the European states are encouraged to abide by the European law sources of dealing with mediation in criminal proceedings, such as Recommendation No. R (99) 19, "Basic principles for the application of restorative justice programs in criminal cases", Recommendations (2001) 9 on litigation alternatives between administrative authorities and private parties, Recommendation CM/Rec (2018) 8 on restorative justice in criminal matters, Guidelines for Better Implementation of the Recommendation on Mediation in Penal Matters CEPEJ (2007) 13.

The complete heterogeneity of national legislation of the European states in the issue of legislative mediation consolidation in the criminal process is observed. Most European states have laws on mediation in the field of civil law relations, and mediation in criminal proceeding is either non-regulated by legislation or rarely applied as a result or the mediation norms in criminal proceeding are included in other laws. Thus, mediation in criminal cases is regulated by separate provisions of legal acts of the mediation in the Czech Republic and Lithuania, and in Belgium, Poland, and France, the norms on mediation are incorporated in the criminal procedure codes.

Based on the results of a study conducted by the European Committee, the best practices of Azerbaijan were analyzed, where criminal law is enshrined in the main legal act on mediation. Lithuania, Poland, Serbia, Turkey, France, the Czech Republic and Switzerland are also cited as examples, and a negative assessment is given to the approach of Germany, where the use of mediation is limited to cases of misconduct (in cases of private prosecution, the district court, before considering the case on the merits, parties obligatory directed to the mediation) (Jirova 2012).

The European Committee has developed some recommendations on general provisions on mediation in criminal proceeding. It is obvious how psychological damage and material loss caused by the crime in the criminal process is possible to be most effectively reduced and compensated for. It is emphasized that the restorative justice methods can tangibly transform the behaviour of the offender, and subsequently facilitates their reintegration into society. These important aspects must be taken into account when introducing criminal law mediation into national legislation.

The European Committee emphasizes the need to comply with the rule that conciliation proceedings should only be exercised with the informed consent of both the victim and the offender. The legislation of the Czech Republic, France, Germany, Lithuania, and Poland is given as a positive example of allowing for such requirements. Meanwhile, in order to prevent the abuse of such alternatives to criminal proceedings, the European Committee petitions for additional guarantees to respect the rights and interests of the parties.

From the viewpoint of rights observance of a crime victim, it is necessary to positively distinguish the two-level procedure developed in Lithuania for selecting cases suitable for mediation, for weeding out persons who are potentially dangerous and unable to reintegrate in this way. At the initial stage, the mediator meets the parties separately and decides on reasonableness to hold a joint meeting. In case of unreasonableness, the mediator can apply separate programs with the participants.

Another important aspect is the special training of the mediators. The representatives of completely different specialties are known to be potential mediators, but the Committee draws attention to the fact that mediators taking part in the resolution of criminal disputes must necessarily have basic knowledge of the criminal justice system. An example is the experience of Serbia, where the law states that a mediator needs training to resolve "disputes of specific types".

The European Committee requests to pay attention to the potential of social organizations in the implementation of the mediation into criminal cases. For example, in the Czech Republic, where the probation and mediation services cooperate with social welfare authorities, educational, religious and other institutions with humanitarian goals.

There is no single definition for the mediation in the European legislation, and there should not be but the Committee offers a specialized focus on the fact that the use of the term "mediation" should not restrict intermediaries in the right to choose different restorative justice programs, which may include family conferences, justice circles and others programs.

In some national legislation of the European states (in particular Azerbaijan, Ireland, Italy, Poland, Finland, Croatia) there are some norms that allow the intermediary to use various methods. But the European Committee notes that the realization of such a right by the mediator must be agreed by the parties each time same as, for example, enshrined in Italian law, where the mediator has the right to suggest using of a different conciliation method in case when the parties have failed to achieve conciliation in the previously chosen way or if the parties have requested the intermediary directly. Thus, a perfect balance is struck when the intermediaries are allowed to offer suggestions but they are left at the discretion of the parties.

The definition of the concept "intermediary" is relatively stable in national laws and contains references to the main characteristic features of his status: independence, neutrality, the function of "supervising" of the parties in the conciliation process clarifying the rights and obligations, principles and stages of the conciliation proceeding, general management of the conciliation process and non-interference into the conciliation terms. At the same time, along with such general characteristic features particular distinctions are also met. Thus, in some European states a person who is willing to become an intermediary must be indicated in a special national register. The formation of such a registry can ensure that the intermediaries included in it have reached the specified age (for example, in Austria above 28 years, in Poland above 26 years, in Azerbaijan above 25 years), have proper training (according to the laws of Spain, Cyprus, Lithuania, Slovenia and Slovakia any university diploma is required, in the Czech Republic it is obligatory to have a Master's Degree and in Turkey a Law Ddegree), have successfully passed a professional exam (this rule is provided in Belgium, Lithuania, Czech Republic and Turkey), carry out conciliation proceedings constantly (for example, the mediator must provide the confirmation of a certain number of mediation services carried out over a certain period of time: in Azerbaijan at least 1 conciliation procedure in 2 years; in Austria 50 h in 5 years; in Serbia 10 h a year) and systematically improve their skills, that certainly contributes to the improvement of their service quality. Generally in the European states lawyers, judges, notaries, and even law enforcement officials are able to perform the functions of a mediator in the presence of relevant training, but only if this activity does not contradict duties and functions of their main profession, also if they are not involved in the same dispute as another party. It is usually practiced in France to involve into mediation person who previously has been working in the field of criminal justice (gendarmes, police officers, etc.) but those who have retired (Maître 2015).

Another important feature of the register is a help in establishing common international criteria for the mediators' accreditation, since it turns out to be possible for the professional mobility of these specialists across the territory of the European states. Similar registers have been created in Austria, Azerbaijan, Cyprus, Lithuania, Serbia, Turkey, and Croatia. The European states come down to the biography of the mediator differently. Thus, the general approach is to limit the ability of people with a criminal record to mediate. Some states have banned the possibility of taking part in the conciliation for those who were tried for corruption-related offenses (Lithuania), others base their restrictions on the punishment applied (for example, in Serbia individuals sentenced to imprisonment cannot be a mediator), some of the states ban people convicted only the intentional and dangerous crimes (Slovenia), but there are also countries where it is forbidden to be a mediator for those ones who have been convicted of crimes committed out of negligence as well (Czech Republic). In French law a particularly strict approach is applied and in addition to a criminal record an intermediary should not have any administrative or even disciplinary penalties.

The European states are offered to develop some codes of professional ethics for the mediators. The importance of the Ethics Code is described in details by the Dutch scholars: most aspects of mediator's neutrality, confidentiality, the ability to audio or video the conciliation proceeding, the admission of students to the proceeding, etc. (Pieter 2018). The mediator's Ethics Code should introduce the grounds and procedure for taking disciplinary actions. For example, in Serbia a mediator is liable for any damage resulting from a breach of the Ethics Code regulations. The question of the mediators' responsibility can be settled not only in the Code of Ethics but also in the national mediation law.

As a result, it is considered advisable creating of a certain body of professional mediators' community, endowed with organizational, administrative and qualification functions and with the right to bring disciplinary actions against the mediator in case of professional misconduct. Same body can be endowed with the right to keep a register of mediators. However, it is recognized that existence of a mediators' register will not solve the problem of so called "shadow services", when the conciliation proceedings will be provided by individuals who are not in the register for various reasons, and therefore it is suggested to include rules of the mandatory agreement approval by the judiciary in national law those which were agreed by the parties as a result of the conciliation proceeding and make a note that only agreements reached with the assistance of a mediator included in the register are subject to such approval. This is the approach found in Belgian law. As additional guarantees, it is suggested to legitimate the possibility of the legal proceeding terms suspension and to admit the rule of mandatory pre-trial settlement of the dispute (when it is provided) as complied with only if the parties have contacted the mediator from the register.

4 Conclusion

The genesis and evolution of restorative justice programs in the European states is characterized by heterogeneity. In some states mediation and other programs are enshrined in legislation and they are applied to criminals of any age who have committed crimes of different degree. In others mediation has not received legislative support in a separate special law but it is successfully applied in practice. In other states programs work only for juvenile and sometimes only for individuals who have committed minor offences. However, the mediation is gradually developing in the criminal proceedings of the European states and the information indicating the refusal from this method as ineffective has not been identified. On the contrary, specialized international committees highly recommending the use of conciliation proceedings in criminal procedures are created. In this regard, we believe that the Russian Federation should also take this experience into account when regulating conciliatory acts in criminal proceedings, which have been developing in practice for at least a long time.

The consolidation of mediation in the criminal procedure legislation is considered to be the most judicious approach, as well as the adoption of a special law in which the conceptual framework is defined in detail and the fundamentals, principles, possible participants, the requirements for them, the features of their status, the features of the proceeding itself are regulated.

The use of the term "mediation" in the criminal legislation of the European states does not mean that only this technique can be used in the conciliation. The choice of a specific type of the reconciliation programs is left to the specialist and this circumstance should not be burdened with any difficulties in interpreting the norms of the law.

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Socio-economic and Legal Factors of Recognition and Enforcement of the Constitutional Right to Education in Russia

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Abstract. Purpose: The main purpose of the article is to substantiate the algorithm for state recognition and provision of the constitutional right to education in the Russian Federation.

Design/Methodology/Approach: By the means of constitutional analysis, the authors identify elements of a sectoral nature in the content of the constitutional right to education, which make it possible in practice to move to building legal relations such as public-private partnerships based on the normative provisions of specialized legislation.

Findings: It's shown that modern Russian federal legislation makes it possible for the constituent entities of the Russian Federation to detail the procedures for rendering assistance to persons, with whom social contracts are concluded in order to stimulate their civic activity, including educational ones.

Originality/Value: The institutional significance of the contractual form of guaranteeing the right to education at the regional level is actualized. Individual study of targeted contracts, their preliminary «economic examination» and an explanation of the socio-economic obligations, which is assumed by the subject of investment, will allow to stop the negative trend of growth in the termination of social contracts by public authorities unilaterally, due to the failure of the recipients of assistance to fulfill their obligations, including knowingly unfair attitude towards them.

Keywords: Modern Russia · Constitutional right to education · Targeted social contracts · Regional legal practice

JEL Codes: R01 · F22 · F63 · J15 · J61 · O15 · R11 · R23 · R58 · Z13 · Z18

1 Introduction

By the beginning of the 21st century, the concept of a social state acquired universally recognized value and, at the same time, varied content in the context of the premise

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of the constitutional equivalence of social human rights and civil or legal (primary) rights. At the same time, the degree of variability comes to the “inclusion” of the purely economic component of individual freedom in the content of socio-economic and labor rights (Stolies 2003). It is impossible to deny the need for economic adjustment and adequate institutional solutions. At the same time, social rights deserve full independent recognition (Tushnet 2004). In essence, these are substantiated claims of the individual to state support in relation to such forms of personal development and survival, which are objectively determined by the nature of a person as a biosocial being and politically consolidated community - a people that consciously finds the highest value of its being as the continuity of generations. A necessary prerequisite for life of a “political kind” is a full-fledged education, risking in a market economy situation being subordinate to the formulas of commodity-money relations under the sign of selective protectionism. The constitutional approach excludes such a scenario.

2 Materials and Method

In the realities of judicial constitutionalism, constitutional justice, which provides democratic expectations and enforcement, is also complementary to the ontological development of social rights. In any case, in the European constitutional doctrine, this is rarely questioned if one does not touch upon the reflection of the risks of legalization of the principle of social justice and relevant social rights as an “activist” institution that could discredit the state in the eyes of potential investors (Sheppele 2001). Indeed, appropriate approaches may not seem appropriate (Sunstein 2005), but in post-Soviet formations they have a great chance of legitimate perception. The latter, in particular, is clearly correlated with the social block of the 2020 constitutional reform initiated by the President of the Russian Federation V. Putin.

The pronounced emphasis on national resources - in view of the decrease in foreign investment empathy - implements a scenario that is largely consistent with the analytical conclusion of Alston (2005), and actualizes a purely economic understanding of social rights, in the spirit of the philosophy of “protection for the poor”. The damage to this perception is clearly manifested in relation to the right to education, which is often and unjustifiably “reduced” to the level of subjective rights (Guseva 2012). Only in the rank of constitutional law of a person and a citizen can it be completely “disclosed” and understood as a complex (complex) structure of authority (which is nominally confirmed by the composition of Article 43 of the Constitution of the Russian Federation), which, in addition to socio-economic and anti-discrimination, has an autonomous personality and cultural component and assuming a balanced political strategy of full recognition and provision (guarantee) (Krylova 2019). A strategy aligned with the necessary harmonization of the requirements for the protection of constitutional sovereignty (Cruz 2013), the goal of maintaining constitutional identity (Blokhin 2018) and protecting intellectual (digital) rights (Pentaev 2018). Any educational policy will not have prospects if it leaves out the problems of family spiritual and moral education that precede and accompany the formation of a comprehensively educated personality (Gromova 2012).

The economically weighted resources of the “fight against poverty” should also be approached with this view in mind. Special attention should be paid to social contracts as a legal form of targeted support for students classified as poor. According to data for the second quarter of 2019, the share of such Russians was 12.7%, or 18.6 million people. There is a negative trend of increasing termination of social contracts by public authorities on a unilateral basis, in view of non-fulfillment by recipients of aid of their obligations, including deliberately unfair treatment of them.

Education as an object of human rights has unique characteristics that assume and ensure responsible integration and harmonization of the personal development of the right holder with the interests of society and the state. Investments in the educational structure as a sphere of constitutional legal use are both private and public investments. And they should not only be financial (Bondar 2016), but also confidential and collaborative. The history of Russian statehood fully confirms this.

During the Imperial period, University education in Russia was de jure a channel for the growth of legal status for people of all classes but the actual scarcity of potential, the privileged format and the class-functional specialization of education were a barrier to this. According to the Nominal decree of February 9, 1737, nobles were allowed to organize the education of their male children, justifying its effectiveness for a professional career. The educational opportunities of other classes were limited to various degrees. The "educational Elevator" worked only on the upper floors of the social building in Russia (Sorokin 1992), but those who managed to circumvent the barriers received real opportunities to improve their socio-political status. Moreover, the three-stage system of primary, secondary and higher education took into account the demand for various types and levels of preparation for labor activity. This structure still seems optimal for the entire configuration of public and private interests in their relation to educational services (Nasonov 2012).

3 Results

Formal legal obstacles to equal access to education in Russia were removed at the beginning of the 20th century, and the Soviet government politically articulated universal education. The Constitution of the Russian Federation, in fact, continued the traditions of the socialist stage in the development of education as an institution of the legal status of a person and citizen. However, permanently modernized educational institutions and practices show a decrease in the ability to solve specialized tasks in a qualitatively different social environment and environment. The demographic crisis, social-property stratification and expansion of virtual technologies and network communications required additional options for setting up the mechanism for ensuring the right to education in the form of concretization of the functions of the social state and legal guarantees of vertical mobility of youth of lain. They cannot be found. And more and more, the inferiority of rates on some innovative trends is visible, even if they allow calculating "digital trajectories" and tracking "digital traces" of students on "cloud" platforms (Kelly 2017). The announced transition from homo sapiens to homo curiosus alarms the manifestations of the critical ignorance of the curious.

In the Russian (and Soviet) tradition, the focus of legal education on a practical orientation has never been called into question, finding "cross-cutting" methodological support in the training courses of most industry disciplines and prevailing approaches.

Therefore, “revelations” about the importance of such an approach with references to foreign experience look rather tendentious (Vereshchagin 2019). The arguments about the need to move beyond the state interest and awareness of the educational motivation of students cannot be recognized as constitutional (Ten 2014). It is also difficult to deny the existence of educational algorithms aimed at infiltrating Western and transnational ideals (Pugachev 2013). It seems more appropriate to clarify the constitutional boundaries and ensure the university-academic freedom of professors and teachers focused on the provision of “educational services” and the continuous improvement of their own qualifications, regardless of personal achievements, scientific authority and status. Constitutional transparency and certification are a prerequisite for the establishment of “continuing education laboratories” for the teaching staff.

The legal statement of the Constitutional Court of the Russian Federation substantiates the actual devolution of Russian education and recognizes the advisability of de-updating the legal connection of the state certificate (diploma) of higher education with the qualification of "educated" against the backdrop of the introduction of the Bologna system in the fashionable style of Internet and network marketing. It is also argued that the constitutional category “state educational standard” does not imply going beyond purely orientating samples for filling in universities with living, adapted content. These judgments are difficult to recognize by revelation. However, the key thesis of the scientist-constitutionalist that the state, which failed to create the prerequisites of the educational system, primarily economic ones, reliably correlated with the constitutional legal and social ideal, cannot retain the privileges provided by the obligatory diplomas reserved for it, needs extensive scientific discussion. In the course of which the polarization process of universities according to the “rating” of accepted students could also receive a constitutional assessment, which also leads to a deterioration in the quality of graduates, regardless of the fair or exaggerated arguments about the “discrimination” of private universities.

4 Conclusions/Recommendations

The recognized problems of the Russian educational reform suggest the intensification of the search for new institutional resources, including targeted forms of socio-economic investment (support) of students. The constitutionally promising model of the social contract needs to be finalized, including the possible transition to a trilateral format with the participation of universities and the decisive involvement of economic and legal specialists in the pre-contractual stage. To reduce the risks of the corruption component in appropriate practices, it seems appropriate to use blockchain technology and smart contracts.

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Trade and Economic Cooperation Within BRICS: Actual Problems and Prospects

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Abstract. Purpose: The purpose of the article is to introduce recommendations aimed at optimizing BRICS cooperation and expanding their interaction in trade and financial sphere for sustainable development and welfare.

Design/Methodology/Approach: Strengthening BRICS cooperation is the best solution to mitigate trade wars, unfair competition and worsening of international economic relations. In this paper, we analyze and determine new challenges for partner – countries in an ongoing of technical and economic reengineering process. The existing data is processed using combination of Bloomberg and Excel tools. Testing of initial hypothesis proved strong requirement of multilateral relations in different spheres that are backed by trade and finance. The analysis of this research concludes that the role of a public entity is to provide favorable conditions for project strategy application, including growth of creativity, innovation, transformation of financial, technological, social, and other areas, connected with research and development.

Findings: The research founds that special attention is to be payed to harmonization of regulations, which stimulates innovations – expensive, but important segment of public and private relations, that is constantly in demand. We consider, that it may be reasonable to take into consideration the international experience as a template how countries can work together to strengthen their economies for sustainable development.

Originality/Value: As perspective approaches to solving the identified problems, we recommend conveying better access to loans for private entities, improving government grants to new industries and technologies as well as providing taxing relief for manufactured exported goods in order to break the deadlock of non - harmonized regulation and pave the way for BRICS welfare.

Keywords: BRICS · International trade · Innovations · Project finance · Economic development · Welfare

JEL Code: F36 · F37

1 Introduction

International trade and economic cooperation of BRICS countries (Brazil, Russia, India, China and South Africa) is one of the priorities listed in the BRICS Economic Partnership Strategy (hereinafter referred to as BRICS Strategy). The list of objectives of the

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BRICS Strategy includes, in particular, the following: promoting the development of market relations and expanding market access opportunities, expanding and diversifying trade and investment cooperation, creating a favorable environment for investors and entrepreneurs in all BRICS countries.

Active trade, economic and investment cooperation, along with other areas, is designed to strengthen balanced and inclusive economic growth, as well as to increase the level of the international competitiveness of BRICS economies, which account for 17.3% of world merchandise trade, 12.7% of world trade in services, and which together form 21% of the world gross domestic product (GDP), at par of the purchasing power of national currencies - about 30% of world GDP.

Purposeful desire to expand and strengthen ties in the field of trade, investment cooperation acquires more and more clear guidelines and is reflected in all the main documents of BRICS. Thus, the actual problems of multilateral trade and economic cooperation in BRICS format were quite widely covered in the Goa Declaration of October 16, 2016, adopted at the end of the VIII BRICS summit in India (Arapova 2016). The leaders of the countries expressed confidence in the need to further stimulate growth on the scale of regional integration with the obligatory observance of the principles of openness and equality in order to ensure the development of investment, trade and commercial relations (Bank of Russia 2017).

2 Methodology

The research was based on statistical data from official websites of international organizations, analytical materials of National Committee on BRICS Research, Bank of Russia, and BRICS declarations. The paper analyzes the state of bilateral trade relations of the BRICS countries, cluster analysis on two selected features. The least squares method has been used to estimate the parameters of gravitational models of foreign trade for each of the countries within the framework of BRICS. The analysis of the effectiveness of the logistics systems of the BRICS countries on the basis of the Logistics Performance Index was carried out. An assessment of the foreign trade and investment policies of the BRICS countries is given. Based on the results obtained, the main current problems and promising ways, the directions of their consistent solution are highlighted.

3 Results

Current statistical data of international organizations, materials of BRICS joint statistical publications confirm the presence of significant achievements in trade and economic cooperation. According to information provided by BRICS Business Council, for the period 2001–2017, there was an increase in the share of trade within BRICS (intragroup) in the total foreign trade turnover of BRICS countries from 6.2% to 10%.

The following Table 1 presents data on the import and export of countries in the framework of BRICS for 2018, the dynamics of indicators for the period from 2014 to 2018.

Table 1. The state of bilateral trade relations of BRICS countries in 2014–2018.

Country	Partner Country	Import (thousand USD)	Average import growth rate for 2014–2018, %	Share of partner country in import, %	Export (thousand USD)	Average export growth rate for 2014–2018, %	Share of partner country in export, %
Brazil (B)	Russia	3,373,742	4	2	1,655,276	−15	1
	India	3,662,824	−14	2	3,909,882	−2	2
	China	34,730,027	−3	19	64,205,647	13	27
	South Africa	662,937	−5	0	1,363,109	3	1
Russia (R)	Brazil	2,469,959	−8	1	2,584,351	3	1
	India	3,224,629	3	1	7,752,309	14	2
	China	52,217,993	4	22	56,040,503	12	12
	South Africa	783,066	3	0	285,733	−3	0
India (I)	Brazil	4,617,881	−1	1	3,561,877	−14	1
	Russia	6,847,458	17	1	2,331,420	4	1
	China	73,738,222	5	15	16,403,899	7	5
	South Africa	6,610,006	3	1	4,013,636	−6	1
China (C)	Brazil	77,141,726	12	4	33,731,542	0	1
	Russia	58,887,066	10	3	48,005,203	0	2
	India	18,850,037	5	1	76,880,637	9	3
	South Africa	27,240,322	−11	1	16,337,354	0	1
South Africa (S)	Brazil	1,483,547	3	2	464,163	−10	0
	Russia	509,785	0	1	403,076	4	0
	India	3,840,265	−4	4	4,460,550	6	5
	China	17,116,573	2	18	8,663,602	1	9

Source: compiled by the authors according to the International Trade Center (International Trade Center 2018)

According to the Table, it can be concluded that China has a dominant position in trade relations with other BRICS countries - the share in imports varies from 15% to 22%, in exports - from 5% to 27%. It is important that China acts primarily as an exporter to BRICS countries, while the share of exports from BRICS partner countries to China is much smaller. Growth rates for 2014–2018 for China, exports are also significantly higher than the growth rates in imports over the same period, with the exception of bilateral trade relations "South Africa - China". Brazil is the main trade partner of China for imports (China's share of imports from Brazil is 4%), the second place is occupied by the Russian Federation with a share of China's total imports equal to 3%. The largest share among the partner countries of China in exports in 2018 belongs to India and is 3%, Russia is in second place (its share in exports is 2%).

To understand the problems and identify prospects for expanding and deepening foreign trade cooperation, it is important to have an idea of the proximity of countries' positions on trade policy issues, on the level of their socio-economic development and a number of other parameters. For the purpose of research, cluster analysis can be applied to form relatively homogeneous groups of objects (in this case, countries).

Two signs were selected to compare BRICS countries. The first sign - GDP per capita at purchasing power parity (PPP) - is an important measure for cross-country analysis, since it reflects not only output, but also income and prices in the country. The share of high-tech exports (%) is the second sign, characterizes the level of development of the manufacturing industries, science and technology. It was previously noted that BRICS countries are striving to increase the share of high value-added goods in mutual foreign trade, but so far low-tech exports prevail, high-tech products have an insignificant share.

Table 2 presents quantitative data for BRICS countries for the implementation of cluster analysis (2017).

Table 2. Baseline data for cluster analysis

Country	Brazil	Russia	India	China	South Africa
GDP at PPP (per capita, $)	15,553.4	25,763.3	7,166.2	16,842.4	13,526.2
The share of high-tech exports, %	12.3	11.5	7.0	23.8	4.6

Source: World Bank Group (2017)

We implement cluster analysis using an agglomerative hierarchical classification algorithm. We apply the "nearest neighbor" principle, choosing the usual Euclidean distance as the distance between objects:

$$p(x_i x_j) = \sqrt{\sum\nolimits_l^k (x_{il} - x_{jl})^2},$$

where l are signs, k is the number of signs.

The following notations are introduced: X1 sign - GDP at PPP (per capita, $), X2 sign - the share of high-tech exports, %; countries: 1 - Brazil, 2 - Russia, 3 - India, 4 - China, 5 - South Africa. The search for the smallest distance is performed, and the closest objects are combined into one relatively homogeneous cluster. The final result of the iterative process (procedure) is presented in Table 3.

The Table shows the smallest distances between objects. As a result, we have 3 clusters: S (1,4), S (2,3), S (5). Therefore, in aggregate, according to the selected criteria, X1 and X2 are the closest countries in pairs: Brazil and China, Russia and India, and South Africa falls into a separate cluster. The results obtained generally correspond to

Table 3. The result of cluster analysis - the matrix of the smallest distances

No.	1,4	2,3	5
1.4	0	8,920.908	2,027.215
2.3	8,920.908	0	12,237.1
5	2,027.215	12,237.1	0

Source: compiled by the authors

the results of the analysis of bilateral trade relations within the framework of BRICS (Table 1). So, China is the main import and export partner for Brazil, Brazil is the main import partner for China. This is also true for India and Russia - India is the second import and export partner for the Russian Federation after China, in turn, Russia is the most important import partner for India (after China).

Along with the cluster analysis procedure, it seems possible to use the so-called gravity model for analyzing and assessing the potential of mutual trade in BRICS format. The gravitational model is used in studies of spatial interactions in the economy - export-import, migration, transport flows. For the analysis of foreign trade, the model was first used by J. Tinbergen in 1962.

The mathematical formulation of the model is:

$$Y_i = \beta_0 \cdot \frac{X_{i1}^{\beta_1} X_{i2}^{\beta_2}}{d_i^{\beta_3}} \cdot \varepsilon_i,$$

where i is the object number (country, region, etc.), Y is the indicator of interaction between objects, $X1,2$ is the size of objects, d is the distance between objects, εi are other factors (random residues in the econometric model).

To analyze the foreign trade interaction of BRICS countries, the following form of recording the gravity model was selected in general:

$$Y = \frac{a_0 \cdot X_1^{a_1}}{X_2^{a_2}} \cdot \varepsilon_i,$$

where $a0, a1, a2$ are the model parameters, Y is the foreign trade turnover (explained variable), $X1$ is the PPP-based GDP per capita (explaining variable), $X2$ is the distance between economic centers - capitals of countries (explaining variable), εi - random perturbations in the model.

Model specification after linearization:

$$ln(y) = ln(a_0) + a_1 \cdot ln(x_1) - a_2 \cdot ln(x_2) + \varepsilon \cdot ln(e)$$

It should be noted that there is a direct dependence of Y on the $X1$ factor (GDP) and inverse dependence on the $X2$ factor (distance) - let the initial hypothesis $H0$ be formulated in this way. We introduce the following variables (we change variables): $Y = ln\ (y)$, $A0 = ln\ (a0)$ is the free term (constant) of the regression equation, $z1 = ln\ (x1)$, $z2 = ln\ (x2)$, $u = ln\ (e)$.

The linear multiple model is represented as follows:

$$Y = A_0 + a_1 z_1 + a_2 z_2 + u$$

In order to obtain an approximate estimate of the parameters (coefficients) of the regression model, the least squares method (LSM) can be used (Martínez-Zarzoso 2013). In the process of LSM - estimation of model parameters, we use the tool "Regression" of the tabular processor Microsoft Excel.

The obtained calculated values (model parameter estimation - LSM) are systematized in Table 4. The values of the standard errors of the parameters are indicated in brackets under the values of the parameters of the regression models.

Table 4. Calculated values of BRICS gravity models of foreign trade

Country	Parameter *a0*	Parameter *a1*	Parameter *a2*	Model standard error	R-squared
Brazil	−22.44756861 (21.47906647)	0.58302025 (1.277931908)	3.508911001 (1.73983906)	1.172918239	0.804620587
Russia	16.2430361 (17.2230611)	4.703081619 (2.329988696)	−5.03826632 (2.000800152)	1.198001149	0.868577931
India	63.35747431 (26.10565975)	−2.993985551 (2.085777805)	−1.982522137 (0.918914793)	0.796323517	0.823917342
China	18.91571605 (6.914499695)	0.148172614 (0.711247399)	−0.250551177 (0.538067998)	0.611839245	0.424641367
South Africa	−3.015729923 (31.7638319)	−1.798425997 (1.636579241)	3.873825958 (3.333127268)	1.486460623	0.684515596

Source: compiled by the authors

The values of the coefficients of determination (R-squared) testify in most cases (except for the model for the PRC) about the good quality of the regressions. For example, in the model for Russia, the R-squared is approximately equal to 0,87, that is, the variation of the explained variable (Y) is almost 87% due to the variation of the explanatory variables (X). The data in table 4 also testify to the confirmation of the initial hypothesis H0 for most of BRICS member countries. Consequently, the value of trade in most cases increases if the incentives for this are the growth of GDP (the country and its trade and economic partners) and the reduction of distance (hence, reduction in transportation costs, risks during transportation of goods, etc.).

To analyze the quality and efficiency of the logistics systems of BRICS member countries, the Logistics Performance Index (LPI) can be used, the data on which are published by the World Bank. The LPI index is calculated once every 2 years and has a range of values from 1 (minimum) to 5 (maximum). The closer the LPI value for a particular country to 5, the higher the efficiency of logistics in that country. It should be noted that LPI is formed on the basis of six indicators of subindexes: customs efficiency and border control (customs), development of trade and transport infrastructure, international shipments, logistics competence, cargo passage tracking and, finally, timeliness of deliveries. According to the World Bank, in 2018, the BRICS countries took the following positions in the international LPI rating: Brazil - 56th place (LPI value – 2.99), Russia - 75th place (2.76), India - 44th place (3.18), China - 26th place (3.61) and South Africa - 33rd place (3.38). The leader in the Logistics Performance Index is Germany, LPI is 4.20 (World Bank Group 2018). Figure 1 below shows how the LPI changed over the period from 2010 to 2018 for each of BRICS countries.

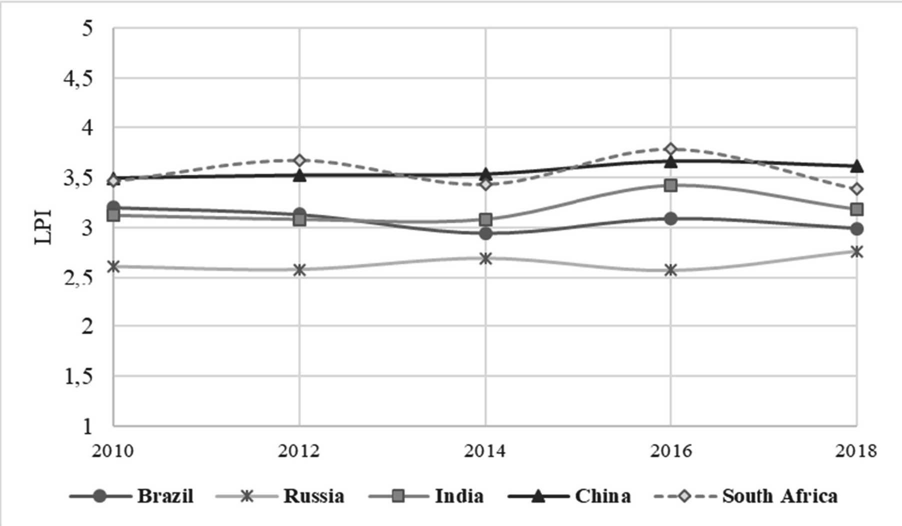

Fig. 1. Dynamics of LPI values for BRICS countries, 2010–2018. *Source*: compiled by the authors according to the World Bank

China throughout the period under review had consistently high estimates of logistics efficiency, while other BRICS countries were characterized by the volatility of estimates by years. Russia has the lowest LPI values in 2010–2018. Figure 2 shows all the values of the sub-indices of the Logistics Performance Index for BRICS countries in 2018.

According to the petal diagram presented in Fig. 2, it is possible to make a conclusion about China's leadership, according to estimates of all LPI components among the rest of BRICS countries. China has the highest values in such subindexes as "timeliness" – 3.83 out of 5, "infrastructure" – 3.75. For Brazil, the most problematic units are "customs", "international shipments" and "infrastructure" (the component data estimates are 2.41; 2.88 and 2.93, respectively). The Russian Federation needs to develop all the blocks, with the greatest attention should be paid to the components of LPI - "customs", "tracking & tracing", "infrastructure". In India, the main difficulties are related to infrastructure – 2.91 and customs – 2.96, and the highest level of development was achieved in the component "timeliness" – 3.5. The Republic of South Africa takes the 2nd place in BRICS after China in terms of the efficiency of the logistics system; it has relatively low marks on the infrastructure block and on the customs sub-index – 3.19 and 3.17, respectively.

