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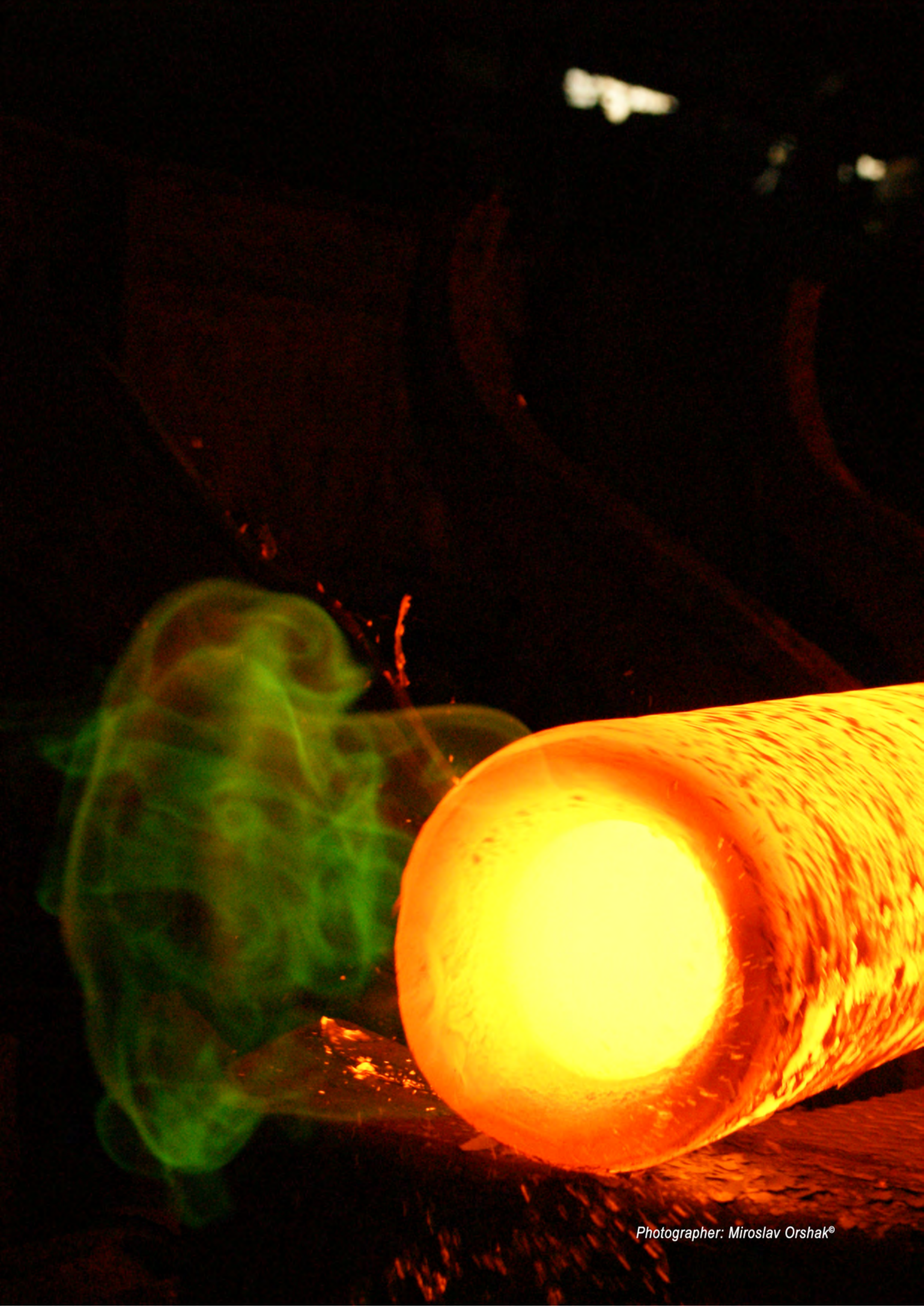
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UDC 338.4

Intellectual capital as a factor of competitiveness increasing

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Abstract
The article studies the content and interrelation of the concepts "intellectual capital" and "competitiveness". It is determined that outstanding world scientists have studied the theoretical and practical problems of the formation of intellectual capital and its development. The study of the importance of factors in the formation of competitiveness allowed us to emphasize the influence of intellectual capital. It has been found out that intellectual capital should be considered as a significant factor in the formation of the enterprise's competitiveness because the intellectual capital becomes an indispensable source for scientific researches and innovations, which are the basis for creating unique competitive advantages of the enterprise and its products. Scientists argue that the effectiveness of innovation depends on the availability and accessibility of knowledge for a wide range of users, which should be created, first of all, by state scientific organizations, higher educational institutions, own research departments of large and medium-sized enterprises. Thus,

the use of intellectual capital for innovation is a factor of competitiveness increasing, which allows modern innovative enterprises to acquire unique competitive advantages.
Keywords: INTELLECTUAL CAPITAL, ENTERPRISE COMPETITIVENESS, INNOVATION, PRODUCTION EFFICIENCY

Problem statement

In the modern world, not only material, energy and human resources are considered to be the most important resources for the development of society. Intellectual capital is another important resource, which plays a leading role in the modern production process and is its basis and competitive advantage. Intellectual funds increasingly have a greater share in the structure of productive assets in modern enterprises.

Scientists of the National Institute of Strategic Studies believe that increasing the effectiveness of innovative processes in the economy and using the potential of science in the process of economic modernization require the activation of the use of intellectual and scientific-technical resources in the industrial processes of industry, which allows consolidating the positive dynamics of the post-crisis period and providing the preconditions for long-term growth on an intensive basis [1].

Analysis of recent research and publications

The theoretical and practical problems of the formation of intellectual capital and its development were studied by outstanding scientists of the whole world such as E. Brooking, E. Dichtl, J. Galbraith, F. Kotler, K.E. Lynn, J. Myers, T. Nilsson, D. Ogilvy, T. Stewart, G. Bagiev, V. Bazilevich, A. Gevko, A. Galchinsky, S. Ilyashenko, V. Inozemtsev, D. Kozeychuk, A. Kozyrev, A. Laut, A. Leonidenko, N. Moiseeva, S. Moskalyuk, V. Pertsia, A. Stas’, A. Shevchenko, T. Yakubova and others.

The majority of domestic and foreign scientists consider the formation of an innovative model of society’s development as one of the most important systemic factors of competitiveness increasing, which provides the technological modernization of the national economy, the growth of production of innovative products and the formation of an innovative culture [2].

Researcher K. Khubiev believes that the present requires a tough fight for the most important resources, first of all, they are not reproducible raw materials, which reserves are limited, as well as reproducible technological and intellectual resources on which the competitiveness of a modern enterprise depends [3].

Determining the importance of factors in the formation of competitiveness allowed one to distinguish the influence of intellectual capital. The works of such scientists as A.M. Mitina and O. S. Murtazina were carried out in this direction.

The objective of the article is to study the influence of intellectual capital in the formation of competitiveness.

Presentation of the main material

Competitiveness is a complex economic category expressing the result of the interaction of all elements of the system of internal (industrial, economic, scientific, technical, etc.) and external (life-making, adaptive) relations between industrial enterprises about the possibility of implementation of this type of product in a particular market or its segment. This is a complex concept that as a result of a tight connection with the category of “competition” covers many aspects, factors and conditions of enterprise rivalry for the adherence of consumers to the goods of certain producers (Fig. 1) [4].

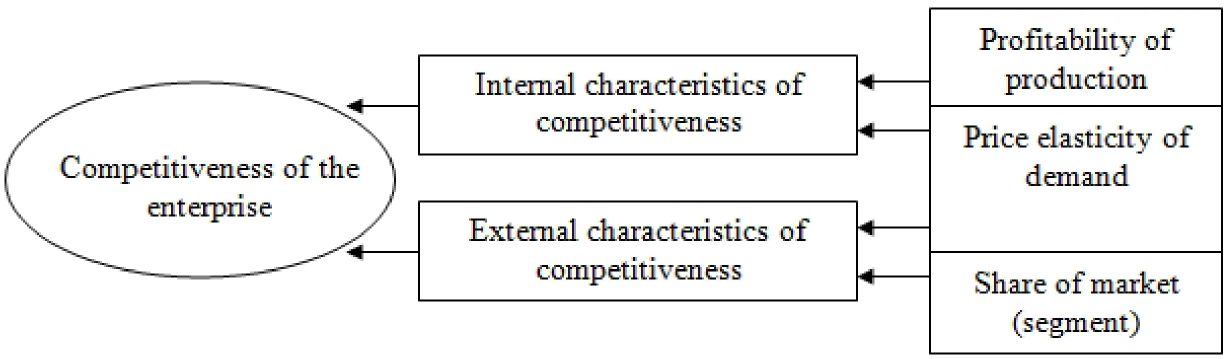

Figure 1. Structure of the concept of enterprise competitiveness [4]

Based on these characteristics, it can be concluded that the enterprises are competitive if they can:

- create competitive science intensive products;
- ensure maximum protection of their business in commodity markets;
- effectively influence the structure of commodity markets with a preponderance in favor of their own enterprise [5].

For the solution of the first of these tasks, it is necessary to intensify research activities or buy the rights to inventions and other scientific and technological achievements.

The second task is solved by fixing the rights to the results of creative activity embodied in the final product.

The third task can be solved only due to the availability of competitive advantages of products, the availability of which gives unique properties to products produced at a particular enterprise.

Thus, in view of the above tasks, it follows that the use of the creative potential and, therefore, the intellectual capital of the enterprise contributes to the competitiveness of the enterprise. We specify the notion of intellectual capital: it is a capital embodied in knowledge, skills, experience, qualifications of workers, as well as in intangible assets, which include software, patents, databases, trademarks that are productively used for getting profit.

The problems of formation and use of intellectual capital are interrelated with the effectiveness of introducing innovative projects at the enterprise. The implementation of innovative processes that involve the development of new technologies and new types of products requires not only financial costs, but also the use of special organizational and economic instruments.

Thus, intellectual capital becomes not only a necessary resource for the implementation of innovations and preservation of competitive advantages, but also an effective tool for the development of the enterprise and increasing its competitiveness. This statement is valid for science-driven industries.

Intellectual capital is the basis of research and development and the source of value for RTD. Intellectual capital is a combination of intangible resources and activities that allow an organization to transform a combination of material, financial and human resources into a system capable of creating additional value. As shown in Figure 2, intellectual capital becomes an indispensable source for research and innovation.

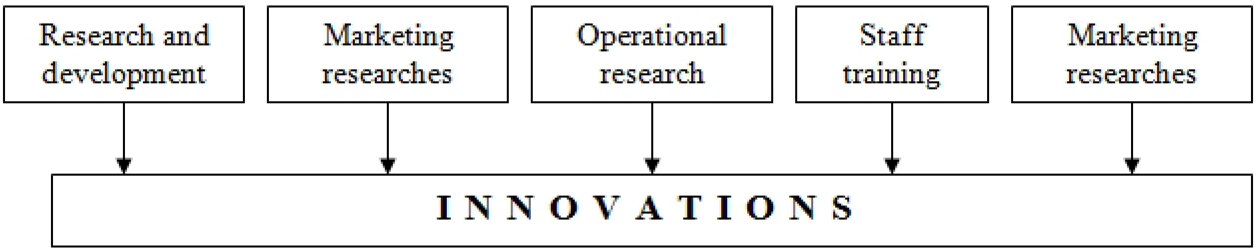

Figure 2. The basis for innovation implementation

It is necessary to characterize each of the blocks:

- research and development are performed to further use of their results in production;
- marketing researches are necessary for market analysis to understand existing needs and desires, with the purpose of developing new products, processes and services that are valuable to customers;
- operational researches are necessary to track how each aspect of the business is performed in order to adjust the business process to achieving a strategic goal;
- staff training is necessary to give the opportunity to people to learn and apply new knowledge, experience, skills in activities that benefit the enterprise.

Development of relations is the construction, preservation and maintenance of a positive image in front of clients, partners and other intermediaries in order to build profitable and long-term relationships. Development of relations includes also the development of brand and image through marketing.

Effective implementation of innovations depends on the availability and accessibility of knowledge for a wide range of users, which are necessary to create, first of all, by state scientific organizations, higher educational institutions, own research subdivisions of large and medium-sized enterprises. An important role here is played by the existence of a clear connection between science and production, as well as the ability to adopt new technologies.

For example, the oldest metallurgical enterprise of Ukraine - PJSC EVRAZ-DMZ needs to be substantially updated, which will concern not only the technical and technological sphere of the main and auxiliary industries, but also all other spheres. To implement effective measures that will increase the competitiveness of this production, it is necessary to implement a set of targeted actions, such as market research, research of modern technologies and means of production, modern products of the metallurgical complex.

This set of measures will be fully based on new knowledge, i.e. the intellectual capital of the enterprise. Directions for reducing production costs, saving material and energy resources, ensuring product qua- lity, increasing its competitiveness in the domestic and foreign markets are actual for the PJSC "EVRAZ - DMZ" enterprise [6]. The solution of all set tasks is possible only when using the existing intellectual capital of the enterprise, and it is also desirable to strengthen it at the expense of new competent personnel in the management and production units.

Figure 3 represents the mechanism for implementing intellectual capital under the conditions of a real production enterprise with the aim of carrying out innovations as one of the main factors for increasing the competitiveness of the enterprise.

In a modern knowledge-based economy, successful innovation requires a variety of intangible investments. These investments create intellectual capital. The value of intellectual capital as a factor in increasing the competitiveness of enterprises depends on intellectual investments, i.e. investments in specialist training, research and development, transfer of know-how, acquisition of licenses for the innovation.

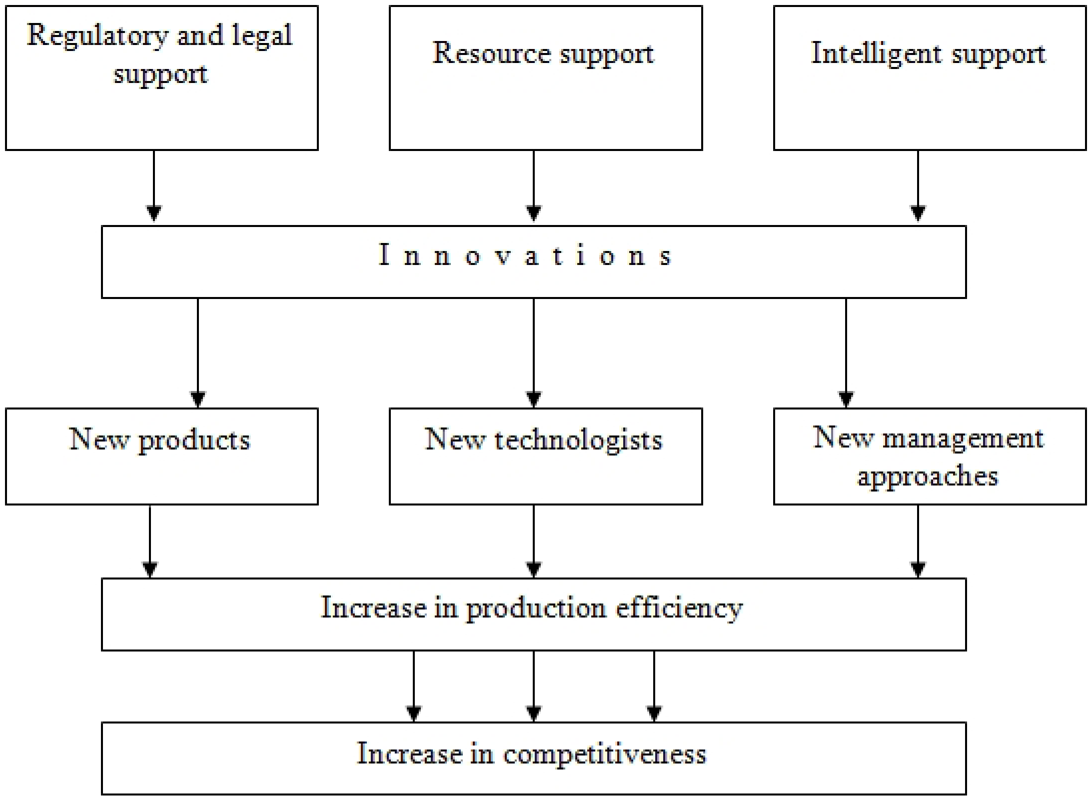

Figure 3. Intellectual capital as a factor of increasing the competitiveness of an enterprise

The appearance on the market of a new high-tech product and the introduction of new technological processes in production lead to an increase in production efficiency.

Conclusions

In general, the increase in production efficiency is characterized by a decrease in resource intensity, increased energy efficiency, increased productivity and reduction in the production cost. New and improved products that have appeared on the market lead to the creation of new market niches or to the conquest of a larger share of the already existing market of these products, which leads to the formation of sustainable competitive advantages of a particular enterprise over competitors, which in turn is the basis for increasing competitiveness.

Thus, at the present stage of economic development, the use of intellectual capital for innovations is the factor of increasing competitiveness, that allows modern innovative enterprises to ensure their survival and development under conditions of fierce competition through the acquisition of unique competitive advantages.

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UDC 669.14'98.046:669.168

Improvement of the properties of low-alloy constructional steels microalloyed with the nitrogen-titan-aluminum complex

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Abstract
The relevance of research aimed at developing cast cost-effective low-alloy steels with carbonitride hardening due to complex microalloying with inexpensive and accessible elements such as titanium, aluminum and nitrogen is shown.
It has been established that for the most effective use of the nitrogen-titanium-aluminum complex when the microalloying of structural steels, it is necessary to create conditions for obtaining maximum amount of fine titanium carbonitrides and to ensure the formation of sufficient number of aluminum nitrides. It is determined that the best quality of the metal is provided at optimal joint micro additives of titanium (0.01-0.03%), aluminum (0.02-0.06%) and nitrogen (0.014-0.020%). At the same time, heat treatment of ferritic-pearlitic steels of (15-20) G (S) ATYUL grade must be carried out in two modes: normalization or quenching at 900-920 °C (during 1.5-2.5 hours) followed by tempering at 650- 690 °C.
The use of complex microalloying with nitrogen, titanium and aluminum of steels of (15-20) G (S) L grade allowed achieving the metal grain refining no less than 2 times; increasing in the yield point in the normalized state by 30-80 MPa, and after quenching and high tempering by 60-130 MPa; increasing in cyclic durability of steel by 1.7 times; increasing in yield strength at 250-450 °C by 2.0-2.5 times under industrial conditions.
Key words: STEEL, MICROALLOYING, NITROGEN, TITAN, ALUMINIUM, CARBONITRIDE HARDENING, STRUCTURE, PROPERTIES

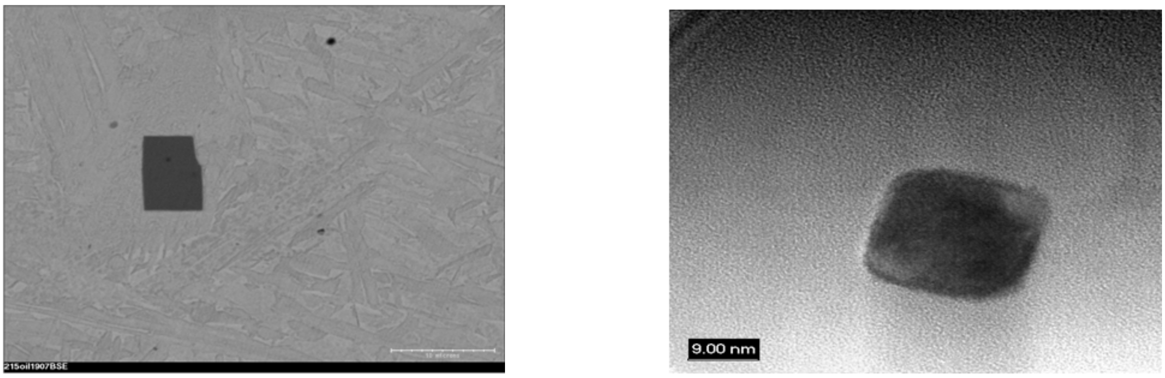
Cast low-alloy steels are usually smelted in electric arc furnaces and, therefore, they contain an increased amount of nitrogen (0.008-0.012%), which negatively affects their quality. However, the binding of free nitrogen to special carbonitrides or nitrides improves the structure and properties of the steel. In the opinion of the authors of [1], the complex carbonitride hardening is the most effective, which leads to the formation in a relatively wide temperature range of nitrides of various elements possessing a sufficiently high but significantly different affinity to nitrogen. As such elements, in addition to the basic vanadium, niobium is usually chosen; aluminum, titanium, zirconium are less often selected.

However, the main disadvantage of using vanadium and niobium is the very high cost of alloying materials. Therefore, studies aimed at developing cast low-alloy steels with carbonitride hardening due to complex microalloying with relatively inexpensive and sufficiently accessible in Ukraine elements (titanium and aluminum) are relevant.

A number of studies have noted the beneficial effect of complex micro-alloying with nitrogen, titanium and aluminum on the quality of cast steels. It has been established [2] that joint additions of nitrogen (0.024-0.045%), titanium (0.16-0.18%) and aluminum (0.06-0.12%) influence better the structure and properties of 40G2L steel than the use of microalloying complex NV-Al. However, the overwhelming majority of researchers ([3]) believe that microalloying with nitrogen and titanium cannot favorably affect the properties of cast low-alloy steels. This is due to the formation of large titanium carbonitrides (up to 35 microns) located in the volume of the grain and not soluble during heat treatment.

