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Revealing of digital images assembling on the basis of maximum coefficients analysis of wavelet transform

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Summary. The method to reveal the assembling of media-data based on wavelet decomposition with the analysis of frequency components of signal decomposition is proposed.
Key words: media-signal, wavelet decomposition, assembling, information technologies.

INTRODUCTION

The task to improve methods of digital signal processing in general, and methods of revealing the objects of media-data modification in particularly is one of the most important tasks in many fields of science and engineering: forensic science, images, video and sound processing, data confidentiality and so on. In this case this work is very relevant because the spheres are being widened due to new methods. The methods of revealing, introducing a new theoretical and algorithm basis, using new reveal methods at the level of apparatus and programmed means which support a computing process [17, 18].

The tasks to evaluate the authenticity are one of the most important tasks in forensic science expertise. Rapid development of methods to evaluate the authenticity of a digital signal has given the rise to a great number of different approaches and algorithms to solve the tasks in this field for the latest 10 years [1, 5, 6, 19].

Proposed methods and algorithms in the most cases have eureka nature and use this or that statistic peculiarity of a digital signal. As a rule, such statistic peculiarities are the result of empirical facts and regularities which seldom claim to be enough general, universal by nature [9, 10, 18, 20].

Practically there are no approaches solving the tasks concerning the evaluation of digital signal authenticity on the basis of a single physical model and consequently there is no mathematical approach in references. At the same time the construction of stable algorithms for authenticity evaluation, their checking, testing and solving of return tasks demand to create and develop consecutive physical and mathematical models of digital graphical signals.

Analyzing the regularities in a signal there is a possibility to evaluate data unity on the basis of the analysis and to single out characteristic features of regularities characteristic the device of signal formation. Creation, encoding and presentation of multi-media data constitute a unique signal with definite statistic characteristic features. [7, 8, 12]. The analysis of this signal for the purpose of its characteristics changes is the basis for conducting the research to reveal its modifications [3, 4, 16]. To guarantee that received data haven't been processed by proper people it is necessary to evaluate given characteristics identifying each of the steps, receiving, initial encoding, channels encoding, and transmission. Each of theses steps as a rule brings unique components to an exit signal and these components are the part of the authenticity system.

METHODS OF RESEARCH

Raster graphic files as the elements of media-data are considered in this work.

In our research we take into account such main characteristics of researched methods in order to reveal the modifications of images as: versions, possibilities regarding space and large-scale change, localization of geometrical sizes and objects coordinates, noise resistance, localization and revealing signal properties, availability of fast computing algorithms, adaptation to peculiarities of analyzed data.

Specific methods are used to reveal computing complexes of signal processing in the form of media-data in compounds, they are also used to reveal the availability of great demands to their adaptation, noise resistance, work speed and the possibility of a data multi-profile analysis. And a specific of applied methods requires the development of a new method which meets above-mentioned requirements. According to all this the analysis of modern methods to reveal the objects of artificial origin have been done, their classification have been performed, their main advantages and drawbacks have been revealed.

On the basis of carried out analysis the evaluation method of media-data authenticity has been proposed, it has been based on the wavelet-analysis means and has been aimed at signal complex processing including: defining the best decomposition basis, wavelet filtration by adaptive thresholds, division into the fields of probable location of searched objects, singling out characterized space and large-scale properties and vectors signs, the initial classification, and also making classification more precise by using a fractal analyzer.

Synthesize the revealing procedure of vectors characteristic features of objects analyzed graphical signals on the basis of wavelet-analysis means.

Wavelet transformation is a presented signal invariant regarding a (shift) change. At every scale ***s*** at the function shift $f(t)$ by value r, wavelet coefficients $Wf(u,s)$ are also shifted by r. Shift takes place, occurs naturally and separately singled out wavelet maximums generated by the peculiarities of an analyzed signal. Such a property allows us to build much simpler and fast-acting revealing and classification algorithms than in the case when a transformed signal depends on the location of its structures.

The property of invariant wavelet transformation comes from its interpretation as operation of convolution:

$$\begin{aligned} &Wf(u,s) = f\psi_s(u) \Rightarrow \exists(t) = f(t-r) \Rightarrow \\ &\Rightarrow Wf(u,s) = f * \psi(u) = WF(T-\tau, s). \end{aligned} \quad (1)$$

In this case there is one problem. It is error accumulation in shear on a uniform discrete net. If a sample pitch is small the convolution indications (1) are approximately approaching at the function shift $f(t)$, however resulted discrete net for W, f (u,s) can not coincide by indications with the net W, f (u,s). The only way out of this situation is to use adaptive schemes of a sample when a discrete indication grate is automatically shifted in a signal shear changing by this the location of wavelet coefficients, and respectively the location of their local maximums.

Wavelet transformation is able to focus on the local structural signals with the help of approaching and distancing procedures based on the alteration of large-scale transformation parameters. At the same time it is known, that these are peculiarities and rough structures which contain main information about a signal, that is particularly those peculiarities on the basis of which different objects presenting in signals can be identified as assembling elements.

To characterize structures with peculiarities (ruptures, regularity disturbance, space-frequency composition and so forth) logically it is necessary to define exact importance of signal smoothness at time intervals and at any point with the help of Lipshits index [2].

If $f(t)$ has a peculiarity at $t = v$, which means that the function un-differentiated at this point, Lipshits index at $t = v$ characterizes function singled behavior. In such a case, Lipshits index having the value $a < 1$ at the point v allows defining the peculiarity nature.

And vice versa, if $f(t)$ satisfies Lipshits uniform conditions $a > m$ in the vicinity of v, so it is by all means m times continuously differentiated in this vicinity.

For points on the surface of wavelet transformation let's rewrite Lipshits smoothness condition as an inequality:

$$\left|Wf(u,s)\right| \le As^{a+1/2}. \qquad (2)$$

To define exact value of Lipshits index let's take the logarithm of both parts of an inequality 2:

$$\log_2\left|Wf(u,s)\right| \le \log_2 A + \left(a + \frac{1}{2}\right)\log_2 s. \qquad (3)$$

Lipshits smoothness in this case is determined by maximum inclination $\log_2\left|Wf(u,s)\right|$ as the function $\log_2 s$ along the line of maximums converging to v, or point-wise according to the following formula:

$$a \ge \frac{\log_2\left|Wf(u,s)\right| - \log_2 A}{\log_2 s} - \frac{1}{2}. \qquad (4)$$

As a result we can come to the conclusion that the usage of wavelets maximums as an "element" of local smoothness $f(t)$ is an effective mean allowing us to receive additional information characterizing an analyzed object.

Besides, the singling out of module wavelet coefficients maximums automatically singles out not only the disturbance of signal local smoothness but allows localizing the peculiarities of function $f(t)$, and also allows defining their nature, character.

Signal peculiarities are singled out by means of abscess finding out in which maximums of module coefficients wavelet transformation at a small scale are converged. The ability of wavelet transformations to single out peculiarities is revealed at its interpretation as multi-scaled differentiated operator. It is proved in [2] that if wavelet $\psi = (-1)^n \theta^{(n)}$ has n zero moments and a compact carrier, the wavelet transformation $Wf(u,s)$ can be re-written by the following way:

$$Wf(u,s) = f * \psi_s(u), \qquad (5)$$

where: $\overline{\psi}_s(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{-t}{s}\right)$.

As $\psi(t) = (-1)^n \frac{d^n\theta(t)}{dt^n}$ then:

$$\begin{aligned} Wf(u,s) &= s^n f * \frac{d^n\overline{\theta}_s(t)}{dt^n} = \\ &= s^n \frac{d^n}{du^n}\left(f * \overline{\theta}_s\right)(u). \end{aligned} \qquad (6)$$

If analytical wavelet has only one zero moment, maximums wavelet transformations are interpreted as maximums of the first-order derivative of function $f(t)$, smoothed out by the nucleus $\overline{\theta}_s$. These are maximums which define the location of ruptures and signal differences. If analytical wavelet has two zero moments, the maximums of module wavelet transformations correspond to the greatest curvatures.

Besides the wavelet maximums locations allow localizing the differences of an analyzed signal. Some segment boundaries can change their location or they can completely disappear with the alteration of large-scale signal presentation that is with the motion along the structure of decomposition / restoration.

Naturally the boundaries of an object outline *C(u,s)*,presented by wavelet coefficients of a peak amplitude “are seen” on a great number of scales. The boundaries presented by the coefficients of small amplitude are only seen on a limited number of scales. So, as an additional object or a segment characteristic feature it is possible to single out its scale limit $j^k_{\max}$, that is the number of decomposition level where the outline is disappearing or converging.

Such a given parameter additionally characterizes the sizes of an analyzed objects and multi-scaled wavelet transformation reaction influencing it. To use this feature as a limit also permits additionally to divide the set of standard objects by the limits of their scale visibility.

Such features of maternal wavelet functions as a number of zero moments and the carrier width play extremely important role for localization and singling out signals peculiarities.

The majority of wavelet functions have a compact carrier that is some interval (a,b), for which $\forall_t \notin (a,b) \Rightarrow \psi(t) = 0$ is performed. However, if wavelet hasn’t this property, the interval with smearing boundaries is defined where $\psi(t) \approx 0$ and on which the carrier can be considered to be compact. The carrier width defines sizes of frequency-time (slot) window formed by wavelet in the time range.

Different wavelet functions have various numbers of zero moments. It is said that wavelet $\psi(t)$ has n zero moments if for any $k < n$ the following condition is performed:

$$\int_{-\infty}^{\infty} t^k \psi(t) dt = 0 . \qquad (7)$$

Wavelet with n zero moments is orthogonal to a polynomial of degree $n-1$, and this value n defines the wavelet sensitivity to a signal irregular polynomial components.

If an analyzed signal $f(t)$ has a feature at the point t_0 and if t_0 is inside of the carrier $\psi_{j,n}(t) = 2^{-j}\psi(2^{-j}t - n)$, so wavelet coefficients $\langle f, \psi_{j,n} \rangle$ have great amplitude.

The size of a carrier function and a number of zero moments are a priori independent. However, limits put on orthogonal wavelets mean that if wavelet function ψ has p zero moments, so the least carrier exists which is equal to $2p-1$. For example, Dobeshi Wavelets are the most optimal in this sense because they have a carrier minimum size at a given number of zero moments.

If $f(t)$ has some isolated features, peculiarities and the interface is very smooth between them in this case it is necessary to choose wavelet with more number of zero moments in order to receive a great number of small wavelet coefficients $\langle f, \psi_{j.n} \rangle$. If density of features is increasing, so it is better to reduce the size of the carrier due to the reducing of a number of zero moments.

Naturally, there is no single, unique basis which is ideally corresponding to present all types of signals. Moreover, it is rather difficult to define what type of wavelet functions is better to be used for one particular analyzed signal. Such a feature of used theoretical base creates some difficulties, however, if it is correctly, professionally used it gives the possibility to adapt to the maximum signals wavelet presentation to their physical essence [2].

Considered approach allows singling out the differences of an analyzed signal, and also the outlines which are on the objects images. While doing investigations the statistical characteristic features of singled out objects outlines have been evaluated. Singled out features permit uniquely to determine geometrical features of objects, their scaled “visibility”, allow singling out the composition of signal features and their nature (character) depending on the nature of analyzed signal. To improve singling out the signal features connected with assembling the filtration on the basis of a fractal analyzer according to the algorithm has additionally been done [2].

RESULTS OF RESEARCH

A number of experiments to check the creation of an approach to reveal the assembling of digital images have been done.

During the experiments model signals the features of which are approaching to the maximum to the features of researched processes have been synthesized. Signal modeling have been performed in Simulink area of Matlab packet by means of simulation of digital device recording graphical signals on the basis of algorithms choice characteristic to the operations of transformation analogue graphical signal into digital one.

Modeling of characteristic feature (singularity) has been done on the basis of the following propositions. Time extent of singularity $Z^j{}_k$, connected with assembling is a random quantity having uniform distribution at interval $\lfloor t_j, t_{j+1} \rfloor$. Singularity height is also a random quantity having uniform distribution at interval $\lfloor a_j, b_j \rfloor$.

During the process of model signal formation the time interval $\Delta t = t_{j+1} - t_j$, contains singularity and takes values from 2 till 120, and the height of singularities $\zeta_{i,j}, i = \overline{1,3}$ takes the value beginning with the level of background (hum) variations and ending with the value exceeding background level twice.

Researches to evaluate the effectiveness on the basis of models of main hum (backgraound) and the object have been done. Necessary parameters and corresponding criteria of evaluation to fulfill the effectiveness analyses have been considered. The research methodic based on the features of proposed revealing method is presented. It is stated that in order to determine the values of identification quality and to calculate the features of finding out the assembling of digital graphical signal instead of the values signal-to-noise ratio (in this case it is possible to speak about the relation “hum-to-signal ratio) here advisably to use ratio of singularity square to window square, that is Sc/S window.

Testing the proposed theoretical statements 6 main types of digital images assembling have been considered with the exception of the replacement of a recording mechanism print (which has been considered apart). Looking at a given drawing (Fig.) we can see that average probability for different types of assembling to reveal modifications of digital signal (DMS) is more than 95% and it is achieved already for signals with ratio signal-to-noise more than 15 dB.

It permits to come to the conclusion that for the truth of a signal the most important signal features are those which are singled out on the basis of model detailed components. Besides it proves the universality regarding to different variants of digital images modifications, high noise resistance (immunity), and performance in terms of error probability, the method of revealing and its high efficiency for signals with quality “lower than average"has been proposed.

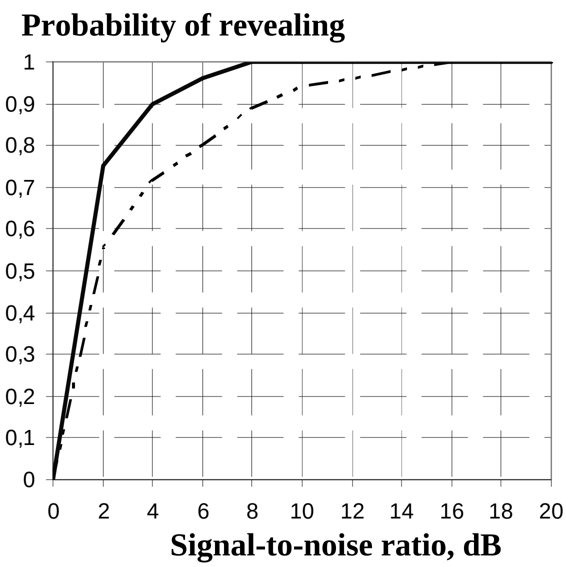

Fig. Graph of dependence of average probability for revealing the features in the assembling area against “signal-to-noise” ratio of digital image

model without fractal analyzer,

model with fractal analyzer

CONCLUSIONS

1. Methods and means used in modern practice to evaluate the authenticity don’t provide the guaranteed revealing traces of digital processing of digital media-data and the

identity between digital graphical signal and the device of its formation.

2. While carrying out the research the model to reveal the assembling of digital image by means of evaluation the distribution of outlined features in the structure of digital image on the basis of maximum wavelet decomposition has been developed, this model proved its efficiency in the process of creation the system for revealing assembling image.

3. Algorithms of singularity classification characteristic to the assembling in the structure of digital graphical signal have been developed and investigated. On the basis of model signals processing it is shown that the developed algorithm permits to reveal large-scale singularity with the probability of amplitude 0, 98, exceeding background level by 1, 1 times.

REFERENCES

1. **Avcibas I., Bayram S., Memon N., Ramkumar M., Sankur B., 2004.:** “A classifier design for detecting image manipulations ,"in Proc. Int. Conf. Image Processing, Singapore, Vol.4, 2645-2648.
2. **Bespalov D.A., 2006.:** Natural parallelism of fast algorithms of wavelet transformation //Izvestiya TRTU. – 200.
3. **Byelozerov E.V., 2011.:** Method of revealing of digital media-data modifications on the basis of adaptive wavelet filtrations usage // Herald V. Dahl East-Ukrainian National University. – № 7 (161). P.1. – 15-21. (in Russian).
4. **Byelozerov E.V., Rybalskiy O.V., Solovyov V.I., Bruhanova Y.A., 2010.:** Methodology of signal gram authenticity checking by revealing of self-similar structures //Information safety. – №2 – 35-49. (in Russian).
5. **Byelozerov E.V., Solovyov V.I., Bruhanova Y.A., 2010.:** Method of authenticity images estimation on the basis of the analysis of their spectral characteristics // Herald of V. Dahl East – Ukrainian National University. – №4 (146). P.1. – 179–184. (in Russian).
6. **Byelozorov E.V., 2013.:** Model to reveal the singularities of a digital graphical signal for finding out of its recording // Herald V. Dahl EUNU. – Lugansk, V. Dahl EUNU. - №6 (195), P.1. – 67–71. (in Russian).
7. **Farid H., 2009.:** “A survey of image forgery detection,” IEEE Signal Processing Magazine, V. 2, № 26, 16–25.
8. **Fridrich J., Soukal D., Lukras J., 2003.:** “Detection of copy-move forgery in digital images,"in Digital Forensics Research Workshop.
9. **Harten A., 1993.:** Discrete multi-resolution analysis and generalized wavelets. //J.App.Num.Math. – V.12. – 153-193.
10. **Kobozeva A.A., 2008.:** General approach to the analysis of information objects state based on the indignation theory //Herald of V. Dahl East-Ukrainian National University. – Lugansk, № 8, P.1, – 72–81. (in Russian).
11. **Li G., Wu Q., Tu D., Sun S., 2007.:** "A Sorted Neighborhood Approach for Detecting Duplicated Regions in Image Forgeries based on DWT and SVD", in Proceedings of IEEE International Conference on Multimedia and Expo, Beijing China, July 2-5, 1750-1753.
12. **McKay C. E., Swaminathan A., Gou H., Wu M., 2008.:** “Image acquisition forensics: Forensic analysis to indentify imaging source" in Proc. IEEE Conf. Acoustic, Speech, and Signal Processing, Las Vegas, NV, 1657-1660.
13. **Myna A. N., Venkateshmurthy M. G., Patil C. G., 2007.:** Detection of Region Duplication Forgery in Digital Images Using Wavelets and Log-Polar Mapping, in: International Conference on Computational Intelligence and Multimedia Applications, Sivakasi, India, 371-377.
14. **Popescu A., Farid H., 2004.:** Exposing digital forgeries by detecting duplicated image regions. //Dartmouth College, Tech. Rep. – TR2004-515. – 24-32.
15. **Rybalskiy O.V., 2006.:** Main theoretical statements to reveal the traces of

phonogram digital processing and peculiarities of its programmed and methodic realization in the expertise of materials and video-sound recording means. (part 1) // Information protection. – K., № 1. – 71-76. (in Russian).
16. **Rybalskiy O.V., Zharikov Yu.F., 2003.:** Modern methods to test the authenticity of magnetic phonograms in forensic-acoustic expertise. – K.: NAVSU. – 300. (in Russian).
17. **Sieriebriak K., 2012.:** Information technologies in Ukraine: problems and obstacles Teka. Commission of motorization and energetics in agriculture – V.12, № 3, 128-135.
18. **Voronova A., 2011.:** Information technologies in public administration practice. TEKA, Commision of Motorization and Power Industry in agriculture, Lublin University of technology, Volodymyr Dahl East-Ukrainian National University of Lugansk, Volume XD, Lublin, 313-318.
19. **Ye S., Sun Q., Chang E., 2007.:** “Detecting digital image forgeries by measuring inconsistencies of blocking artifact,"in IEEE International Conference on Multimedia and Expo, 12-15.
20. Zhu B., Swanson M.D., Tewfik A.H., 2004.: “When seeing isn’t believing [multimedia authentication technologies],” //IEEE Signal Processing Magazine - Mar. – V. 21, № 2. – 40-49.

ВЫЯВЛЕНИЕ МОНТАЖА ЦИФРОВЫХ ИЗОБРАЖЕНИЙ НА ОСНОВЕ АНАЛИЗА МАКСИМУМОВ КОЭФФИЦИЕНТОВ ВЕЙВЛЕТ-ПРЕОБРАЗОВАНИЯ

Евгений Белозеров

Аннотация. Рассмотрены вопросы оценки подлинности цифровых изображений. В качестве элементов оценки подлинности предложено использовать структурные особенности изображений различной формы и протяженности, связанные с устройством записи изображения. Рассмотрен метод выявления структурных особенностей на основе вейвлет-декомпозиции сигнала. Предложен метод выявления монтажа медиа-данных, основанный на анализе частотной составляющей вейвлет-декомпозиции изображения.

Ключевые слова: медиа-сигнал, вейвлет декомпозиция, монтаж, информационные технологии.

Define the operational hydro-solid waste handling system

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Summary: The article deals with the determination of the refractive efficiency of industrial hydrotransport system of evacuation of ash materials. As, which offered value for used hydraulic power divided by the weight of the transported material. We study the dependence of the specific hydraulic capacity of the various influencing factors: the density of the solid material, the concentration of the slurry, the slurry flow rate (flow rate). The analysis of the obtained surfaces of the response, and made recommendations regarding the choice of rational transportation parameters of slurries of solid wastes from coal.
Keywords: hydraulic fluid, power, speed, concentration of the expense.

INTRODUCTION

Thermal power stations in Ukraine producing electricity by burning various types of hydrocarbon fuels. This produces solid wastes, which are solid particles of various sizes and are divided into ash and slag. [2, 7]

Ash has a size of 0 to 1.2 mm, and activated carbon filter, scrubbers and electrostatic precipitators. Slag – the large sintered particles with sizes up to 100 mm and more. For its further transport it is necessary to pre-grinding [8].

Are four main types of disposal of ash and slag: hydraulic, pneumatic, mechanical and combined. Because by a high transport capacity and reliability of the most commonly accepted a hydraulic ash removal (Group Metering) based on the use of hydro-transport pipeline systems. The main disadvantages of hydraulic ash removal should be: low efficiency due to the excessive consumption of specific carrier medium (per ton of ash accounts for up to 50 m^3 of water), high specific cue equipment wear due to transport abrasives, significant expenditures of labor on maintenance of hydraulic ash removal facilities, repair of pumps, gravity fed canals and pipelines external hydraulic ash, waterlogging of soils in the area of storage of ashes. The means to make the content is about 7,8-11,2 million a year or more, depending on the power of TES [9, 22, 25].

MATERIALS AND METHODS

Improvements in energy efficiency and the evacuation of ash were studied by such scholars as Berestovoy A.M., Bragin, B.F., Beletsky V., Vlasov, Y., Krill S.I., Krut A.A., Melent'ev B. Oh., Murko V.I., Nagli O.Z., Svitliy J.G., Silin M.O., Smoldyrev A.E., Semin D., Ulshin V.A., Ur’ev N.B., Chernetskaya-Beletskaya N.B., Yufin A.P., O.M. Yahno etc. The main areas of work listed scientists and many other researchers were: classification and theoretical lighting flow of ash slurry thickening of ash, as well as the modernization of hydraulic ash removal units. However, currently most promising should be considered as a combined ash removal system, which provides a high concentration of solids in the hydraulic part of the system. Also on the study of rational parameters of the flow and the scientific substantiation not be proper attention [3, 15, 19, 20].

In connection with the above, the actual is rational, the task as selecting the concentration of the solid and the transport velocity, corresponding to the minimum value of the energy moving in the system unit of transported the solid component.

The purpose of the article. Definition of rational parameters of solid transportation unit of the material in the industrial hydrotransport system topic (IHTS).

RESULTS, DISCUSSION

Calculations hydrotransport systems is determining the critical flow rate u_{cr}, ensures weighing and moving through the pipe bulk solids and hydraulic gradient Δi_{mix}, design pressure necessary for supplying the pulp. [1]

Minimum speed that prevents subsidence can be determined from the balance of the stress on the forces acting on the elementary final volume of small fraction two-phase medium, with holding extremely large particle fraction. The particle solids accepted sphere-like shape, which corresponds to the most severe cases (Fig. 1) [4, 5, 6]:

$$\tau_0+\mu_{st}\cdot\dot{\gamma}+\Delta p+\frac{1}{2}\rho_{mix}\cdot\left[2\left(\dot{\gamma}\cdot\Delta z\right)\cdot u_{z1}+\left(\dot{\gamma}\cdot\Delta z\right)^2\right]-\\-\frac{\left(\rho_{sol}-\rho_{mix}\right)\cdot\pi\cdot r_p^3\cdot g}{\Delta z^2}=0, \quad (1)$$

where: ρ_{sol} and ρ_{mix} is respectively the density of solid phase and slurry, kg/m^3,

Δp is pressure drop, Pa,

Δz is typical size, m,

u_{z1} is speed lengthways axis of the pipe, m/s,

r_p is the radius of particles of solid material, m,

$\dot{\gamma}$ is shear rate, s^{-1},

τ_0 is initial shear stress, Pa,

μ_{st} is structural viscosity, Pa·s,

g is acceleration of gravity, m/s^2.

Algebraic transformations and excluding members of a higher order of smallness received (error less than 3%):

$$u_{\kappa p}=K_u\sqrt{\left(\frac{\left(\frac{\rho_{sol}}{\rho_{mix}}-1\right)\cdot\pi\cdot g}{4}-\frac{\tau_0}{\rho_{mix}\cdot r_p}\right)\left(\frac{D^2}{2D+d_p}\right)}, \quad (2)$$

where:

D is the diameter of the pipe, m,

d_p is diameter particles of maximum size, m,

K_u is the adjustment factor, for straight sections $K_u=1$.

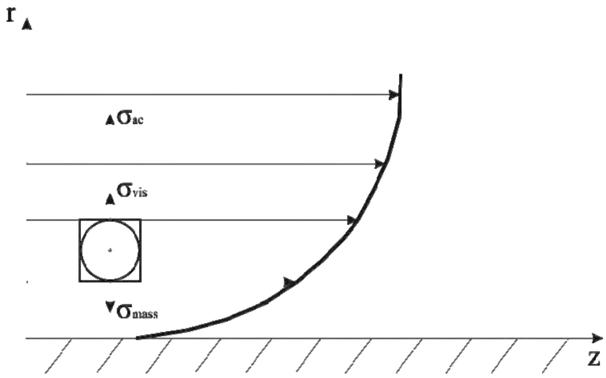

Fig. 1. Scheme of the stress action of external forces on elementary final volume:
σ_{ac} – stress from the action of hydrodynamic forces, Pa,
σ_{vis} – stress from the forces of viscosity, Pa,
σ_{mass} – stress from the action of mass forces, Pa

Let us calculate the dependence obtained by the slurry density of 1250, 1333, 1428 kg/m^3 and a solid component density of 2000 kg/m^3, initial shear stress is 0,016, 0,4436, 2,9 Pa for the maximum particle size of 800 and 500 micron diameter pipe ranged from 50 to 300 mm (Fig. 2) [16, 17].

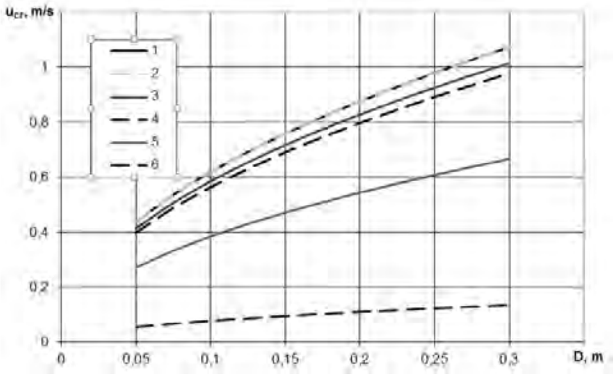

Fig. 2. Dependence of the critical velocity in the structural mode of transportation on the pipeline diameter with a large particle size values of 800 and 500 m, respectively

Theoretical studies have shown that at low mass concentration of solid component and the magnitude of the initial shear stress a major stake in keeping the particles invest Archimedes force and hydrodynamic forces, and in the case of a significant increase caused by the increase of mass concentration, and also viscous forces, accompanied by a sharp decrease critical speed transportation [12, 13].

For comparison of the obtained values of the critical transport speed according to the relationship proposed by the author and others to the procedures performed calculation of critical velocity of the slurry density of 1250, 1333, 1428kg/m^3 with the solid component density of 2000 kg/m^3, initial shear stress is 0,016, 0,4436, 2,9 Pa, the maximum size of the particles – 800 and 500 mm diameter water pipeline D ranged from 50 to 300 mm (Fig. 3).

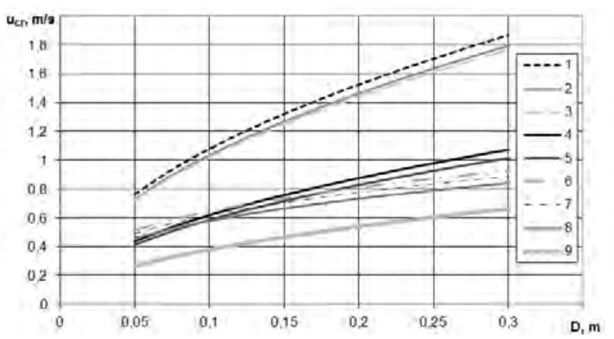

Fig. 3. The values of the critical velocity transport calculated using a variety of dependencies
VNIIGidrougol – 1, 2, 3, author – 4, 5, 9, Instruction on hydraulic transport soil – 6, 7, 8

The analysis presented in figure 3 dependences allows us to establish that the values of the critical velocity calculated by the method VNIIGidrougol (curves 1-3) is significantly higher than for the other two methods with the same diameter of the pipeline. Along with this, the values of critical velocity (curves 1-3, 6-8) increase with increasing concentration of the solid component, which contradicts the experimental data, where there is a reduction of the critical transport velocity with increasing mass concentration and density of the slurry.

During the experiments the mass concentration of solid 40% has been established the existence of stabilizing land loss (minimum of shallow mini), which corresponds to an effective Reynolds number and range speed (0,4-0,48) m/s, average of the readings accepted by the critical velocity equal to the transport (0,44 m/s) (Fig. 4). This fact is explained by the deposition of fraction and reduced flow area of the pipeline, which is confirmed by visualization workflow on the transparent area equipment (the appearance of a dark area in the bottom-part pipeline). The experimental data are in good agreement with the theoretical The study, according to which the value of the critical velocity is 0,44 m/s at a mass concentration of the solid component of 40% and decreases with increasing content of the solid phase.

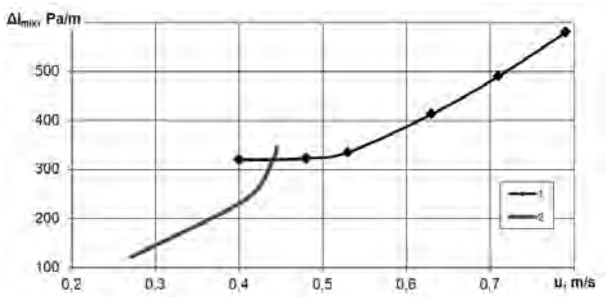

Fig. 4. The pattern of pressure loss change from flow velocity at C = 40 % (1) and the line of critical velocity in the range of concentrations (C = 40... 60 %) (2)

Changing the current recorded piezometer readings and visually, it was when the mass concentration of the solid component 40, 50 and 60% in the measuring range from

0,5 to 2 m/s for straight sections, horizontal and vertical turns 180° and 90° change in flow regime was observed.

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In general, the motion of viscous media is described by differential equations Reynolds, who obtained by substituting into the Navier-Stokes equations instead of the actual values of the velocity and pressure of their averaged and pulsating pressures [10, 11, 14, 18].

While taking into account the flow channel round-sectional area (tube) have in the case of laminar steady state for a straight pipe section (Eq. 3) takes the form:

$$\begin{cases} -\dfrac{\partial p}{\partial z}+\dfrac{1}{r}\cdot\dfrac{\partial(\tau_{zr}r)}{\partial r}=0, \\ -\dfrac{\partial p}{\partial r}=0, \\ \dfrac{\partial u_r}{\partial r}+\dfrac{\partial u_z}{\partial z}=0, \end{cases} \qquad (3)$$

where: u_r, u_z are the components of the velocity of the mixture along the radius and the axis of the tube, m/s,

r is radius from the axis of the tube, m,

τ_{zr} – stress on the action of surface forces, Pa.

Present a mathematical model (Eq. 3) describes for concentrated slurries waste power station structurally mode on a circular pipe of constant diameter [21, 23, 24, 26, 27].

Value of dynamic viscosity in the equation is taken conditionally constant, which can lead to significant errors in determining the parameters of the flow of concentrated slurries. In order to clarify obtained by the results in this paper used the numerical solution of equations (Eq. 3, 4), which allowed us to obtain approximation dependences presented in the text below.

$$\tau_{zr}\approx\left(\left(\exp\left(8,776-\frac{491,99}{C}\right)\cdot\left(\frac{\partial u_z}{\partial r}\right)^{-0,566}\right)\frac{\partial u_z}{\partial r}\right), \qquad (4)$$

where: C is value of the mass concentration of the solid phase.

The proposed mathematical model describes the waste slurries under the imposed boundary conditions.

Theoretical experiments show that when the slurry in the structural mode specific loss of pressure change in powers nonquadratic degree that caused the destruction of the local structure with increasing transportation speed.

The obtained dependences can be approximated by functions of the form $\Delta i_{40}=755u^{1,39}$, $\Delta i_{50}=840u^{1,38}$, $\Delta i_{60}=1000u^{1,51}$ that allows to obtain a generalized dependence of pressure loss on the pipe diameter *D*, the solid phase concentration *C* and velocity *u* (the error is about 5%):

$$\Delta i=\frac{D^2}{a_pD^2+b_p} \qquad (5)$$

or caliber

$$\Delta p_c=\frac{D^3}{a_pD^2+b_p}, \qquad (6)$$

where: a_p, b_p are coefficients depending on the vehicle speed and concentration of the solid phase.