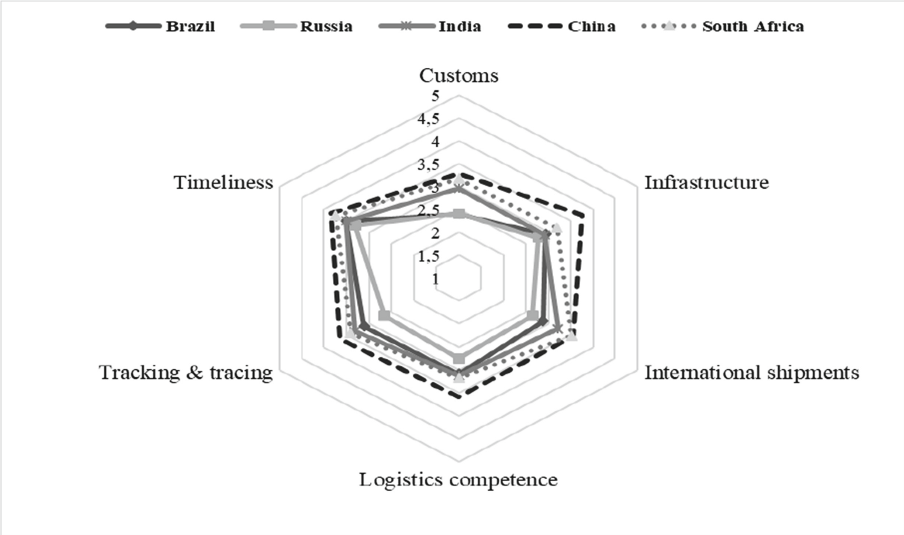

Fig. 2. Values of LPI sub-indices for BRICS countries, 2018. *Source*: compiled by the authors according to the World Bank

From the point of view of the further development of the first component of LPI, the customs authorities of BRICS countries are actively implementing measures to strengthen cooperation; the previously mentioned Regulation on the Committee on Customs Cooperation is adopted. At the same time, the development of trade and transport infrastructure determines the significant needs for financing, attracting investment resources. At the present stage, the investment policy of BRICS countries is characterized by increased openness of the investment regimes of the states. The values of the Index of restrictions on foreign direct investment (FDI) are 0.10 - in Brazil, 0.24 - in India (but higher than, for example, the OECD average is 0.07), 0.06 - in South Africa (Sakharov 2017).

In Brazil, since 2015, the priority nature of investments in infrastructure development has been designated; in 2016, the implementation of the Investment Partnership Program was announced. Tax rebates and deductions are granted to foreign investors at the regional level. India is consistently overcoming the structural constraints of the investment environment under the Make in India program, which has been in operation since 2014. South Africa passed the Promotion and Protection of Investment Bill in 2015. However, there is the right to impose restrictions and expropriate property of investors, guided by considerations of national interests in the country. In China, there are restrictions on FDI from the standpoint of national security, and the most “closed” areas include infrastructure and transport, large-scale engineering, and high-tech industries. In general, the investment regimes of BRICS countries can be described as relatively open.

4 Conclusion

According to the results of the analysis of bilateral trade relations of countries within the framework of BRICS, mutual foreign trade of countries based on gravity models, the effectiveness of the logistics systems of the countries, it is possible to draw the following main conclusions.

Firstly, to date, the PRC occupies a central place in trade relations in BRICS, while the shares of other countries are incomparably small, especially in terms of exports. The most diversified structure is also characteristic of Chinese exports, while at the same time, commodity and low-technology exports still dominate in the trade turnover within BRICS, while the share of high value-added goods is small. This, in particular, is related to the specifics of the sectoral potential of the participating countries, their desire to ensure first of all food security, to realize the potential of a rich natural resource potential. Nevertheless, already by 2025, BRICS countries set the development of a “knowledge economy”, the intensive development of infrastructure, and growth through new high-tech sectors as their goals.

Secondly, BRICS member countries are largely removed from each other, which complicates the process of transporting goods, increases transportation costs and various risks. Given the changes in the external environment, currency fluctuations, this problem is further complicated. There are changes in the value-added chains, in price ratios, which, in accordance with the gravity model of foreign trade, are then directly reflected in the value of trade.

Thirdly, following the adoption of various declarations by BRICS, more and more attention is focused on the objective need for infrastructure development. At the same time, the insufficient level of development of infrastructure, mainly transport and logistics, significantly hinders the expansion and deepening of trade and economic cooperation between countries. In addition, the official documents of BRICS indicate insufficient funding for such areas as infrastructure development. The data on the Logistics Performance Index confirms the urgency of this problem for the overwhelming majority of BRICS countries.

In addition to the above obstacles that hinder trade and economic cooperation in a multilateral format, problems in the field of customs cooperation, industrial development, and investment cooperation also need to be addressed. Despite the dominance of bilateral relations within the framework of BRICS, many of these problems should be solved jointly, in a combination of three, four countries and BRICS as a whole, depending on the degree of complexity of the problem and its significance for members of the association.

The development of electronic commerce should be highlighted as one of the most promising solutions to the problem of the geographical distance of countries. The expediency of this has been emphasized repeatedly at meetings in BRICS format. At the present stage, the government-to-business (G2B) business model has become most common in BRICS. In the future, the introduction of other business models - B2B, B2C, C2C is also important, in order to ensure full cooperation and realization of the interests of all the main participants: government, business and consumers. There is a potential for cooperation in the field of e-commerce, for example, through the cross-border e-commerce platform in Russia "Global Rus Trade", support is provided for the export of building materials and industrial equipment to BRICS countries.

According to BRICS E-commerce Cooperation Initiative China (2017), services for cloud computing data, electronic payments, and a search engine are developing in China. The most important role in the growth of e-commerce is played by the Alibaba Group, in particular, in the use of B2B and B2C models. Promoting the development of large, small and medium-sized businesses has an online platform in India – "IndiaMart". In addition, a program to protect against the risks of non-payment and non-receipt of goods is being developed in conjunction with ICICI Bank. In the future, the most important results of the development of electronic commerce should be: reducing the cost of organizing trade interaction, developing direct trade cooperation without intermediaries.

In order to develop the infrastructure, it is necessary to apply the mechanisms of investment crediting, project financing, due to high capital intensity, long-term projects, as well as complex coordination of various multilateral aspects of inter-country cooperation. That is, along with the need for large amounts of funds, there is a need for highly qualified legal, accounting, auditing and other support for large projects. In this context, it is advisable to emphasize the organizing role of banks, especially such international financial institutions as the New Development Bank (NDB BRICS). The success of the implementation of strategic projects within the framework of BRICS depends on the effectiveness of the functioning of such institutions.

Public-private partnership (PPP) is crucial for the development of trade, economic and investment cooperation of BRICS countries as a factor in reducing risks for project participants (Yarygina 2013). In the format of PPP one of the most important characteristics is multilateral interaction, during which problems and the search for solutions are openly discussed by all participants, joint tasks are formed. It is important to continue the development of this form of interaction, in order to expand the range of projects from bilateral to multilateral and promote the effective solution of the economic growth objectives of BRICS member countries.

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Assessment of the State and Prospects of Development of Cross-Country Entrepreneurship of Small and Medium-Sized Businesses in the Stavropol Territory

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Abstract. Purpose: The purpose of the study is to substantiate the possibilities of developing international cooperation and exports based on the assessment of the state of cross-country entrepreneurship of small and medium-sized businesses in the Stavropol Territory. This will allow us to justify the choice of forms of international cooperation with strategic partners in the field of small and medium-sized businesses.

Design/methodology/approach: The scientific relevance of the study is associated with the presence of unrealized opportunities for the wide use of forms of strategic partnership in the process of international cooperation and integration of small and medium-sized businesses based on the modernization of infrastructure support.

Findings: The author evaluates and conducts a critical analysis of the infrastructure provision for small and medium-sized businesses in the field of export and justifies the need for its improvement.

Originality/value: The author's interest in identifying the directions of development of international cooperation and integration of small and medium-sized businesses in terms of creating general conditions for state support of export activities is noteworthy. The author came to the conclusion that it is necessary to improve the quality of the regulatory environment for small and medium-sized businesses in order to provide state support for international cooperation and export processes.

The author substantiates the primary importance of infrastructure aspects (financial, innovation, institutional, telecommunications, information infrastructure) for improving the effectiveness of managing the process of international cooperation and integration of small and medium-sized businesses in the Stavropol Territory.

Keywords: International cooperation · International integration · Small and medium-sized enterprises · Export · Cross-country entrepreneurship

JEL Classification: F 15 · M 20

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1 Introduction

Entrepreneurship occupies a special place in economic relations and is the basis for the development of socio-economic systems. Despite the inherent flexibility and innovative activity of business structures, they are the most vulnerable from the point of view of the influence of numerous environmental factors and therefore require the creation of the most favourable conditions for business development. Prospects for the development of small and medium-sized businesses are associated with their more active involvement in the processes of international cooperation and integration.

The relevance of the study is associated with the presence of unrealized opportunities for expanding the forms of international cooperation of small and medium-sized businesses, which need to be identified and described, as well as to form a set of systemic measures for their development. The main purpose of state support for small and medium-sized businesses is related to solving such tasks as expanding the participation of business entities in external economic affairs and increasing their export potential. Sustainable development of the entrepreneurial environment in the sphere of small and medium-sized businesses largely depends on the formation of effective institutions and institutional support mechanisms, which largely determine the effectiveness of the entrepreneurial initiative in general, and international cooperation and exports in particular. One of the problems of developing cross-country entrepreneurship in the field of small and medium-sized businesses is the lack of a systematic approach to decision-making.

2 Materials and Method

Advanced empirical analysis and local conceptual generalization of the collected data, analysis of trends and conditions of international cooperation of small and medium-sized businesses in the context of digital transformation offered sufficient grounds for considering that the main conclusions and provisions of the dissertation research are conceptually verified, scientifically based. The reliability of the results obtained is ensured by the breadth and complexity of the scientific analysis of the subject, the compatibility of the approaches used by the author to the study of scientific methods for harmonizing the forms of strategic partnership in the field of international cooperation and export.

Research methodology includes the identification of infrastructure bottlenecks that create obstacles for the development of international cooperation and integration of small and medium-sized businesses in the southern region of Russia – the Stavropol territory, as well as the determination of the specifics of export cooperation, which consists in the absence of sectoral innovation technologies and segmental provision of public services to support international cooperation and integration of small and medium-sized businesses.

Methodological basis of the research was the comparative methods and statistical analysis in the study of trends in cross-national entrepreneurship, regression analysis, which selected as the methodological support of this study, the systemic and institutional approaches in developing recommendations on the use of forms of international cooperation and integration, as well as other scientific methods and principles of knowledge. The combination of these methods allowed identifying the potential opportunities and strengths of international integration and cooperation aimed at the overall implementation of priority projects of socio-economic significance for the strategic development of the Russian Federation.

3 Results

The urgent need to develop forms of international cooperation of small and medium-sized businesses at the present stage of development of the Russian economy determines the need to modernize the infrastructure of international cooperation and export of small and medium-sized businesses, in connection with which it is necessary to conduct a study of cross-country entrepreneurship of small and medium-sized businesses in the Stavropol region.

Consider the dynamics of exports, imports and their balance in the region in 2005–2019 (Fig. 1).

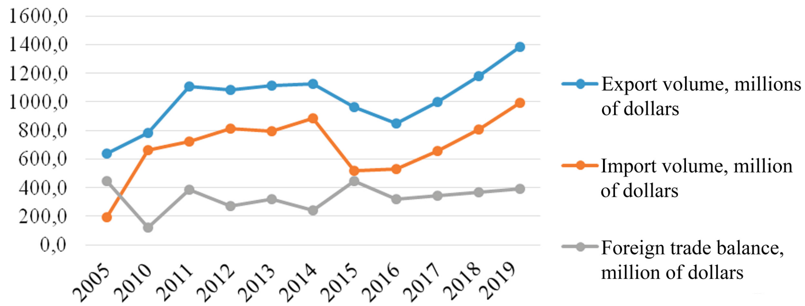

Fig. 1. The dynamics of exports, imports and foreign trade balance of enterprises of the Stavropol territory in 2005–2019. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2019).

The volume of exports and imports of the Stavropol territory is characterized by general trends, in particular, a decline in 2015–2016 and a rise in 2017–2019. The foreign trade balance is at the same level – $ 391.4 million in 2019 (1385.89–994.498). Exports exceed imports by 1.39 times, that is, they are almost at the same level (Anopchenko 2018).

To assess the importance of exports for the development of the economy of the Stavropol territory, we will conduct a regression analysis of the impact of export volume (x) on the value of gross domestic product (y) in the Stavropol territory in 2005–2019. Using this method, on the example of scientists who have been working in this topic for a long time, the dependence of indicators reflecting the results of entrepreneurship development is revealed (Litvinova 2019).

We will analyze the impact of exports on the regional gross product on the basis of data describing the dynamics of these indicators in the Stavropol territory in 2005–2019 (Table 1).

Table 1. Dynamics of export volume and gross regional product in the Stavropol Territory in 2005–2019

Time period (calendar year)	Gross regional product, million rubles	Export volume, million US dollars
	y	x
2005	14,659.3	641.2
2010	330,791	782.6
2011	396,792	1,108.6
2012	431,753	1,083.4
2013	480,905	1,114.3
2014	540,797	1,126.2
2015	621,198	964.2
2016	651,925	849.7
2017	684,172	1,000.2
2018	718,013	1,177.36
2019	753,529	1,385.89

Source: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2019)

Regression dependencies are identified during the extended analysis (Table 2).

Table 2. Results of regression analysis of the impact of export volume (x) on the value of gross domestic product (y) in the Stavropol territory in 2005–2019.

1. Regression statistics						
Multiple R	0.6858					
R Square	0.4703					
Adjusted R Square	0.4115					
Standard error	165179.4122					
Observations	11					
2. ANOVA						
	DF	SS	MS	F	F Value	
Regression	1	2.18054E + 11	2.18054E + 11	7.9919	0.0198	
Residual	9	2.45558E + 11	27284238198			
Total	10	4.63612E + 11				

(*continued*)

Table 2. (*continued*)

1. Regression statistics						
3. Student's t-test						
	Coefficients	Standard error	tStat	P-Value	Lower 95%	Upper 95%
Intercept	−221892.8809	264099.5944	−0.8402	0.4226	−819327.6700	375541.9082
x	717.9640	253.9667	2.8270	0.0198	143.4514	1292,4766

Source: calculated by the author in the computer program "Microsoft Excel" using the function "Data analysis: Regression" on the Data tab page, (the function is not standard and can be configured additionally)

The regression curve of the influence of export volume on the value of gross domestic product in the Stavropol territory can be illustrated as follows (Fig. 2).

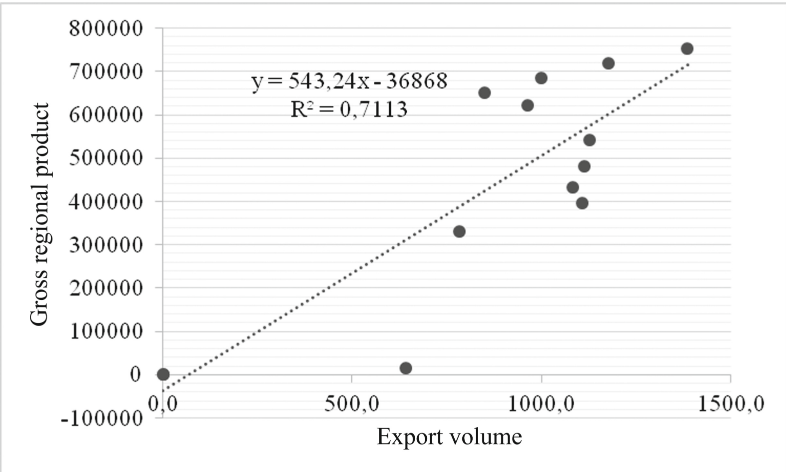

Fig. 2. Regression curve of the impact of export volume (x) on the value of gross domestic product (y) in the Stavropol Territory in 2005–2019. *Source*: calculated and built by the author

According to statistical analysis, an increase in exports by $ 1 million leads to an increase in the gross domestic product in the Stavropol territory by 543.24 million rubles. The obtained value of the multiple correlation coefficient R = 0.6858 indicates that the change in gross domestic product can be explained by a change in the volume of exports by 68.58% (moderate correlation of indicators).

The observed value of Fisher's F-test (7.9919) exceeds the table value (at the significance level $\alpha = 0.05$ and k1 = m = 1 and k2 = n–m–1 = 11–1–1 = 9, it is 5.12), this allows us to recognize the equation as statistically significant. The observed value of the Student's t-test (2.8270) exceeds the table value (at the significance level $\alpha = 0.05$ and n−2 = 11–2 = 9, it is 2.26), which also confirms the statistical significance of the compiled equation of paired linear regression.

Consequently, the export activity of entrepreneurship largely determines the growth and development of the economy of the Stavropol region. To identify the share of small and medium-sized businesses in its overall structure, we will turn to the socio-economic indicators of the region (Fig. 3).

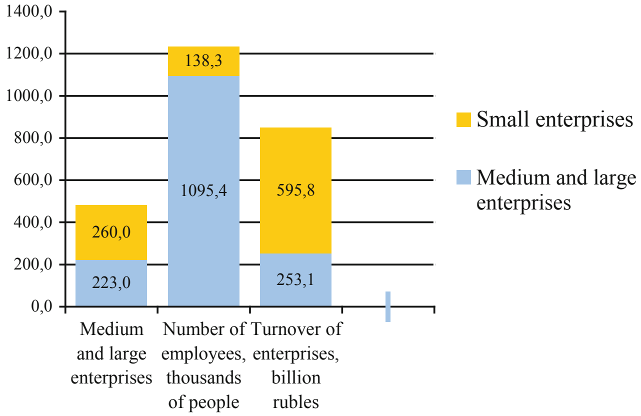

Fig. 3. Indicators of the share of small enterprises in the structure of the economy of the Stavropol Territory in 2018. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2018).

According to the obtained statistical data, the share of small enterprises (22,300 units) in the total number of enterprises of the Stavropol territory (48,295 units) is 53.84%. The number of employees of small enterprises (183.3 thousand people) in the total employed population of the Stavropol region (1233.7 thousand people) is 11.21%. Turnover of small enterprises (595.8 billion rubles) in the total turnover of entrepreneurship in the Stavropol territory (848.9 billion rubles), it is 70.18%. At the same time, it should be noted that in the official statistics of Rosstat, only small businesses are singled out separately (Ostrovskaya 2017).

The dynamics of financial performance of enterprises of the Stavropol territory in 2005–2019 is shown in Fig. 4.

The net financial result (difference in profit and loss) of the enterprises of the Stavropol region is relatively stable – in 2019 it is 49,631 million rubles. That is, in general, entrepreneurship is profitable. At the same time, the share of unprofitable enterprises in 2019 was 29%. The debt of enterprises on loans (that is, the rate of using borrowed financial resources) showed a sharp decline in 2012. In 2019 it amounted to 184,244 million rubles, or 371.23% of the net financial result. The volume of investments in fixed assets of enterprises of the Stavropol territory increases annually – in 2019 it amounted to 181,458 million rubles, data on their structure by sources of financing are shown in Fig. 5.

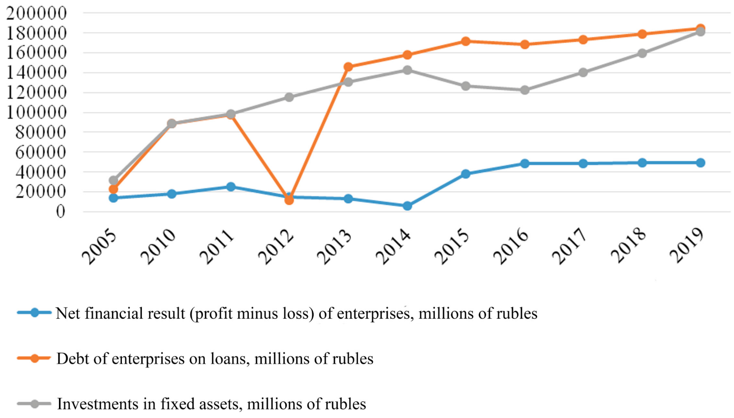

Fig. 4. Dynamics of financial performance indicators of enterprises of the Stavropol territory in 2005–2019. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2018).

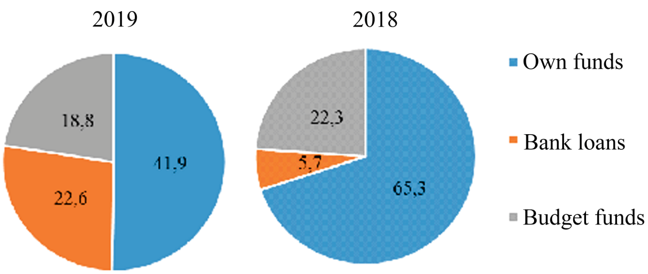

Fig. 5. Structure of investments in fixed assets of the Stavropol territory enterprises in 2010 and 2018 by funding sources. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2018).

The share of own funds of enterprises of the Stavropol region in the structure of investments in fixed assets in 2018 was 65.3%, an increase of 1.56 times compared to 2010, when it was 41.9%. The share of budget funds increased from 18.8% in 2010 to 22.3% in 2019. The share of bank loans decreased by 3.96 times from 22.6% in 2010 to 5.7% in 2018.

Thus, the unavailability of borrowed financial resources is an infrastructure barrier to the development of international cooperation and integration of small and medium-sized businesses in the Stavropol Territory. Small and medium-sized enterprises tend to have limited financial resources of their own (Tikhonova 2017).

Creating special (more favourable) conditions for crediting export activities of small and medium-sized businesses in the Stavropol territory, as well as expanding regional state financial support for international cooperation and integration of small and medium-sized businesses are ways to overcome the shortage of external (in relation to enterprises) resources and overcome the identified infrastructure barrier (Pereverzeva 2016).

The dynamics of various indicators of innovative activity of enterprises in the Stavropol territory in 2005–2019 is shown in Fig. 6.

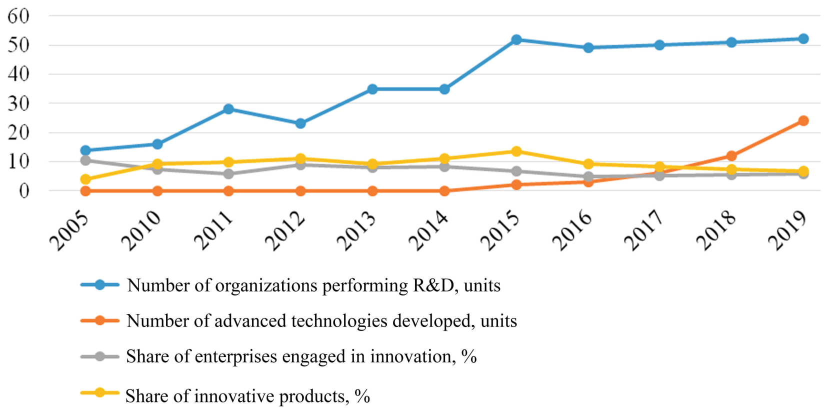

Fig. 6. The dynamics of individual indicators of innovation activity of enterprises in the Stavropol region in the years 2005–2019. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2019).

The number of organizations performing R&D (research and development) in the Stavropol region in 2019 amounted to 52 units, an increase of 3.71 times compared to 2005, when it was 14 units. The number of developed advanced production technologies in 2019 amounted to 24 units, and during 2005–2014 it was zero. The share of enterprises engaged in innovation in 2019 was 5.9%, a decrease of 1.78 times compared to 2010, when it was 10.5%. The share of innovative products in 2019 was 6.6%, a decrease compared to 2015 (13.5%) by 1.28 times.

The dynamics of the number of personnel engaged in R&D and the number of advanced production technologies used by enterprises in the Stavropol territory can be presented as follows (Fig. 7).

The number of employees engaged in R&D in 2019 amounted to 2,839 people, an increase of 1.64 times compared to 2005, when it was 1,734 people. The number of advanced production technologies used by enterprises in the Stavropol territory in 2019 amounted to 1987 units, an increase of 4.35 times compared to 2005, when it was 457 units.

The number of advanced production technologies used (1987 units) is many times higher than the number of developed technologies (24 units), confirming the generally low innovative activity of enterprises in the Stavropol territory (Abdrakhmanova 2017; Chistova 2013).

Although the regulatory framework for international cooperation and integration of small and medium-sized businesses in the Stavropol territory has been formed, the level of e-government development in this region is low – 52nd out of 83 in 2017. (E-Government Expert Center 2017). Consequently, the low availability of electronic public services is one of the infrastructure barriers to the development of international cooperation and integration of small and medium-sized businesses in the Stavropol region.

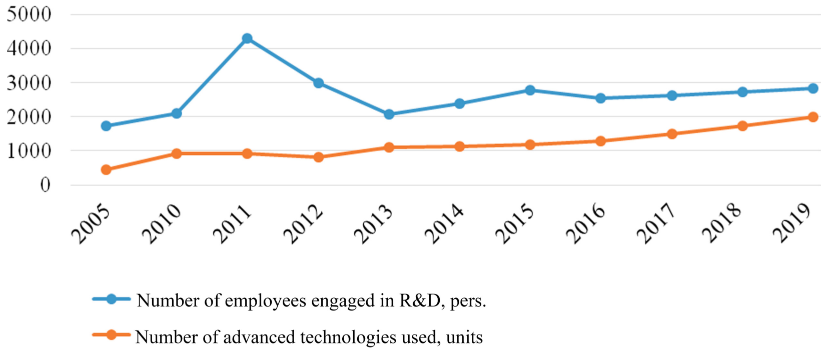

Fig. 7. Dynamics of the number of personnel engaged in R&D in the Stavropol territory in 2005–2019. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2018).

The dynamics of the use of modern information and communication technologies by enterprises in the Stavropol territory in 2005–2019 is shown in Fig. 8.

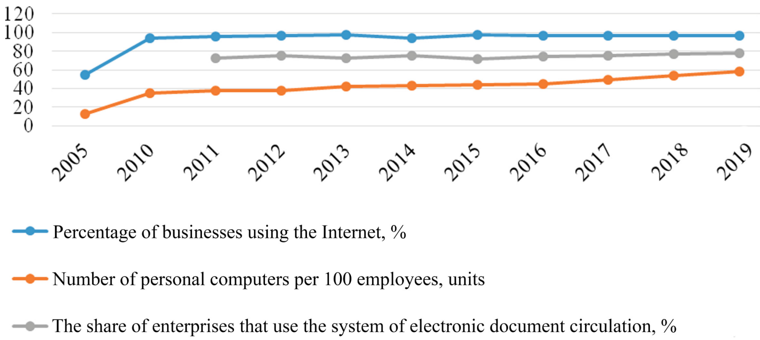

Fig. 8. Dynamics of the use of modern information and communication technologies by enterprises in the Stavropol territory in 2005–2019. *Source*: compiled and calculated by the author on the basis of data from the Federal State Statistics Service (2018).

It is obvious that the share of enterprises using the Internet in the Stavropol territory in 2019 is very high and amounts to 96.7%. The number of personal computers per 100 employees in 2019 is 58.1. The share of enterprises using electronic document management systems is 77.7%. At the same time, the cost of information and communication technologies is 4,323.6 million rubles, that is, 0.5% of the turnover and therefore quite high.

4 Conclusion

Recommendations and conclusions are based on the use of a significant amount of research sources on various theories and sections of economics: business economics, management theory, competitive analysis theory, and institutional theory.

The analysis of the experience of using international partnership accumulated by world and domestic science and practice allowed the author to confirm the opinion that conceptually the basis of international cooperation and integration of small and medium-sized businesses is expressed in the internationalization of enterprises, which makes it possible to overcome emerging crises and gain new competitive advantages in the world market.

According to the results of the study, it was found that export-oriented small and medium-sized businesses receive the necessary level of support for their projects in the field of foreign economic activity through a specialized mechanism that ensures coordination of efforts of all elements of the state export support system. The formation of the author's perspective of the study is a practical concept for optimizing the management of international cooperation and integration of small and medium-sized businesses.

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University Modernization in the Conditions of Industrialization of Production and Intelligent Machines

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Abstract. *The aim of the research* is to study the world's leading trends in the development of education in the conditions of total digitalization and formation of a new type of society based on industrial production with the help of highly intelligent machines and equipment. This issue is of particular importance in the context of education modernization, the expansion of the role of educational organizations in the processes of formation and development of an individual, and the growing requirements for the professional qualities of graduates.

Research methodology: Determined by the provisions of the system, competency, activity, design, personality-oriented approaches, and the principles of vocational guidance.

Results: As a result of studying the leading problems and development trends of modern society and education, we have identified a system of leading trends that determine key positions in the educational policy of the university as a regional center for innovative development and an accelerator of progress. The leading directions of development are identified, which provide qualitatively new results in training specialists for work in the new economy, digitalization and automation of routine labor. Also development paths are identified in the conditions of strategic uncertainty. Elements of the development in the university as an educational system that combines the needs of cities and communities with educational needs are formulated.

Conclusions/recommendations of the study is determined by the fact that a system of actions is formed that ensures the sustainable development of the university, the modernization of the educational process, the organization of networking and partnerships in the interests of training new types of specialists. This people can work in the conditions of work automation, while the role of intelligent machines and development digital economy is increasing.

Keywords: Strategic development · Training · Labor automation · Y800

JEL Code: Y800

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1 Introduction

Dynamic processes in modern higher education are due to objective changes of the external environment, structural rearrangements of educational systems, and refinements in the all-Russian educational system strategies.

Modern researchers single out a large group of problems of a global scale that have a significant impact on the development of education as a global system: the digital divide, the imbalance of information flows, growing economic and social inequality, growing risks of collective and individual security, growing global inequality, etc. (Laszlo et al. 2016).

According to experts, mass education of the industrial era is currently not effective: there is no adequate preparation for life in a complex changing world, the ability to cooperate, critical, systemic thinking and the creative potential of students are not sufficiently developed.

Education is aimed at maintaining existing values and their reproduction, which only exacerbates the prevailing contradictions.

In his study, Baltes et al. (2000) highlight the following three main factors that create the need for transformation of higher education:

1. The growing complexity of socio-technical systems (such as transport, energy, telecom, mass production, etc.) are socio-economic, political and cultural environments that are increasingly acquiring the features of VUCA (Volatile, Uncertain, Complex, Ambiguous).
2. Growing inadequate opportunities for the transformation of the educational system due to increased investment in the scientific industrial model of education and production, which is slowing down society's readiness for the challenges in the 21st century.
3. Development of digital technologies, cognitive and mathematical sciences, biomechanics and other related sciences, providing high mobility of "big data", development of production with highly intelligent machines, as well as personal-oriented and collective ways of learning (Battles et al. 2000).

This creates conditions for formation of a new type of education based on personalization, use of up-to-date open content, cooperation between participants of the educational process, employers and stakeholders, at same time creating flexible interactive educational spaces (Vaganova et al. 2019).

In this case, global digitalization and automation are becoming a leading factor and a communicative element that allows combining the cultural, educational and scientific components of education into a single environment (Luksha et al. 2014).

Researchers in sociology also note a number of global changes in social development that can be combined into a single direction: technological acceleration, brightly manifested and increasing in the field of social development. According to Heiligen such acceleration of social and technical development can even mean the transition to a new stage of civilizational development — a society of the "world brain". The researchers refer to the following factors as the reasons for this acceleration and its further increase:

– The dynamics of the development of various innovations from research universities and corporate institutes to the creation of national innovation systems that provide a continuous flow of new technologies;
– The creation of network technologies (from television to the Internet and social networks) that implement the rapid use of received innovations;
– Globalization processes determine the creation of global technology standards, professional requirements and educational processes.

A combination of these trends tells us that there is an inevitable transformation of educational systems in accordance with the requirements of a new lifestyle and changes in professional fields. Moreover, the formation of exclusively "digital skills" does not give an effective result: there is an increase in demand for meta-competencies - creative abilities, the ability to negotiate and collaborate, empathy, etc. More and more attention is being paid to the processes of the formation of social and emotional intelligences. It is these competencies that are referred to as "skills of the future", allowing people to successfully operate in the context of continuous socio-economic and technological changes (Lapshova et al. 2019), (Luksha et al. 2014), (Markova et al. 2017), (Fedorov et al. 2017), (Laszlo et al. 2016).

2 Materials and Method

This study used the provisions of the system, competency, activity, design, personality-oriented approaches, and the principles of vocational guidance. A clinical approach was also used, focused on immersing the future teacher in an educational organization, which ensures the formation of competencies, the accumulation of subjective experience, and positioning oneself in the professional and pedagogical space.

A questionnaire method allowed revealing the interest of teachers in this format of interaction, in determining its "most effective form of organizing student practice", providing opportunities for "prospective employment", "early professionalization" of students, "potential employer to participate in the preparation of future teachers", "design and implementation new examples of practical pedagogical experience", etc.

In order to create innovative platforms, training schools were created, necessary to create best practices, improve the skills of the pedagogical staff of the region and the country and turn it into an advanced Russian educational center (training of schoolchildren, students, teachers, educational leaders, research and development center, a testing center for new technologies).

A new design of the educational environment based on the principles of manufacturability, convenience for all categories of students and compliance with the requirements of modern education was also developed. A regional social and pedagogical cluster has also been formed, focused on the consolidation of partnerships in the field of education and the formation of a resource base for further development.

A methodology for calculating the need for pedagogical staff has been developed and used, which will allow to form a clear idea of the existing imbalances and formats for solving these problems.

The collective management of the regional educational system requires the establishment of deliberative bodies to ensure human development through networking, exchange, and resource sharing processes.

3 Results

In order to modernize the educational activities of higher education institutions, a concept has been developed for the development of the educational ecosystem, which is presented as a system of measures aimed at significantly improving the quality of education in the region, increasing the competitiveness of general education, and bringing the region to a leading position in the country in this area of activity.

Each proposed event is based on a practically tested project, which has proved its effectiveness in the research of the University of Minin. The concept is based on the strategic priorities and targets of the national education project, as indicators of the national project and regional requirements are maximally focused on the prospects of education development and inclusion of educational systems in the world educational agenda.

1. Formation of clinical practice bases for future teachers. Creation of a simulator school (Fedorov et al. 2017).
   The formation of clinical practice bases for pedagogical specialties has been started by the university since 2013 to optimize the educational process at the university and strengthen its professionally applied aspect. A system of joint training, support and retention of students in the teacher's profession and in other professions relevant to modern school was developed.
   The project showed good results in terms of faster employment, adaptation of graduates in the workplace, and the formation of changes in schools.
   The university's experience in implementing the project allows us to create a full-fledged training simulator school, implemented on the principle of a training center, and an innovative platform for the formation of the region.
   School — simulator will allow to implement and implement new formats of organization of the educational process, carry out consulting activities and full-fledged tutoring, become an effective tool training of students and methodical support of already working teachers, will provide broadcasting of best practices, improving the skills of the pedagogical staff of the region and the country and turn it into an advanced Russian educational center (Fedorov et al. 2017; Gruzdeva et al. 2018).
2. Modeling of educational space. Inverted class.
   Modernization of the educational process requires significant changes in space, namely, the formation of a new educational ecosystem that meets the technological needs of the educational process and creating a comfortable environment for educator and learners (Jacobs et al. 2014; Markova et al. 2018; Semarkhanova et al. 2018).