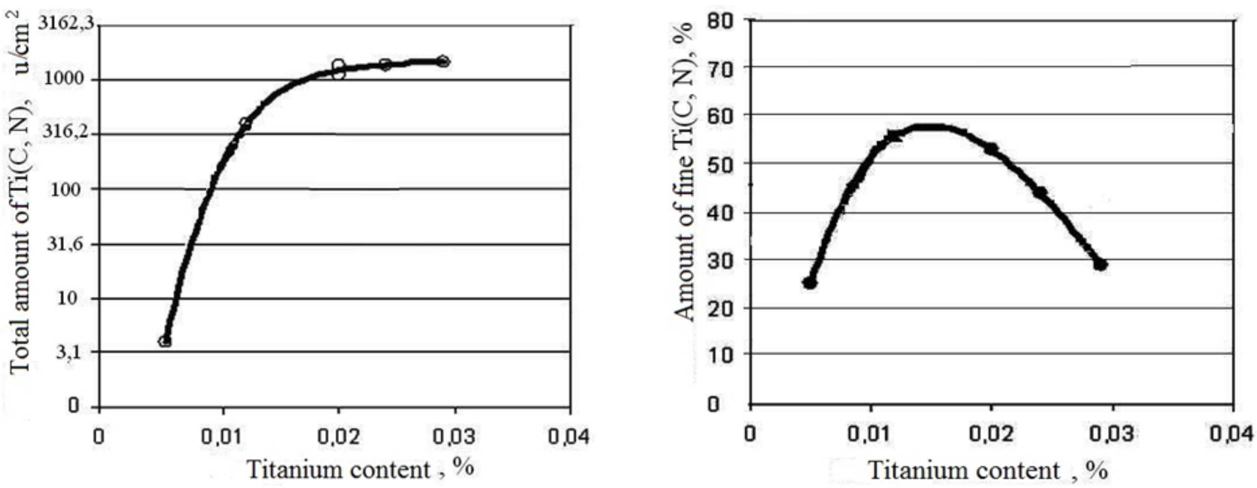
It is known [1] that the intragranular arrangement of titanium carbonitrides positively influences the formation of the primary structure and the grain size and the properties of the cast metal, respectively. In the development of ATYU grade steels, the authors of [4] have proceeded from the premise that titanium carbonitrides predominantly regulate the cast structure and aluminum nitrides - grain formation during heat treatment.

The work [4] shows that the formation of two types of titanium carbonitrides is possible in the production of St20ATYU hot-rolled steel. The first type of Ti (C, N) (Fig. 1, a) has rather large dimensions (1-12 microns) and is formed in liquid steel. The second type of titanium carbonitrides (Fig. 1, b) has nano sizes (10-200 nm) and is most likely released upon solidification and cooling of the steel in the solid state. As follows from the data of [4], for the most effective use of complex microalloying of cast low-alloy steels with nitrogen, titanium and aluminum, it is necessary to create conditions for obtaining as many fine titanium carbonitrides as possible and to provide thermodynamic and kinetic possibilities for the formation of aluminum nitrides in sufficient volume.



a) × 2500 b) × 800000

Figure 1. Titanium carbonitrides in steel of St20ATYU grade [4]



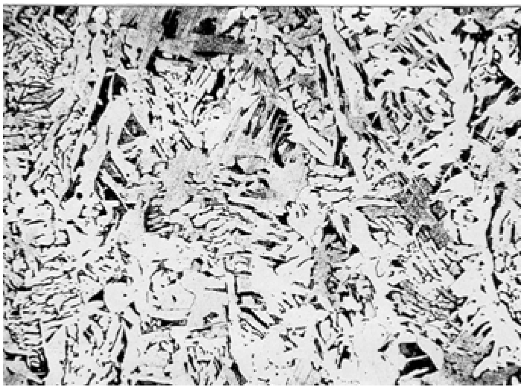
a) b)

Figure 2. Influence of the titanium content on the total amount (a) and the fraction of fine (b) carbonitrides in 20GATYUL steel

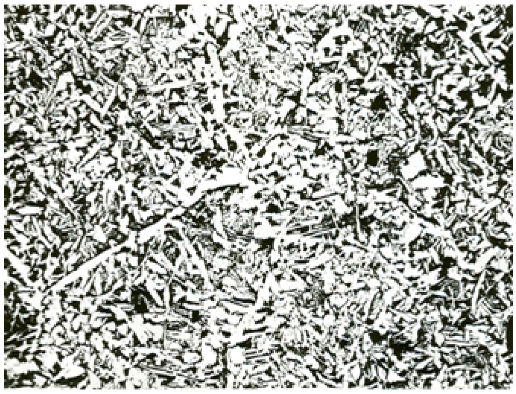
By a metallographic analysis of 20GL steel samples containing 0.014-0.015% nitrogen, the influence of the titanium concentration (0.003-0.11%) on the size and quantity of carbonitrides was determined. It has been found that when the content of titanium in steel rises from 0.003 to 0.020%, a sharp increase in the amount of carbonitrides (Fig. 2a) occurs, the size of which is within the range of 10-200 nm. It is determined that the greatest amount of fine particles of Ti (C, N) occurs at a titanium concentration of 0.012-0.018%. When the titanium content rises from 0.020 to 0.030%, the increase in the amount of carbonitrides decreases, and their size increases to 1-10 microns. However, the number of fine titanium carbonitrides (30-50% of the total amount (Fig. 2, b)) is sufficient for significant reduction of the size of the primary grain, dispersion and grain boundary hardening. Further increase in the concentration of titanium from 0.031% to 0.110% almost does not affect the amount of its carbonitrides, but significantly increases their sizes (up to 15-35 microns) and changes the stoichiometric composition (towards the greater carbon content).

Thus, it is necessary to regulate the titanium content in the range from 0.010 to 0.030% in order to obtain a great number of fine titanium carbonitrides, which favorably influence their structure (Fig.3) and properties (Table 1) in the cast steel of ATYU grade.

The mechanical properties of steels containing the ATYU complex (Table 1) correlate well with the results of metallographic analysis. Microalloying with titanium in optimal limits significantly increases the strength and impact toughness of 20GATYUL steel. In this case, the maximum increase in strength (50-80 MPa) is observed with a titanium content of 0.020-0.025%, i.e. with the greatest total amount of titanium carbonitrides, as well as with a high proportion of fine particles (≥ 45 %). At the same time, the increase in the impact strength (by 1.5-2.0 times) affects only the rise in the number of fine particles of Ti (C, N) ([Ti] = 0.012-0.018%). It should be noted that with titanium content ≥ 0.031 %, the plasticity of the metal falls sharply.



0.003% Ti



0.016% Ti

Figure 3. Effect of titanium on the cast structure of 20G (C) ATYUL (x100) steel

Table 1. Influence of titanium content on the properties of 20GATYL steel in the normalized state

No	[Ti], %	Mechanical properties			
		σ, MPa	σ, MPa	δ , %	KCU^{-60}, J/cm²
1.	0.003	390	580	25	35.5
2.	0.008	405	590	26	39.0
3.	0.010	420	600	28	42.5
4.	0.012	445	640	23	54.5
5.	0.013	430	630	25	57.0
6.	0.016	420	600	26	61.5
7.	0.018	430	610	28	70.5
8.	0.020	460	660	26	52.5
9.	0.022	450	640	28	48.0
10.	0.023	450	630	26	52.0
11.	0.025	470	660	23	39.0
12.	0.028	420	610	25	50.0
13.	0.031	415	640	17	49.0
14.	0.046	410	610	16	46.0
15.	0.060	410	610	16	42.0
16.	0.110	440	640	14	24.5

To obtain a large amount of titanium carbonitrides and especially aluminum nitrides, the concentration of nitrogen in the steel should be as high as possible, but it also should not lead to the formation of gas bubbles, which are responsible for the casting defects. On the basis of thermodynamic calculations and the data of [5, 6], the content of nitrogen in cast ferritic-pearlitic steels of (15-20) G (S) ATYUL grade should be from 0.014 to 0.020%.

Microalloying with aluminum should ensure the most complete purification of the solid solution from nitrogen, maximize grain refinement and not deteriorate the flowability of steel. An expression for calculating the optimal aluminum content in a metal was obtained by the thermodynamic analysis of the formation of aluminum nitrides in cast steels of (15-20) G (C) ATYUL grade and the data of [6]:

$$\lg\left([Al]-[Al]_{ox.}-[Al]_{sol.solut.}\right)=-\frac{6770}{T}+1.33-0.183[C]+ \\ +0,045[Mn]-0,044[Si]-\lg\left([N]-[N]_{Ti(N,C)}-[N]_{sol.solut}\right), \qquad (1)$$

where [Al], [C], [Mn], [Si], [N] – content of aluminum, carbon, manganese, silicon and nitrogen respectively,%;

$[Al]_{ox.}$ - content of aluminum bound to oxides;

$[Al]_{sol.solut}$ and $[N]_{sol.solut}$ - content of aluminum and nitrogen in the solid solution respectively, %;

$[N]_{Ti\{N,C\}}$ - content of nitrogen bound to titanium carbonitrides,%.

By thermodynamic calculations using the technic given in [5], it was determined that with optimal microalloying of steels (15-20) G (S) ATYUL grade with nitrogen and titanium, the titanium carbonitrides formed were similar in composition to TiN. Then it can be written:

$$[N]_{Ti(N,C)}=0,29\cdot[Ti], \qquad (2)$$

where 0.29 – stoichiometric coefficient for pure titanium nitride;

[Ti] – content of titanium in steel,%.

According to [7], in cast low-alloy steels, the content of aluminum bound to oxides is usually constant and equal to 0.006%. The authors of [8] have established that in ferrite-pearlitic steels of the ATYU grade, the nitrogen content of the solid solution is 0.0071-0.0113%, and that of aluminum is 0.0046-0.0108%. Using the data of [7, 8], calculations based on expressions (1) and (2) for the heat treatment temperature range (Table 2) show that the content of aluminum in steels of (15-20) G (S) ATYUL grade should be 0.020 -0.060%.

Table 2. Influence of the temperature-time mode of heat treatment on the structure of steels of (15-20) G (S) ATYUL grade

<table>
<tr><th rowspan="2">Temperature, º C</th><th rowspan="2">Duration of holding, min.</th><th rowspan="2">Grade of ferritic grain</th><th rowspan="2">General characteristics of the microstructure</th><th colspan="2">Phase characteristics</th></tr>
<tr><th>Ferrite</th><th>Perlite</th></tr>
<tr><td rowspan="4">850</td><td>40</td><td>5, 6</td><td rowspan="11">Ferrite-pearlite (F-P) with sections of martensite (M) and bainite (B)</td><td rowspan="2">Nonequiaxial</td><td rowspan="8">Granular</td></tr>
<tr><td>90</td><td>5, 6, 8</td></tr>
<tr><td>120</td><td>5, 6, 7, 8</td><td rowspan="2">Grains of 8 points are equiaxial, and the rest are nonequiaxial.</td></tr>
<tr><td>150</td><td>6, 5, 8</td></tr>
<tr><td rowspan="4">870</td><td>40</td><td>7, 6, 8</td><td rowspan="4"></td></tr>
<tr><td>90</td><td>7, 6</td></tr>
<tr><td>120</td><td>7, 8</td></tr>
<tr><td>150</td><td>7, 8, (9)</td></tr>
<tr><td rowspan="4">900</td><td>40</td><td>8, 7, (9)</td><td rowspan="2">Fine grains are equiaxial, large are of irregular form</td><td rowspan="12">Lamellar finely-differentiated</td></tr>
<tr><td>90</td><td>8, 9</td></tr>
<tr><td>120</td><td>8</td><td rowspan="2">Equiaxed grains by borders of carbides release</td></tr>
<tr><td>150</td><td>8</td><td>F-P</td></tr>
<tr><td rowspan="4">920</td><td>40</td><td>8</td><td>F-P with sections of M and B</td><td rowspan="2">Equiaxial</td></tr>
<tr><td>90</td><td>8</td><td rowspan="3">F-P</td></tr>
<tr><td>120</td><td>8</td><td rowspan="2">Equiaxial by borders of carbides release</td></tr>
<tr><td>150</td><td>8</td></tr>
<tr><td rowspan="4">950</td><td>40</td><td>8</td><td rowspan="4">F-P with sections of M and B</td><td rowspan="4">Equiaxial by borders of carbides release</td></tr>
<tr><td>90</td><td>8</td></tr>
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Based on the analysis of the data given in Table. 2, it is determined that for steels of (15-20) G (S) ATYUL grade, the total completion of recrystallization processes (equiaxed ferrite grain - 8 points, absence of bainite and martensite, thinly differentiated perlite) occurs at a temperature of 920 ° C for 1.5 hours, and at 900 °C for 2.5 hours.

It should be noted that according to GOST 977-88 "Steel castings", the heat treatment temperature for base steels 20GL and 20GSL is 870-890 °C. Thus, microalloying of cast ferritic-pearlitic steels with nitrogen, titanium and aluminum increases the heat treatment temperature by 30 °C.

Taking into account the relatively high content of aluminum and nitrogen in a solid solution of ATYU steels, as well as the fact that during the phase transition

− grefining of the metal grain no less than 2 times;

− increase in the yield point in the normalized state by 30-80 MPa (9-23%), and after quenching and high tempering by 60-130 MPa (13-29%);

− increase in cyclic durability of steel by more than 1.7 times;

− increase in yield strength at 250-450 °C by 170-250 MPa (2.0-2.5 times).

Industrial development of the technology of smelting of 20GATYUL steel was carried out under the conditions of PJSC "Kremenchug Steel Plant" at the production of castings for car building. On the basis of the whole complex of carried out studies, TS U 27.1-33686285-002: 2007 "Castings made of 20GL steel with increased strength for car building" have been developed, which together with "Ukrzaliznytsia" order No. 000180 / TsV allow mass production of 20GL steel micro-alloyed in complex with nitrogen, titanium and aluminum.

Production of steels of (15-20) GSATYUL grade is established under the conditions of PJSC "Armaprom" (Mirgorod). Application of microalloyed steel of 20 GSL grade in accordance with OST 108.961.02 and OST 108.961.03 allows us to increase significantly the operational reliability and durability of cast products for power engineering. The use of 15GSATYUL steel according to TS U 27.1 - 21871578 - 001: 2008 provides a significant reduction in the metal capacity of casting valves, as well as the possibility of its use even under extreme conditions of the Far North ($KCV^{-60} \geq 29.4$ J/cm^2). At the same time, the low carbon equivalent of 15GSATYUL steel allows welding (for example, casting of blocking cast-iron fittings in to the pipeline) under the "field" conditions excluding heating with subsequent heat treatment.

Conclusions

It has been established that the optimal use of complex microalloying of cast low-alloy steels with nitrogen, titanium and aluminum favorably affects their structure and properties. Temperature-time modes of heat treatment of ferrite-pearlitic steels of (15-20) G (S) ATYUL grade, which provide the best quality of metal, are determined.

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UDC 621.74:669-14

The relative viscosity of the liquid-glass slurry filled with cooper slag

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Abstract
Objective is to determine the influence of the content of copper slag in liquid-glass slurry, temperature and specific gravity of the liquid-glass applied on the value of its relative viscosity. The relative viscosity of the refractory slurry was determined by a standard technique in the viscometer VZ-4. The results of investigation of influence of cooper slag serving as filler on the relative viscosity of

glass-liquid slurry depending on its temperature, fullness and density of the of sodium liquid-glass are presented. It is found that with increasing copper slag content in refractory slurry (from 0.1 to 0.4 kg per 1dm³ of liquid-glass), the specific density of the liquid-glass applied (from 1150 to 1300 kg /m³) and temperature decrease (from 50 to 20 °C), its relative viscosity increases according to a power law. As a result of the mathematical processing of the experimental data, the empirical relationship has been obtained, the value of the relative error is less than 2.6%.
The data obtained allow us to take decision rapidly on the necessary adjustment of the refractory slurry composition in the foundry shop conditions.
Key words: MOLD, LIQUID-GLASS, TEMPERATURE, FULLNESS, RELATIVE VISCOSITY

The state of the question

Sodium liquid-glass with the value of the silicate module M_{SiO2} = 2.8…3.2 is a non-deficient and relatively inexpensive domestic bonding material, which, in particular, is used for making ceramic shell molds (hereinafter CS). Significant disadvantages of liquid-glass as a component of CS are the reasons of the fact that it is used to perform only 2 ... 3 outer layers of CS.

Powder quartz usually is a filler of such liquid-glass slurries. It is a natural material, which is obtained as a result of quartz sand grinding [1, 2]. An alternative to powder quartz of liquid-glass slurries can be powder refractory materials of technogenic origin. Copper slag is among these materials, this is a waste of an abrasive powder of copper-smelting slags, the effect of which on the properties of a liquid-glass slurry has not been known until now.

Objective is investigation of the effect of the fullness of a liquid-glass slurry with a powdered copper slag, the specific density of the liquid-glass and the temperature on its relative viscosity.

Results of the research

The studies were carried out in the temperature range from 20 to 50 °C on slurries prepared on the basis of sodium liquid-glass (GOST 13078-81) with the value of the silicate module of M_{SiO2} = 3.0…3.2 and specific density from 1150 to 1300 kg/m³ at 20 °C. A finely dispersed copper slag was used as the filler of the slurries, the amount of which (fullness of the slurry with a powder refractory - m) in the liquid-glass was from 0.1 to 0.4 kg per 1 dm³ of the liquid-glass. The chemical composition and properties of the copper slag are given in Table 1.

Table 1. Properties and chemical composition of the copper slag

Characteristic	Value
Density of the material, kg/m³	3300 – 3900
Bulk weight, kg/m³	1600 – 1900
Ferrous oxide (Fe_2O_3), %	40 – 50
Silicon oxide (SiO_2), %	25 – 35
Magnesium oxide (MgO), %	No more than 5%
Calcium oxide (CaO), %	6 – 10

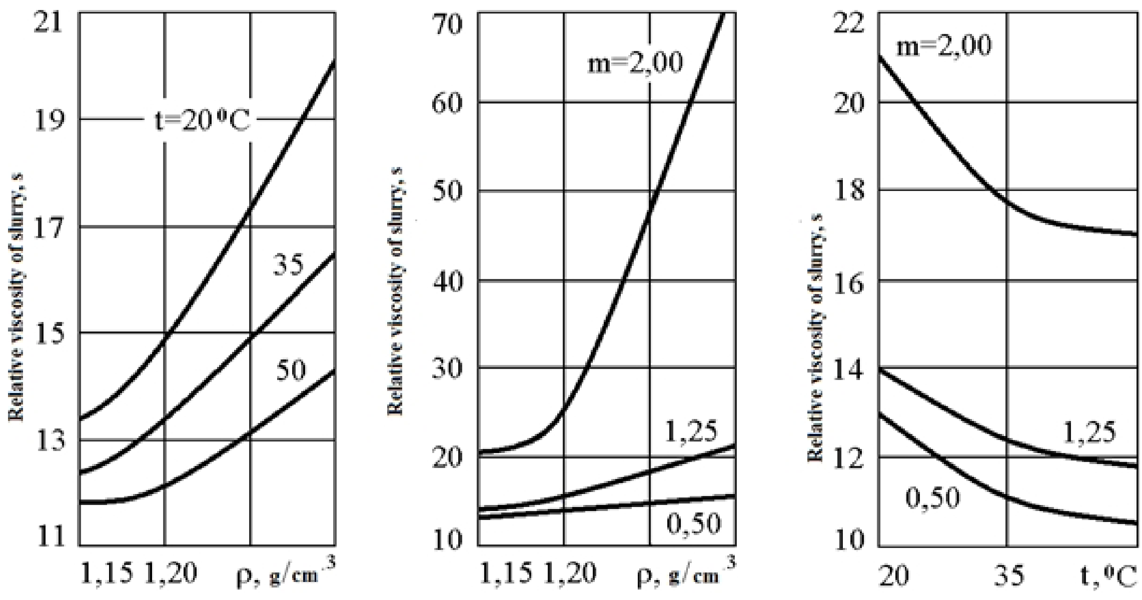
Preparation of liquid-glass slurries and determination of their viscosity were carried out according to the procedure of [3]. To prepare the refractory slurry into a liquid-glass of a certain specific density, appropriate weighed portions of the previously sieved copper slag were introduced and after careful mixing the temperature and the relative viscosity were determined. The relative viscosity was determined using a viscometer VZ-4 and a stopwatch. For the true value of the relative viscosity of the slurry (τ) under given experimental conditions, its average arithmetic value was taken based on the results of three measurements, if their values did not differ by more than 5%.

To construct a mathematical model τ = f(r,m,t), the obtained data were processed according to the procedure given in [4].

As a result of mathematical processing of the experimental data, the following empirical dependence was obtained (the magnitude of the relative error is less than 2.6%):

$$y = 12{,}3\cdot t + 16\cdot\rho_{PC} + 57{,}5m - 8{,}2\cdot t\cdot\rho_{PC} - 88{,}8\cdot t\cdot m - 91\cdot\rho_{PC}\cdot m - 29{,}06\cdot t\cdot\rho_{PC}\cdot(t - \rho_{PC}) + 246{,}9\cdot t\cdot m\cdot(t - m) + 48{,}8\cdot\rho_{PC}\cdot m\cdot(\rho_{PC} - m) + 64{,}8\cdot t\cdot\rho_{PC}\cdot(t - \rho_{PC})^2 + 109\cdot t\cdot m\cdot(t - m)^2 + 32{,}3\cdot\rho_{PC}\cdot m\cdot(\rho_{PC} - m)^2 - 2027\cdot t^2\cdot\rho_{PC}\cdot m - 1445\cdot t\cdot\rho_{PC}^2\cdot m - 5126\cdot t\cdot\rho_{PC}\cdot m^2,$$

where τ – relative viscosity, s; ρ – the density of the liquid-glass, g / cm^3; m – fullness of liquid-glass slurry with copper slag, kg/dm^3; t – temperature of the liquid-glass slurry , °C, as well as dependences presented in Figure 1.



a) b) c)

Figure 1. The relative viscosity dependence on the density of the slurry of liquid-glass and temperature at fullness of slurry m = 1.25 kg/dm^3 (a), on the density of the liquid-glass and the fullness of the slurry t = 20 °C (b), on the fullness of the slurry and temperature at ρ

Analysis of the course of dependences in Figure 1 shows that the relative viscosity of the slurry based on liquid-glass and copper slag increases with a decrease in its temperature, an increase in the slurry density and its fullness with a copper slag.