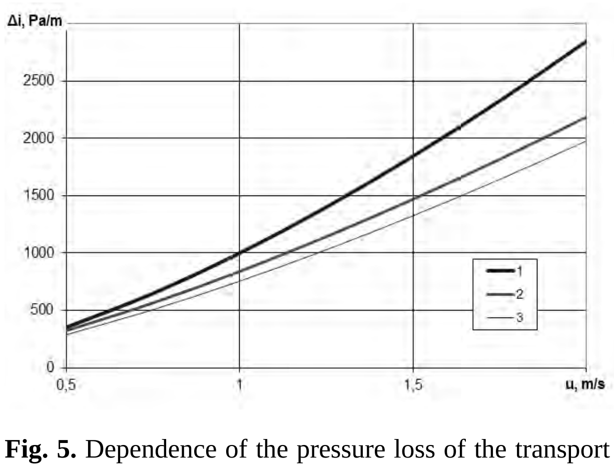

Fig. 5. Dependence of the pressure loss of the transport velocity of concentrated ash slurry in the structural mode by rectilinear portion of the line with a mass concentration of the solid component
1, 2, 3 respectively 60, 50 and 40 %

Experimentally established that right linear portion of loss of pressure in a concentrated ash slurry for range velocity zone of 0,5-2,0 m/s and the concentrations of 40-60% can be determined from the regression equation [8]:

$$\Delta i_{mix} = 1251,28 + 112,49u - 5221,3C + \\ + 186,97u^2 + 4667C^2 + 1550u \cdot C, \tag{7}$$

where: u is value of the transport velocity, m/s.

Represented by the expression (Eq. 7) a response surface (Fig. 6).

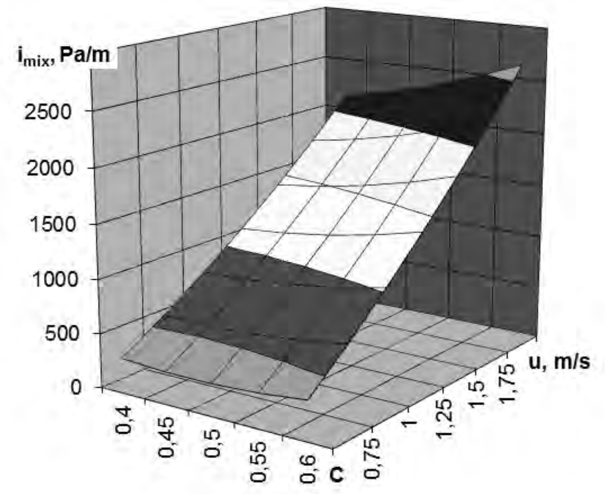

Fig. 6. Response surface for the straight section with variables and

Analysis which revealed that a fixed value of the concentration dependence of the velocity head loss of transport has almost linear character of the increase. At a fixed speed transport resistance also describes a monotonically increasing function.

For the numerical definition of rational transportation parameters execute calculation consumed hydraulic power to move the ash slurry at a distance of 2260 m, which corresponds to the length ash pipeline Luhansk's power station. Calculations will be performed for different speeds of transportation, solid component concentration at a fixed value of the mixture (Fig. 7) [16, 17, 28, 29]:

$$N_{mix} = \Delta i_{mix} \cdot L \cdot Q_{mix}, \tag{9}$$

where: L – pipe length, m,
Q_{mix} – volume pumped mixture, m^3/s.

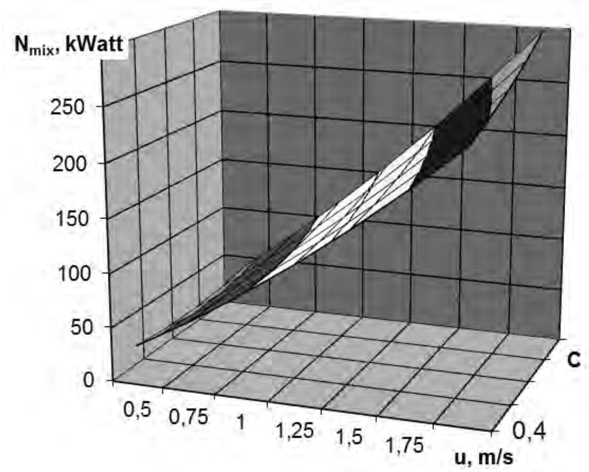

Fig. 7. Hydraulic power dependence on the values of the transport velocity and the concentration of the solid component of a fixed value of flow slurry ($Q_{mix} = 0,05\,\mathrm{m}^3$/s)

Similarly, the value is determined by spending hydraulic power for other values of the slurry flow.

An increase in the hydraulic consumed power during transportation slurry as an increase in vehicle speed, and with increasing concentration, and the change is exponential in nature.

Consumption of solid component can be determined from the expression:

$$Q_{sol} = \frac{Q_{mix} \cdot \rho_{mix} \cdot C \cdot 3600}{\rho_{sol}}. \tag{10}$$

Analysis of the surface in Figure 8 it possible to establish that the change in flow rate of the solid phase from the slurry expenses da obeys a power law, and concentration – linear.

Value of the specific hydraulic power unit for moving solid material but one can be calculated from the ratio (Fig. 9).

$$N_{mix.sol} = \frac{N_{mix}}{Q_{sol} \cdot \rho_{sol}}. \tag{11}$$

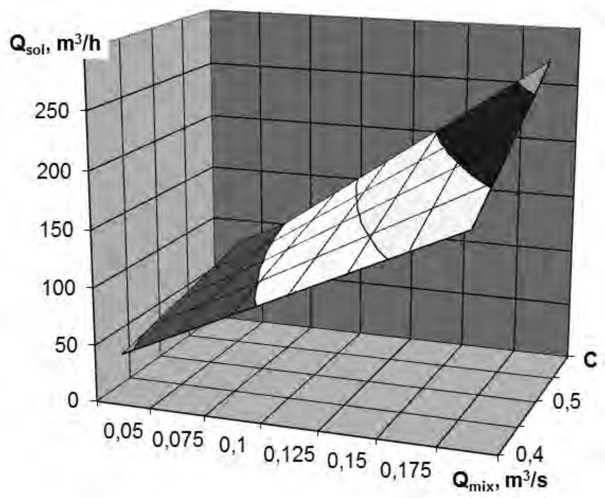

Fig. 8. Flow rate of the solid component, depending on the concentration of the mixture *C* and slurry flow rate Q_{mix}

Analysis of the dependence of the specific hydraulic power unit of the material transported revealed that with increasing flow rate of the slurry (transport velocity) observed uneven change its dramatic change occurs at low flow rates with a further stabilization of growth. With increasing concentration of the solid component occurs at least at a weight concentration of solids of 0,55, which is particularly evident at low cost of the slurry.

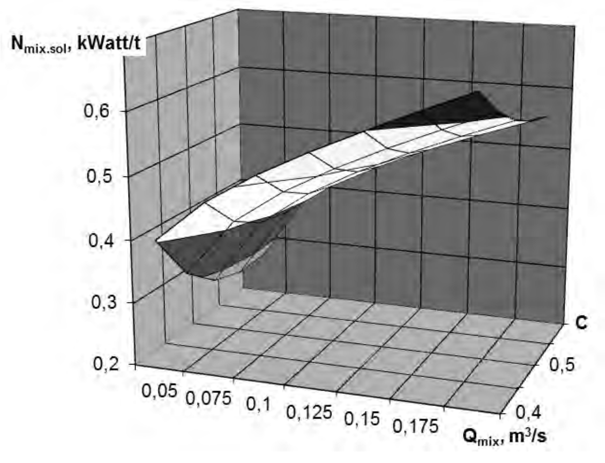

Fig. 9. Dependence of specific hydraulic power unit of the solid material from the slurry flow (conveying speed) and the mass of solid components

CONCLUSIONS

1. Basic design parameters of hydraulic transport system for moving waste solid fuel are critical transport velocity and hydraulic gradient.

2. The critical velocity for highly concentrated ash slurries should be determined taking into account the rheology of the transported medium and their size, based on the diameter of the pipeline.

3. Determination of specific head loss for evacuation systems ashes also has its specificity that is associated with a change in the members of the deviator stress tensor in the Navier-Stokes equations.

4. The main quantity that characterizes the movement of the unit cost of the transported material, it should assume a specific hydraulic power expended by a predetermined displacement volume of the solid phase.

5. Specific hydraulic power is used for transportation depends on several parameters, primarily the flow of slurry (conveying speed), concentration of the solid component in the slurry, its density, etc.

6. Dependence of the specific hydraulic power of the factors presented by is complex, while there is a sharp increase in its consumption increases slurry (speed transporting) and a minimum at a solids content of about 0,55.

7. Based on the studies should be encouraged to transport with minimum possible speed, which ensures reliable movement of ash and slag, and mass solids content of about 55 %.

REFERENCES

1. **Asaulenko I.A., Vitoshkin J.K., Karasik V.M., Krill S.I., Ocheretko V.F., 1981.:** Theory and applied aspects hydrotransportation solid materials. – K.: Science. Dumka. – 353-362. (in Russian).
2. **Burov V.D., Romm E.V., Elizarov D.P., 2009.:** Thermal power plants: a textbook for high schools. – M.: Publishing House MEI. – 466. (in Russian).
3. **Chaltsev M.M., 2000.:** On the analogy of certain patterns of Hydromechanics and hydrotransport pneumatic systems// Bulletin (Collected Works of NTU and tau). – K.: RIO NTU. – Vol. 4. – 292-295. (in Ukrainian).

4. **Chaltsev M.N., 2000.:** On the calculation of the critical velocity in pipeline transportation systems, pneumatic// The collection of scientific papers Kirovograd State Technological University. Technology in agricultural production, industry machinery, automation. – Kirovograd. – V.7. – 125-129. (in Russian).
5. **Chaltsev M.N., Krill S.I., 2010.:** By On the methods of calculating the basic parameters of pneumatic bulk material along horizontal pipes// Applied hydromechanics. – K. – № 4 (84), Vol.12. – 36-44. (in Russian).
6. **Chaltzev M., Vovk L. 2011.:** Analytical investigation into velocity change of the transported material in a pipeline bend// TEKA: Commission of motorisation and power industry in agriculture Lublin university of technology Dahl’s East-ukrainian national university of Lugansk. – Lublin. – Vol. XI B. – 20-29.
7. **Chernetska-Biletska N.B., Varakuta E.O., Kapustin D.O., 2012.:** The method of calculation of key indicators hydraulic conveying of solid residues power station// Journal of Dahl’s East-Ukrainian National University. – Lugansk. – № 5 (176). – 137-142. (in Ukrainian).
8. **Chernecka-Biletska N.B., Kapustin D., 2012.:** Transporting waste power station as slag slurry// Innovative technology in rail transport: the third scientific-practical. Conf. studio., PhD student. and mol. Scientists, 13-15 September. 2012, Krasny Liman: abstracts reported. – Lugansk. – 92-96. (in Ukrainian).
9. **Dzhvarsheishvili A.G., 1981.:** The pipeline system of mining and processing enterprises. – Moscow: Nedra. – 384. (in Russian).
10. **Fikhtengol'ts G.M., 2001.:** Course of differential and the integral calculus. V.3. – M.: Fizmatlit. – 622. (in Russian).
11. **Fukagata K., Kasagi N., 2003.:** Drag reduction in turbulent pipe flow with feedback control applied partially to wall. Int. J. Heat Fluid Flow 24. – 480-490.
12. **Gorokhovsky M., Chtab A., 2003.:** Hypothetical "heavy particles dynamics in LES of turbulent dispersed two-phase channel flow. Center for Turbulence Research Annual Research Briefs. – 205-211.
13. **Harada S., Tanaka T., Tsuji Y., 2000.:** Fluid force acting on a falling particle toward a plane wall. Proc. Of ASME FEDSM'00. 2000 ASME Fluids. – 1-5.
14. **Hirsch C., 2007.:** Numerical Computation of Internal and External Flows. Elsevier. – 696.
15. **Hodakov G.S., 2003.:** Rheology of suspensions. Phase flow theory and its experimental validation// Rus. chem. magazine (magazine Russia. chem. Islands about them. DIMendeleyev). – № 2. – Vol. XLVII. (in Russian).
16. **Kapustin D.O., 2012.:** The study of non-Newtonian behavior of concentrated withtin hydromixes// Innovative technologies for rail trans-port: III Intern. scientific-practical. conf., February 26. – 04 rem. 2012, Tel Aviv (Israel): abstracts reported. – Lugansk. – 19-21. (in Ukrainian).
17. **Kapustin D.O., 2012.:** Rheological study of concentrated withtin hydromixes// Journal of Dahl’s East-Ukrainian National University. – Lugansk. – № 3 (174). – 73-79. (in Ukrainian).
18. **Kawaguchi T., Horii Y., Tanaka T., Tsuji Y., 2003.:** DEM Simulation of One-Dimensional Plug Motion in Stand-pipe Flow and Development of Plug Flow Model// Proc. of the 2nd Asian Particle Technology Symposium 2003 (APT 2003), Penang, Malaysia (2003). – 495-500.
19. **Krill S.I., 1982.:** Critical modes of hydraulic pipeline transport of solids// Fluid. – Issue. 45. – 88-94. (in Russian).
20. **Levchenko D., Meleychuk S., Arseniev V., 2012.:** Regime characteristics of vacuum unit with a vortex ejector stage with different geometry of its flow path// Procedia Engineering, Vol. 39. – 28-34.
21. **Mehrotra V., Silcox Geoffrey D., Smith Phillip J., 1999.:** Monte Carlo particle dispersion simulation application in coal fired furnaces: comparison with experimental data. Second International Conference CFD in the Minerals and Process Industries CSIRO, Melbourne, Australia. – 287-292.
22. **Pokrovskaya V.N., 1985.:** Pipelines in mining industry. – Moscow: Nedra. – 192. (in Russian).
23. **Risuhin L.I. Cherneckaya N.B., Kovalenko A.A., Shvornikova A.M., Kapustin D.A., 2010.:** Rational choice and design of industrial equipment of hydro systems: monograph. – Lugansk, ENU. – 92. (in Russian).
24. **Slater, S. A., Young J. B., 2001.:** The calculation of inertial particle transport in dilute gas-particle flows. Intl J. Multiphase Flow 27. – 61-87.

25. **Smoldyrev A.E., 1975.:** Hydro and pneumatic transport. – Moscow: Metallurgy. – 384. (in Russian).
26. **Soldati A., 2002.:** Influence of large-scale streamwise vortcal EHD flows on wall turbulence. Intl J. Heat Fluid Flow 23. – 441-443.
27. **Syomin D., Rogovoy A., 2010.:** Power characteristics of super-chargers with vortex work chamber// Polish academy of sciences branch in Lublin. TEKA. Commission of motorization and power industry in agriculture. Volume XB. TEKA Kom. Mot. Energ. Roln. – OL PAN, № 19. – 232-240.
28. **Tsibin L.A., Shanaev J.F., 1976.:** Hydraulics and pumps. – Moscow: Higher School. – 256. (in Russian).
29. **Ulianitsky A.V., 1993.:** Rationale for minimum energy consumption in a horizontal pneumatic conveying of bulk materials: dis. the candidate tehn. science. – Odessa. – 182.

ОПРЕДЕЛЕНИЕ РЕЖИМА РАБОТЫ ГИДРОТРАНСПОРТНОЙ СИСТЕМЫ ПЕРЕМЕЩЕНИЯ ТВЕРДЫХ ОТХОДОВ

Наталия Чернецкая-Белецкая, Александр Кущенко, Евгений Варакута, Анна Шворникова, Денис Капустин

А н н о т а ц и я : В статье рассматриваются вопросы определения показателя эффективности работы промышленной гидротранспортной системы эвакуации золошлаковых материалов. В качестве, которого предложена величина затрачиваемой гидравлической мощности, отнесенная к массе транспортируемого материала. Исследуется зависимость удельной гидравлической мощности от различных факторов влияния: плотности твердого материала, концентрации гидросмеси, расхода гидросмеси (скорости течения). Проведен анализ полученных поверхностей отклика и составлены рекомендации касательно выбора рациональных параметров транспортирования гидросмесей твердых отходов сжигания угля.

К л ю ч е в ы е с л о в а : гидросмесь, мощность, скорость, концентрация, расход.

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Research of improved mathematical models at operational tests of diesel locomotives

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S u m m a r y . This paper presents the application of mathematical simulation studies at new locomotives operational testing.
The basic specification is determined that defines conditions, procedures, and amount of operational tests. The general procedure of operational tests is defined on the basis of which the ways of models improvement is described. Group of parameters is proposed and formed that describe the operation of traction rolling stock and have to be determined at operation. Goals of operational testing operation are defined, that allows range of control parameters and volumes of works for the gathering of statistical data narrowing. The possibility of improved models using for modernized locomotives operation in concerning new locomotives is determined. The possibility of replacing certain stages of operational tests implementation by mathematical simulation, which provides possibility of the total cost of operation reducing, is determined. The dependence between operational testing goals and control parameters is defined, which are determined during their operation. The dependence between the volume range of control parameters determined during the test and the reliability of their results, which also determines the operation cost, is defined. Benefits of improved operation models application comparing with existing developing diesel traction rolling stock are defined.
K e y w o r d s : diesel locomotives, operational tests, mathematical model, control parameters, test results.

INTRODUCTION

To ensure the transportation process on the railway network of Ukraine and maintaining the technical condition of traction rolling at a high level it is necessary to supply the rolling stock of railway enterprises [1]. It is also necessary to carry out tests after its manufacturing or upgrading. For operational characteristics of the rolling stock determining and verification of the specified values in the technical documentation operational tests are carried out (operational tests - tests carried out at operation [2]). For traction rolling stock they are power consumption, trains weight norms at concrete area, reliability, maintainability etc. Thus, entire group testing, and appropriate corrective actions results are key elements of any development. Undoubtedly, testing is technological process that is planned and provided by all necessary resources and strict technology compliance is quality guarantee, meeting deadlines is the key to success. Technology development and operational on the basis of experience is creative process based on analysis of carried out scientific researches and experimental operations, knowledge of standard base and scientific development trends and forecasts [2, 3]. Without passing the entire test cycle, including maintenance, in accordance with the regulations on the creation, development and production of products, vehicles may not be admitted to regular use, which is associated with the possibility of occurrence of situations that can lead to disastrous consequences, both for locomotive teams, and the entire surrounding space.

In terms of public sector financing and upgrading of rolling stock reducing and the growing trend of railways electrification in Ukraine, the actual question of diesel locomotive buying reduction that by-turn complicates tests financing. However, diesel locomotives are still necessary for rail traffic on diselectrified areas and switching services. With the development of intelligent control hardware and implementation of on-board diagnostic systems and predicting changes of technical condition in new locomotives becomes possible when tested using the accumulated information for further modeling of their work. Way out of this situation is the use of mathematical modeling in the performance tests. This procedure, using mathematical tools of mathematical and statistical methods and forecasting expertise allows forming a mathematical description of physical processes of normal operation test locomotive, or allows you to make assumptions about the acquisition of a test object technical condition stipulated in consequence of his actions. In this case, mathematical simulation makes possible replacing some stages of testing that simplifies and reduces their implementation cost.

MATERIALS AND METHODS

One of the methods proposed for the upgrading of railway rolling stock is existing diesel upgrading with partial or full technical retooling and conduct a number of technical operations for checking and confirmation possible extension of the object. Thus, to assess changes in its condition over the extended life, the various methods those are based on accumulated data for the entire operation and different methods of assessment using various technical and software, both known and individually designed are used [4-6].

According to regulative documents [2, 7-9], which regulate products development and production, locomotives without fail must pass through number of tests, which include operational tests. This type of testing provides verification or identification of all operating parameters established or modernized locomotive that can be achieved at the locomotive work. Testing necessity is noted in [3, 6, 10, 11], which defines the basic principles of General Assessment complex testing and performance testing for critical components including new and modernized rolling stock using control systems to extend their service. In these works is considered in addition to the technical aspects of testing, from the point of view of the changes of the vehicle and the change in value of the life cycle, depending on technical service and operational needs.

As it is shown in publications [11-14], determining the parameters of new locomotives will not necessarily require control of all working parameters list, some of which are fixed at the stage of preliminary tests or using mathematical simulation.

The authors of [15-20] offer wide range of technical state criterions based on multivariate analysis of components using, diagnosing business processes, and mathematical simulation individual processes of interaction and simulation of cost reducing operations. Based on said above and also existing methods that anticipate monitoring and analyzing the full range of traction rolling stock parameters during the operational test, the improved model of their carrying out is formulated [21].

OBJECT OF INVESTIGATION AND PROBLEMS

It is necessary to determine the applicability of advanced mathematical models of operational tests of modernized locomotives for testing new or modernized locomotives to test their technical parameters before admission to regular operation.

From the point of view of necessity of locomotives tests carrying out we need to determine the operational tests types, the volume of sample benchmarks locomotives and models of their carrying out for the possibility of testing the first sample of rolling stock and then sending it into operation. This problem is solved by control parameters optimization using the information obtained from on-board intelligent system management and diesel diagnostics system.

The analysis of procedures for operational testing of locomotives indicates on necessity of determination changes in performance parameters at locomotive run. During any type of performance testing provides total control specified parameter list of the engine according to the established procedure.

To determine the performance of the new traction rolling stock during the type test performance we recommend to use their implementation improved methods. Its feature is the use of a rational nomenclature benchmarks that will control the parameters of the test object changes depending on the test purpose. Thus to evaluate the nodes that are used on other types of rolling stock may use the collected statistical base with regard to design locomotive and operation area.

The following methods were used at locomotive operational tests:

a) methods of statistical information analysis and calculation of their uptime probability and methods of mathematical statistics and probability theory are used to analyze and collect statistics on locomotives work during trials to determine the effectiveness of their use in freight movement on the main railway tracks of Ukraine,

b) numerical methods are used for solving equations of modeling and optimization theory for refinement of structural formulas classification and development to create models operational tests. Analytical and expert methods of comparison are used for targets selection. Methods of heuristic forecasting, iterative and variational calculus are used to fulfill the criteria comparing the results of performance tests of TRS. Methods of statistical results analysis are applied to determine the results of the developed mathematical model of testing performance.

Expert methods of reasonably estimating the operational parameters, methods of predicting resource and diagnostics are used for the task of improving the process of modernized locomotives operational testing.

Methods of statistical simulation based on accumulated statistical data are applied at improving the operational test operation.

Conditional methods of optimization and nonlinear programming methods are used at constructing and verifying the mathematical models correctness (verifying mathematical model adequacy) [22].

Methods of mathematical statistics, theory of locomotive traction and traction calculations are used to determine the fuel and oil discharge for traction trains at operational tests.

Empirical assessing methods for the technical object condition examination are used at assessing locomotive operation working ability.

Existing procedure of operational tests are improved and can be generally described as the next logical consistent steps:

- determining of purpose of TRS operational tests. At this step, the test’s customer (the manufacturer or product’s consumer) determines the desired testing result,

- choosing of type of operational tests. This step involves the installation of concrete type of operational tests according to the conducting purpose,

- evaluation criteria and TRS benchmarks range depending on the purpose choosing. The choice of evaluating test results criteria is made after defining the purpose and determining the operational tests type. The nomenclature of control indexes, which will be monitored and recorded during their implementation, is defined to get data about operational tests and criteria calculation. This procedure provides choosing by qualified expert team the necessity list of work parameters of diesel locomotive examination by exhausting and assessing the impact of each parameter on the total range of tests outcome, which is defined by their purpose,

- creation of operational model, formulating of objective function. Step provides mathematical model of operational testing creating, based on the purpose and definition of criteria for evaluating the test results. Also in mathematical model there is the plan of observing test progress, which will determine the accumulation of reliable data,
- setting limits taking into account control indexes, operational tests operation, statistic data collecting. This step of operational tests operation provides limiting operation according to the purpose of carrying out the test and the plan of observations. After all conditions are provided, tests themselves are carrying out, in which the locomotive is performing certain types of work on the railroad and areas of statistical database is forming,
- analysis and data processing, test results evaluating. After all tests are carried out the evaluation and calculation of indexes starts, which according to the established purpose will give detailed data about the results of their implementation and customer response as for the further effective work of the tested locomotive.

The procedure of operational tests operation is developed as for evaluation criteria and control TRS indexes choosing according to the purpose (Fig. 1). The method of determining the nomenclature of control parameters in order to get the results of operational tests operation of diesel locomotives is improved for this reason, which unlike existing methods considers determining the parameters influence.

It is necessary to define technical and economic parameters in order to describe various parameters of the tested locomotives. Let's grouped them into the corresponding arrays:

$$\Pi_{lok} = \{M_l^{nad}, M_l^{f \cdot pr \cdot}, M_l^{ekspl \cdot}, M_l^{TO,PR}\}, \qquad (1)$$

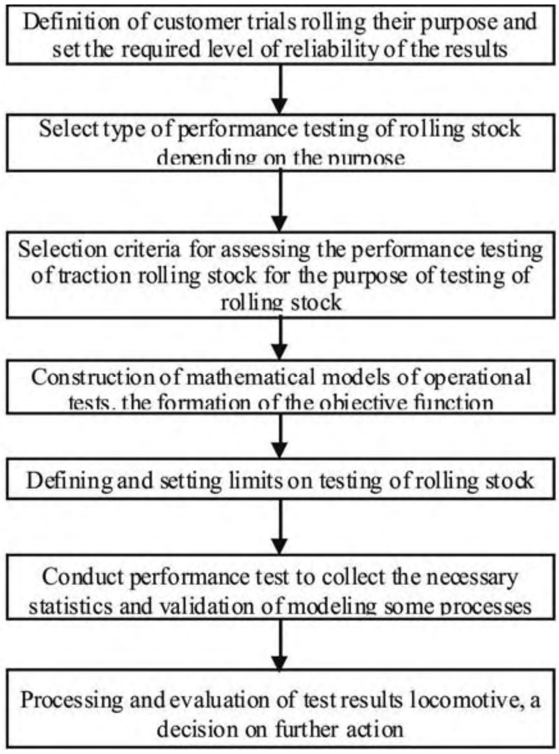

Fig. 1. Scheme performance testing procedure of rolling stock

where: Π_{lok} is the total array of locomotive factors at operational,

M_l^{nad} is array of locomotive reliability. This array includes the next factors: reliability factor, durability factor (average resource, assigned resource, average durability, assigned durability, gamma -percent factor, gamma percent durability), maintainability factor (probability of recovery working condition, average recovery time working condition, intensity recovery), safety indicators (average safety term, gamma-term safety term), complex reliability (coefficient of readiness, operational readiness rate, rate of technical use),

$M_l^{f \cdot pr \cdot}$ is array of functional locomotive purpose. This array includes the following factors: structural speed, power, service weight, changing the load from the axis of the wheel pair on the track, speed of prolonged regime, continued tractive force,

$M_l^{ekspl \cdot}$ is array of operational locomotive factors. This array includes the following factors: the operational locomotive speed, technical speed, operating type works, specified locomotive weight, fuel-power recourses discharge (PER) for locomotive traction, average daily locomotive efficiency, specific PER discharge per unit of performed work, mileage, tractive force,

$M_l^{TO,PR}$ is array of technical operational and repair locomotives factors. This array includes: time cycles of service and operational (TO) and routine repairs (PR), the number of TO and PR cycles, run cycles between TO and PR.

Evaluation of operational TRS tests is performed by composed nomenclature of control work parameters according to the the purpose, tasks and test type. The analytical base of statistic data of tested locomotives is formed on this basis.

The current method of determining the nomenclature of control indicators is based on their definition according to the type of tests by regulations. Improvement of the method of obtaining complete data during operational TRS testing sequence seems necessary processes and consists in determining the range of indicators that are included in the comparison criterion.

Expert ranking methods are used to determine rational nomenclature indicators. Owing to this, their quantitative characteristics are determined normalized to one ordinal grading scale, which determines their order and importance. The ponderability of indexes is determined by the values of ranks that are set by qualified experts at control parameters analyzing, which form the general nomenclature. This procedure consists in determining the priority of indicators monitoring for the type of operational test by experts.

Data collection during the service tests modernized locomotives performed using a combination of statistical methods for input and control methods for quantitative traits, which involves the use of appropriate sampling quality control, based on the application of mathematical statistics to verify compliance with the requirements of product quality and action, and also measure and record the numerical values of the trait for each unit of this group are designed to match with some continuous scale.

The accumulation of statistics and performance sampling test results performed formed range of indicators used to create any expert methods of weight parameters, given that their composition is described by the theory of sets, and then determine their quantitative characteristics for both uniform criteria and carry them to bring one ordinal grading scale, which is determined by the order and the importance of determining characteristics. For installation of a rational nomenclature according to the types of performance tests to determine the weight coefficient of performance. Definite weight ratio would indicate the need for inclusion of quality products (benchmark) to the respective nomenclature.

The methods of determining the weight coefficient of performance include analytical, expert and sociological methods, and methods based on the analysis of the impact of quality products on the effectiveness of its creation and use or consumption.

Determination of parameters of importance in this case is the expert ranking methods. This procedure will determine a rational number of control parameters in a higher weight factor that will influence the result of start-up and will reduce labor content operations to collect data in their testing. Expert ranking method is also used for the distribution parameters into groups according to their importance.

This method consists in placing expert performance engine in order of importance or advantages in weight. Attention is paid to so called rank. It is assigned the highest rank for a more meaningful indicator relating to conduct this type of test.

All involved experts who established the benefits of monitoring indicators in tests in accordance with their beliefs consider the following list of parameters : the duration of the tests of experimental trips , the probability of failure-free operation , technical speed (in loaded , empty and average per trip), volume work (Freight), the total mileage engine during testing average mileage of locomotives during trials, the total fuel consumption, average fuel consumption of the train (train loaded, empty, average per trip), the total consumption of oil, the average weight of the train (in loaded condition, empty , for the trip), productivity (in the loaded condition, empty, on average per trip), the total consumption of sand (for travel and all-time studies), duration of TO-2, the number of TO-2, ran to the TO-2, the coefficient of availability, MTBF, the probability of recovery, the recovery of working locomotive labor content recovery medium term of safety, failure rate, the rate of operational readiness rate of technical applications, construction speed, engine power, mass locomotive change in axle load locomotive speed long regime thrust long mode, normalized weight train duration TO-3, the number of TO- 3, run to the TO-3, duration of PR-1, the number of PR-1 to PR mileage-1, the duration of the PR-2, the number of PR-2, PR mileage to 2, the duration of the PR-3, the number of PR -3, PR mileage to 3.

The procedure for selecting the control parameters of the engine, taking into account the objective function of operational testing - reducing the overall cost of their implementation, can narrow the range of control parameters to the minimum required by the exclusion from the number of parameters that do not appear to meet the primary goal of operational testing and indirectly their characterize and call themselves enough time for a significant portion control and processing parameters that affect the length, volume, which specifies the observation plan and a list of restrictions on the type of operational test in comparison with the existing method, which made establishing a list of all range performance of the engine during testing.

The basic data defining the number of parameters that are relevant groups (range), and the value of the degree of reliability is the weight factor and the number of parameters corresponding to the specified limit entry to the group, respectively. Valuation tests performed on these same parameters.

Forming groups of indicators to determine the degree of reliability indices is as follows:

- Set the value of the weight ratio of control parameters, which should not be exceeded,

- As defined by the coefficient determined by the number of control parameters, perform this condition,

Of the obtained number of indicators and the level of significance of the coefficient determined by the degree of reliability of test results.

Cost of comparative performance tests of serial and modernized locomotive type M62 on economic efficiency is based on the received range of control parameters, test length and the number of people involved.

The calculation of the ranks sum for each object of the assessment is carried out to determine the ponderability coefficients of tested diesel locomotive performance engine performed as follows:

$$S_{ij} = \sum_{i=1}^{n} \sum_{j=1}^{m} x_{ij} \,, \tag{2}$$

where: S_{ij} is sum of ranks of the *i*-th parameter by *j*-th expert,

n is number of considered parameters,

m is number of experts,

x_{ij} is evaluation of *i* factor given by *j* expert.

Determination of weight coefficients *g* of locomotive working factors for testing is based on defined sum of ranks by the well-known formula:

$$g_i = \frac{\sum_{i=1}^{n} x_{ij}}{\sum_{\substack{i=1 \\ j=1}}^{n,m} x_{ij}} \,. \tag{3}$$

The excess of the ponderability coefficient value of the specified value is the condition getting of control indicators to the group.

We use known formula to determine the degree of test results reliability:

$$m = \frac{\sigma}{\sqrt{n}}, \quad (4)$$

where: σ is standard deviation,

n is number of control parameters during operational tests operation, which are in group.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}, \quad (5)$$

where: x_i – analyzed index (the weight coefficient parameter),

$\bar{x}$ – mean values of the group.

The procedure of control parameters choosing of the diesel locomotive work, taking into account the objective function of operational testing – reducing the overall cost of their implementation, allows narrowing the control parameters nomenclature to the minimum required by excluding the number of parameters that do not appear to meet the primary goal of operational testing and characterize them indirectly and need much time for significant portion control and processing parameters that affect the continuity, volume, which specifies the observation plan and list of restrictions on the type of operational test in comparison with the existing method, which made establishing list of all nomenclature of diesel locomotive work indicators at testing.

The results of calculations for convenience has been kept to a Table. 1 and shown in Fig. 2.

Table 1. Determining the reliability of test results and the cost of their implementation by the number of targets

Factor of importance, at least	Number of parameters	Dispersion	Mean-square deviation	The reliability of test results
$\geq 0{,}04$	4	$9{,}17\times10^{-07}$	$9{,}57\times10^{-04}$	0,10
$\geq 0{,}035$	10	$6{,}06\times10^{-06}$	$2{,}46\times10^{-03}$	0,12
$\geq 0{,}03$	14	$1{,}92\times10^{-05}$	$4{,}38\times10^{-03}$	0,25
$\geq 0{,}025$	18	$3{,}11\times10^{-05}$	$5{,}58\times10^{-03}$	0,59
$\geq 0{,}0225$	20	$3{,}84\times10^{-05}$	$6{,}20\times10^{-03}$	0,89
$\geq 0{,}02$	21	$4{,}45\times10^{-05}$	$6{,}67\times10^{-03}$	0,89
$\geq 0{,}015$	31	$8{,}11\times10^{-05}$	$9{,}01\times10^{-03}$	0,89
$\geq 0{,}01$	41	$1{,}02\times10^{-04}$	$1{,}01\times10^{-02}$	0,91
$\geq 0{,}005$	43	$1{,}12\times10^{-04}$	$1{,}06\times10^{-02}$	0,92
≥ 0	45	$1{,}26\times10^{-04}$	$1{,}12\times10^{-02}$	0,92

The dependence of the cost changes of the operational test on volume of control indicators nomenclature is shown by diagram considering the results reliability in these tests (Fig. 2).

The nomenclature of control indicators influence on tests results reliability, which determines their cost and is the reference value at analyzing the results of operational tests and presenting conclusions.