3. Development of experimental platforms.
   The system of experimental platforms of Minin University — as one of the elements of the regional socio-pedagogical cluster and the system of organization of scientific and methodical support of experimental activities. It began to form in 2013 and includes experimental sites created by Minin University on the basis of more than 60 educational organizations of the region.
   Minin University, as an innovative element of the cluster, created an institution for measuring and evaluating the quality of education, focused on scientific research in the field of education.
4. Professional pedagogical associations. Development of the expert community. The cluster of Minin University ensures a close interaction with the professional community through professional associations of educators.
   In our opinion, the potential of the educational community is high and can be used in the interests of the region. It is possible to form an expert pool, including the most reputable teachers and heads of educational organizations capable of analytics and expert assessment of educational institutions processes of the region, in order to shape public opinion on various issues (Westley et al. 2015).
5. Regional personnel designer as a tool for self-determination and subsequent support for personal development in the professional sphere.
   Professional self-determination of a person is a complex and currently problematic process for all applicants in the region. Traditional career guidance activities require rethinking, taking into account the need for personal and effective follow-up by specialists of various ages. Environmental turbulence, and new challenges make the career guidance process almost equal in time to the process of professional activity of the individual (Fedorov et al. 2017; Fedorov et al. 2017; Vander et al. 2014).
   We have developed a regional model for managing the professional and life path of future specialists. At the center of the model are the processes of formation and management of the personal professional educational route of the person from the moment of choosing a professional concept to the moment of attaining the status of a mentor, implemented in the context of a strategic plan for the development of the region (Watts et al. 2010; Watts et al. 2009).

The introduction of a model for managing the professional and educational route of future specialists involves the implementation of the following processes:

- development of a diagnostic complex for the professional development of the personality of students in grades 8–9, 10–11;
- development and implementation of IT services in the format “Personnel Designer” and organization based on its testing by focus groups;
- development of the service “Student’s Personal Account” and its integration with the service “Personnel Designer”;
- formation of a personnel office, the main information base of which is information about regional employers and vacancies;
- integration of the HR Designer service with the postgraduate support service;
- launch into operation of integrated service and its support.

6. Calculation of the need for teaching staff. Targeted training. Formation of the pedagogical elite of the region and teams for changes in educational organizations. Minin University has developed a methodology for analyzing the age structures of regional pedagogical communities and for calculating their current need for teaching staff. Simulation of actions in the event of imbalances at different levels is carried out.

At the moment, we understand that the systematic impact on the quality of the regional pedagogical community within the framework of the national project will require inevitable impacts on teachers, thereby ensuring either a change in pedagogical generations or a phased formation of a new staff in the region.

In addition, the project to form the "Change Teams" is an effective way to eliminate the imbalance of teachers and introduce innovations in schools. This form of work with graduates involves their group employment in an educational organization with subsequent organizational and methodological support of activities (Fedorov et al. 2017; Gruzdeva et al. 2018; Ilyashenko et al. 2018; Smirnova et al. 2018).

Analyzing the experience of implementing the above projects in recent years, one can trace the obvious positive dynamics both for each of them and the development of the regional education system as a whole.

When assessing the results on the organization of clinical practice bases and its possible potential. We propose to strengthen its effect by concentrating the best methodological and technical developments on the site of the 10 most effective organizations - the practice bases that ensure the implementation of the scientific and pedagogical process in accordance with the direction and profile of the educational program, the development of students competencies in the course of certain types of work related to future professional activities, as shown in Fig. 1.

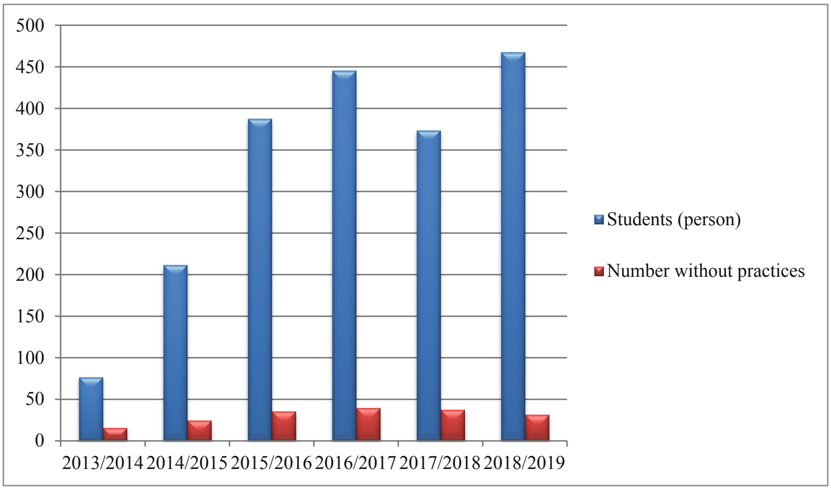

Fig. 1. Dynamics of development of clinical practice bases

The project for the development of the expert community also showed its effectiveness: for the period from 2017 to 2020, 17 associations of teachers of the Nizhny Novgorod region were formed and started their activities in the Nizhny Novgorod region.

The dynamics in the development of experimental sites is also positive: for three years, the University of Minin created them on the basis of more than 60 educational organizations in the region.

In our opinion, the potential of the educational community is high and can be used in the interests of the region. It is possible to form an expert pool, including the most respected teachers and heads of educational organizations, capable of analyzing and expertly evaluating the educational processes in the region, and forming public opinion on various issues.

As a result of the identified global trends in the development of society and the production sector and the developed system of actions for the university development strategy, as a point of concentration of the educational policy of the region, we count on the following effects:

- there will be a solution to the personnel problems of the region through a change in approaches and the mechanism of interaction "university-region" for the training of teachers
- inevitably there will be an update in the teaching staff, the introduction of practice schools, increased mentoring in the profession, the teaching profession will abandon the traditional "inertia" and be able to prepare new personnel for the digital economy;
- there will be a reduction in the term for the introduction of pedagogical innovations in educational practice;
- the quality of teaching activity will significantly change due to the introduction of modern techniques and teaching methods;
- methodical support of the activities of teachers will change, and demonstration of the best educational practices will become a regular aspect of the work;
- formation of a permanent platform for the professional development of teachers on the basis of the university will occur;
- there will be an increase in the level of quality of vocational education, the duration of an active professional life of the region's population, which, in turn, will improve the economic, social and demographic situation in the region;
- conditions will be created for the formation of sustainable professional communities - specialists of a new formation who want to work actively throughout their careers, work in the region, and for the development of the region.

4 Conclusion

Thus, as a result of the measures we proposed, there will be a qualitative change in the educational process at all levels of its implementation, a pedagogical university, being a powerful translator of educational policy and practice, will be able to ensure the mass introduction of advanced educational technologies in the educational process. An individual vocational and educational route will be built for a school student, an entrant, a student and specialist, continuous professional and psychological support for a student, a young and mature specialist ("lifelong education"), and a model for managing the professional and educational route of future specialists, comprehensive support for professional self-determination, professional realization, career growth, personal development and personal success.

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Educational Inequality in Russian Regions: Mathematical Modeling

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Abstract. The regional education system is a complex dynamic system that is in constant interaction with the external environment. The article presents results of a study for conditions for the regional systems development in secondary basic education.

At the first stage, the Russian regions were clustered according to eight indexes. The "Social potential of childhood in Russian regions" database was used as data source, which contains more than 150 control and target factors with description of the mastering educational programs results for primary, secondary basic and secondary complete education, socio-economic, demographic, infrastructural, natural, ecological, and other indicators of 85 subjects in Russia. Also, the database contains summary data of information and analytical reports for the regional information processing centers (RIPC), the regional centers of the education quality assessment (RCEQA), the analytical collections of National Research University for Higher School of Economics.

With using special software product Deductor Studio, all database relevance on the availability of outliers and extreme values were analyzed, as well as the analysis of data quality. After data realization to proper form, a series of the experiments were conducted to obtain more accurate result of the cluster analysis.

As a result of using the EM-clustering algorithm, five clusters were identified. In the description of clusters' profiles, capacity, importance and composition of clusters were determined. The evaluation and the analysis of average values for cluster-forming factors and average values for all 85 regions of the country was conducted.

Keywords: Children · Educational space · Regionalization · Cluster analysis · Educational infrastructure indexes · Regional factors

JEL Code: C31 · C55 · C65 · H75 · I24 · N30

1 Introduction

The evaluation of regional educational environment now occupies not the last part in research of Russian and foreign scientists.

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The relevance of a problem is connected, on the one hand, with globalization and integration processes of the international and European education standards into Russian educational system, and, on the other hand, with the intrastate processes of financial budgetary and extra-budgetary redistribution of funds and the need of maintaining national, cultural and ethnic identity of the regions.

In the researches of Alexander, Colony (1990), Adamsky (2012), Archer (1979), Budon (1974), Gelpi (1987), Coleman (1966, 1968, 1987), Kaluve et al. (1993), Parson (1961) some theoretical and socio-managerial models of regional education and assessment of the educational potential regions.

As can be seen, the process of regionalization is relevant and significant (Rakitina et al. 2018). The most optimal form of the assessment and the analysis of regional environment is using of the clustering method. Many publications are devoted to the clustering process, noting that it is a convenient way of spatial organization and the identification of spatial interactions (Bolshakov et al. 2016). According to the degree of problem elaboration among works on theoretical and methodological foundations for the cluster approach, for instance, in professional education, special attention the works of Russian researchers: Kutsenko (2009, 2010), Mateeva (2009), Proskurina (2012).

The team of the Institute of Education of Higher School of Economics conducted a research in the evaluation of the educational infrastructure state for subjects of Russia. On the basis of the contextual data, all subjects of Russia were divided into relevant groups, within which the comparison takes place.

The availability of high-quality infrastructure is seen as a basic condition for the effective functioning of the education system. The quality index of the educational infrastructure is calculated as the average value of normalized indexes and it is described totality of material conditions for the educational process implementation (The collection, 2019). We use components of given index as input values for clustering Russian regions.

The purpose of given research is clustering of Russian regions for subsequent modeling of conditions in development of regional systems of secondary basic education.

2 Materials and Methods

The research of statistical data from regions of Russia made it possible to form "Social potential of childhood in the Russian regions" database, consisting of 143 control factors (x), as well as 15 target factors (y), characterizing the effectiveness of secondary basic education. The quantitative filling of factors was conducted by referring to sources of the statistical information for 2017 in 85 subjects of Russia. The statistical data for research were taken from "Regions of Russia" collections, the showcases of statistical data, as well as information and the analytical reports of regional information processing centers (RIPC), the regional centers of the education quality assessment (RCEQA), collection of National Research University for Higher School of Economics "Index of the educational infrastructure in Russian regions" (Showcase of statistical data 2018; Regions of Russia 2017; Filipova, Vysotskaya 2018).

For calculations and visualization of results, the Deductor Studio program was used (Chechurin et al. 2018).

3 The Research Results and Discussion

For clustering 8 indicators were selected, which in the database have its own address, indexed Y or x: Y9 – as quality index of preschool education; Y10 – as quality index of secondary basic education; Y11 – as quality index of the additional education; Y12 – as quality index of secondary-special education; x10 – as population density, persons/km2; x17 – as the ratio of GRP per capita to the cost of a fixed set of consumer goods and services, units; x18 – as share of the expenditures on education in the consolidated budgets of subjects in the Russian Federation and territorial state extra-budgetary funds, %; x19 – as the ratio of state debt for subject to the income of the consolidated budget for subject and territorial state non-budgetary funds, %.

These factors give a general idea of the socio-economic state for region and the importance of regional educational space that is expressed through development indexes of the educational infrastructure and financial activity for the educational system of regions (Filipova, Vysotskaya 2018).

In the process of results analyzing in splitting into groups according to criteria such as comparison matrix, scatter diagram, cluster profiles, etc., EM-clustering algorithm (Analyst Guide Deductor 2019). The initial clustering parameters were defined: splitting original dataset into subsets - randomly; lower likelihood threshold is 0.2; the required level of model accuracy is 10–5; maximum number of iterations is 300; a fixed number of clusters - five (Filipova et al. 2017). The Russian regions were divided into five clusters.

As a result of EM-clustering algorithm applying, we will compose Table, characterizing cluster profiles by the following indexes: Capacity is a number of data set records, included in the cluster; Share - proportion of regions number in the cluster in total of subjects in Russia, %;

Relevance - is degree of the influence for given field on formation of particular cluster (determined by Fisher's F-criterion), %. The results are shown in Table 1.

Table 1. Cluster profiles

Cluster number	0	1	2	3	4
Capacity	22	21	11	18	13
Share	25.9	24.7	12.9	21.2	15.3
Relevance Y9	100	61.7	20.4	95.2	100
Relevance Y10	93.8	99.9	71.3	82.4	100
Relevance Y11	90.8	100	92.5	97.9	98.9
Relevance Y12	49.6	100	92.9	97.2	54.4
Relevance x10	88.5	32.1	99.5	71.3	7.7
Relevance x17	95.2	91.4	18.8	55.4	99.9
Relevance x18	96.2	99.1	7.1	98.7	100
Relevance x19	98.8	52.1	31.4	3.1	99.6

Source: developed and compiled by the authors

As can be seen from Table 1, the first cluster includes 21 regions that is 24.7% of total number for all regions in country. The formation of the second cluster composition was most strongly influenced by factors Y11 and Y12 (100%). The relevance of factors Y10 - (99.9%) and x18 (99.1%), x10 (32.1).

The second cluster is the smallest and it includes only 11 subjects. The determination of groups for regions with similar characteristics and relations is based on factors x10 (99.5%), Y12 (92.9%), Y11 (92.5%), x18 (7.1%).

The third cluster includes 18 regions. In the analyzing degree of factors influence on formation of the third cluster, it can be seen that there are no factors having significance of 100%, but four factors have rather high values of 98.7; 97.9; 97.2 and 95.2%, which corresponds to factors x18; Y11; Y12 and Y9.

The fourth cluster includes 13 regions. This cluster has three determining factors at once that are relevant 100%: Y9; Y10 and x18. Factor x17 has very strong impact on formation of cluster 4 (99.9%). In general, all cluster-forming ones showed high values of the influence, except for factor x10 - as population density, persons/km^2 (7.7%).

The assessment of the average values for cluster-forming factors is presented in Table 2.

Table 2. Comparison of average values for factors in the clusters

Cluster	Factor							
	Y9	Y10	Y11	Y12	x10	x17	x18	x19
0	0.42	0.42	0.45	0.53	19.46	21.22	22.03	42.10
1	0.46	0.39	0.41	0.43	33.72	33.08	25.84	27.44
2	0.47	0.47	0.52	0.56	54.43	27.32	23.72	32.77
3	0.52	0.47	0.52	0.56	22.00	28.62	25.73	30.30
4	0.58	0.56	0.56	0.55	347.49	57.98	18.52	14.61
The average value in the Russian Federation	0.48	0.45	0.48	0.52	78.22	32.13	23.44	30.57

Source: developed and compiled by the authors

Next, it will be conducted a comparative analysis of the average value for cluster-forming factors and the average value for 85 regions of Russia.

As can be seen from Table 2, zero cluster is characterized by the lowest average values of the indexes Y9 (quality index of preschool education), x10 (Population density), x17 (Ratio of per capita GRP to cost of fixed set of consumer goods and services) and x18 (share of the expenditures on education in the consolidated budgets for subjects of Russia and territorial state extra-budgetary funds). Most of given factors have the highest importance in the composition cluster determining. In the consideration of values for the educational infrastructure indices, it can be seen that factors Y9−Y11 are lower than the average all-Russian values. The exception is factor Y12 (quality index of secondary-special education) that has value above the national average. In the comparison of given information with other socio-economic indexes, it can be concluded that regions of cluster 0 are regions with low level of the economic well-being and the educational infrastructure development, belong to the subsidized regions.

All indicators of the first cluster for the educational space assessing have values below the average for the country. These are regions with poorly developed infrastructure of the additional and secondary specialized education (it has an insufficient material and technical base, low rates of digitalization of the educational processes, etc.), while it is worth noting that share values of the expenditures on education in the regional budgets are the largest around the country.

The second cluster is regions "average" in terms of socio-economic development. At the same time, the indexes for the educational infrastructure assessing are higher than the average Russian values, except for value of Y9 indicator (quality index of preschool education). It is also worth noting that the cluster average of Y12 indicator (quality index of secondary-special education) in the first and second clusters (0.56) is much higher than the national average (0.52), that indicates the uneven development of the educational space in the regions.

The values of the third cluster indicators are inferior only to the average indicators of the fourth cluster. In the comparison of the indexes for the educational environment, we see that all factors have values above the average Russian level. The regions of such cluster can be classified as one of the most optimal regions of Russia from the educational and infrastructural point of view.

The fourth cluster is the most successful, rich, and developed. In the consideration of the regional cluster, we see that performance of the actors such as Moscow, Moscow oblast and Saint-Petersburg had significant impact on exceed the national average values for cluster-forming factors.

Next, move on to mathematical modeling of such task factors as:

Y3 - as the Average unified state exam score for 2017/2018 academic year;
Y7 – is the average score for Unified State Exam in 2017/2018 academic year;
Y14 - is a number of diplomas for final of All-Russian Olympiads.

Each cluster was built regression equations for the identified factors. The equations themselves, indicate influencing factors and values of the determination ratio are presented in Tables 3, 4, 5, 6, 7 and 8.

Table 3. The equations Y3, Y7 и Y14 in cluster 0

The objective factor	R2	Equation
Y3	0.8272	70.5476–0.1289*x19–0.0639*x35–0.0004304*x48– −0.0017*x105 + 0.002*x132
Y7	0.8177	4.209–0,0239*x60–0.00001924*x62 + 0.00002256*x124 + 0.00003556* 136
Y14	0.8521	109.3865–1.1552*x30 + 0.0116*x44 + 2.1421*x50 + 0.0048*x54

Source: developed and compiled by the authors

The regression equation, presented in Table 3, shows the same strong dependence between target and control factors. For instance, value of factor Y3 depends on factors such as the ratio of state debt for subject to revenues of the consolidated budget in the region, the ratio of children amount, rested in camps among the enrolled children, distance from Moscow to centers of the regions, number of students in need of transportation to the organization in 1−4 classes, the average number of the educational support personnel. It should be noted that factor x48 (Distance from Moscow to the centers of the regions by highway), is considered as not regulated, but significant one.

Table 4. The equations Y3, Y7 и Y14 in cluster 1

The objective factor	R2	Equation
Y3	0.7703	29.3187 + 0.1509* x13 + 0.0276* x47
Y7	0.8002	4.7708 – 0.0747* x4 – 0.012* x36
Y14	0.9364	3.45 – 0.1463* x41 + 0.3607* x114 – 0.0002704* x129 + 0.00028* x138

Source: developed and compiled by the authors

From Table 4 it can be seen that mathematical model of resulting factors contains the smallest number of control factors. Also, it is observed that the equations differ in the strength of link.

Table 5. The equations Y3, Y7 and Y14 in cluster 2

The objective factor	R2	Equation
Y3	0.9963	40.5048 + 1.2467* x20 −0.5482* x42 – 0.0714* x117 + 0.0001968* x132
Y7	0.8694	3.6764 + 0.0007614* x77 + 0.0004054* x131
Y14	0.9994	88.847 + 0.7201* x1 + 5.5976* x11 + 0.0361* x23 + 0.008* x24 – 0.759* x40

Source: developed and compiled by the authors

The equations, presented in Table 5, demonstrate regional characteristics in terms of composition for governing factors. In particular, such factors as x20 (population under working age), x42 (salary ratio of medical workers to the average salary for region) and x117 (number of the educational institutions with part-time classes and distance learning) have significant impact on target indicator Y3 (Average Unified State Exam score for 2017/2018 academic year). Thus, we fix that factors of social infrastructure have significant impact on the considered indexes.

Table 6. The equations Y3, Y7 и Y14 in cluster 3

The objective factor	R2	Equation
Y3	0.0002666	58.5143 – 0.0205* x1
Y7	0.751	3.3079 – 0.0238* x17 + 0.0584* x50 + 0.0686* x58
Y14	0.9959	−13.5608 + 0.7152* x 10 + 1.6445* x 11 + 0.00003075* x 49 −0.0377* x 52 – 15.591* x 61 + 0.0924* x 102 + 0.0123* x 132 + 0.0015* x 133

Source: developed and compiled by the authors

The results of mathematical modeling in the average USE score for 2017/2018 academic year are intended to be unsatisfactory, since the ratio of determination is 0.0002666. This value can be explained by significant heterogeneity of the cluster composition.

Table 7. The equations Y3, Y7 и Y14 in cluster 4

The objective factor	R2	Equation
Y3	0.9999	53.5918 – 0.0212* x39 – 0.0049*x88–0.0004524*x106–0.2371*x114 + 0.0083* x125 + 0.00004491* x140
Y7	0.8109	4.1881 – 0.08* x21
Y14	0.9985	54.7575 – 0.5893* x40 + 0.0082* x55 + 0.4294* x66 – 0.0001279*x136

Source: developed and compiled by the authors

The equations of modeling results for cluster 4 is to be expected to have a high ratio of determination that indicates its high reliability and uniformity of the clusters composition.

Thus, results of mathematical modeling indicate significant influence of regional characteristics on target factors. The set of factors, included in regression equations for each cluster, is unique.

At the same time, there are several factors, the influence of which extends simultaneously into several clusters, such factors include: x132 (the average number of training and support staff), x1 (the rate of natural population growth), x4 (the staffing of medical positions in units, providing medical outpatient care), x50 (the innovative activity of the industrial organizations).

Table 8. The identification of control factors

x1	Bias index for CDF of the Russian language in grade 4
x4	Bias index for CDF of the mathematics in grade 5
x10	Population density, persons/km2
x11	Natural population growth rate, %
x13	The proportion of students in the urban schools; total number of students at schools, %
x17	The ratio of GRP per capita to the cost of fixed set for consumer goods and services, units
x19	The ratio of the state debt for subject to the income of the consolidated budget for subject and territorial state non-budgetary funds, %
x20	Population under working age in 2017
x21	The share of students at the beginning of school year in children's music, art, choreographic and art schools of the Russian Ministry of Culture of total population for young working age, %
x23	The average number of members in club formations per 1,000 persons of population, persons
x24	The number of theater spectators and the number of visits to museums per 1000 population, persons
x35	The ratio of children, rested in health camps to the number of school children in total
x36	The number of children who died in the first year of life by main categories of death causes per 10,000 live births per year
x39	The number of doctors per 10 thousand persons of population
x40	Staffing of medical positions in units providing medical care on an outpatient basis
x41	Provision with doctors per 10 thousand persons
x42	The ratio of salary for medical workers to the average salary of the region, times
x47	The ratio of marriages and divorces
x48	Distances from Moscow to regional centers along highway, km
x49	GRP per capita
x50	The innovative activity of the industrial production organizations
x52	Air pollutants from stationary sources, tons/person
x55	Fresh water use, m3/person
x58	Population with cash incomes below subsistence minimum, in percentage of total population
x61	The ratio of private institutions for all educational organizations, %
x66	Electronic terminals
x77	Special software for solving organizational, managerial and economic tasks

(*continued*)

Table 8. (*continued*)

x1	Bias index for CDF of the Russian language in grade 4
x88	The application of e-learning in secondary general education
x102	The presence of scanner in the library
x105	The number of students in need of transportation to the organization and (or) back to grades 1–4
x106	The number of students in need of transportation to the organization and (or) back to grades 5–9
x114	Number of the educational institutions serving as boarding schools
x117	The number of educational institutions having part-time classes and distance learning
x125	Number of students in preparatory classes, persons
x129	The average number of teaching staff, persons
x131	The average number of teachers for the additional education, persons
x132	The average number of training and support staff, persons
x133	The average number of other staff, persons
x136	The expenses of the educational institutions for other payments, thousand rubles
x138	The expenses of the educational institutions for communication services, thousand rubles
x140	The expenses of the educational institutions for utilities, thousand rubles

Source: developed and compiled by the authors

4 Conclusion

The study was divided into five cluster groups by level of the educational infrastructure development, socio-demographic and economic indexes. The clustering regions makes it possible to model conditions for the educational environment development, for instance, coordination and examination of the activities in the educational institutions, the effective methods for selection and assessment of the educational innovations for wide distribution, advanced training and exchange of experience, etc.

For different types of the regional environments, its own regression equations were built that describe the influence of control factors on target indexes.

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Human Capital as a Driver for Improved Performance of the Innovations-Intensive Construction Cluster

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Abstract. Purpose: This paper aims at revisiting the role of the human capital training in the construction industry growth and development. Authors suggest key professional, as well as cognitive and emotional skills that could become game changers for education of civil engineers.

Design/Methodology/Approach: The manuscript is a review that provides economical background of the current state of the construction industry domain, advocating the crucial input of the human capital development in Russian Federation. The problem is scrutinized in the framework of the regional construction cluster activity, emphasizing the role of transferable skills and mental health for cluster's actors. The corresponding analysis is performed in the view of the Strategy-2030 implementation. This plan is elaborated through the Ministry of Construction Industry, Housing, and Utilities Sector. The authors argue that strategy sets goals, the necessity of achieving which will inevitably lead to the unfolding of human capital program in Russia.

Findings: Based on the data of cognitive neuroscience authors provide the list of critical areas of personal development that engineers and other professionals of the field should be able to cultivate in the coming decade. The intertwining of the scientific, business and educational domains is also carefully considered for this training process.

Originality/Value: This manuscript is the first document in Russian Federation exhibiting the road map for construction industry's human capital development. The paper may serve as the basis for the transformation of the educational process into a human capital – friendly one and may open the opportunity to boost the corresponding economic sectors.

Keywords: Human capital development · Construction cluster · Digital economy · Cognitive neuroscience

JEL Code: E24 · I3 · J24 · Q5

1 Introduction

Construction industry plays a significant role in economic and social life of Russian Federation (Tutarishev, Popov Tutarishev and Popov, 2015; Gumba, Karpenko, Shumeiko

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2019). During the years of 2019–2020 construction sector as well as the economy in general experiences temporary recession. (Ministry of Economic Development of Russian Federation 2019). This negative dynamics incentifies stakeholders to actively search for novel governance approaches beyond commonly used ones, e.g. Megaprojects implementation (Government of Russia 2020) or mortgage lending fostering (Garipova 2014). In this respect, more and more attention at different levels of public and private administration is drawn to the *human capital* (HC) factor. Global data demonstrates that investments in HC lead to the productivity boost and overall economic growth. There is a widespread consensus that the value of HC asset is extremely high and its estimate in Russia alone reaches tens of trillions of US dollars (Kapeliushnikov 2012). At the same time, human capital development in Russian Federation so far has been of unsystematic nature, sporadically occurring in schools, universities or sometimes as an employer initiative. It could be stated that there is a hidden management resource with potentially high economic outcome in Russia. In this manuscript, we scrutinize the role of HC unfolding for augmenting production and management efficacy of a regional construction cluster. Cluster system is characterized by a deep integration between multidisciplinary organizations and social institutions.

2 Materials and Method

Human capital along with physical capital is one of the key factors of production. HC could be simply defined as a set of skills, knowledge and competencies (including good mental health or emotional intelligence for instance), which workforce possesses and investments in which create economic profit (United Nations Economic Commission for Europe 2016; Aganbegyan 2017). The last few decades have been marked by the persistent scientific investigations and corresponding progress in HC cultivation. The importance of these efforts has been proven by a number of Nobel prizes received by researches of this field. The last award was granted just recently to the Paul Romer (2018), the co-author of innovations-based theory of economic development. The key element of this approach is investments in education, human capital and knowledge (Romer 1994).

One of the popular estimates of HC value is performed based on Jorgenson-Fraumeni method. According to (Kapeliushnikov 2012) the level of per capita HC in Russia in 2010 was equal to 200,000 USD roughly (5.1 times increase to 2002's level). In the framework of this analysis gross domestic product exhibited pronounced growth as well and reached 10,000 USD in 2010 (4.2 times increase during the analogous period). However comparison of Russian (2010) and US (2006) data shows that domestic HC level was 3 times less than American (GDP is 9 times lower for the same years). Using the alternative estimate by the World Bank presented in (Lange, Wodon, Carey 2018) per capita HC value in Russia is even less optimistic: it is 5 times lower than the average value for OECD countries. There is a broad public discussion on the reasons of the observed lag and human capital issues (e.g. low labor productivity) are at the frontline of this debate.

World Bank's analysis (Lange, Wodon, Carey 2018) additionally reveals that HC's share constitutes just 46% of national net wealth in Russian Federation, which is significantly lower than in OECD countries, where it is estimated at the level of 70% roughly (Table 1). This analysis underlies that despite vast natural resources possessed by Russia there is a growing gap between market's demand for modernly skilled workforce and the structure of national net wealth. According to (Aganbegyan, Kleeva, Krotova 2018) in current circumstances, HC development is indeed the keystone of sustainable socio-economic development and establishment of knowledge economy in Russia. However, as it was laid out before, the country still has not unfolded a large-scale HC program. It is worth mentioning though that leaders in some sectors are already taking consolidated steps towards training their teams using state of the art methods. For instance, Russian financial giant Sberbank is consistently investing in their employees at different levels. Learning from the best world practices, the bank established its own University and hired internationally-renown experts. These initiatives lead not only to clearing the backlog in productivity, but moreover bring this organization to a position of an international innovative leader in some of the practices (Sberbank 2019).

Table 1. The structure of national net wealth. World Bank data (Lange, Wodon, Carey 2018)

Nation's assets	Russian Federation	OECR countries (averaged)
Human capital	46%	70%
Physical capital and technology	33%	28%
Natural resources and misc	21%	2%

3 Results

Construction is one of the Russian economy's strategic sectors. In the course of the last decade this industry consistently occupies 5–7% in the GDPs composition (if accounted for housing and utilities sector the total share reaches as much as 14%). The sector also demonstrates stable growth of market participants' number: roughly 80,000 construction-related organizations and 2 million people were registered as of 2017 (Federal Department of Statistics 2018). At the same time, the industry's key objective is still the same as in the XX century - the provision of quality housing (President Administration of Russian Federation 2020). The lion's share of housing stock in Russia is critically worn down, and living conditions often do not match modern requirements (Bogomolova, Kozlovski, Moiseenko 2018). For instance housing quality indicator measured in square meters per person is still lower than in most of the European countries (Минстрой РФ, 2018). Concurrently with solving this issue the framework of National Priority Projects requires construction of large-scale infrastructure objects, including those built in tight cooperation with other countries (infrastructural elements of new silk road "Belt and Road Initiative一带一路" for instance). Finally, construction and installation of social objects and facilities of utilities sector is also of high importance and receives serious attention from the State.

To achieve these and other primary goals the Ministry of Construction Industry of Russian Federation has kindled the implementation of the “Strategy-2030”. In essence, it is a large-scale plan of industry’s innovative development for the next ten years (Ministry of Construction Industry of Russian Federation 2018). Main routes of this strategy could be boiled down to the following: 1) innovations-based retooling of the industry; 2) development of human resources capacity in construction science, education, and technology; 3) integration of Russia into global processes of innovations’ generation and their corresponding applications. The expected outcomes of the plan execution include but are not limited to: 1) implementation of digital predictive (mathematical and computational) modeling and energetically efficient sustainable technologies, that should help to optimize construction estimated costs and operation costs; 2) attraction of up to one million of new workers that possess knowledge and skills adequate for Strategy’s objectives. Nowdays “Strategy-2030” becomes widely accepted as the key indicator and benchmark of Russian construction industry’s development for years to come. Thus, it is reasonable to scrutinize the role of HC development through the prism of Strategy’s roadmap as well.

One of the most promising approaches to reach stated objectives is the development of regional construction clusters (Ramazanova and Borisova 2016). Modern construction cluster is a robust value chain, which encompasses an alliance of organizations including educational institutes and is knowledge-intensive in its essence. Due to geographical linkages and vibrant interdisciplinary environment cluster is positioned to efficiently source innovations using human capital. For instance at all stages of construction process consolidation of design, educational, building and public enterprises is intended to increase productivity, improve building rates, decrease costs, while improving safety and sustainability at the same time.

In the Table 2, the set of competencies that are relevant for Strategy-2030’s implementation from the education of civil engineers standpoint is presented. These professionals are the key actors in multidisciplinary construction streamline. They act as a connecting hub between all other members of the cluster and thus special attention is attracted to their multidisciplinary training and education. We provide the intricate analysis of their main skills and competencies right below.

First, according to the Russian market demand, the field in the next decade will truly benefit from recruiting engineers with managerial decision-making skills. This is urgent not only in relation to well-planned construction of objects, buildings and complexes, but in regards to ability to assess natural and historical environment impacts as well (Galkina and Grinkrug 2020). Such skills are further reinforced if accompanied by the training in building legislation and law-related aspects of housing and public utilities sectors. It is vital for cluster’s members to understand potential ramifications and challenges related to inadequate legal framework in Russia and they should be ready to participate in development of novel efficient regulations of urban development if needed. In this respect familiarity with engineering infrastructure’s wear and tear and training on correct accounting of decay (at all stages of buildings life cycle) are crucial as well; issues of conservation and regeneration of cities’ heritage will get more and more often on agenda in the coming years. Engineers should be prepared to create attractive architectural solutions, which sit unobtrusively and do not disturb the existing landscape and infrastructure. It is substantial for them to execute preservation of cultural and historical urban areas without raising project costs. Considering the tight state's budget, it is only possible by the virtue of creativity, non-standardized thinking, and good managerial decision-making.

Along these lines, the second group of skills, namely related to communication, could be deciphered. Emerging integration in global innovations processes is not feasible without comprehension of foreign cultures and languages by Russian students. As of today, most international conferences and forums are held in English- and Sino-speaking environment. Those young professionals and companies' representatives who are prepared to participate in informal off-stage talks and meetings (where most of the deals are sealed) get the best outcomes from such mass events and consequently develop their enterprise more.

The third array of skills has to do with novelties of digital era. Marketing for example, is one of the domains where IT-driven changes are obvious and profound. Russian market of PR, SMM, and internet advertisement goes through the stage of active growth and becomes visible in construction. In this area, the common inputs from engineers of the future will probably encompass the principles of end-product promotion, brand building, and the end-user orientation. The other key competency of civil engineer lies in modern high-tech IT solutions domain (e.g. 3D modeling). Rapid shift in development and functioning of online platforms, mobile apps, and databases encourages employers to consider the corresponding knowledge as a competitive advantage and invest in it more. The proliferation of high-tech approaches ultimately taps into education process as well. In Russian Federation transition to online forms of study kindled by 2020 pandemics and shaped by the state driven digitalization (Amosov and Baena 2019) is all-pervasive now and will more and more be in the focus of the corresponding agencies and entities.