With an increase in the temperature of the slurry from 20 to 50 °C, the content of the copper slag in it can be increased by 3 ... 4 times without changing its relative viscosity. The most intensive change in the conditional viscosity is observed with an increase in the specific density of liquid-glass more than 1200 kg/m^3, fullness of more than 1.8 and a temperature of over 35 °C. The nature of the received dependences is similar to the dependences for the liquid-glass slurries filled with powder quartz or ash from Pridneprovsk thermo power plant [1].

Conclusions

1. The objective influence of copper slag, as a filler, on the relative viscosity of a liquid-glass slurry was established depending on its fullness and temperature, and also the density of the sodium liquid-glass used.

2. When using a copper slag in a liquid-glass slurry in a foundry shop conditions, the dependences obtained will allow us rapidly make a decision on adjusting its composition in order to provide the required level of properties of the manufactured ceramic shell molds.

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UDC 629.4.015

Ways of improving the units construction of hydraulic shock absorbers of passenger cars on the bogie of KVZ-CNII type

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Abstract
Long-term operational experience, numerous theoretical and experimental studies show that the dynamic qualities of a passenger car are significantly influenced by the technical condition of hydraulic shock absorbers. When malfunctions or changes in the working parameters of the absorbers occur, the accelerations of the car body oscillations increase, the smoothness of the movement deteriorates and the level of the stressed state of the load-bearing elements of the structure increases. The article describes the results of the work on the search for rational design schemes and technical solutions to improve the operation of hydraulic shock absorbers in operating conditions.
The side forces transmitted to the rod of the shock absorber in the dynamics are investigated based on the computer model of passenger car dynamics for high-speed movement in the "Universal Mechanism" software package. In SolidWorks CAD, the calculation of the rod-guide system stresses was carried out. The project for upgrading the units of the hydraulic shock absorber NTs-1100 was proposed.
Keywords: HYDRAULIC SHOCK ABSORBER, COMPUTER MODEL OF THE ABSORBER, TECHNICAL CONDITION, UNITS MODERNIZATION, SIDE FORCES

Introduction

Long-term operational experience, numerous theoretical and experimental studies show that the dynamic qualities of a passenger car are significantly influenced by the technical condition of hydraulic shock absorbers. When malfunctions or changes in the working parameters of the absorbers occur, the accelerations of the car body oscillations increase, the smoothness of the movement deteriorates and the level of the stressed state of the load-bearing elements of the structure increases. The purpose of this article is to analyze the problems in the operation of hydraulic absorbers of domestic production on the basis of the analogue – NTs-1100 type, which occur when operating passenger cars and searching for technical solutions aimed at improving the design of these absorbers.

Materials and methods

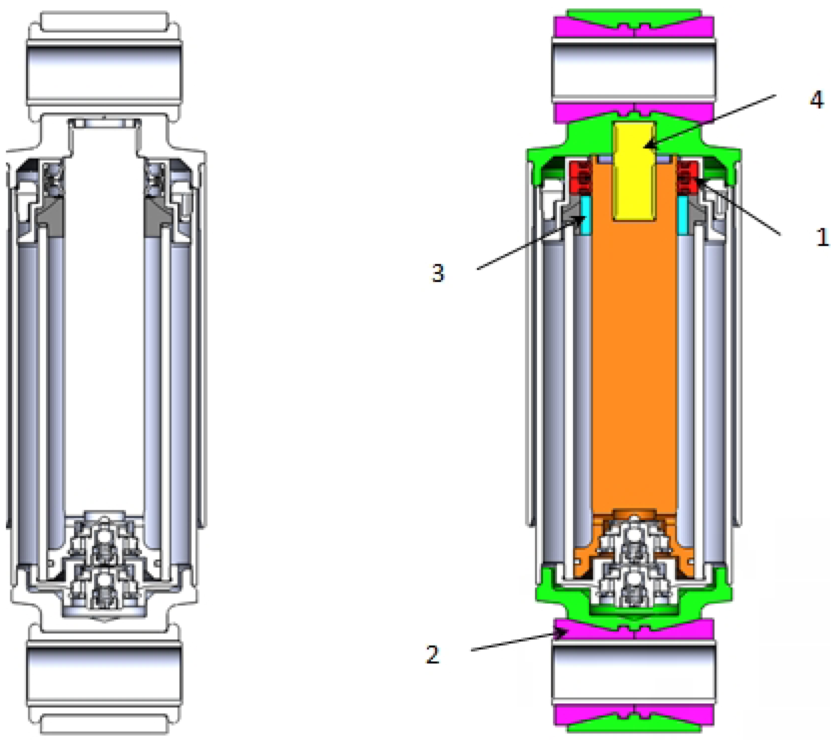
Analysis of the technical condition of hydraulic shock absorbers in operation shows that the most common faults are as follows:

- Loss of working fluid due to reduced density of the hydraulic system;
- Increase of gaps in the “rod-guide” system which causes the resistance parameter decreasing from the maximum to -25% of the nominal value;
- Loosening of the threaded connection of the rod to the upper head of the hydraulic shock absorber as a result of repeated bending loads (when skewing) and stretching-compression;
- The rod thread stripping at frequent disassembly due to the replacement of rubber sealing cups;
- Wear and destruction of the guide and “overtempering” of metal in the working area of the rod due to temperature overheating caused by the structural features of the absorber mounting units from the effect of significant side forces when skewing, which lead to wedging in operation.

To solve the problems associated with the occurrence of malfunctions of NTs-1100 type hydraulic shock absorbers, it is suggested to carry out complex modernization of the units. The main activities that are envisaged by the modernization project include:

- Replacement of sealing rubber cups (Fig.1, pos. 1)
- Changing the pin joint of the shock absorber mountings (Fig. 1, pos.2)
- Changing the design of the guide (Fig.1, pos.3)
- Changing the rod attachment to the upper head of the absorber (Fig. 1, pos.4).

The design of the project is shown in Figure 1.



a) b)

Figure 1. The hydraulic shock absorber

a) before modernization; b) after modernization

In order to determine the values of the side forces acting on the units of the hydraulic shock absorber in “Universal Mechanism” software package, a computer model of the dynamics of the passenger car on the bogies of KVZ-CNII type [1, 2] was examined under conditions close to operational ones.

The calculation conditions were chosen according to which the object was investigated. They include high-speed mode of the car motion, V = 20-140 km / h; rectilinear and curved sections of the rail track; state of the rail track– the absence and presence of horizontal and vertical unevenness; stiffness parameters of the bogie driving dog $C_{d.d.}$ = 2500 - 4700 kgf/cm; before the start of integration, the system is in a state of static equilibrium; the integration time is 12 seconds.

Results

The results of calculating side forces transmitted to the hydraulic shock absorber were obtained according to the accepted conditions of numerical integration (Fig. 2).

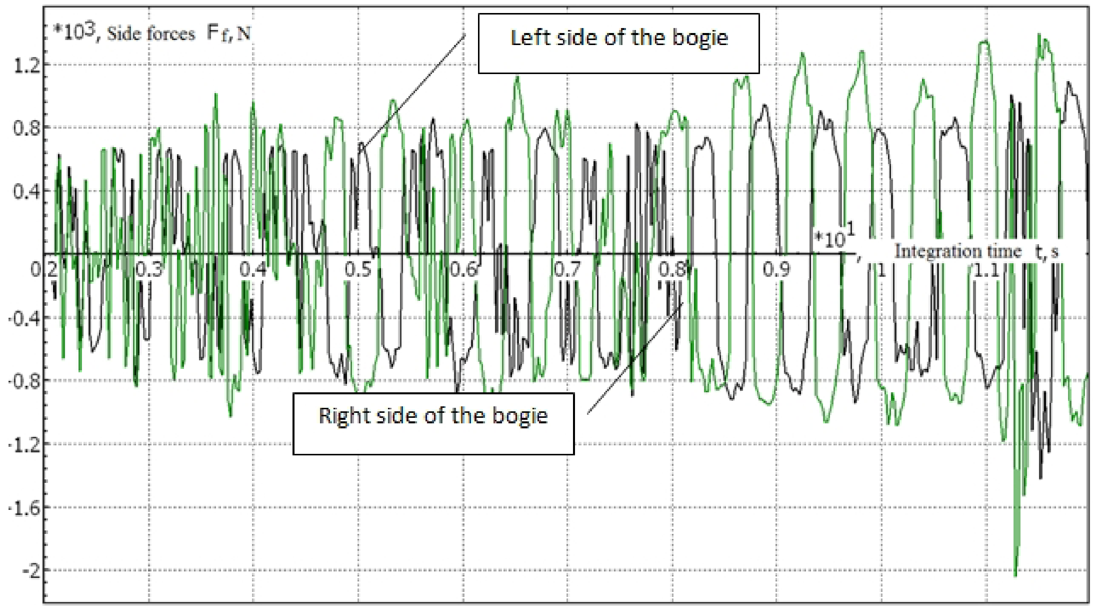


Figure 2. Oscillogram of side forces transmitted to the rod of shock absorber when moving in the straight section of the track at V = 80 km/h obtained by computer simulation in the “Universal Mechanism” software package

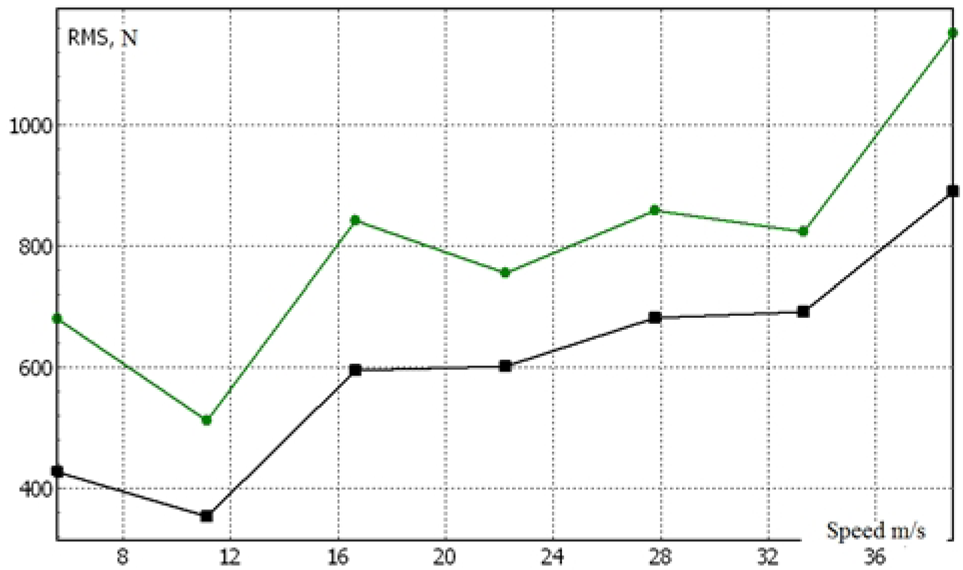


Figure 3. Dependence of the RMS side forces, which are transmitted to mounting units of the hydraulic shock absorber at the stiffness of the driving dog of $C_{d.d.}$ = 2500 kgf / cm in the route speed range up to 140 km / h on the straight section

To determine the dependence of longitudinal loads changes on the conditions of high-speed motion, an imitation study has been carried out in the dynamics of the passenger car model taking into account the stiffness parameters of the bogie driving dog as an element that perceives longitudinal forces acting on the central spring suspension and limits the relative rotation angles of the bogie frame relative to the bolster and rail track. The variation in the side force when speed increasing is shown in Figures 3-6.

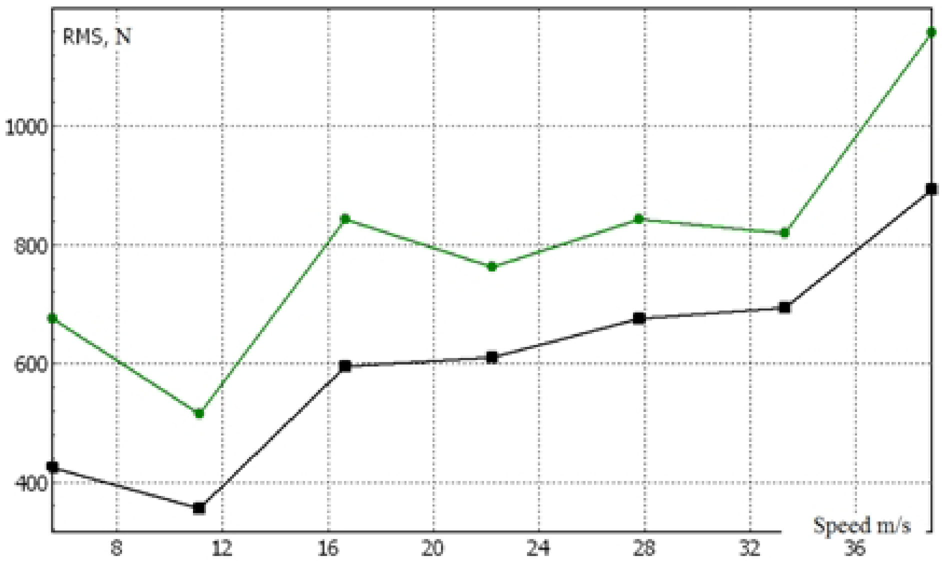


Figure 4. Dependence of RMS side forces, which are transmitted to mounting units of the hydraulic shock absorber at the stiffness of the driving dog $C_{d.d.}$ = 4700 kgf / cm in the route speed range up to 140 km / h on the straight section

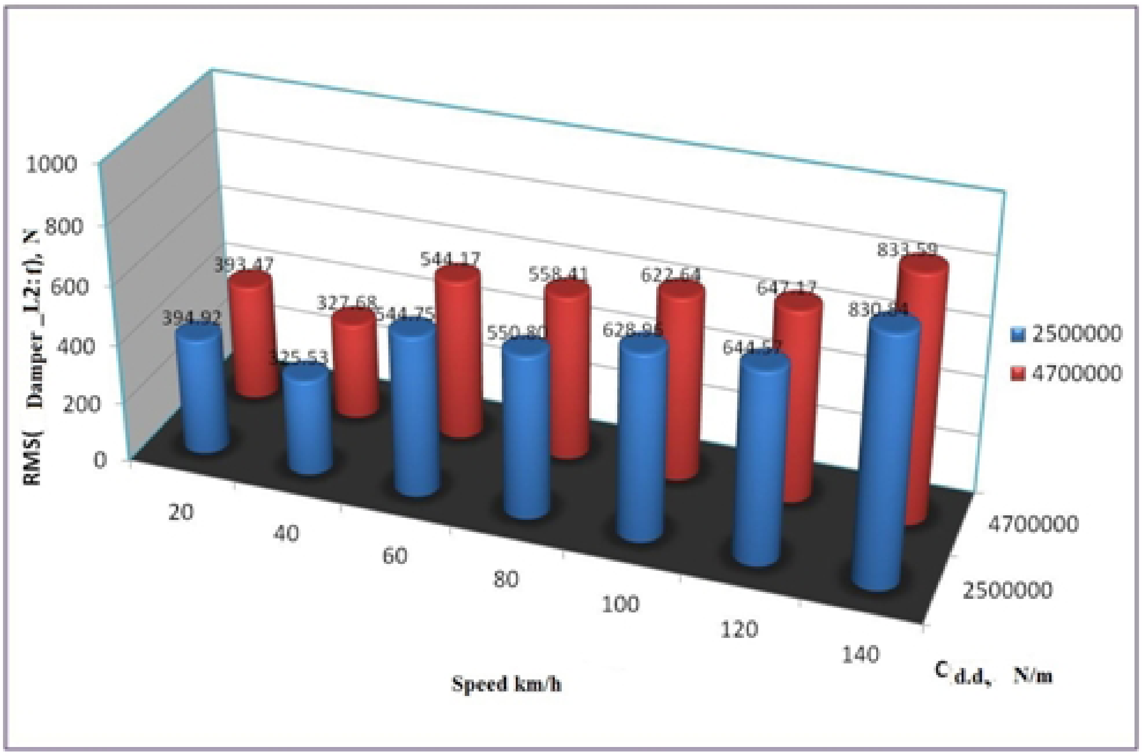


Figure 5. Dependence of RMS side forces, which are transmitted to mounting units of the hydraulic shock absorber (left side of the bogie) at the stiffness of the driving dog $C_{d.d.}$ = 2500 - 4700 kgf / cm in the route speed range up to 140 km / h on the straight section of the track

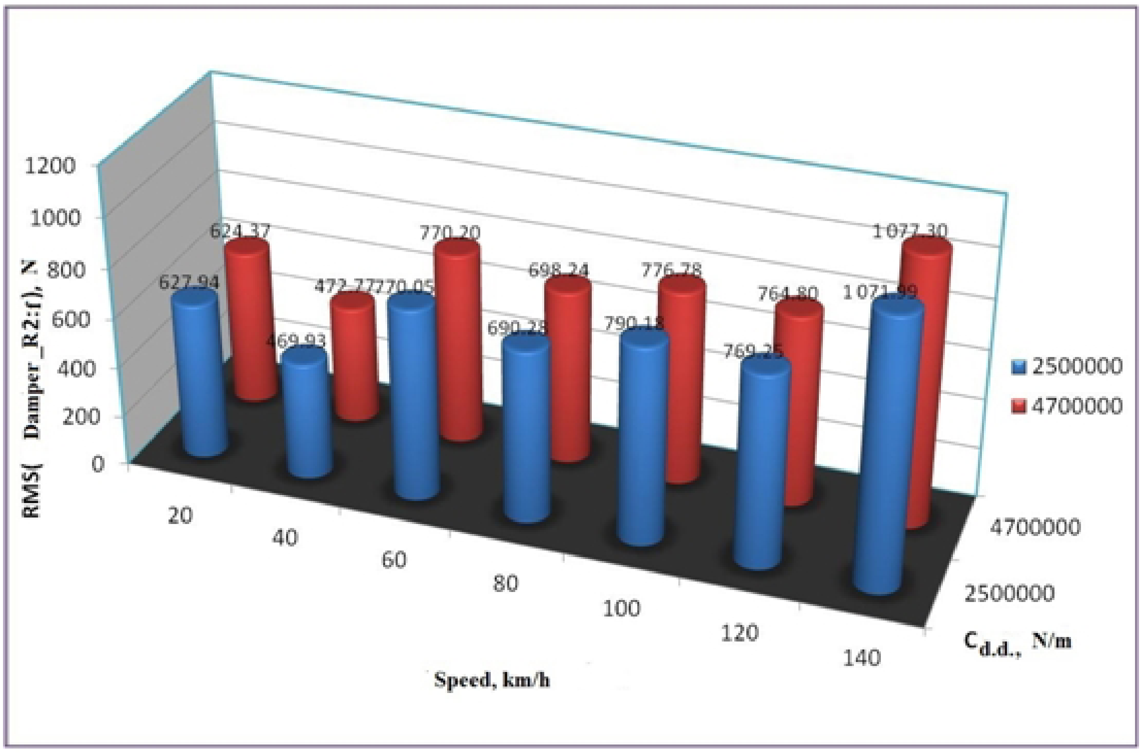


Figure 6. Dependence RMS side forces, which are transmitted to mounting units of the hydraulic shock absorber (right side of the bogie) with the stiffness of the driving dog $C_{d.d.}$ = 2500 - 4700 kgf /cm in the route speed range up to 140 km / h on the straight section of the track

According to the results of the model calculation, the table 1 of the initial data was formed.

Table 1

Motion speed, km / h	Rail track section	Horizontal and vertical rail track unevenness	Driving dog stiffness, $C_{d.d.}$, kgf /cm	RMS of side forces, N
140	straight	Absent	2500	460.37
140	straight	Absent	4700	455.02
140	straight	Present	2500	1151.52
140	straight	Present	4700	1157.96
120	curve, R = 600 m	Absent	2500	475.21
120	curve, R = 600 m	Absent	4700	469.47
140	curve, R = 600 m	Present	2500	1089.66
140	curve, R = 600 m	Present	4700	1091.95
140	curve, R = 1000 m	Absent	2500	477.02
120	curve, R = 1000 m	Absent	4700	476.51
140	curve, R = 1000 m	Present	2500	1257.29
140	curve, R = 1000 m	Present	4700	1251.51

According to the results of analysis, it is established that:

- with the growth of the passenger car speed, the level of side forces transmitted to the hydraulic shock absorber is gradually increased;

- the value of the stiffness parameter of the driving dog, which is within the limits of $C_{d.d.}$ = 2500-4700 kgf /cm does not significantly affect the obtained values of side forces. They are almost on the same level;

- when taking into account the unevenness of the rail track more than 2.5 times, the horizontal forces value transmitted to the shock absorber mounting units increases;

- root-mean-square deviations of the side forces can reach more than 1000 N at the motion speeds (V = 110-130 km/h).

The obtained results determining the horizontal side forces that are transmitted to the shock absorber indicate a real possibility of a situation when with the increase in the level of side forces, there will be a "wedging action" in the absorber operation, which will lead to a partial or complete loss of the shock absorber performance.

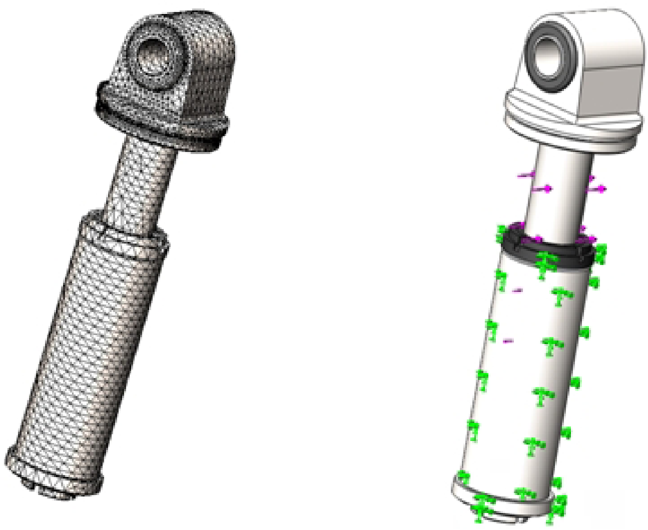
An imitation study of the created computer model of shock absorber was carried out in order to find the distribution of stresses from the action of side horizontal forces when "wedging action" in the "rod-guide system" using the SolidWorks software package. When performing the calculation, the properties of the materials of the consti- tuent units were taken into account, and the accuracy of the geometry of the elements was maintained in accordance with the drawings of the design documentation for the hydraulic shock absorber Nts-1100.