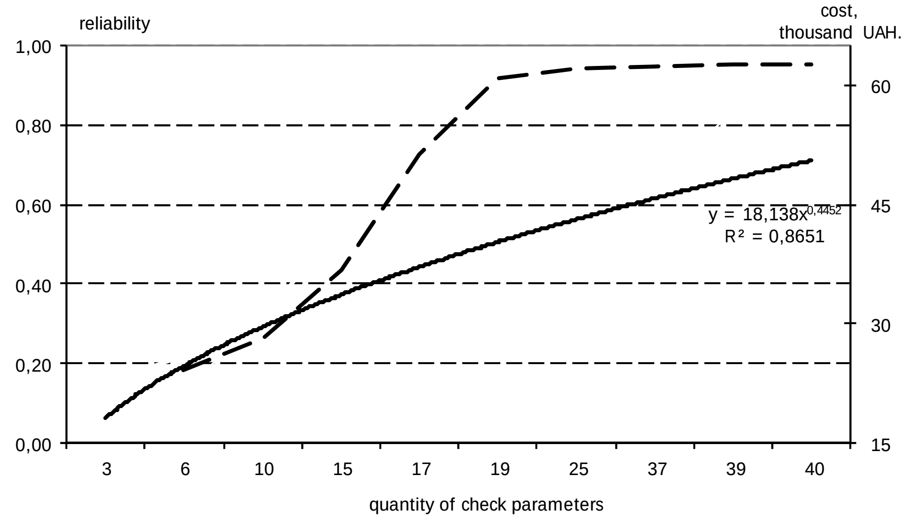

Fig. 2. Dependence of the cost changes of the operational test on volume of control indicators nomenclature

Taking into account the operational tests purpose (definition of technical and economic characteristics of locomotives in operational), and using expert methods, criterion of tests evaluation is chosen. This criterion forms the function of control indicators of tested locomotives and depends on the fuel and oil discharge of diesel locomotives.

The mathematical model adequacy of operational tests on economical efficiency is verified against their implementation cost, shows the error value (Eq. 6) and is less than 0.08:

$$\beta = \frac{1}{N} \cdot \sum_{M_{por}^{pot},\lim} \frac{\left| E_{por.\,\mathrm{M}_{por}^{opt}}^{ekspl.vypr.} - E_{por.\,\Pi_{por}^{isn}}^{ekspl.vypr.} \right|}{E_{por.\,\Pi_{por}^{isn}}^{ekspl.vypr.}}, \qquad (6)$$

where:

β is indicator of mathematical model adequacy,

N is number of tested locomotives,

$E_{por.\,\mathrm{M}_{por}^{opt}}^{ekspl.vypr.}$ is cost of comparative operational tests on the economic efficiency of the developed model, UAH,

$E_{por.\,\Pi_{por}^{isn}}^{ekspl.vypr.}$ is cost of comparative operational tests on the cost-effectiveness according to Program-methodology, UAH.

In such a way we show the steps of mathematical model improving of operational tests operation. Mathematical model universality is confirmed by possibility of its application for a similar locomotives testing of various types, conditions, purposes and limitations, when they match given in the paper purposes.

The advantage of the improved model for new locomotives testing is possibility to use the accumulated statistical database of management systems and locomotive diagnostics, which seems to be very effective data for simulation of standard operational in different modes and determine possible results.

Also very important reason for the use of advanced models is the possibility of purposeful design tests to determine specific, predetermined characteristics that required the customer to decide whether to implement this type of rolling stock.

CONCLUSIONS

1. Using the rational nomenclature of control indicators at operational tests for new or modernized locomotives make it possible to reduce their implementation cost, which also influence on the overall locomotive life cycle cost at the initial stage.
2. The results of investigation make it possible to establish the possibility to use the improved models of operational testing for new locomotives by choosing rational number of controlled parameters, which are determined and monitored according to the testing purpose.
3. The dependence of the accuracy degree of the locomotives operational tests results on the number of control parameters that are allows developing models of operations on the basis of rational nomenclature indicators tests.
4. Operational tests procedure is improved, which takes into account choosing the rational nomenclature of control indicators as well as collection and processing the statistical data on testing itself and its terms.

REFERENCES

1. "UZ" will update the locomotive fleet [E. resource]: - Mode of access: http://society.lb.ua/life/2012/11/16/179218_ukrzaliznitsya_sleduyushchem_godu.html. (in Russian).
2. **GOST 16504 - 81** The system of state testing products. Testing and quality control. Basic terms and definitions [text]. - Instead of GOST 16504-74, introduced. 1982 - 01 - 01. - Moscow: Interstate. Sonnet Standards: Standards Press, 1981 . – 29. (in Russian).
3. **Nazarov O.N., Kobzev S.A., 2009.:** Tests of railway equipment: Market Trends and Prospects // Railway transport. Moscow - 2009, № 3. 20-25. (in Russian).
4. **Gorobec V.L., Sawin V.L., 2004.:** Theory and methods of extending the life of rolling stock [Text] // Problems of railway transport. Dynamics, durability and safety of movement of rolling stock: XI Intern. Conf. Dnepropetrovsk 26-29 May 2004 - D: DIIT , 2004. – 67. (in Russian).
5. **Gorobec V.L., Zaitsev V.A., 2005.:** Methods of assessment and service life of locomotives Ukraine [Text]// The introduction of high technologies on the trunk and industrial transpor: II Scientific -

practical. Intern. Conf. Alushta, 5-9 June 2006 - Alushta: DIIT – Dneprotehtrans, – 7. (in Russian).
6. **Domin R. Y., Dmitriev D.V., 2004.:** Performance testing of automated current control running parts of passenger cars [Text] (abstracts of scientific and practical. Conf.) // Problems and prospects of development of transport systems: engineering, technology, economics and management. - Kyiv. 2004. – 35-36. (in Ukrainian).
7. **DSTU 32.0.08.001-97.** Procedure for developing and putting into production of products for the needs of railway transport in the Ministry of Transport of Ukraine [text]. - Enter. 1999-05-10 - Kyiv: Ukraine Industry Standard: Ministry of Transport of Ukraine, 2000. I, 96 p. (in Ukrainian).
8. **GOST 15.309-98.** Testing and acceptance of the products. The main provisions [text]. - Enter. 2000-06-02 - Kyiv: State Standard of Ukraine: Standards Press, 2000. IV, 18. (System development and launch of new products). (in Russian).
9. **GOST 32.53-96.** The organization and procedure of acceptance and certification tests of traction rolling stock [text]. - Enter. 1996-07-01. - Moscow: Russian State Standard: Standards Press, 1996. - IV, 16. - (The test system rolling stock). (in Russian).
10. **Grishchenko S.G., 2010.:** Approvals modernized and new rolling stock // Lokomotiv- Inform. H.: "Technostandart" – 2010, № 3. 18-21. (in Russian).
11. Spacium ready for testing [Text] // Railways of the World - 2009, № 3, 31 - 36 (According to the company Bombardier Transportation). (in Russian).
12. **Stolz T., 2011.:** The new shunting locomotives railways of Switzerland. - Chemins de Fer, France, 2011, № 527, 28-31.
13. **Stoltz T., 2012.:** Innovative locomotive Eem 923 Swiss Federal Railways. - Chemins de Fer, France, 2012, № 532, 9.
14. **Krivosheya Y.V., V.I. Doroshko, Gatchenko V.A., 2009.:** Improving the performance of shunting locomotives by improving the management of diesel-generator set // Proceedings of UkrDAZT. – 2009. – № 108. 60-64. (in Russian).
15. **Zbigniew Burski, Joanna Tarasińska, Romuald Sadkevič, 2003.:** The methodological aspects of using multifactoral analysis of variance in the examination of exploitation of engine sets / TEKA Komisji Motoryzacji i Energetyki Rolnictwa III. 45-54.
16. **Mieczysław Dziubiński, 2003.:** Model testing of the diagnostic process / TEKA Komisji Motoryzacji i Energetyki Rolnictwa III. 91-98.
17. **Yuriy Yu. Osenin, Igor I. Sosnov, 2011.:** Mathematical modeling of the unstationary friction interaction of the working elements of the locomotive disk brake / TEKA Kom. Mot. i Energ. Roln. - OL PAN, 11B, 111-120.
18. **Valeriy Starchenko, Vitaliy Pogidaev, Anastasiya Kolyakina, Nataliya Ishchenko, 2011.:** Mathematical model to minimize operating costs / TEKA Kom . Mot. i Energ. Roln. - OL PAN, 2011 , 11B, 177-184.
19. **Aleksandr Golubenko, Yelena Nozhenko, Valentin Mohyla, 2011.:** The simulation of the operation of diesel locomotive d49 when using the ozonized fuel / TEKA Komisji Motoryzacji i Energetyki Rolnictwa XC. Commission of Motorization and Power Industry in Agriculture.
20. **Kononenko I.V., Kolesnik M.E., 2013.:** Model and the method of multi-criteria optimization project content with fuzzy input data / East European Journal of advanced technology Kharkov: Technology Centre , № 1/10 (61). 9-13. (in Russian).
21. **Zenkovsky A.M., Kamchatny O.V. Bragin N.I.,2012.:** Optimization models of operational tests modernized locomotives M62 type on the performance [Text] / Bulletin of the Volodymyr Dahl East-Ukrainian National University. - № 5 (176). Part 2. – 11-15. (in Ukrainian).
22. **Polovko A.M., Gurov S.V., 2006.:** Fundamentals of reliability theory [Text], - 2nd ed., Rev. and add. - St. Petersburg.: BHV - St. Petersburg, 2006. – 706. (in Russian).

ИССЛЕДОВАНИЕ ПРИМЕНЕНИЯ УСОВЕРШЕНСТВОВАННЫХ МАТЕМАТИЧЕСКИХ МОДЕЛЕЙ ПРИ ПРОВЕДЕНИИ ЭКСПЛУАТАЦИОННЫХ ИСПЫТАНИЙ ТЕПЛОВОЗОВ

Анатолий Фалендыш, Артем Зиньковский, Никита Брагин

Аннотация. В статье представлено исследование применения математического моделирования при проведении эксплуатационных испытаний новых тепловозов.
Установленный основной перечень нормативной документации, определяющей предпосылки, порядок и объемы проведения эксплуатационных испытаний. Определена общая процедура проведения эксплуатационных испытаний, на основе которой установлены пути совершенствования моделей их проведения. Предложен и сформированы группы параметров, описывающих работу тягового подвижного состава и должны определяться в ходе испытаний. Определены цели проведения эксплуатационных испытаний, что позволило сузить номенклатуру контрольных параметров и объемы выполняемых работ по сбору статистических данных. Определена возможность применения усовершенствованных моделей проведения испытаний модернизированных

тепловозов в отношении вновь созданных локомотивов. Установленная возможность выполнения замены некоторых этапов эксплуатационных испытаний математическим моделированием, что обеспечивает возможность сокращения общей суммы затрат на проведение испытаний. Исследована зависимость между целью эксплуатационных испытаний и контрольных параметров, которые определяются во время их проведения. Установленная зависимость между объемом номенклатуры контрольных параметров, определяемых в ходе испытаний и достоверностью их результатов, также определяет цену проведения испытаний. Определены преимущества применения усовершенствованных моделей проведения эксплуатационных испытаний над существующими при применении для дизельного тягового подвижного состава, который разрабатывается.

Ключевые слова: эксплуатационные испытания тепловозов, математическая модель, параметры управления, результаты испытаний.

Equipment selection and modernization for producing flour products of whole-grain wheat with mollusc hydrolyzate additive

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S u m m a r y . The main types of equipment used for dispersing grain paste are analysed in the article. Popular brands of grinding equipment of both home and foreign manufacture are investigated. Guidelines concerning equipment selection for producing flour products of whole-grain wheat with the mollusc hydrolyzate additive are given.
K e y w o r d s . Industrial meat grinder, cutter, hasher, grain paste, mollusc hydrolyzate.

INTRODUCTION

The concept National Policy of Ukraine in the direction of healthy nutrition includes the following directions of work in the case of foodstuffs: improving the quality, broadening the range, improving the nutritional value and flavor advantages of baked goods.

The solution of this problem is possible in those enterprises of public catering and restaurant business, where the factory is equipped with modern appliances, use of new energy saving technologies.

Baked goods are the key foodstuffs in the diet of most people. Therefore the number of companies involved in baked goods' production is constantly increasing at the domestic market and consequently the competition in this sector of food industry is going up too [2, 1]. To improve profitability of the production it is necessary to raise the demand for our goods and the introduction of new sorts and kinds of baked goods into the market favours it. Flour products made of whole-grain wheat can be referred to these goods which are able to bring an extra profit to the production. Whole-grain baked goods have gustatory properties new for the consumer and enhanced content of healthy ingredients, they also have high nutritive value. These goods have found their consumer very quickly in spite of their price which is considerably higher than that of an ordinary loaf of bread. The popularization of healthy life-style has done a lot to make the goods popular as the flour products made of whole-grain wheat have become its integral part in respect of food [3].

RESEARCH AND PUBLICATION ANALYSIS

Since ancient times, grain production and its processing has an important influence on the people's lives. Grain is a natural source of starch, protein, vitamins and other biologically useful compounds, which are essential in the human diet [4, 5].

Given that in our country bread is a one of staple food, the task of reducing the energy value of bakery products and enrich their dietary fiber, vitamins and minerals is important and relevant.

The most effective and economically feasible solution to this problem is the development of technologies of bread from a whole (dispersed) grain, which can significantly increase the nutritional value of products through conservation peripheral layers of the grains [19].

The increase in production and expansion of assortment of grain bread indicate the prospects of this technology In this case improving the quality and safety of grain baked goods is a very important [11, 10, 27].

New technologies of grain processing provide for removal of coats, a germ and aleurone layer when being ground that allows to increase the consumer value of the goods but it decreases their nutritive value because the bulk of vitamins, microelements and dietary fibers are removed with these anatomic parts [7, 20, 22]. Besides a great number of research works of the following famous scholars (L.Ya. Auerman, A.N. Bakh, A.B. Vakar, E.D. Kazakov, N.P. Koz’mina, V.L. Kretovich and others) are dedicated to the problem of efficient grain material use [13, 12, 15].

Today bakery production has taken extensive industrial scale. In the search for ways to increase the assortment of baked goods, large bread factories and small bakeries turned their attention to the modern bakery equipment.

Modern bakery production is characterized by a high level of mechanization and automation of technological processes, the introduction of new technologies and the constant expansion of assortment of baked goods, as well as the development of low power companies of different ownership forms. In order to properly organize the production and to produce competitive products it is necessary to take into account modern trends in baking, to modernize production in time, to expand its range [14, 16].

Food equipment producers offer lines capable of producing whole-grain baked goods. The equipment enables us to prepare the grain (to shell the outer layer of fruit coat and mineral mud), to drive the grain to the germination stage (activation), to make fine-dispersed grain paste which is the bulk of the dough. Unfortunately this type of equipment is not all-purpose and it cannot make ordinary baked goods and modern producers of these goods dislike it [6, 18, 17].

There is not sufficient information concerning ways of intensifying the process of preliminary preparation of wheat grain, purposeful regulating of the properties of semi-finished goods and the food value of baked goods made of whole-grain wheat in the literature [25, 28, 14].

OBJECTIVE AND PROBLEM FORMULATION

The producers expand the range of baked goods by using ready-made mixtures and additives for production of non-traditional sorts, for example, grain products. These baked goods are made according to the traditional technology mostly in a speeded up way with the use of up-to-date equipment.

The objective of our article is to analyse the tendencies of using the equipment which is used at the stage of dispersing grain and to give some guidelines concerning the equipment selection for producing flour products of whole-grain wheat with the mollusc hydrolyzate additive according to the innovative technology.

PRINCIPAL CONTENTS

Whole grain has a high biological value. In such grain is awakening the forces of germinal organism, is activating enzymes, all the substances, contained in the whole grain, are stored in their native state, including dietary fiber, shell and germ, vitamins, amino acids, minerals, protein.

All the elements of whole grains are easily digested. Its use has no side effects, leads to the normalization of metabolism and weight loss in overweight people.

It should be noted that besides useful properties for the human body, whole grain products are another valuable benefit - a significant reduction of its production costs as compared with traditional technologies.

In the production of grains baked goods, grain refinement process is one of the main. The degree of grain refinement effects on the sensory evaluation of the finished product: appearance, looseness crumb sensation when chewed.

Grain grinding is one of the most power-consuming operations. A new technology of producing flour products has been developed by us where in order to reduce power inputs watering of grain for 48 hours in liquid phase before dispersion has been offered.

Machine-instrumental scheme of production baked products from whole grains of wheat in restaurant industry is shown in Fig. 1.

In general technological scheme of production baked products from whole grains of wheat comprises the following steps:

1 – Preparation of grain to soak,

2 – soaking grains in liquid phase during 48 hours,

3 – grain refinement in an industrial grinder (or hasher),

4 – dough kneading,

5 – fermentation of dough,

6 – forming dough,

7 – baking flour products,

8 – cooling of finished products,

9 – storage and sale.

Industrial grinders as equipment for dispersing the grain paste in the restaurant industry have been offered by us.

An industrial grinder plays one of the main roles in the professional kitchen. Having high capacity the grinders are very space-saving, they do not require special skills and are very easy in handling. They are widely used at meat-processing shops, in sausage and fish production, at public catering establishments and in household use. A grinder is an electromechanical or mechanical device for processing meat into homogeneous ground meat. The electric grinder has much higher capacity in comparison with the manual one. Any mechanical grinders in addition to the function of protecting the motor from overheating have the reverse function [9, 21, 26].

Let’s consider some makes of grinders which can be used for dispersing the grain paste:

– MIM 300 (600) (Belarus) – the capacity of the grinder is 300 (600) kg/h. Grinders of desktop type for being connected to a three-phased network of alternating current. This is the most widespread and time-tested at different public catering establishments machine which is worth an excellent mark according to its reliability and performance quality.

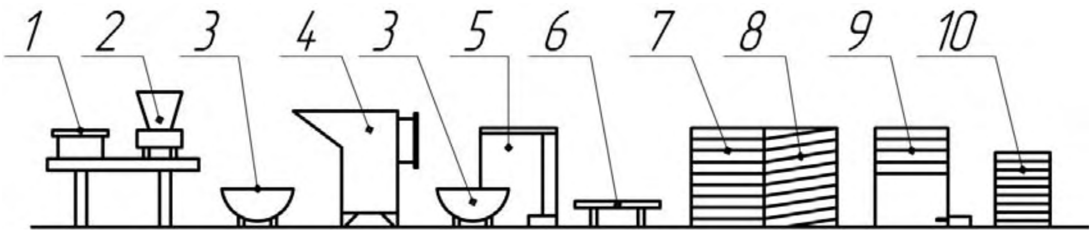

Fig. 1. Machine-instrumental scheme of production baked products from whole grains of wheat in restaurant industry: 1 – hand sieve, 2 – scales, 3 – bowl, 4 – grinding mechanism (or hasher), 5 – dough-mixing machine, 6 – production table, 7 – trays, 8 – equipment for proofer of dough pieces, 9 – equipment for baking products, 10 – shelving unit of finished product

Grinder MIM-300 is made of stainless steel with an aluminium-body cutter. Its two-button control is located on the side face of the machine. The engine is almost noiseless and has a worm reducer ensuring smooth and uniform operation of the machine and considerably reducing the necessity of making adjustments and routine maintenance. The system of replaceable knives of different modification is used with the help of which it is possible to choose the best variant for obtaining grain paste of different grinding degrees. The stationary safety device installed above the feeding hole eliminates the possibility of the maintenance staff's hands touching the screw of the operating grinder.

The main technical parameters of the grinder MIM - 300 as follows:

1) Productivity - 300 kg / h,

2) auger rotational speed - 250 rev / min,

3) external diameter - 82 mm,

4) the lattice number 1: the diameter and number of holes - 3 mm/217,

5) the lattice number 2: the diameter and number of holes - 5 mm/90,

6) Power - 1.0 kW,

7) Voltage - 380 V,

8) Weight - not more than 48 kg.

– Grinder Everest TC 8-2000 (Italy). These grinders are light owing to their body made of aluminium. Operational parts and those coming in contact with wheat grain are made of food stainless steel. The noiseless engine of the grinder has an oil-bath reducer. It doesn't need any special maintenance and it is guaranteed to operate without any problems for a long time.

Cutting set Salvinox "Enterprise System" consists of a screw, a blade and cast-iron gratings. Self-sharpening blades ensure the best grinding of wheat grain. Everest Equipment is easily disassembled and therefore its cleaning becomes extremely easy. Some parts of the grinder (for example, its screw, blade, grating and feed hopper) can be washed in a dishwashing machine.

The most popular make of Everest grinder is TC 8. These grinders can process up to 30 kg/h. Grinders of this type are good for small restaurants, cafes, cafeterias and shops that have not too many clients.

Specifications grinder following:

1) Power - 0.37 kW,

2) Voltage - 220 V,

3) blade system - ½ Unger (1 knife + 1 pound),

4) Weight - 12 kg.

- Grinder Kenwood MG720 (UK). One of the most powerful of those that are produced by the company. It can easily handle a minute with 3 kg of soaked grains, transforming it into grain mixture. Can run on two speeds and in reverse. Operating sleeve and grille made of the increased diameter. This improves performance grinder. Grinder has a power 2 kW, voltage - 220 V, productivity - 180 kg / h.

- Grinder professional SIRMAN TC 32 COLORADO.

Grinder SIRMAN TC 32 COLORADO with reversing and professional working characteristics are used in restaurants, small public catering establishments, coffee shops, mobile shops and kitchens.

Corps SIRMAN TC 32 COLORADO completely made of stainless steel. Productivity SIRMAN TC 32 COLORADO is high - it is able to crush up to 400 kg of soaked grains per hour. For continuous use apply powerful Standard motor IP 55. Reducer is in the oil bath with toothed wheel, with a double system of protection from liquids quickly attached to the neck without tools.

Node grinding is completely made of stainless steel, can be easily disassembled for cleaning. Removable hopper with lock (32 CE). User Controls 24 volts with reverse (CE).

Options:

- The safety interlock system for use lattices with holes> 8 mm.

- Openings for partial or complete system "Unger".

- Controls stainless steel IP 67.

Grinder SIRMAN are easy to operate and manage. Durable and reliable, easy to disassemble, which facilitates cleaning and maintenance. Occupy a minimum of space.

The set includes a lattice of stainless steel with a diameter of 6 mm and a self-sharpening stainless steel blade.

We suggest using hashers and cutters as equipment dispersing the grain paste at enterprises of food industry.

Hashers are intended for medium and fine grinding of input materials.

The main parts of a hasher are a drive unit, feeding and grinding mechanisms. The feeding mechanism has a feeding box in which there is either an installed feeder (forced feed) or there is not any (input materials are loaded in a self-flowing way).

The grinding mechanism of hasher can be conical, parallel and plane. The latter has become the most widespread. This has been caused not only by convenience and quickness of its maintenance but by the possibility of executing step-by-step grinding and also by simplicity of its manufacture and its reliable performance. It is represented by an interchange of stationary gratings and rotating knives.

The grinding mechanism consisting of takeup, intermediate and output gratings, double-sided and one-sided multiblade knives is the most widespread one. The design peculiarity of a grating instrument is the form and size of holes representing annular cutting rims. The speed of the material outflow and the quality of its grinding depend on the diameter of the holes. The form of the holes can be round, square, oval, bean-like with faceting or without it, etc. Three- and four-bladed, solid and compound knives with one-sided or double-sided sharpening, with straightline or curvilinear cutting rims are used.

The drive unit of a hasher is electromechanical. It can be common and separate for feeding and cutting mechanisms, one- and multiple-speed according to its design. The application of separate drive is connected with stating different cutting rates of the feeding and cutting mechanisms' operation depending on the properties of the material to be ground.

The diameter of the grating is considered to be the main technical feature. Hashers for grinding soft meat material with 112, 114, 120, 160 and 200 mm grating diameters are mostly used.

The most popular hashers nowadays are as follows:

– Single-screw hasher LPK-1000 V. It is intended for non-stop grinding of the grain paste. Its widespread use is connected with the following advantages: high capacity, simplicity of the main mechanism design, easiness of assembling and disassembling for sanitization, ease of use and reliable performance.

All case parts including the frame and lining panels are made of stainless steel.

Technical Specifications of the hasher are:

productivity – 1100 kg / h,

bootable volume bowl - not more than 135 liters,

nominal diameter of the outlet lattice – 114 mm,

installed power - no more than 9 kW,

weight of the hasher – 443 kg.

– Hasher MP-160. Its compact size, medium load height and high reliability are the main advantages.

The height of charging hopper will allow booting using a lifting device and manually. Hasher is equipped with all accessories necessary for operation. A wide range replaceable lattices provides a grain mixture of different degree of crushing.

Technical Specifications of the hasher are:

productivity – 3000 kg / h,

bootable volume bowl – not more than 70 liters,

nominal diameter of the outlet lattice – 160 mm,

installed power – no more than 15 kW,

weight of the hasher – 815 kg.

- Hasher K6-FVP-160 is designed for continuous grinding of the grain mass.

Hasher: K6-FVP-160 is used for secondary and fine crushing. During operation hasher has several technology advantages, such as a hasher MP -160, namely:

• high productivity,

• simplicity of design basic mechanisms,

• ease of assembly and disassembly for sanitary treatment,

• ease of use,

• reliability.

Technical Specifications are:

productivity – 4000 kg / h,

bootable volume bowl - not more than 270 liters,

nominal diameter of the outlet lattice – 160 mm,

installed power - no more than 32.2 kW,

weight of the hasher – 1200 kg.

Dispersing gives the opportunity to improve consumer properties of finished products. Such grinding completely exclude the presence larger solid particles of grain.

Grain mass becomes homogeneous and free from solids particles of grain after processing in a grinder or a hasher. At chewing crumb flour products whole grain wheat is fully consistent crumb of bakery products made from flour.

The use of cutters, which are used in shops for the production of sausage products is particularly interesting for the fine grinding of the grain mass.

In the processing in cutter the grain mass finely crushed and transformed into a homogeneous smooth paste.

Machine-instrumental scheme of production baked products from whole grains of wheat using the cutter is shown in Fig. 2.

When using a cutter in the processing line according to our technology there is no necessity to use dough-mixing machines as the cutter both disperses and mixes the grain paste. Are very popular with Russian and Ukrainian buyers. Electrolux concern [8]:

- Cutters of the French company Robot Coupe.

The cutter consist of structure on which are mounted its main parts:

bowl, which rotates on a vertical shaft and is intended for supplying a product under the knife,

cutterhead comprising a set of knives (usually two or more units) for cutting the product and mixing,

motor.

Cutters Robot Coupe developed to prepare thin mincemeats, whipped cream, emulsion, for grinding and kneading dough in the shortest possible time, and for chopping, ensuring high quality of the final product. They are compact, low noise, equipped with powerful ventilated motors, which provide efficient work even with meat and dough. Direct drive without a belts or Gearwheels transmission provides a maximum power. With using the convenient and ergonomic handles bowl cutter can be moved with one hand. All working parts of the device are easy to clean. We propose to use these cutters for chopping soaked grains.

Robot Coup offers the most complete range of desktop cutters with bowls the volume between 2.9 and 60 liters [24].

Advantages cutters Robot Coupe:

Accuracy. Pulsation mode improves accuracy of cuts. Some models have an adjustable rate that provides a variety of uses and a wide selection of prepared dishes.

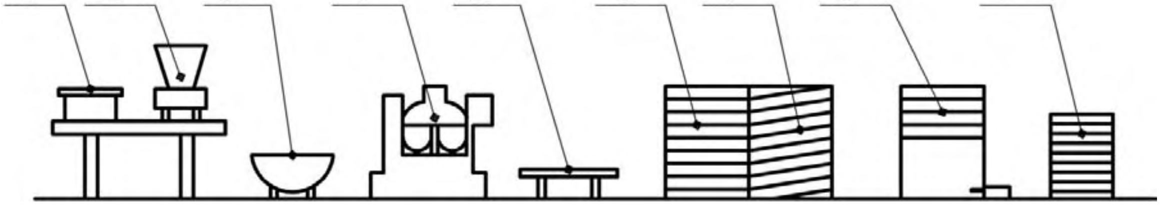

Fig. 2. Machine-instrumental scheme of production baked products from whole grains of wheat in food processing industry: 1 – hand sieve, 2 – scales, 3 – bowl, 4 – grinding cutter, 5 – production table, 6 – trays, 7 – equipment for proofer of dough pieces, 8 – equipment for baking products, 9 – shelving unit of finished products

Low rise blade can operate effectively even with a small amount of the product.

Induction motor, which is designed for intensive work is characterized by high reliability and durability.

Effective system of protection in all models: When opening the cover machine is switched off. Also has a function of forced stoppage of the knife.

Models cutters from R8, have additional accessories to create a vacuum in the bowl as you work [23]. This improves the quality of the final product.

Speed of base models is 1500 rev / min, and it is the most effective arrangements for majority of products. Models with additional speed 3000 rev / min (from R4) reduce the cooking time twice and give a greater degree of grinding.

Models with an index V.V. equipped with a smooth control of speed from 300 to 3000 rev / min, individual models – from 50 to 3000 rev / min. (R10V.V.).

- Cutters Italian brands Sirman, Fimar, Mastro and Gam.

Cutters of these brands can split up (nuts, crackers, chocolate, and even knead dough as the dumplings), chop meat (large chopped, finely chopped and chopped whipped mass), grind any food (onion, dried apricots, prunes, crab sticks, squid, boiled meat, cheese, boiled eggs and grains, etc.).

The grinding depends on the time work, so the cutter is easy to form a product of fine grinding (chopped whipped mass, soufflés, pates).

Knives-nozzles are made of solid steel with a wavy blade, which is subject to heat treatment.

For continuous operation, the cutter is used high-ventilated motors.

The motor and bowl are located nearby, allowing you to isolate heat from the processed product.

The speed variator enables control power.

The system of double microswitch on the cover ensures safety level when conveying the cutter.

Cutters Italian brands Sirman, Fimar, Mastro and Gam are widely popular among chefs of restaurants, cafeterias, pastry shops, due to its reliability, stable operation.

Concern Electrolux (Italy) offers cutters under the brand name Dito-Electrolux. It aggregates one-and twospeeds or continuously variable speed blades. All models cutters are arranged on the tables. They are structurally similar and consist of two parts: a durable aluminum frame and stainless steel bowl with a clear plastic lid. Inside the enclosure is an electric motor that spins the blade shaft. Cutters are equipped with smooth or serrated knives. As accessories are offered special knives, scrapers for mounting on cover, coasters made of stainless steel.

Several cutters are unique in its characteristics. For example, in aggregates of K 45/55/70 useful volume of the bowl is 75% of the rated value - today it is the largest on the market, the volume of real holding capacity of this class of cutters. Aggregates in this series are equipped with a powerful asynchronous motor that can withstand continuous operation in a professional kitchen. The frame is made of aluminum in order to effectively dissipate the heat working motor. Because of this motor requires no additional cooling system (including ventilation slots in the bottom of the frame, through which moisture can get into the electrical components). All models with adjustable speed maximum speed is increased to 3300 rev/min.

Cutter Dito-Electrolux K series can be used not only in a professional kitchen, but also in health care and child care centers to prepare meals for special diets and diet menus [29]. These units are designed for crushing the solid ingredients, for the preparation of meat and minced pates, for mixing and emulsifying sauces, mousses, for pureeing of cooked and raw vegetables, including those of raw carrots and raw red cabbage, which, being hard and fibrous products, are considered to be complex for uniform grinding.

Cutters Dito-Electrolux feature button pulsed mode, which is necessary for grinding solid products in the initial stage of crushing and at the final stage, for any product.

Operator safety is guaranteed by the limit switches and safety devices. Motor can not be started if the cover of cutter is open, or if the bowl is missing or incorrectly installed. When the cover is opening, the motor stops, which guarantees the safety of the operator and protects him from splashes.

We consider that this brand cutter ideal for grinding soaked grains.

The brands Celme (Italy), JEJU (Taiwan), LA FELSINEA (Italy), YAZICILAR (Turkey) and Torgmash (Belarus) are less popular but nevertheless they are well bought too.

A series of professional cutters satisfies the needs of any modern kitchen in a short time.

CONCLUSION

1. Based on analysis of equipment for the production of whole-grain wheat from whole grain of wheat we concluded that it is preferable not to use a specialized line but a multibusiness line equipment, which enables to produce several types of farinaceous products, including bakery products from whole grain wheat.

2. A promising direction for the production of grain products is the use of conventional equipment for the processing of the other raw materials, such as meat.

3. We have developed a new technology of bakery products from whole grains wheat, which allows the use of traditional equipment meat industry with a minor modernization for the production of baked goods.

4. Based on the literature review, we proposed to use lattices of holes with a diameter of 5 mm and 3 mm in the hasher and in the industrial grinders as the upgrading equipment for grind the grain mass..

5. For the production of bakery products from whole grains of wheat should be used or hasher (industrial grinder) together with the dough-mixer machine or should be used cutter that allows to conduct grinding and mixing operations on the same machine.

REFERENCES

1. **Apet T.К., Pashuk Z.N., 1997.:** Bread and bakery products (Technology cooking, recipe, baking): reference guide. – Mn.: LLC «Potpourri». – 320.
2. **Arsenyeva L.Yu., 1987.:** Development of technology for bread flour with low gluten content by using hydrophilic additives: diss. Ph. D. – К. – 17-20. (in Ukrainian).
3. **Auerman L.Ya., 1984.:** Technology bakery production. **-** I.: Light and food industries. – 66-67. (in Ukrainian).
4. **Belyaev M.I., 1990.:** Catering equipment. In 3 volumes V. 1 – Mechanical Equipment. – M. Ekonomika. – 559. (in Russian).
5. **Bernardin J., 1980.:** The rheology of concentrated gliadin solution. CC, 52, 3, p. II. – 136-145.
6. **Bratersky F.D., 1994.:** Enzymes grain.– M.: Kolos – 196. (in Russian).
7. **Cherevko A.I., Popov L.N., 1988.**: Catering equipment. In 3 Vols. – V. 2. – Trade and technological equipment. – M. Ekonomika. – 271. (in Russian).
8. **Chizhov K.N., 1973.:** Protein gluten and its transformation in the process of baking. – M.: food industry. – 135. (in Russian).
9. **Deynichenko G.V., Efimova V.A., Postnov G.M., 2003.:** Catering equipment. Reference to 3. parts. – part 1. – Kharkov. – "The world of engineering and technology". – 256. (in Ukrainian).
10. **Drobot V.I., 2002.:** Bakery Production Technology. – К.: Logos. – 149-155. (in Ukrainian).
11. **Grishin A.S., Enkin L.S., 1974.:** Effect of different methods on the quality of bread testoprigotovleniya. – M.: food industry. – 111. (in Russian).
12. **Karnaushenko L., Shevchenko P., 2000.:** Practical application of protein isolates in bread // Bakery products, № 9. – 19-20. (in Ukrainian).
13. **Kavetsky G.D., 2006.**: Technological processes and production (food) [Text]. – M.: Kolos. – 368. (in Russian).
14. **Kirpichnikov V.P., Leenson G.H., 1990.:** Directory of mechanics. Catering. Moscow: Economics. – 382. (in Russian).
15. **Kretovich L., 1991**.: Biochemistry of grain and bread. Moscow: Nauka. – 136. (in Russian).
16. **Leonov I.T., Chupahin V.M., 1965**.: Mechanized and automated production lines. **-** Moscow: Food Industry. – 28-30. (in Russian).
17. **Machikhin S.A., Katznelson Y.M., Mikhailenko V.G. etc., 1988.:** Intensification of bakery production – M.: TsNIITEIhleboproduktov. – 64. (in Russian).