In such hyper-digitalized world, where the amount of new information and technologies' sophistication is exponentially rising, a wide range of new era's soft skills come into play. Most of these transferrable competencies have to do with cognitive and emotional aspects of psyche. Sustainable impact of this competencies' training allows inclusive growth in many domains and should be reflected in civil engineers' preparation as well. The other disrupting factor decreasing the productivity in construction clusters is emotions-related threats, e.g. various forms of stress. It is well-known, that stress-management and emotional intelligence are key aspects of resilient psyche. The ability to govern work-life balance is especially important from the minimizing health care cost point of view. Data from developed countries demonstrates that costs associated with mental health for instance (stress, emotional burning out, sick leave etc.) may reach altogether up to 5% of GDP, thus stretching to the level of construction industry itself (OECD/EU, 2018).

Table 2. Short list of civil engineer's key competencies that are relevant within the Strategy-2030 framework

Type of competency	Skill	Goals of the "Strategy-2030"
Communication -related	Ability to work in the interdisciplinary team of cluster Mentoring Ability to work with international colleagues, understanding cultural peculiarities Networking	Increase cluster productivity Preparation of well-trained professional for industry Integration in the global innovative processes Efficient interaction within cluster
Self-organization	Ability to search and analyze large volumes of new data	Increase cluster productivity
Creativity	Creative non-standardized thinking	Save and comfortable environment
Self-reflection	Emotional intelligence Resilience and stress-management	Increase cluster productivity, decrease health-care costs
Job related	Linguistic skills (English and Chinese are in priority) Marketing basics Knowledge of building legislation Mathematics and programming skills (incl. Development of mobile apps and 3D modelling) The knowledge principles of digital economy	Integration in the global innovative processes Increase cluster productivity Efficient interaction within cluster

4 Conclusion

The Strategy-2030's objectives require innovative and at the same time reliable solutions that allow for mitigation of unnecessary risks. One of the overarching approaches proved to be efficient for economy growth worldwide in this respect is human capital development implementation. In the previous sections, we have scrutinized its possible implications for the buildout of regional construction cluster, but the outcomes of this approach could be far more profound. Building industry is tightly interdependent with other sectors of economy, such as health care and education; thereby it possesses the opportunity to become the "locomotive" for these sectors development as well. Infrastructural renovation, erection of high-tech schools and hospitals give serious boost to corresponding domains and in the long-run return as a positive feedback loop in the form of healthier and better-educated professionals for construction industry itself (Tikhonovich 2012). The efficacious results of HC developing program in such crucial sector of economy as construction will inevitably establish the credibility and may lead to the transfer of this approach to other sectors. The process can have a cumulative effect and become the driver of economics growth on the national level. Considering the peculiarities of current socio-economic situation in Russia, such success could not only dramatically rebalance the structure of national wealth, but may also reduce the dependence of quality of life on natural resources prices and other volatile factors.

Finally, it is not possible to discuss such crucial economic transformations without touching upon the instruments for anticipated human potential development. Since the end of 90's one of the key roles in creation of such tools is orchestrated by the cognitive neuroscience (Londhe, 2018; Berridge and Kringelbach 2011). The understanding of human brain functioning principles that are investigated in this field consistently helps to determine key behavioral and cognitive determinants that are solid prerequisites for HC development. Training of emotional awareness, resilience, memory aspects, as well as the development of attentional and other networks appear to be the base for transferable skills cultivation, which already proved its efficiency in productivity increase (Wilson, Briscoe 2004). As a result of this evidence-based research, well-being and mental health are now under close attention of super-players who corner the global market of innovations (Lehmann, Schenkenhofer, Wirsching 2019) – such as Google, Apple, Amazon or Sberbank and lead to foundation of local science-intensive companies, e.g. Neuro trans-skills Center (Dzyuba 2016). We believe that such timely partnership of science, business and industrial clusters will be one of the pillars for sustainable economy growth and will lead to the quality of life rise in Russian Federation as well as worldwide for decades to come.

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Key Competencies in Pedagogical Activities

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Abstract. Purpose: to conduct a comparative analysis and correlation of the key (universal) competencies and character qualities of the international version specialist with the Federal State Educational Standard of Higher Education of Russia (using the example of pedagogical directions of training), as well as identify the opinions of students and teachers on the expression of these competencies at home and their significance for pedagogical activities.

Design/Methodology/Approach: International and domestic studies of the issue show the use of systemic and comparative approaches to justify the development of key competencies in the practice of different countries. This revealed the set of "4K" and character qualities necessary for the successful implementation of the specialist. The authors complement the study with ideas of a competent approach for higher education.

Results: Competency groups have been identified that are most relevant and provide basic training in "4K" recruitment and character qualities. The most popular competence from the set "4K" and similarly - character qualities are determined. Expressed and significant competency groups in students and teachers are shown.

Originality/value: The results of the study can form the basis for the development of a personalized learning model, as a response to the challenge of receiving education in the form and scope that each student needs personally, and which will correspond to his understanding of the importance of key competencies.

Keywords: Key competencies · Universal competencies · "4K" - competencies · Students · Teachers

JEL Code: I23 · J24

1 Introduction

The issue of key competencies is extremely important and we are actively discussing today in the pedagogical community. In 2005, under the auspices of the Organization for Economic Cooperation and Development (OECD), the implementation of the international integrated program "Definition and selection of competencies: theoretical and conceptual foundations – DeSeCo" was initiated. In 2015, the project "Joint Problem

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Solving", which includes 4K, was among the most significant studies of the quality of education at the international level "PISA".

The well-known history of the issue began with the report "New Vision of Education" at the World Forum in Davos in 2016, which outlined the necessary educational results: basic literacy, competencies and qualities of the character of modern man (Fadel et al. 2018, World Economic Forum 2016, Marope, etc. 2019). In the Russian version, the most famous competencies are the 4K set: communication, collaboration, creativity and critical thinking. 4K" - a holistic group, the elements of which differ from other competencies of the 21st century in that they are implemented on any subject material and are a complex manifestation of the cognitive and personal characteristics of a person observed in behavior.

2 Materials and Method

The research is based on a systemic one that provides the study of an object as a system, including the development of systems research methods (Averyanov 1985; Afanasyev 1980; Blauberg 1973; Leontiev 1977; Mishchenko 1997; Yudin, 1997 etc.) and comparative approaches. In a comparative approach, based on the isolation of three types of studies (descriptive, analytical, generalizing), Wulfson (1996) identifies the problem of the ratio of general, special and single as the leading methodological problem of research in education. Analysis of studies by comparative educators (Wulfson 1996; Kolobova et al. 1999) in the field of education made it possible to state the implementation of research by domestic scientists in the line of humanism. The concepts of competency in education are based on theoretical developments (Elkonin 2002; Kogan 2003; Tomilin 2003; Frumin 2003; Bolotov 2005; Laptev 2005; Serikov 2005, etc.), devoted to the formation of experience in solving life problems in the aspect of the manifestation of competencies, the fulfillment of social roles.

Methods of analysis, concretization, generalization, questionnaire, ranking, mathematical statistics were used.

3 Results

In Russia, the studies of the Higher School of Economics in the form of the project "Program for the Development of Skills of the 21st Century" that are supported by Sberbank through the Contribution to the Future Fund deserve attention. This program includes several subprojects. One of them is the 4K of the modern world. The project includes the creation of lesson projects in primary and basic schools, implementing technologies for the development of competencies "4K" and methods of formative assessment for the teacher (Pinskaya and Mikhailova 2019). Other options for gaining experience in the development of "4K" include the following: the author's project "4Brain.ru," the online school "Foxward," the Small Academy of Sciences "Intelligence of the Future" in Obninsk.

In April 2020, the next collaborative report of several universities in the world edited by the HSE "Universal Competencies and New Literacy: From Slogans to Reality" was presented at the International Moscow Salon of Education (Dobryakova et al. 2020). In addition to a comparative analysis of the introduction of models for the development of 21st century competencies in different countries, it seems interesting to distinguish labor functions from the Professional Standard of the Teacher, which belong to universal ones. Examples of educational practices for the school are given. The conclusion makes an important conclusion: a revision of the principles of teacher training is necessary. "To learn the skills of the 21st century, you need to have a teacher of the 21st century," this phrase has become an axiom.

However, the report provides an example of general cultural competencies as important educational results of future teachers from the Federal State Educational Standard for Higher Education (FSES HE) 2015. Although preparations are already underway for the new FSES HE as revised in 2018. Universal ones have been identified and correlated in relation to the primary level of education (key) competencies with metapedmet educational results of the Federal State Educational Standard for Primary General Education (FSES PGE).

We define the investigated phenomena as universal competencies (UC) (Federal Educational Standard of Higher Education, 2018), although we can talk synonymously about key competencies or key skills:… "are there significant differences in the use of different terms to denote" 21st century skills ": key competencies," soft "/" flexible "skills, universal actions, etc. Our answer is no "(Frumin et al. 2018, Korpachyova et al. 2020).

We believe that the correlation of these factors can be presented in this way (Table 1).

Table 1. Ratio of Federal Educational Standard of Higher Education universal competencies, 4K competencies and character qualities

Category of universal competencies	Code and name of universal competence at the undergraduate level	Code and name of universal competence at the magistracy level	4K - competencies	Qualities of character
1. System and critical thinking	UC-1. Capable of searching, critical analysis and synthesis of information, using a systematic approach to solve tasks	UC-1. Able to perform critical analysis of problem situations based on a systemic approach, develop an action strategy	Critical thinking, creativity	Curiosity, initiative

(*continued*)

Table 1. (*continued*)

Category of universal competencies	Code and name of universal competence at the undergraduate level	Code and name of universal competence at the magistracy level	4К - competencies	Qualities of character
2. Development and implementation of projects	UC-2. Able to determine the range of tasks within the set goal and choose the best ways to solve them, based on the existing legal norms of available resources and restrictions	UC-2. Able to manage the project at all stages of its life cycle	**Critical thinking, creativity, cooperation, communication**	**Curiosity, initiative, leadership, social and cultural awareness**
3.Teamwork and Leadership	UC-3. Able to carry out social interaction and realize his role in the team	UC-3. Able to organize and lead the work of the team, developing a team strategy to achieve the goal	**Critical thinking, creativity, cooperation, communication**	**Initiative, leadership, adaptability, social and cultural awareness**
4. Communication	UC-4 Capable of carrying out business communication in oral and written form in the state language of the Russian Federation and foreign language (s)	UC-4 Able to use modern communication technologies, including in foreign language (s), for academic and professional interaction	Critical thinking, communication	Social and cultural awareness, adaptability
5. Intercultural interaction	UC-5. Able to perceive the intercultural diversity of society in a socio-historical, ethical and philosophical context	UC-5. Able to analyse and take into account the diversity of cultural interaction in the process of intercultural interaction	Critical thinking, cooperation, communication	Social and cultural awareness, adaptability

(*continued*)

Table 1. (*continued*)

Category of universal competencies	Code and name of universal competence at the undergraduate level	Code and name of universal competence at the magistracy level	4К - competencies	Qualities of character
6. Self-organization and self-development (including health)	UC-6. Able to manage his time, build and implement the trajectory of self-development based on the principles of education throughout life	UC-6. Able to identify and implement priorities of own activities and ways to improve them on the basis of self-evaluation	Critical thinking, creativity,	Curiosity, perseverance, leadership
7. Health and safety	UC-7. Able to maintain the proper level of physical fitness to ensure full social and professional activity		**Critical thinking, creativity, cooperation, communication**	Perseverance, adaptability

Critical thinking. It is necessary for any activity, as it is the ability to objectively and comprehensively evaluate any information and decision-making based on the analysis of alternatives.

Creativity. According to D. Halpern (2000), critical thinking is creative thinking, and we agree with it (Savina, Kotlyarova 2020). Creativity as an ability to find fundamentally new approaches to solving problems is extremely necessary for project activities, since a project by definition always provides a unique product.

Communication. It is an ability to communicate with different categories of people at the verbal and non-verbal level. It is necessary in those categories of universal competencies where communication with other people is contemplated.

Cooperation. This is the ability to interact effectively with others to solve a variety of tasks, including projects. This includes the ability to seek help, accept someone else's opinion, integrate their part of the work into the common cause, etc. (Adnan 2015).

The most controversial here seems to us is the question of the relationship of character qualities with the Criminal Code. The report highlighted six such qualities of character: *curiosity, initiative, perseverance, adaptability, leadership, social and cultural awareness*. It is not clear why the latter refers to character qualities, but in this article we did not aim to carry out a terminological analysis of concepts.

1. *Curiosity* (love of knowledge) - the desire to know the new, keen interest, openness to the new, the desire to satisfy cognitive needs. This quality is necessary for the search and analysis of information (“System and critical thinking”), the development and implementation of projects, and the construction of its development trajectory (“Self-organization and self-development”).
2. *Initiative* (undertaking) - an individual’s ability to independent activity, mental or physical will activity, timely manifested in the organization of actions aimed at achieving both his own and public goals. This quality is clearly necessary for the organization of teamwork, its management, it is necessary for self-development, for the search and critical understanding of any information.
3. *Perseverance* is perseverance in achieving goals, the ability to overcome obstacles. Without this quality, self-development is impossible, which does not have a final time limit, and in the path of which difficulties are always encountered.
4. *Adaptability* is the ability to adapt to changing circumstances. We believe that it is most suitable for such competency groups as: “Communication,” “Teamwork and Leadership”, “Intercultural Interaction” and “Life Safety.” Working with people, especially of different nationalities, requires tolerance and therefore adaptability.
5. . *Leadership* - the ability to lead others (themselves) to achieve goals. This quality of character is by definition suitable for the group of the same name, but it is also necessary for the implementation of projects, since the content of the competence includes the management of projects at all stages of its life cycle.
6. *Social and cultural awareness* - knowledge about the national-cultural characteristics of peoples and countries. In essence, the concepts can immediately be attributed to the group “Communication”, “Intercultural Interaction,” as well as, to a lesser extent, to the groups “Development and Implementation of Projects,” “Teamwork and Leadership,” given that there can be different composition in project teams.

Therefore, the following number of elections received character qualities: adaptability - 4 in undergraduate and 3 in magistracy, curiosity, initiative, leadership, social and cultural awareness - 3 in undergraduate and 3 in magistracy, perseverance - 2 in undergraduate and 1 in magistracy. Competency groups in which the largest number of character qualities are represented (four each) – “Project development and implementation,” “Team work and leadership.”

Our analysis showed that from the standpoint of the system approach, as well as the Pareto 20:80 principles, two groups of competencies are of greatest importance – “Project development and implementation,” “Team work and leadership.” They provide basic training in “4K” recruitment and character qualities.

Our research includes the study of opinions of teachers-practitioners and students of a pedagogical university, on personal assessment, indicated key (universal) competencies (UC). We excluded from the Communication UC-4 list since communication in a foreign language also is its part that is difficult for assessment. In the questionnaire, the sixth group of competencies was separately presented by UC-7 – “Health Protection.” Thus, the final version of the questionnaire contained six competency groups: “Systemic and critical thinking,” “Development and implementation of projects,” “Teamwork and leadership,” “Intercultural interaction,” “Self-organization and self-development,” "Healthy conservation." Respondents were asked to evaluate their universal competencies on the combined content of the Federal Educational Standard of Higher Education of undergraduate and master's degrees from 0 to 5 points.

Further, we asked to express our opinion on the importance of the Criminal Code in professional pedagogical activity from 0 to 5 points. The survey was attended by teachers of preschool (n = 26) and primary (n = 23) education; undergraduate students (as potential undergraduates) 1 course (n = 14), 3 courses (n = 13), 4 courses (n = 17) profiles "Preschool education," "Preschool education and Music." A total of 49 teachers, 44 students. Among teachers, 31% have work experience of up to 5 years, 20% - from 6 to 19 years, 49% - from 20 years and above (Table 2).

Table 2. Results of diagnostics of severity and significance of key (universal) competencies in teachers and students

Competency groups	Students				Teachers			
	Degree, points	Rank	Importance, points	Rank	Degree, points	Rank	Importance, points	Rank
1	159.22	3	198.61	3	199	3.5	230	3
2	146	6	197.74	4	199	3.5	228	4
3	152.87	5	203.61	2	203	1.5	227	5
4	157.77	4	197.48	5	184	6	214	6
5	161.61	2	204.35	1	203	1.5	235	1
6	162.33	1	190.87	6	197	5	231	2
$\bar{x}$	21.35		27.11		24.18		27.86	
σ	4.16		2.9		3.12		2.37	

Analyzing the table, we draw conclusions about the difference in opinions of students and teachers. Both the severity of all competencies at home and their significance for the profession are more pronounced among teachers. At the same time, the average quadratic deviation in both cases is greater in students, which indicates an unstable understanding by students of the analyzed phenomena.

Students put the category "Healthy Saving" in first place, which is only in fifth place among teachers. At the same time, teachers consider its importance for the profession to be quite high - second place, and students - the most insignificant, the last sixth place.

The second place in terms of expression and the first in importance among students is received by the category "Self-organization and self-development," which shows its importance for the student's educational activities and their understanding of the complexity and multitasking of the future profession. We see similar results in teachers - 1.5 and 1 rank, respectively. In the analysis of this category, teachers and students are unanimous, and this competence turned out to be the most significant for the profession, and all respondents consider themselves prepared for its implementation at a high level compared to other categories.

In the last places, students noted “Project development and implementation” and “Team work and leadership.” At the same time, they rated the value for the profession of these categories higher - 4th and 2nd place, respectively. Teachers have a higher rank of competence, but they rated the significance of the category “Teamwork and Leadership” low - 5. This raises questions, since project activities in education are actively implemented, from project activities in the educational process to the development of programs for the development of educational organizations of various types and types.

The first places in terms of severity among teachers, once again, received the categories “Self-organization and self-development” and “Teamwork and leadership.” In importance - this is “Self-organization and self-development” and “Healthy conservation.”

The last places in the ranking of severity among teachers are occupied by “Intercultural Interaction” and, as already mentioned, “Health Protection”. And in ranking significance – “Teamwork and leadership” and “Intercultural interaction”. Here we note that the category “Intercultural Interaction” also in all positions was low rated by students, - rank 4 and 5, respectively.

Thus, we see a clear leader – “Self-organization and self-development” and the same outsider – “Intercultural interaction”.

Then we answered the question: are the opinions of the respondents related to each other? We were interested in whether there is a relationship between opinion about its level of competence development and the assessment of the importance of competencies for the profession. For this, Spearman rank correlation coefficients were calculated (the scores for each respondent were used for all categories of competencies separately in terms of severity and significance): students among themselves, $r_s = -0.143$; teachers among themselves, $r_s = 0.371$; students and teachers by severity, $r_s = -0.114$; students and educators by importance, $r_s = 0.257$. That is, we use two individual and two group characteristic hierarchies.

With $n = 6$, $r_{кр} = 0.85$, $p \geq 0.05$, all values show the statistical insignificance of the dependence of the studied parameters. However, correlation trends differ. In the first case, the dependence of students’ opinions about themselves and about the profession has a weak and negative correlation close to zero enough, which can be defined as lack of connection. In the second case, the dependence of teachers’ opinions about themselves and about the profession is more pronounced, there is a tendency towards although weak, but direct correlation. The expression of competencies in students and teachers does not correlate and is also close to zero. Thus, we conclude that the assessment of the importance of the profession has no connection with the self-assessment of competencies in students. Also, the self-esteem of competencies among students and teachers varies significantly. But it can be assumed that teachers and students seem to assess the significance of key competencies in pedagogical activities. And there is a tendency among teachers to connect the self-esteem of the competencies studied with their significance for the profession. The correlation does not reflect the causal relationship between variables, but shows that a change in one variable will occur with a proportional change in another. The revealed trends should be further studied by increasing the number of people in the samples, as well as applied both in professional training of bachelors and in postgraduate education.

4 Conclusion

In the theoretical part of the question, we can pay attention to the following aspects. Critical thinking is the most sought-after competence from the 4K set. Competency groups, where "4K" is included in full: "Development and implementation of projects," "Teamwork and leadership," "Life safety."

Of greatest importance is the quality of character adaptability, further - curiosity, initiative, leadership, social and cultural awareness, slightly less important - perseverance.

Competency groups in which the largest number of character qualities are represented – "Project development and implementation," "Team work and leadership," "Self-organization and self-development."

In such a way, two groups of competencies are of the greatest importance – "Project development and implementation," "Team work and leadership." They provide basic training in "4K" recruitment and character qualities.

The empirical part made it possible to conclude the following. The leader in assessing the degree and significance of all groups of respondents is "Self-organization and self-development" (expressed and significant); the least noted in all cases is "Intercultural interaction" (not expressed and not significant). Students consider themselves more prepared for Healthy Conservation, Intercultural Communication and Systemic and Critical Thinking; least of all for Teamwork and Leadership. Teachers are quite prepared for all groups, except for "Healthy Saving".

It can be assumed that teachers and students seem to assess the significance of key competencies in pedagogical activities. And there is also a tendency among teachers to the interdependence of self-assessment of the studied competencies and their importance for the profession, i.e., if they are confident in the greater importance of key competencies in pedagogical activities, then their self-assessment of these competencies will also increase.

The prospects for further research are extremely important and multifaceted. It is also important to study the opinions of students and undergraduates of various training profiles. We want to note that it is necessary to study the development of the Communication competence group, which will be divided into a state and a foreign language, which does not allow respondents to adequately form a general assessment of it. Almost significant is the allocation and design of educational tools for the development of key competencies: individual methods, techniques, forms, means, in general, technologies (Savina, Kotlyarova 2019). The development of a personalized learning model, as an answer to the challenge of receiving education in the form and scope that each student needs personally, and which will correspond to his understanding of the importance of key competencies, seems to us to be relevant and separate direction.

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Analysis of Risk Assessment Models Used to Implement the Labor Safety Management System Algorithm

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Abstract. Purpose: the purpose of the research is:

– analysis of existing risk assessment methodologies;
– selection of an effective methodology for implementation of the professional risk management system algorithm;
– select a risk management model.

Methodology: The methodology developed in the state standard for the assessment and calculation of professional risks of railway personnel is more acceptable for implementation by modern employers. As part of this publication, a study of risk-oriented approaches tools has been conducted using the example of a contingent of construction organizations.

Results: Using the example of the construction industry enterprise, the implementation of the methodology was considered. The choice of this industry for research is due to the high level of industrial injuries in organizations engaged in construction and installation work, as well as the popularity of such work not only as a main activity, but also in the form of auxiliary units in enterprises. The results of this research are one of the stages towards the development of risk assessment algorithms relevant to the scientific, legislative and professional communities due to the lack of an approved procedure in Russian legislation today.

Conclusion: Based on the results of the methodology research, an effective risk management model “Risk Assessment & Safety Management Model (RASM)” was considered. The model establishes the risk and causes of accidents.

Keywords: Labor safety · Personnel · Enterprise · Employer · Risk · Protection

JEL-code: J50

1 Introduction

Today, a comprehensive approach in the field of occupational safety is the construction of a labor safety management mechanism at the enterprise. In the Russian Federation,

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this process is regulated by the article 212 of the Labor Code of the Russian Federation and Order of the Ministry of Labor of August 19, 2016 No. 438n (Consultant-plus 2016).

In general, HSEMS in Russian enterprises reaches the necessary level of completeness within the framework of the current philosophy of safe work. One of the main areas of implementation of occupational safety management mechanisms is the assessment of occupational risks. However, the approved methodology at the state level in Russia does not yet exist.

the purpose of the research is:

– analysis of existing risk assessment methodologies;
– selection of an effective methodology for implementation of the professional risk management system algorithm;

As part of this publication, a study of risk-oriented approaches tools has been conducted using the example of a contingent of construction organizations.

The results of this research are one of the stages towards the development of risk assessment algorithms relevant to the scientific, legislative and professional communities due to the lack of an approved procedure in Russian legislation today.

2 Materials and Methods

Today, within the framework of the risk-based approach, only the method of assessing the enterprise's activities has been introduced by applying checklists during the implementation of planned inspections of the state labor inspectorate. As such, in the given mode it does not correspond to the ideology of risk theory - the estimated indicators are devoted to a complex of measures already implemented by the employer (conducting professional medical examinations, training staff, providing personal protective equipment). Whereas, lists of hazards, risks or failures of controls, which are usually developed on the basis of previous experience, the results of a previous risk assessment or the results of failures that occurred in the past, have been applied since 2019. An indirect connection with the topic of research in the methodology broadcast by the supervisory authorities only gives a calculation of the risk category of the enterprise in order to establish the periodicity of inspections. Among the indicators that form such a level of risk: information about accidents of varying severity, facts of wage arrears and administrative offenses, the number of personnel, industry affiliation of the organization.

Establishing the necessary risk assessment model involves taking into account:

– complexity of risk analysis methods;
– nature of risk assessment based on available information and relevant objectives,
– number of resources;
– the final results in the form of quantitative attributes.

In general, a set of applied methodologies groups risk assessment models according to the level of information available in the evaluator's location: monitoring, additional methods, scenario analysis, functional analysis, and statistical methods. The result of the risk assessment can be obtained in both linguistic and quantitative form.

To date, there are different approaches to risk assessment, among which there are both classic and updated versions of risk theory models. The classic models most attractive for assessing occupational risks include:

1) The “bow-tie” method is formed on the assessment of barriers between causes, consequences and dangerous events. It is implemented in the form of a diagram (Fig. 1)

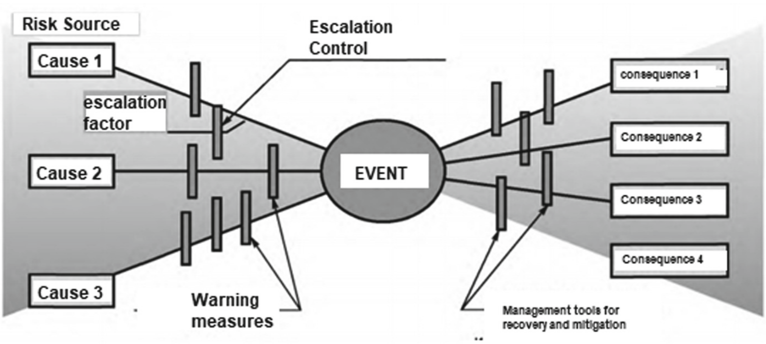

Fig. 1. Layout diagram of the bow-tie method. *Source*: compiled by the author based on State Standard R ISO/MEK 31010-2011 (2012).

2) Risk index - a method using score scores to rank and compare risk levels.
3) The Bayes method associates a priori data with posteriors, that is, it is assumed that there is a degree of confidence in a certain event. Whereas the classical approach is based on objective evidence.

Coincidentally, the third method served as the main one for the formation of the risk assessment methodology implemented in the State Standard “Methods for Assessing and Calculating Professional Risks of Railway Workers” (GOST R 12.0.011-2017 2018). Developers assume the obsolescence of a semantic approach to risk in terms of analyzing events that have occurred. The risk measure, according to researchers, describes events that are in the uncertainty zone of future scenarios for the development of situations.

The methodology implemented in the above-mentioned state standard puts forward a number of conditions:

– risk is understood as a result of the uncertainty of the state of the system “technology - man - nature”;
– “probability” does not depend on the “frequency” of monitoring events from the past, but is to be considered as a “measure of the probability of a risk situation in the future”;
– the employer is recognized as the “owner of the risk”;
– “risk assessment” becomes an additional source for motivation in decision-making, in order to prevent risk events in the future;

– implementation of the method is based on routine activities to develop "certain measures";
– risk assessment activities become effective only with a comprehensive approach to the enterprise management system (Fedorets 2018).

The mathematical apparatus of the method provides for a number of conditions:

1) If the effectiveness of protective measures E is zero, then the action of danger leads to damage to the life and health of personnel. At the same time, the probability of harm is equal to 1, and the risk is equal to the maximum potential damage.
2) With E = 1, the harm also becomes zero. So R = 0.
3) If the effect of protective measures contains values 0 < E < 1, then the risk value

$$R = W(1 - E).$$

Consequently, scientific ideas have been formed that can change the vector of the development of a safety culture at work:

– it is impossible to avoid the risk of implementing a risk event for the employee in the absence of actions to reduce the probability of identified danger;
– the implementation of protective measures to prevent the implementation of a risk event is aimed at reducing the likelihood of danger, and not the severity of harm;
– value of protective measure performance is inversely proportional to risk after its implementation.

3 Results

To create a more meaningful idea of the above methodology, we will consider its implementation using the example of a construction enterprise. The choice of this industry for research is due, firstly, to the significant level of personnel injury, and secondly, to the performance of such work in all types of enterprises.

The initial stage involves identifying hazards. Once hazards have been identified, their sources, activation methods and signs of danger should be identified. Avoiding the operation of a hazardous object will lead to a complete absence of danger and associated risk. There are situations where excluding a hazardous object will result in a complete violation of the technological cycle of the enterprise. In this case, it will be necessary not to take such radical measures and limit itself to the possibility of excluding or changing a dangerous action. Thus, the site of work at the height is a source of danger during construction and installation works, but the exclusion of this type of work from the Job Instruction is impossible due to the need to mount the required steel structures at the height established according to the project of work execution. In this case, the source of danger is considered to be the performance of high-altitude work by personnel in the absence of the required personal protective equipment or protection of working surface differences.

The next aspect is the establishment at the workplace of personnel of harmful and dangerous production factors. As a rule, in construction, a quantitative study of factor levels reveals an excess of mainly fibrogenic aerosols, chemicals and industrial noise. The result of the impact is the development of an acute or chronic form of occupational disease in the employee.

In the current Occupational Safety Management System, level studies are carried out under a procedure called "Special Assessment of Working Conditions." The frequency of the HSEMS is 1 times every 5 years. The twinning of this procedure is the production control, carried out with the established periodicity at least 1 times a year in order to ensure the safety of work for man and the environment. In addition, the procedure for interviewing personnel makes a significant contribution to the identification of harmful factors. Complaints and proposals of employees are a true characteristic of working conditions. After all, from the point of view of the management or experts implementing the above procedures, a number of factors may not be noticeable in principle.

According to statistics, key positions among dangerous factors in construction are occupied by work at height (28%), work with equipment (14.6%) and road traffic incidents (14.6%).

In addition to the usual classification of production factors when assessing professional risks, you should not forget about external factors. These include a set of meteorological conditions, dangerous flora and fauna in the place of work, the behavior of 3 persons, as well as dangerous factors caused by the location in the nearby territory of production facilities that are not controlled by the management of the enterprise. It is impossible to manage such factors by the risk owner, however, their implementation should be monitored at the enterprise.

We announce a number of assumptions acceptable in determining risk factors:

1) Risk factors should be identified by industry standards, not identified can lead to a large-scale accident;
2) Risk factors should be understood in the context of activities and their impact on material assets and employees;
3) When quantifying, the auditor's experience, statistical data, historical aspects of the workplace are used;
4) The interaction of risk factors with each other should be assessed;
5) Information and training of personnel on risk factors should be relevant.

Established registers of production and external factors are used to further assess the severity of the consequences.

The evaluation indicators can be information on the duration of temporary disability, a decrease in the level of labor productivity and labor losses when an employee has a disability or his death in a fatal industrial injury.

The risk realization probability estimation method, depending on harmful and dangerous factors, is positioned on setting the probability value range from 0 to 1.

The value "0" is associated with the elimination of hazards from the organization process and the required list, and component "1" is associated with the identification of hazards for which no protective measures are provided, the performance of which is assessed.

The enterprise needs to develop a set of measures used to reduce occupational risks based on the identification of harmful and dangerous factors, each of which establishes an efficiency indicator - a percentage of the reduction in the probability of implementing a risk event corresponding to the implementation of a dangerous or harmful factor.

Thus, it is possible for the construction organization to form the following register of categories of protective measures with assignment of performance indicator E:

Category 1 (E = 1) - measures of a technical nature, the effectiveness of which does not depend on the quality of the labor protection management mechanism or on the possible actions of the employee (use of collective protection tools);
Category 2 (E = 0.8) - technical measures that cannot be violated at random, but which effectiveness is limited by the admissibility of their deliberate violation by the employee himself or by insufficient technical reliability of production systems (equipping the equipment with noise insulation surfaces, safety mechanisms, operation of protective barriers and installation of grounding devices);
Category 3 (E = 0.7) - technical and organizational-technical measures that do not exclude accidental violation by personnel (use of signal colors and safety signs;
Category 4 (E = 0.6) - organizational measures based on conscientious and predictable behavior of employees (training and instruction on labor protection, registration of work permits, monitoring of work performance);
Category 5 (E = 0.5) - use of personal protective equipment, responding measures.

As a tool for quantifying occupational risk, a simplified matrix method can be used using a point system for interpreting results or a formulaic calculation of the probability of injury to an employee, determined through the effectiveness of a protective measure aimed at reducing occupational risk.

The risk assessment at the final stage consists in comparing the quantitative value of the risk assessment with the established criterion:

– Risk is unacceptable and requires the development and adoption of management measures (protective measures);
– Risk is acceptable and does not require management measures (protective measures);
– Risk is acceptable but requires management (protective measures) or additional monitoring measures;
– The risk which isn't taken into consideration in this connection is subject to an exception of the register.

Examples of acceptable risk values can be fire risk thresholds (up to 10^{-6} year^{-1}) risk values for some production facilities (up to 10^{-4} year^{-1}).

4 Conclusion

In general, it is easier to assess risks than to develop effective methods for managing them. Risk experts believe that it is important to identify hazards and develop corrective measures, and the numerical risk indicator is not so significant.

A series of international standards on risk management was launched in 2009 to assist business leaders.

Also, the founder of the foreign educational portal, Rick Curtis, developed a practical model called "Risk Assessment & Safety Management Model (RASM)" for risk management, presented in Fig. 2.