Before the beginning of stress determination by the finite element method, a grid of high quality was created on the solid body of the absorber model with a total number of elements – 86802 and units – 142680 without distorted elements by Jacobian.

The calculation procedure assumes a complete fixation of the guide and working cylinder with the restriction of all degrees of freedom and the application of side horizontal forces determined by "Universal Mechanism" software package to the elements of the upper part of the shock absorber (head with the rod) (Fig. 7).

The distribution of stresses in the guide will have the following form taking into account peak side loads (Fig. 8).

The obtained values of the maximum stresses arising in the guide of the shock absorber with applied side horizontal forces up to 2500 N are shown in Fig. 9.



a) b)

Figure 7. Creation of a grid (a) and a scheme for applying external loads to the elements of the shock absorber (b)

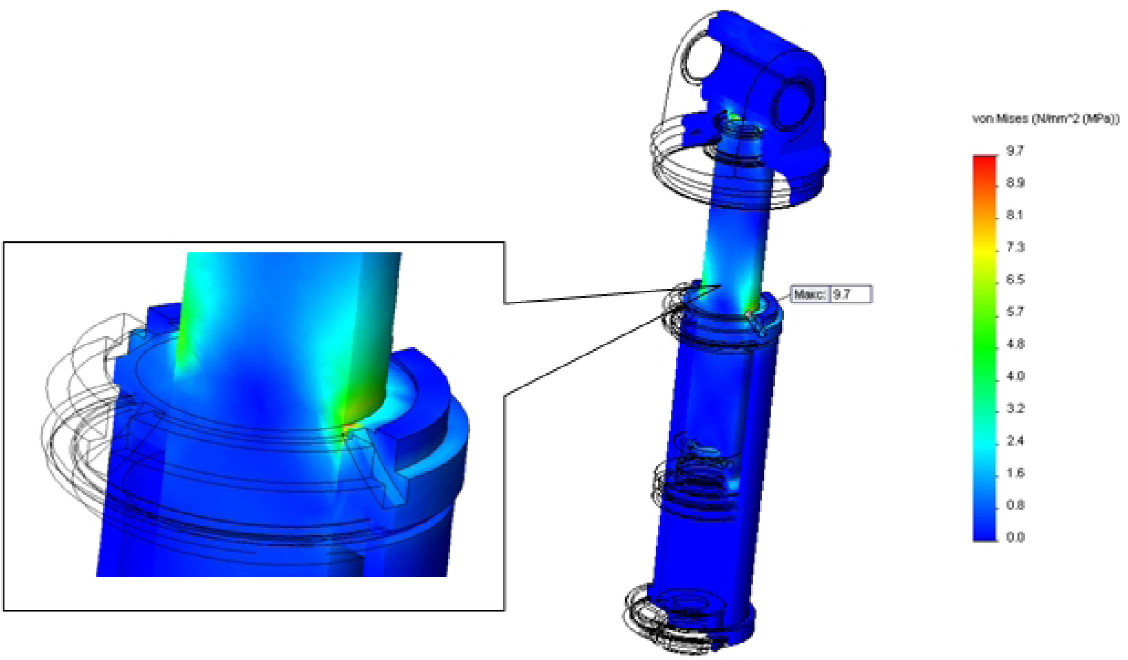


Figure 8. Graphical representation of the stress distribution when the longitudinal side force is applied to the hydraulic shock absorber F_f = 2000 N

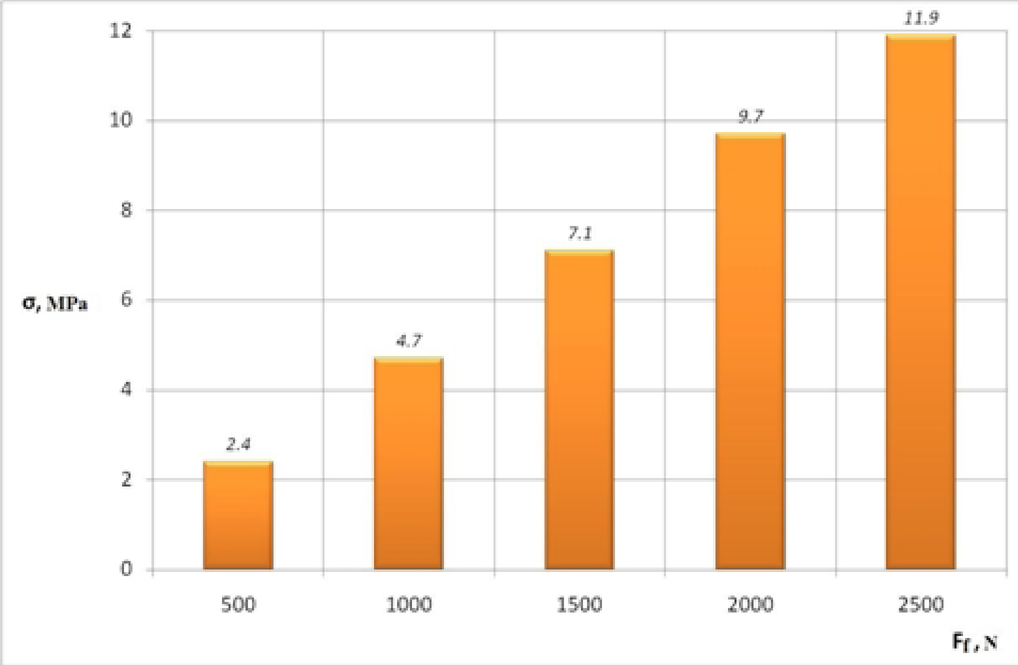


Figure 9. The nature of the change in the values of the stresses in the guide of the shock absorber from the action of side forces

Considering the constant cyclicity of the longitudinal loads action during the movement of the car, which are transmitted to the mounting units of the absorber, their negative influence on the elements of the shock absorber can be argued. The carried out researches explain the reason for the "wedging action" of the shock absorber, the occurrence of wear and failure of the guide, the "overtempering" of the rod metal, the deformation of the working cylinder surface. In general, with the increase in side horizontal forces, the operating conditions of the shock absorber are deteriorated, the heating temperature of the "rod-guide" friction pair increases, which in turn can lead to the loss of the properties of the working fluid when critical values are reached.

Conclusions

1. The proposed technical solution for the complex modernization of the hydraulic shock absorber will improve the quality of its operation, reduce the risk of loss of serviceability as a result of "wedging" from the action of the side forces, increase the service life.

2. By means of computer simulation, the character of the change in longitudinal side forces, which are transmitted to the shock absorber mounting units and their influence on the stress state of the absorber elements, was investigated. The range of values of root-mean-square deviations of longitudinal forces in the framework of high-speed motion V = 20÷140 km/h was determined.

Acknowledgements

The authors express their gratitude to G.Yu. Chernyak for active participation in the work on creating a computer model of the dynamics of a passenger car on bogies of KVZ-TsNII type. The work was carried out in the framework of scientific and research work to determine the effect of hydraulic shock absorbers on the dynamic performance of cars by means of simulation.

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UDC 669.141.24:669.14.018.294.3

Optimization of chemical composition of steel for railroad wheels providing stabilization of mechanical and increase of operational properties

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Abstract
In connection with the increase in axle loads of freight cars on the railways and the increase of their speed of movement, the requirements to the service and operational properties of railway wheels, including wear resistance and thermal resistance, are significantly increasing. One of the main factors affecting these indicators is the chemical composition of steel for railway wheels.
To determine the influence of chemical elements on the service properties of railway wheels, composition of steel was structured as a chemically unified system, which was carried out on the basis of factor and physic-chemical analyzes with separation of elements into subsystems: matrix, alloying, microalloying and impurity. In this method, the influence of each of the subsystems is considered comprehensively through the physic-chemical parameters of the “convolution” of the chemical composition of each of them, which reduces the parametric of the forecast models, increases their information capacity and allows obtaining adequate and stable models according to scheme “chemical composition - microstructure - mechanical properties of steels for railway wheels”. On the basis of computational and laboratory experiments, the “restricted” limits and the proportions of the elemental composition are proved, which ensure the required mechanical properties and increase the resistance to thermal effects arising from the operation of railway wheels during braking were justified. The influence of vanadium as one of the effective micro-alloying elements, which have a positive effect on the strength properties of railway wheels has been established.
Keywords: RAILWAY WHEELS, CHEMICAL COMPOSITION, MECHANICAL PROPERTIES OF STEEL PRODUCTS, THERMODYNAMIC INFLUENCE, “NARROWED” RANGES, INTEGRAL PARAMETERS OF THE INTERATOMIC INTERACTION

The state of the question

When using the wheels in each of their elements, a complex rapidly changing in time system of compressive and tensile stresses occurs. Stresses in the wheel-rail contact lead to damage, the vast majority of which can be classified as tread surface wear, thermal defects, fatigue defects and brittle fracture of the metal. In addition, during braking in the contact zone of the wheel with the rail, rapid high-temperature heating of the rim metal above the critical temperature Ac_3 can occur followed by accelerated cooling, as a result of which phase recrystallization of the metal with the formation of a new structural component – martensite is possible in these areas. Structural transformations in local areas of the wheel rim cause internal stresses and, as a consequence, the emerging of microcracks, which under the action of impact loads and the emerging stress center at their apices develop into the rim and propagate along the boundary between the microvolume of the metal undergoing transformation and the base metal. This leads to formation of chips of thermal origin.

Therefore, strict requirements are imposed not only on the design of the wheel, but also on the quality of the material used to produce it. The wheel should have a high level of strength, plastic properties, impact toughness and fracture toughness with low sensitivity to thermal effects.

The necessary combination of properties is achieved mainly due to the selection of the optimal structural state of the metal, which is determined by the chemical composition of the wheel steel and the thermal treatment modes of the wheels. When choosing a material, we proceed from the specific operating conditions of the wheels and their purpose. Currently, the requirements for the wheel metal are significantly increased in connection with the planned increase in the railways of Ukraine of axle loads of freight cars up to 25 tons and a rise of the passenger trains speed. The problem of their wear and heat resistance is put first. Thus, the development of new composition and optimization of the existing one of wheel steels due to reducing the carbon content by compensating it as a reinforcing agent with elements of the matrix micro-alloying system (Si, Mn, V) is an urgent task.

The complexity of developing new steel grades for wheels is due to the necessity of meeting a number of special requirements. Above all wheel steel should have high wear resistance and contact strength. The easiest way to improve these characteristics is to increase the carbon content. However, to increase the resistance of wheel steel to the formation of a "white layer" on the rolling surface, which conduce the occurrence of defects of braking (thermal) origin, the carbon content in it must be reduced in order to reduce the tendency of the steel to thermal cracking and brittle failure. At the same time, the weakening of steel become necessary to compensate by the introduction of inexpensive alloying elements and the use of more efficient heat treatment processes [1-3].

Increasing the efficiency of controlling the processes ensuring the production of high-quality wheel steel requires the development of information and mathematical support based on an adequate connection between the chemical composition of steel and the service properties of metal products.

The effectiveness of solving strategic problems ensuring the competitiveness of metal products in specific industrial conditions is largely determined by the degree of computerization of scientific and technical services and manufacturing areas, the availability of workable information and analytical systems for a comprehensive analysis of current production data.

The methodology of creating and practical use of information-analytical systems [4, 5] being developed in ISI NAS of Ukraine on the basis of databases and models of metal melts is the basis for automating the multidimensional search for optimal solutions.

Modern information technologies allow solving problems with various types of data and obtaining samples for any information that provides the solution of forecasting problems based on complex analysis and interpretation of diverse data.

Taking into account the heat treatment technology, a representative array of experimental data was formed in order to identify the main regularities, the effect of the composition of steel for railroad wheels on the complex of its properties. It includes information on the characteristics of 69 melts of steel of the following grade –T (open-hearth production), ER7 (n=20), ER8 (n=5) and grade –T (n=36), (CCP) under the conditions of PJSC "Interpipe NTRP".

Mechanical properties of steel products and chemical composition of steel for special purposes usually have wide fluctuations, noisiness, and often data incompleteness. In this regard, the concept of assessing the reliability of data was adopted by means of successive elaboration of areas ("microscope" principle) on the basis of a step-by-step analysis of the initial information.

For the purpose of the multidimensional analysis of the data, the mathematical software is generated. Along with the traditional software of the primary data analysis, it includes the original methods of purposeful data projection, searching for hidden regularities on the basis of the methods of physic-chemical modeling of multicomponent metal melts covering a wide range of alloying elements. The use of modern information technologies is an effective tool for solving the problems of optimizing the quality of metal products for a specific purpose.

Presentation of the main materials of the study

To assess the influence of the chemical composition of wheel steel on its mechanical properties and the temperature of phase transformations, the method of physical and chemical modeling developed in ISI NAS of Ukraine has been used. Its principle is to describe the chemical composition of the melt by a complex of integrated model parameters of interatomic interaction characterizing its chemical and structural state.

The implementation of the developed methodology includes [6, 7]:

1. Calculation of the model parameters of the interatomic interaction for a given chemical composition of the charge Z^Y (e) and structural d (10^{-1}nm) states that are defined as the result of a pairwise interaction of all its (m) components by solving a system of nonlinear $m^2 - m + 1$ equations:

$$\begin{cases} a - f(\Delta e_{ij}^{'}) = 0, \\ d - f(\Delta e_{ij}^{"}) = 0, \qquad i = 1,2,...,m-1,\ j = i+1,...,m, \\ 4 \cdot Z^X(a, \Delta e^{'}) + Z^Y(d, \Delta e^{"}) = 0, \end{cases} \quad (1)$$

where $\Delta e_{ij}^{'}$ - the number of electrons that are localized when interacting in the direction of communication $i-j$ at a distance a (along the diagonal of the bcc or fcc lattices), $\Delta e_{ij}^{"}$ - at a distance $d = 0{,}866 \cdot a$ along the face,

$$\Delta e^{'} = (\Delta e_{12}^{'}, \Delta e_{13}^{'}, .\Delta e_{ij}^{'}., \Delta e_{m-1,m}^{'}),$$

$$\Delta e^{"} = (\Delta e_{12}^{"}, \Delta e_{13}^{"}, .\Delta e_{ij}^{"}., \Delta e_{m-1,m}^{"}) \ .$$

As a result of the solution of the given non-linear system of equations, we determine:

$$a,\ \Delta e_{ij}^{'},\ \Delta e_{ij}^{"},\ i = 1,...,m-1,\ j = i+1,...,m.$$

The parameter Z^Y is determined by averaging the effective charges of all types of bonds $i-j$ with the bond length d :

$$Z^Y = \sum_{k=1}^{m} \frac{\lg Ru_k^o - \lg(d/2)}{tg\alpha_k} \cdot n_k^2 + 2 \cdot \sum_{k=1}^{m-1} \sum_{l=k+1}^{m} n_k \cdot n_l \cdot \Delta e_{kl}^{"}, \quad (2)$$

Where n_k - mole fraction, Ru_k^o - the radius of an unpolarized atom, $tg\alpha_k$ - a parameter that characterizes the change in the electron density upon ionization of the atom of the *k-th* component;

2. Construction on the basis of forecast models experimental data for basic mechanical characteristics ($\sigma_в$, δ, HB and etc.) as functions of individual model parameters and their combinations;

3. Determination of the recommended ranges for changing the integral parameters providing the required level of properties.

4. Determination of the chemical composition of steel that meets the required ranges of integral parameters based on optimization methods.

Using integral parameters Z^Y and d as a “convolution” of the chemical composition of a multi-component melt allows increasing the information capacity of models and reducing their parametricity. The regression equations describing their mechanical properties were obtained on the basis of the above experimental data on carbon steels for railway wheels ($r \geq 0.85$):

$$\sigma_в = 2808 + 6685 \cdot Z^Y - 3646 \cdot d$$

$$HB30mm = 2091 + 1502 \cdot Z^Y - 1331 \cdot d$$

$$\delta = 86 \cdot d - 36 \cdot Z^Y - 178$$

The high accuracy of the models allows using the computational experiment methodology to determine the optimal composition of wheel steel. The depen- dence of the strength properties of carbon steels for railroad wheels on the integral charge state parameter Z^Y was used to determine the boundary conditions (Fig.1).

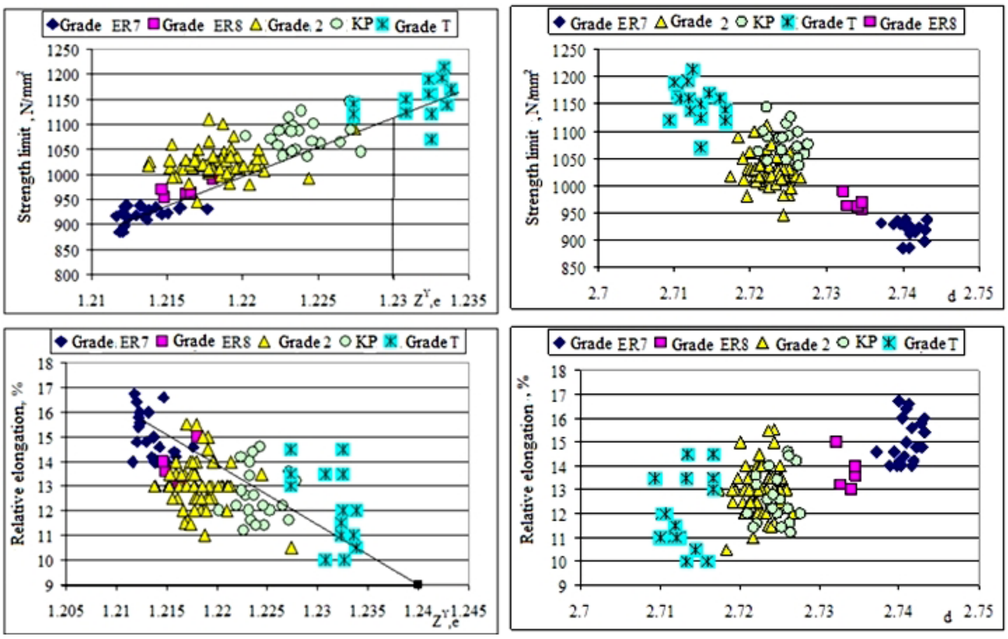

Figure 1. Dependence of mechanical properties of wheel steel grades on model parameters

From Fig. 1 it follows that the change of the parameter $1.235 \le z^Y \le 1.24$ provides the required properties of wheel steel grades. To reveal the influence of elements on the service properties, the steel composition is structured as a chemically unified system that is implemented on the basis of factorial and physico-chemical analyzes dividing them into subsystems - matrix, alloying, micro-alloying and impurity. In case of this approach, the influence of each of the subsystems is considered comprehensively through the physic-chemical parameters of the "convolution" of the chemical composition of each of them, which provides a reduction in the dimension of the forecast models and allows obtaining adequate and stable models in the composition-structure-thermal processing-mechanical properties scheme.

A distinctive feature of the developed model is that not physic-mechanical properties, but a set of corresponding interatomic interaction parameters characterizing the melt and its constituent parts as a chemically unified system are given as optimization criteria. By imposing restrictions on these parameters, it is possible to achieve a certain internal structure of the melt, which, in turn, will provide a given set of mechanical properties.

Fig. 2 shows an example of the results of structuring the chemical composition of steel for railway wheels of the following grades: «2», «T», «ER7», «ER8».

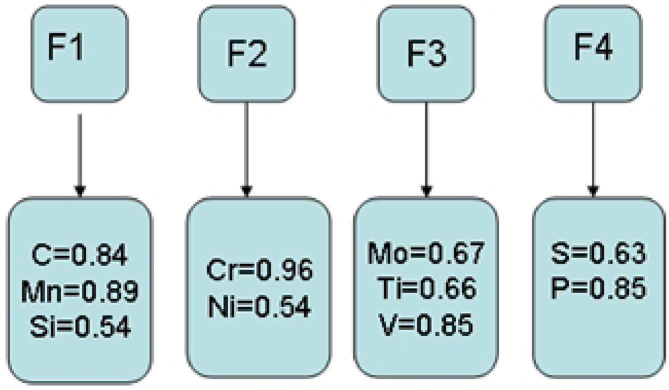

Figure 2. Significant loads of variables on integral factors

On the basis of the identified factors and their corresponding physic-chemical interpretation, the expert makes a decision on the presented options for structuring the choice of model parameters for constructing forecast models and justifying the boundary conditions of optimization parameters. Thus, if the physical meaning of grouping the chemical composition of matrix (factor F1) and impurity (factor F4) subsystems is obvious, then the structure of factors F2 and F3 loaded with impurity micro-alloy elements requires an appropriate interpretation. Significant loads of microalloying elements Cr, Ni and Ti, V, Mo are in accordance with the current data on the physic-chemical properties and reactive ability in solid solutions and melts which are carbon and nitride-forming that explains the logic of their association into one group.

The most characteristic parameters at the heating (cooling) of steel are the critical temperatures of phase transformations (As_1 and As_3). In accordance with the values of the temperature As_1 and As_3, heat treatment modes are also assigned to give the steel the necessary operational properties. To increase the stability of steel to thermal effects, such their alloying is justified, which increases the critical temperature values of austenite transformation and extends the intercritical interval.

On the basis of an analysis of the reference experimental data [8, 9] for predicting the values of critical temperatures and the values of intercritical interval ΔAs using the integral parameters of the interatomic interaction, the following equations were obtained:

$$Ac_3, {}^0C = 301480,86 - 96,01Z^Y - 1572,26d - 296435tg\alpha \qquad r = 0.8 \qquad (3)$$

$$\Delta Ac, {}^0C = 21255 + 143,55Z^Y - 595,1d - 222770tg\alpha \qquad r = 0.89 \qquad (4)$$

Using the graphical dependencies shown in Fig. 1, as well as the extreme nature of the curves for critical temperatures allows us to determine the boundary conditions for the solution of the problem of selection the optimal composition of the elements of the matrix subsystem from the following ratios :

$$0,8 \le \frac{Si}{Mn} \le 1,0\ , \quad 1,6 \le Si + Mn \le 1,8$$

As it follows from Fig. 3, the required constraint system is corresponded to all the silicon and manganese ratios meeting the boundary conditions determining the widest range of phase transformation temperatures, which ensures the prevention of phase transformations when the rim of the wheel is overheated during braking.