18. **Matveev I.V., Belyavskaya I.G., 2001.:** Food additives and bread improvers as pastry. – M.: Publ MGUPP. – 115. (in Russian).
19. **Mokshina O., Riabchykov M., 2012.:** Prediction of quality of sewing department under unsteady operating mode change. Teka // Lublin university of technology, Vol.12, № 3. – 109-113.
20. **Neznanov N.A., Talantov V.N. etc., 1992.:** The intensification of the maturation process for semi-wheat bread-based regulation of biotechnological properties of baker's yeast. – M.: TsNIITEIhleboproduktov. – 28. (in Russian).
21. **Riabchykov M., Chelysheva S., Voloshina O., Mokshina O., 2013.**: Thermomechanical polymer material molding techniques. Teka // University of Engineeryng and Economics in Rzeszow, Vol.13, № 4. – 208-218.
22. **Safonov O.N., Pepper F.V, 2000.:** System studies of food processing technology. – Kharkiv, 193. (in Ukrainian).
23. **Shcherbakov V.G., Lobanov V.G., Prudnikova T.N., 1999**.: Biochemistry of plant material. – M.: Kolos, 376. (in Russian).
24. **Shlelenko L.A., 2006.:** The bread in healthy eating / [Electron. resource], access mode: http://www.gosniihp.ru/17.htm
25. **Skuratov O.D., 2002.:** Product quality control of physical and chemical methods. 1. bakery products. – M.: DeLee. – 100. (in Russian).
26. **Tsiganova T.B., 2001.:** Technology bakery production. – M.: Kolos. – 430. (in Russian).
27. **Uleysky N.T., Uleysky R.I.**, 2000.: Mechanical and thermal equipment catering. Rostov n / D: Phoenix. – 33. (in Russian).
28. **Usembaeva J.K., 1999.:** Biotechnology regulatory framework and the intensification of bakery production with new raw materials: diss…Doct. Techn. Science. – M. – 626. (in Russian).
29. **Zolin V.P.**, 2000.: Technological equipment catering. – Moscow: IRPO, Academy. – 20. (in Russian).

ПОДБОР ОБОРУДОВАНИЯ ДЛЯ ПРОИЗВОДСТВА МУЧНЫХ ИЗДЕЛИЙ ИЗ ЦЕЛЬНОГО ЗЕРНА ПШЕНИЦЫ С ДОБАВКОЙ ГИДРОЛИЗАТА ИЗ МОЛЛЮСКОВ

Инна Дейнека, Елена Киреева,
Дмитрий Крамаренко

Аннотация. В статье проанализированы основные виды оборудования, которое можно использовать для диспергирования зерновой массы. Исследованы популярные марки оборудования для измельчения как отечественного так и зарубежного производства. Даны рекомендации по подбору оборудования для производства мучных изделий из цельного зерна пшеницы с использованием гидролизата из моллюсков.

Ключевые слова. Промышленная мясорубка, куттер, волчок, зерновая масса, гидролизат из моллюсков.

Improving the means of experimental determination of dynamic loading of the rolling stock

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Summary: The article presents the results of research on the mobile control system running tests and dynamic diagnostics of rolling stock.
Key words: Means of test controller, test control, technical diagnostics.

INTRODUCTION

The rolling stock of railways, being in the process of production, exploitation or repair, is characterized by certain, apt to the changes technical properties on that it is possible to estimate the state of object by realization of warranty and control tests.

In the process of exploitation, a rolling stock, as well as any difficult technical system, is apt to the refuses reasons of that can be: violation of technology of making of separate elements, heavy external environments, and failure to observe of norms of technological processes of loading, unloading and transporting of loads, aging and wear of knots. For this reason important and an actual task is introduction on the railways of Ukraine of the periodic proof-testing and dynamic diagnostics of units of rolling stock during all life cycle [9].

To that end in SE "DNDC UZ" a study on development of the mobile system of the working proof-testing and dynamic diagnostics of units of rolling stock is undertaken.

ANALYSIS OF PUBLICATIONS

Modern progress of measuring technique trends give wide market abilities of new instrumental approaches for the estimation of dynamic internals, terms of safety of motion of trains and operative acceptance of measures on warning of emergency situations [5, 16].

Taking into account successful experience of introduction of the systems of diagnostics of carriage part of passenger carriages and locomotives, there is a necessity of further perfection of facilities and methods of experimental estimation of working dynamic internals and indexes of safety during all life cycle of rolling stock [3, 4].

AIM AND METHODS OF RESEARCHES

Creation of the mobile system of the working proof-testing and dynamic diagnostics of units of rolling stock with development of subsystem of express-treatment on determination of indexes of safety.

For the decision of the put tasks the methods of classic mechanics, object-oriented programming, digital treatment of signals, mathematical statistics were used.

RESULTS OF RESEARCHES

The mobile system of the working proof-testing and dynamic diagnostics of units of rolling stock on the base of platform of National Instruments CompactRIO allows deciding the wide spectrum of the tasks related to control of the state of transport vehicles, both in the conditions of tests and in the regular modes of exploitation [14].

The system plugs in itself two functional options: estimation of indexes of durability, dynamics and safety of motion real-time (Fig. 1), and also implementation of tests in autonomous behavior of "black box" (Fig. 2, 3) [6].

Fig. 1. Tests with the use of the mobile system in real-time

Fig. 2. Tests with the use of the mobile system in autonomous behavior of "black box"

Fig. 3. A measuring equipment is in the protected corps

The created system consists of next subsystems: collection of measuring information, determination of level of comfort, determinations of smoothness of motion and determination of indexes of safety in the mode express of treatment.

Executes **the subsystems of collection of measuring information** collection, storage and visualization of change of informative signals of sensors of moving, vibroaccelerations and mechanical deformations. In addition, for the analysis of influence of rate of movement on the change of the controlled parameters, the receipts of time-signals and determination of current positions are used data of receiver of GPS [18].

The system consists of:

- comptroller of CompactRIO - 9104,
- an undercarriage on 8 modules with the built-in programmable logical integrated circuit (PLIS),
- two universal modules of Analog-to-digital converter 9205 with maximal frequency of discretisation 250 kHz [19],
- five modules of tensometry 9237 with maximal frequency 50 kHz on a channel [20],
- module-receiver of SEA with RIOGxxxMobile.

Due to built-in there PLIS, CompactRIO has the opportunity to realize the algorithms of processing of measuring data at vehicle level with the determined period of implementation of 25 nanoseconds without the transfer of loading on central processing unit of comptroller.

The typical device of CompactRIO is plugged in itself by a comptroller with the real-time executive of PharLab or VxWorks, undercarriage and modules of input-conclusion. An undercarriage is carried on itself by a PLIS kernel, directly unites with the universal or specialized modules of input-conclusion, having built-in facilities of concordance and treatment of informative signals. There are different models undercarriages having a different amount of slots for the modules, and differ on descriptions of microcircuits PLIS. Due to a noninteraction, vehicle descriptions, insignificant sizes, weight, and also to possibility of work in unfavorable terms, CompactRIO can be used for the decision of wide spectrum of tasks on collection of measuring information and management by technical processes.

Majority of software for CompactRIO is developed on a chart that envisages his conditional dividing into three levels: virtual device of HOST VI on the managing personal COMPUTER with Windows OS, RT VI on a comptroller with the real time OS and FPGA VI on PLIS, that does not have own OS, because logic of work of the program will be realized directly at vehicle level. Each of the presented levels has the specific functional and will realize the separate functions of the system on the whole [28].

Typical tasks executable by means of HOST VI on the computer with Windows:

- maintenance of data on a computer and access to the databases,
- integration with the external informative systems,
- organization of interface.

Typical tasks executable in RT VI on the comptroller of the real time:

- processing of data,
- management,
- maintenance of data in built-in memory of comptroller and on external carriers.

Typical tasks executable in FPGA VI on PLIS:

- input-conclusion,
- vehicle clocking and management by the process of co-operating with an equipment,
- low-level treatment of signals.

PLIS is a microcircuit functionality of that is determined at programming or "configuration", that is more widespread term during work with this class of the integrated circuits. A package of LabView FPGA Module is adding to the software environment of LabView, that allows to set to the logician of work PLIS as an ordinary virtual device instead of her programming with the use of the specialized language of VHDL. This package allows to create the programs with synchronous and asynchronous parallel cycles executable at vehicle level and provides the collection and analysis of data determined at times.

The programmatic package of LabVIEW FPGA Module fully undertakes the multi-stage process of transformation of virtual device in a binary PLIS code. On the first stage a virtual device is converted in a text code in language of VHDL, that after it is compiled by the standard industrial compiler of Xilinx ISE in a binary kind. In the process of compiling there is optimization of code on speed implementations and amounts of the involved logical valves.

The result of compiling is a binary file (bitstreamfile), fully PLIS determines configuration. At the start of the program a binary file is loaded on an undercarriage, it means a process of configuration PLIS. A binary file can be writtenin in a built-in flash drive and automatically loaded at including of the system. In case of setting off feed configuration is not saved, therefore, after the repeated including, a binary file must be high-usage again.

At the corresponding tuning configuration can be downloaded automatically from the flash drive of device PLIS or by the program, by means of comptroller.

The virtual devices of FPGA VI can be executed fully, regardless of other components of the system, and to save a capacity even at the failure of comptroller. Moreover, on PLIS can be organized a buffer that prevents the loss of data in a similar situation.

PLIS is intended foremost for clocking, synchronization, management, capture of data and digital rough-down of informative signals. For a management by every module of input-conclusion, supports of functional of tire of PCI the special code is generated, using resources of PLIS. All, that will stop behind after it, intended for realization of logic userdefined. Thus, amount of resources of PLIS, necessary for concrete application, depends on complication algorithms and involved facilities of input-conclusion.

A virtual device for the comptroller of CompactRIO usually includes two or more than cycles: cycle with critical priority, in that the algorithms of management and processing of data, and cycle, will be realized with normal priority, that is responsible for maintenance of data, remote web-interface and connection on the network of Ethernet or tire of RS - 232.

For raising on the level of comptroller of the real time of the data got from the modules platform of CompactRIO, three ways provide for: through the elements of front panel, by means of variable, and through DMA FIFO buffer. The first two approaches are comparatively simple, from the point of view of realization, however nonoptimal from the point of view of efficiency. But the method of DMA FIFO allows jam-free to accept data got on high-frequencies of discretisation from the great number of the modules.

One of advantages of the mode of DMA consists in that communication of data takes place regardless of processor of comptroller. Devices of PLIS, supporting buffer of DMA FIFO, have a direct access to memory, unlike another ways requiring obligatory participation of processor. Direct access to memory will be realized by means of capture of tire of PCI (busmastering) by a device of PLIS at that he gets access to the management by a tire and access to memory, passing a processor.

The buffer of DMA FIFO consists of two departments: one part is in memory of PLIS, other - in memory of comptroller. On PLIS can come true memberwise record or reading from a buffer by means of knots of methods of FIFO Read and FIFO Write, and on a comptroller a record or reading of selections of elements can be conducted. Connection of two parts of buffer comes true by means of hardware and software of comptroller of DMA. Thus, from the point of view of software, they look as a single buffer of FIFO.

The virtual device of FPGA VI, placed on PLIS, will realize the functional of initialising, clocking, questioning of the modules of capture of data and subsequent loading of the got counting out in the buffer of DMA FIFO. For providing of determined the structure of "FlatSequenceStructure", in that the elements of questioning of the modules and record are located in a buffer, is used the sequence of implementation of commands.

DMA FIFO a buffer is cyclic polled through the time domain set by a timer at the level of comptroller of the real time, whereupon counting out, got as integers in accordance with dynamic range and bit of the module of collection, is rationed to the values of acceleration and deformations. The obtained data are given on a virtual device, that provides their treatment and storage on the external store of USB connected by means of tire.

The comptrollers of CompactRIO have built-in USB 2.0 comptroller, however not all stores support this standard, can bring to the considerable delays records over, that, in turn, result in the repletion of DMA FIFO buffer and improper work of the system on the whole.

The virtual device of management is absent in the presented system, takes place on the personal computer, and instead of him a mechanism that is named LabViewRemotePanel is used. This function will realize the so-called model of Customer-Server, where by a server comptroller, and by a client is any computer with set LabView . CompactRIO is licensed by default on one external connecting, however their amount can be extended.

For activating of RemotePanel on a comptroller it is necessary in tuning of project to activate Web-server and to choose those virtual devices to that it is necessary to settle remote access. This function allows considerably to shorten the expenses of time, that is needed for development of HOST VI, however can create loading on the network of telecommunications [7].

Except the modules of capture of data, for synchronization of time and receipt of values of current speed and coordinates, to the comptroller connected also GPS-receiver set on an undercarriage the same as and standard modules. Because a receiver is produced by a strange company, LabViewRealTimeModule does not have standard facilities for the receipt of data of GPS, therefore for co-operating with him drawn on the set of the closed virtual devices, set separately. In addition, for providing of the correct functioning of the module in composition a project in FPGA VI it is necessary also to add SubVI, supplied together with the module. In case if initialising went well, data of GPS appear as a cluster or directly in a text format that can be used for debugging of software or another tasks [18].

The subsystem of determination of level of comfort is based on the requirements of standard of UIC 513 and advising DSTU UIC 513 [10, 29]. These documents envisage the estimation of comfort of passengers of carriages of main railways in that passengers regularly occupy positions "sitting" or "upright".

On the accepted methodology the index of comfort settles accounts on accelerations: a) baskets in middle part, above pivot knots in three directions (simplified method - *NMV*), b) on a pillow in vertical, transversal direction, on the back of arm-chair end-on and vertical accelerations of basket (complete method in position "sitting" − *NVA*), c) baskets are in middle part, above pivot knots in three directions (complete method in position "upright" − *NVD*).

For the exception of high-frequency constituents in the spectrum of output signal and choice for the analysis of stripe of frequencies, corresponding to the eigentones of carriage, in the process of rough-down of data digital filtration of signal is used. Depending on the axis of acceleration and site of accelerometer three types of filter are used with different gain-frequency characteristics.

For accelerations, measureable an accelerometer that takes place at the level of sex, filters the gain-frequency characteristic of that is described by a Equation 1.

$$H_A(s)=\frac{s^2\cdot 4\pi^2\cdot f_2^2}{\left(s^2+\frac{2\pi\cdot f_1}{Q_1}\cdot s+4\pi^2 f_1^2\right)\left(s^2+\frac{2\pi\cdot f_2}{Q_1}\cdot s+4\pi^2 f_2^2\right)}. \tag{1}$$

For the accelerations measured at the level of places for a seat, expression of frequency response function looks like Equation 2.

$$H_B(s)=\frac{(s+2\pi\cdot f_3)\left(s^2+\frac{2\pi\cdot f_5}{Q_3}\cdot s+4\pi^2 f_5^2\right)}{\left(s^2+\frac{2\pi\cdot f_4}{Q_2}\cdot s+4\pi^2 f_4^2\right)\left(s^2+\frac{2\pi\cdot f_6}{Q_4}\cdot s+4\pi^2 f_6^2\right)}\cdot\frac{2\pi\cdot Kf_4^2\cdot f_6^2}{f_3\cdot f_5^2}, \tag{2}$$

and for the accelerations measured on a pillow and back of places for a seat:

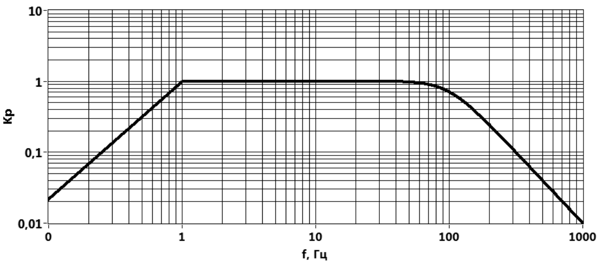
$$H_C(s),H_D(s)=\frac{(s+2\pi\cdot f_3)}{\left(s^2+\frac{2\pi\cdot f_4}{Q_2}\cdot s+4\pi^2 f_4^2\right)}\cdot\frac{2\pi\cdot Kf_4^2}{f_3}. \tag{3}$$

In Table 1 brought coefficients over of filters.

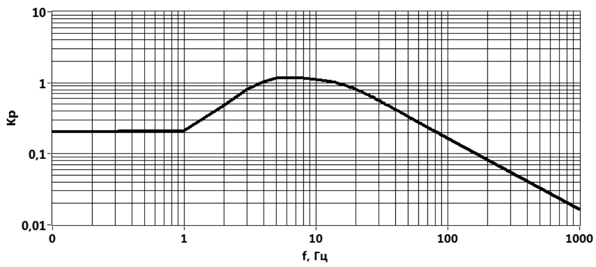
The gain-frequency characteristics of the used filters are presented on a Fig. 4.

Table 1. Coefficients of filters in accordance with the requirements of standard of UIC 513

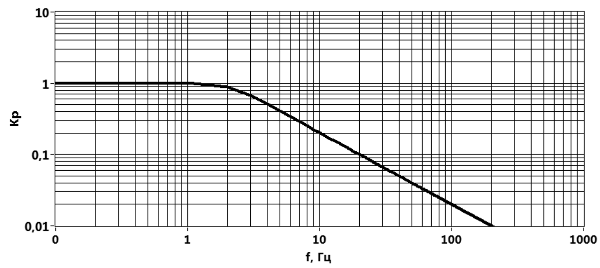
Band limits			Parameters of amplitude-frequencyfunction							
f_1 (Hz)	f_2 (Hz)	Q_1	f_3 (Hz)	f_4 (Hz)	f_5 (Hz)	f_6 (Hz)	Q_2	Q_3	Q_4	K
0,4	100	0,71	-	-	-	-	-	-	-	-
0,4	100	0,71	16	16	2,5	4	0,63	0,8	0,8	0,4
0,4	100	0,71	8	8	-	-	0,63	-	-	1,0
0,4	100	0,71	2	2	-	-	0,63	-	-	1,0



a



b



c

Fig. 4. Frequency response function of the used digital filters: a – $H_A(s)$, b – $H_B(s)$, c – $H_C(s)$, $H_D(s)$

In the process of treatment instead of formulas (1-3) without considerable influence on results it is possible to use the simplified presentation of Frequency response function [29]:

$$F_b(f)=\begin{cases} 0.4 & for \quad 0,4 \le f < 2 \\ 0.2\cdot f & for \quad 2 \le f < 5 \\ 1 & for \quad 5 \le f < 16 \\ 16/f & for \quad 16 \le f < f_{max} \end{cases} \tag{4}$$

$$F_c^*(f)=\begin{cases} 1 & for \quad 0.4 \le f < 8 \\ 8/f & for \quad 8 \le f \le f_{max} \end{cases} \tag{5}$$

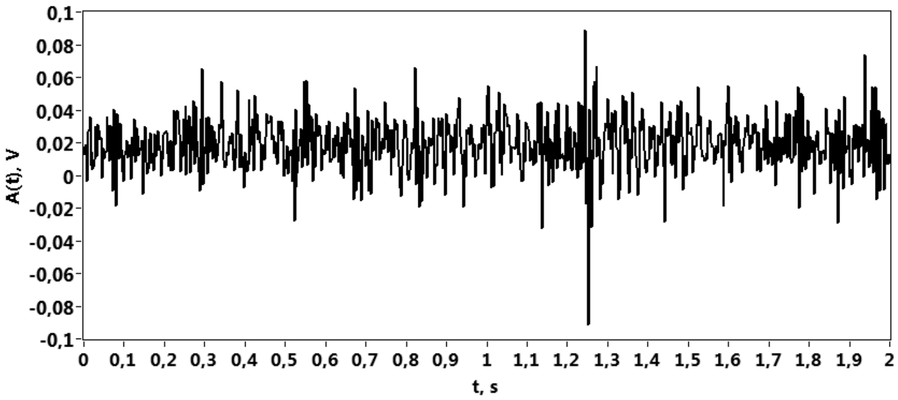
$$F_d^*(f)=\begin{cases} 1 & for \quad 0.4 \le f < 2 \\ 2/f & for \quad 2 \le f \le f_{max} \end{cases} \tag{6},$$

where: $H_A(s)$ corresponds $F_b(f)$, $H_B(s)$ accordingly $F_c^*(f)$, and $H_C(s)$, $H_D(s)$ – $F_d^*(f)$.

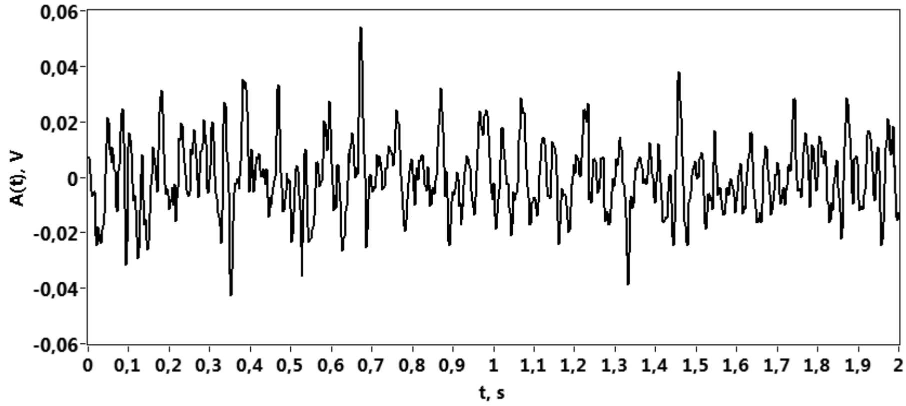
On a Fig. 5 results over of filtration of the signal, got from the accelerometer of the passenger carriage that moved at a speed of 70km/h (Fig. 5, a) located on the floor, are brought, before and after (Fig. 5, b) passing of filter.

In accordance with the requirements of standards [10, 29] the index of comfort, that is estimated on a next scale, settles accounts: N<1 − very good comfort, 1<N>2 − good comfort, 2<N>4 − middle comfort, 4<N>5 − bad comfort, N>5 − very bad comfort.

Technical implementation of subsystem is executed on the basis of results of working tests of model carriage 62-7067. The expected values of index of comfort of *NMV* are confronted with a border value *[N]=4,0.* The results of calculations are driven to the Table 2.



a



b

Fig. 5. Results of the filter

Table 2. Index of comfort of carriage № 8 models 62-7067 double-system electric train on a line Kyiv-Kharkiv

Index	Speed, km/h	Mean	SCO	Percentage of the limit value,%
N_{MVI} (index of comfort zone I, caster)	61-70	2,6	0,3	65,4
	71-80	2,8	0,3	69,7
	81-90	3,2	0,1	80,4
	91-100	3,1	0,3	77,5
	101-110	3,7	0,1	92,4
	111-120	3,6	0,3	88,8
	121-130	3,9	0,2	98,0
	131-140	3,9	0,3	97,5
	141-150	3,6	0,2	90,2
	151-160	3,0	0,3	75,6
N_{MVm} (index of comfort in the middle of the body)	61-70	2,2	0,3	55,9
	71-80	2,4	0,3	60,8
	81-90	2,6	0,6	66,0
	91-100	2,6	0,2	65,9
	101-110	3,1	0,1	77,1
	111-120	2,9	0,4	72,7
	121-130	3,1	0,1	77,0
	131-140	3,1	0,3	76,6
	141-150	3,0	0,1	75,5
	151-160	2,2	0,5	55,0
N_{MV1I} (index of comfort zone II caster)	61-70	2,4	0,1	60,4
	71-80	2,6	0,3	64,0
	81-90	2,6	0,6	66,1
	91-100	2,6	0,3	65,3
	101-110	3,2	0,2	80,2

	111-120	2,9	0,3	73,0
	121-130	3,2	0,1	79,1
	131-140	3,7	0,4	91,4
	141-150	3,0	0,1	75,5
	151-160	2,6	0,3	65,6

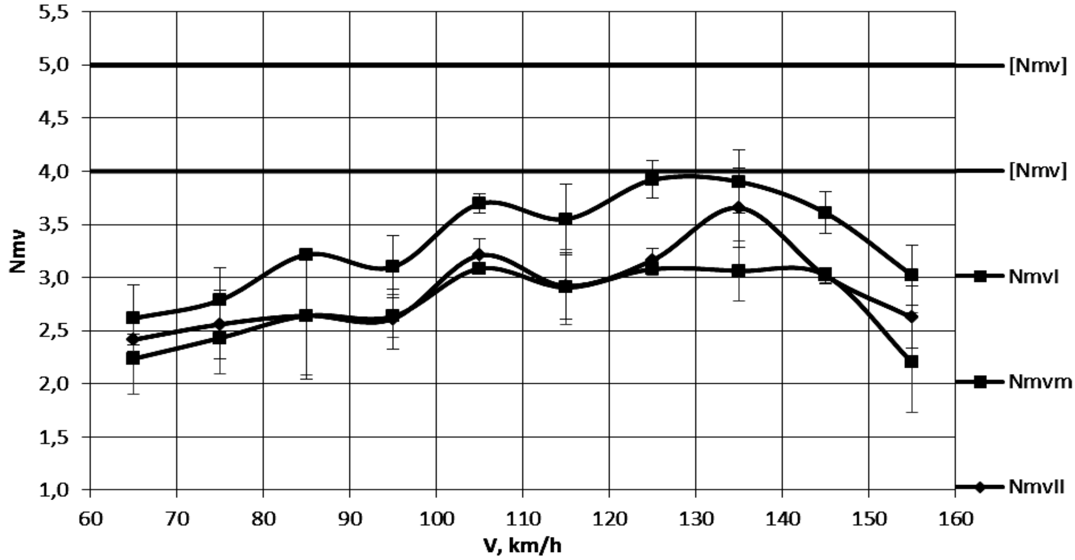


Fig. 6. Indexes of comfort for the carriage of model 62-7067 double-system electric train on a line Kyiv-Kharkiv (*NmvI*, *NmvII* - indexes of comfort in the zone of king-pin of I and II, *Nmvm* – index of comfort in the middle of basket)

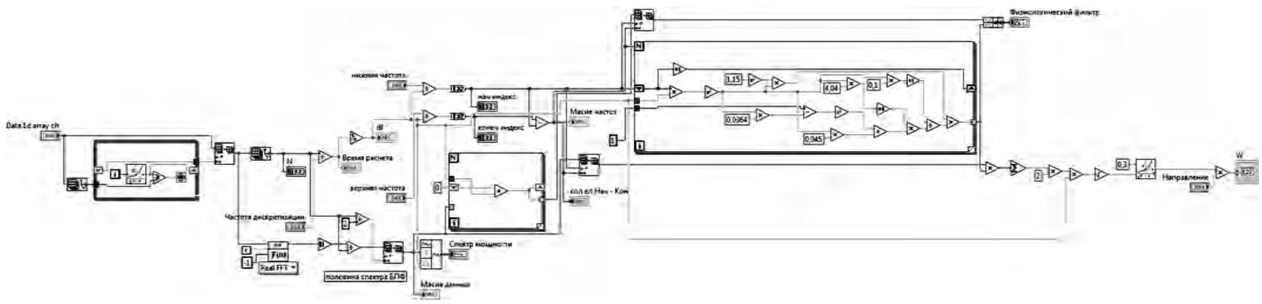


Fig. 7. General view of the block diagram

From tabular data the charts of dependences of indexes of comfort are built from the rate of movement (Fig. 6). Apparently, the terms of comfort perceptibly get worse in the range of rate of movement 120-140 km/h.

The subsystem of determination of smoothness of motion is based on the requirements of standard [10] by the c account of recommendations [1, 24]. These documents are intended for an estimation to the comfort of ride by verification of accordance of index to the smoothness of motion of carriage to the norms envisaged by technical documentation on carriages. The index of smoothness of motion depends on intensity and spectral composition of accelerations of basket of carriage.

On the accepted methodology the indexes of smoothness of motion of *Wz* settle accounts on the accelerations of basket above caster knots on the exit of "physiological filter". In accordance with it the indexes of smoothness of motion settle accounts in vertical (*Wzv*) and horizontal (*Wzh*) directions. The general view of Block Diagram is presented on a Fig. 7.

The data in Table 3 characterize the assessment of the indicators according to the smoothness of the recommendations [10, 21].

Table 3. Rating wagon ride quality index based on smoothness *Wz*

Estimation of working internalss of carriage	*Wz*
Very good	2
Good	2 – 2,5
Sufficient for passenger carriages	2,5 – 3
Maximum for passenger carriages	3 – 3,25
Sufficient for a locomotive	3,25 – 3,5
Maximum for a locomotive	3,5 – 3,75
Sufficient for freight carriages	3,6 – 4
Maximum for freight carriages	4 – 4,25
Maximum for a man from the physiological point of view	4,5
Dangerous from the point of view of tails of rolling stock from rails	5

The calculation of indexes of smoothness of motion is realized on a next algorithm: determined size of block for calculations, entry block determined size by an algorithm on founding 2, and by means of intrinsic function of LABVIEW transformation of Fourier is conducted for the construction of spectrum of power, on the basis of transformation of Fourier building arrays of frequencies and arrays of data in set range of frequencies from 0,5 Hz to 20 Hz, the value of the rationed gain-frequency characteristic of correcting filter settles accounts in obedience to expression (Equation 7), block diagram, that shown on a Fig. 8.

$$q_н(f) = 1.15 \cdot \sqrt{\frac{(1+0{,}1 \cdot f^2)}{(1+4{,}04 f^2)\cdot((1+0{,}0364 f^2)^2 + 0{,}045 f)}}, \tag{7}$$

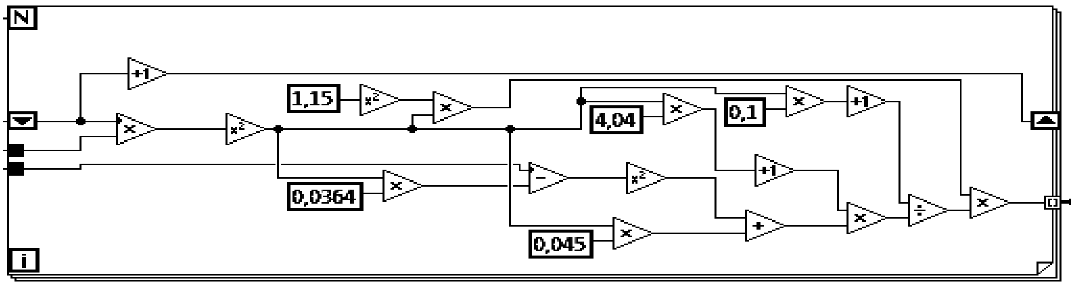


Fig. 8. Block diagram of the correction filter

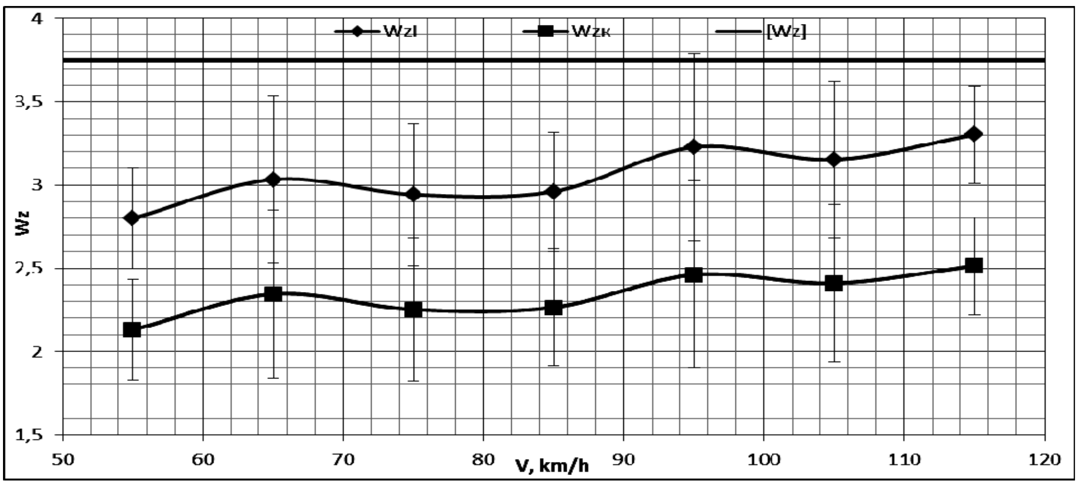


Fig. 9. Indexes of smoothness of motion of electric locomotive of CHS2 are in vertical direction (*WzI* – index of smoothness of motion in a caster section, *Wzk* – index of smoothness of motion in an operator's cab)

The eventual index of smoothness of motion of *Wz* for the array of data settles accounts on a formula:

$$W = a \cdot \tilde{a}_k^{0,3}, \qquad (8)$$

where: $\alpha=4,346$ − for vertical vibrations,

$\alpha=4,676$ − for horizontal (transversal) vibrations,

$\tilde{a}_k^{0,3}$ − mean quadratic value of vibroaccelerations on the exit of correcting filter.

Example of results of estimation of smoothness of motion for the electric locomotive of CHS2 is made an on Fig. 9.

The obtained values of smoothness on compare with the allowable limit for locomotives $[Wz]=3,75$ [22].

A subsystem of expresstreatment is a complex of software set on the personal PC and will realize determinations and reflections of indexes of safety real-time with the interval of updating of result one time in two seconds or one time on 100 meters of the passed way.

According to operating methodologies of model tests on railways of track a 1520 mm is envisaged determination of indexes of safety of motion on basis so-called "frame forces" that operate from the side of frame constructions of working parts on wheel pairs [2]. However, because of that these descriptions do not give the direct picture of power cooperation of wheels with rails that results in the decline of authenticity of the results got in the process of working researches [12, 26, 23].