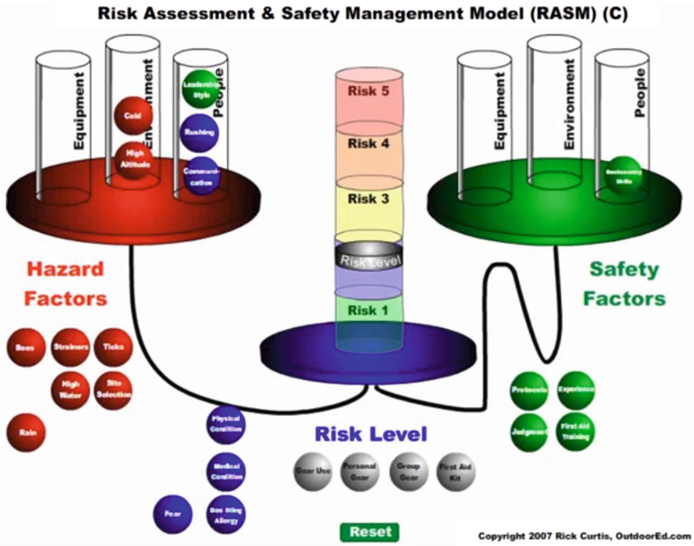

Fig. 2. Risk assessment and safety management model. Source: compiled by the author based on the model by Rick Curtis (2007)

The RASM model shows "Risk Level" risk change dynamics. 5-point scale of risk level, indicated by color: green (low level) - red (critical level). Blue assumes a level of protection. Hazard factors are indicated on the left in the form of Hazard Factor balls. Balls are placed in cylinders meaning hazard categories: "people", "cars", "nature." On the right there are safety factors in the form of Safety Factors protection balls. Protection balls are added to the cylinders on the left, making the situation acceptable.

Thus, the ability to manage risk can translate it into a positive zone, and this allows you to increase the chances of an enterprise for potential development and win in a competitive job market.

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Development of HR-Management Tools for an Innovation-Oriented Organization Using System Analysis

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Abstract. The HR-management system of modern innovation-oriented organizations is characterized by a variety of decision support tools. The main goal of the study is to substantiate the features and algorithm for solving the urgent problem of systemic risk assessment in the structure of HR management and to rank HR risks for identifying the most effective strategy for their minimization.

The solution to this problem is based on the system analysis methodology - the key methodology for making multi-criteria decisions in the area of HR management, the main characteristics of which are taking into account multidimensional criteria (the assessment of its alternatives aren't always unambiguous) and different types of qualitative risk indicators and complexly structured factors. The result of a systematic analysis of HR-risks of an innovation-oriented organization (university) was the classification of the risks characteristic of the HR-management system, according to their sources (taking into account the effects). The identified four integrated risks in the organization's HR management system include the integrated risks of individual human capital management «Lack of employee competencies» and «Lack of managerial competencies», and also the integrated risks «Failures» in the organization's strategic policy and «Failures» in the organization's motivational policy.

Application of the Dematel method to solving the problem of multi-criteria analysis of causal relationships between integrated HR risks made it possible to identify a pattern among the many existing in the complex system under study, to rank risks by priority and to develop a strategy for their minimization. The novelty of the author's approach lies in the substantiation of the algorithm for systemic risk assessment in the structure of HR management using the Dematel multi-criteria analysis method, which has demonstrated its effectiveness in terms of identifying the «cause-effect» pattern in a complex HR risk management system and also of ranking the organization's HR risks.

Keywords: HR-management · HR-risks · Innovation-oriented organization · Systems analysis · Dematel method

JEL-codes: J24 · O15 · M54

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1 Introduction

In the context of globalization, one of the key factors of sustainable and innovative development and competitiveness of an organization is quick adaptation to new realities.

High-speed processes of technology change lead to deep transformations affecting market and non-market sectors of the economy, and, accordingly, increase the importance of innovation-oriented development of organizations (Taking the Reins: HR's opportunity to play a leadership role in governance, risk management and compliance 2008). An increasingly important place among organizations of an innovative type is occupied by modern universities as knowledge-producing institutions - integrators of the scientific, educational and cultural elite - highly qualified personnel of the innovative development economy.

An effective HR management system is one of the most significant sectors of the formation of a strategy for achieving the goals of sustainable innovative development of the organization, due to the fact that human resources are the main strategic factor source of the innovatively active dynamics of all areas of university activity (Lazareva and Karaycheva 2017; Magau and Roodt 2010).

The creation of an effective HR management system, in turn, requires the development and implementation of system tools that allow identifying and ranking the most significant risks for the HR management sphere, fully defining directions and adequate tools for their minimization (Lazareva et al. 2018).

In accordance with international ratings, personnel management risks are in the top 10 (5th place) of the most significant risks for the organization (The 2009 Ernest & Young Business Risk Report 2009).

In the context of the intensification of the scientific search for strategies and tools for managing HR risks, various sources of this type of risk have been identified, and some effects of managerial decisions, which are made in the area of HR management of an innovative organization have been assessed (Berhil et al. 2020; Colman 2007; Endovitsky and Durakova 2019; Heslop et al. 2005; Martin and Schmidt 2010; Meyer and Robbins 2010; Meyer et al. 2011; Mitrofanova et al. 2017; Munnik 2008; Paul and Mitlacher 2008). However, theoretical approaches from the standpoint of risk management focus on separate, disconnected from each other, sources of risks - high staff turnover, excessive personnel costs, lack/insufficient of the staff motivation. Understanding of the consistency and interdependence of management decisions aimed at minimizing HR risks is reflected in the increasing instrumental support of such decisions using system analysis.

The HR-management system of modern innovation-oriented organizations is characterized by a variety of decision support tools. Econometrics (Anopchenko et al. 2015) and systems analysis methods, in particular, the hierarchy analysis method (Lazareva et al. 2020; Lazareva and Karaycheva 2017) are increasingly being used in the human resource management system.

The main purpose of this study is to substantiate the peculiarities of human resource management in an organization that provide a solution to the urgent problem of systemic risk assessment in the structure of HR management and also to develop a strategy for their minimization in order to increase the degree of sustainability of innovative type development. The novelty of the author's approach consists in substantiating and demonstrating the effectiveness of the Dematel multi-criteria analysis method in solving the assigned tasks - a relatively new system analysis method that allows solving multi-criteria optimization problems.

The Dematel method, originally developed to study a complex and interconnected group of indicators, and it's recognized by the authors of this article as one of the best tools for multivariate analysis of causal relationships between management decision criteria, which can serve as the basis for ranking them according to the estimated effects (Chiu et al. 2006; Liou et al. 2007; Tzeng et al. 2007; Zuo et al. 2016).

Risk assessment in HR management is becoming a tool that helps company management to identify strengths and weaknesses in terms of human resource management and to identify the relationship between integrated HR risks.

2 Materials and Methods

A managerial decision in the area of HR management belongs to the class of multi-criteria due to such characteristics, which are taking into account multidimensional criteria (assessment by which alternatives are not always unambiguous), as well as various qualitative risk indicators and complexly structured factors.

One of the most common methods of systems analysis that allows solving this kind of multi-criteria optimization problems - the foundation of decision support in the area of HR management of an organization, is undoubtedly the Dematel method (Lin and Tzeng 2009; Shieh et al. 2010; Wu and Lee 2007).

Based on works of these authors: Shieh et al. (2010), Sumrit and Anuntavoranich (2013), Tzeng et al. (2007), Yang et al. (2008), we present the implementation procedure for the Dematel system analysis method (Fig. 1).

At the first stage, a group of m experts is created to assess the degree of mutual influence of the four identified (generally n) integrated HR risks - decision criteria. The expert group, which was created for the survey, includes 9 experts who are heads of various departments of the university. Based on the method of pairwise comparison, an expert assessment of the degree of mutual influence of certain two criteria is sequentially performed (the degree of influence of criterion i on criterion j is denoted as x_{ij}). The application of the DEMATEL analytical methodology to the survey results made it possible to determine the causal relationships and the most significant integrated HR risks.

Integer evaluations of experts are measured on a scale of «0 (no influence), 1 (weak influence), 2 (medium influence), 3 (high influence), 4 (very high influence)». The assessments of each of the experts are presented in the form of a non-negative matrix of size $(n \times n)X^k = \left[x_{ij}^k\right]$, where k is the number of experts participating in the assessment process, $1 \leq k \leq m$.

Thus, X^1, X^2, X^3,.., X^m - are assessment matrices of m experts.

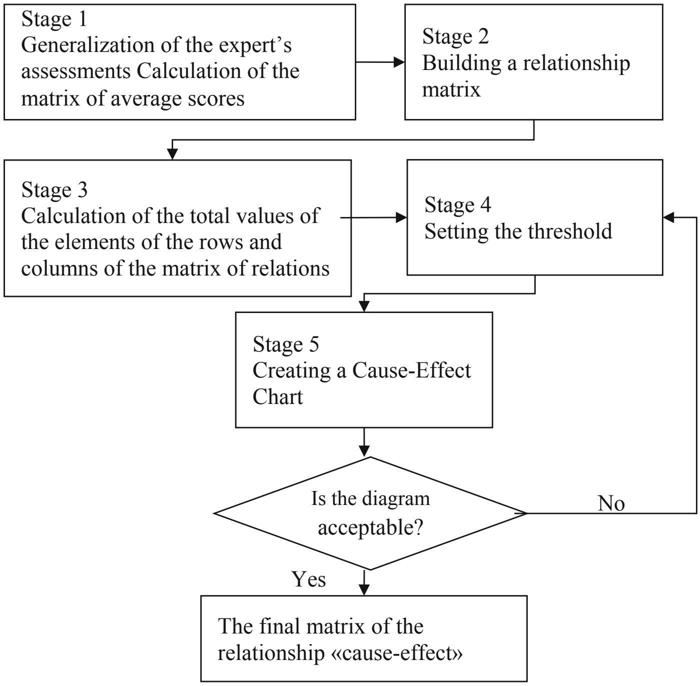

Fig. 1. Stages of applying the Dematel method to solving the problem of multi-criteria analysis of cause-and-effect relationships between integrated HR risks

A matrix of average estimates is built to combine the judgments of m experts, the elements of which are calculated by the formula (1).

$$z_{ij} = \frac{1}{m}\sum\nolimits_{i=1}^{m} x_{ij}^{k} \tag{1}$$

In the second stage, matrix D is calculated. The value of each element in matrix D varies from 0 to 1, and the matrix elements are denoted as $\left[\mathrm{d_{ij}}\right]$.

$$\left[d_{ij}\right]_{n\times n} = \lambda\left[z_{ij}\right]_{n\times n} \tag{2}$$

$$\lambda = min\left[\frac{1}{\underset{0\le i\le n}{max}\sum\nolimits_{j=1}^{n}\|z_{ij}\|}, \frac{1}{\underset{0\le i\le n}{max}\sum\nolimits_{i=1}^{n}\|z_{ij}\|}\right] \tag{3}$$

At the stage 3, a matrix of relations T is constructed. The calculation is performed in accordance with Eq. (5), in which variable I is a unit matrix of size $(n \times n)$. The t_{ij} element evaluates the indirect effects of criterion i on criterion j, while the matrix of relations T reflects the general relationship between each pair of system criteria.

$$T = \lim_{m\to\infty}\left(D + D^2 + .. + D^m\right) = \sum\nolimits_{m=1}^{\infty} D^i \tag{4}$$

$$\sum_{m=1}^{\infty} D^i = D^1 + D^2 + \cdots + D^m$$

$$T = D(I - D)^{-1} \tag{5}$$

At stage 4, it's necessary to calculate the sums of the elements of the rows and columns of the matrix T. In the matrix of relations T, the sum of the elements of the rows and the sum of the elements of the columns are represented as vectors r and c, respectively.

$$r = [r_i]_{n\times 1} = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1}, \tag{6}$$

$$c = \left[c_j\right]'_{1\times n} = \left(\sum_{j=1}^{n} t_{ij}\right)'_{1\times n} \tag{7}$$

Where $\left[c_j\right]'$ is denoted as the transposition matrix.

Let the element r_i will be the sum of the elements of the i-th row in the matrix T. The value r_i indicates the total amount of direct and indirect influence of criterion i on other criteria.

Let c_j will be the sum of the elements of the j-th column in the matrix T. The value of c_j shows the total effect of direct and indirect influences of all other criteria on criterion j. If $j = i$, the value $(r_i + c_i)$ represents the cumulative effects. On the contrary, the value $(r_i - c_i)$ shows the net contribution by criterion i in this system. Moreover, when the value $(r_i - c_i)$ is positive, the criterion i is considered as purely causal. When the value $(r_i - c_i)$ is negative, criterion i is purely resultant.

At the fifth stage, it's necessary to set the threshold value (α). The threshold value α is calculated as the average value of the elements in the matrix T according to the formula (8). This calculation aims to eliminate some of the minor effects of the elements in the T matrix.

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[t_{ij}\right]}{N}, \tag{8}$$

where N is the total number of elements of the matrix T.

In the stage 6, a causal diagram is constructed. A "cause and effect" diagram is constructed by comparing all sets of coordinates $(r_i + c_i, r_i - c_i)$ to visualize complex relationships and to provide information about the most important criteria and assess their mutual influence.

3 Results

The result of the verification of the algorithm for the systemic assessment of HR risks on the information base of the Baltic Federal University named after I. Kant began to identify and group by the sources of occurrence (taking into account the effects) of the risks characteristic of the HR-management system of the organization (Table 1).

Table 1. Risk groups in the organization's HR management system

HR-risks	Effects in the organization	Source of risk	Author/Publication
Integrated risk of individual human capital management "Lack of employee competencies" (HR 1)			
Lack of skills	Negatively affects the productivity of employees and the economic development of the organization	Employee	Colman 2007; Meyer et al. 2011
False competencies of an employee	Falsification of qualifications resulting in low labor productivity		Heslop et al. 2005; Mitrofanova et al. 2017
Integrated risk "'Failures' in the strategic policy of the organization" (HR 2)			
High staff turnover	They costs millions of currency units annually to the organization	Organization	Meyer et al. 2011; Meyer and Robbins 2010
Removal of employees from office	Reduces productivity, and as a result, the organization's loss of the organization's funds		Munnik 2008; Paul and Mitlacher 2008
Loss of employees occupying key positions/leaving of narrowly focused specialists	Increased costs of the organization for hiring new employees and decreased productivity		Endovitsky and Durakova 2019
Integrated risk of individual human capital management "Lack of managerial competencies" (HR 3)			
Ineffective HR management system	Can lead to disruption, low productivity, loss of staff, and dissatisfaction	HR managers, employees in management positions	Martin and Schmidt 2010; Mitrofanova et al. 2017; Endovitsky and Durakova 2019
Excessive personnel costs	Additional costs and structural increases in management costs/staff insurance		Berhil et al. 2020

(*continued*)

Table 1. (*continued*)

HR-risks	Effects in the organization	Source of risk	Author/Publication
Integrated risk "'Failures' in the organization's motivational policy" (HR 4)			
Lack (insufficient) staff motivation	Increased organizational costs and decreased productivity	Organization, employee	Mitrofanova et al. 2017; Endovitsky and Durakova 2019
Lack of career growth of employees	Low employee engagement, lower annual profit for the organization		Mitrofanova et al. 2017

The identified four integrated (aggregated) risks in the organization's HR management system include the integrated risks of individual human capital management "Lack of employee competencies" (HR 1) and "Lack of managerial competencies" (HR 3), as well as integrated risks "'Failures' in the strategic policy of the organization" (HR 2) and "'Failures' in the organization's motivational policy" (HR 4). The integrated risk HR 1 includes the risks of a lack of skills and false competencies of the employee; the integrated risk of HR 2 includes the risks of high staff turnover, dismissal of employees from their positions, and the loss of "key" employees (narrowly focused specialists). The main risks, which are taken into account in the structure of the integrated risk HR 3, are the risks of an ineffective personnel management system and excessive personnel costs, in the structure of the integrated risk HR 4 - the risks of lack (insufficient) of staff motivation and career growth of employees.

Matrices $X^k = \left[x_{ij}^k\right]$ show expert opinions on each integrated HR risk group:

$$X^1 = \begin{matrix} 0 & 2 & 3 & 1 \\ 2 & 0 & 3 & 2 \\ 3 & 1 & 0 & 3 \\ 3 & 3 & 2 & 0 \end{matrix} X^2 = \begin{matrix} 0 & 3 & 2 & 1 \\ 3 & 0 & 1 & 4 \\ 2 & 3 & 0 & 1 \\ 4 & 2 & 1 & 0 \end{matrix} X^3 = \begin{matrix} 0 & 2 & 2 & 1 \\ 3 & 0 & 2 & 3 \\ 1 & 2 & 0 & 1 \\ 2 & 3 & 1 & 0 \end{matrix}$$

$$X^4 = \begin{matrix} 0 & 2 & 3 & 4 \\ 2 & 0 & 1 & 2 \\ 2 & 2 & 0 & 1 \\ 3 & 3 & 1 & 0 \end{matrix} X^5 = \begin{matrix} 0 & 3 & 3 & 2 \\ 3 & 0 & 2 & 2 \\ 2 & 1 & 0 & 1 \\ 2 & 3 & 2 & 0 \end{matrix} X^6 = \begin{matrix} 0 & 1 & 1 & 2 \\ 2 & 0 & 1 & 2 \\ 3 & 2 & 0 & 2 \\ 1 & 2 & 2 & 0 \end{matrix}$$

$$X^7 = \begin{matrix} 0 & 2 & 2 & 3 \\ 3 & 0 & 2 & 1 \\ 2 & 2 & 0 & 2 \\ 3 & 1 & 2 & 0 \end{matrix} X^8 = \begin{matrix} 0 & 1 & 2 & 2 \\ 2 & 0 & 2 & 2 \\ 3 & 1 & 0 & 1 \\ 2 & 2 & 1 & 0 \end{matrix} X^9 = \begin{matrix} 0 & 2 & 3 & 1 \\ 3 & 0 & 2 & 2 \\ 4 & 1 & 0 & 2 \\ 3 & 2 & 2 & 0 \end{matrix}$$

The process of assessing the criteria - integrated HR risks is schematically shown in Fig. 2.

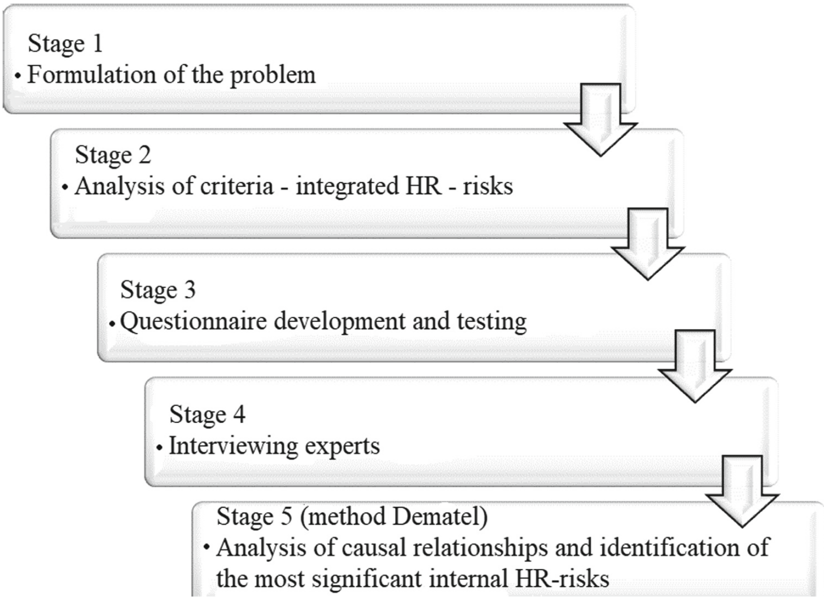

Fig. 2. Procedure for assessing integrated HR risks

Further, according to formula (1), the matrix of average estimates Z is constructed:

$$Z = \begin{matrix} 0 & 2 & 2{,}333333 & 1{,}888889 \\ 2{,}555556 & 0 & 1{,}777778 & 1{,}888889 \\ 2{,}444444 & 1{,}666667 & 0 & 1{,}555556 \\ 2{,}555556 & 2{,}333333 & 1{,}555556 & 0 \end{matrix}$$

The coefficient λ was calculated by the formula (3) and matrix D by the formula (2):

$$\lambda = 0{,}132352941$$

$$D = \begin{matrix} 0 & 0{,}264706 & 0{,}308824 & 0{,}25 \\ 0{,}338235 & 0 & 0{,}235294 & 0{,}25 \\ 0{,}323529 & 0{,}220588 & 0 & 0{,}205882 \\ 0{,}338235 & 0{,}308824 & 0{,}205882 & 0 \end{matrix}$$

The final matrix of relations T is calculated in accordance with formulas (4), (5):

$$T = \begin{matrix} 1{,}0992 & 1{,}1192 & 1{,}1382 & 1{,}0444 \\ 1{,}3718 & 0{,}929 & 1{,}1105 & 1{,}0581 \\ 1{,}2654 & 1{,}0326 & 0{,}8425 & 0{,}9614 \\ 1{,}409 & 1{,}1989 & 1{,}122 & 0{,}8877 \end{matrix}$$

The results of calculating the vectors r and c in accordance with formulas (6) and (7) are presented in Table 2.

Table 2. Calculation results - assessments of integrated HR risks

	HR 1	HR 2	HR 3	HR 4	r_i	c_j	$r_i + c_j$	$r_i - c_j$
HR 1	1.0992*	1.1192*	1.1382*	1.0444*	4.401	5.1454	9.5464	−0.7444
HR 2	1.3718*	0.929*	1.1105*	1.0581*	4.4694	4.2797	8.7491	0.1897
HR 3	1.2654*	1.0326*	0.8425*	0.9614*	4.1019	4.2132	8.3151	−0.1113
HR 4	1.409*	1.1989*	1.22*	0.8877*	4.6176	3.9516	8.5692	0.666

We set the threshold value α (formula (8)):

$$\alpha = 35.1798/16 = 2.198738$$

The values of the t_{ij} estimates, which exceed the threshold value α, are shown in Table 2 as t_{ij}^{*}. These values reflect the degree of relationship between integrated HR risks. The relationship of the four integrated HR risks (I_i) is visually shown in Fig. 3.

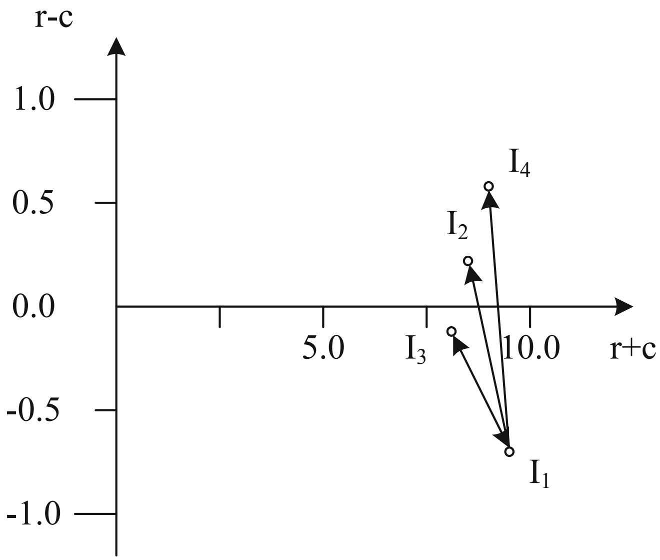

Fig. 3. Visualization of the relationship of four integrated HR risks

4 Conclusion/Recommendations

The results of the study indicate the effectiveness of applying the system analysis methodology and the new Dematel method that implements it to solving the problem of assessing risks in the structure of HR management and to rank HR risks for identifying the most effective strategy for their minimization. The novelty of the author's approach, which consists in substantiating the algorithm for systematic risk assessment in the structure of HR management using the Dematel method of multi-criteria analysis, provided the implementation of a structured analytical procedure for identifying the "cause-effect" pattern in a complex HR risk management system and ranking the organization's HR risks. The result of verification of the proposed algorithm on the information base of the Baltic Federal University named after I. Kant was the algorithmic identification of the priorities of the strategy for minimizing HR risks - overcoming "failures" in the motivational and strategic policy of the organization.

The integrated HR risk scores were ranked according to the values $(r_i + c_j)$.

Based on Table 2, the integrated risk of individual human capital management "Lack of employee competencies" (HR 1) turned out to be the most significant $((r + c) = 9.5464)$. The integrated risk of individual human capital management "Lack of managerial competencies" (HR 3) got the least significant assessment $((r + c) = 8.3151)$. In general, the sequence of priority values of the integrated HR risks looks like HR 1 > HR 2 > HR 4 > HR 3.

Based on the $(r - c)$ values, the integrated HR risks were divided into two groups: the cause group and the effect group.

If the value $(r - c)$ is positive, the integrated HR risks are classified into a group of reasons that directly affect other types of risks. In this study, the group of reasons includes risks - components of integrated risks HR 2 and HR 4, having values $(r - c)$ of 0.666 and 0.1897, respectively. HR risks with the highest values $(r - c)$ have the most significant direct impact on other risk groups. The risks of lack (inadequacy) of staff motivation and lack of career growth for employees, integrated into HR risk 4, were assessed as the most important in terms of the degree of impact on other types of risks.

The effect group includes risks associated with a lack of skills, the choice of employees with false competencies (HR 1) and an ineffective personnel management system, excessive personnel costs (HR 3), the values $(r - c)$ for which were -0.7444 and -0.1113, respectively.

The results of this study allow recommending the Dematel method for a systematic assessment of risks in the structure of HR management and for ranking HR risks in order to identify the most effective strategy for their minimization.

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Managing Human Resources in the Digital Economy

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Abstract. Purpose: Give the concept of "human resources", "competence of personnel". Define the main components of competencies: functional, situational, social, intellectual. Consider a group of external and internal factors affecting the personnel capacity of the organization. Identify the relationship between economic, productive (innovative) functions. Determine the components of human resources potential in the era of the digital economy.

Approach: The authors distinguish a systematic approach to the consideration of the concept of "human resources". The human resources at the entrance of the organization is considered as a resource with a certain cost: knowledge, skills, experience. The human resources in the organization is designed to perform the following functions: economic, production (innovative) communication. During the performance of functional duties, a situational approach is considered, based on factors that affect the organization of the production process.

Results: It is shown that human resources are an intellectual resource of the organization, which allows transforming the acquired knowledge into technological processes, introducing innovations, producing competitive products, which is also reflected in the results of the organization's activities. The competent use of human resources opens up new ways of economic development of the organization.

Originality/Value: The components of human resources capacity have been established, the relationship between the components of competencies and the factors affecting them has been identified. Functional relationship of human resources capacity is considered. The principles of managing the digital economy in the modern conditions of the organization are supplemented.

Keywords: Human resources · Competence · Functions · Factors · Principles and rules of the digital economy · Advantages of the digital economy

JEL Code: M51

1 Introduction

Human resources management in the era of global digitalization is given special attention, in view of the fact that personnel capacity is the main resource of the organization participating in the production and management activities of the organization. The work of human resources capacity directly affects the economic performance of the organization.

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In view of the changes taking place in the external environment, such concepts as the competence of human resources in the era of the digital economy come first. Competency of human resources is the sum of knowledge, skills and skills that a person acquires and multiplies during work activity. The human resources of the organization's personnel are realized through the abilities and capabilities of people to perform a certain type of activity.

Kibanov considers "human resources" - as a set of physical and spiritual qualities of a person who determine the possibility and boundaries of his participation in labor activity, the ability to achieve the intended result, improve in professional and personal development "(Bolotova and Zakharova 2015).

Zushchina and Kostin believe that the human resources is the limit of the participation of workers in production, taking into account their psychophysiological characteristics, the level of professional knowledge, accumulated experience "(Bolotova and Zakharova 2015).

Human resources is the main part (subsystem) of labor potential, which includes the professional and qualification side of labor potential. Thus, he characterizes the volume of special knowledge, skills and skills, competencies of workers (Shirshova and Glukhov 2019).

The staffing capacity of the organization should be viewed from different perspectives that do not contradict each other, but rather complement the definition. On the one hand, the organization's human resources capacity should be considered as the production capacity (force) that purposefully moves the organization to the result. In this case, the economic performance of the organization is taken into account. On the other hand, the personnel potential is the intellectual resource of the organization, which allows transforming the acquired knowledge into technological processes, introducing innovations, producing competitive products, which is also reflected in the results of the organization's work. The competent use of personnel potential opens up new ways of economic development of the organization (Gabdullin 2019).

2 Materials and Methods

The digital economy, which covers all areas of the country's activities and ensures its competitiveness, poses new requirements for the formation of key competencies in human resources. Digital competencies, first of all, should be focused on intellectual and innovative knowledge, on the ability to create a business based on innovations in the field of IR. This opens up wide opportunities for educational activities to universities that set ambitious goals in preparing the intellectual, creative, scientific and human resources potential of the country (Burdakova et al. 2019).

When considering the topic "Management of personnel potential in the era of the digital economy," general scientific research methods were used: a systematic approach, a method of analysis and synthesis, and generalization.

3 Results

In the world of the digital economy, many factors influence human resources capacity (Gao and Haworth 2019; Goswami et al. 2019). Classically, they can be divided into two groups: external and internal. External factors include:

– the demographic situation in the country;
– level of socio-economic development,
– public policy,
– R&D rate,
– the state of the labour market,
– education system,
– entrepreneurial investment,
– level of innovative development and others (Villajos et al. 2019).

We will discuss in more detail the demographic situation in the country.

According to Federal State Statistics Service (2019), since 2019 there has been a decrease in population dynamics. The decline in the population is due to the outflow of skilled personnel, a change in the structure of the labor market, an increase in the mortality rate of the population, which negatively affects the state economy.

In our opinion, such a factor as the training of competent personnel in the areas of training, as well as retraining of personnel deserves attention. To this end, the State pays special attention to educational institutions at the regional and federal levels.

The Institute of Education opens the way for students to gain knowledge and professional skills, creates human capital, increases the dynamics of the standard of living of citizens and acts as the basis for the economic development and progress of mankind as a whole. Unfortunately, more than 30% of educational institutions graduate from specialists who cannot be employed in the future. The key reasons for the negative impact on the field of vocational training include low demand for highly skilled jobs with unstable economic growth. So, the representative of the foundation for the development of Internet initiatives Kirill Varlamov says that due to the onset of the digitalization process in the domestic economy, Russia can experience both unemployment and a shortage of qualified personnel.

According to a Gartner study, due to a shortage of digital specialists - only 30% of positions will retain the status of free in the technological sphere. BCG members revealed that 25% of IT specialists working in online recruitment databases cope with work in the company and can replace more than 10 thousand people (Gartner 2019).

Internal factors affecting human resources capacity include:

– level and type of production;
– technological;
– production;
– technical;
– organizational structure of the organization;
– corporate culture, etc.

In addition to the above external and internal factors affecting human resources capacity, there is a classification of factors according to the following characteristics:

1) by the nature of influence: objective and subjective;
2) in the direction of influence: positive and negative factors;
3) by the nature of the description: quantitative and qualitative factors (Syrbu 2015).

Staff capacity in the organization is designed to perform the following functions:

- The economic function is to increase the efficiency of the use of knowledge in order to increase the productivity of the organization;
- production (innovative) function acts as an engine of ideas, creation of new products, services, business processes. Employees in the performance of this function are characterized not only by professional knowledge, work experience, creative solution of the problem, but also by the desire to transfer the acquired knowledge to the younger generation. Thus, information is exchanged, knowledge is transferred, which contributes to the creation of a new management function - knowledge management. The goal, which is to accumulate intellectual knowledge, disseminate experience;
- a communication function whose task is to build interpersonal relationships, choose the type of behavior corresponding to the organizational culture.

All the above functions are interconnected and play a role in the management of personnel potential (Bolotova and Zakharova 2015).

The structure of human resources capacity and its interrelationships is shown in Fig. 1.

Consideration of such components of human resources potential as professional, intellectual and innovative potential deserves attention. Staffing capacity components are presented in Table 1.

In the era of the digital economy, conceptual knowledge of human resources potential comes to the fore, which provides the organization with a competitive advantage in the market of services provided (Ignatiev et al. 2018).

The digital economy in modern conditions is based on the following management principles:

- improvement of the management system;
- resource efficiency;
- progressivity of product development;
- integration;
- comprehensiveness;
- organizational effectiveness;
- universality;
- economic value;
- competence of personnel.

It must constantly adapt to changes taking place in the external environment and affect all levels of management. With regard to the digital economy, attention should be drawn to a number of advantages it offers:

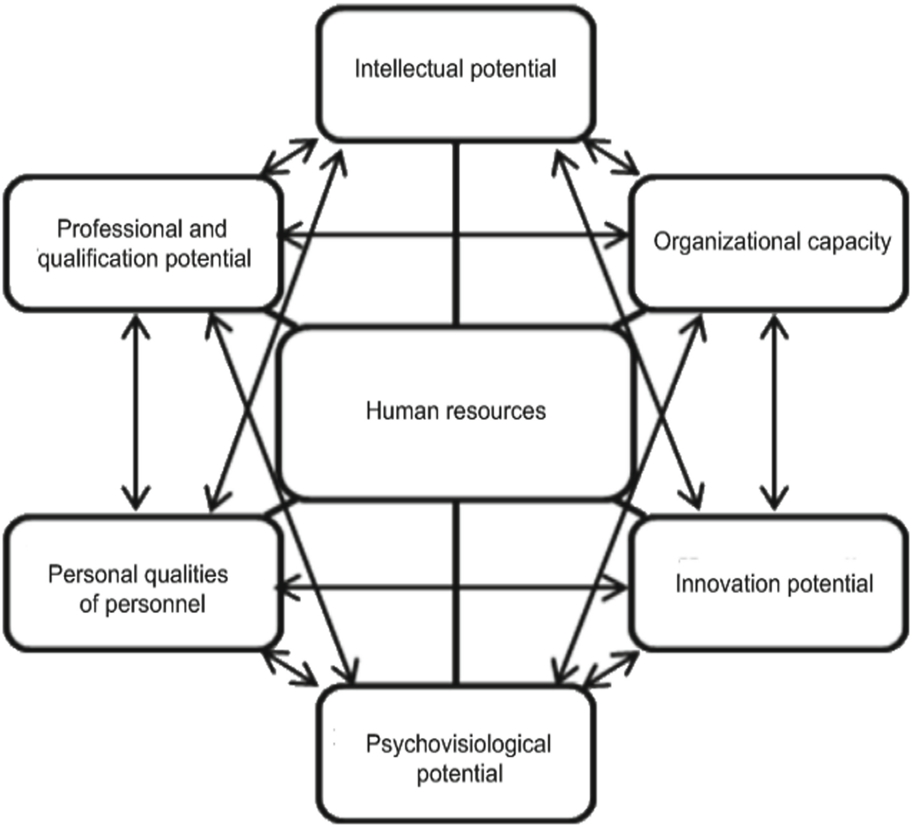

Fig. 1. Human resources structure. *Source*: developed and compiled by the authors

Table 1. Human resources components

Professional potential (knowledge, skills and experience)	Intellectual potential	Innovation potential
- ability to analyze information - ability to think logically and systemically - make informed decisions - strategic thinking - ability and desire to risk justifiably - ability to work for the result	- knowledge (acquired, accumulated, transferred) with value (value and usefulness of information) - analysis and synthesis of problem solution - observation of events - similarity of conclusions - creative abilities - generating ideas	- anticipation - taking into account risks - innovation - innovation management

Source: developed and compiled by the authors

– new jobs;
– the appearance of a positive motive for work;
– reduction of training costs;
– free schedule of work;
– transparency of the economy;
– transition to online business.