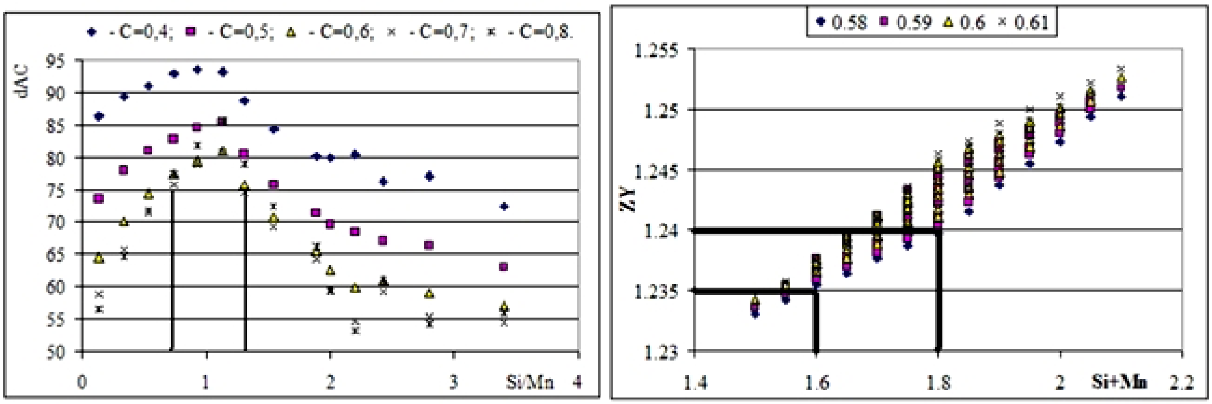

Figure 3. Temperature dependence of phase transformations and the charge state parameter Z^Y of carbon steels for the production of railway wheels on their chemical composition

The solution of the presented inequalities is implemented graphically (Fig. 4). The indicated boundary conditions correspond to values for silicon of 0.7-0.9%; for manganese of 0.8-1.0%.

Limitations on carbon 0.55-0.6 are obtained from a comparative analysis of its effect on the integral parameter Z^Y while ensuring the limitations $1,6 \le Si + Mn \le 1,8$ (Fig.5).

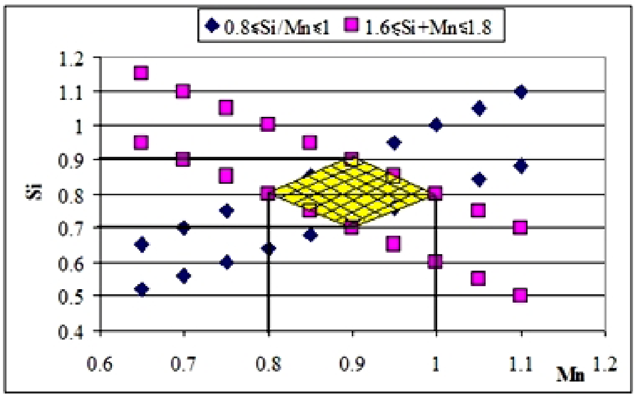

Figure 4. Graphical interpretation of the solution of the ratios $0,8 \le \frac{Si}{Mn} \le 1,0$ and $1,6 \le Si + Mn \le 1,8$

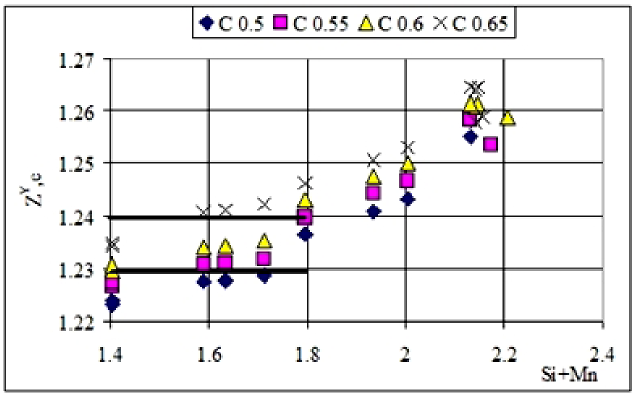

Figure 5. Justification of carbon concentration for specified limits on the indicator Z^Y depending on the content of silicon and manganese

The ranges of the elements of the matrix system obtained during the computational experiment provide the required technological properties: carbon (0.55-0.60%); manganese (0.8-1.0%); silicon (0.7-0.9%).

Fig. 6 shows the relationship between the ultimate strength and the charge state parameter of the subsystem (Mo, Ti, V). As the value of the indicator Z^Y_{MoTiV} increases, the values of the strength limit are reduced.

In the course of the computational experiment (Fig. 7), it has been found that additional vanadium microalloying to 0.08% leads to a decrease in the index Z^Y_{MoTiV} to 1.6e, which, in turn, has a positive effect on the strength properties of steel.

The construction of cartograms of changing the mechanical properties of the steels produced by PJSC "Interpipe NTRP" (Fig. 8) allows us to calculate the prospective area of mechanical properties for steel ER7 additionally alloyed with vanadium.

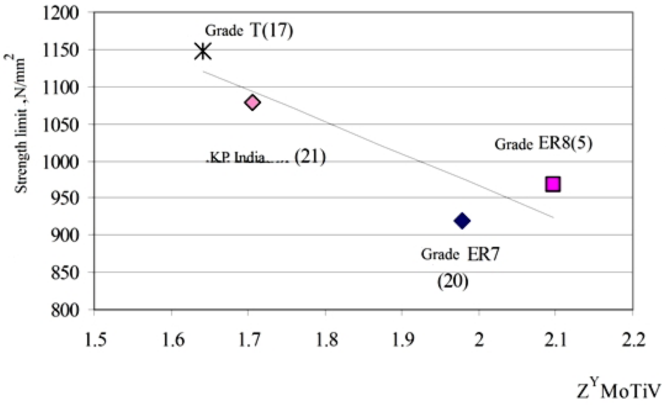

Figure 6. Dependence of the strength limit on the model parameters of the micro-impurity subsystem

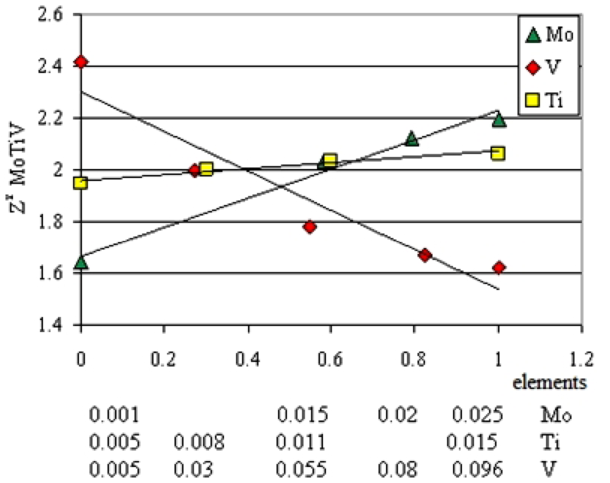

Figure 7. Effect of elements of the impurity-microalloying subsystem Z^{Y}_{MoTiV} on the change in the parameters of the interatomic interaction

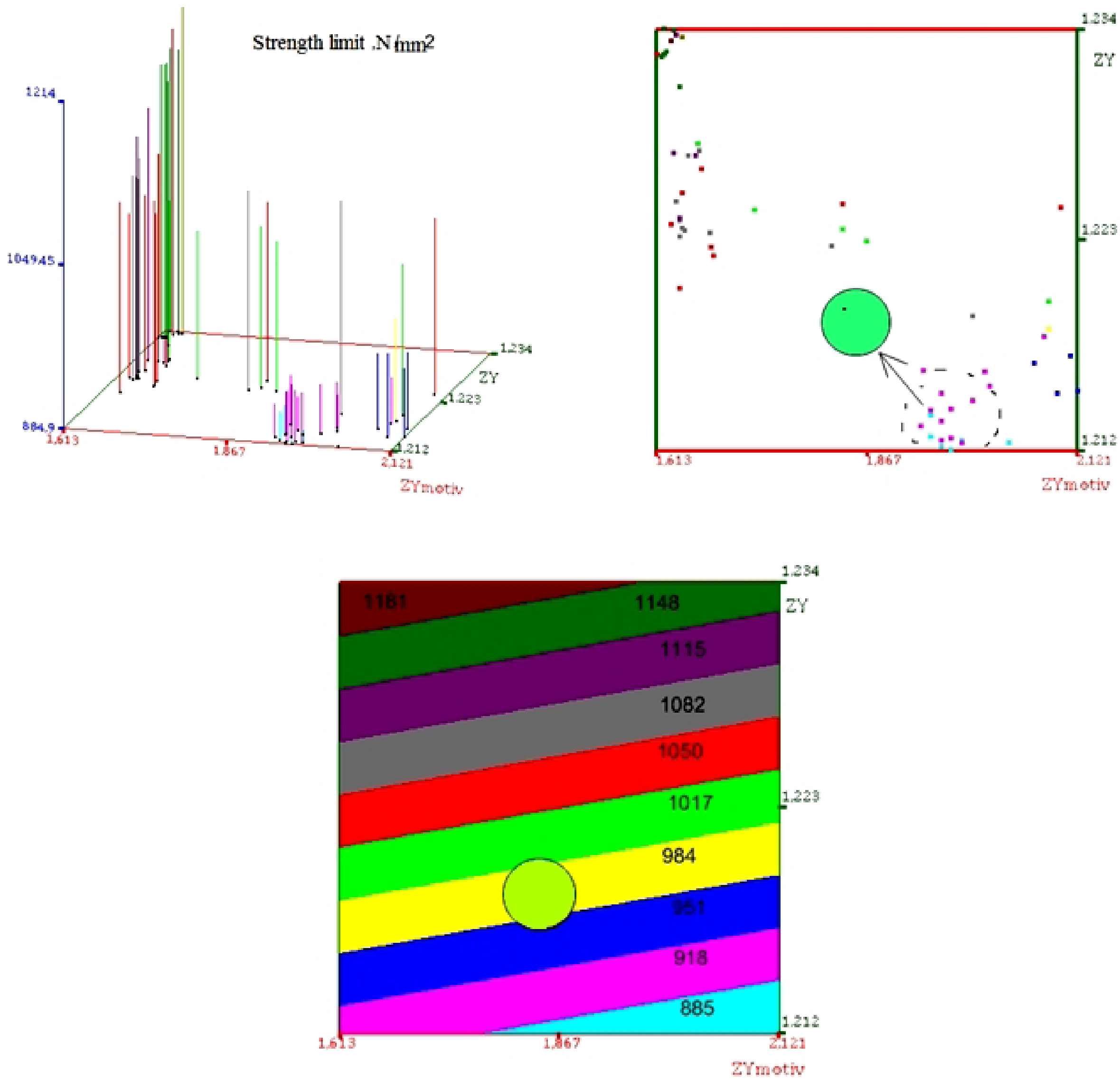

Figure 8. The effect of microalloying of steel ER7 with vanadium

An increase in the thermal stability of steel due to vanadium microalloying forms dispersed carbide or intermetallide phases of high stability, which are not prone to coarsening at elevated temperatures. Vanadium strengthens ferrite more strongly than tungsten and chromium, and approaches the degree of influence on strength to molybdenum. Vanadium makes it difficult to coagulate the carbide phase. The formation of dispersed uniformly distributed carbides containing vanadium and a decrease in the diffusion mobility of carbon atoms due to the presence of vanadium in the solution significantly increase the strength of vanadium steel at elevated temperatures [10]. After the tempering of the steel at temperatures of 400-6600 °C, carbide formation processes develop rather slowly, the carbides VC and Me_7C_3 are present in the form of dispersed precipitates hardening steel. Vanadium is recommended for microalloying as an element that efficiently reduce the grain structure of steel.

Conclusions

1. The method that allows us to reveal hidden patterns of the chemical composition influence on the physic - mechanical properties of the wheel steel at the level of interatomic interaction was proposed.

2. "Narrowed" change ranges of matrix system (C= 0.55-0.60%; Mn= 0.8-1.0%; Si= 0.7-0.9%) providing the required mechanical properties of railway wheels corresponding to GOST 10791-2011 were determined on the basis of laboratory studies, computational experiment and optimization procedures of "Optimization" software complex, as well as graphical interpretation of the obtained dependences on the basis of experimental data on the composition and properties of railway wheels produced in the conditions of PJSC "Interpipe NTRP".

3. Based on the technique of structuring the total composition of steel (matrix, alloying, microalloying), the influence of elements of the impurity-microalloying subsystem on the formation of strength properties was revealed. The contribution of vanadium, as one of the effective elements of microalloying, in the formation of the strength properties of solid-rolled railway wheels was substantiated.

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UDC 621.774. 38

Complex study of dynamics of automatic pipe-rolling plant

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Abstract
The complex solution of a problem of dynamics for the chosen "working stand - shell - mandrel-bar" model of automatic pipe-rolling plant TPA taking into account time-varying of the system mass is considered. The differential equations of the movement for elastic elements of the chosen multi mass model of a working stand and specified differential equations of longitudinal oscillations of a mandrel with a bar taking into account change in time of mechanical system mass of automatic mill TPA are worked out. Results of research of dynamics of interaction of the rolled shell with elements of a working stand of the mill taking into account their elasticity are given. Expressions for the corresponding form of oscillations of deformable elements of a working stand of the automatic mill are obtained. Features of dynamics of the mill working stand elements are revealed. Dynamic functioning of a mandrel with a bar in the deformation zone and elastic system of the mechanism of holding of the mill mandrel are presented taking into account influence of non-stationary forces of technological resistance and variability of inertness of the attached mass of the piercing hollow billet. Nature of behavior of the mandrel holding mechanism is established taking into account change in time of the rolled pipe mass and non-stationary cyclic influence from the deformation zone. The complex analysis of non-stationary oscillations of "shell– mandrel –bar" mechanical system is represented by the coefficient of system dynamism.
Key words: AUTOMATIC MILL, WORKING STAND, SHELL, MANDREL, BAR, VIBRATION, ROLLING FORCE, DYNAMICS, VARIABLE MASS, DIFFERENTIAL EQUATION, LONGITUDINAL RIGIDITY, THICKNESS VARIATION, FORCED OSCILLATIONS, AMPLITUDE, FREQUENCY, MESHCHERSKY'S TASK

Introduction

Pipe-rolling plants with automatic mill are designed to produce hot-rolled seamless pipes of a wide range. The ability to quickly switch from one type of pipe production to another one defines the high efficiency of using TPA with automatic mill, while not excluding rolling of tubes of small batches.

Increasing production rate of seamless pipes on mills in the production line of pipe-rolling plants (APP) entails tightening the operation mode, both the main and auxiliary equipment.

Automatic mill is the most narrow place due to the current structural features of the sequence diagram in implementing the required processes in the production of seamless pipe in TPA production line [1]. Automatic mill distinctive feature is the presence of significant dynamic processes. Dynamic load in the mill and drive line at the stage of the workpiece grip is 3...4 times higher than the load at the steady rolling process.

Such character of loading reduces durability and reliability of the main equipment of automatic mills.

An analysis of literary sources

In the known studies of automatic mills dynamics of impact interaction of the workpiece and the rolls when gripping is considered without taking into account the elastic linkages of the system base equipment or the grip process is studied from an energy point of view apart from the steady rolling process. These assumptions lead to significant differences in the design loads of automatic mills elements from loads obtained in experimental studies.

In order to form a stable geometry of pipes rolled on automatic mill TPA, the stable dynamics of the base equipment has a practical value. Among the set of loads acting on the blocks and parts of automatic mill, the least unstudied are significant in size and non-stationary time-varying dynamic loads.

Problem statement

Experience of operation of domestic automatic mills TPA shows that when the forced feeding of the shells into mill grooves (accelerated feeding of the shell into the deformation zone is provided), there is some improvement in the grip of the shell by working rolls. The gripping of the shell by the rolls of the automatic mill, among other things, is significantly complicated by the fact that the shell during interacting with the working rolls is in contact with the mandrel and the bar system of the mandrel holding mechanism in the groove. These special conditions, along with all other factors, form the initial conditions of the technological process and affect the complex stress-strain state of the elements of the working stand and the rolled shell in the deformation zone, and form the nonstationary dynamics of the mill equipment in general. In this case, the forced supply of the rolled shell to the deformation zone of the mill by shell pushing aggravates the character of the dynamic processes formation. Determination of the real load spectrum allowed us to obtain recommendations for improving the automatic mill equipment in order to increase its technological capabilities, reliability and durability.

A number of works have been devoted to the investigation of complex dynamic processes of interaction between the rolled shell and rolls and the mandrel of mills [1 - 4].

In this case, a mathematical model of the non-linear process of the nonstationary interaction of rolled metal with mill rolls was considered in [3], the analysis of which later allowed us to obtain an expression for the corresponding simplified form of the dynamic load during transient processes.

This work was carried out in a complex formulation on the basis of the development of the previously accepted calculation scheme and the mathematical model of the dynamics of the basic units of the automatic mill. A definite attempt has been made to establish the influence of the basic parameters of the interaction of working rollers with a shell, a mandrel, and a mandrel holding mechanism. Obviously, the proposed approach is more correct and necessary for studying complex dynamic phenomena in the base elements of the working stand and the output side of the automatic mill.

It is known that for the implementation of stable technological operations of rolling the shell on the mill, by stabilizing the dynamics of the work stand and vibrating activity of the bar of the mandrel holding mechanism, numerous restraining, guiding, centering and thrust-adjusting mechanisms are used on the output side of domestic automatic mills [1, 4]. The mandrel holder perceives significant static and time-varying non-stationary dynamic loads on the side of the rolled shell. Due to the fact that the mandrel holder has considerable flexibility and a large mass, in the considered mechanical system significant in size and time-varying non-stationary dynamic loads occur; they cause its longitudinal oscillations along the rolling axis of the shell according to the corresponding harmonic forms. The mandrel together with the bar of its holding mechanism oscillates in the deformation zone. The center pilot of the mandrel deviates from the design position in the deformation zone (groove gorge of the working rolls) that often causes not standardized wall thickness variation of the shell (pipe) by technical documentation. The intensity of the non-stationary interrelated action from the side of the working stand and the deformation zone on the mandrel, the time varying in the inertia of the pipe and the stiffness parameters of the mandrel holder significantly complicate the description of the dynamic processes (Figure 1).

Ways of intensification of the technological process and issues of improving the quality of the rolled pipes dictate the conditions for improving the designs of all basic mechanisms of the working stand and the mandrel holding system.

Work objective

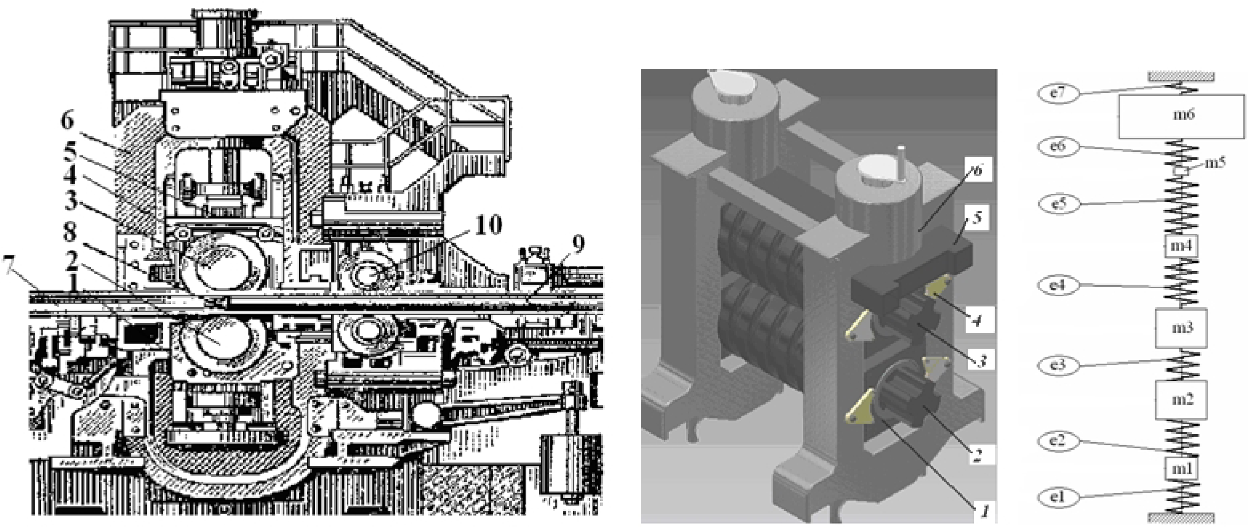
The objective of the work is to study the developed dynamic model “working stand - tube billet - mandrel – bar system”, which will allow us to analyze the dynamic state of the elements both of the work stand and the bar system with the mandrel during the whole process of rolling the pre-pierced shell and on the basis of the above, to develop radical proposals for a comprehensive modernization of equipment at the output side of the mill.

Adjustment of the required parameters of the deformation zone is carried out in a complex way: by setting the working rolls with a wedge mechanism, the position of the mandrel on the roll gorge, the fixed-adjusting mechanism and the modernized intermediate wires installed along the entire output side of the automatic mill [4].

Method for solving the problem

In order to form scientifically grounded proposals for improving the design of the working stand, the equipment for the output side of the mill and the technology of producing pipes in mills, it is necessary to study more deeply the influence of various parameters and features of the technological process of rolling shells on the behavior of the entire mechanical system of the mill and the quality of the finished product.