On the railways of countries EC the estimation of indexes of safety of motion of speed rolling stock is regulated by the standards, setting the next methods of tests [17, 15, 30]:

a) Normal method: measuring of forces of pin cooperation of *Y* (transversal) and *Q* (vertical),

b) Simplified method: measuring of lateral force (*H*) and accelerations of basket in transversal ($\ddot{y}^*$) and vertical ($\ddot{z}^*$) directions,

c) Simplified method: measuring of transversal acceleration of frame of light cart ($\ddot{y}^+$) and accelerations of basket in transversal ($\ddot{y}^*$) and vertical ($\ddot{z}^*$) directions.

With the purpose of introduction of the modern going near the estimation of indexes of safety of motion in DNDC UZ work on technical implementation of the simplified method of tests, was executed based on measuring of accelerations, ($\ddot{y}^+, \ddot{y}^*, \ddot{z}^*$) [11].

For each of indexes the certain a standard parameters of filtration are set, namely: for the transversal acceleration of frame of light cart($\ddot{y}^+$) the filter of LFS is used at frequency of shear 10 Hz, for the transversal acceleration of basket($\ddot{y}^*$) – is a filter of LFS at frequency of cut 6 Hz, for the vertical acceleration of basket ($\ddot{z}^*$) – band-pass filter is with range 0,4-4 Hz.

After implementation of filtration the expected value ($\bar{x}$) and standard deviation (*s*) settle accounts for further determination of maximally possible values of accelerations(X_{max}) on a next formula:

$$X_{\max} = \bar{x} + k \cdot s, \qquad (9)$$

where: *k* – is a coefficient depending on the set level of authenticity (for determination of indexes of safety of *k* = 3).

The defined values are compared to the maximum values that is certain the standard of UIC 518 as follows: vertical acceleration of basket − $(\ddot{z}_s^*)_{\lim} = 3$ m/s², transversal acceleration of basket – $(\ddot{y}_s^*)_{\lim} = 3$ m/s² for direct areas and curves of large radius, $(\ddot{y}_s^*)_{\lim} = 2,8$ m/s² − for small curves by a radius 400≤R≤600, ($(\ddot{y}_s^*)_{\lim} = 2,6$ m/s² − for very small curves by a radius 250≤R≤400, transversal acceleration of frame of light cart determined on a next formula:

$$(\ddot{y}^+)_{\lim}=12 - M_b/5, \qquad (10)$$

where: M_b – is mass of light cart in tones.

The interface of the worked out programmatic complex of expresstreatment of indexes of safety of motion on the standard of UIC 518 is presented on a Fig. 10.

Fig. 10. Interface of subsystem of expresstreatment of indexes of safety

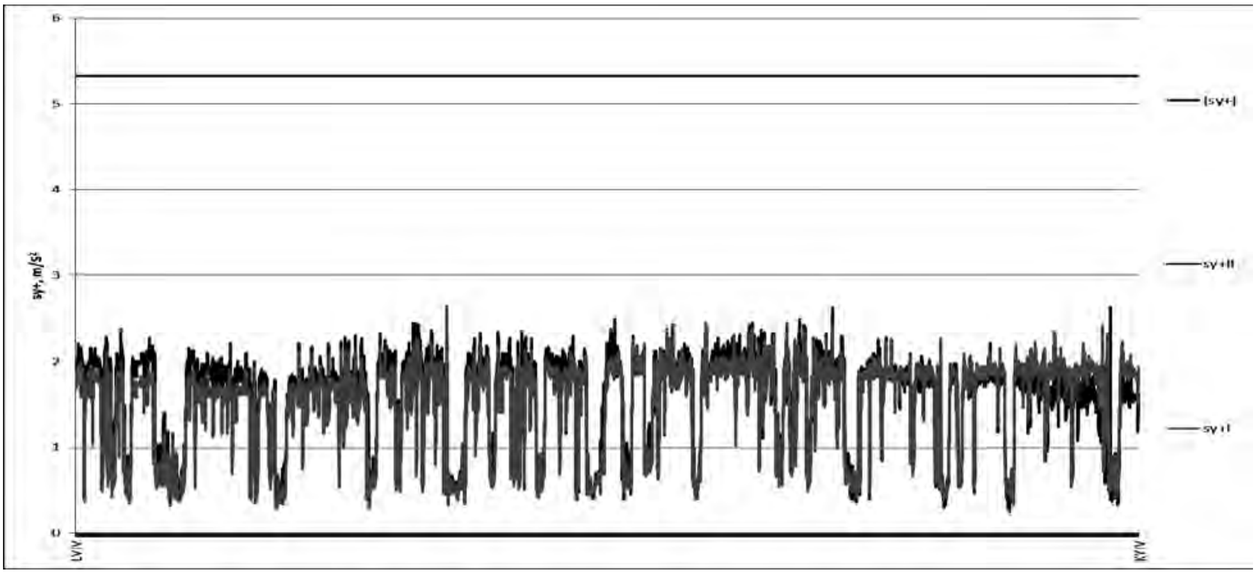


Fig. 11. Standart deviations of transversal accelerations of frame of the light carts measured in an experience journey en-route Lviv-Kyiv

An experience introduction of subsystem is carried out on the basis of results of working tests of model carriage 68-7041 on the routes of the following : Kharkiv-Kyiv, Kyiv-Donetsk and Lviv-Kyiv.

On a Fig. 11 standard deviations of horizontal transversal accelerations of frame of light cart are presented fixed during motion of research train en-route Lviv-Kyiv, Coming from that mass of light model cart 68-7041 makes 6,68 tons, $(s\ddot{y}_s^+)_{lim}$ =5,33m/s^2 [8, 25, 26]. As be obvious from the presented results, most standard deviations of accelerations no less what in two times below maximum legitimate value, that testifies to the considerable supply to stability of carriage from tails from rails.

CONCLUSIONS

1. In DNDC UZ worked out informatively-measuring system, providing a testability rolling stock during all life cycle, and also executed technical implementation of the system at the working tests of locomotives, railcar of rolling stock, passenger and freight carriages. The created system will allow to improve quality and speed of diagnostic

operations and, as a result, considerably to promote safety of transportations.

2. Drawing on a similar hardwarily-programmatic complex allows to provide not only the accumulations of basic measuring data for further treatment but also real-time to watch appearance of dangerous office hours and correct motion of tests.

3. In future it is assumed to perfect the informatively-measuring system in part of increase of level of dust and water tight, and also by addition of the modules of Wi-Fi and 3G-link.

REFERENCES

1. **Dmitriev D., 2010.:** Generalization of experience with DSTU UIC 513:2004. Collection of scientific works DonIZT, № 23. – 182-187. (in Russian).
2. **Domin J., Chernyak A., 2003.:** Bases of dynamics of carriages : study guide. – K.: KUETT. – 270. (in Ukrainian).
3. **Domin R., Chernyak A., 2008.:** Vehicle-board diagnostics of the locomotive. Problems and prospect of development of transport systems minds reform of railway transport: management of economy and technology, Materials of IV international research and practice conference, Series of "Technician, technology". – K.: DETUT, – 43-44. (in Russian).
4. **Domin J., Dmitriev D., Domin R., 2005.:** Operating tests of CAS of current control of the technical state of working parts of passenger carriages and way. Railway transport of Ukraine, №3/1. –107-114. (in Russian).
5. **Domin J., Domin R., Dmitriev D., 2003.:** Computer checking of the state of working parts of passenger carriages. Railway transport of Ukraine, №5. – P. 4-6. (in Russian).
6. **Domin R., Mostovych A., Kolomiiets A., 2013.:** Facilities of instrumental estimation of the technical state of rolling stock. International information scientific and technological magazine "Wagon park", №6. – 10-15. (in Ukrainian).
7. **Domin R., Mostovych A., Kolomiiets A., Suslov E., Jerebko V., 2011.:** Modern tool for the tests of rolling stock. Railway transport of Ukraine, №6. – 16-18. (in Ukrainian).
8. **Domin R., Mostovych A., Kolomiiets A., 2013.:** Implementation of modern approaches in relation to the estimation of indexes of safety of motion. Materials of VI of the International research and practice conference of "Problem and prospect of development of transport systems in the conditions of reformation of railway transport: management, economy and technologies", - Series of "Technician, technology", K.: DETUT. – 45-47. (in Ukrainian).
9. **DSTU 2389:1994.:** Terms and determinations: Technical diagnostic and control of the technical state. - [Valid from 1995-01-01]. - K.: Ukrainian State Standard. – 24. (in Ukrainian).
10. **DSTU UIC 513:2004**, **2006.:** Mainline coaches. Discipline in relation to the evaluation of comfort of passenger's dependently from vibration (UIC 513: 1994, IDT), Valid from 2006.01.01. - Kyiv: Dergspogivstandart of Ukraine. – 32. (in Ukrainian).
11. **EUROPEAN STANDARD EN 14363, 2010.:**, Railway of applications - Testing for the acceptance of running characteristics of railway vehicles - Testing of running behavior and stationary tests. – 120.
12. **Gorbunov N., Kostyukevich A., Kravchenko K., Kovtanets M., 2011.:** Influence of operatonal factors on redistribution of wheel pairs vertical loads upon rails / N. Gorbunov, // TEKA Commission of Motorization and Power Industry in Agriculture XIA. Poland. – 92-99.
13. **GOST 2860-94.:** Terms and Definitions: Reliability engineering. – K.: State Standard of Ukraine. – 90. (in Ukrainian).
14. **Instruction on exploitation and specification of CompactRIO 9012/9014, 2007.:** Built intellectual controller of the real time CompactRIO, - USA, Texas, Austin: National Instruments. – 19.
15. **Instruction RD 24.050.37.95., 1995.:** Freight coaches. Test methods for durability and drivability. – 102 p. (in Russian).
16. **Kirpa G., Domin J., Domin R., Dmitriev D., 2008.:** Patent of Ukraine 83459, MPK (2006) V61K 9/00. A device for continuous control of the mechanical rolling stock, - № u2003076579, claimed 14.07.03, publ. 25.07.08. Bull. № 14. (in Ukrainian).
17. **Norms for calculation and design of railway wagons MPS 1520 mm (non-self), 1996.:** - M,: GhosNIEV-VNIIZhT. – 352. (in Russian).
18. **Operation Instructions and Safety Guidelines cRIO Mobile Modules, 2011.:** Gxxx Series, − Germany, Troisdorf: Datentechnik GmbH. – 28.
19. **Operating instructions and specifications NI 9205, 2008.:** USA, Texas, Austin: National Instruments. – 36.
20. **Operating instructions and specifications NI 9237, 2009.:** − USA, Texas, Austin: National Instruments. – 40.
21. **OST 24.050.28-81, 1981.:** Coaches, Methods of measurement and evaluation of vibration, - Instead OST 24,050,28-74, - Enter, 01.01.83, - M,: Mintyazhtranspmash USSR. – 34. (in Russian).
22. **OST 24.050.16-85, 1985.:** Coaches, Methodology for determining smoothness, Introduced, 1.1.87, - M,: Mintyazhtranspmash USSR. – 16. (in Russian).

23. **Sapronova S., 2010.:** Modeling of locomotive wheel profile form. TEKA Commission of Motorization and Power Industry in Agriculture VX. Poland. – 270-278.
24. **SOU MPP 45.060-204: 2007, 2007.:** Coaches, Smoothness of motion, Methods of determination, Valid from 2008.04.01. – K.: Ministry of policy of Ukraine. – 15. (in Ukrainian).
25. **Specification 62.7066.TZ, 2010.:** "Electric two-system for interregional messages at the speed of 160 km/h", Kremenchuk: KVBZ. 79.
26. **Standards for calculating and assessing the strength of load-bearing elements, dynamic qualities and impact on the path of the vehicle-locomotives Railway MPS RF 1520 mm, 1998.: -** M,: VNIIZhT. – 145. (in Russian).
27. **TSI, 2011.:** Technical specification for interoperability relating to the rolling stock subsystem 'Locomotives and passenger rolling stock' of the trans-European conventional rail system, – [Valid from 2011-05-26]. – Brussels, 148.
28. **Fedosov V., Nesterenko A., 2007.:** Digital treatment of signals is in LabVIEW – M.: DMK Press. – 427 p. (in Russian).
29. **UIC Code 513 OR, 1994.:** Guidelines for evaluating passenger comfort in relation to vibration in railway vehicles, – 1st edition, 01.07.94, – International Union of Railways.
30. **UIC Code 518, 2009.:** Testing of and approval of railway vehicles from the point of view of their dynamic behavior - Safety - Track of fatigue - Ride of quality, 4-th ed, (September 2009), Paris: International Union of Railways.

СОВЕРШЕНСТВОВАНИЕ СРЕДСТВ ЭКСПЕРИМЕНТАЛЬНОГО ОПРЕДЕЛЕНИЯ ДИНАМИЧЕСКОЙ НАГРУЖЕННОСТИ ХОДОВЫХ ЧАСТЕЙ ПОДВИЖНОГО СОСТАВА

Ростислав Дёмин, Анатолий Мостович,
Александр Коломиец

Аннотация. В статье приведены результаты исследований по созданию мобильной системы контрольных ходовых испытаний и динамической диагностики подвижного состава.

Ключевые слова: средство испытаний, контролер, испытания контрольные, диагностика техническая.

Features of welding using integrated protection environment

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Summary. This article presents the results of experimental studies on welding in a complex protection environment (CPE). There are presented peculiarities of welding in the lower and in the ceiling spatial position. Application possibilities of welding using CPE in the regional enterprises are also presented
Key words: welding, complex protection environment, welding deformation.

INTRODUCTION

Currently, about 30% of the machinery industry production are welded constructions of metal with the thickness from 2 mm to 6 mm [3, 21, 23], such as railway cars, containers for transportation of bulk cargo [4], evaporators, liquid separators, absorbers, filters, heat exchangers, distillation columns, etc. In the manufacture, volume of such welding structures reaches 70%, which leads to a more expensive product [14, 27, 30]. One way to reduce the final cost of welded products is the use of resource-saving technologies [15, 24, 25, 28, 29] and reduce the consumables cost [1, 16, 18, 19, 26].

ANALYSIS OF PUBLICATIONS, MATERIALS, METHODS

The most widely used method is arc welding, because of its ease of implementation, a high concentration of thermal energy, reliability, welds stability characteristics comparative simplicity of mechanization [12, 22].

The most promising is the use of resource-saving technologies in welding, modifying and combining of existing technologies, the choice of the least energy-intensive methods of welding Fig. 1.

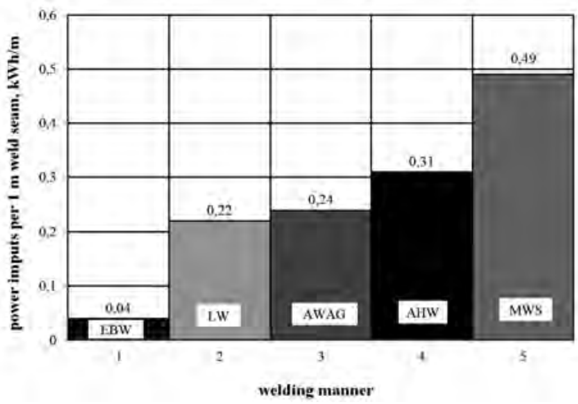

Fig. 1. Cost sharing of electrical energy per 1 m of weld of the connection C4 for various ways of the welding: EBW – electron-beam welding, LW – laser welding, AWAG – automatic arc welding in active gases, AHW – automatic hidden arc welding, MWS – manual arc welding

At the same time, it is necessary to develop and implement welding methods with minimal negative impact on the welder and the environment, use technology of effective capture [9, 10] and recycling or disposal of welding fumes.

The problems of resource-saving in welding, welding fume and aerosols capture, anti-ultraviolet radiation of the arc must be addressed comprehensively. One way of solving this is to use complex protection environment (CPE) in arc welding [2, 8].

THE PURPOSE AND MISSION STATEMENT OF THE RESEARCH

The aim of this work is to study the characteristics of the welding process using the CPE in different positions. To fulfill the purpose the following objectives have been stated: To investigate the characteristics of welding to the CPE in the down position, investigate the features of the CPE welding in the overhead position, to explore the possibility of using welding with the CPE in the enterprises of the region.

THE MAIN SECTION WITH THE RESULTS AND THEIR ANALYSIS

Depending on the relative position of the welded details, welded joints are divided into: butt, lap, tee, corner, face (side). All types of welded joints, their assembly and weld seam geometry is rigidly regulated by GOST 5264-80, GOST 16037-80, GOST 8713-79, GOST 14771-76, GOST 14776-79, GOST 11534-75, etc., and retreat from them is not valid.

Experimental studies were carried out on steel VSt.3ps (GOST 11474-76), the size of the welded plates is 300X200 mm, 5 mm thick. There was used welding wire Sv-08 (GOST 2246-70) with a diameter of 2.5 mm. Welding equipment: automatic ADS-1000-1 with the power supply VSU-300. For CPE there was used a dispersed generator developed by [5] (Fig. 2).

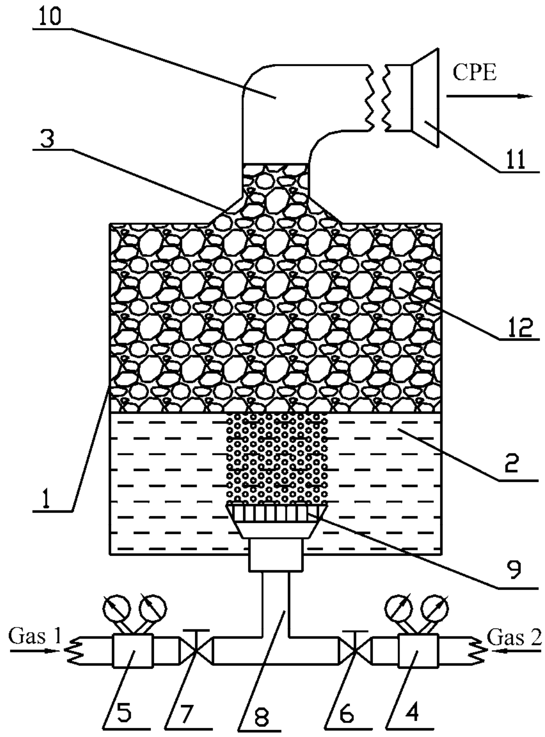

Fig. 2. The circuit of the generator for deriving CPE: 1 – the generator cage, 2 – a solute of superficially active substance, 3 – a fitting pipe, 4 and 5 – gas reducers, 6 and 7 – valves of adjusting of pressure of gas, 8 – handset for a gas intake, 9 – the gas breaker plate, 10 – a flexible tube for feeding CPE, 11 – a replaceable nozzle for feeding КЗС, 12 – CPE

The compositions of the CPE are under the identification numbers №1, №2, №3, №4, №5, №6 [7]. Welding mode: arc voltage U_a=30 V, welding current I_w=250 A, welding speed V_w=30 m/h.

The experimental results showed that the CPE welding can be carried out in all positions (the lower, vertical, horizontal and overhead). The main features of welding in different positions do not differ significantly from the classical concepts. However, there is a number of features associated with the use of the CPE.

The main feature of welding in CPE is the complexity of welded parts seam visual tracking. Insufficient supply of CPE results in penetration of the weld zone of atmospheric air and in defects in the form of pores.

Welding features using CPE lower position.

When welding using CPE lower position, it is necessary to take into account the complex forces acting on the molten metal droplet Fig. 3. According to researches [20], main forces are: the axial component of the electromagnetic force P_{em}, directed from a smaller to a larger section of the conductor, the force of gravity P, is directed downward, the strength of the surface tension P_σ, holding the drop of the electrode.

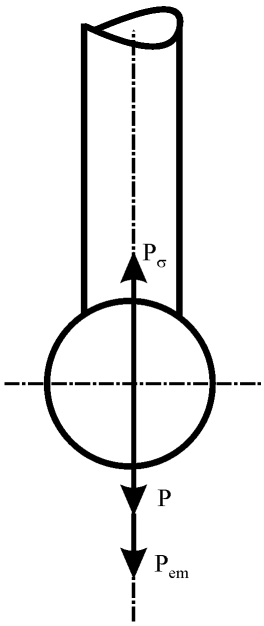

Fig. 3. Diagram of the forces acting on the molten metal droplet electrode for the lower spatial position welding

The strength of a jet of vapor pressure when welding on the reverse polarity is small and is not taken into account (exerts its effect in by welding on straight polarity).

The component of the electromagnetic force:

$$P_{em} = B \cdot I^2 \cdot \left(1 + 4.6 \cdot \lg \frac{r_c}{r_e}\right), \quad (1)$$

where: P_{em} – the component of the electromagnetic force (N), B – aspect ratio (N/A^2), r_c and r_e – radius of the arc column and the electrode (m), I – the arc current (A).

The drops surface tension:

$$P_\sigma = \pi \cdot d_e \cdot \sigma, \quad (2)$$

where: P_σ – the drops surface tension (N), d_e – electrode diameter (m), σ – The surface tension of the drop metal at the edge of "drop-electrode" (N/m).

The force of gravity for the drop:

$$P = \frac{4}{3}\pi \cdot R^3 \cdot \gamma \cdot g, \quad (3)$$

where: P – the force of gravity for the drop (N), R – drop radius (m), γ – density of the liquid steel (kg/m^3), g – acceleration of free fall (m/s^2).

The condition for a tear drop is:

$$P_{em} + P \geq P_\sigma. \quad (4)$$

When welding in the CPE, the following values are included in the formula (Eq. 1–3): $B=5\cdot10^{-8}$ (N/A^2), $r_c=1.1\cdot10^{-3}$ (m), $r_e=0.8\cdot10^{-3}$ (m), $d_e=1.6\cdot10^{-3}$ (м), $\sigma=1.22$ (N/m), $R=1.8\cdot10^{-3}$ (m), $\gamma=7\cdot10^3$ (kg/m^3), $g=9.8$ (m/s^2).

After substituting the values of (Eq. 1–4), we obtain:

$$6.18 \cdot 10^{-3} + 0.97 \cdot 10^{-3} > 6.13 \cdot 10^{-3},$$

i.e. tear drop condition is satisfied.

Welding features using CPE overhead position.

A similar (Eq. 4) calculation can be made for different spatial positions and determine the possibility of electrode metal transfer into the weld pool for subsequent adjustment of welding modes.

For example, the condition (Eq. 4) in the case of ceiling seams welding becomes:

$$P_{em} \geq P_\sigma + P. \quad (5)$$

After substituting the values in the formula, it can be seen that the condition of tear drops is not fulfilled, that is, transfer of electrode metal is complicated.

From the analysis of (Eq. 1-3) it can be seen that on the transfer of electrode metal into the weld pool greatest effect is made by current (quadratic dependence). However, the ability to control the metal transfer by changing the value of welding current , in most cases depleted, as evidenced by welding methods with forced transport of the metal electrode overlapping the mechanical vibration to the electrode and the electric pulse welding. In our opinion there is an additional opportunity to improve the transfer of welding droplets by changing the surface tension of the drop. In the given example (the remaining conditions being unchanged) σ value must be reduced to a value of 1.037, then tear drop condition (Eq. 5) is satisfied. Reduction of σ can be achieved, for example, by introducing 1.5-2% vol. of oxygen into the CPE (Fig. 4).

The less σ, the smaller liquid droplets are and there appears the likelihood of transition to fogging and spray transfer of metal. In this way the additive of oxygen up to 5% reduces the surface tension of the steel during welding in an inert gas.

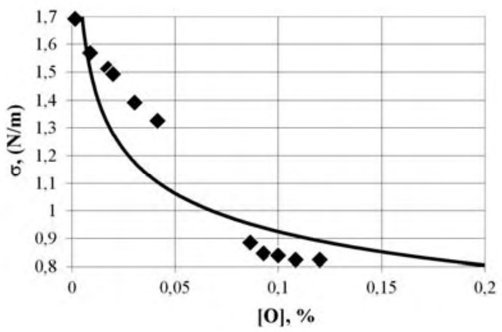

Fig. 4. Influence of density of oxygen on a surface tension of alloys Fe-O at 1600 °C

When welding on the reverse polarity the anode spot is stable at the end of the liquid drop and the current is increased, the density remains constant, and the spot size increases. Therefore, drop overheating and boiling occur at lower currents than on normal polarity when the cathode spot moves randomly. With current density increasing, for example, for j>20 A/mm^2 electrocapillarity effect can be observed, accompanied by σ decrease contributing to spray transfer of metal.

Therefore, the change in the composition of CPE can produce favorable conditions for the transfer of electrode metal into the weld pool, as CPE composition change varies its redox potential, the drops temperature and the arc electrode metal, the drops surface tension.

Another feature is that the CPE should securely protect the weld pool and the arc of the air space in the overhead position. This is achieved using CPE with gas phase He.

The condition of air marginalization when welding in the overhead position:

$$\frac{m_{CPE}}{V_{CPE}} \le \rho_{air}, \tag{6}$$

where: m_{CPE} – CPE weight (kg), V_{CPE} – CPE volume (m^3), ρ_{air} – density of air (ρ_{air}=1.206 kg/m^3).

After the transformation (Eq. 6), we obtain the expression for determining the multiplicity of CPE, at which the density is less than that of the CPE air:

$$k \ge \frac{(\rho_l - \rho_{He})}{(\rho_{air} - \rho_{He})}, \tag{7}$$

where: ρ_l – the density of the CPE liquid phase (ρ_l=1.05·10^3 kg/m^3).

After substitution of the numerical values in the expression (Eq. 7), we obtain the value of the multiplicity of the CPE k≥1021.724.

Possible applications of the CPE in the welding industry.

The use of welding to the CPE in the manufacture of structures, was primarily determined by local companies. These companies were "Lugansk Teplovoz", "Snezhnyansk khimmash" and Stakhanov Wagon Works.

At "Lugansk Teplovoz" there were developed new types of diesel-trains and passenger cars with a high level of comfort that do not require major repairs body for 35 – 40 years (Fig. 5).

The total weight of the construction of cars new type is much less due to the use of steel 10H13G18DU with special strength properties. Roof and side walls are responsible nodes. According to the specifications the roof is made of steel VSt3ps GOST11474-76 and the side wall – of stainless steel 10H13G18DU. The thickness of the metal roof and the side wall is 1.5 mm and in certain areas of the side wall it is 1 mm. The frame is made of steel bent channel VSt3ps with the thickness of 2.5 mm. The roof is made of three spans, the length of two of them is 9570±3 mm, and – 5470±3 mm. The transition from the roof to the side wall is performed with the inclined and bent sheets 1003.55.00.148 and 1003.55.00.149 of VSt3ps steel. Sheet width is 320±1 mm, the width

Fig. 5. A general view of the diesel-trains and diesel train car

of the flat part is 304±1 mm, bending angle is about 160^{o}. In the upper part (the connection of roof with list) there is performed a continuous seam due to the requirements of tightness. At the bottom there is a connection of dissimilar materials. The great length of the upper seam (total length of about 25 m) and the presence of dissimilar materials in conjunction with the side wall sheets causes the significant deformation sheets 1003.55.00.148 and 1003.55.00.149, which leads to deterioration of appearance and aerodynamics of the car.

Traditional methods for reducing strain during welding and post weld treatment (dressing, rolling, stretching, heat treatment, etc.) are not applicable because of the large dimensions of the product [10, 11].

It was suggested to use cooling with CPE on the entire length of the seam (Fig. 6).

As a result, the welding area $2b_{\text{п}}$ was 30% narrowed in a one-sided feeding CPE and 45 – 50 % for double-sided CPE feed, which leads to lower overall deformations to an acceptable level. Forced cooling has a positive effect on the structure of welds, as evidenced by joint research with "Lugansk Teplovoz" [11, 12, 13]. This method allows to reduce the stress and strain of the base metal by heat during welding [17].

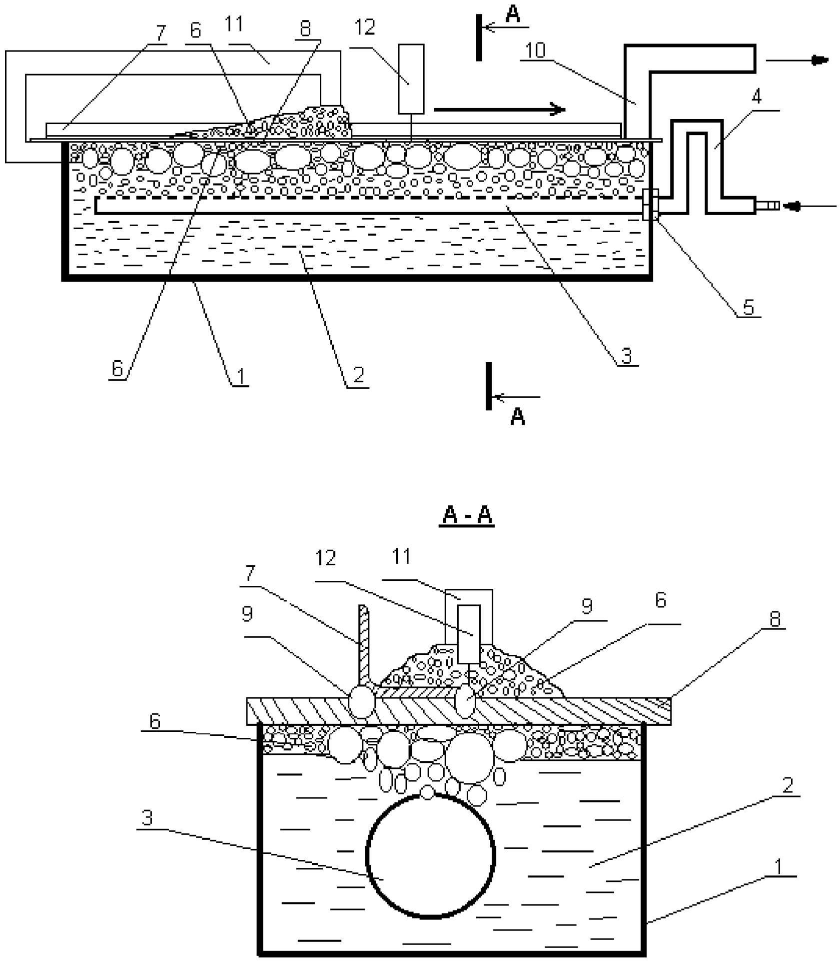

Fig. 6. The scheme of the welding with forced cooling CPE: 1 – a tank with a liquid phase CPE, 2 – CPE liquid phase, 3 – dispersant, 4 – cutter to prevent splashing in the system for supplying an activating gas, 5 – nut to prevent spillage of liquid, 6 – CPE layer to drain parasitic heat from the welding zone, 7 – welded element, 8 –sheet metal, 9 – welds, 10 – sleeve for removing excess CPE, generating steam and gas, 11 – sleeve for supplying CPE welded to the outer side elements, 12 – the welding head

It minimizes the structural transformations in the weld metal and heat affected zone, the tendency to intergranular corrosion after exposure to welding thermal-cycle, reduces the probability of the formation of metastable structures, phases and the associated instability of the product dimensional characteristics in time.

As a result of CPE, dimensions of the core and compressive stresses in the sheet decreased, and they did not reach critical values, therefore, buckling did not occur, and the deformation of the sheet does not exceed the permissible levels.

Comparing the results of measurement of car sidewalls deformations assembled and welded with cooling and without cooling, it is seen that in cars that are welded with cooling, deformation is less than 60 – 70 %.

The use of CPE welding in the manufacture of diesel train car wall reduced labor costs by reducing the welding deformation and at the same time improve the quality of products.

Stakhanov Wagon Works "SWW" launched production of containers under the base of KAMAZ, GAZ trucks, etc. (Fig. 7).

The container is a thin-list structure made of VSt3ps steel in the form of duct with walls with thickness of 3 mm, reinforced ribs in the form of channel sections of steel bent VSt3 thickness of 3 – 4 mm. Semi-automatic welding CO_2 is used as a welding method. Welding mode: I_w=120 – 150 A, U_a=20 – 22 V, V_w=16 – 18 m/h. The current technology of the container provides for forced water cooling from the back side of the seam weld ribs in the form of U-sections (Fig. 8).

Fig. 7. Exterior view of the SWW

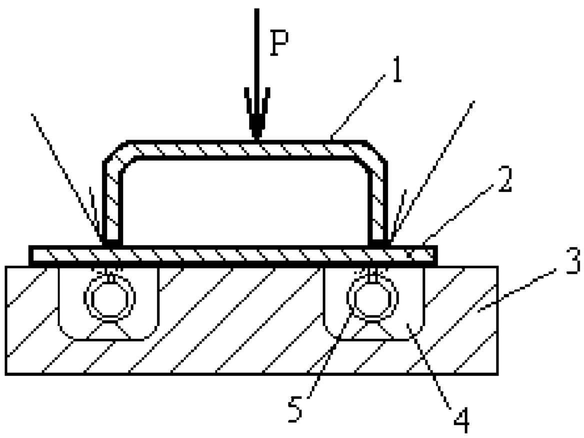

Fig. 8. Cooling scheme design for welding stiffeners: 1 – U-section, 2 – list 3 – bedding, 4 – trench, 5 – a tube with holes

The cooling results in a narrowing of the core sheet by 70 % and overall shrinkage force is reduced by 45% [17]. In addition , application center of the force is shifted up and to the various sections of the eccentricity of the application shrink force towards the center of gravity is reduced by an average of 20%. The total reduction in residual strain was 56 % compared to welding in the free state. As a result, the longitudinal deflection of 2.9 mm.

However, the allowable strain – 1 mm to 1 m long. To achieve acceptable values of deformations on the technology there are used clamping devices (i.e. anchorage welding)

We have proposed to use a combined method of forced heat (water and by CPE) to reduce the welding deformation. Container design has a number of nodes that are difficult to weld with forced cooling using the current technology, e.g. Fig. 9. The main challenge is to hold the refrigerant – water on the surface of a complex profile of welded parts.

Combined method of heat removal is illustrated in Fig. 8 and is the following. The nodes are welded water-cooled from the back side of the seam according to the existing technology, additional heat is performed by CPE, which is served at the welding torch from the front and in profile of the welded stiffeners in the form of a sill.