The use of the digital economy is aimed at a qualitatively new level of development of technologies and information infrastructure.

Modern information and communication technologies significantly change all social relations, in connection with which it is noted that a new, information society is currently being formed, which is called the "digital economy."

Thus, new opportunities are opened for the development of the economic structure of society, which create a new social environment for the future generation.

However, there are a number of reasons that prevent the organization from switching to a digital economy. The reasons for the organization's transition to the digital economy are presented in Table 2.

Table 2. Reasons impeding the transition of the organization to the digital economy

Demographic situation	Recruitment	Staff development
1. Outflow of young personnel	Focus on affordable labour	Adaptation period (loss of interest in work)
2. Environmental risks	No Data Bank	Increase in staff training costs
3. Ageing of the population	personnel	Not realizing personal goals
4. Reduced labour supply	Lack of social assistance programmes	Poor motivational attitude
5. Changes in the quantitative and qualitative structure of personnel	Partial Employment Scheme	Lack of growth prospects

Source: developed and compiled by the authors

Rapid change in the external environment poses new challenges for organizations to address and address as a matter of priority. One of these tasks is to increase the competitiveness of the organization through the competent use of human resources. The question of the competence of personnel is rightly raised. Where to take and what to teach staff? What exactly should competence include?

Competence of personnel potential is the sum of the constituent competencies:

– functional - analytical abilities, knowledge of cross-functional features of work, knowledge of information technologies, ability to build a personal trajectory of development;

- situational - determines the ability to quickly and flexibly respond to production, management and organizational changes taking place in the organization (Kraev and Tikhonov 2019);

social is the skills of building the communicative behavior of workers in the organization, the ability to work in a team. Social competence is the sum of the individual competencies of employees. Individual competence includes: the psychophysiological component, the characteristic type of person; value - orientation and status component, and intellectual competence.

- intellectual is the ability to analyze the problem, anticipate events and risks, the ability to think creatively and make non-standard decisions, work ahead of schedule, anticipating a positive result (Faskhiev 2020).

In terms of competency management in the organization, it should be borne in mind not only the amount of knowledge accumulated, but also the exchange of knowledge (Omelehuk et al. 2020; Petrov et al. 2020).

In 2018, the Government of the Russian Federation adopted a plan to implement the transition of the state to the digital economy. Priority was given to such areas as: personnel and education, development of the information system, information security, regulatory and legal support.

Currently, in the digital market in the business sector, online business is gaining interest more quickly, having such advantages as simplicity, availability of free services and resources, an abundance of various types of goods and services, and the absence of a language barrier.

A distinctive feature of the digital economy is the geographical distance of the location of companies providing a range of services to buyers (Ryabtsev et al. 2017; Syrbu 2015).

The digital economy should be based on the following principles:

1. Introduction of information technology into business relations.
2. Expansion of intangible activities (leading to increased profitability).
3. Globalization. There is an erosion of borders between participants in the trade process based on decentralization, automation and artificial intelligence.
4. Bilateral market - a platform for interaction between two persons, where the transaction is carried out through an intermediary or platform. Within the framework of the digital economy, the two-way market can include online platforms (for example, a TaoBao trading platform, a SuperJob job search site).

The success of a two-way market directly depends on the number of users in the network.

The digital economy serves as a powerful lever for economic development, improving the information society. Information in electronic form is becoming increasingly valuable. The growth of the economy changes the nature of the worker's work.

4 Conclusion

During the training process in the digital economy, we believe that the following recommendations should be used:

- formation of competence groups related to information and communication technologies (ICT) for graduates of all specialties in universities;
- Establishment of distance learning courses and modules;
- Creation of projects for additional education of citizens as part of independent work to develop ICT skills and skills;
- introduction into the processes of general final certification of narrowly directed digital means of educational activity;
- strengthening and expanding the interaction of universities with organizations connected in the IT field;
- Creation of vocational retraining modules for citizens who have already completed higher education.

There is a need to revise training requirements that aim to:

1) development of competencies;
2) conducting classes in the form of online courses;
3) the development of personal educational routes for the formation of labor trajectories.

In our opinion, this is necessary to include adaptation processes in the era of the digital economy, where the intellectual competence of personnel potential becomes especially important. Thus, human capacity becomes the main resource and ensures competitiveness in the domestic and external markets.

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The Role of the Culture of Economic Security in the Development of the Enterprise

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Abstract. Introduction This article examines the role of a culture of economic security for the development of socio-economic systems. The relevance of solving the problems of inefficiency of the institutional environment and the possibility of overcoming its negative impact on the activities of enterprises through the formation of a high level of a culture of economic relations is justified.

Methodology The methodological basis of the author's study is the institutional concept of economic security formulated by de Soto, which allows involving an instrumentation of institutional and sociological approaches. This made it possible to ensure the necessary methodological diffusion and take into account the influence of non-economic factors on economic development. The work uses such general scientific methods as the method of scientific generalization, heuristic, and the method of deduction.

Results The application of this methodology allowed the authors to conclude that the low level of economic culture leads to the development of shadow economic relations, to the habitualization of shadow practices that pose a threat to economic security. The characteristics of the levels of economic security culture, their subjects, forms of manifestation, risks of non-compliance, as well as measures to overcome them are presented. The sequence of stages of the formation of a culture of economic safety at enterprises operating in the field of nuclear energy has been determined. The choice of the example is due to the strategic, state-wide importance of issues of safety of nuclear power facilities in all its aspects, including economic. The authors propose a set of measures agreed on the tasks and deadlines for implementation, performers and resource support, allowing to achieve the set goals of economic development of enterprises with maximum efficiency. A preliminary assessment of the effectiveness of its implementation is given using the methodology for assessing the effectiveness of the implementation of state and municipal programs.

Conclusion Based on the study, it was determined that, as a result of the implementation of the set of proposed measures to improve the efficiency of the external environment at all its levels, based on the ethics of economic relations, the goal will be achieved to reduce the attractiveness of the shadow sector for business and reduce its scale.

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Keywords: Economic security · Culture of economic security · Shadow economy · Institutional environment

JEL Code: B52 · D73 · E26 · O17 · Z13

1 Introduction

The problems of the development of the national economy at all its levels - from federal to corporate - do not lose their relevance. This is primarily due to the dynamism of the external environment, characterized by the variability of factors, conditions and creating unpredictable risks for economic actors. Macroeconomic factors, especially the regulatory framework, can seriously constrain and, in some cases, block the implementation of strategic enterprise plans. The legal environment, together with economic, political and social norms, represents an institutional environment - a special "power structure" of the economy - combining the rules of legal and legitimate behavior of economic entities and ensuring the implementation of a regulatory and control mechanism (Zmiyak et al. 2020). An effective institutional environment is an integrative factor in the development of the national economic system, and, conversely, because of its excessive rigidity, it creates threats to security.

The analysis of the quality of the modern institutional environment is devoted to a significant number of scientific publications, expert reports posted in domestic and foreign sources (Kurbatova and Levin 2010; Krasnikova 2009; Schnaider and Enste 1997; Menshikov 2008; Mayminas 1999). At the same time, many authors agree that its non-adaptability to the needs of economic agents (and compromise in the matter of harmonizing the economic interests of all market agents is difficult to achieve) can be significantly smoothed out by a high level of economic culture. According to the Law of the Russian Federation "On Security," the concept of safety is characterized by a state of protection of vital interests. Thus, the multidimensional tasks of ensuring security are obvious - both the prevention of external threats, and the strengthening of human rights and freedoms, the protection of the material and spiritual values of society, the integrity of the country, etc. (Ilyin 2013).

2 Methodology

In order to substantiate the above statement on the significance of the institutional environment, reference is made to the institutional approach of the Economic Security Study underlying the concept of de Soto (1995). This concept allows us to attract the toolkit of sociology, thereby providing the methodological diffusion necessary for the study of economic phenomena, which allows us to take into account the whole variety of problems of reality. There are also many non-economic factors of economic development that both destructive and positively affect its results. It is necessary to diagnose their impact, develop incentives or deterrence measures. The position of researchers Kulkov (2017) and Shishkov (2001) is interesting, noting that the involvement of non-economic factors in the object of study makes it possible to penetrate into economic relations and more accurately know them. Many experts and scientists agree with this approach, since no matter how ideal economic instruments are, they will not become effective if the need and their application are not shared by all economic agents (Mierin and Makeeva 2013; Afanasenko 2019).

In such a way, in particular, Afanasenko (2017) notes that ethical and legal norms together constitute a single legal space, and the institution of morality is more stable in time than law. Unlike legal norms, it has the property of continuity, is less dynamic and is most often shared by the majority. This is due to the fact that moral (informal) norms are based on the commonality of interests, life positions and values and have the property of conjugation, arising where the malfunction of a formal institution can lead to the violation of important functions of the socio-economic system. That is why it is essential to prevent the formation of institutional traps, which include, in particular, the shadow economy and corruption (Manokhina 2011). The results obtained by the authors of the article are based on studies by such authoritative authors as Abalkin 1994; Afanasenko 2019; Kozlovsky 1999; Latov 2007; Nureyev 2010; Plotnikov et al. 2020; Golovko and Rudenko 2014; Hayek 1991; De Soto 1995; Plotnikov and Uskova 2018; Feofilova et al. 2016; North 1990.

3 Results

Shadow economic relations negatively affect the development of the national economy as a whole. Most scientists and experts see them as a threat to economic security due to the consolidation of ineffective informal practices of economic behavior, their habitualization (Golovko and Rudenko 2014). There is a position that the inefficiency of the measures used to counter the shadow economy and corruption is associated with a low level of entrepreneurial culture. The development of mechanisms to improve the ethics of economic relations can help to overcome the growth of shadow transactions and further develop such negative trends as:

- increasing the risks of entrepreneurial activity accompanying each corruption conspiracy;
- increasing mutual mistrust between economic agents arising from fears of unfair actions by the counterparty;
- undermining the business reputation and image of the organization, unfavourable situations in relations with partners;
- intentional or unintentional actions/omissions of the employees of the organization contrary to the mission and strategic guidelines of the company;
- increased costs of creating and maintaining a system of internal control, protection against leakage of information resources that make up trade secrets, etc.

The culture of economic security can be defined as a system of values, norms, rules that guide the development of any socio-economic system, ensuring its movement towards increased efficiency and security. This is achieved by:

- Creating a high level of personal (individual) and corporate (solidarity) responsibility for the results (Ugnich et al. 2016);

- increasing mutual trust of all participants in business processes, both insiders and external partners (suppliers, customers, contractors, etc.);
- the necessary and permissible level of transparency of economic processes.

In conditions of turbulence and continuing imperfection of the institutional environment, a high level of a culture of economic security allows to minimize the above risks.

The development of a culture of economic security depends on how effectively destructive factors are diagnosed and taken measures to prevent and/or overcome them, and how effectively the tasks of monitoring and auditing the activities of all economic actors, including the State, are solved.

Macro-, micro- and nano-levels of the culture of economic security can be distinguished, each of which is characterized by its own specificity - subjects/carriers of values, form of manifestation, risks (Fig. 1).

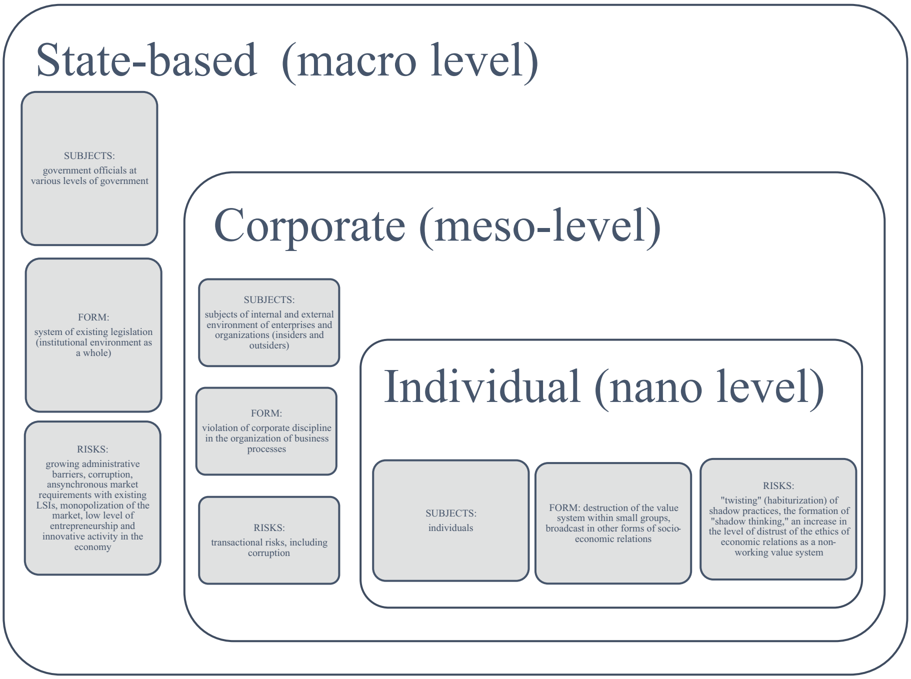

Fig. 1. Levels, forms and risks of violation of the culture of economic security

Depending on the subjects, level and forms of manifestation of problems of ensuring a culture of economic security, measures are formed that help to minimize risks and ensure greater stability of socio-economic systems of each level in relation to internal and external threats (Fig. 2).

In this article, an enterprise in the field of nuclear energy was chosen for an example of an algorithm for introducing an economic safety culture. The safety of the operating

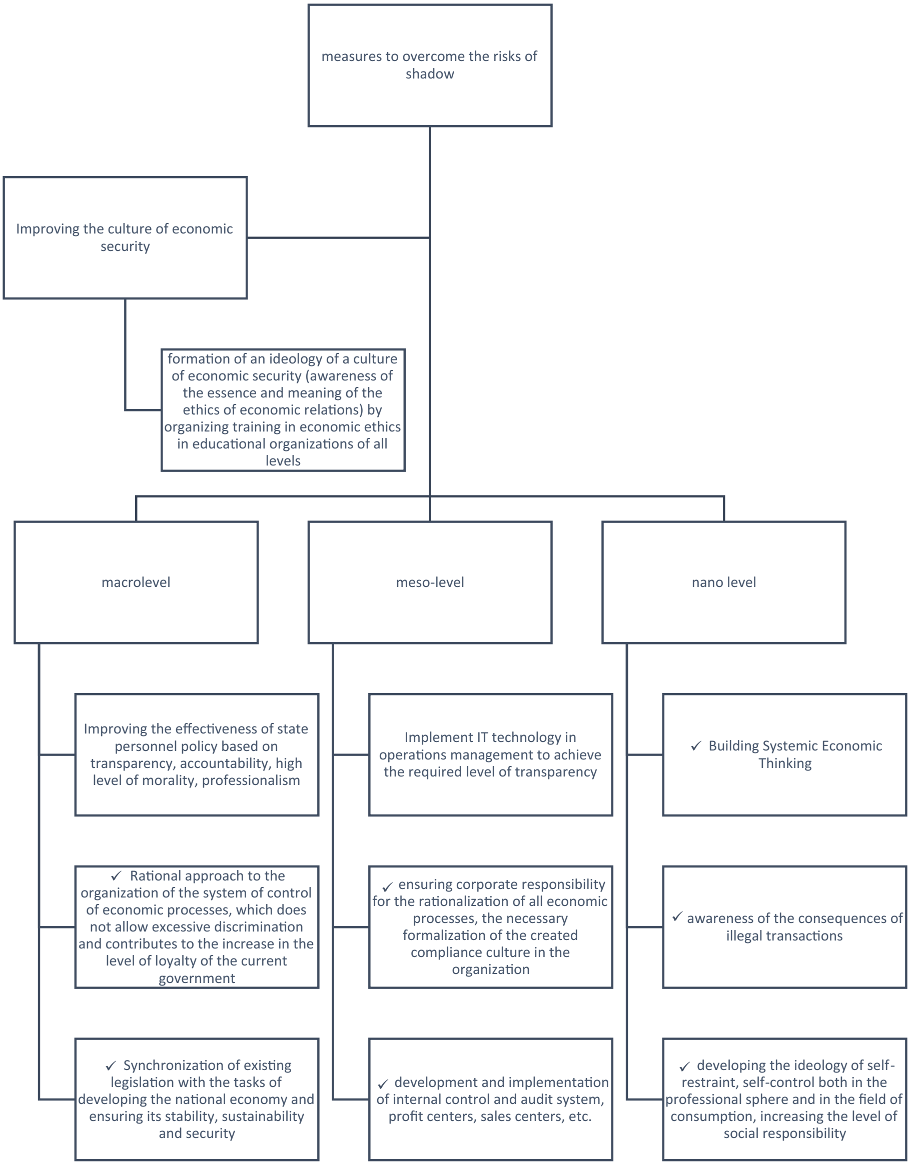

Fig. 2. Actions to address the risks and consequences of a low level of economic security culture at various levels

system of nuclear industry enterprises depends on many factors, each of which has a certain priority. Along with the problems arising from dysfunction in the technological subsystem, the inefficiency of economic processes affects the final results of the entire socio-economic system.

The nuclear industry is characterized by a significant influx of investment both from private business and from the state. This creates interest, including from unscrupulous economic insiders and outsiders, in organizing attempts to misallocate resources (Golovko et al. 2018).

The process of introducing a culture of economic security and its organic integration into the existing system of corporate values is quite complex and long. The algorithm proposed by the authors is based on a set of fundamental rules that should guide both developers and users to ensure the success of this large-scale project. These are the principles of legality, demonstration of the personal example of management of adherence to the developed system of rules and values, transparency and engagement, relevance and effectiveness, responsibility and inevitability of punishment, continuity of monitoring.

The methodological basis for the development and implementation of the project on the formation of a culture of economic security can be a balanced system of indicators and contains several stages (Fig. 3).

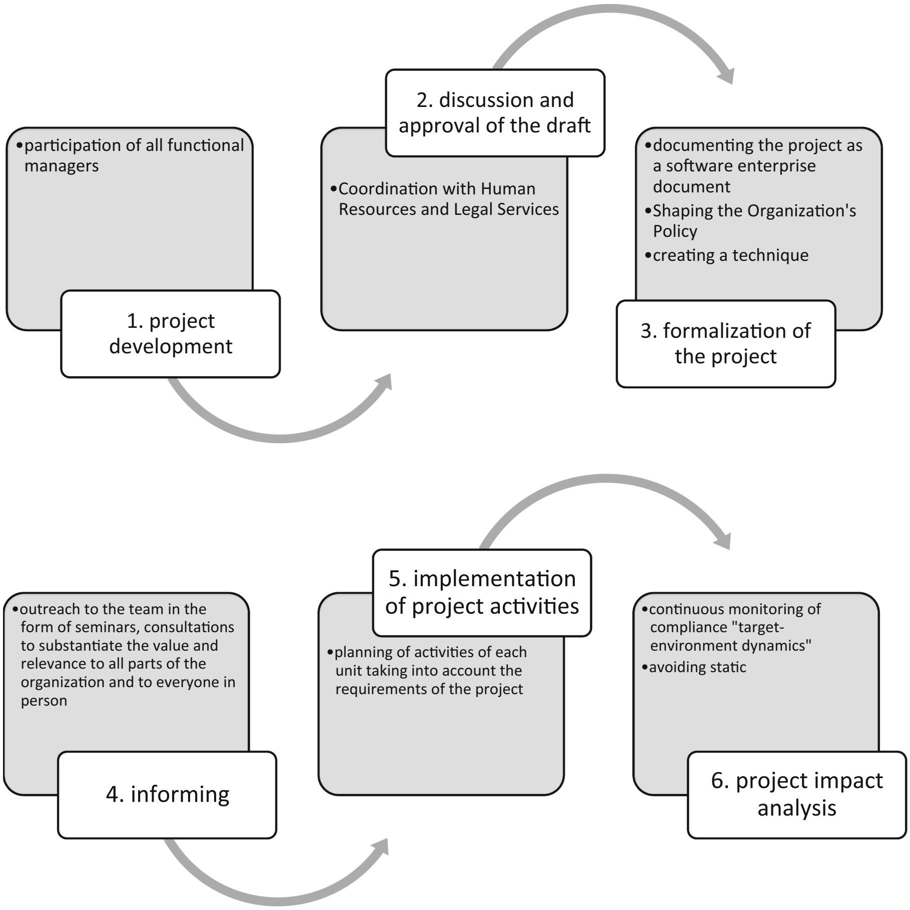

Fig. 3. Stages of implementation of the economic safety culture project

Logically, a document formalizing the algorithm for introducing a culture of economic security in an organization can be structured as shown in Fig. 4.

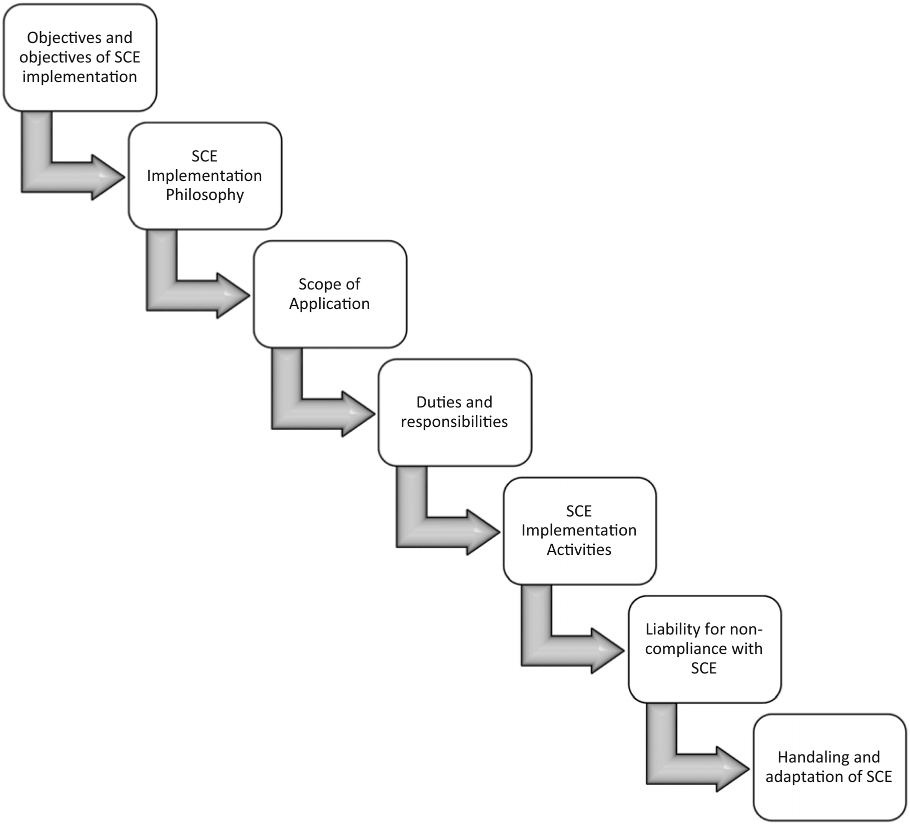

Fig. 4. Structure of the project to introduce a culture of economic security at the corporate level

The activities outlined in the fifth paragraph of the algorithm should include the development of regulatory frameworks, special procedures for adaptation and human development of the organization, a number of monitoring procedures and a mandatory effectiveness assessment. Basic (approximate) corporate-level measures for the formation of a culture of economic security:

– Legal and regulatory support aimed at the development, implementation and possible codification of such elements as: standards of ethics of internal and external economic relations; anti-corruption rules, which regulate, including, conflicts of interest, donation processes.
– development of special procedures aimed at improving economic security;
– adaptation and human development with a view to promoting active citizenship in economic security;

– control and audit;
– analysis and evaluation of the effectiveness of measures to introduce a culture of economic security.

Many indicators need to be developed and approved for monitoring and performance evaluation, which can be differentiated and detailed according to the specific characteristics of the enterprise and the position of management. We propose to use the system of indicators for state and municipal programs proposed by several (Rykova and Fokina 2014; Lapin et al. 2013; Afanasyev and Shash 2013).

The level of achievement of targets can be calculated using the following formula:

$$E_g = \frac{1}{m} \times \sum_{i=1}^{m} S_i \tag{1}$$

where Eg – level of achievement of the goal;

S_i – assessment of achievement of the i-th indicator set in the project;

m – the total number of indicators.

We need to note that the positive dynamics of various indicators can be estimated in different ways, for example, as: a) growth (income, reserves, savings, etc.), and b) decrease (costs, cost, losses, etc.). In this regard, their calculation should be carried out in comparison of the planned and actual indicator:

Accordingly, they can be calculated by comparing the planned key figure (P) and the actual key figure (F):

a)

$$S_{i1} = \frac{F_i}{P_i} \times 100\%; \tag{2}$$

b)

$$S_{i2} = \frac{P_i}{F_i} \times 100\% \tag{3}$$

where P – planned indicators;

F – actual values.

The evaluation of the effectiveness of the resources used for the organization and implementation of project activities can be calculated in the same way as cost-effectiveness indicators, for example:

$$E_c = \frac{M_g}{M_{fin}} \tag{4}$$

where Ec – Resource use Efficiency;

Mg – level of project activities execution (ratio of fact to plan).

Mfin – level of execution of planned resource expenditures (ratio of fact to plan).

Testing of the proposed technique was carried out at the industrial enterprise of nuclear power engineering JSC “Atommashexport.” Here is an example of calculating

Table 1. Results of testing of methodology for evaluation of efficiency of measures of economic safety culture implementation project using example of cost efficiency indicator at industrial enterprise of JSC "Atommashexport" in 2018

Description of the activity within the framework of the SCE development project	Indicators		
	Eg = Ec	Mfin	Mg
Legal and regulatory support	104.4	75.1	78.4
Special procedures	97.2	101.2	98.4
Human capital development	93.2	105.1	98.0
Monitoring and audit	98.0	80.1	78.5
Information and promotion	80.2	102.7	82.4

one indicator Ec (Table 1), the contents of each of the activities have been discussed above.

The results of the evaluation presented in Table 1 provide an opportunity to conclude that individual actual expenditures exceed planned expenditures. This has a negative impact on economic efficiency, but, as noted above, not all activities are cost-effective in the short term. For the first year of the proposed project, efficiency is quite high. In the above example, the result is oriented to the long-term perspective, since the correct perception and integration of the principles of the economic safety culture into the professional activities of the employees of Atommashexport JSC in the future will lead to an increase in the efficiency of all types of costs while reducing the number of activities.

4 Conclusion

The presented results of the author's study make it possible to draw the following conclusions. An integrated approach to the process of introducing a culture of economic security is characterized as a completely new approach, since it is based on the methodology of a balanced system of indicators. The reduction of shadow transactions in all forms and areas of their manifestation will be facilitated by improving the effectiveness of the institutional and corporate business environment, observing the principles of economic ethics by all business entities and government entities. The key factor remains the continuity of work, the scientific validity of all management decisions, the strategic approach to enterprise management in general and costs, in particular. We should not hope for quick results, since value benchmarks are taking a long time to form and a very little time to be destroyed.

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Adaptation of the Priority Model of Public-Private Partnership to the Conditions of Digitalization of the Russian and Abkhazian Economies

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Abstract. Purpose: The article is devoted to identifying the features of international public-private partnership projects in the field of digitalization of the Russian and Abkhazian economies, on the basis of which the requirements for the partnership model and the process of its adaptation to the conditions of international cooperation are determined.

Design/Methodology/Approach: The research is based on data on foreign economic relations between Russia and Abkhazia, dynamics of Russian goods exports to Abkhazia, practical experience in implementing PPP projects in partner countries, and characteristics of the regulatory framework for bilateral cooperation. The main research method is the dialectical method of cognition, as well as methods of quantitative data analysis.

Findings: The study identifies priority areas for the development of international cooperation between Abkhazia and Russia in the form of public-private partnership projects.

Originality/Value: The importance of public-private partnership as the most important form of interaction between business and the state, which is especially necessary for the development of the digital economy, is substantiated in the study. It is revealed that the priority model for international cooperation of States in the field of PPP is the concession model, which requires further improvement of the national legislation of the Russian Federation and the Republic of Abkhazia in the field of PPP, as well as international unification of the legal regulation of concession agreements, taking into account the challenges of innovative and technological cooperation.

Keywords: Public-private partnership · Model · PPP projects · International cooperation · Digitalization of the economy

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1 Introduction

There is no doubt that each of the models used in public-private partnership has its own advantages and limitations that determine the effectiveness of its use in a particular situation. In terms of international cooperation of Russia and Abkhazia for implementation of joint innovative technological programs in the field of the digitalization of the economy, one of the effective PPP models, in the view of the authors of the study, supports the concession model.

At the same time, positive results can be achieved by using other models, primarily the contractual model.

Whatever model of public-private partnership is chosen, it is necessary to adapt it to the conditions of partnership, based on the peculiarities of the legal systems of international partners, the economic situation in the markets of both countries, and the current geopolitical situation.

Taking into account the current economic realities in relations between the Russian Federation and the Republic of Abkhazia, in our opinion, international projects with the participation of Abkhazian state authorities and representatives of Russian business will be increasingly in demand. This distribution of partner positions is due to the fact that representatives of Russian business have large resources, compared to potential partners, in the field of digitalization: experience in project implementation, financial and material resources, management competencies.

2 Materials and Method

This research is based on the methodological basis of general scientific, economic and managerial research, scientific and dialectical method of cognition. Thus, scientific work contains a theoretical substantiation of the importance of international cooperation in the field of digitalization of the Russian and Abkhazian economies, implemented in the form of public-private partnerships; the main characteristics of priority of the PPP model and its adaptation to these conditions of use.

3 Results

Practical experience in implementing PPP projects in Russia allows us to identify promising areas for the development and implementation of international economic PPP projects in the Russian Federation (Dorina et al. 2019). We have accumulated experience in implementing effective infrastructure projects involving the creation of infrastructure facilities in accordance with ROSINFRA (2019).

In our opinion, the current conditions of international cooperation between Russia and Abkhazia can be sufficiently described by analyzing the foreign economic relations between the two countries. Russian and Abkhazian business structures conduct the necessary analysis of the business environment in terms of identifying opportunities and threats to implementation. The current structure of export-import operations between partners makes it possible to determine the most promising areas of international cooperation between Russia and Abkhazia. And the selection of large innovative high-tech projects can serve as an information base for creating an array of public-private partnership projects implemented within the framework of international cooperation between Russia and Abkhazia.

For potential participants in an international PPP project, to a certain extent, the existing foreign economic relations and the actual structure of imports and exports can serve as an information base for getting signals about which projects (industries) are interesting for Abkhazia and where Russian business can easily enter with a partnership initiative.

For the period 2017–2019, there is a positive trend in the export of Russian goods to Abkhazia (Table 1) (Russian Export Center 2019).

At the same time, a positive factor for the Russian side is a reduction in the export of raw materials to 3% in 2019, while non-resource non-energy exports of Russian goods account for 70.3% of the total volume of Russian exports to Abkhazia. Pharmaceutical and food products, as well as plastic products, account for a fairly high share of exports of Russian non-primary goods.

Table 1. Dynamics of Russian goods export to Abkhazia

Indicator	Value of indicators by year, million US dollars			Shareinexport, %		
	2017	2018	2019	2017	2018	2019
Export, total	206.9	192.3	211.4	100.0	100.0	100.0
Commodityexport	19.6	10.2	6.4	9.5	5.3	3.0
Non-resourceexports	38.8	45.6	56.4	18.8	23.7	26.7
Non-recourse non-energy exports	148.5	136.5	148.6	71.8	71.0	70.3

Such information refers to secondary sources of information and its collection does not require significant resources. In Russia, there are several sources of information available to entrepreneurs, which are provided free of charge. First of all, these are websites created on the initiative of government bodies to promote the foreign economic activity of Russian entrepreneurs, develop international relations with foreign partners, such as the RussianExportCenter, and Russian Foreign Trade. These are also websites of commercial organizations and consulting firms that have extensive experience in implementing international projects, for example, the website of REALEXPORT LLC, where, in addition to information about the volume and structure of imports and exports, legal acts regulating business activities in Abkhazia are also available. This information is useful for Russian representatives of the business community who are planning to participate in international public-private partnership projects with the Abkhazian side. In general, the legal framework for bilateral cooperation is quite extensive, currently including more than a hundred legal acts (Dabagyan 2015).

Despite this, in our opinion, future participants of the PPP project should take into account the existing gaps in the Abkhazian legislation in the field of public-private partnership, which can significantly limit the possibilities of project implementation, the variety of possible tools and models of partnership. First of all, the negative factors hindering the development of PPPs include the fact that the law “On public-private partnership” in Abkhazia is still under consideration.

Analysis of the legal framework in the field of entrepreneurship (the RA law “On investment activities”, the RA law “On banks and banking activities”, the RA law “On international agreements of the Republic of Abkhazia”, etc.), strategic documents, state programs, publications of government representatives and leading experts in the field of economics and management also allows us to identify priority areas for the implementation of international projects in terms of promising areas of development of the Abkhazian economy (Parakhina et al. 2019).

These include, of course, major infrastructure projects, including joint energy projects, projects for the development of the tourism and agricultural sectors (Lopatina et al. 2014). In the tourism industry, which is currently the engine of the Abkhazian economy, one of the priorities is to change the quality of the Russian tourist flow: from renting cheap housing from private owners to VIP-type “all-inclusive” recreation in modern health and entertainment complexes. The next strategic goal is to expand the geography of inbound tourism (Yemelyanov 2011; Vorontsova et al. 2013).

To solve these tasks, the tourist business is interested in interacting with Russian businesses that have extensive experience in the entertainment industry, building modern hotels with a SPA complex, a game zone, a climbing wall, a paintball park, a virtual reality club, an artificial ice rink, etc.