The solution of this problem causes some adjustment of the calculation scheme and the further development of the mathematical model of the investigated system “working stand-mandrel-bar” the most accurately reflecting the actual processes occurring in the initial mechanical system of the automatic mill.



a) b) c)

Figure 1. Automatic pipe-rolling plant

a) three-dimensional model b) generalized dynamic system of elements of the working stand c) 1 - bottom chock; 2 – bottom roll; 3 – top roll; 4 - bottom chock; 5 - wedge mechanism for moving the top roll; 6 - stand of the working stand; 7- shell; 8- mandrel; 9 - mandrel bar; 8 - register plate; 9 - wedge pressure device; 10 - stripper rolls of the shell

In the present work, the developed dynamic and mathematical models “working stand-mandrel-mandrel bar” of an automatic mill are considered in the complex as an object of research.

This work differs from the known works [1-4] by complex approach to the study of interrelated dynamic processes with subsequent consideration of the time-varying inert characteristics of the rolled shell and the cyclically changing non-stationary technological loads acting on the side of the deformation zone of the working stand of the mill.

We turn to the compilation of mathematical models of the subsystems under consideration in order to investigate the interaction of the shell with the working stand units, the mandrel and the holding mechanism of the automatic mill bar system.

Mathematical models of the initial mechanical system of the automatic mill are represented in the form of mathematical models of interrelated subsystems: differential equations describing the behavior of the multi-mass model of the elements of the mill working stand (Fig. 1); differential equation describing the behavior of the selected model of the bar holding bar mechanism of the mandrel (Fig. 3).

Next, we proceed to simplifying the multi-mass dynamic model of the TPA mill stand and to the solution of the problem (Fig. 1b). The multi-mass dynamic model of the system is reducible to the three-mass model of the system using the technique [2, 3]. We present the problem in the basic statement of the problems of the mechanical system dynamics with taking into account of certain initial conditions.

Differential equations of motion of the elements of the working stand of cold reducing mill (CRM) in the first approximation for the accepted three-mass model of the system will be written as follows:

$$\begin{cases} M_1 \dfrac{d^2 y_1(t)}{dt^2} = P - C_{01} y_1(t) - C_{12}\left(y_1(t) - y_2(t)\right) - \mu_1 \dfrac{dy_1(t)}{dt}; \\ M_2 \dfrac{d^2 y_2(t)}{dt^2} = -P - C_{12}\left(y_2(t) - y_1(t)\right) - C_{23}\left(y_2(t) - y_3(t)\right) - \mu_2 \dfrac{dy_2(t)}{dt}; \\ M_3 \dfrac{d^2 y_3(t)}{dt^2} = -C_{30} y_3(t) - C_{23}\left(y_3(t) - y_2(t)\right) - \mu_3 \dfrac{dy_3(t)}{dt}, \end{cases} \quad (1)$$

where M_i ($i = 1{,}3$) – given masses of elements of automatic mill working stand; C_i ($i = 1{,}3$) –given stiffness of the elements of mill working stand; y_i($i = 1{,}3$) – dynamic displacement of the elements of mill working stand in the vertical plane; $P(t) = P_0 + P_1 \sin(\omega t)$ – the vertical harmonic component of the pipe rolling force – frequency billet ω (P_0 static and P_1 amplitude value of the pipe rolling force).

Differential equations (1) are compiled and presented in the formulation of the Cauchy problem, which describes with sufficient accuracy the forced oscillations of the elements of the elastic subsystems of working stand of the automatic mill. Further, the solution of the system of differential equations (1) is implemented numerically using the Runge-Kutta method for the most common forms of oscillations of the “working stand-shell” system. Let us perform a more accurate calculation for the selected model of the forced oscillations of the elastic subsystems of the rolls of the automatic mill working stand on the basis of the initial data taken from [3, 4, 8]. Dynamic features and conditions for the functioning of the elements of the elastic subsystems of the rolls space (changes in the gap between the rolls) of the working stand of the automatic mill TPA 350 are shown in Fig. 2.

Analysis of calculation results (Fig. 2) and experimental studies show that the differential equations (1) with a sufficiently high degree of accuracy describe the forced oscillations of the elements of the elastic subsystems of the inter-rolls space of the rolls unit of the mill working stand. However, the obtained results are insufficient to establish the real reasons for the formation of the wall thickness difference in the automatic mill TPA. Next, we turn to the study of the longitudinal oscillations of the mandrel with the bar of its holding mechanism (Fig. 3). We turn to the adjusted solution of the problem of forced oscillations of a mandrel with bar system of its holding mechanism on the output side of the automatic mill TPA taking into account time-varying of the mass of the system.

To construct a correct model of the dynamic state of the system and the subsequent analysis of the mechanism of formation of the given wall thickness variation, we use the corresponding differential equation for the longitudinal motion of the mandrel with the bar along the rolling axis [2, 6].

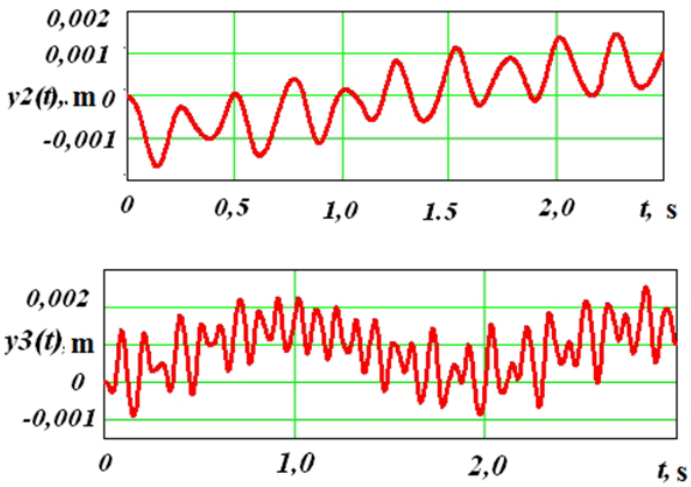
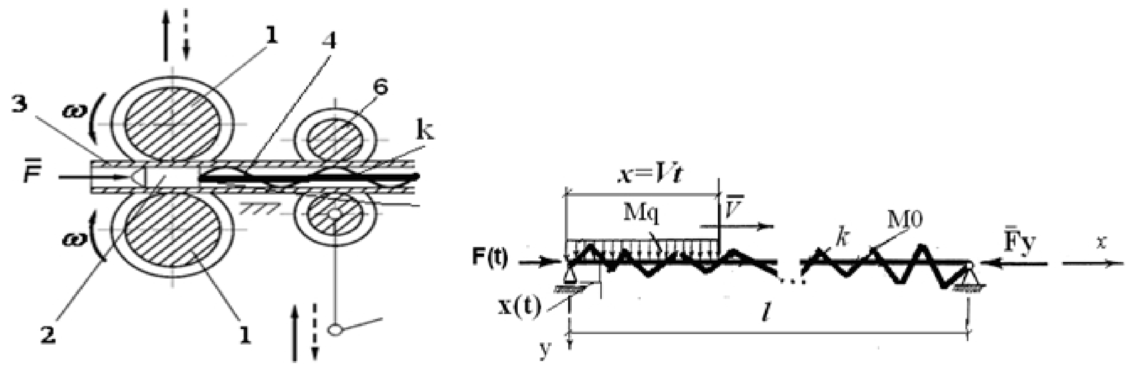


Figure 2. Dynamics of the elements of the rolls unit of the working stand of automatic mill TPA 350 (rough tube with diameter of 320 × 10 mm, material - steel 13GMF): $y_2(t)$ – bottom roll moving; $y_3(t)$ – top roll moving

We assume the bar elasticity force in the longitudinal direction of the rolling axis according to Hooke’s linear law within the assumptions that the elastic bar with the mandrel is held on the rolling axis of the centering wires:

$$F(t) = kx(t).$$

Here k – given longitudinal stiffness of all the mandrel holding mechanism units (rigidity of the elastic systems of all units of the mill outlet side in the direction of rolling axis).



a) b)

Figure 3. a) Mandrel holding mechanism of automatic mill TPA; b) design scheme of the mechanical system

Under the assumption that the internal friction in the mechanical system is small compared to the cyclic technological load $F_0 \sin(\omega t)$ and nonstationary dynamic loads are insignificant according to [5, 6], we obtain a differential equation of the longitudinal movement of the mandrel with the bar.

$$M(t)\frac{d^2x(t)}{dt^2} + \frac{dM(t)}{dt}\frac{dx(t)}{dt} + kx(t) = F_0 \sin(\omega t) H(t), \tag{2}$$

Where $x(t)$ – longitudinal displacement of mandrel in the deformation zone along the rolling axis; $M(t)$ – attached system mass variable in time taking into account the initial mass of the mandrel holding mechanism ; $H(t)$ – Pulse Heaviside function; ω – the frequency of the change in the driving force (according to [5, 6] is equal to the frequency of the wall thickness variation after the piercing mill TPA).

Let us note that the time-varying mass per unit length of rolled shells causes a change in the inertia of the whole mandrel holding mechanism, which largely determines the nature of non-stationary dynamic processes in the mechanical system.

Based on the results of a number of investigations of the automatic mill [1-3], the law of mass change of the system taking into account the variability in time of the mobile tube mass takes the following form:

$$M(t) = M_0 + M_q \left.\frac{x}{l}\right|_{x=\upsilon t} = M_0(1+\gamma t),$$

Where $\gamma = \frac{M_q}{M_0}\frac{\upsilon}{l}$ – index of inertness (mass change rate) of the mechanical system ($\gamma > 0$ the mass of the system increases); $M_q = m_q l$ – mass of the rolled shell; υ – speed of movement (rolling) of the shell along the mandrel bar; $M_0 = m_0 l$ – initial mass of the bar system.

Based on studies of the dynamics of a body of variable mass of the formulation of the fundamental problem of I. V. Meshchersky [4], we take into account the important reactive add $\frac{dM(t)}{dt}\frac{dx(t)}{dt}$ of the inertial load of the rolled pipe in equation (1).

Therefore, to analyze the corresponding part of equation (2) taking into account the change in the mass of the system, the Cauchy problem under certain initial conditions is formulated. Under the assumption that there is internal viscous friction in the mechanical system in comparison to the cyclic technological loads according to [5, 6], we obtain the differential equation of the longitudinal movement of the mandrel with the bar. Then the differential equation of the longitudinal oscillations of the mandrel with the bar (2) taking into account the law of the tube mass variation in time in the statement of the Cauchy problem acquires the form:

$$\begin{cases} M_0(1+\gamma t)\dfrac{d^2x(t)}{dt^2}+(M_0\gamma\varepsilon+\mu)\dfrac{dx(t)}{dt}+kx(t)=F_0\sin(\omega t)H(t); \\ x(0)=x_0; \qquad \dfrac{dx(0)}{dt}=\upsilon_0. \end{cases} \qquad (3)$$

Next, we proceed to determine the dynamic coefficient under the action of the reactive component. Taking into account the action of the reactive force, we solve the differential equation (5) for given initial conditions of the problem. After dividing the parts of equation (3) by M_0 we write:

$$(1+\gamma t)\frac{d^2x(t)}{dt^2}+\frac{M_0\gamma\varepsilon+\mu}{M_0}\frac{dx(t)}{dt}+\omega_0^2x(t)=\frac{F_0\sin(\omega t)}{M_0}H(t), \qquad (4)$$

where $\omega_0^2=k/M_0$ – the square of the frequency of free longitudinal oscillations of the mandrel with the bar; μ – coefficient of viscous resistance of the system; ε – coefficient of internal friction in the mechanical system.

Analysis of the results

The inhomogeneous differential equation (4) is compiled and represented in the formulation of the basic Cauchy problem, which describes the forced oscillations of the mandrel with the bar of the piercing mill with sufficient accuracy. Further, the solution of the differential equation (4) is implemented numerically by the Runge-Kutta method for the most common forms of oscillations of the subsystem “shell -mandrel-bar”.

Let us perform a more accurate calculation on the basis of the compiled mathematical model of the problem of forced oscillations of a mandrel with a bar in the example of an automatic mill TPA 350. To do this, we take the following initial data for automatic mill: $l=12{,}5$ m; $\upsilon=4$ m/s; $M_0=m_0l$; $M_q=m_ql$; $m_0=150$ kg/m; $m_q=100$ kg/m; $k=24\cdot10^6$ N/m; $\varepsilon=1$, $\mu=0{,}6$ Ns/m $t\in[0;6]c$. The results of numerical analysis of the differential equation (4) of the longitudinal oscillations of the mandrel together with the bar of its holding mechanism during rolling of rough pipes (liners) with a diameter of 320 × 10 mm, material - 13GMF steel on automatic TPA 350 are shown in Fig. 4.

The results of numerical analysis of the differential equation (4) of the longitudinal oscillations of the mandrel with the bar of its holding mechanism during rolling of rough pipes (shells) with a diameter of 320 × 10 mm (material - 13GMF steel) on automatic mill TPA 350 are shown in Fig. 4.

The calculated curve shown in Fig. 4 indicates the extremely unsatisfactory cyclic operating conditions of the mandrel with the bar during the process of shell rolling on the mill. The amplitude of the forced longitudinal oscillation of the mandrel in the rolls gorge of the working stand is 0.03-0.032 m, which exceeds the permissible adjustment values of the longitudinal movements of the mandrel in the groove of the deformation zone. Note that the adjustment value according to the grooving and the rolling table is 0.020 m.

Thus, when the reactive force acts, the nonstationary behavior of the “shell -mandrel-bar” system changes respectively. At the same time, the maxima of the dynamic coefficient become opposite to those that have been previously obtained for analogous models without taking into account the reactive force [3, 5].

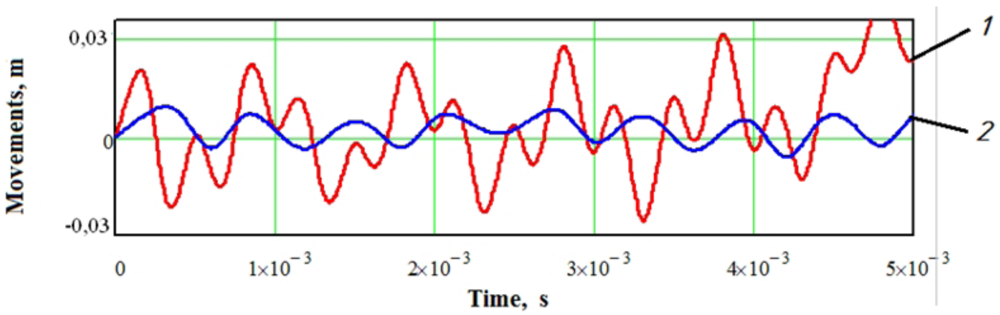


Figure 4. Longitudinal oscillations of mandrel with bar of automatic mill TPA 350 (rough tube (shell) 320 × 10 mm, material - steel 13GMF):

1 - before modernization of the mandrel holding mechanism; 2 - after the modernization of the mechanical system

Calculations show that under the action of reactive force in the system "shell (tube) - mandrel - bar" with a linearly increasing mass, the first maximum of the dynamic coefficient isK $K_{\partial} < 2$, and the subsequent maxima are less than the first. Consequently, there is a certain stabilization of the dynamics of the "shell (tube) - mandrel-bar" system, which is close to the results of experimental studies of the automatic mill TPA 350 [1, 4].

An analysis of the results of a complex calculation of the dynamics of an automatic mill indicates that the mathematical models compiled reliably of the describe nonstationary dynamic phenomena in the system "shell -working stand-mandrel-bar". The amplitude-frequency characteristics of dynamic processes when longitudinal oscillations of the system during the entire process of rolling the shell on the automatic mill TPA 350 exceed the permissible level of oscillations of the mechanical system.

In the course of implementation of the technological process, the dynamism of the system "shell (tube) - working stand - mandrel - bar" entails the formation of an increased wall thickness variation of the shell, which further is complex and difficult to remove. It is obvious that taking into account the dynamics of the mill working stand, the intensity of the impact from the deformation zone and the variability of the mass of the rolled shell approaching with the rolling speed $\vec{\upsilon}$ are the defining parameters in the framework of considered model of the problem.

The possibility of complex mathematical modeling of different modes of shell rolling at the stage of designing the technological processes of pipes rolling on an automatic mill TPA 350 significantly distinguishes the results obtained from the results of earlier known works in the field of studying the dynamics and vibrational activity of the elastic subsystems of the working stand and the elements of the mandrel holding mechanism [1, 4]. Fig. 5 shows the change of the wall thickness variation (thickness gauges of ultrasonic testing) along the length of the batch of roughing pipes (cartridges) rolled on an automatic mill TPA 350

Fig. 5 shows the variation in the difference (ultrasonic thickness measurements) along the length of the batch of roughing pipes (shells) rolled on an automatic mill TPA 350.

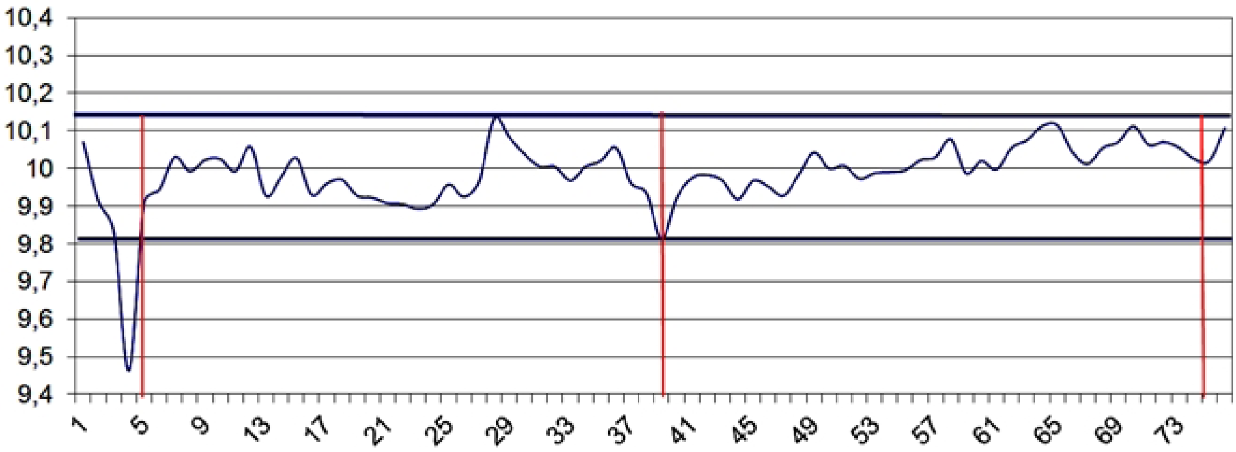


Figure 5. Longitudinal development drawing of the average thickness of the rough pipe wall (diameter 320 × 10 mm, material - steel 13GMF) after the automatic mill TPA 350 (red indicates the periods of high wall thickness variability of the system)

Excluding the influence of a number of other factors ("temperature wedge") when rolling on a longitudinal rolling mill, we can distinguish the effect of the oscillatory movements of the "shell- working stand-mandrel-bar" system. At the same time, its period of oscillations and the commensurate amplitude of oscillations with oscillations of the mechanical system "shell-working stand-mandrel-bar" of automatic mill in each respective period are clear.

In general, without taking into account the change in the magnitude of the longitudinal wall thickness variation due to the temperature change along the ends of the rolled pipe, it can be concluded that the additional change in longitudinal wall thickness variation (Fig. 5) should be done by a significant amount. So, when rolling a rough pipe with a diameter of 320 × 10 mm (material - steel 13GMF), the longitudinal component of the wall thickness variation increased by another 0.3 mm.

The results dictate the need for modernization of the mandrel bar holding mechanism and changing the design of the mill working stand by creating a prestressed stand, installing rolls on the basis of rolling bearings, anti-bending devices of working rolls of modern roller guides.

Conclusions

The design schemes of the interconnected mechanical subsystems of the automatic mill TPA have been clarified and mathematical models of the dynamics of the system "working stand-shell-mandrel-bar" have been developed within the framework of adopted models. The variability in time of the mass of the rolled pipe, the cyclic nature of the technological load of the deformation zone, the elasticity parameters and the dissipation of the base elements of the automatic mill working stand and the mandrel holding mechanism are taken into account.

The study of the dynamics of the mandrel holding mechanism showed that, when the intensive impact from the deformation zone on the working stand and the mandrel, taking into account the variability in time of the mass of the rolled shell is the most important factor in determining the dynamism of the system. It is established that the dynamics of the automatic mill TPA 350 are changed monotonically during longitudinal oscillations of the mandrel in the deformation zone. In this case, the reactive force and other inert characteristics of the system have a significant impact on the dynamics of the mandrel with the bar and the working stand of the mill, which ultimately determines the basic parameters of the mechanism for the formation of the shells wall thickness variation.

Results of numerical solution of differential equations of oscillations of the multi-mass model elements of elastic subsystems of the working stand and longitudinal oscillations of the mandrel with a bar of an automatic mill TPA 350 are presented. This allowed to evaluate the amplitude-frequency characteristics in complex of both the mill working stand rolls and the longitudinal displacements of the mandrel itself in the deformation zone taking into account the variability in time of the mass of the rolled shell. It is found that the amplitude of the forced vibrations of the working stand in the respective phases reaches 0.0023 m, and the displacement of the mandrel over the wedge of the working rolls is 0.032 m. The obtained amplitude greatly exceeds the permissible values of the stand parameters of the automatic mill TPA 350 deformation zone and leads to an increased wall thickness variation in the shells.

At the stage of designation of technological processes for shells rolling, by means of complex mathematical modeling of the dynamics of the working stand and the study of longitudinal oscillations of the mandrel with its holding mechanism, rational rolling modes have been established by calculation taking into account the predicted indices of the shells wall thickness variation and finished pipes. Calculations show that, for example, when rolling shells with a diameter of 320x10, the material is 13GMF steel, a stable rolling process is performed at the optimum rolling speed of the shell on the automatic mill TPA 350 of no more than 3.2 m/s.

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UDC 621.778.04.