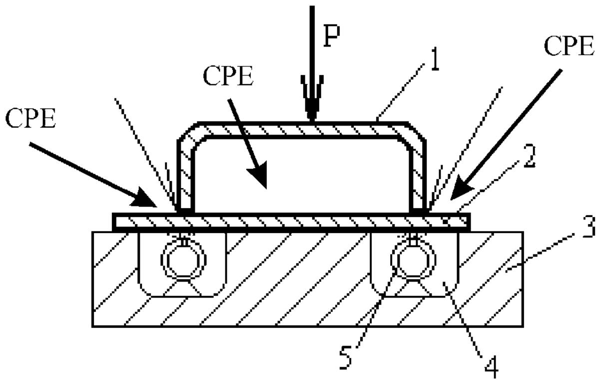

Fig. 9. Welding scheme of combined heatsink

Container units welding shown in Fig. 10 is implemented on standard welding modes recommended by the technology of the container manufacturing, with the forced cooling of CPE units. And also there are welded full-scale test sample data nodes in a CPE. Refrigerant in the form of CPE was fed to the front side of welded seams, as well as in the cavity formed by profile rolling in the form of U-sections and beams of rectangular, square cross-section forms, by introducing into the cavity of sleeve feed CPE.

Combined heat sink reduces the residual strain by an average of 60%, which makes it possible to abandon the cumbersome pressers and do not exceed the allowable values of deformations.

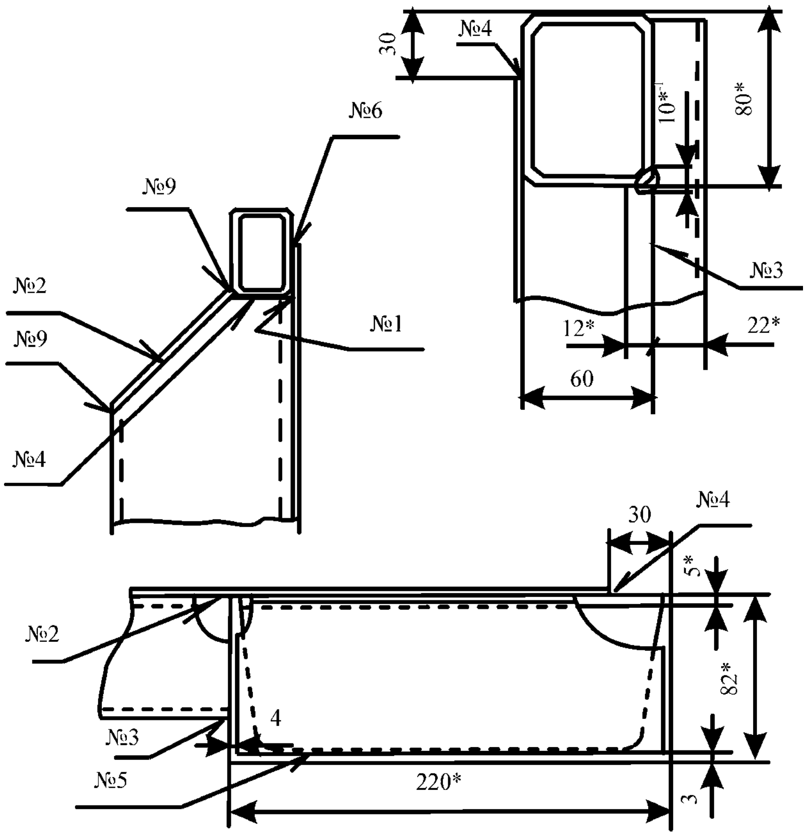

Fig. 10. Welded container sidewall nodes, welded with forced cooling by CPE

The results of this work provide a basis to conclude that the possibility of the use of welding the container in CPE, as well as the possibility of welding important structures of low carbon structural steel in CPE.

Chemical equipment nomenclature manufactured by the "Snezhnyansk khimmash" includes evaporators, liquid traps, adsorbers, filters, heat exchangers, rectificational column at manufacture of which there are used welding shells up to 6000 mm and a diameter of 1600 mm, the thickness of the metal 3, 4, 6, mm.

Relation of core sizes is different (Table 1), e.g., at a thickness of 3 mm, diameter 273 mm, length 1500 mm (Fig. 11).

Shells are made with one or more welds. All types of welding lead to a residual deformation, for example, bend along the longitudinal axis amounts to 6±2 mm, there is formed a non-circular cross-section, which requires calibration and post weld dressing.

For the manufacture of shells there were used VSt3sp, 09G2C, 15HM.

Table 1. The spectrum scheme for construction of welded oil separator, manufactured by "Snezhnyansk khimmash"

Обозначение	D_y	L	B	H	∅ А Б	Volume (m^3)	Mass (kg)
MOB-125	500	1900	650	670	125	0.320	240
MOB-150	600	2260	750	770	150	0.550	370
MOB-200	700	2360	650	870	200	0.630	480
50 MA	257	1230	440	420	50	0.05	102
80 MA	307	1350	480	490	80	0.078	140
100 MA	408	1800	550	550	100	0.180	227

For the manufacture of chemical equipment it is necessary to ensure receipt of designs with minimal deviations from the standard sizes. To minimize the welding strains on the shells there was proposed to use forced heat against welding torch. In the automatic welding shells 3 mm – 4 mm I_W=120 – 150 A, U_a=20 – 22 V, V_W=16 – 18 m/h, feeding CPE about 20 – 40 mm against the welding torch according to the proposed in [6], the deformation of deflection is reduced by an average of 40 – 50 %, thus reducing the cost and time for post-weld operations.

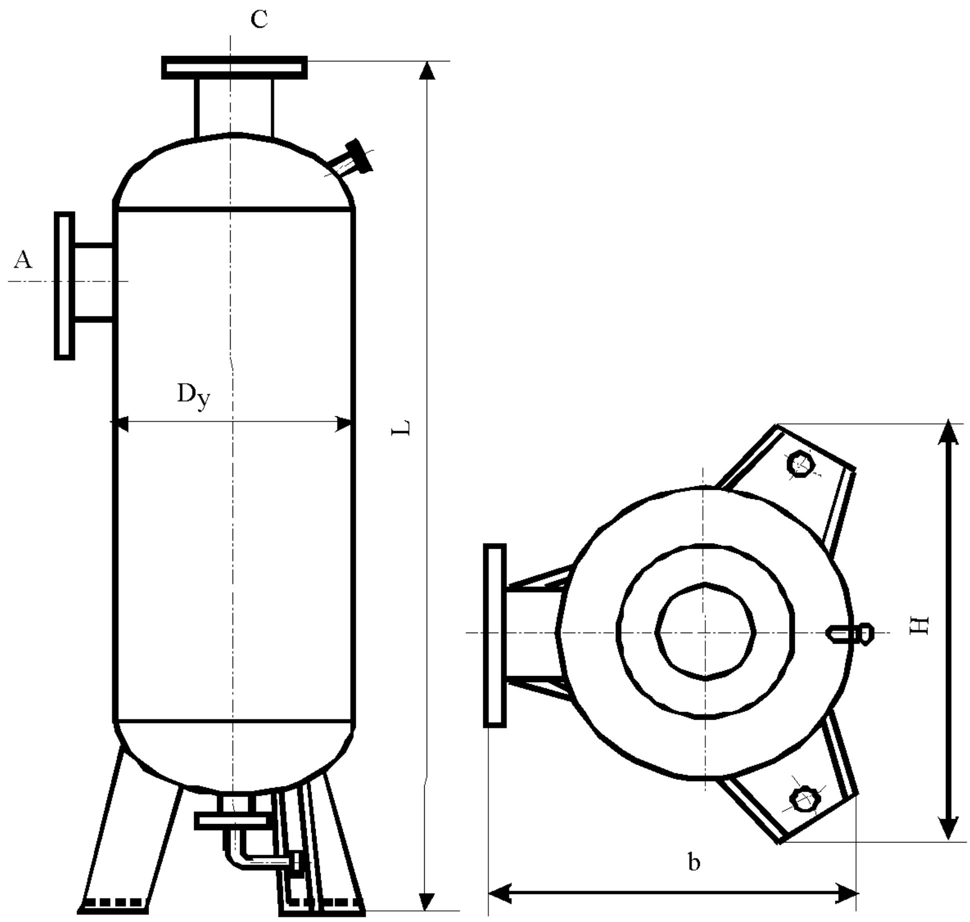

Fig. 11. Scheme for construction of welded oil separator, manufactured by "Snezhnyansk khimmash"

CONCLUSIONS

1. For ceiling seams welding as filler gas CPE there is a need to use helium (He) or a gas mixture which is lighter than air.

2. Changing the composition of the CPE can adjust the surface tension of the molten metal.

3. The use of the CPE, as the refrigerant is possible for constructions (welded nods) of any shape and contour, in any position.

4. Welding with the CPE fits easily into the process and helps to reduce residual stresses and strains.

5. When using a combined method of heat (water on the back side of the seam, and CPE – from the front) there is minimal residual deformation, which eliminates the anchorage of welded structures.

6. CPE may be used as a protective environment for products of structural steels.

7. There were suggested the methods and apparatus for welding of thin sheet hull structures with minimal residual strains.

REFERENCES

1. **Asnis A. and others, 1982.:** Welding in the mixture of active gases. – Kiev: Nauk. dumka. – 214. (in Russian).
2. **Druz O., 2011.:** Parameter association of the mode of welding with the sizes of area of plastic deformations. Publ. EUU., 2011. – №_E. // nbuv.gov.ua› Nvdu/2011_2/11donzpd.pdf. (in Ukrainian).
3. **Eremin E., Kulishenko B., Barmin L., 1976.:** Application forced cooling at welding of heat treatment transformer steel // Automatic welding. – № 8. – 14-18. (in Russian).
4. **Fomin O., Burlutsky O., 2013.:** Prediction trends exterior designs gondola by analyzing arrays infringement. Lublin. TEKA Com. Mot. i Energ. Roln. – OL PAN, 2013. – Vol. 13, No3. – 51-55.
5. **Galtsov I. and others, 2002.:** Method of the arc welding in the environment of foam: Patent. Ukraine : MPK[7] B23K9/035, B23K9/038/ – № 47739 A/UA, Statem. 27.08.2001, Publ. 15.07.2002, Bull. № 7 – 3. (in Ukrainian).
6. **Gedrovich A. and others, 2004.:** Merhod of reduction of remaining welding deformations and tensions Patent. Ukraine : MPK[7] B23K9/035,

B23K9/038 – № 64105 A/UA, Statem. 09.12.2002, Publ. 16.02.2004, Bull. № 2 – 3. (in Ukrainian).
7. **Gedrovich A. and others, 2008.:** Composition of complex protective environment: Patent. Ukraine : MPK[7] B23K09/04, B23K09/16, B23K35/36 – № 8374/UA, Statem. 09.11.2006, Publ. 12.05.2008, Bull. № 9 – 3. (in Ukrainian).
8. **Gedrovich A. and others, 2010.:** Features of welding in the complex protective environment of the thin-walled build constructions. Naukoviy visnik LNAU, 2010. – № 3. – 216-223. Lugansk: Publ. LNAU. (in Ukrainian).
9. **Gedrovich A., Shinkareva T., Golofaev A., 2011.:** Urgent problems of the working environment in the foundry. Lublin. TEKA Com. Mot. i Energ. Roln. – OL PAN, 2011. – Vol. XI A. – 225-231.
10. **Gedrovich A., Shinkareva T., 2012.:** The development of means for dust cleaningas an important direction for air improvement in the foundry. Lublin. TEKA Com. Mot. i Energ. Roln. – OL PAN, 2012. – Vol. 12, No3. – 136-139.
11. **Gidkov A.B. and others, 2000.:** Influence different ways of heatsink on an active area at welding // Automatic welding. – № 3. – 40-42. (in Russian).
12. **Gidkov A.B. and others, 2000.:** Application heatsink devices for the decline of welding deformations and tensions // Automatic welding. – № 2. – 45-49. (in Russian).
13. **Gidkov A.B. and others, 2003.:** Alternative technologie of adjusting deformations and tensions in welded metal wares: Scien. monogr. – Lugansk: publishing house EUU name of V. Dal, – 96. (in Russian).
14. **Gracheva K., 1984.:** Economy, organization and planning of welding production. – M.: Mashinostroenie, – 368. (in Russian).
15. **Gvozdetskiy V., 1974.:** Contraction post of welding arc. // Automatic welding. – №2. – 1-4. (in Russian).
16. **Kasatkin B., Lobanov L., Pavlovskiy V. and others, 1973.:** Absorb heat paste for adjusting of thermdeformative welding cycles // Automatic welding. – №11. – 46–48. (in Russian).
17. **Labeysh V.G., 1983.:** Liquid cooling of high temperature metal. – L.: Publishing house Leningrad University, – 172. (in Russian).
18. **Lenivkin V. and others, 1978.:** Influence of coverage of welding wire on technological properties of arc in protective gases. // Welding production. – №5. – 42-45. (in Russian).
19. **Lenivkin V. and others, 1989.:** Technological properties of welding arc in protective gases — M.: Mashinostroenie. – 264. (in Russian).
20. **Leskov G., 1970.:** Electric welding arc. M.: Mashinostroenie, – 335. (in Russian).
21. **Lobanov L., Pavlovskiy V., Loginov V., Pashin N., 1990.:** Adjusting of termdeformative cycles at welding of sheet constructions with application absorber heat // Automatic welding. – № 9. – 25-29. (in Russian).
22. **Paton B., 2003.:** Moden directions of researches and developments in area of welding and durability of constructions. // Automatic welding – №10-11. – 7-14. (in Russian).
23. **Paton B., Voropay N., 1979.:** Welding by the activated fluxible electrode in protective gas. // Automatic welding – №1. – 3-12. (in Russian).
24. **Pohodnya I. and others, 1991.:** Negative ions in the post of arc digit // Automatic welding – №8. – 22-25. (in Russian).
25. **Savich I., Maksimov S., Gusachenko A., Korobanova O., 1988.:** Estimation of weldability low-aloyed steel taking into account the rapid cooling in the conditions of the submarine welding // Automatic welding. – № 12. – 19-25. (in Russian).
26. **Savitskiy M. and others, 2000.:** Methods of application of activators for welding of steel in rare gas. // Automatic welding. – №3. – 34-39. (in Russian).
27. **Shebeko L., Gitlevich A., 1986.:** Economy, organization and planning of welding production. – M.: Mashinostroenie, – 264. (in Russian).
28. **Skulskiy V., Loginov V., Lipodaev V., Pavlovskiy V., Losi E., Savoley N., 1988.:** Welding steel 02X8H22C6 with the speed-up cooling // Automatic welding. – № 7. – 4-10. (in Russian).
29. **Wells M., 1986.:** Effect of forced gas cooling on GTA weld pools. // Welding Journal. Vol. 65. N12. 314-321.
30. **Yurev V., 1972.:** Reference manual on setting of norms of materials and electric power for a welding technique. – M.: Mashinostroenie, – 52. (in Russian).

ОСОБЕННОСТИ СВАРКИ С ПРИМЕНЕНИЕМ КОМПЛЕКСНОЙ ЗАЩИТНОЙ СРЕДЫ

Олег Друзь, Светлана Житная.

Аннотация. В данной статье изложены результаты экспериментальных исследований по сварке в комплексной защитной среде (КЗС). Приведены особенности сварки в нижнем и потолочном пространственном положении. Описаны возможности применения сварки с применением КЗС на предприятиях региона.

Ключевые слова: сварка, комплексная защитная среда, сварочные деформации.

Simulation model of abrasive material motion

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Summary. The paper describes a simulation model of the motion of an abrasive material, the implementation of which is developed to the special modeling algorithm. The model allows to predict the effect of the parameters of jet-abrasive two-phase flow on the distribution of abrasive particles on the surface of the rail for certain time, when starting and on the move. The author's computer program for the implementation of the simulation model is developed.

Key words: the two-phase flow, abrasive material, simulation model.

INTRODUCTION

Currently the problem connected with the appearance of wheel pairs of locomotives slipping and skidding is not solved sufficiently. Slipping and skidding take place when traction or braking force applied to the wheel from the side of the locomotive exceed cohesion force between wheel and the rail and so they are directly related to traffic safety.

Therefore, the main task when conducting the locomotive is to avoid an opportunity of appearance and increase the process of slipping or skidding through the realization of a consistently high value of cohesion coefficient of wheel and rail.

ANALYSIS OF RECENT STUDIES AND PUBLICATIONS

In works [4, 11, 13, 17] analysis of researches of methods for increasing and stabilizing the friction interaction of locomotive wheels with the rails is considered. It is known that many of them give an opportunity to significantly increase implemented coefficient of cohesion. For example, the positive effect is provided by chemical methods of cleaning the surfaces of rails, electric arc, plasma, laser cleaning, applying in a zone of contact of wheels and rails particles of solids and others. However, the application of most of these methods entails significant difficulties in the operation and might cause unwanted side effects, are uneconomic, etc. Definition of the most effective methods for increasing the cohesion of the wheels with the rails in operation is performed by the method of expert estimations, where it is necessary to involve knowledge, intuition, and experience of many competent and highly qualified professionals-experts [7, 11, 22].

Analysis of the results of the expert survey had showed that the most effective is the method of increasing the friction between wheel and rail is impact of two-phase jet-abrasive flow [3, 8, 14, 19]. In this case, abrasive material (sand) under the action of compressed air is directed on the surface of rail, affecting wheel-rail friction contact status, which is specifically:

- removing surface dirt,
- formation of surface roughness, which, depending on the mode of influence can provide a significant increase in the coefficient of cohesion,
- proper filing of sand in contact of wheel and rail.

In the works [9, 23] it is shown that, in terms of traction, the best result is achieved when applying sand in one layer with some distance between the grains (0.06 kg/m^2).

OBJECTIVES

Study of the process of movement of abrasive particles from the nozzle with consideration of various factors because of the high complexity of the retrieval and analysis of results in the implementation of the bench and field experiments, so the purpose of this work is to create a simulation model describing the influence process of the motion of particles on the dynamics of the distribution of the width of the rail head for certain time.

THE RESEARCH RESULTS

Created simulation model is based on the use of algorithmic models implemented on a personal computer, to study the process of the movement of abrasive particles. For realization of the method a special modeling algorithm was developed and a block scheme of it is presented in Fig.1. In accordance with it programmatically generated information describing the elementary processes of the system taking into account interrelations and mutual influences. The modeling algorithm was built in accordance with the logical structure of the system and with maintain the consistency of the proceeding processes and displaying the main states of the system.

The main stages of the developed model are:

1. Modeling the input and external influences.

2. Reproduction of the work of the modeled process (modeling algorithm).

3. Processing the simulation results and their interpretation.

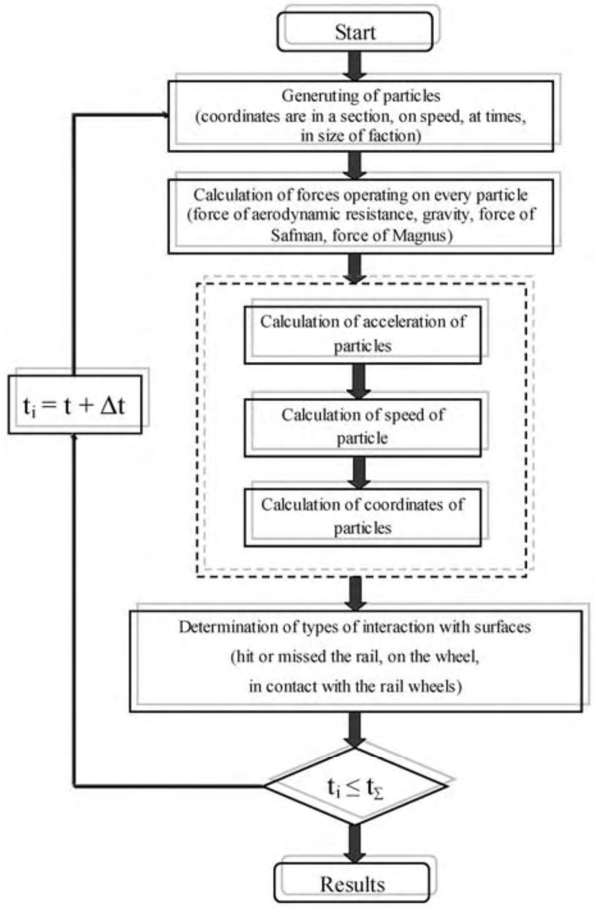

Fig. 1. Simulation model algorithm block scheme

The system may contain elements of continuous and discrete steps, be influenced by many random factors (a side wind, air eddies in the area of contact, etc), so the use of the developed simulation model allows to investigate dynamics of functioning of the process over time. The model allows you to easily change the values of parameters of the process and its initial conditions.

Simulation results are an important factor for decision-making when checking for new ideas, as it allows to investigate the large number of alternatives (options), considering different scenarios for any input. It allows to make predictions when discussing the future system or the studied processes in those cases when in reality it might lead to economic costs [17, 18, 21].

As this method of simulation is numerical, results obtained on completion of the simulation, correspond to the fixed values of parameters of the investigated process and its initial conditions. For the analysis of the developed method you need to repeatedly simulate the process of its functioning, varying the input data entering, so you can get the statistics of the results, which then can be approximated. Implementation of the developed model was made on a personal computer with high performance.

In the basis of the developed simulation model is the method of particles (discrete-cell), involving the calculation of provisions and the relevant parameters for each simulation particles at different points in time, and also an important feature of this method is the possibility of accounting for the effects of a large number of diverse factors. This allows you to get detailed space and time considering picture of the distribution of the particle flow on the surface. Model of the motion of two-phase flow describes the motion of particles, taking into account collisions of the particles in the flow and their reflection from the surface of rails and wheels. Performing numerical simulation of the motion of particle, size distribution, speed, time, and their spatial location in the cross section of the nozzle (coordinates of each particle), at the initial moment of time is determined by the terms of the problem as well as the technological parameters of the feeding device. Each particle simulation is set in accordance with one real particle number is a numerical experiment determined on the basis of the volume concentration of the flow specified in the initial conditions. Particles are modeled as hard balls with given density.

When describing two-phase flow (solid abrasive particles in the air stream) discrete-path based approach (Euler-Lagrange) is used. This is justified by the choice of the method of particles to create the model and the fact that this approach is used for simulation of two-phase flows with solid phase. Thus for the particles Lagrange method is used, and for the air phase it's Euler method [1, 10, 30]. For visual illustrations of opportunities of use of the Lagrangian trajectory method for studying the behavior of solid particles in turbulent streams of air [26, 27, 28] works can be considered.

The calculation scheme of the model of the motion of particles and particles parameters scheme at the exit of the nozzle is presented on Fig. 2, 3.

Let's consider the motion of particles through a pipeline under the influence of carrier air flow.

The distribution of particle size has been studied in metrological laboratory of PAO «Luganskteplovoz» on a universal measuring microscope UIM-21 (Fig. 4). For the research the abrasive material (sand moulding) is used according to GOST 2138-91 and images of it are presented on Fig. 5. The sand creates the best cohesion conditions of locomotive wheels with the rails as a result of homogeneity of particle sizes (0.2-0.5 mm), the largest quartz content (not less than 75%) and the minimum content of harmful, especially clay (not more than 3%), impurities and inclusions.

More clearly the geometrical form of the investigated abrasive particles can be seen and their sizes determined, using a microscope MPB-3 (Fig. 6).

The plot of the distribution density of values of the diameter of abrasive particles P_i is shown in Fig. 7.

Studied particles have clearly expressed a crystalline structure, and are rather close to spherical in shape. According to the classification proposed Murdasov A.V. in his works [15, 20], studied abrasive particles by type of form can be taken an isometric.

At the beginning of the modeling particles are generated according to the law of uniform distribution (from the theory of probability): coordinates in the cross section of the nozzle, speed, diameter and time.

Uniform distribution in the numerical line interval [a, b], a<b, is a probability distributions, having a density:

$$p(x)=\begin{cases}\dfrac{1}{b-a}, & x\in[a,b],\\ 0, & x\notin[a,b].\end{cases} \tag{1}$$

Distribution function is determined by formula:

$$F(x)=\begin{cases}0, & x\le a,\\ \dfrac{x-a}{b-a}, & a<x\le b,\\ 1, & x>b.\end{cases} \tag{2}$$

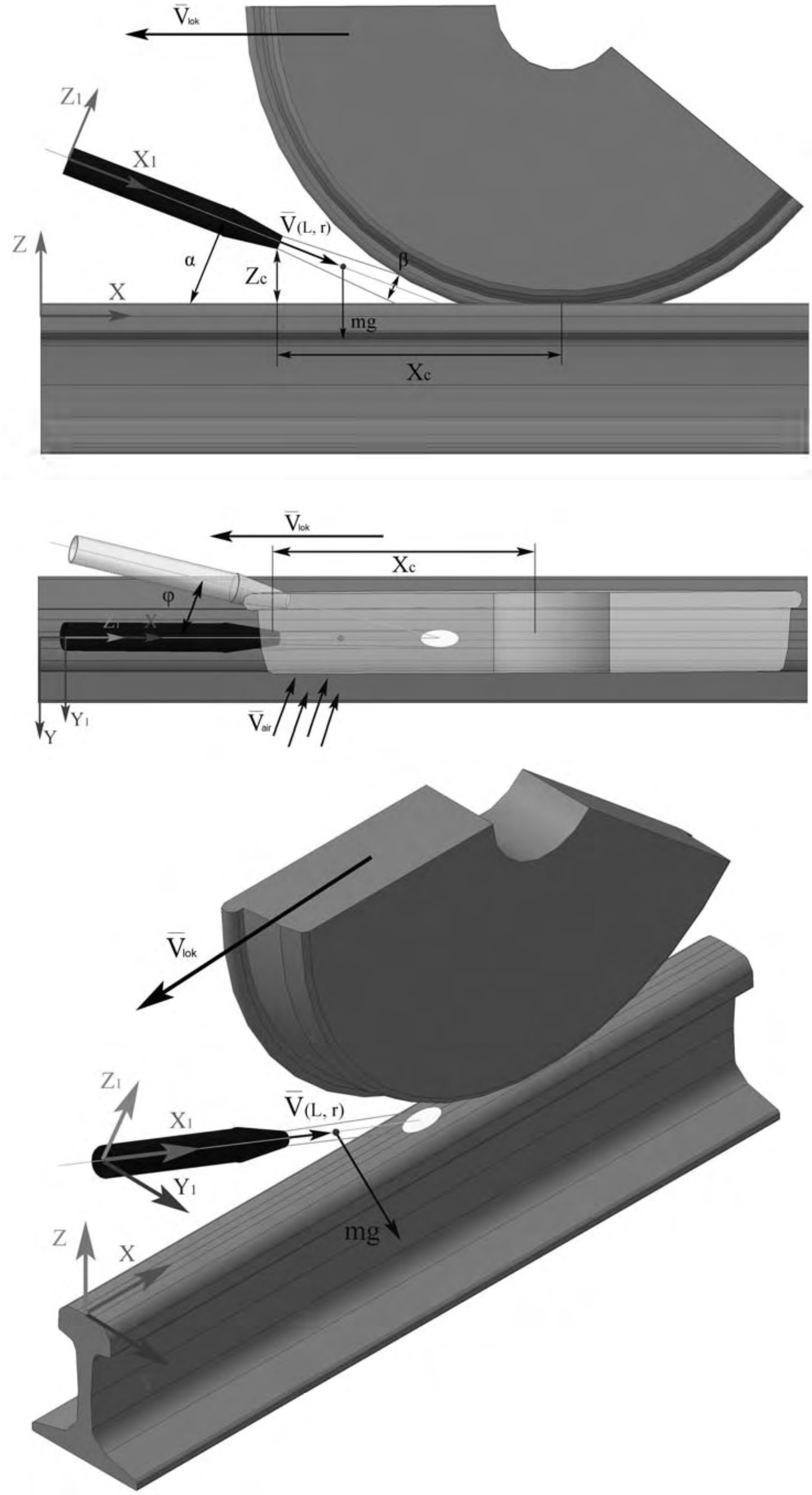

Fig. 2. Calculation scheme of particle movement modeling

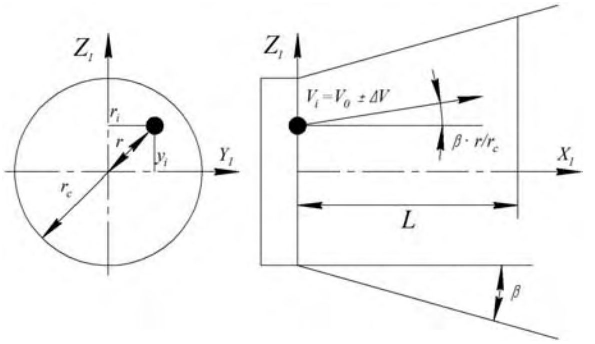

Fig. 3. Particles parameters scheme at the exit of the nozzle

Fig. 4. The universal measuring microscope UIM-21

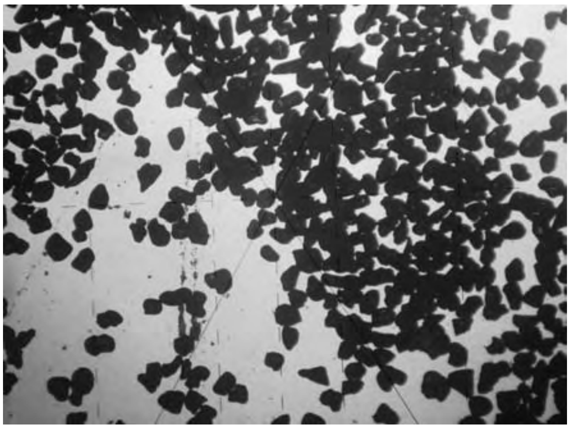

Fig. 5. Picture of abrasive material taken with UIM-21 microscope

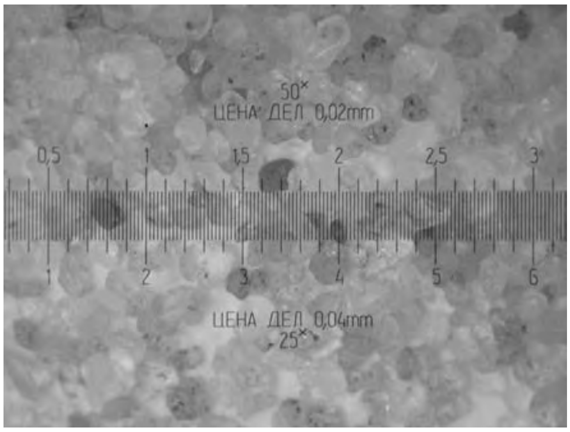

Fig. 6. Picture of abrasive material taken with MPB-3 microscope

And characteristics function respectively is:

$$\varphi(t) = \frac{1}{it(b-a)}(e^{itb} - e^{ita}). \qquad (3)$$

After an output from the nozzle the particles are influented by speed field of the carrier-phase, consisting of several air flows (Fig. 2): air stream from the nozzle $\vec{V}(L,r)$, locomotive movement conditioned air flow $\vec{V}_{lok}$ and wind conditioned air flow of arbitrary speed and direction $\vec{V}_{air}$.

Thus, the motion of the particles of sand from the nozzle to the contact surfaces of wheel and rail are exposed to the air flow with the speed of:

$$\vec{V}_n = \vec{V}(L,r) + \vec{V}_{air} - \vec{V}_{lok}, \qquad (4)$$

where: L is the distance from the nozzle exit,

r is distance from the central axis of the nozzle.

We shall consider $\vec{V}_{air}$ and $\vec{V}_{lok}$ have a uniform distribution of speeds and these speed and direction of flow are known. The orientation of vector $\vec{V}(L,r)$ depends on the orientation of the nozzle on the rail.

Immediately after the release of particles from the nozzle the process of expansion jets cross-section begins. It takes place because of influence of waves of depression, which penetrate the volume of jet and move particles, that are no more limited by walls of nozzle, its radius to the external border.

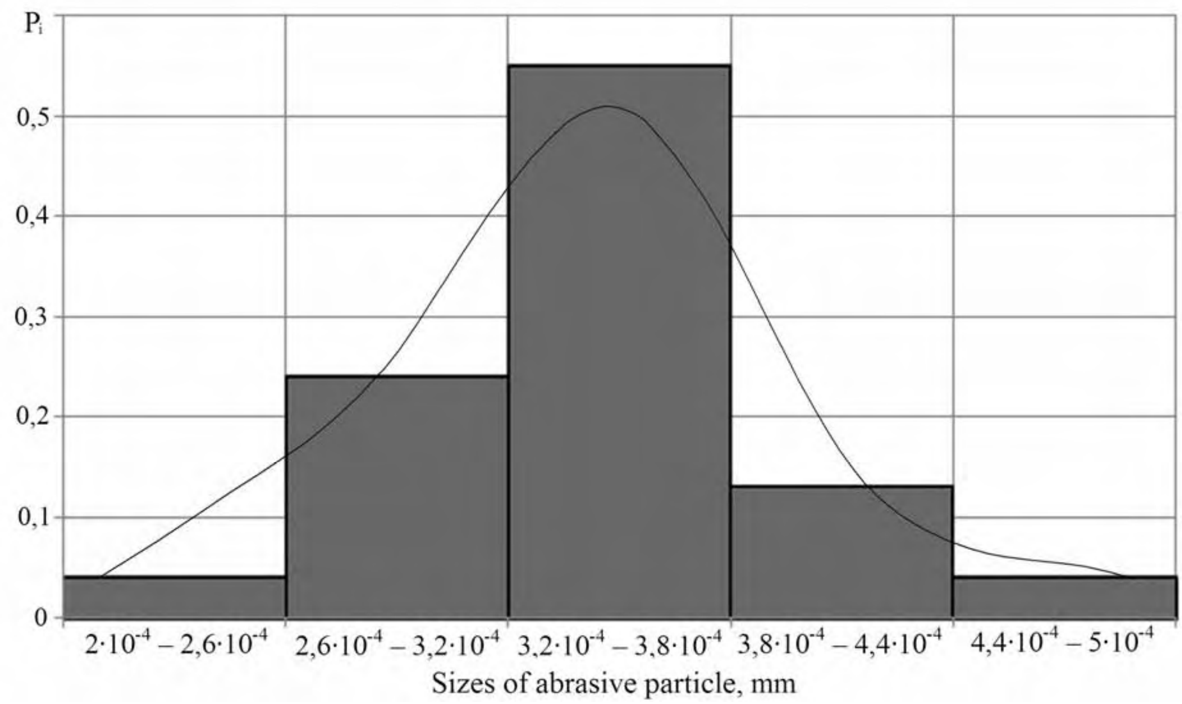

Fig. 7. The plot of the distribution density of values of the diameter of abrasive particles

For the description of the jet speed field as the distance from the nozzle use the dependence obtained in [31] when modeling of two-phase turbulent jet with solid particles:

$$V(L,r)=V_0\left(1-\frac{3c\rho_B L}{2d_a\rho_a}\right)^{1/2}\left[1-\left(\frac{r}{R_c+Ltg\beta}\right)^{3/2}\right]^2, \quad (5)$$

where: V_0 is initial axial flow speed at the nozzle exit, c is particle form depending coefficient, ρ_{air} is air density, L is the distance from the nozzle exit, d_a is the mathematical expectation of the diameters of spherical particles,

ρ_a is abrasive density, r_c is constructive nozzle radius, β is flow angle.