The priority direction for the development of international cooperation between Abkhazia and Russia in the form of public-private partnership projects is the implementation of projects for the digital transformation of the Russian and Abkhazian economies, including in the field of tourism.

Digitalization of tourism services, in our opinion, is also a promising area of international Russian-Abkhazian PPP projects. The experience of the Stavropol territory can be widely used in creating a virtual tourist map of the region, online tourist routes, tourist information stands, creating services for finding attractions on the territory of the Caucasian Mineral Waters (CMW) and the region as a whole.

The experience gained by Russian businesses in interacting with tour operators in the digital environment through the development and support of websites, starting from the moment of online sales and ending with feedback and support, is also in demand in the Republic of Abkhazia. Effective use of the CRM system is important for tour operators (Kvashnina and Oreshkova 2012).

Based on the above, we can offer the Abkhazian side international projects for the tourism industry based on more radical innovations, for example, using blockchain technology, which allows to safely make transparent transactions without the participation of banking structures in different countries, protect cryptocurrency wallets with at least two-factor authorization, and without the risk of sudden blocking of a plastic card. This determines the prospect of tourist trips without the need for the tourist to worry about the safety of such valuable things as documents and money.

This is especially true for Abkhazia, where according to the results of marketing research, one of the obstacles to the development of inbound tourism, respondents call the low level of tourist security.

In our opinion, the classical instruments of the concession model should be adapted to the conditions of international cooperation between Russia and Abkhazia, including with respect to the main challenges of innovative and technological cooperation.

It seems appropriate to form an institutional mechanism for public-private partnership, including the adaptation of PPP models and assessment of their effectiveness from the perspective of developing international innovation and technology cooperation, creating conditions for investment processes, and attracting additional resources in the context of digital economy. We would like to pay special attention to the fact that the priority model for international cooperation of states in the field of PPP, in our opinion, is the concession model (Karlina et al. 2018).

Therefore, we believe that the use of the PPP concession model is appropriate for international cooperation between Russia and Abkhazia, provided that the necessary adaptation mechanisms are developed and implemented to reduce the impact of the factors considered that limit its use in the context of digitalization of the economy.

We consider the following as the main directions for creating the proposed adaptation mechanism:

– improvement of the current Russian legislation and formation of legal support in Abkhazia, regulating the legal aspects of the application of concession agreements, including solving problems in the field of priority of international law over the same norms in the framework of national legislation;
– organization of the processes of international unification of the legal regulation of concession agreements, including in the sphere of active digital transformation of the economies of Russia and Abkhazia, where one of the main problems remains the regulation of intellectual property issues;
– formation of an organizational management mechanism in the field of management and practical use of concession agreements: organizational structure, interdepartmental commission in the state administration bodies;
– use of various forms and tools of public dialogue to increase the confidence of state authorities and business in the implementation of concession agreements (especially in financial matters, risk sharing of partners), as well as to identify priority areas for the use of concession agreements for innovative and technological development of both countries, digital transformation of the Russian and Abkhazian economies;
– reduction of bureaucratic barriers that hinder the development of concession agreements in regions and municipalities.

  As we can see, not all areas of the proposed adaptation mechanism are fully under the control of the Russian and Abkhazian sides, as participants in international cooperation. However, state structures in both countries must influence managed and partially managed factors (Mankova 2016).

  Within the framework of such international cooperation, much attention should be paid to the development and implementation of innovative PPP projects, including in the field of digitalization. The methodological basis of such projects is the appropriate tools, among which the transfer of innovations occupies a special place.

4 Conclusion

Thus, the research team has identified the concession model as a priority model that is maximally adapted to the conditions of international cooperation between Russia and Abkhazia.

The starting point for choosing a PPP model and adapting it to the conditions of development and implementation of an international project can be considered the direction and dynamics of foreign economic relations of a country, a specific region, and a potential foreign partner.

Summing up the research, it is possible to draw some conclusions:

– public-private partnership is a modern economic and legal reality that is indispensable for the development of the digital economy;
– the concession model is a priority model for international cooperation between states in the field of PPP;
– the national legislation of Abkhazia and Russia in the field of PPP, as well as the international unification of legal regulation of concession agreements, require further improvement to adapt the concession model to the conditions of international cooperation, taking into account the challenges of innovation and technological cooperation.

The directions for adapting the concession model to the conditions of international cooperation in the implementation of PPP projects, including in the field of digital transformation of the Russian economy and the IT sphere, involve eliminating gaps in the legislation on PPP in the IT sphere, implementing measures to increase the interest of private business in partnership with the state, stimulating its active participation in competitive procedures; establishing a public dialogue when discussing projects and programs implemented through PPP projects; effective expert assessment of companies for project implementation.

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Tools for Interaction Between Government and Business Structures in Russia and Belarus in the Context of Digitalization

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Abstract. Purpose: The article is aimed at theoretical generalization of tools for interaction between government and business structures in Russia and Belarus within the framework of the partner model being implemented in practice, as well as identification, interpretation and grouping of specific tools for interaction between government and business in the context of the realization of the modern partner and developing network model of interaction.

Design/methodology/approach: The results obtained by the authors' team were based on the study of monographic materials, current research and publications of scientists on the problem under study, as well as the practical experience of consultants and data from official international rating agencies. The authors used the tools of scientific research, approaches of critical analysis and synthesis of points of view on the research problem, methods of quantitative analysis of statistical data.

Findings: The study summarizes the tools of interaction between government and business in Russia and Belarus within the current partnership model in the context of digitalization and identifies possible directions for its development.

Originality/value: The authors found that the most developed tool for partnership between the state and business structures in Russia and Belarus, including in the context of digitalization, is public-private partnership. A promising trend of interaction between the considered agents in the digital information space - the electronic state-is revealed. It is proposed to form an integrated tool complex that covers all areas of interaction between the state and business within the authors' typology. Based on scientific foresight, the authors have developed additional tools for partnership between government and business in the context of digitalization, which becomes relevant in the process of developing a network partnership model.

Keywords: Government · Business · Partnership · Tools · Public-private partnership

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1 Introduction

There are a large number of tools for interaction between government and business structures, among which it is necessary to note the development of the regulatory framework, which is the basis for mutually beneficial cooperation between the state and business, increasing the role of public associations, business unions, associations and similar structures, the development of public-private partnership (PPP) institutions, etc.

There can be no doubt that the most methodically developed and empirically based tool for the relationship between government and business, which has proved its effectiveness, including in Russia and Belarus, is the PPP. Even today, there are a number of unresolved issues in Russia that do not contribute to the further development of this popular interaction tool. In particular, this is the problem of the correlation of the roles of each of the parties in such a partnership (Gelman 2017). It is still quite difficult for the Russian state to move from "administrative" regulation measures to coordinating the interests of government, business and society through public dialogue. And the increasing economic and political role of the Russian state is accompanied by increased control and regulatory functions. Cooperation between the state and foreign businesses remains more fruitful in terms of partnership.

2 Materials and Method

As research methods that were used by the authors' team in the process of forming a point of view on the problem under study, it is advisable to specify the methods of intuitive knowledge and scientific foresight, deductive and inductive logic, and others. Scientists carried out a theoretical search, generalization and interpretation of research issues, critical analysis and synthesis of points of view of members of the scientific community, practicing consultants and business representatives on the presented topic. The authors also used methods of quantitative analysis of statistical data and data from official international rating agencies.

3 Results

In the context of digitalization of the Russian and Belarusian economies, any models of interaction between government and business widely use such a tool as "e-government", which is not yet fully functioning in the Russian Federation and Belarus, but is actively developing. E-government helps to minimize contacts between officials and entrepreneurs in the interaction between the state and business, and helps to fight corruption. Thus, an important part of e-government has become the "one window" technology, which makes it possible to reduce the cost and increase the speed of providing public services through the use of information computer technologies for interdepartmental interaction, as well as cloud computing and services, open data, electronic signature and other technologies.

We join the opinion of Melnikova and Abubikerova (2018) about the growing contradiction of the provisions of this concept to the intensive development of information technologies and the formation of a network society.

The very logic of the existence of a network society determines the direct access of all elements of the network to each other and, accordingly, a fundamentally different non-hierarchical management model. For this purpose, some experts introduced the term "e-government" into scientific use.

The creation of an information and communication system for interaction and dialogue is designed to strengthen the role and participation of citizens in public administration and decision-making using digital technologies, which gives impetus to the development of e-democracy within the framework of e-government. In fact, this is the most advanced stage, and it should be noted that most often the key role of e-government is reduced to the function of providing services, which allows a number of researchers to speak of the phenomenon of the "service state".

It is worth pointing out that the phenomenon of e-government is considered in the framework of the concept of creating a single information space of the Union state as a mechanism for integration (Ryzhova 2018).

In the world ranking of countries for the development of e-government e-Government Survey-2020 (United Nations Department of Economic and Social Affairs (2020)), published periodically by the United Nations (usually updated every two years), Russia ranks 36th, and Belarus - 40th. At the same time, in comparison with the previous ratings of 2014–2018, Russia's position is decreasing (it lost 9 points compared to 2014), while Belarus' position is improving (it has risen by 15 points). It is important that the position of countries in the ranking depends on indices that take into account both the level of development of online services and telecommunications structure (i.e., factors that determine customer orientation or, in other words, the sign of a "service state" in e-government), and the human resource and the degree of participation in decision-making through digital technologies of the population (i.e., a criterion that reflects the stage of development of e-democracy). After analyzing the indicators of Russia and Belarus, it can be stated that although the countries demonstrate a high level of indices, the development of e-government in Russia and Belarus has passed only two stages – consulting and public services (Dorina et al. 2019).

Thus we can assume that in Russia the dynamic development of these areas provided a higher place in last rating of 2014 and the drop in the rating by 2020 is determined by the slowing growth rate because the next step logically should be the creation of a system of interaction and involvement of population in decision-making, but this is not progressing so fast as required. In Belarus, on the contrary, there is an active transition from the stage of consulting to the provision of public services, the rapid development of electronic online services, so it is natural that this provided an increase in the rating in the development of e-government. However, no matter how dynamically e-government develops separately in Russia and Belarus, this potential is currently poorly used within the framework of the Union state. As a result, the official website of the Standing Committee of the Union state currently has only an Internet reception of all official potential resources (Official Website of the Standing Committee of the Union State (2020)). It is noteworthy that the official plan of measures adopted jointly to create a common information space of the Union state for 2018–2022 (Supreme State Council of the Union State 2018) does not contain a single item aimed at the development of e-government.

After analyzing the current situation, we can conclude that with a sufficiently high level of e-government development in Russia and Belarus, the Union state is at the first stage of development of a single e-government. Thus, there is not even an independent service function, and only such services as informing and consulting are provided.

Representatives of the scientific community identify areas of interaction between government and business, each of which is characterized by the use of specific tools for such interaction (Moiseev et al. 2013; Lopatina et al. 2014).

Recognizing this point of view as rational, the authors proposed to identify the five most important types of interaction between government and business structures and, within each of them, indicate the appropriate tools, the development of which should be given special importance:

- financial interaction (tools: financial sections of programs and plans at various levels; financial support for targeted programs);
- material interaction (tools: public procurement, supply of goods and services for public needs);
- project and management interaction(tools: drafting development programs and strategies for socio-economic development of regions); "strategic outsourcing" (tools: transfer of a number of business processes or parts of a state-owned company's business function to representatives of business structures); organization of joint ventures (tools: risk management in the implementation of important and large-scale projects of social significance);
- regulatory and legal interaction: procedures for competitive interaction between business and government (tools: competition regulated by state authorities; implementation of state orders and grants, etc.); interaction in the implementation of the legislative function (tools: activities of business associations, nonprofit organizations, and business coalitions acting as accumulators and representatives of the most common interests of business of all forms and levels; interaction within the framework of agreements and treaties (tools: public partnerships and municipal private partnerships, agreements on socio-economic cooperation; professional codes and ethical declarations, social (non-financial) reporting, a set of methods and techniques of corporate governance and corporate social responsibility of business, an arsenal of standards and regulations, etc.) (Parakhina et al. 2019);
- territorial and communicative interaction (tools: public and coordination councils under government bodies, which also include business representatives; special economic zones and territories of advanced development, technology parks; network and professional self-regulating communities and reference groups, etc.).

As part of the priority strategic development of partner models in Russia, which is justified in the study, we have developed tools for interaction between the state and business, which can be divided into basic, typical for all types of partner models, and additional, which are manifested exclusively in the network partnership model based on breakthrough development (Table 1).

Table 1. Basic and additional tools and interests of interaction between government and business in the model of network partnership based on breakthrough development

Area of cooperation	The tools of interaction	Interests of business structures	Interests of power structures
Additional component			
Initiating the development of basic socio-economic documents and plans within the digital economy (economic relations of production, distribution, exchange and consumption mediated by a network organization, the Internet, cellular communications, digital IT technologies); transfer the management of network processes to the network community; innovative partnerships; network alliances and consortia	Participation of the society in the financing of business initiatives and innovations represented by its individual citizens using network technologies –crowd investing and crowd funding (Kickstarter model); developed "strategic outsourcing"; crowdsourcing; sharing economy	Businesses are interested in a broad innovation field, open data, demand-side support for innovation, large-scale investment, mobility of all resources, and an optimal combination of government regulation and self-regulation of network processes through the network community	The interest of the state is to transfer most of the regulatory functions to the participants of the network community; control of processes by the type of system administration; state regulation of complex economic or social problems, the severity of which the network community is not able or not interested to reduce independently

(*continued*)

Table 1. (*continued*)

Area of cooperation	The tools of interaction	Interests of business structures	Interests of power structures
Basic component			
Development of a joint legal framework, strategic documents, target programs and their implementation, creation of public-and municipal-private partnerships, social partnership	Public dialogue between government and business in various forms: public and coordination councils, activities of self-regulating and reference groups; joint development and expertise of territorial development strategies by individual representatives of business and government, etc.; implementation of partnership: agreements on socio-economic cooperation; co-financing of social programs in the framework of intersectoral interaction, corporate social responsibility and social reporting; investment projects in the framework of target and inclusion in state programs; the performance of state contracts, the PPP and MPP, etc.	Business is interested in regulatory impact assessments from the point of view of redundancy of restrictions and obligations for business entities, providing additional preferences and benefits for business, and solving problems through public dialogue. Within the partnership – administrative and political assistance of government agencies in implementing projects; sharing risks with a public partner; obtaining guaranteed income; access to investment resources; obtaining reputational advantages, and so on	The state is interested in the accelerated implementation of large-scale projects that are significant for society through additional funding from extra-budgetary sources; outsourcing of non-core tasks and inefficiently performed functions, including involvement in solving social problems; obtaining high-quality products from businesses that are in demand; creating new jobs; filling budgets of all levels with taxes

4 Conclusion

The study shows that the Russian Federation uses a large number of tools for interaction between the government and business structures, among which the most methodically developed and empirically based, proven to be effective, including in Russia and Belarus, the tool for relations between the state and business is public-private partnership.

The role of e-government as a priority technology for interaction between government and business structures is substantiated.

The article highlights a promising trend in the development of relations between government and business structures in the context of digitalization, in which the e-government in a broad sense is designed to develop as a guarantor of the legal framework of all elements of the information space (digital economy, digital education and mass communications) and ensure citizens' rights in this information space (consulting and service functions of providing public services for citizens of countries – participants of the Union state and their subsequent involvement in the decision-making process via electronic platforms).

Within the framework of the priority strategic development of partner models in Russia highlighted in the study, we have developed tools for interaction between the state and business, which can be divided into basic, typical for all types of partner models, and additional, which are manifested exclusively in the network partnership model based on breakthrough development.

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Development of Innovative Methods of Lead Management in Retail Trade in the Region

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Abstract. Purpose: The purpose of the article is to develop an applied approach to solving the problem of forming methodological tools for marketing solutions in retail aimed at lead generation of retail customers.

Design/methodology/approach: The relevance of the theoretical understanding of the subject is also due to the problems of developing marketing solutions for retail trade enterprises, which are primarily associated with the individualization of relations with consumers, personalization of marketing communications, and the possibility of influencing the decision-making process.

Findings: In developing recommendations for the use of marketing control tools, it is necessary to focus on the concept of marketing audit as a comparative analysis of the actual and planned sales results of a retail enterprise. In this work, one of the universal tools for managing retail sales is the sales funnel. Since it is important for this research to find productive marketing solutions for retail businesses, it is advisable to use lead generation as a driver of sales growth when forming a sales funnel.

Originality/value: The authors of the study established the rules of lead generation in retail trade, which contains, together with a description of the tasks and sequence of stages, a toolkit of lead generation activities divided into three groups according to the phases of lead generation: the initial phase – identification of leads, the main phase – lead generation activity, and the final phase – retail sales.

Keywords: Marketing solutions · Strategic solutions · Tactical solutions · Retail · Sales funnel · Lead generation · Innovative lead management

JEL Code: M31

1 Introduction

Retail trade largely determines the level of regional development, as it is one of the most dynamic and popular areas of the regional economy. To ensure the progressive

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development of retail trade in conditions characterized, on the one hand, by increased activity and interest of customers, and, on the other, by full or partial lockdown, it is necessary to form an adapted algorithm for step-by-step work with new potential customers. In other words, only innovative methods of lead management will attract new potential customers through the use of traditional marketing technologies that take into account the specifics of the economic state of the region.

The problem of organizing a marketing audit of retail trade in order to ensure the growth of its quantitative indicators, among which the sales volume is important, currently remains insufficiently studied. In order to increase their turnover, retail businesses must systematically conduct marketing audits that will identify productive tools for strategic control (Ostrovskaya et al. 2017). In this regard, it is essential that the identification of effective tools of marketing audit in retail trade. When developing recommendations for the use of marketing control tools, it is necessary to focus on the concept of marketing audit as a comparative analysis of the actual and planned sales results of a retail enterprise.

2 Materials and Method

The marketing orientation of management in trade is described by researchers who are mainly based on conceptual approaches, such as Kohli and Jaworski (1990), Webster et al. (2005). Kotler et al. (2019), Gordon (2001), Malhotra (2003) and others dealt with marketing and marketing management issues in general. The design of the authors' analysis was determined by the fact of a limited number of studies in the direction of retail consumer marketing.

The review of the scientific literature in this area of study allowed us to confirm the opinion that the instrumental support of marketing solutions in retail aimed at forming the lead generation flow of customers has not been fully reflected in economic research. The design of our research includes the formation of conceptual directions for improving marketing management solutions in retail. Determining the essential and structural content of the retail sales funnel based on lead generation of target groups will help to solve the tasks set.

3 Results

One of the universal retail management tools is the sales funnel. In fact, the sales funnel in retail allows to distribute customers by stages of the sales process, it indicates the path that the client is following, starting from the stage of awareness of a particular product by the buyer and up to the moment of concluding a transaction (BizHint 2016).

The classic structure of the sales funnel is based on the concept of customer behavior psychology AIDA and has the following configuration:

– initial phase, in other words, cold contact;
– adaptive phase, i.e. interest;
– the illustration phase, i.e. persuasion;
– selection phase, or purchase.

In retail, it is crucial not just to close a deal, but to initiate repeated purchases, i.e. to continue working with customers and form a loyal customer base.

The key tasks of using the sales funnel in retail were identified as the following:

1) determining the target audience for sales;
2) building of the process of interaction with the consumer;
3) conversion calculation at each stage;
4) identifying the "weak link" in the sales chain;
5) ability to assess the performance of sales staff;
6) forecast of overall business performance.

In addition, the sales funnel of a commercial enterprise makes it possible to organize a thorough study of the dynamics of the following indicators: the number of cold contacts, the number of citizens who showed interest, the number of buyers who reached the final level, the amount of the average bill from one purchase.

There is no objection to the fact that the sales funnel is an informative analytical tool that allows generating sales statistics in the retail segment (Tatasheva et al. 2017).

We recommend building a sales funnel in the analyzed segment based on a number of criteria: new customers, current customers, sales channels, products, target audience, territories (stores), and employees.

It should be clarified that the standard components for analysis, in our opinion, should include such indicators as the entrance to the funnel, the results at the exit, the total transformation, the transformation between stages, the length of the funnel, the length of each stage.

Analysis of these components allows to determine the stage at which the main loss of customers occurs, which makes it possible to adjust business processes. Since it is important for this study to find productive marketing solutions for retail businesses, it is advisable to use lead generation as a driver of sales growth when forming a sales funnel.

The main goal of lead generation is to manage the number of potential customers, which objectively affects the growth of sales. Given the fact that retail businesses of different formats have their own target market and this is not always a wide range of customers, but it should be systematically expanded by attracting new customers, the use of marketing tactics of lead generation can be considered very relevant. And those stores that assure that they do not feel the need for new customers are characterized either by a limited sales market, or lack of their own resources, or have serious difficulties in building the lead generation process (Nazipov 2016).

The use of the authors' algorhythm on lead generation allows to solve the following tasks:

1) identification of potential consumers;
2) testing methods of marketing tactics;
3) search for contact details of potential buyers;
4) making a list of potential consumers;
5) determining the level of interest of specific potential buyers;
6) the achievement of certain quantitative indicators of sales;
7) maximum return on investment.

At the first stage, the target audience of a retail trade enterprise is determined. At this stage, demographic, geographical, behavioral, and psychographic characteristics are evaluated.

Next, we prepare and test marketing materials for lead generation. This process is aimed at consistent implementation of the following activities:

– preparation and trial distribution of marketing materials within the test project;
– getting customer feedback and analyzing the reasons for customer objections;
– the product/service repositioning;
– improvement of marketing materials.

At the third stage in retail, it is necessary to organize the identification or, in other words, the initial search for leads. When considering the retail sector, we primarily consider individuals who acquire the status of customers by making purchases in stores, rather than the corporate sector. The use of contact data of individuals who have not given their consent in the Russian Federation is a violation of Federal Law No. 152-FZ "on personal data" (ConsultantPlus Legal Reference System 2020). Accordingly, it is unacceptable to use the contact information of individuals collected by partners and/or competitors, posted on free domains, since all personal information is the property of an individual. According to the law on personal data, their owner must first confirm their consent to receive information. In this regard, it is fundamentally important to use the contacts of individuals to send bulk sms and e-mail only to those recipients who have confirmed their consent to receive news from a particular merchant. Customers' consent can be obtained by filling out a questionnaire by the buyer when issuing loyalty cards or by filling out a registration form on the corporate website.

Once the database of potential leads is formed, it is necessary to organize their qualification. During this process, it is important to assess the interest of potential customers and the possibility for purchase. As a result, the qualification highlights the most and least potential leads in terms of sales. They are called hot, warm, and cold. In retail lead generation, there are three key criteria for evaluating the potential of a lead – need, interest, and budget. For premium products, contact in the decision-making process also plays an important role.

In the process of lead qualification, it is necessary to record the results of contacts with potential buyers and analyze positive responses. At this stage, "hot", "warm" and "cold" leads are identified. The "cold" lead is aware of the point of sale, its product, services, but does not feel an urgent need to buy. The "warm" lead is interested in the store's products and services, they are ready to buy, but the payment has not been made yet. The "hot" lead has a well-formed need, the necessary budget, and is ready or has already made purchases. In the process of lead qualification, a so-called "lead funnel" is built. One of the researchers of lead generation formulated the term as follows: The "lead funnel" systematizes all stages of the cycle from the moment of attracting attention to the fact of sale" (Aldarova 2017).

The fifth stage of lead generation is based on optimization and systematization of marketing activities in relation to "hot" and "warm" leads (Bakharev and Nekrasov 2017).

We will create tools for lead generation activities that are used in the retail sector to help strengthen the interest of leads:

1) personal interaction:

   – telesailing;
   – marketing research.

2) mailing lists:

   – personalized e-mail;
   – direct mail, letters and flyers;
   – sms mailing lists.

3) interaction on the Internet –

   – using a corporate site to collect leads;
   – contextual advertising in search engines;
   – social networks as a source of leads;
   – advertising on online resources for the purpose of lead generation.

4) offline advertising with lead generation elements:

   – advertising in the media (print media, radio, TV);
   – outdoor advertising;
   – indoor advertising in public gathering places.

5) technologies of interactive interaction with the consumer.

In response to digital marketing activity, the merchant receives sales (Kusakina et al. 2019).

At this stage, it is important to emphasize the specifics of lead generation and sales management in retail. There is no denying that a lot of things in lead generation depend on the correct choice of the target audience, marketing channel and information message, but not everything. Systematically, initiators receive a certain number of responses that come from interested, but still thinking customers. At this stage, it is important to analyze the reasons for objection and organize a business process for the maturation of cold leads. The goal of this stage is not to lose the clients' contacts, but to continue working with them for further lead generation activity.

At the final stage, to evaluate the effectiveness of lead generation, the percentage of lead conversion to sales is calculated, that is, the ratio of real and potential customers. Conversion makes it possible to evaluate not only the quality of leads, but also the effectiveness of the entire lead generation process.

Thus, considering the set of tools for lead generation activities, we propose to divide them into three groups according to the phases of lead generation, denoting them as follows:

– the initial phase - identification of leads;
– main phase - lead generation activity;
– the final phase – retail sales.

The developed regulations on lead generation for retail enterprises have a high degree of relevance and significance.

The practical use of technical and technological innovations that have not yet been tested in practice, contributing to the effective automation of lead generation techniques, is possible with the involvement of venture capital. It is venture entrepreneurship that will support the innovative activity of retail trade in the organization of lead management and ensure the successful commercial implementation of the developed idea and technology with minimal costs (Lopatina et al. 2014).

4 Conclusion

Thus, in the course of the study, it was found that the retail sales funnel allows not only to study the results obtained, but also to actually manage them, acting as a universal and fundamental tool for marketing solutions for business development. This means that the ability to build an effective sales funnel can help you gain a significant advantage over your competitors, and your business can get great opportunities to expand.

The authors' task was solved by creating a guide to the formation of a sales funnel based on lead generation, not at the expense of excessive complexity, which would make it difficult to apply such a technique in practice, but by developing simple and visual tools that would allow the management of retail enterprises to make effective management decisions without excessive effort to master this tool.

It should be stressed that the need for the developed algorithm arises for any commercial enterprise, regardless of the format, as it helps to solve the main task of retail trade - increasing sales. It is important to note that the formation of a sales funnel based on the built-up lead generation in retail has recently undergone some changes in the context of new technologies, including the "Internet of things". This technology combines a network of physical objects – "things" equipped with built-in technologies for interacting with each other or with the external environment, eliminating the need for human participation in some actions and operations.

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From the Construction of Schools to the Digitalization of Education: Critical Issues of Education in the Caucasus in the Conditions of Integration of Educational Spaces in Russia and South Ossetia

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Abstract. Purpose: In the context of the ongoing integration processes, we have attempted to analyze the social factors affecting the realization of the right to education in Russia and South Ossetia and, based on their comparison, to conclude the degree of integration of the educational spaces of both States.

Design/Methodology/Approach: The analysis of the education system and the actual possibility of realizing the right to education in historical terms make it possible to better understand the modern problems that exist in education. The Russian Federation, recognizing the Republic of Ossetia as an independent State in 2008, not only committed itself to ensuring the security of the population of South Ossetia, but also pledged to assist in the development and modernization of education.

Findings: To achieve the task, the legislation on education in the Caucasus of the period XIX-XX centuries, the modern legislation on education of the Russian Federation and the South Ossetia were analyzed. This analysis made it possible to draw up an idea of state educational policy in the Caucasus in various historical periods and at present.

Then we analyzed historical sources (analytical reports of educational authorities, monographic literature, etc.) containing information on various problems in the field of education in the Caucasus that complicate the realization of the right to education.

Originality/Value: In 2019, in order to identify social factors (problems) that currently affect the realization of the human right to education, a sociological study was conducted in the subjects of the North Caucasus Federal District of the Russian Federation and in the South Ossetia, covering almost 2,000 people. Based on the pooled data, we made conclusions on the degree of integration of educational spaces in Russia and South Ossetia. In general, the integration of educational spaces has already occurred. The educational environment of South Ossetia is characterized by the same negative social factors that manifest themselves in the educational space of the subjects of the North Caucasus Federal District of the Russian Federation.

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Keywords: Right to education · Problems in education · Education system · Caucasus · South ossetia

JEL Code: I20 · I28

1 Introduction

The Republic of South Ossetia has never had experience in the independent development of the national education system. Education, as a social sphere, was influenced first by the Russian Empire, then the Union of Soviet Socialist Republics, then Georgia. Currently, the Russian Federation has a decisive influence on the development of education in South Ossetia.

Education in the modern sense in the territory of South Ossetia appeared only in 1847, when the first school was opened in the village of Java. In that period, a stormy and controversial process of development of public education in the Caucasus has begun (Gatagova 1993).

The population of South Ossetia, being on the south side of the Caucasian ridge and without reliable transport links with the Ossetians living in its northern part, was subordinate to Tiflis in terms of educational state policy, even though it was in the field of politics of the Russian Empire. This geographical aspect of the division of the Ossetian people seriously affected all spheres of life in South Ossetia during the XIX and XX centuries, including the field of education.

It cannot be said that the Ossetian population was uneducated. In the late XVII - early XIX century. Parish schools (extremely small in composition of students) are widespread. In the second half of the XIX - early XX centuries. Shool network in South Ossetia is increasing. Ministerial schools appear along with parish schools. The number of children studying in them is increasing.

However, the formation of the educational space of South Ossetia was slow and difficult, in extremely difficult conditions. There were no pedagogical personnel, no material resources, no adapted premises, the necessary pedagogical principles and techniques were not used, the traditions and customs of the people were ignored (Beteeva 2006).

There was no mass public education until the arrival of Soviet power in Transcaucasia. The modern system of public education of South Ossetia began to be created since 1921. Since 1922, South Ossetia received the status of an autonomous region as part of the Georgian Soviet Socialist Republic. Authorities in South Ossetia, with the support of the local population, were able to organize work to eliminate illiteracy.

In the 1925–1926 academic year in South Ossetia there were 104 schools, one pedagogical college, one orphanage and a kindergarten. In total, 5,128 students studied in schools this year, among them Ossetians – 3,365, Georgians – 1,391, Russians – 25, Armenians – 222, Jews – 125. By 1930, the literacy rate in South Ossetia reached 90% of the population.

Since 1936, the education system of South Ossetia was included in the general education system of the USSR (Kulumbegov 2016). After the collapse of the USSR since 1992, South Ossetia de facto became a state with its own symbols and constitutions, although it was part of Georgia as an autonomy.

On March 18, 2015, the Agreement on Alliance and Integration was signed between the Russian Federation and the Republic of South Ossetia. To a large extent, this integration has already taken place, given the objective impossibility of the existence of South Ossetia without the Russian Federation. But full integration is possible only in the context of the unification of the two States, which at present is not necessary for objective reasons of an international legal nature. The state policy of South Ossetia, including in the field of education, is under the serious influence of Russia (Trofimov 2017).

In this regard, the degree of integration of the South Ossetian and Russian educational space is of interest. It is important to understand what qualitative and quantitative indicators of education can answer this question. Most often, the topic of integration is discussed when discussing the political prospects for the development of cooperation between the two states.

2 Materials and Method

Various methods and approaches have been used to study the scientific problem, which allow us to establish the degree of actual integration of the educational spaces of the two states.

Methods of interpreting the legal norms (functional and systematic) contained in the legislation on the education of the Russian Federation and South Ossetia and the norms contained in interstate acts concluded between these countries on education issues were used.

The actual state of the educational space of South Ossetia and subjects of the North Caucasus Federal District of the Russian Federation comparable in qualitative and quantitative characteristics with the South Ossetia Regional District was studied. At the same time, the dynamics of the development of the educational space of the South Ossetia since 2015 was also taken into account to 2019.

To identify problems in the field of education of the constituent entities of the Russian Federation located within the North Caucasus Federal District and the South Ossetia, a sociological survey of the population was conducted in 2019, in which both ordinary citizens and employees of the educational system took part.

At the same time, at this stage of the research, the state of higher education and the problems (Smirnov 2020) that are characteristic of higher education in Russia and South Ossetia were not considered.

3 Results

In our view, the degree of integration of the educational spaces of the Republic of South Ossetia and the Russian Federation should be considered through the prism of guaranteeing the realization of the human right to education and the absence of problems complicating the realization of this right.

In fact, this is a multi-component research, since the possibility of realizing the right to education depends on numerous factors that manifest themselves differently in the conditions of Russia and South Ossetia. Bringing the maximum number of factors to the same denominator will indicate the degree of integration.

The first factor to be considered is the legal enforcement of the right to education. The Constitution of the Russian Federation of December 12, 1993 and the Constitution of the Republic of South Ossetia of April 8, 2001 guarantee everyone the right to education. At the same time, fixing that preschool, basic general and secondary vocational education in state educational institutions is publicly accessible and free. Laws on education currently in force in Russia and South Ossetia (Official Website of the Parliament of the Republic of South Ossetia, 2017; Reference Legal System of ¼ Plus, 2020) show in comparative analysis a significant degree of similarity. Many provisions of the South Ossetian legislative act are copied from the Russian counterpart, although the law of the Republic of South Ossetia enshrines national features. Both legislative acts, as one of the fundamental principles of State policy in the field of education, establish the creation of favorable conditions for the integration of the education system with the education systems of other States on an equal and mutually beneficial basis.

The second factor to be considered is the construction of the education system. By the time the USSR collapsed, there was a developed and successful Soviet education system in South Ossetia (Dzidzoev 2008). Throughout the past years, the education system of the South Ossetia has continued to evolve in the same paradigm. The education system of the Russian Federation is also based on the Soviet system. According to the law of the Republic of South Ossetia, the education system is a set of interacting continuing educational programs and state educational standards of various levels and directions, educational management bodies and organizations subordinate to them, regardless of their organizational and legal forms, types and types (part 1 of article 2). Both laws regulate the internal structure and content of the education system.

State educational standards and state educational programs used in the educational process of the Republic of South Ossetia are those of Russia. In this regard, we note that in November 2015 in Tskhinvala (South Ossetia), at the 15th meeting of the Intergovernmental Commission, a plan of measures was signed to assist in improving the quality of education in the Republic of South Ossetia on the basis of the Agreement between the Republic of South Ossetia and the Russian Federation "On Alliance and Integration." One of the points was the issue of conducting advanced training of teachers in South Ossetia by Russian specialists. The list of topics of advanced training courses included the following: "Implementation of Federal Educational Standard of preschool, primary and basic general education."

The legislation of both countries establishes general education, vocational education, supplementary education and vocational education. The levels of school and vocational education in Russia and South Ossetia also coincide, as do the terms of study. Russian and South Ossetian schools teach in Russian. The types of educational organizations are the same.