Production of billets of die-rolled section when vibratory drawing

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Abstract
The results of the analysis of energy-power parameters of die-rolled sections production by vibratory drawing considering kinematic parameters of process are presented. Technological process and vibratory drawing device with a cyclic support when using of the self-turned-out piston as an elastic support were developed.
Key words: VIBRATORY DRAWING, CYCLIC SUPPORT, DIE-ROLLED SECTION, SHAPING, INERT FORCES, SELF-TURNED-OUT PISTON

Production of billets of die-rolled section under stamping of turbine blade from hardly deformed nickel and titanic is extremely urgent and perspective. Conventional technology of billets production for blades stamping, for example, made of heat-resistant nickel alloy ZHSBKP of bars with a diameter of 40-50 mm comprises hot rolling by a few dozen passes with intermediate heating. Pieces of smaller diameter turbine blades get cutting treatment on lathes. However, coefficient of metal usage according to this technology does not exceed 0.05-0.14 [1-3].

Products with variable cross section can be obtained by shaping and stretching in the conditions of superplasticity. The main advantages of the process are associated with large deformation ability of superplastic materials, non-contact conditions of deformation and high resistance of shaping processes. These products are obtained under the condition that one of the velocities defining the kinematics of the processing is constant, and another is changed according to a given program. The method is effective in small-scale production with a wide range of products [4-5]. Commercial development of this process is constrained by the lack of knowledge about the shaping and kinematics of the deformation zone, as well as its low performance.

In general, to obtain billets with periodic profile made of nickel and titanium alloys is an independent task in the general problem of improving blade production technology (one-lock, two-lock blades).

The effectiveness and feasibility of industrial application of drawing process using sonic and ultrasonic frequency ranges of oscillations have been proved by works of many researchers. The intermittent nature when the vibration of the deformation tool or treated metal leads to a number of positive factors intensifying processes of metalworking.

For certain schemes and modes of vibration deformation (in particular, when vibratory drawing), the effect of periodic change of the wire or rod diameter along its axis was observed. On the one hand, it can be seen as a negative factor leading to a distortion of the geometry of the resulting item. On the other hand, this opens the possibility for obtaining wire and rods with periodically repeating sections. In any case, at negative or positive assessment of this factor, this process needs to be managed and its laws should be known. Perhaps this phenomenon can be explained by the analysis of the following phenomena.

1. The implementation of the conditions under which one of the velocities determining the kinematics of the process is constant and the other varies according to a given law. Periodic workpiece profile was first obtained when vibratory drawing with longitudinal vibrations of the die [2], at a certain vibrations frequency. However, there is a whole arsenal of methods to change one of the velocities when the vibratory drawing: connection of vibrations to drawing die or treated metal, which are directed across or around (rotational) of drawing axis and angular ones. Also a combination of transverse vibrations with longitudinal ones, drawing with a cyclic support, drawing with pulsating counterstrain, step, two-step vibratory drawing, drawing through the two dies vibrating in opposite phases, three-stage vibratory drawing, drawing through a system of multiple dies loaded in turn finds its application.

2. Frictional self-excited vibrations. Under the conditions of the friction of solid bodies at a constant or intermittent draft force, the harshness of sliding was

observed and it was accompanied by a more or less periodic stops. Possible explanations of slip instability are associated with the presence of a falling-speed characteristic of the friction force or the emergence of the so-called “jump” ΔT of the friction force in the transition from rest to sliding. At each jump, the rise of amplitude of normally asymmetric oscillations occurs resulting in compression of a deformable material. This type of oscillation in a vibratory drawing is a violation of the law of motion of the vibrating tool and, as a consequence, frequency of not only microgeometry but also geometry of workpieces under treatment. To evaluate the nature of this phenomenon is possible by solving the problem of elastic-plastic deformation during vibratory drawing with setting the appropriate boundary conditions associated with the law of friction, which takes into account the friction self-oscillations.

3. Loss of stability of deformable system. In the process of shaping, there are four types of deformable metal plastic stability [3, 4]: slip bands, centered thinning, secondary slip bands, undulations.

When leaving the deformation zone in the process of vibratory drawing a die-rolled section of the workpiece may occur at local thinning and stretching during the formation of undulation. Loss of stability nature occurs under the scheme other than Euler. The ratio of the deforming load *P* and the characteristic movement *U* is expressed concave downward curve. This *P* - *U* dependency is observed under tension conditions. The ascending part of the curve corresponds to sustainable forms of equilibrium. At the maximum point, the load takes a stationary value remaining constant at infinitely small changes *U* corresponding to adjacent forms of equilibrium. The system state at the maximum point is critical, and the corresponding values *P* = *Pcr* and *U* = *Ucr* are critical load and displacement. The critical load *Pct* coincides with the maximum carrying load of the system *Pmax*. Under such a load, the local loss of stability in the form of local thinning is possible. The problem of the stability of elastic-plastic deformation is solved by studying the motion of the system near equilibrium. A condition under which small disturbances provokes movement deducing system from the vicinity of the equilibrium state is instable. To assess the critical deformation in which the process of plastic strain of bar, rod or wire becomes unstable is possible in the following way. Let us consider rod stretching by force $P(t) = P_0 sin(w\ t\text{-}A)$. In turn, $P(t) = \sigma F$, where σ normal stress in a cross section of the bar, F – the cross-sectional area.

When the condition (1) the neck journal is formed.

$$dP = \left(\frac{d\sigma_{11}}{d\varepsilon} d\varepsilon + \frac{d\sigma_{11}}{d\dot{\varepsilon}} d\dot{\varepsilon} + \frac{d\sigma}{dt} dt \right) F + \frac{\sigma_{11} dF}{d\varepsilon} d\varepsilon \langle 0 \,, \tag{1}$$

For deformable bar, various close states are possible, for which the decrease in the cross section is compensated by the increase of stress due to hardening. However, the material of the deformable system (bar) has some irregularities, the so-called "weak spots" as geometric and structural nature. "Neck" is formed and rapidly developed due to local deviations from the correct shape and inhomogeneities conditions in one of the spots. When transforming the equation (1), we obtain the condition of unstable deformation:

$$\frac{d\sigma_{11}}{d\varepsilon} = \frac{\sigma_{11}}{(1+\varepsilon)} \tag{2}$$

For the material which is hardened according to a power law, the rheological properties are described by the following ratio $\sigma = c\varepsilon^n \dot{\varepsilon}^m$, where $\dot{\varepsilon} = \frac{d\varepsilon_1}{dt} = \frac{d(\ln \ell)}{dt}$ - deformation rate of the bar elongation. When *m* = *0*, the material does not have viscous properties $\varepsilon_{cr} = \frac{n}{1-n}$, where ε_{cr} – critical deformation.

Formation of periodic profile occurs out of the deformation zone under the influence, on the one hand, of the constant pulling force, on the other hand, of cycling support with counterstrain during vibration of dies. Under these conditions, when the workpiece is subjected to tensile and compressive loads, the conditions of unstable equilibrium occur after reaching the maximum (critical) load. For a quantitative description and the study of non-equilibrium, unstable processes [7], it is possible to use equilibrium approach to show the plasticity within the thermodynamic and total system approaches [8]. To assess the degree of deformation of the workpiece at the exit from the deformation zone, the changes of the surface area of the deformable workpiece were efficiently used. Application of the workpiece surface as a deformation criterion relates to the fact that the surface is generally one of the major defects of the crystal structure [9] and it is associated with forming of the additional workpiece surface.

4. Impact of inert forces.

When vibratory drawing with a sufficiently high rate, the significant role is played by inertial forces, emerging and propagating of waves in the metal, the localization of the plastic deformation, etc. The latter factor may lead to destabilization of the transverse dimensions of the obtained product. The equations of motion and incompressible will be of the following form:

$$div\overline{\upsilon} = 0; \quad (3)$$

$$\frac{\partial}{\partial x_i}\left[\frac{T(\upsilon_i)}{H(\upsilon_i)}\left(\frac{\partial \upsilon_i}{\partial x_k}+\frac{\partial \upsilon_k}{\partial x_i}\right)+\delta_{ik}\sigma_0\right]+\rho F_i=\rho\frac{d\upsilon_i}{dt} . \quad (4)$$

It is possible to consider the drawing process in one-dimension when the equations of motion acquire the simplest form:

$$\rho\left(\frac{\partial \upsilon_1}{\partial t}+\upsilon_1\frac{\partial \upsilon_1}{\partial x_1}\right)=\frac{\partial \sigma_0}{\partial x_1}+\frac{4}{3}\frac{\partial}{\partial x_1}\left(\frac{T(\upsilon_1)}{H(\upsilon_1)}\frac{\partial \upsilon_1}{\partial x_1}\right) . \quad (5)$$

For a perfect plastic material in the absence of convection, this equation can be written as follows:

$$\rho\frac{\partial \upsilon_1}{\partial t}=\frac{\partial \sigma_1}{\partial x_1}, \quad (6)$$

Taking into account that deformations are low, i.e. $\frac{\partial U}{\partial x_1} < 1$, so $\frac{\partial \upsilon_1}{\partial t}=\frac{\partial^2 U}{\partial t^2}$. As:

$$\frac{\partial \sigma_1}{\partial x_1}=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial \varepsilon_1}{\partial x_1}=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial}{\partial x_1}\left(\frac{\partial U}{\partial x_1}\right)=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial^2 U}{\partial x_1^2}, \quad (7)$$

we obtain wave equation:

$$\frac{\partial^2 U}{\partial t^2}=\frac{1}{\rho^2}\frac{d\sigma_1}{d\varepsilon_1}\frac{\partial^2 U}{\partial x_1^2}, \quad (8)$$

where ρ - density of the material of the deformable system.

In equation (8) $\frac{d\sigma_{11}}{d\varepsilon_1}=\text{var}$ it is necessary to use special methods of its solution and analysis of the results obtained. Let us consider the solution variant at the assumption of the validity of the hypothesis of "flat diametrical cross sections" that fits into the framework sufficient for engineering calculation methods. The elementary energy required to change the speed of some infinitely small mass of the material dm in the deformation zone is equal to the momentum of the weight applied to the force:

$$dF\cdot dt=d\dot{U}\cdot dm. \quad (9)$$

Taking into account the predominantly axial flow of deformable material, we replace differentials of speed, time and weight by their values:

$$dm=\rho F d\ell , \quad (10)$$

$$d\dot{U}=V_0\frac{d\ell}{\ell} , \quad (11)$$

$$dt=\frac{d\ell}{V_0} , \quad (12)$$

where V_0 – drawing speed.

After transformation we will obtain:

$$dF=\rho V_0^2 F\frac{d\ell}{\ell}. \quad (13)$$

Equation (1) takes the form:

$$d(\mathrm{P}\pm F)=\sigma_{11}dF+Fd\sigma_{11}=0 , \quad (14)$$

When $$d\sigma_{11}=\frac{\partial \sigma_{11}}{\partial \varepsilon_{11}}d\varepsilon+\frac{\partial \sigma_{11}}{\partial \dot{\varepsilon}_{11}}d\dot{\varepsilon}_{11}+\frac{\partial \sigma_{11}}{\partial t}dt . \quad (15)$$

The required condition takes the form:

$$\frac{1}{\sigma_{11}}\left(\frac{\partial \sigma_{11}}{\partial \varepsilon}d\varepsilon+\frac{\partial \sigma_{11}}{\partial \dot{\varepsilon}}d\dot{\varepsilon}+\frac{\partial \sigma_{11}}{\partial t}dt\right)=\frac{d\varepsilon}{1+\varepsilon} . \quad (16)$$

At the law of strain-speed hardening, we get:

$$n\varepsilon^{n-1}\dot{\varepsilon}^{m}d\varepsilon + m\varepsilon^{n}\dot{\varepsilon}^{m-1}d\dot{\varepsilon} + \frac{\partial}{\partial t}\left(\varepsilon^{n}\dot{\varepsilon}^{m}\right)dt = \frac{\varepsilon^{n}\dot{\varepsilon}^{m}d\varepsilon}{1+\varepsilon} \quad (17)$$

For a material with a low-speed hardening m ≈ 0, we get to the differential equation of the following form:

$$n d\varepsilon + n d\dot{\varepsilon} = \frac{\varepsilon d\varepsilon}{1+\varepsilon} \cdot \quad (18)$$

Thinning on the sample appears in the following ratio of deformation and its speed:

$$\dot{\varepsilon}(t) = \dot{\varepsilon}(0)\left[\varepsilon(n-1) - \ln(1+\varepsilon)\right] \cdot \quad (19)$$

By analogy, for viscous materials with low strain hardening n = 0, we obtain:

$$\dot{\varepsilon}(t) = \dot{\varepsilon}(0)(1+\varepsilon)^{\frac{1}{2m}} . \quad (20)$$

Thus, the conditions for sustainable shaping are provided when the obtained ratio of kinematic parameters of drawing.

5. The bilateral compression of the workpiece element at the outlet of the deformation zone

Drawing cylinder of a die prevents radial flow of the workpiece material, which is similar to the action of external friction forces in the sinking strain of cylindrical workpieces. Compression of the workpiece element at the outlet of the die may be provided by applying an elastic support. The latter may be performed in an annular container 3 with deformable walls filled with fluid under pressure Fig.1. [2]

It is more preferably to carry out the elastic support as a self-turned-out piston Fig. 2.

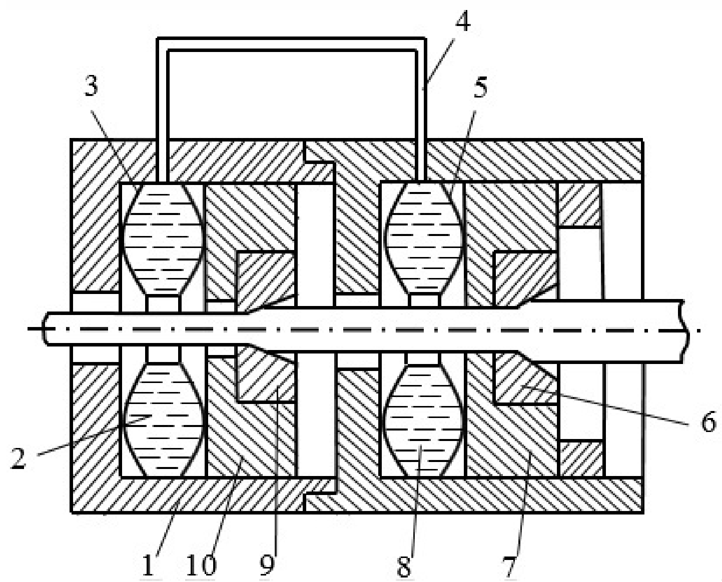

Figure 1. Self-oscillatory hydromechanical devices for metal drawing: 1 - body frame; 2, 8 - liquid; 3, 5 - container with elastic annular walls; 4 - the connecting channel; 6, 9 - dies; 7, 10 – die plates

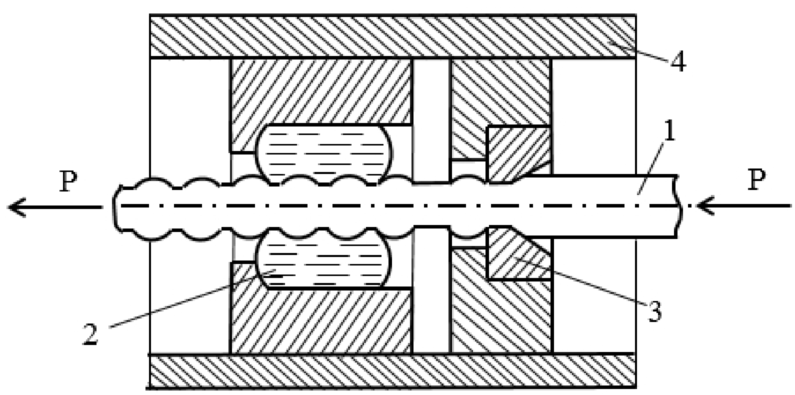

Figure 2. Vibratory drawing with cyclic support when being used as elastic support of self-turned-out piston: 1 - blank; 2 - self-turned-out piston; 3 – die; 4 - die plate

In accordance with the principle of Saint-Venant, the action radial forces attenuates with distance from the contact surfaces. Therefore, when bilateral compression of blanks, the linear stress state scheme occurs in the middle of the length of the compressed blank element.

Conclusions

1. The effect of the periodic variation of the diameter of bar or wire when vibratory drawing is connected with friction vibrations, loss of stability during the deformation as at occurring of a yield stresses in the bar material, and at the formation of a "neck", as well as the result of inert forces.

2. The obtained dependences allow us to determine the conditions of the unstable strain and stabilize the process of obtaining a periodic profile by controlling the process parameters of vibratory drawing.

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Examination and enhancement of checker works by means of choosing rational cell dimensions

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Abstract
The choice of rational cell dimensions of checker block is made to reduce material consumption and dimensions of Cowper blast heaters. An impact of cell dimensions variation (diameter of checker flue) and center between them upon the change of specific heating surface of checker works and also open area, specific brick volume and equivalent half thickness of wall between cells, minimal thickness of the latter is studied. Dependences between specific brick volume, equivalent and minimal wall thickness and the checker flue diameter in case of the changes of the latter from 0.1 up to 41 mm are established. It is shown that the installment of horizontal passages in checker blocks facilitate the change of flue diameters $d \le 15$ mm
Key words: COWPER BLAST HEATERS, CHECKER, HEAT EXCHANGE, CELL DIMENSIONS

Operating Cowper blast heaters (CBH) are required to enhance technical characteristics of resistance, material consumption, environmental compatibility and thermal performance efficiency.[1-3]. To reduce material consumption (dimensions) of CBH checker works and thus of linings and housings, heat loss through brickwork, thermal pollutions, the cell dimensions are being reduced over the last years that increases specific heating surface [4-6].

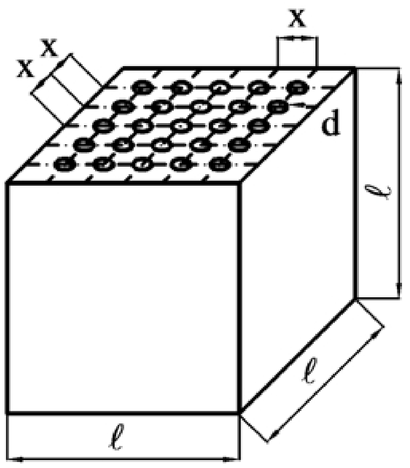

Figure1. Regular hexahedron as an element of checker work

Formulas to calculate specific heating surfaces of checkers are shown below:

For regular hexahedron

In a study [7], authors demonstrate that if ℓ is the base of regular hexahedron, center *x* between gaps of checker cells is changed by k times and diameter of cells d is changed by p times, where $p \neq k$

$$\ell_2 = k \cdot \ell;\ x_2 = k \cdot x;\ d_2 = p \cdot d = \varepsilon \cdot k \cdot d, \qquad (1)$$

where

$$\varepsilon = \frac{p}{k}, \text{ and } p = \varepsilon \cdot k, \qquad (2)$$

then specific open area will be changed ε^2 times

If $p > k$ and $\varepsilon > 1$, specific open area S_2 increases by ε^2 times in comparison with the initial specific open area S

$$S_2 = S \cdot \varepsilon^2. \qquad (3)$$

In a study [7], it is illustrated that the modified specific heating surface F_2 and the initial specific area F are bound by equation

$$F_2 = F \cdot \frac{\varepsilon}{k}. \qquad (4)$$

If $d_1 \cdot \varepsilon > x_1$, then checker flues are overlapped and the heating surface is reduced.

Under quite big value of ε area filled with checker work is disappeared, it is destructed into separate fibers

$$S \to 1,\ F \to 0. \qquad (5)$$

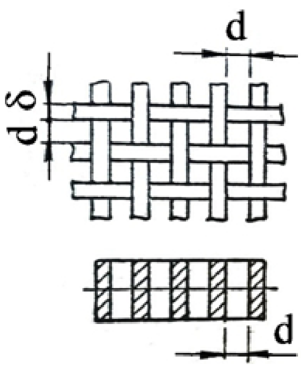

Figure 2. Cowper Stove checker with square cells

For Cowper stove checker with square cells

Specific heating surface F of Cowper stove checker with square cells (Fig. 2) and dimension d [8] and actual brick thickness δ is calculated as follows:

$$F=\frac{4\cdot d}{(d+\delta)^2} \qquad (6)$$

Calculation data shown below in a table 1 is accomplished according to equation (6).

Table 1. Dependence of the maximal specific heating surface of Cowper stove checker work with square cells on its diameter

	Dimensions of the checker cell diameter, d , mm									
	40	30	25	20	15	10	5	1	0,5	0,1
F , m²/m³	100	133.3	160	200	266.7	400	800	4000	8000	40000

For hexagon checker with round holes

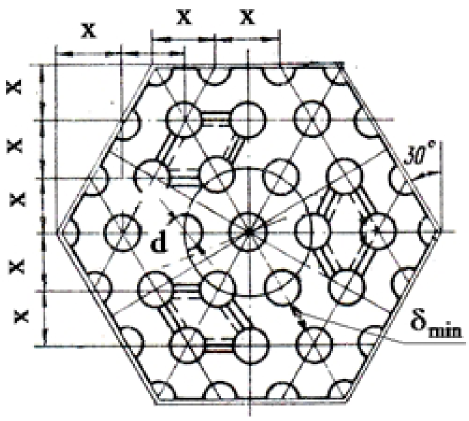

Figure 3. Hexagon checker with round holes

Based on the dependences for parameters of hexagon checker (Fig. 3) with round holes [9], there were data close to specific ones according to dependences (1)-(14) out of [7]:

- specific heating surface, $\frac{m^2}{m^3}$

$$F=\frac{4\cdot S}{d}; \qquad (7)$$

- specific open area of the checker work, $\frac{m^2}{m^2}$

$$S=1-V_к=\frac{\pi\cdot d^2}{4\cdot x^2}, \qquad (8)$$

where Vк - specific brick volume, $\frac{m^3}{m^3}$;

- space between holes

$$x=d+\delta_{min}; \qquad (9)$$

- equivalent wall half thickness in a block [8], m:

$$r_{eq}=(1-S)\cdot\frac{d}{4\cdot S}. \qquad (10)$$

Minimal wall thickness between cells, m

$$\delta_{min}=d\cdot\left(\frac{\sqrt{A}}{S}-1\right) \qquad (11)$$

where $A=0.905$ for hexagon checker works with round holes

Dependence of checker block parameters and checker flue diameter are shown in a Table 2

Table 2. Parameters of checker blocks with round holes

	Cell dimensions d , mm								
	41	30	25	20	15	12.5	10	1	0.1
Vк, m³/m³	0.6969	0.6867	0.6932	0.6932	0.6932	0.6932	0.6932	0.6932	0.6932
r_3, mm	23.57	16.44	14.12	11.3	8.47	7.06	5.649	0.5649	0.05649
δ_{min}, mm	25	17.5	15	12	9	7.5	6	0.6	0.06

Thereby with duration of periods

$$\tau >> \frac{r_{eq}^2}{2\cdot a}$$

(a-heat diffusivity, m²/s), i.e. time of brick thermal inertia, increase of brick thickness leads to reduction of accumulating capacity, damping of brick tempe- rature fluctuation for the period and gain of heat exchange capacity.