Equation of motion of a single solid particles in a turbulent gas flow is:

$$\rho_a \frac{\pi d_{ai}^3}{6}\frac{d\vec{V}_i}{dt}=\sum_k \vec{F}_i^k(r_a,t), \quad (6)$$

where: d_{ai} is diameter of i sand particle, $\vec{V}_i$ is speed of i-й particle, $\vec{F}_i^k(r_a,t)$ are external forces influenting the particle, r_a is particle coordinate, t is time.

Primary structural factors affecting the movement of particles in the flow of the carrier-phase are: gravity, the force of aerodynamic resistance, Safman force, Magnus force, turboforez force (due to the pressure gradient), the thermoforez force and interaction between the particles.

In the pipeline on a grain of sand force of aerodynamic resistance $\vec{F}_A$ (Fig. 8) takes action, cause of which is the difference in air velocity U and speed of a particle that moves in V (Fig. 9). The action of the aerodynamic resistance force leads to the acceleration of particles, if $U > V$ and, on the contrary, to the slowdown in the case when $U < V$. Formula of aerodynamic force has the following form:

$$\vec{F}_A = C_D\rho\frac{\pi d_p^2}{4}\frac{\left|\vec{U}-\vec{V}\right|\left(\vec{U}-\vec{V}\right)}{2}, \quad (7)$$

where: C_D is aerodynamic resistance coefficient of particles, ρ is the density of the gas, $\vec{U}$ is gas speed projection.

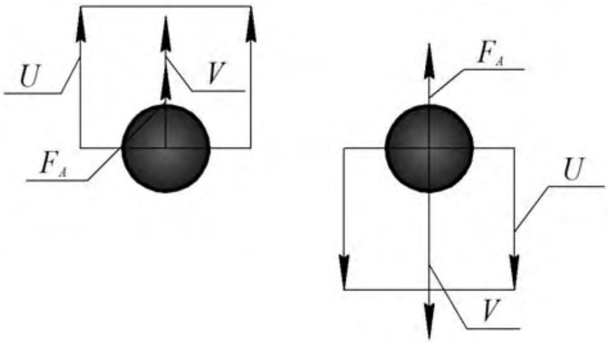

Fig. 8. Scheme of motion of a particle under the action of the aerodynamic resistance force

Along with the aerodynamic resistance force $\vec{F}_A$ gravity force $\vec{F}_g$ acts on the particle, which is one of the most important power of the factors determining the dynamics of the particles. Influence of gravity on the movement of particles will be significant and its accounting is needed.

An expression for the force of gravity has the following form:

$$\vec{F}_g = \rho_p \frac{\pi d_p^3}{6} \vec{g}. \qquad (8)$$

The heterogeneity of the profile of the averaged speed of carrying flow of air causes the action of the Safman force on a particle $\vec{F}_S$, the difference in relative velocities of the flow of the particles with different parties leads to the differential pressure. The motion of particles is performed in the direction of low pressure (Fig. 9) [28]. The Safman force acting on a particle moving in a stream with a linear profile speed is determined by the following formula:

$$F_S = k_S \nu^{1/2} \rho d_p^2 (U_x - V_x) \left(\frac{dU_x}{dr} \right)^{1/2}. \qquad (9)$$

In case when $U_x / (\nu dU_x / dr)^{1/2} << 1$, coefficient value is $k_S = 1{,}61$ [30],

ν is coefficient of kinematic viscosity.

Safman forces can have a significant impact on the movement of particles as they move in the near-wall region, where there are large gradients of the averaged speed of air carrier.

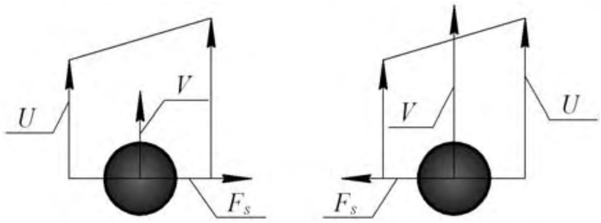

Fig. 9. Scheme of transverse particle motion in a nonuniform flow under the action of Safman forces

During movement in the gas flow particles of complex shape (non-spherical) always revolve. With regard to the spherical particles, they will also rotate in the flow of heterogeneous profile speed. Spinning particle entrains air. As a result, on the side where the direction of the flow and rotational elements of the gas are the same, the pressure becomes low in comparison with the area where these directions are opposite. Thus, the particle will move towards the low pressure (Fig. 10). The magnitude of the force acting on a particle at its rotation is described by the Magnus force $\vec{F}_M$ [2, 24]:

$$\vec{F}_M = k_M \rho \left(\frac{d_p}{2} \right)^3 \left(\vec{W} \times \vec{\omega}_p \right), \qquad (10)$$

where: $k_M(Re)$ – factor, variable depending on the Reynolds number,

$\vec{W}$ – the constrain speed of the flow,

$\vec{\omega}_p$ – speed of rotation of the particles.

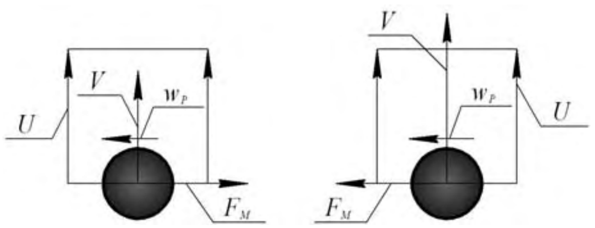

Fig. 10. Scheme of migration of a rotating particle under the action of Magnus force

Analysis of the influence of Magnus force on motion of particles held in [29]. It is shown that the Magnus force is almost always then Safman force. However, the neglect of transverse displacement of particles due to the actions of the Magnus force in high-speed flows, which are implementing large speed gradients of gas and, consequently, higher speed of rotation of particles, is illegal.

When departing from the nozzle on the particle there are the force of aerodynamic resistance from possible side winds $\vec{F}_{A1}$ and the force of air resistance from the movement of the locomotive $\vec{F}_{A2}$.

Reason of occurrence of thermoforez force is the heterogeneity of the temperature profile of the carrier gas. In view of the fact that in the present case, the temperature gradients are small, thermoforez force is not taken into account.

In [12] it's shown, when the supply of sand of locomotive sand system (1 g/l) already in the initial section of a jet in solid phase particles are moving segmentally not influencing each other. At a distance of 40 mm from the outlet section of the nozzle concentration of the flow decreases so that the free air space is more than 12 times the size of the particles and their probability of collision during the movement of the rail surface (or wheel) does not exceed 1%. Given this fact, the interaction between the particles can be neglected.

Turboforez force occurs because of the heterogeneous pulsing speed profile of carrier gas. In this work the turboforez force is ignored.

The algorithm of operation of the simulation model of the motion of abrasive material from the nozzle to the contact surfaces of wheel and rail (Fig. 1) is the following sequence of actions.

1. According to the given consumption of sand Q_n and the mathematical expectation of the size of abrasive particles (Fig. 7) is determined by the performance of the sand system (the number of particles in a unit of time). Then, using the model of a Poisson stream, each particle is assigned to the time of appearance t_i in the $0 \ldots t_\Sigma$ interval. In addition, each particle of the randomly settings:

– the starting point coordinates (y_i, z_i) in the nozzle section (Fig. 2, 3),

– speed of movement on exit from the nozzle in the range $V_i = V_0 \pm \Delta V$, где $\Delta V = 0.05 \cdot V_0$,

– speed orientation V_i,

– angle $\beta \cdot r / r_c$ to the flow axis,

– the size of particles in accordance with the distribution presented in Fig. 7.

2. At each step of integration, on the generated sequence of appearance of particles, the need to include in the calculation of particle condition $t \geq t_i$, where t is current time, is checked. If the condition $t \geq t_i$ is executed, the particle is included in the list of the particles in flight.

3. For each particle in flight, determined by the forces acting on a particle (right part of the equation 6). Using the Verle algorithm, according to which the calculation of the position of the particle is on its previous $\vec{r}(t-\Delta t)$ and current $\vec{r}(t+\Delta t)$ coordinate takes place. Given that the first derivative by time is speed $\vec{v}(t)$, and the second is acceleration $\vec{a}(t)$, numerical integration of the equations of motion (6) can be written as:

$$\begin{aligned}\vec{r}(t+\Delta t) &= \vec{r}(t) + \vec{v}(t)\Delta t + \frac{1}{2}\vec{a}(t)\Delta t^2 + \\ &+ \frac{1}{6}\vec{b}(t)\Delta t^3 + O(\Delta t^4),\end{aligned} \tag{11}$$

$$\begin{aligned}\vec{r}(t-\Delta t) &= \vec{r}(t) - \vec{v}(t)\Delta t + \frac{1}{2}\vec{a}(t)\Delta t^2 + \\ &- \frac{1}{6}\vec{b}(t)\Delta t^3 + O(\Delta t^4),\end{aligned} \tag{12}$$

where: t is time, Δt is step of integration of time, $\vec{r}(t)$ is the position of a particle at time t, $\vec{v}(t)$ is particle speed, $\vec{a}(t)$ particle acceleration.

Adding these two equations and expressing $\vec{r}(t+\Delta t)$, we have the following:

$$\vec{r}(t+\Delta t) = 2\vec{r}(t) - \vec{r}(t-\Delta t) + \vec{a}(t)\Delta t^2 + O(\Delta t^4). \tag{13}$$

As we integrate the equations of Newton, acceleration of particles are easily expressed through the force, which in its turn is a function of position $\vec{r}(t)$:

$$\vec{a}(t)=\frac{\vec{F}(\vec{r}(t))}{m}=-\frac{1}{m}\nabla U_p(\vec{r}(t)), \qquad (14)$$

where: m is particle mass, U_p particle potential energy.

The expression for the speed can be obtained by subtracting equation (12) from equation (11):

$$\vec{v}(t)=\frac{1}{2}\Delta t[\vec{r}(t+\Delta t)-\vec{r}(t-\Delta t)]+O(\Delta t^2). \qquad (15)$$

As a result, the new values are determined by accelerations, velocities and coordinates of the particles.

4. Using the new coordinates of the particles, a check is performed for the interaction of particles with the surface of rail and wheels. There are several variants of interaction:

➢ particle moves in the direction of the rail surface. In this case, there is no additional action,

➢ particle has reached the surface. In this case, you define the parameters for the interaction of particles with the surface (the particle speed at the moment of impact, angle of attack, the coordinates of the point on the surface, the speed with which the particle is reflected from the surface). Information about the interaction entered the statistics of particle interaction with a surface,

➢ particle got into the contact area between the wheel and rail. Information about the paid statistics particles caught in contact, and the particle is excluded from further consideration,

➢ particle crossed the boundaries of the space, which may be a collision with the surface of rail or wheels. Particle is excluded from further consideration.

5. If calculation time did not exceeded t_Σ, the calculation continues from the second paragraph of this algorithm.

6. After completion of settlements processing of statistics information about the interactions of particles with the surface of particles, trapped in a wheel-rail contact.

For modeling of the system on a PC as a computer program, modeling algorithm was recorded on the input universal algorithmic language C++ in the Borland C++ Builder 6.0 environement [5].In the program interface window (Fig. 11) input of the initial data for modeling is held.

Developed program the first time, the Using for a series of calculations for the purpose of selection of the parameters of filing of an abrasive material, providing the necessary modes of interaction of particles with the surface of the sand. Results of modeling are presented on Fig. 12-15.

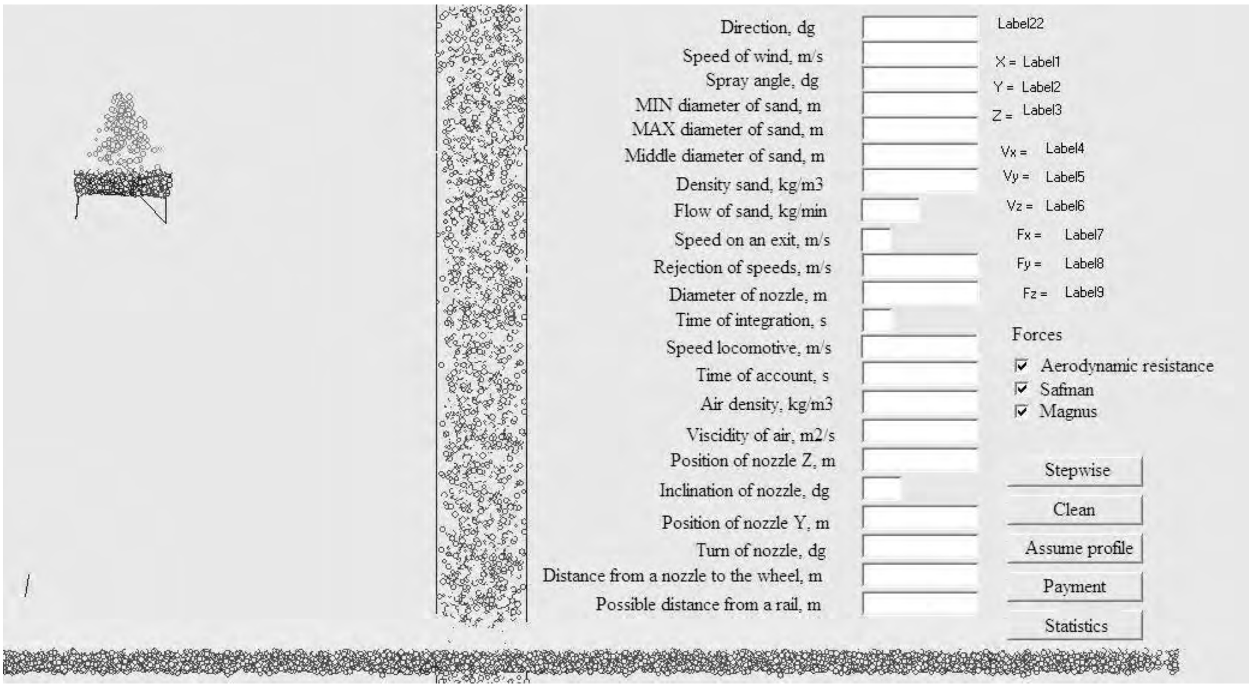

Fig. 11. The interface of the simulation model implemented in the form of a computer program

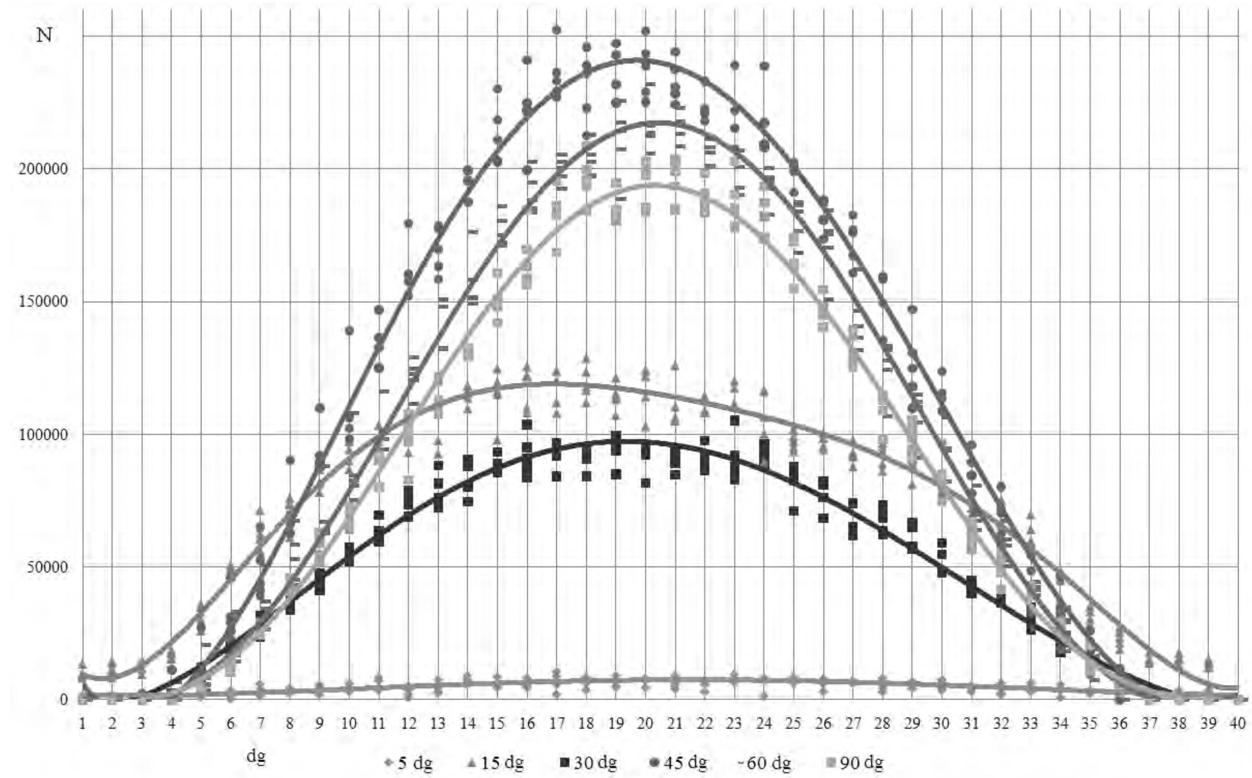

Fig. 12. Distribution of particles on the surface of rail from the different angles of filing

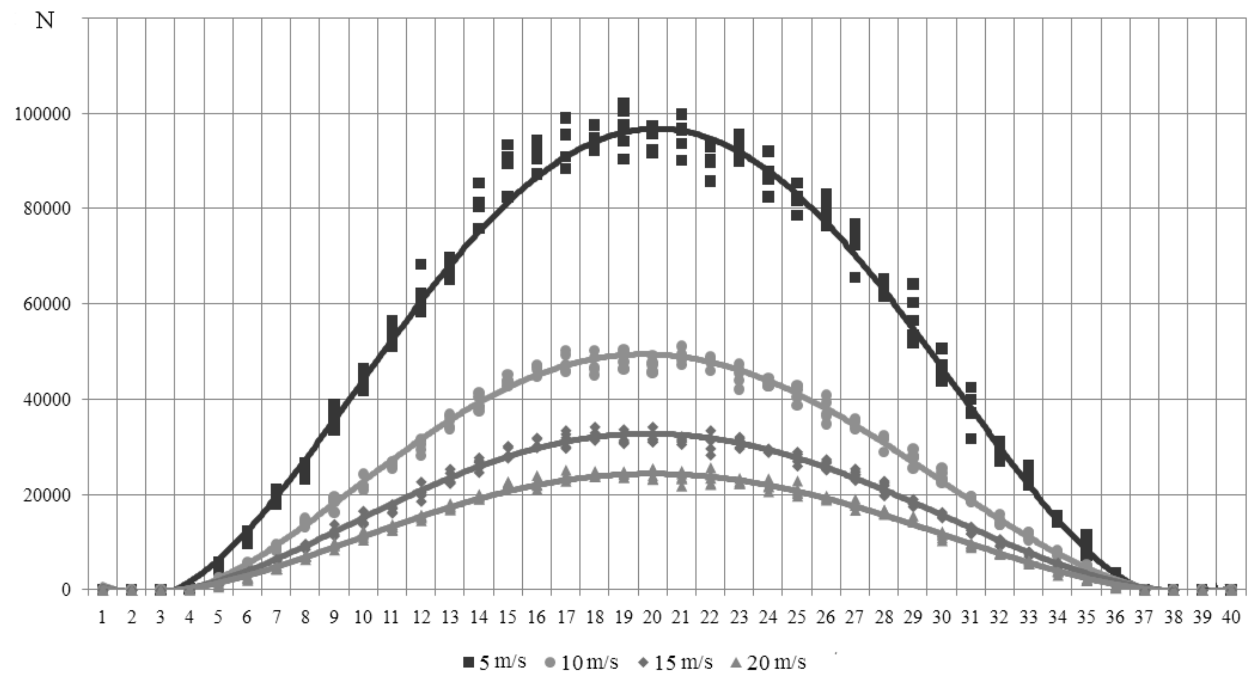

Fig. 13. Distribution of particles on the surface of the rail at various locomotive speeds (the flow speed is 10 m/s)

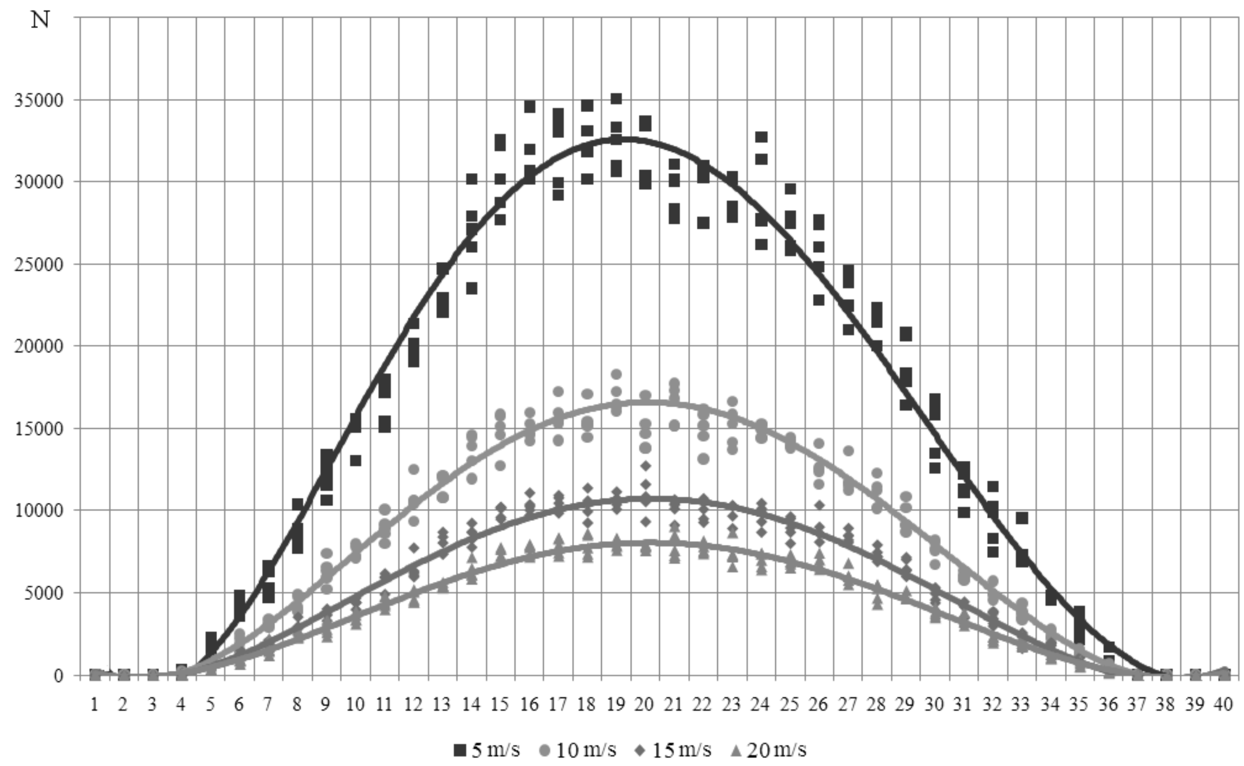

Fig. 14. Distribution of particles on the surface of the rail at various locomotive speeds (the flow speed is 30 m/s)

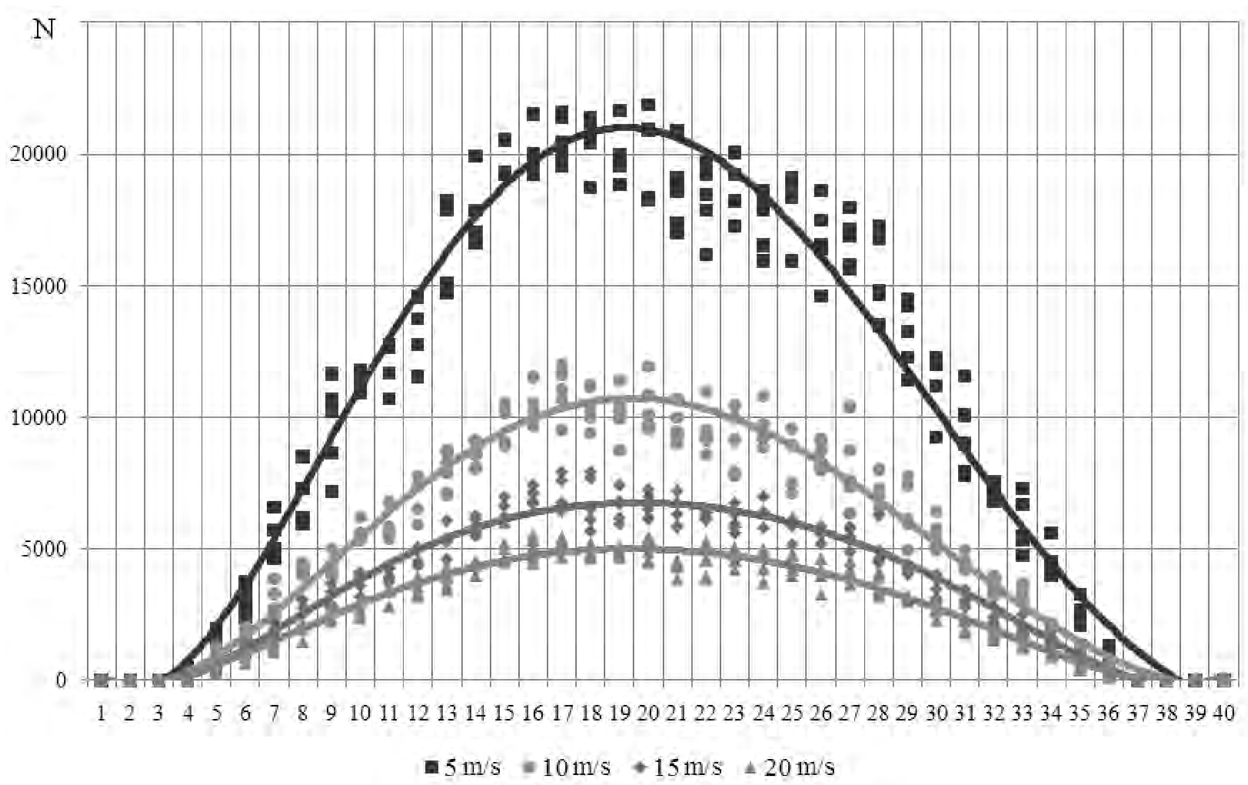

Fig. 15. Distribution of particles on the surface of the rail at various locomotive speeds (the flow speed is 50 m/s)

CONCLUSIONS

1. Modeling based on the first time developed simulation model of the motion of an abrasive material allows to predict the effect of the parameters of jet-abrasive two-phase flow on the distribution of abrasive particles on the surface of the rail for certain time, when starting and on the move.

2. The simulation results allow to adjust the parameters of the system of jet-abrasive influence on the formation of the surface layer of the rail and put up the dependence of the performance of this system on the speed of motion of a locomotive.

REFERENCES

1. **Belotserkovskii O.M., Davydov Y.M., 1982.:** Method of large particles in gas dynamics – M., 158. (in Russian).
2. **Dubnishchev Y.N., Rinkevichyus B.S., 1982.:** The laser doppler anemometry – M.: Nauka, 303. (in Russian).
3. **Golubenko A.L., Gorbunov N.I., Kashura A.L., Kostyukevich A.I., Kravchenko K.A., Popov S.V., Kovtanets M.V., Krisanov M.A., 2010.:** Patent of Ukraine № 48516 for utility model Method for increasing the adhesion of the contact patch of the wheel rail / № u200908745, stated. 20.08.2009, publ. 25.03.2010, bul. № 6, 6. (in Russian).
4. **Gorbunov N., Kovtanets M., Prosvirova O., Garkushin E., 2011.:** Clutch control in the system of "wheel-rail" // III International conference «Transport Problems 2011», Silesian University of Technology, 432-440.
5. **Gorbunov N., Kovtanets M., Kostyukevich O., Kravchenko K., Prosvirova O., 2013.:** Certificate of registration of copyright №47808 14.04.2013. (in Ukrainian).
6. **Gorbunov N., Kovtanets M., Nozhenko V., Prosvirova O., 2013.:** Analysis of the influence of jet-abrasive flow parameters on wheel and rail friction coefficient // TEKA. Commission of Motorization and Power Industry in Agriculture, Vol. 13, No.3, 68-74.
7. **Gorbunov N.I., Kostyukevich A.I., Kashura A.L., Vivdenko Y.G., 1998.:** About the methods of preparation to the acceptance of technical decision / Collection of scientific works East Ukrainian state university, Lugansk, 47-53. (in Russian).
8. **Gorbunov N.I., Kovtanets M.V., Kravchenko K.A., Mogila V.I., Petrenko V.A, Nozhenko V.S., Nozhenko H.S., 2012.:** Patent of Ukraine №69853 for utility model System increase friction coefficient in the contact zone of the wheel rail / № u201114163, stated. 30.11.2011, publ. 10.05.2012, bul.№ 9, 5. (in Russian).
9. **Haas S., 2005.:** Verbesserung des Haftwerts zwischen Rad und Schiene durch fahrzeugseitige ma durch fahrzeugseitige Maß ßnahmen / Schienenfahrzeugtagung, Graz, 24.
10. **Hockney R., Eastwood J., 1987.:** Method for simulation of particles / translated from English. – M.: World, 640.
11. **Khlebnikov V.N., 1976.:** Research of methods of increase of coefficient of rolling friction of wheels with rails / Railway transport abroad. – M.: CRITE MRP, 1976, №4(174). 18-34. (in Russian).
12. **Knothe K., Le-The. H., 1985.:** Method for the analysis of the tangential stresses and the wear distribution between two elastic bodies of revolution in rolling contact, Int. J. Solids Structures Vol. 21, №. 8, 889-906.
13. **Kovtanets M.V., Kravchenko K.A., Gorbunov N.N., Boyko G.A., 2012.:** Application of expert evaluation for adoption of technical solutions [Electronic scientific specialized edition] // Science news Dahl University: Lugansk, collected works № 7. (in Russian).
14. **Kostyukevich A.I., Gorbunov N.I., Kovtanets M.V., 2013.:** Experimental verification of the effectiveness of the jet-abrasive action on the rails to improve the frictional properties of the contact "wheel-rail" // Bulletin EUNU. Dahl № 18 (207) P. 1. Publisher EUNU. Dahl, Lugansk, 33-37. (in Russian).
15. **Koshin A.A., Sopeltsev A.B., 2010.:** Study of particle size distribution and microgeometrical performance abrasive grain grinding wheels used in the stripping grinding / Bulletin SUSU, № 10, 77-82. (in Russian)
16. **Krasheninin A., Osenin J, Matvienko S., 2013.:** Improving efficiency of train traction operational standards: an approach with usage of simulation // TEKA. Commission of Motorization and Power Industry in Agriculture, Vol. 13, No.3, 98-102.
17. **Luzhnov J.M., 2003.:** Adhesion of the wheels with the rails, The nature and regularities, M.: Intext, 144. (in Russian).
18. **Mikhailov E., Semenov S., Panchenko E, 2013.:** The possibility of reducing kinematic slip with two-point contacting with rail wheel railway vehicle // TEKA. Commission of Motorization and Power Industry in Agriculture, Vol. 13, No.3, 139-145.
19. **Mokrousov S.D, Gorbunov N.N., Kovtanets M.V., Shcherbakov V.P., Mogila V.I., Naysh N.M. 2013.:** Patent of Ukraine №77313 for utility model The method of increasing the adhesion of the contact patch of the wheel rail / № u201208878, stated. 18.07.2012, publ. 11.02.2013, bul.№ 3, 5. (in Russian).
20. **Murdasos A.V., 1968.:** Investigation of the process stripping grinding rental, Dis. PhD, Ural

branch of the All-Union Scientific Research Institute of Abrasives and Grinding, Chelyabinsk, 23. (in Russian).

21. **Nozhenko V., Gorbunov N., Mokroysov S., Chernikov V., Kovtanez M., Demin R., 2012.:** Experimental measurement complex running gear for research and of interaction conditions rolling stock .// An international journal on motorization, vehicle operation, energy efficiency and mechanical engineering.Vol. 12. № 4 Lublin – Lugansk.Teka, 190-196.
22. **Orlov A.I., 2005.:** Theory of making decision. Train aid. – M.: Publisher "Examination", 656 c. (in Russian)
23. **Osenin J.I., Marchenko D.N., Shvedchikova I.A., 1997.:** Frictional interaction wheel and rail – Lugansk: Publisher EUSU, 227. (in Russian).
24. **Smirnov V.I., 1997.:** Laser diagnostics of turbulence: dis. PhD: 01.02.05 – Moscow: MEI, 39. (in Russian).
25. **Somerscales E.C., 1981.:** Laser doppler velocimeter / Methods of Experimental Physics (ed. by Emrich R.J.). – London: Academic Press. V. 18 (fluid dynamics, part A), 93-240.
26. **Sommerfeld M., 1990.:** Nymerical simylation of the particle dispersion in turbulent flow: the importrance of particle lift forces and different particle/wall collision models / Numerical Methods for Multiphase Flows. ASME, Vol.91, 11-18.
27. **Sommerfeld M., 1992.:** Modelling of particle/wall collisions in confined gas-particle flows / Int. J. Multiphase Flows. V.18. №6, 905-926.
28. **Sommerfeld M., Qui H., 1993.:** Characterization of particle-laden, confined swirling flows by phase-doppler anemometry and numerical calculation / Int. J. Multiphase Flow. V.19. №6, 1093-1127.
29. **Tsuji Y., Morikawa Y., Tanaka T., Kazimine T., Nisida S., 1988.:** Measurements of an axisymmetric jet laden with coarse particles, Int. J. Multiphase Flow, Vol.14, 565-574.
30. **Varaskin A.Y., 2003.:** Turbulent flow of gas and solid particles – M.: FIZMATLIT, 192. (in Russian).
31. **Yurchenko V.A., 2005.:** Mathematical model of two-phase turbulent jet with particles of large diameter / Proceedings of the universities. North. – Caucasus. region. Ser. Techn. Science. Number 1, 51-55. (in Russian).