The third factor to be considered is the logistical and economic support of the education system. Equality of opportunity in education implies the accessibility of quality education to all segments of the population, regardless of material and social status. And if in Russia and South Ossetia the accessibility of education is guaranteed at the legislative level, in practice, problems still often arise.

Russia, as a large and economically wealthy state, successfully solves issues of logistical support for the field of education. The situation in South Ossetia is different.

For this reason, it is more appropriate to compare the Republic of South Ossetia with the constituent entities of the Russian Federation located within the North Caucasus Federal District. Although such a comparison will not be quite correct due to the inconsistency of the population and, accordingly, the number of students and scientific and pedagogical workers: a little more than 55,000 people live in South Ossetia.

So, as of the first half of 2019, 3891 people were employed in the field of education of the South Ossetia. with an average monthly salary of 18,210 rub (Statistical compendium of the Republic of South Ossetia 2019).

In 2018, 13,749 people were employed in the field of education in the Kabardino-Balkarian Republic of the Russian Federation, while the average salary of pedagogical workers was 21,364.25 rub (Ministry of Education, Science and Youth Affairs of the Kabardino-Balkarian Republic 2018).

In the Stavropol Territory in 2017, the average salary of scientific and pedagogical workers of preschool and school levels of education amounted to 34 447.75 rub (Ministry of Education of the Stavropol Territory 2018).

In 2017–2018, 67,140 people were employed in the education system of the Republic of Dagestan, of which 44,968 were scientific and pedagogical personnel of schools (Ministry of Education and Science of the Republic of Dagestan 2018). As can be seen, the remuneration of pedagogical workers in the South Ossetia is less than in the North Caucasus constituent entities of the Russian Federation, but not significantly.

As for logistics, in 2017 in the capital of South Ossetia, the city of Tskhinval, 8.3% of schools were in dilapidated and disrepair, 8.3% needed major repairs. In rural areas, 7.8% of school buildings were in dilapidated and disrepair, and 13% were in need of major repairs.

For comparison, as follows from the report of August 23, 2018, the Minister of Education and Science of the Republic of Dagestan as of 2018, only 33.9% of school buildings met the regulatory requirements in the Republic of Dagestan, and 9.1% of all schools were in disrepair (Ministry of Education and Science of the Republic of Dagestan 2018).

4 Conclusion

The research conducted showed that the educational spaces of Russia and South Ossetia are in a high degree of integration. The integration of educational spaces is due to political, economic and organizational and technical reasons.

First, South Ossetia is completely in the political orbit of the Russian Federation. In its domestic and foreign policy, it focuses on Russia. In turn, Russia ensures the security and independence of South Ossetia.

Secondly, the economic development of South Ossetia depends entirely on the financial assistance of the Russian Federation, which is also the main and only foreign economic partner of the Republic of South Ossetia.

Thirdly, the organizational educational space of South Ossetia was created as a copy of the educational space of Russia. The same are the legal provision of education, the levels and types of education, the types of educational organizations, educational standards and programs, educational methods and textbooks. Graduates of South Ossetian schools, having Russian passports, enter Russian universities (in 2019, out of 509 graduates of South Ossetian schools, 191 entered universities of the Russian Federation).

At the international level, the legal basis for the integration of educational spaces in Russia and South Ossetia was laid in 2015. Agreement on "Alliance and Integration".

In addition, problems in the field of education are also found in the degree of integration, as a result of the implementation of the same educational policy in Russia and South Ossetia. These are problems of financial support for education, the material and technical condition of educational organizations, as well as the accessibility of education.

In general, it can be argued that in the current conditions of the actual integration of educational spaces, this process is most beneficial to South Ossetia, as a party that receives significant advantages from cooperation with Russia and, due to this, it has significantly modernized its own education in recent years.

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Meaning-Making Orientations for the Self-development of a Future Teacher in an Integrative Educational Environment

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Abstract. The identification of the natural essence of meaning and its definition is one of the challenges of the philosophy of education. The article considers the problem of classifying meanings and meaning-making orientations in the activities of a future teacher. The meaning-making orientations of the future teacher's self-development are worldview concepts which have a great importance for the formation of his spiritual and moral personality. The purpose of the empirical study was to determine the interdependence of self-development and leadership as life orientations, which are necessary for a future teacher to make professional and pedagogical activities successfully.

The leading approach to the study of the process of personal and professional self-development of a future teacher in the modern educational environment is an integrative-environmental methodological approach that allows to understand deeper the organization of self-development. The essence of the integrative-environmental approach is the holistic integration of previously separated disjoined components. The integrative-environmental approach is based on the understanding of integration of educational environments as their "unity of diversity", and meanwhile, a new objectivity is being creating with the emerging qualities and potentials of elements, their connections and relationships.

As a result of the research, the classification of meanings and meaning-making orientations in the future teacher's activity is determined. Empirical research shows that all students-future teachers- are characterized by a high degree of self-development. Besides, the results of the study illustrate that there is a significant relationship between leadership and the ability to self-development: the higher is the ability to self-development, the more pronounced the leadership of the students is.

The novelty of the research results in comparison with previously published materials lies in a qualitatively different approach to substantiating the self-development of a future teacher based on life-orientations. Such presentation will significantly improve the process of self-development of a future teacher as a person and as a professional in an integrative educational environment.

Keywords: Personal and professional self-development · Integrative educational environment · Meaning-making orientations

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1 Introduction

Nowadays, it is generally recognized that a literate person who is in the process of self-development sees and uses the opportunities, which are opened to him, perceives the signals of the society (people, institutions, the State). At the same time, the priority is given to social (communication) skills, self-regulation, the ability to accept responsibility, adaptation and self-development in an uncertain future.

Self-development of the teacher as a person and as a professional has a meaning-making nature, and the meaning of it is the driving force of the process of self-development. The teacher creates a developing environment himself, integrating its resources into personally significant meanings.

In modern science the problem of classification of meanings and meaning- making orientations in pedagogical activity is poorly studied. It is associated with the definition of the purpose of the teacher's existence, its destiny and place in the world. The meaning-making orientations for the future teacher's self-development are worldview concepts that have a great importance for the formation of his spiritual and moral personality.

Identifying the natural essence of meaning and its definition is one of the challenges of the philosophy of education. According to Sartre, the meaning is a phenomenon of being this meaning is possessed by being itself, on the basis of which it is found [9]. The approaches to the study of meaning in modern scientific knowledge are considered in various aspects: abroad - there is the psychoanalytic approach of S. Freud and the theory of A. Adler, Jung's theory, the theory of personality and psychotherapy, the theory of personal and individual differences, Flow theory and "flow experience", the theory of P.H. Phenix, existential personality by Maddi, Kelly's theory of personal constructs, Levin's theory of personality, and others. In national science approaches to the study of meaning are discussed in the following fundamental concepts and writings of scholars: the psychology of meaning by Leontiev, the unity of knowledge and experience (theory of meaning structures) of S. L. Rubinstein, dynamic semantic system, the semantic relations, the meaning of professional work by N.V Kuzmina, and others.

The multiplicity of definitions of meaning, equally convincing and heuristic, suggests that beneath the concept of meaning lies not a specific psychological structure that allows an unambiguous definition, but a complex and multifaceted semantic reality that takes various forms and manifests itself in various psychological influences.

Meaning is an implied concept, and it depends directly on the knowledge of the subject. An unknown thing may seem meaningless if you don't know how to use it, that is, how to make profit of it. And, on the contrary, through ignorance, a thing can be endowed with false useful qualities and may have, from this point of view, a significant value.

Any theory of personality and individual differences cannot do without understanding the meaning as an important primary given. The concept of personal meaning deals with the concept of significance. In the hierarchical system-factor model of personality, which was built by J. Royce with A. Powell, personal meaning occupies the top of the hierarchy. Personal meaning is not something that exists in the external world. This is a vision that each of us must create anew for ourselves. The connection between meaning and worldview is a key for Royce. Meaning appears as a function of the internal structure of the personality, the structure outside of it, and the structure of the interaction of the organism with the environment. Life is perceived by us not only in the light of everyday activities, but also in the light of the global meaning of our life [11].

The position of Royce and Powell is directly opposite to the Frankl's position. In the search of personal meaning a person is faced with three questions: 1) what world do I live in? 2) how can I live my life to meet my needs and values the best way? 3) who am I? Answering these questions, a person forms his own view of the world, lifestyle and image of the Self [10].

The personal construct theory by G. Kelly, which a number of followers directly call the theory of personal meanings, belongs to those theories where meaning is considered exclusively as a phenomenon of consciousness. Constructs represent the subjective parameters of categorization and evaluation of events that may not necessarily be expressed in a verbal form. In fact, personal development consists in the development, enrichment, improvement of personal constructs. This process occurs continuously in every person. The main Kelly's pathos was aimed at learning the specifics of each person's personality. The meanings of events are purely subjective and are only projected into the world. The meaningfulness of Kelly's life is related to the ability to see the present in the past, the future - in the present [3]. The most detailed approach to meaning in the aspect of integration of personal and social reality is the theory of P. H. Phenix, which is reflected his work "Realms of meaning" [12]. The concept setting is an expression of personal meaning in terms of activity and is a readiness to perform a certain activity [1].

In the eighties, the main progress in the development of the ideas about the structural organization of the semantic sphere of personality is associated with the works of Nasinovskaya (classification of semantic formations), Bratus ("the semantic sphere of personality"), Stolin, Asmolov ("dynamic semantic system"), Vasilyuk (the concept of semantic dynamics), Zeigarnik, Ivannikov (semantic self-regulation).

The half-century history of the development of the ideas about the semantic sphere of personality in the line of the activity approach allows us to say that the concept of personal meaning – semantic formations – the semantic sphere of personality occupies a strong place in the system of scientific psychology.

2 Methodology

The leading approach to the study of the process of personal and professional self-development of the future teacher in the modern educational environment is an integrative-environmental methodological approach that allows to understand deeper the organization of self-development of the future teacher. The essence of the integrative-environmental approach is the holistic unity of previously separated homogeneous and heterogeneous components. The integrative-environment approach is based on the understanding of integration of educational environments as their "unity of diversity", and, meanwhile a new objectivity with the emerging qualities and potentials of elements, its connections and relationships is being creating.

Scientific methods such as analysis, synthesis, abstraction, generalization, classification, questioning, testing, as well as correlation analysis and other mathematical methods of processing the results of empirical research are used to obtain the research results.

To conduct an empirical study, the following methods were used to determine the level of self-development of future teachers, their leadership and other qualities that are important for obtaining the research result:

– methods for diagnosing the ability to self-development (according to Maralov);
– test of readiness for self-development (Pavlov);
– test "Diagnostics of leadership" (Zharikov, Krushelnitskii).

3 Results

According to our opinion, personally, it can be considered both the internal personal component (individually oriented) and the external personal component (socially oriented); both materially oriented and ideally oriented.

The main meaning of the life constants is different vectors from the vital to the higher. Depending on their choice, the aims and development of internal needs are determined: professional, social, individual, spiritual, moral, material, and so on. Meanings give a person an energy resource to move along the chosen path (ladder) and justify the past life stage (lived years). Moreover, not all meanings are higher, but they all have an ideal basis, since they allow a person to live for them. They can be divided into three meaning-forming vectors in the context of self-development of the future teacher in an integrative educational environment in accordance with the classification of A. Pavlov [13].

Life's meaning-making orientations:

1) "life for the sake of life" - is one of the most natural meanings, based on the basic instinct of self-preservation, the meaning-forming quality of which is survival. One of the pedagogical tasks is to teach the younger generation the basics of life safety; survival in the face of pandemics, climate, social-economic changes, this sense is very relevant today;
2) the meaning - "life for pleasure" - in the aspect of self-development of the future teacher's personality can be considered from the position of obtaining satisfaction from the results of pedagogical activity (positive properties and qualities of the student, learning material, lesson, event, etc.);
3) for some, "living for wealth, money" is a fundamental meaning, because the meaning of existence is accumulation, but it is difficult to imagine a person engaged in teaching and trying to accumulate or earn a lot of money doing it.

Now let's consider social meaning-forming orientations in the aspect of self-development of the future teacher.

1) "Life for children" (based on parental instinct). The meaning-forming position here is the expansion of the family (children, grandchildren, great-grandchildren).
2) "Life for work", or place of work (educational institution) is formed on the basis of territorial instinct (small homeland), a special variant of it – the nesting instinct. A person has three main life priorities: work, family, and friends. And if these priorities are united by the place of work, then the person "lives by it".

3) "Life for the sake of a large social group" (homeland, nation, etc.). This meaning of life is actualized in moments of danger threatening a large group of people; in the absence of such danger, it is usually not declared.
4) "Life for the sake of friendship" - the meaning-organizing position here is friendship, the quantity and quality of friendly actions;
5) "Life for the sake of career (power)", is formed on the basis of hierarchical instinct. The meaning-organizing position here is a movement along the career or power ladder. The cult of a person who has chosen the path of success and achievement the goals is the result of the development of industrial and post-industrial society [2].
6) "Life for the sake of a particular person" - based on the instinct of following (parent, colleague, etc.). This meaning is often chosen by teachers-performers themselves.

Next, let's look at the ideal meaning-making orientations.

1) "Life for the sake of knowledge (study, science)" - is formed on the basis of a tentative research instinct. The thirst for novelty and not only the frequency of events, but also the novelty of personal experience comes hence [2];
2) "Life for the sake of creativity (art)". Creative people live for the sake of creating images (paintings, books, movies). This meaning can be embedded in the life scenario "life for the sake of creativity". At the same time, it is important that a person has a meaning-making ability, that is, he is able to "scoop" out of his profession all new and new meanings [5];
3) "Life for the sake of self-improvement" (the improvement of abilities, spiritual and moral self-improvement). Rubinstein wrote: "People who choose the profession of a teacher or doctor for the sake of money, power or prestige, rather than out of love for children and compassion for the sick, should not be surprised if their work seems tedious and poorly paid, they will be disappointed" [8].

It is not necessary to prove that the teacher's life is difficult, there are many difficulties in his professional activity, difficulties of conflict situations, such episodes when it seems that the work loses its meaning. The specific nature of the teacher's work is that the "current" immediate results are secondary; the main meaning of his professional activity is in its remote results.

The meaning-making orientations for the future teacher's self-development are considered in the context of the integrative professional-developing educational environment of the teacher. In a general and initial sense, an integrative environment is an infinite set of micro-environments in a professionally developing macro-environment, which is a complex self-organizing system of a non-linear nature. In other words, the macro-environment is replicated in smaller structures-micro-environments. Integrative professional-developing macro-environment is characterized by structural diversity. The idea of its level organization is indicated in the very concept of an integrative environment.

Personal and professional self-development is carried out on a concentric principle as a result of the transition to new levels of development in a spiral, that is, this process is continuous (Fig. 1).

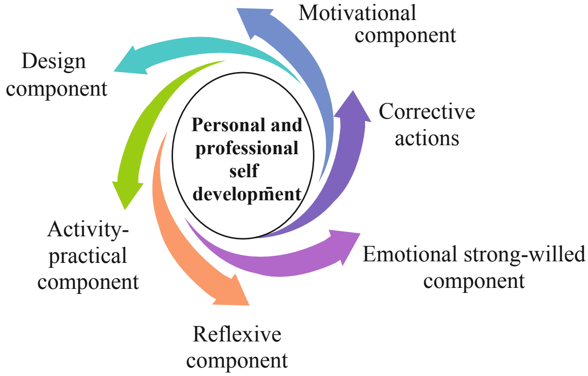

Fig. 1. Structure of personal and professional self-development of a teacher

The purpose of the empirical study was to determine the interdependence of self-development and leadership as life-oriented points, necessary for a future teacher to make professional and pedagogical activities successfully.

Self-development is a natural meaning-making vector of the student's personality-the future teacher. Self-development is the natural basis of educational activity. Thus, as a result of testing using the method of Pavlov, it was found that 76.5% of students of 2–5 years have the most favorable combination of readiness for self-development and self-knowledge for further personal development. In other words, in this category of students, the desire to learn more about themselves is combined with the need for real self-improvement. Another category of students who took part in the study (23.5%) has greater opportunities for self-development than the desire to understand them. According to the results of this research, we can conclude that in any case, all students of 2–5 years are characterized by a high degree of self-development.

A method for diagnosing the ability to self-development (according to Maralov) was used to establish the levels of self-development in this research. The high level is characterized by active self-development, the average level-an emerging system of self-development, the low level-stopped self-development.

The results of the research, presented in Table 1, showed that students of 1–5 years have a high level of active self-development (68.5%), and the emerging system of self-development is also characterized, the dependence of self-development on external conditions (average level) - 31.5% of students who took part in the research (Fig. 2 and Table 2).

Table 1. The levels of formation of the students' self-development

No.	Year (course)	Number of students	High level		Average level		Low level	
			Number	%	Number	%	Number	%
1	2	12	6	50	6	50	–	–
2	3	14	10	71.4	4	28.6	–	–

(*continued*)

Table 1. (*continued*)

No.	Year (course)	Number of students	High level		Average level		Low level	
			Number	%	Number	%	Number	%
3	4	38	28	73.7	10	26.3	–	–
4	5	9	6	66.7	3	33.3	–	–
5	**Total**	**73**	**50**	**68.5**	**23**	**31.5**	–	–

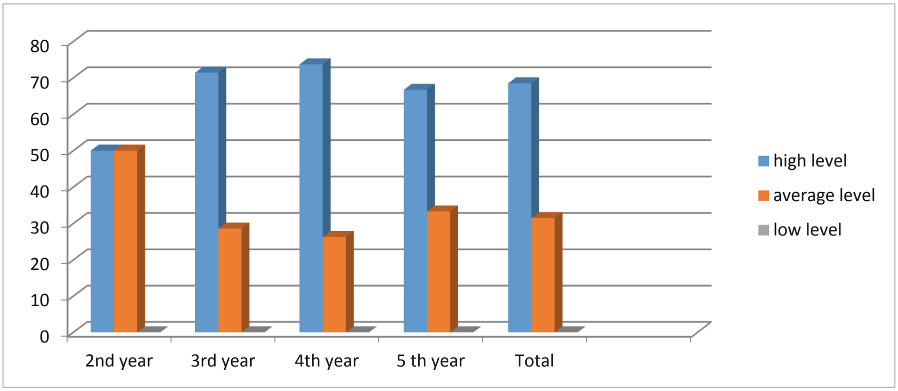

Fig. 2. Levels of formation of students ' self-development (in %)

Table 2. Correlation between self-development ability and leadership

	Year (course)	Number of students	Leadership, points	The ability to self-development, points	Correlation coefficient, r	Determination coefficient, D	Student'st-test, t_Φ
1	2	12	24.9	56.1	0.861652	74.2%	t_f (5.35) > t_{st} (2.228)
2	3	14	29.4	62.0	0.544392	29.6%	t_f (2.24) > t_{st} (2.179)
3	4	38	25.2	57.3	0.558822	31.2%	t_f (4.04) > t_{st} (2.021)
4	5	9	27.2	56.7	0.755974	57.1%	t_f (3.05) > t_{st} (2.365)
5	**Total**	**73**	**26.7**	**58.0**	**0.68021**	**46.3%**	t_f **(7.82) >** t_{st} **(1.990)**

The received correlation coefficients illustrate that there are positive significant relationships between leadership and the ability to self-development (a strong relationship for years 2 and 5, and an average relationship for years 3 and 4).

The coefficient of determination, in this case, shows that on average 46.3% of the relationship between leadership and the ability to self-development is due to their mutual influence, i.e. the higher the ability to self-development is, the more pronounced the leadership of students s. At the same time, the coefficient of determination is significantly higher for students of the 2nd year (74.2%) and 5th year (57.1%) than for 4th (31.2%) and 3rd (29.6%) years.

To assess the credibility of the correlation coefficient between leadership and the ability to self-development, the student's t-test was used, which is calculated using the formula:

$$t_f = \frac{r_{xy}\sqrt{\mathrm{n}-2}}{\sqrt{1-\mathrm{r}_{\mathrm{xy}}^2}}$$

where r_{xy} is the sample correlation coefficient;
n is the sample size.
At the average value of the correlation coefficient (2–5 years in general):

$$t_f = \frac{0.68021\sqrt{73-2}}{\sqrt{1-0.68021^2}} = 7.82.$$

The table critical value of t_{st} for $\mathrm{n} - 2 = 71$ and $\alpha = 0.05$ is 1.990. Since, t_f (7.82) > t_{st} (1,990), the null hypothesis is rejected, there is a significant positive relationship between the features. The found correlation coefficient is reliable.

4 Conclusion

Thus, based on the conducted empirical research, the following conclusions can be formulated:

1. All students-future teachers are characterized by a high degree of self-development.
2. Students are characterized by a high level of active self-development, as well as (to a lesser extent) an emerging system of self-development that depends on external conditions.
3. There is a significant relationship between leadership and the ability to self-development: the higher the ability to self-development is, the more pronounced the leadership of students. In turn, leadership ensure the process of self-development.

In the projecting of individual professional development trajectories of the teacher, the leading role belongs to Foresight studies as a technology for the study of the future. In its broadest sense, Foresight can be defined as the practice of working with the future, which includes its vision, management, and routing. A Foresight is neither a forecast of events nor a plan of action. This is a map of probable events. These events may occur in the future, and it is important to take them into account for making decisions in the present. Foresight includes actions aimed at thinking about the future (forecasting and developing basic scenarios for self-development), discussing the future (conducting a discussion), outlining the future (creating a desired image of the future and determining ways to achieve it).

It is important to emphasize that route options, “bifurcation points” should be presented in the construction of the teacher’s individual professional development trajectories as routes to the future based on event fractals. In this case, bifurcation refers to the point where the paths of self-development branch off. When the bifurcation point is reached, there is a choice of possible directions for further personal and professional self-development.

The pedagogical component of the research consists in the organization of tutor support for personal and professional self-development of the teacher at all its stages – from motivation to the implementation of reflection on his own development. The process of self-development of a teacher is based on self-organization of activities. At the same time, it is possible to provide advisory and methodological assistance in the implementation of this process. For this purpose, tutor’s support of self-development is effective.

The main tasks of tutor’s support for the teacher’s self-development as a person and professional in an integrative educational environment are:

– providing advice in the projecting and implementation of individual professional development trajectory based on fractal methodology;
– assistance to the teacher in diagnosing the process of his own development and analyzing its results.

The novelty of the research results in comparison with previously published materials lies in a qualitatively different approach to substantiating the self-development of the future teacher on the basis of life orientations. This presentation will significantly improve the process of self-development of the future teacher as a person and professional in an integrative educational environment.

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Features of Application of Machine-Readable and Algorithmic Language in the Contemporary Budget Law

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Abstract. Purpose: The purpose of this article is to study the application of machine-readable rules in the branches of the budget law and general law. Some considerations of the problems related to the use of a machine-readable and algorithmic language in rule-making activity are examined .

Design/methodology/approach: The methodological background for the implementation of budget-law rules algorithmization in the digital era is a package of scientific research methods: theoretical methods (analysis and study of regulations stipulating the implementation and development of machine-readable rules in the budgetary activities of the state and municipalities); analysis and synthesis (a scientific search for the opportunities and advantages of algorithmic budgetary relations).

Findings: For the most correct and uniform understanding of the integral parts of the social relations under consideration, the authors pay heed to the categorical and conceptual framework, displaying the inter-branch relations and the dual legal nature of the relations arising out of the interaction between digital technologies and law. The summary and classification of the main lines and trends of state policy on the regulation of the legal rules' algorithmization made it possible to unveil the relevance and usefulness of machine-readable rules in budget law and legal proceedings.

Uniqueness/value: The analysis demonstrates that all financial legal relationships cannot be automated. The truthfulness and applicability of scientific estimates rely on the quality of budget rules. The feature of budget rules such as certainty increases the potential for their automation. The use of machine-readable and algorithmic rules in budget law will make the legislative branch predictable, operating under predesigned algorithms (requirements) and having a predetermined result. The statement on the formalization of the budget rules automation at the federal level is considered in detail.

Keywords: Finance · Financial law · Budget · Budget law · Machine-readable law · Law algorithmization

JEL Classification Codes: K220 · K240

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1 Introduction

The advantages of digitalization, automation, algorithmization, and robotization can no longer be doubted in the context of a pandemic that swept the whole world since it was a technology that backed the development of many processes in the hard times of the global lockdown. The applicability of technologies to legal regulation is still debated by the most prominent scientific communities, including the annual St. Petersburg Legal Forum and the Skolkovo conference on modern technologies and projects in the field of LegalTech. The government authorities and business representatives view algorithmization of modern legal processes and rule-making as an urgent need, as well as the legal community does not deny its necessity and apparent advantages. Automation as a means of transaction costs reduces the number of intermediaries and, as a result, heightens efficiency (Mungalov 2017).

The author of The Code and Other Laws of Cyberspace recognized "the most influential book on law and cyberspace of today" and Professor of Law Lawrence Lessig expresses his main idea in the title of the book, justifying the opinion that the concept of West Coast Code governs behavior in no small measure like as the legal code. Lawrence Lessing finds similar software code and architecture, which is a limiter and a kind of regulator of different areas of life, and the law established by the state. At the same time, the law is still broader than the code, in the event of conflict or contradiction, the law prevails (Lessig 2006). It is worth mentioning that Stanford University is one of the leading institutions in the field of computer law and legal computer science. The work done by legal scholars in Skolkovo deserves attention. The contribution of Vashkevich, a leading expert in the field of law automation and legal technologies and the author of the book "Machine-readable law: law as electricity" is seen as meaningful (Vashkevich 2019).

According to Vashkevich's opinion, the law should be like electricity, indispensable, and invisible. The law should be machine-readable and automated, so that the part of legislative and private rules can be converted into program code and automatically executed by software, thus helping people, business, and the state avoid mistakes, abide by laws, accurately predict the consequences of their acts, be fully aware of their rights.

What are the prospects of conversion of financial law into machine-readable and automated? The Russian theoreticians of financial law did not conduct scientific research on this topic, but we think that the issues of budget rules' algorithmization can be a high-potential inter-branch area in the financial legal science.

Renewal of financial law is underway to adjust its terminological and conceptual framework to the needs of time and technological progress. Moreover, it's natural that in modern financial law new concepts are introduced and others are transformed. With that, the branch of financial law should follow the guidelines aimed at people's interests, especially the private interests of an individual, not public ones. Civilian Budget Project, a document that ensures the budget presentation and budget execution reports in an intelligible form, deserves approval. The budget for civilians is developed to communicate to them (interested users) the objectives and priorities of budget policy, the conditions of budget generation and execution, sources of budget revenues, justifications for budget expenditures, expected and achieved results of budget allocations utilization, as well as involvement of civilians in the discussion of budget decisions. The design of a single portal of the budgetary system Electronic budget is also a merit of digitalization of public finance regulation.

An electronic budget is a display of electronic budgetary activities in a digital environment, which enables current financial monitoring, as well as transparency and openness of the state financial measures, and higher efficiency of budget expenditures.

Financial law shows the specific trend of modern economic processes. Bearing in mind the reserved attitude of the financial and legal industry to innovations, we should recognize that an innovative theoretical and legislative breakthrough is critical. Cutting-edge technologies provide brand-new facilities as well as influence financial law. On the one hand, technological breakthrough and digitalization lay the foundation for higher performance of financial and legal mechanisms, on the other hand, such innovations can be deemed as new challenges to financial law.

2 Materials and Method

The analysis of publications revealed that there are no monographs on the issues of algorithmization of budget law rules. In the modern context of economic digitalization posing new challenges for the law as a regulator, the study of machine-readable rules from the perspective of public financial relations is important.

The methodological background of the development and implementation of machine-readable law algorithm for the regulation of budgetary relations is a suite of research methods. These are theoretical methods (analysis and study of rules and regulations stipulating the incorporation and development of algorithmic and machine-readable languages in budget law); theoretical analysis and synthesis, analysis of the state of machine-readable law in Russia and the world, inference techniques; general scientific methods (modeling of possible scenarios of machine-readable law application, analysis, synthesis, generalization, alignment, classification); empirical methods (observation, survey methods, monographic studies, methods of statistical treatment and qualitative analysis of scientific findings (Klyukovskaya 2018).

3 Findings

In the system of financial law, budget law has one of the central places and acts as a backbone element. The relationship between budget law and other institutions of financial law is constant, which is explained by its leading and coordinating role in the country's financial system. The budget law rules are distinguished by all features of financial and legal rules.

In our opinion, the validity of the study on the prospects of conversion of the budget law rules into a machine-readable form and their automated execution should proceed from the nature of these rules. The proportion of automated norms depends on the branch of law, technological, intrinsic legal, and ethical constraints. Automation of budget law suggests automated development, interpretation, and enforcement of rules using information technology. This calls for special technological and organizational infrastructure, as well as an understanding of the legal respects of legal technology updates. Machine-readable rules as elements are now part of smart contracts and smart solutions. Budget law doesn't work properly due to the many conflicting subordinate acts, the uncertainty of regulation, caused, among other things, by the opportunity of regions and local self-government bodies to take part in the rule-making and adopt independent rules and regulations in the field of the budget law.

Digital platforms are deregulated and guided by their laws, i.e. operate almost independently. Therefore, modern centralized public law is incompatible with the new world. The state of matters will change only if the law gets all the attributes of the technology. The study gave the promising outlook of incorporating machine-readable norms in budget relations as an opportunity for self-execution, automation of law enforcement in terms of budget execution, provision of high-quality financial supervision over parties' compliance with the terms, etc.

The accuracy and predictability for machine-readable law for budgetary law rules that are intrinsic by nature will allow getting the same result under the same initial data.

4 Conclusion

The concept of the step-by-step digitalization of the legal system was offered three years ago by the Government of the Russian Federation and was widely discussed at one of the innovative scientific platforms LegalTech in Skolkovo. Exactly after this event the issues of law digitalization have become known to the scientific community.

One of the priorities of the digital economy is the development of standard digital language as an indispensable condition of the transition to automation and algorithmization of lawmaking. The criterion for the self-execution of the budget law rules is their algorithmization and recognition by the machine. Legal computer programming languages at the present stage allow for the execution of action algorithms and verification of observance with simple requirements (Chechel 2017). However, the available computer programming languages have limited capabilities, since they cannot yet, relatively speaking, compare the terms of a specific agreement with the text of the law, for example, civil law regulations (Zikeev 2019).

Foremost, automation of budget law will positively affect the population and ensure public interests. Budget law will be available on a wide scale. The need to interpret the rules written in specialized legal language will cease to exist. Codification of budget-law rules translated instantly into plain language or presented as a code or algorithm will enable civilians and other parties to budget-law relations to examine, understand, and apply the rules of the budget law.

Soon it will become possible to automate the functions of state budgetary control over the execution of budget-law rues by parties. The new technology will facilitate the state in improving super services for both population and regions, local self-government bodies.

The utilization of a machine-readable and algorithmic language can qualitatively change budget-law relations, provide legal certainty and ease of budget execution, as well as eliminate the challenges to budget control. The number of disputes and the amount of financial costs will be reduced, which will have a positive effect on budgets' execution.

Machine-readable law will grant the legal certainty of budget rules and general availability of budget law. For this purpose, new automated laws can be passed simultaneously in a plain and machine-readable language.

The study also revealed the disadvantages of algorithmization and mechanization of budgetary relations.

A huge number of fragmented sources of law subject to functional recodification is the main technological obstacle on the way of machine-readable law establishment.

The basic value of law which is a product of consent (compromise) based on the values proclaimed since the time of Roman law is abstract nature, which allows for the application of rules to an unlimited number of cases and situations.

Machine-readable law in contrast to factual one is an empirical, algorithmic, and deterministic phenomenon (Voronin 2019). Relying on algorithms, the legislator and law enforcement officer can reduce their acts to automated decision-making, which does not account data defying calculations.

Thus, algorithms and artificial intelligence both are a window of opportunity for the legal community and the source of risks and threats to the humanistic spirit and essence of the law. After all, the law is a kind of social rule, i.e., these are, in the first instance, the rights of human as a member of society (Zorkin 2020).

Machine-readable rules in the field of budget law can be deemed as a promising area from the perspective of the transition to self-execution and automation of law enforcement as it pertains to budget execution, control over compliance with the terms established by laws or administrative regulations, etc.

The glory of the budget law algorithmization is a long way off, but one should understand that conventional legal methods for regulation of budget relations should prevail over mathematical ones.

In conclusion, we would like to cite the words by the Chairman of the Constitutional Court of the Russian Federation that "even in the vent of the algorithmization triumph, the law will not operate through statistical or mathematical methods so far as the law has its legal methods of regulation, conceptual framework, and legal arrangements. Along with that, the law does not exist apart from other social phenomena, including economic and cultural ones. Therefore, we can talk about changing the law paradigm and shifting from an outdated postmodern perception of law to recognition of the fundamental values of metamodern law" (Zorkin 2020).

The employment of conventional legal methods for regulation of budgetary relations is an overriding priority, but algorithmization of the budget law and the use of mathematical methods are estimated as a natural, inevitable digitalization of contemporary social relations.

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Future Challenges on the Way to Industrial Development of Equipment and Technologies in the Digital Economy and Industry 4.0 (Conclusion)

To conclude this book, it is a fair assumption to say that it has formed a meta-scientific vision of current problems and ways of industrial development of equipment and technologies in the digital economy and Industry 4.0. From the perspective of engineering and technologies, it has been shown that industrial development must imply automation, but it cannot be universal—automation must have its specific nature at every enterprise and be applicable to each particular production process. In general, neo-industrialization requires that manufacturing enterprises be more flexible.

The Fourth Industrial Revolution is increasingly clearly going outside the framework of the non-financial sector and covers all sectors of the economy even as we speak. The proposed recommendations for modernizing the economy and improving the organization and management in public and corporate governance will be of use both at the level of particular countries in the world and at the level of regions as part of national economic systems. In addition, the book has formed a cohesive view of the prospects for development of institutions and improvement of the legal system in the digital economy and Industry 4.0. The book has made an important contribution to the refinement and development of scientific thought in the field of training and management of digital personnel in Industry 4.0.

The scientific findings obtained in the book have formed a consistent scientific vision of current problems and ways of industrial development of equipment and technologies and covered new topical issues of the digital issues economy and Industry 4.0. Among them is the question of how applied solutions for industrial

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development of equipment and technologies must be adapted to the specifics of each particular country and region. This book is further complemented with case studies through the example of different economic systems which determine the prospects for future academic pursuits.

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