Increase of heating area with brick volume $V_b=const$ results in damping of temperature fluctuation in a checker and rise of heat recovery factor r_o and thus heating temperature of blast:

$$r_o = \frac{t_{av.bl}}{t_{av.g}} ,$$

$t_{av.bl}$ - average temperature of heating of blast for the period °C; $t_{av.g}$ - average gas temperature for the heating period °C. And vice versa, increase of brick volume with the heating area F= const results in r_o =const and impacts the temperature fluctuation only [10].

Dependence of maximal specific heating surface of Cowper stove checker work on flue dimension d where $\delta_{cm} \to 0$ is made accordingly (6)

Actual heating surfaces tend to the stated maximal specific heating surfaces.

For regular hexahedron

It was previously demonstrated for the equation

$$F_1 = \frac{n \cdot \pi \cdot d}{k \cdot \ell^2} = F \cdot \frac{1}{k}$$

that F_1 is a monotonic function k without extremum. The case is:

$$\frac{\partial F_1}{\partial k} = \frac{-F}{k^2} ; \ -F\frac{1}{k^2} = 0 ; \ \frac{1}{k^2} = 0 \ \text{where } k \to \infty .$$

$$k = \frac{d_1}{d} \to \infty \ \text{where } d \to 0 \ \text{will be } F_{1min}$$

$$\frac{\partial^2 F_1}{\partial k^2} = 2 \cdot F \cdot \frac{1}{k^3} > 0 , \ \text{i.e. where } \frac{\partial F_1}{\partial k} = \frac{-F}{k^2}$$

$F_1 \to 0$ where $k \to \infty$.

Our concern is an assumption

$$F_{max} . \text{ B } F_1 = \frac{F}{k} ,$$

F_1 will have the largest value when

$$k = \frac{d_1}{d} \to 0 , \text{i.e. where } d_1 \to 0$$

$$S = \frac{n \cdot \pi \cdot d^2}{4 \cdot \ell^2} = S_2 \cdot \frac{1}{\varepsilon^2} ; \qquad \varepsilon = \frac{p}{k}$$

$$F = \frac{n \cdot \pi \cdot d}{\ell^2} = F_2 \cdot \frac{k}{\varepsilon} .$$

Where $n = \frac{1}{x^2}$ - quantity of holes for 1 m^2 of checker cross section (squared with the side 1 m); x is the distance between holes in a checker.

$$S = \frac{n \cdot \pi \cdot d^2}{4} = \frac{1}{x^2} \cdot \frac{\pi \cdot d^2}{4} ; \qquad \frac{dS}{dx} = \frac{-\pi \cdot d^2}{2 \cdot x^3} ;$$

$$-\frac{\pi \cdot d^2}{2 \cdot x^3} = 0 \ \text{where } x \to \infty ;$$

$$\frac{d^2 S}{dx^2} = \frac{3 \cdot \pi \cdot d^2}{2 \cdot x^4} > 0 ,$$

i.e. we have min S where $x \to \infty$

The hexahedron heating area in 1 m^3 checker work, $\frac{m^2}{m^3}$

$$F = \frac{\pi \cdot d}{x^2} , \ \frac{x}{d} = \varepsilon \ \text{or } F = \frac{1}{\left(\frac{x}{d}\right)^2} \cdot \frac{\pi \cdot d}{d^2} = \frac{1}{\left(\frac{x}{d}\right)^2} \cdot \frac{\pi}{d} .$$

Where $d = const$ and x=var .

$$\frac{dF}{dx} = \frac{-2 \cdot \pi \cdot d}{x^3} ; \ \frac{-2 \cdot \pi \cdot d}{x^3} = 0 \ \text{where } x \to \infty$$

$$\frac{d^2 F}{[d(x)]^2} = \frac{6 \cdot \pi \cdot d}{x^4} > 0 . \ \text{As } \frac{d^2 F}{[d(x)]^2} > 0 ,$$

then $x \to \infty$, we have $F \to 0$, i.e. F_{min}.

When d=var and x=const where $d \to 0$ and $F \to 0$.

For Cowper Stove checker work

$$F = \frac{4 \cdot d}{(d + \delta)^2} = \frac{4}{d + 2 \cdot \delta + \frac{\delta^2}{d}} .$$

F increases when the wall thickness δ and flue diameter are reduced. If $\delta \to 0$, then

$$F \to \frac{4}{d}$$

For hexagon checker with round holes

Let us differentiate the equation

$$F = \frac{\ell^2 \cdot \pi \cdot d}{x^2 \cdot \ell^2} = \frac{\pi \cdot d}{x^2}$$

with respect to d:

$$\frac{dF}{d(\mathrm{d})} = \frac{1}{\mathrm{x}^2} \cdot \pi \cdot 1 > 0$$

For $F = \frac{1}{x^2} \cdot \pi \cdot d$.

When $d \to 0$ and $F \to 0$, the whole open area is filled with checker work.

When $x \to \infty$ and $F \to 0$, it results from the equation

$$S = \frac{\ell^2 \cdot \pi \cdot d^2}{x^2 \cdot 4 \cdot \ell^2} = \frac{F \cdot d}{4}$$

when $d \to 0$, $S \to 0$; and when $x \to \infty$, $S \to 0$.

Conclusion

The impact of checker flue diameter and center between cells on the values of specific brick volume, equivalent wall thickness between checker flues and minimal wall thickness between cells was explored.

The dependences of specific brick volume, equivalent and minimal wall thickness on the diameter of checker flue in case of changes of the latter from 0.1 up to 41 mm were shown.

It is verified that within limits when the wall thickness between checker flues goes to zero we will get the minimal specific open area of flue and its heating surface

Horizontal passages in the checker blocks provide an opportunity to shift to diameter of checker flues d ≤15mm and that significantly reduces the dimensions of Cowper stove heaters, material consumption of firebricks and metal cover and heat losses.

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UDC 66.045

Determination of coefficients of heat output of hot-blast stove checkers with horizontal passages

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Abstract
The benefits and results of physical modeling of new design of block checkers with horizontal passages are shown in the paper. They are developed by fellows of department of Ecology, Heat-Transfer and Labour Protection of National Metallurgical Academy of Ukraine in cooperation with Zaporozhogneupor PJSC. The main objective of experimental study was to determine the convection heat transfer coefficient and gasdynamic resistance of checker, as its main thermal characteristics. Dependences for determination of coefficients of convection heat transfer were defined from the obtained ratios of similarity criteria Nu = f (Re) for the rough continuous channel, vertical channels with two and three horizontal passages, and also the checker block with horizontal passages.
KEY WORDS: HOT-BLAST STOVE, CHECKER, HEAT EXCHANGE, HEAT TRANSFER COEFFICIENT

Block checkers with horizontal passages of the hot-blast stove possess the following advantages over those, which are produced in accordance with GOST 20901-75 and without horizontal passages [1, 2]:

- the increased service life due to existence of horizontal channels on the upper and lower surfaces of blocks and possibility of gas-flow from the neighboring channels in case of clogging the vertical channel at some height;
- higher coefficient of heat transfer due to existence of zones of the increased turbulization (vortex formation) in the area of vertical channels crossing with horizontal ones.

The coefficient of heat transfer of the checker block with vertical channels and horizontal passages was defined by machine (Fig. 1). The models of checker channels consisting of three steel pipes (diameter ø is 21 mm and length is 1300 mm): single rough continuous 1, with two 2 or 3 horizontal passages are experimentally investigated. The models imitating horizontal passages 4 in pipes 2, 3 were placed in vertical channels with an identical step on height equal to 60 mm. Pipes 1, 2, 3 were arranged in the tank 5 heated by P-shaped electric heaters 6 with power of 5 kW. Air was regulated by valves 7 and directed to the investigated channels 1, 2, 3 through pipes 8. The air consumption through the pipes was measured by means of flowmeters 9. Temperature of air heating in the explored channels was measured by spirit thermometers 10.

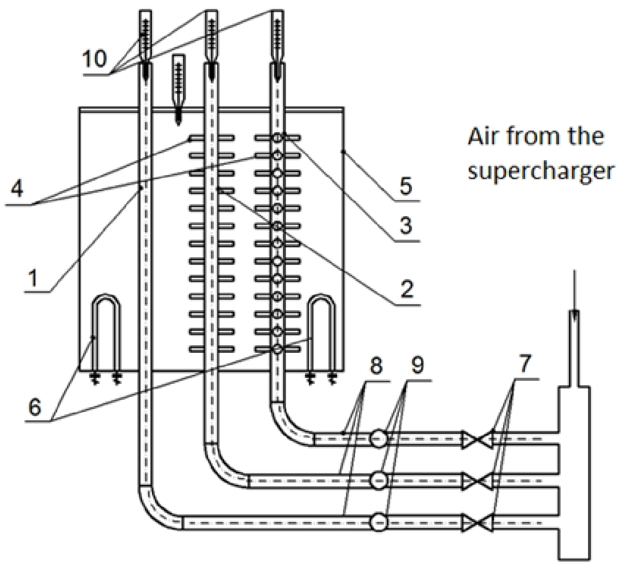

Figure 1. The scheme of machine for determination of gasdynamic and thermal characteristics of checker with horizontal passages

1,2,3 – model of checker channels consisting of three pipes: single rough continuous with two and three horizontal passages respectively; 4 – the models imitating horizontal passages in pipes with a step on height of 60 mm; 5 – tank; 6 – electric heaters; 7 – adjusting valves; 8 – the measuring airfeeding pipes; 9 – air flowmeters; 10 – thermometers for measurement of air temperature at the exit from the explored canals

Water in the tank 5 was heated to boiling state by means of autotransformer and held equal to temperature of boiling 100 ºC, at the same time the air consumption in the studied channels 1, 2, 3 was identical. In laminar region at equal of air consumption, the indicators of thermometers 10 were equal. In turbulent area in a single rough continuous pipe 1, the minimum temperature took place, and in a pipe with three horizontal branches 3 – maximum one. The experiment was conducted before a steady thermal state, which was defined by stabilization of indicators of thermometers 10.

Results of processing of experimental data in the form of dimensionless dependences for a single rough continuous pipe, pipes with two and three horizontal passages and the checker block are presented in Table 1 and in Figures 2, 3, 4.

Table 1. Dependences for determination of coefficients of heat transfer convection

Channels name	Convection heat transfer coefficients, W/(m²·K)
Checker made of six-sided blocks with round holes [3]	$\alpha_к = 0.0218 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,8}$ *at* $\mathrm{Re} > 4260$; $\alpha_к = 2.95 \cdot 10^{-4} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,31}$ *at* $1700 \le \mathrm{Re} < 4260$; $\alpha_к = 1.83 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,14}$ *at* $\mathrm{Re} < 1700$. λ – checker heat transfer coefficient, W/(m · K); d – hydraulic diameter of the channel, m
Rough continuous steel channel (single pipe), $a_{к1}$	$\alpha_{к1} = 0.008255 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,875}$; $Nu = 0,0147 \cdot \mathrm{Re}^{0,82}$ *at* $\mathrm{Re} > 3500$; $\alpha_{к1} = 4.467 \cdot 10^{-12} \cdot (\lambda/d) \cdot \mathrm{Re}^{3,5}$; $Nu = 2.26 \cdot 10^{-13} \cdot \mathrm{Re}^{3,87}$ *at* $2500 \le \mathrm{Re} < 3500$; $\alpha_{к1} = 0.708 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 1.185 \cdot \mathrm{Re}^{0,1615}$ *at* $\mathrm{Re} < 2500$.
The vertical channel with 2 horizontal passages, $a_{к2}$	$\alpha_{к2} = 0.0012217 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,866}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} > 3200$; $\alpha_{к2} = 1.936 \cdot 10^{-6} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,933}$; $Nu = 2.03 \cdot 10^{-8} \cdot \mathrm{Re}^{2,521}$ *at* $2000 \le \mathrm{Re} < 3200$; $\alpha_{к2} = 0.776 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} < 2000$.
The vertical channel with 3 horizontal passages, $a_{к3}$	$\alpha_{к3} = 0.00933 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,9}$; $Nu = 0.00809 \cdot \mathrm{Re}^{0,923}$ *at* $\mathrm{Re} > 3200$; $\alpha_{к3} = 1.936 \cdot 10^{-6} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,933}$; $Nu = 2.03 \cdot 10^{-8} \cdot \mathrm{Re}^{2,521}$ *at* $2000 \le \mathrm{Re} < 3200$; $\alpha_{к3} = 0.776 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,233}$; $Nu = 0.405 \cdot \mathrm{Re}^{0,323}$ *at* $\mathrm{Re} < 2000$.
Checker with horizontal passages, $a_{к\ hp}$	$\alpha_{к\ hp} = 1.412 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,184}$ *at* $\mathrm{Re} < 1820$; $\alpha_{к\ hp} = 1.089 \cdot 10^{-7} \cdot (\lambda/d) \cdot \mathrm{Re}^{1,31}$ *at* $1820 \le \mathrm{Re} < 3020$; $\alpha_{к\ hp} = 0.068 \cdot (\lambda/d) \cdot \mathrm{Re}^{0,675}$ *at* $\mathrm{Re} \ge 3020$.

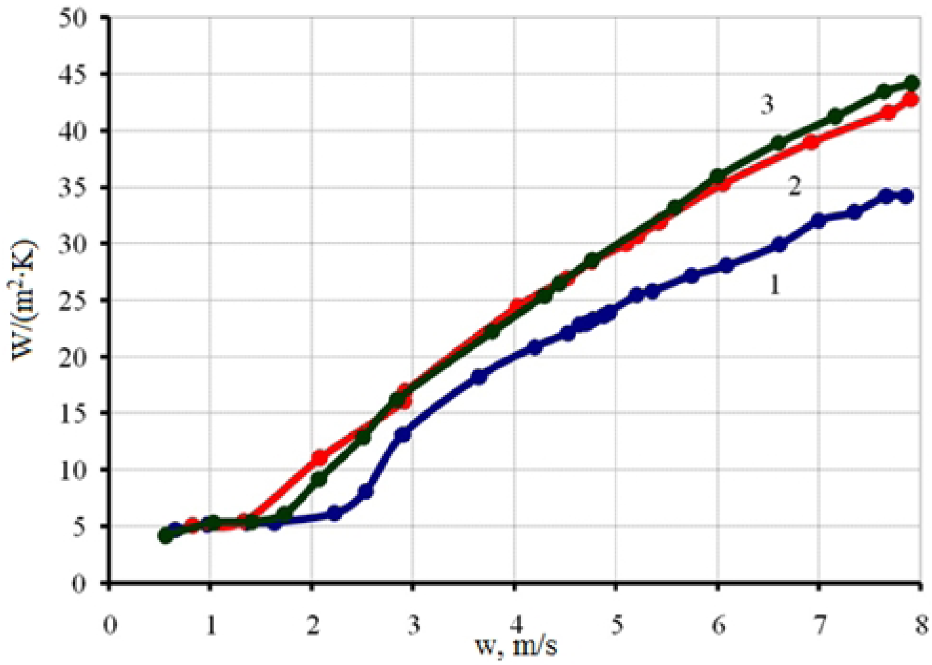

Figure 2. Dependence of convection heat transfer coefficient on air speed for rough continuous channel 1, for channels with two 2 and 3 horizontal passages 3

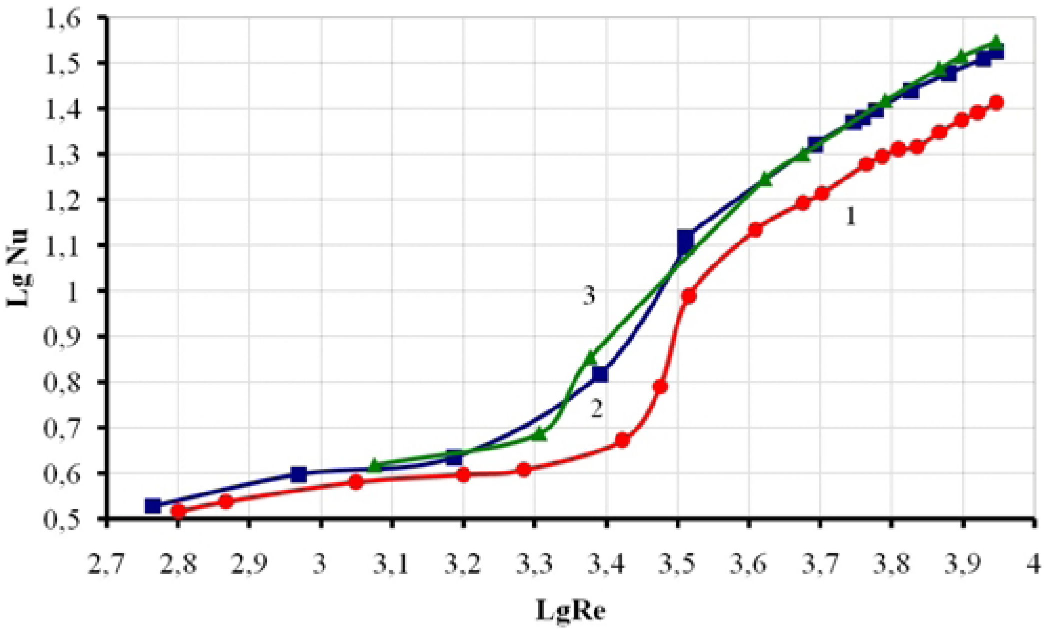

Figure 3. Dependence of Nusselt criterion on Reynolds criterion in logarithmic coordinates for rough continuous channel 1, for channels with two 2 and 3 horizontal passages 3

The convection heat transfer coefficients for the checker block with horizontal passages (Fig. 4) are determined by expression:

$$\alpha_{\kappa\ hp} = \frac{\alpha_{\kappa 1}\cdot n_1 + \alpha_{\kappa 2}\cdot n_2 + \alpha_{\kappa 3}\cdot n_3}{n_1 + n_2 + n_3}$$

where $a_{\kappa i}$ were taken for identical numbers Re_i, and $a_{\kappa 1}$, n_1 are convection heat transfer coefficient and number of rough continuous channels; $a_{\kappa 2}$, n_2- convection heat transfer coefficient and number channels with 2 horizotal passages; $a_{\kappa 3}$, n_3 - convection heat transfer coefficient and number channels with 3 horizotal passages.

At that n1=n3=1, n2=10.

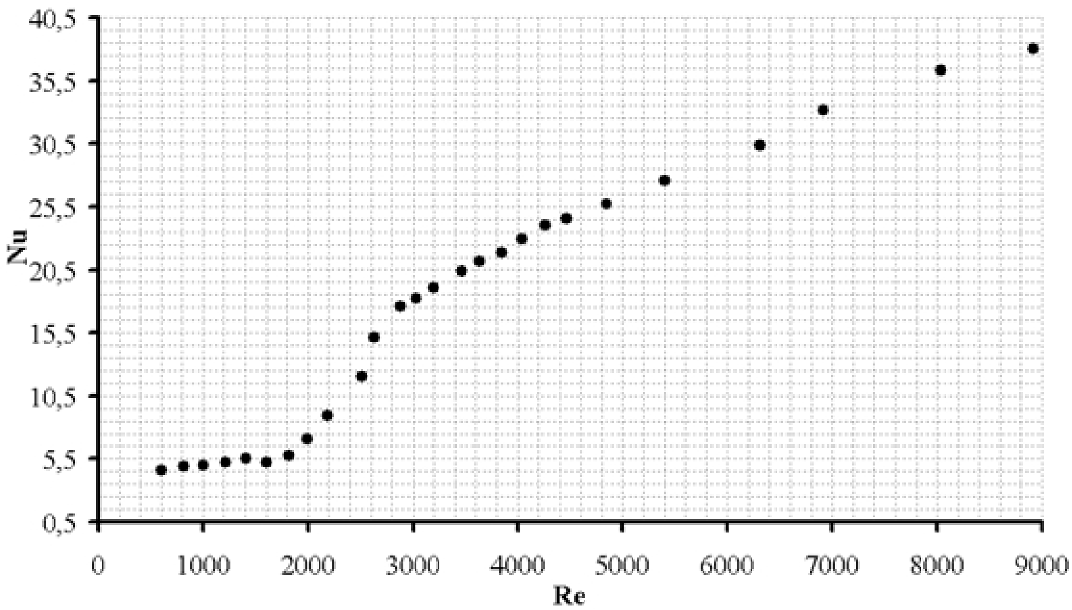

Figure 4. Dependence of Nusselt criterion on Reynolds criterion for the checker block with horizontal passages

Conclusions

Gasdynamic and thermal characteristics of checker with horizontal passages on experimental installation are investigated. Dependences of Nusselt criterion on Reynolds criterion for the continuous rough channel and channels with two and three horizontal passages in laminar, transitional and turbulent areas of a current are obtained. On the basis of the obtained experimental dependences, we performed calculation of coefficients of heat transfer and criteria of Nu for a regenerative block checker of the air heater with horizontal passages which can be used in design calculations.

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Technical translation:

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Page-proofs:

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The journal is registered by Ministry of Justice of Ukraine. Registration Certificate No. 15475-4047P of July 13, 2009.

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