ИМИТАЦИОННАЯ МОДЕЛЬ ДВИЖЕНИЯ АБРАЗИВНОГО МАТЕРИАЛА

Николай Горбунов, Максим Ковтанец, Ростислав Дёмин

Аннотация. В работе рассматривается имитационная модель движения абразивного материала, реализация которой выполняется по разработанному специальному моделирующему алгоритму. Модель позволяет спрогнозировать влияние параметров струйно-абразивного двухфазного потока на распределение абразивных частиц по исследуемой поверхности рельса в течение определенного времени, при трогании и движении со скоростью. Разработано авторскую компьютерную программу для реализации данной имитационной модели.

Ключевые слова: двухфазный поток, абразивный материал, имитационная модель.

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Analysis of railway vehicle braking and assessment of technical solutions efficiency using risk-based methods for technical systems

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S u m m a r y. This article provides analysis of the factors that affect probability of skidding and reducing the braking performance of the vehicle. The analysis of advisability of applying the theory of the risks is provided to estimate the braking process of a railway vehicle to determine the probability of fulfillment of the condition non-skidding braking and making for further design and operational decisions. The analysis of the risk-based methods is provided with practical recommendations on its usage in the railway transport science.

K e y w o r d s. Train braking, risk theory, skidding, reliability, cohesion.

INTRODUCTION

VNIIZHT together with scientists from the University of Newcastle (NewRail), the Czech research Institute of railway transport (VUZ Velim), the Spanish Foundation of Railways (FFE), Australian railway research centre (CRC for Rail Innovation), Japanese technical research Institute of railway transport (RTRI), Turkish state Railways (TCDD), the Korean research Institute of railway transport, the Slovenian research Institute of railway transport carried out large-scale study to prioritize areas of scientific research, the development of which will be primarily to promote the effective development of railway transport.

According to the research data, traffic safety and the interaction of the wheel-rail system occupy the 2nd and 6th places in ranged list of 20 basic directions of scientific researches, as well as leading position in their respective clusters.

These fields of study correspond to the analysis of the rail vehicle braking process with the purpose of definition of probability of occurrence skidding with methods of the risk theory for technical systems, which is described in the article.

The analysis of the risk-based methods is provided with practical recommendations on its usage in the railway transport science. This responds to other high-priority research direction - intellectualization of railway vehicle engineering process.

BACKGROUND RESEARCH ANALYSIS

Currently methods of risk management of technical systems are widespread. Specialists in different areas of industry are interested in this subject. Methods based on risk assessment allow you to define, assess risks and take reasonable decisions to take measures for their elimination or reduction [30]. H.M. Son, V.N. Lubenko, V.N. Tryaskin according to the results of the analysis of the basic methods used for risk-analysis of technical systems, make a conclusion about the positive results of the application of these methods in the safety of technical systems ensuring complex.

In the Karpychev V.A., Andreev P.A. works through the analysis of distribution of failures of the basic units of the brake system, trends in the development of rolling stock and scientific works in the field of braking equipment indicated the urgency of substantiation of the parameters of the braking system from the conditions of skidding prevention of wheel pair through one of the methods of system analysis [26, 29].

In this article the condition of skidding prevention is also considered using the fault-tree method is given as the basis for forecasting skidding-free braking.

Reliability of operation of the studied object, as a general system indicator allows to systematize the solving of the multifaceted problems. Specifically, it allows to cover adverse factors influencing on the object that have different origins, and to consider their causal relationships in operation.

OBJECTIVES AND PROBLEMS

The article aims to analyze the possibility of application of existing methods of the theory of risk for technical systems and to predict the negative phenomena arising during a rail vehicle braking. Factors affecting the probability of skidding are considered as sources of system failures.

The other objective is the analysis of the risk-based methods to consider practical recommendations on its usage in the railway transport science.

RISK-BASED METHODS FOR ANALYSIS OF RAILWAY VEHICLE BRAKING AND ASSESSMENT OF TECHNICAL SOLUTIONS EFFICIENCY

Skidding is railway vehicle wheels slide on rails, in which the linear velocity of wheels surface is lower then the speed of the support surface relative to the vehicle. Rail vehicles skidding causes abrasion of blocked wheels in place of their contact with the rail and the occurrence of flat spot on the wheel bandage - so-called slider. The presence of sliders (asymmetry of the wheel relative to the axis of rotation) causes the increase of noise, vibration, asymmetric wear of rails.

Physical nature of braking force, as it’s based on the phenomenon of adhesion of the wheels with the rails, will always involve a certain probability of blocking of wheel pairs, and any change brake efficiency results in a corresponding change of this probability. It should be borne in mind that the relatively high probability of blocking is incompatible with the safety and leads to high costs for disassembly and repair of cars, small is conditioned by reduced brake pressing and, therefore, an extension of brake ways, negatively affecting the throughput capacity of railways [5-9]. Therefore, the task of ensuring the required traffic safety and the probability skidding-free braking arises.

The authors analyze the factors influencing the probability of skidding and methods of the decision on necessity of application of antiskid protection with the submission of risk theory for technical systems. To highlight the main groups of factors, it is necessary to analyze the condition skidding-free braking.

Mostly, blocking of wheel pairs is not instantaneous. Previously wheel-pair starts to slip, it’s speed is less than its translational speed of rolling stock [31]. This increases the braking force by rising the coefficient of friction. Therefore, the maximum amount of braking force is limited by the terms of cohesion of wheels with the rails. Therefore in order to avoid a skid maximum braking clicking accept is cosidered such that the braking force does not exceed the force of cohesion of wheel and rail. This is described by the following rule [13, 20]:

$$F_T^{\max} \le F_c \tag{1}$$

or

$$\varphi P_T \le \Psi P, \tag{2}$$

where: φ is adhesion coefficient, P_T is braking pads pressure on the axis, Ψ is cohesion coefficient, P is axial load.

In the base of the cohesion process there is friction interaction taking place between wheels and rails. Adhesive force has the friction forces nature, and as noted above, in the first approximation it is equal to the multiplication of the normal pressure of the wheel on the coefficient of wheel and rail friction. However, these values are not fixed and depend on the properties of the rolling stock and railway. Analysis of the factors influencing on implementation of braking forces [19, 25] allowed to present rate of locomotive cohesion as following:

$$\psi = \psi_o(\mu) \cdot \eta, \tag{3}$$

where: $\psi = \psi_o$ is the basic cohesion coefficient, reflecting the influence of frictional properties of the surfaces of friction of the wheels and rails, μ is the coefficient of static friction of the central rolling path of wheel along the rail, η is resulting factor of coupling weight of the locomotive. This parameter should be seen as multiplied influences of factors characterizing the influence of design features of rolling stock and rail, as well as the mode of trains motion on the grade of realization of the limit cohesion coefficient.

Thus, according to the results of the analysis of researches [3-5] there are the following groups of factors affecting the probability of skidding-free braking. This is, first of all, factors affecting wheel and rail cohesion. These include major factors of coupling weight of the locomotive, specifically:

- the impact of differences traction motors characteristics,
- the difference in the diameters of wheel pairs bandages,
- irregularity of static hanging on the axes and the wheels of the locomotive,
- sustainable redistribution of vertical loads on the axes, caused by development of brake force [11].

Another group of factors affecting the value of the coefficient of cohesion, coupling weight of the locomotive dynamic factors. These include:

- redistribution of the weight of the carriage from the inertial forces [13],
- redistribution of the weight of the carriage from the longitudinal dynamic forces [12],
- vertical loads and efforts along the axes of locomotives periodic oscillations.

Other cohesion coefficient factors are:

- influence of the curvilinear section of the way on the value of the implementation of the braking force,
- the coefficient of static friction of the wheel rolling along the rail central path,
- statical and dynamical wheelset disbalancing [28],
- presence of the eccentricity of the circle of the axle [10],
- hardness of the way [23].

During the analysis of factors leading to significant fluctuations in the values of the coefficient of cohesion of the wheels and rails, it was found that a considerable influence on the implemented cohesion coefficients is a change of frictional properties of the surfaces of friction of the wheels and the rails, dependent on many external factors. Thus, the following group of factors influencing the coefficient of friction is the state of the wheels and rails [19]. Significant impact on the contact surfaces and, consequently, on the value of the cohesion coefficient is provided by:

- air, as wetted parts of the surfaces working in the atmosphere, air humidity and atmospheric phenomena,

- lubricant, grease and other organic substances that enter the contact surface,

- mechanical impurities minerals - dross, dirt, dust, the products of wear of brake pads and wheels, particles of the transported cargo, etc.

Also, in addition to the factors of cohesion coefficient, it is necessary to take into account factors affecting friction coefficient of friction pair of the brake, as the braking force depends on it [15-17]. It can be attributed to such factors as following.

- speed of movement,

- specific pressing force of the shoe,

- materials of friction elements.

To assess the impact of the factors given above on the probability of skidding mainly empirical research are used, the results of which are presented in the form of dependence of the coefficient of cohesion or friction from a particular factor or their group. To determine the most important factors that should be considered in the calculations of probability, risk, and other characteristics of skidding-free braking, expert ranging is often used.

Large class of riskology methods used for the analysis of technical systems [9] is based on formalized views of the simulated objects, processes, goals, properties in the form of a set of characters (nodes, vertices) and alleged or actual relationships between them. Models of processes in the studied systems should reflect the emergence of individual prerequisites and their development in a causal chain of incidents in the form of charts, cause-and-effect relations, influence diagrams. Widespread chart in the form of a stream of graphs (graphs of states and transitions), event tree (targets, properties) and functional networks of various purposes and structures.

The most widely used type of influence diagrams are «trees» - graphs with branching structure and with additional logical conditions. The main advantages of these models are:

- comparative simplicity of the building,

- deductive nature of identifing cause-effect relations of the investigated phenomena,

- the direction of their significant factors, ease of conversion of such models,

- visibility of reaction of the system under study on the changing patterns,

- decomposition of the tree and the process of its consideration,

- qualitative analysis of investigated processes,

- ease further formalization and algorithmization,

- suitability for processing on the computing facilities,

- availability for statistical modeling and quantification of the studied phenomena, processes and their properties.

To review the process of braking as a model of the influence diagrams, you can use the results of analyses of factors affecting the probability of skidding, after reducing them to an appropriate form of presentation [22].

As shown, the majority of factors easy yield probability estimates and weights, in which they can be used to build the chart of influence in one or more of the forms given above.

When the analysis and evaluation of uncertainties associated with the event, risk is the possibility of losses as a result of system failure, and may be measured in the form of pairs of factors, one of which the probability of occurrence of an event, and another potential outcome or consequence associated with the occurrence of the event. This pair can be represented by the equation [24]:

$$R = P \cdot C, \tag{4}$$

where: P is the probability of occurrence of an unwanted event, C is the result of the occurrence of the event.

Risks of the system can result from interaction with dangerous natural phenomena of ageing and degradation or under the influence of human and organizational factors. Therefore, the risk can be classified as voluntary or nonfree, depending on the probability of events which lead to the risk under the control of persons at risk. Losses associated with events that can be classified as either reversible or irreversible, depending on the loss of property or life accordingly.

Risk assessment is a technical and scientific process in which the risks of this situation for the modeled system are considered. Risk assessment provides qualitative and quantitative information that decision-makers can use to manage risk. Risk assessment provides the answer to three questions:

- What can go wrong?
- What is the probability that this goes wrong?
- What are the consequences, if it's really going down?

To assess the risk the most frequently used methods are [31]:

- situational analysis - What-If Analysis,
- Checklist Analysis,
- Hazard and Operability Study (HAZOP),
- Failure Modes and Effects Analysis (FMEA),
- Fault Tree Analysis (FTA),
- Event Tree Analysis (ETA).

Risk assessment methods can be classified depending on how the risk is determined – by quantitative or qualitative analysis. In the framework of the risk analysis for the determination and assessment of the probability and consequences of the occurrence of an unwanted event is used expert opinion, quantitative analysis is based on statistical methods and databases. The choice of quantitative or qualitative risk assessment method depends on the availability of data for the assessment of risks and the level of convenience.

The situational analysis method [15] is a brain-storming, where the mapping information (hazard identification) is performed using a series of questions that begin with the «What if» words.

Questions are formulated based on experience. May be made any security considerations, even if it is not formulated in the form of a «What if» question. Questions are divided into specific areas of research, and a group of one or more knowledgeable people consistently refers to each area.

When using the situational analysis, the researchers are provided with a list of questions and answers regarding the issue. Also a tabular list of dangerous situations and their consequences, measures and possible recommendations to reduce risk can be received.

Analysis of the checklist [15] is a method, which is based on the features of the method of situational analysis associated with a brainstorming session, and that a more systematic, as it uses the checklist drawn up in advance on the basis of the experience. This checklist is a written list of items that can detect known types of hazards, the efficiency of the planning and potential emergency situations associated with the system, equipment or operations. It can be used to address specific elements of the system or procedures. Traditional checklists widely vary in depth and often used to determine compliance. Checklists are limited experience of experts, therefore, they must develop experts who have experience in various fields and experience in the analyzed systems. Checklists should be regularly checked and updated, which will ensure the possibility of their use at the moment. If the checklist is incomplete, units that are not listed, you can skip.

The results of this method are usually represented in the form of a table which includes the following:

- potential emergency situations,
- influence,
- safety measures in order to make an assumption about ways to reduce risk.

Analysis of hazards and operability (HAZOP) [15] is a formal systematic method for identifying hazards by enumerating the possible deviations from the normal course of operations and by assessing the consequences of these deviations. Deviation derived from a set of predetermined indicators, which help to structure and stimulate the creative process of finding potential deviations. Deviations are defined as those that are likely to have significant consequences, analyzing the future, identifying their possible causes.

The main activity is a key feature of the HAZOP is carried out by an interdisciplinary group of experts describe this system. HAZOP usually is carried out not for the physical system, and for a representative model of the system which is called «project model». Restrictions on its form do not exist, if it is clearly documented and understood by all members of the group.

The results of the method of HAZOP is that found the group of experts, including a list of identified hazards and issues arising during operations, the causes, consequences, security measures, as well as conclusions and recommendations for further analysis.

Analysis of the nature of failures and consequences (FMEA) [15] is a systematic method by which the analyst considers various situations and errors in the elements of the system components and evaluates the consequences of these errors.

FMEA is used in the analysis of individual errors in the system's components, which directly leads to an accident, or significantly contributes to its occurrence, but do not apply to the error message. Usually when analyzing hazards FMEA is used as a method of qualitative analysis, although it could be extended to rank the priorities allocated on the basis of the severity and probability of occurrence of errors.

FMEA allows analyzing the potential defects, their causes and consequences, to assess the risks of their appearance and is not detected in the design and manufacture, and also to take measures to eliminate or reduce the probability and damage from their appearance.

The results of FMEA analysis are presented in tables with a list of equipment, species and reasons for possible failures, frequency, effects, and criticality and means of detection of a malfunction (signaling and control devices etc) and recommendations for reducing the risk.

The probabilistic analysis is a riskology instrument as well. At the most fundamental level, the probability is expressed as a lifetime or annual probability of a fault.

Qualitative assessment of the probability of a malfunction, also called the probability of damage, can be defined as a measure of the propensity to damage to structures. The elements of a design may be subject to one or more types of damage, and in some cases they may be associated. In qualitative form of simple statistical analysis, combined with a technical judgment, can be used to assess the probability of a fault.

The classification scheme is the probability of a fault can be developed and contingent indicators can be defined for each category (Table 1). Classification probabilities in Table 1 includes four classes: an extreme, high, moderate and low.

In Table 1 there also presents the approximate scheme of indicators that can be applied to overcome probable damage.

Table 1. Example of the fault probability classification

Probability class	Probability indicator
Extreme	4
High	3
Moderate	2
Low	1

Expert opinion and experience, borrowed from other industries and the classification society rules, can be used as a guide for assigning probability of damage.

You can also develop a level of consequences. This is what happens implicitly when developing design standards. Consequently, different levels of security are depending on the severity of the anticipated consequences. The suggested approach (Table 2) these four levels: catastrophic, hard, significant, and low. To simplify the representation of the effects, introduced the category overall result.

Table 2. Example of the consequences classification

Consequences class	Consequences indicator
Catastrophic	4
Hard	3
Significant	2
Low	1

For assigning risk index each combination of the probability of a fault and fault consequences are used in Table 3. Risk indicators listed in the table are convenient to measure in a logarithmic scale. Risk indicators characterize the relative order of magnitude of risk. The choice of a logarithmic scale is not mandatory, but recommended for facilities due to the following mathematical properties of logarithms [2]:

$$R = P \cdot C,$$
$$\log R = \log P + \log C, \qquad (5)$$
$$R_I = P_I + C_I,$$

where: R_I is risk indicator, P_I is the probability, C_I is index of consequences.

The value of risk you can get on the Table 3 compiling a measure of the probability and consequences.

Table 3. Table of risks

Probability		Consequences			
		Low	Significant	Hard	Catastrophic
		1	2	3	4
Extreme	4	5	6	7	8
High	3	4	5	6	7
Moderate	2	3	4	5	6
Low	1	2	3	4	5

From the risks table we have the following.

- if $R_I \leq 4$, object has a low risk level,

- if $4 < R_I < 6$, object has a average risk level,

- if $R_I \geq 6$, object has a high risk level.

For estimation of technical condition of designs of a ship is the main question of the admissible values of wear or other defect.

Risk indicator for an item can be obtained by summing up the measure of the probability of malfunctions and investigation faulty item [2]. This approach allows you to select the elements of design with the different values of risk indicators that can be used for different purposes.

The economic uncertainty entails the influence of certain risk factors on their future earnings. Investment risks threaten the decrease of profit in comparison with the possible or even losses. So when making decisions on investment management firms, investment funds must necessarily take into account the impact of the investment risk.

To calculate the possible variants of the riskiness of the investment project, depending on various circumstances, use the following approaches:

a) an analysis of sensitivity of the project to changes of individual factors that affect yield. Such factors include price, cost, production cost of the equipment etc. Assessment of the importance of the influence of these factors on the overall profitability of the project, and in accordance with the results of the measures are taken on a thorough study of investment plans, and reduction of risk associated with the identified factors,

b) analysis of the forecasting scenarios of development of economic environment and the implementation of the investment project. The calculation is carried out in three variants:

- basic calculation of averages, the most likely conditions,

- optimistic scenario for the best course of events for all the factors affecting the profitability of the project,

- pessimistic scenario, in which lays the worst possible situation in the country and in the particular market,

c) method of statistical tests, which with the help of computer equipment is rendered by the many choices of return of the project based on the performance indicators-factors in the specified ranges of their change. As a result, the average statistical characteristics of their variation and distribution for further analysis of the most important indicators of project profitability and riskiness of the project in different directions.

For a quantitative estimation of investment risks there are different statistical-mathematical methods that calculate indicators of project efficiency in conditions unfavorable for investments event. In particular, the authors propose the use of Monte Carlo simulation to calculate the economic risk of the investment project on implementation of new technical solutions in the railway transport.

According to this method, first, we construct a mathematical model of the resulting index as a function of variables and parameters. Then, a series of simulation experiments is hold. The mathematical model is recalculated each time a new experiment. The results of all of simulation experiments are combined in the sample and analyzed using statistical methods to obtain a probability distribution of the resultant value and calculation of the main gauges of risk of the project.

In the general case the numerical method of solving mathematical problems modeling of random variables is called Monte Carlo method.

The scheme of the use of Monte Carlo method in quantitative risk analysis is this: we construct a mathematical model of the resulting index as a function of variables and parameters. Variables are considered random components of the project, value of which there shall be deterministic. The mathematical model is recalculated each time a new simulation experiment, during which the importance of the major uncertain variables are randomly selected on the basis of random number generation. The results of all of simulation experiments are combined in the sample and analyzed using statistical methods to obtain a probability distribution of the resultant value and calculation of the main gauges of risk of the project.

Application of the Monte-Carlo method in calculations of projects on introduction of new technical solutions requires the creation of a special software.

Development of computer software is necessary for the following reasons:

1) is the repetition of simulation experiments (more than 100 iterations),

2) used models are complex (very large number of variables accounting for the distribution functions, conditions of correlation and etc),

3) processing of simulation results is greatly simplified,

4) easy demonstration of the method.

The process of risk analysis of Monte Carlo can be split into three phases: mathematical model, the implementation of the simulation, analysis of the results.

The first step in the process of risk analysis is to create a mathematical model. Because of the actual Monte Carlo simulation is used a computer program, the main process of simulation is precisely the formulation of the model project. Each investment project requires the creation of its unique model. Therefore, its specific view -is fully a product of creativity of the developer.

The main logic of the procedure of construction of the model is the following: the definition of the variables included in the model, definition of the distribution to which these variables are subjected to the definition of related (functional and stochastic dependence between the variables).

Following this procedure, you need to create a model that will look as follows:

$$\mathrm{NPV} = f\,(x_1,\ldots, x_i,\ldots, x_n, a_1,\ldots, a_j,\ldots,a_m), \quad (6)$$

where: x_i are risk variables, n is number of risk variables, a_j are fixed model parameters, m is number of model parameters.

The definition of the variables included in the model is a separate stage of the risk analysis that reflects first of all the results of the study of risk at a qualitative level. For example, surveys of experts allow to select the most «narrow» place of the project.

In addition, an important role in the selection of key variables plays a sensitivity analysis, which calculation of rating of elasticities is made. On the basis of rating elasticities are selected most at risk variables, that is, those fluctuations that cause the greatest deviation of the results of the project. They can be included in the model.

However, the decision about inclusion of the variable in the model should be based on several factors, in particular:

1) the sensitivity of the project to changes in variables,

2) the degree of variables uncertainty (i.e. the possible ranges changed).

When forming a model, you must try to allocate as a risk variables only the most important, significant variables. The reasons for limiting the number of risk variables in the model are as follows:

1) increasing the number of dependent variables of the model increases the possibility of receiving contradictory scenario through the complexity in accounting and control dependencies and correlated,

2) increasing the number of variables grows costs (financial and time)required for a correct and accurate determination of their probability distribution and terms correlated.

If not specified condition of probabilistic dependency of the risk variables, it is considered that the variables are independent and follow some distribution.

Distribution law specifies the probability of choosing the values within a certain range. Standard investment calculations use one type of probability distribution for all project variables included in the estimated model is deterministic distribution when only the specific value of the variable is chosen with probability equal to one (p=1). Now, the basic model of the investment project can be regarded as a deterministic analysis and the private model for the deterministic risk variables.

For each risk variable is a random variable, in the process of creating a model, you must choose the type of allocation.

The task of selection of the distribution of the difficult primarily takes place due to the limited statistical data. In practice we often use such probability distribution laws as normal, triangular, uniform, discrete.

Algorithm for solving the problem of selection of the distribution is the following:

1) determine the possible limits of variation of risk variable (range),

2) choose a general view of the distribution law,

3) taking into account the range of variation of the variable and the overall evaluate the main numerical characteristics of the distribution law (continuous case) or assign a possible meaning of the risk variable probability of their implementation (the discrete case).

The problem of choosing the type of probability distribution is very important as the accuracy of the distribution law with the specified limits changes in the risk variables directly affects the quality of the model and the estimation accuracy.

The main stage of the simulation, in which with the help of computer program, the algorithm of the method of Monte-Carlo is set, is the stage of implementation of the simulation. It’s performed as follows:

1. The generation of random numbers is done by computer operations to retrieve a random number of independent and uniformly distributed on the interval [0, 1] of values. Each received new random number is set as the value of the distribution function for the relevant risk variable.

2. The value of each independent risk variable is restored as an argument of the probability distribution functions of the risk variable. This takes into account the existence of probabilistic dependency.

3. The values of the variables are substituted into the model and integrated parameter of efficiency of the project is calculated.

4. Set out in paragraphs 1-3 algorithm is repeated n times. The simulation results (i.e. NPV or other indicator), thus calculated and saved for each simulation experiment.

Each simulated experiment is a random scenario. The number of simulation experiments or accidental scenarios should be large enough to make the sample representative in relation to the infinite number of possible combinations.

Size of the random sample of n depends on the number of variables in the model, the range of values in risk variables, and from the desired accuracy of obtaining the results.

At this stage there is a problem to determine the error of simulation results depending on the number of simulation experiments. The choice of n is of great importance for assessment of the quality of the model, i.e. the accuracy of the distribution of the NPV and its characteristics.

The final step in the process of risk analysis is the analysis and interpretation of the results obtained at the stage of the simulation.

Analysis of the results of the simulation can be divided into two types: graphic analysis and analysis of the quantitative indicators.

The result of carrying out simulation experiments is a sample of n NPV values (or another result indicator).

The probability that the project will result below a certain value of the results, where the value of the index was below this value is multiplied by the probability of the realization of one of the observations.

Building a graph of the cumulative distribution of the frequency of occurrence of the results, you can calculate the probability that the outcome of the project will be above or below the specified value.

To conduct graphical analysis it is necessary to construct a probability distribution functions of the resultant value (NPV or other).

Thus, it is necessary to build a histogram of NPV. Histogram is important in the analysis of the results of simulation modeling, because it allows you to choose the distribution of the resulting index.

Histogram is built by splitting of variation series on k grouping intervals. The choice of k is carried out in accordance with the recommendations of mathematical statistics. Further on the consistency of the empirical data to the selected distribution law with the help of χ^2consent criterion.

As noted, the analysis of quantitative indicators is carried out for such characteristics of the investment project efficiency, as NPV, but similar calculations can be performed for other performance indicators.

The probability of realization of inefficient project is calculated on the basis of the test results after conducting a simulation. This statistic is a good criterion to assess the riskiness of the project, as is dimensionless and defines risk as the possibility of losses. At the same time, the probability of realization of inefficient project can be regarded as an indicator of the sustainability of the project. The smaller the value is, the more stable the project is, and generally less risky.

The authors have developed a computer program for risk assessment and economic security of introduction of innovative projects, which defines the break-even point, effects and costs of the innovative project on implementation of new technical decisions on railway transport for predictable values of the factors of effect and cost, using the method of Monte Carlo, that is performed by receiving a large number of realizations of the stochastic process, which is formed in such a way that its probabilistic characteristics coincide with the identical problem to be solved.

Исходные данные

Факторы эффекта

Фактор	Ед. изм.	Мин.	Макс.	Ср.
Энергосбережение (сырья)	грн.	600	1 500	
Ресурсосбережение	грн.	0	500	
Экономия трудозатрат	грн.	-60	160	
Экологосбережение	грн.	700	1 400	

Факторы затрат

Фактор	Ед. изм.	Мин.	Макс.	Цена
Интеллектуальные затраты	чел./час	25	40	40
Материальные затраты	грн.	200	500	1
Трудовые затраты	чел./час	8	16	20
Сервисное обслуживание	чел./час	2	10	20

OK Очистить

Fig. 1. Window of input parameters

In the first window of the program you must enter a minimum and maximum values of the factors of effect and costs, which are accounted for in the calculations (Fig. 1). Also for the factors of costs is the price.

In the next window, there are results of simulation of the stochastic process (Fig. 2). A law used to simulate the distribution of probabilities is converted normal. The tables contain data on the probability of the corresponding values of an effect or costs, break-even probability of the project.

For all tables are built columnar chart. The cost chart is illustrated (Fig. 3).

Thus, Monte Carlo method simulation is a development of scenario approach to risk analysis and simultaneously that could be attributed to the group-theoretic probability of risk analysis methods. On the basis of statistical data and expert estimates, analysts select laws of the distribution of some of the components of the project and on the basis of repeated simulation experiments with a given level of accuracy you can find the distribution of the resulting parameter and calculate its main characteristics: the expectation, variance, standard deviation.

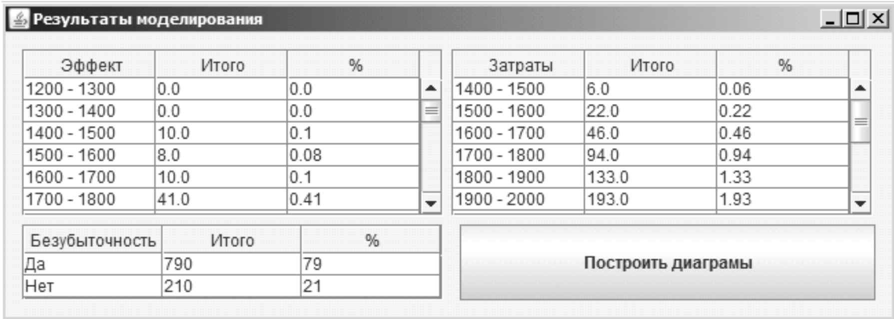

Fig. 2. The results of modeling

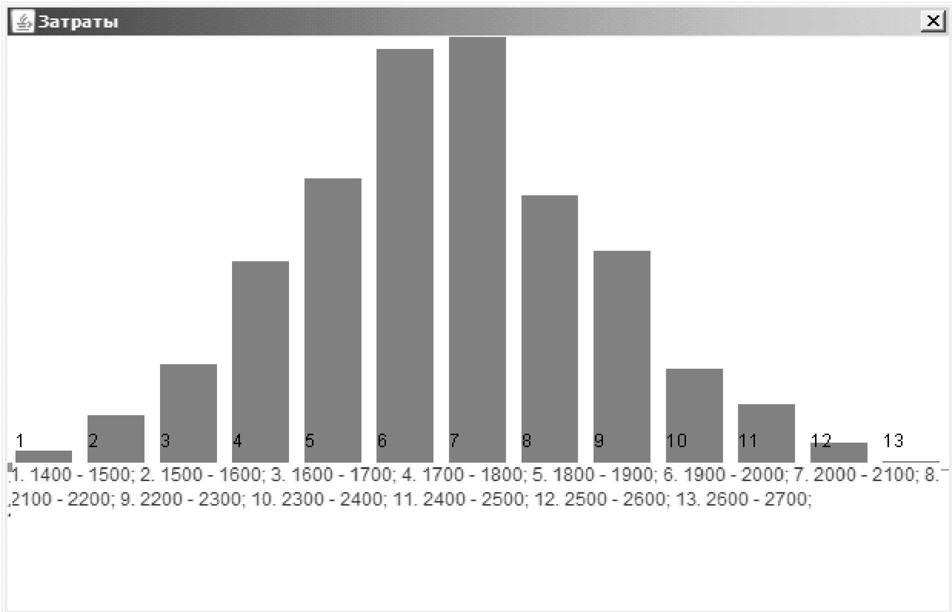

Fig. 3. Costs diagram

Simulation consists of three stages: the construction of mathematical model, the implementation of the simulation, analysis of the results.

At the stage of constructing a mathematical model of selected risk variables (random components of the cash flows of the project) on the basis of the rating and evaluation elasticities predictability variable, according to available statistical data and expert information for each risk variable is selected, the distribution, conditions are taken into account probabilistic dependency variables.

Simulation is performed using a specially designed computer program, which also contains estimates of the effectiveness of the project.

Integrated approach to risk assessment, implemented with the application of the Monte-Carlo method is that the analyst of different indicators: the probability distribution of the resulting design variable, estimates of the mean values of average standard deviation and coefficient of variation result indicator, any other special way designed measures of risk (ratio of expected losses, the probability of realization of inefficient project).

Investment decisions in railway transport can be based on the results of the visual analysis, i.e. the study of the risk profile and the cumulative risk profile, received in the result of the simulation.

Important gauge of integral project risk is the index of expected loss and the probability of realization of inefficient project.

CONCLUSIONS

1. Skidding of a rail vehicle leads to negative phenomena, such as abrasion of blocked wheels in place of their collision with rail, the arrival of the wheel bandages slide. Application of the theory of risk for technical systems for the analysis of the train braking of the vehicle to determine the probability of the skidding and the making a decision on the necessity of applying anti-skidding protection on the basis of the analysis of the factors affecting the fulfillment of the conditions of skidding-free braking allows qualitative analysis and quantitative assessment of the investigated processes are relatively easier to build, clarity, ease further formalization and algorithmization.

2. Analysis of existing methods of risk assessment for technical systems shows that the calculation of risk does not replace the existing system for the safety monitoring but is expanding its capabilities. Risk assessment allows developing the program of control of structural elements, starting with the initial control strategy and the last update of this strategy. In addition, according to the results of risk assessment, knowing zone structures with high level of risk, you can pre-plan the necessary volume of repair.

3. Analysis and determination of the values of the risk indicators allow not only assessing and forecasting the technical condition of elements of the system. On this basis it is possible to develop measures to increase the reliability of structures, justify the overhaul periods and to formulate the requirements to structural elements.

REFERENCES

1. **Ayyub B.M., Beach J.E., Sarcam S., Assakkaf I.A., 2002.:** Risk Analysis and Management for Marine Systems, Naval Engineers Journal,Vol. 114, №2, 181-206.
2. **Eddows E., Stansfield M., 2003.:** Decision-making Methods, M., 12-72. (in Russian).
3. **Golubenko A.L., Tiupalo N.F., Nozhenko Y.S., Mogila V.I., Vasilev I.P., Ignatev O.L., 2009.:** Effect of ozonation on the physical and chemical characteristics of diesel and biodiesel, Lokomotivinform, May-June, 9-13.
4. **Golubenko A., Mogila V., Nozhenko H., 2007.:** Energy of diesel locomotive's electrodynamic braking for increase of efficiency of diesel locomotive engines, Coll. of scientific labours, Zilina, Issue 69, 163-170.
5. **Gorbunov N., 2011.:** Clutch control in the system of "wheel-rail", Silesian University of Technology Faculty of Transport (Poland), Transport Problems, 432-440.
6. **Gorbunov N.I., 2011.:** Improving energy efficiency using disc brakes, Proceedings of the 3rd interuniversity scientific conference of teachers, young scientists and students, "Energy-saving technologies and the operation of machinery and equipment" (November 29-30, 2011), Donetsk: DonIZT, 97-98. (in Russian).
7. **Gorbunov N.I., Kravchenko E.A., Popov S.V., Kovtanec M.V., Nozhenko V.S., 2009.:** Increasing the technical and economic efficiency of the friction interaction between wheel and rail, Proceedings of the IX International Conference on Tribology and Reliability, October 8-10, St. Petersburg, PGUPS, 18-29. (in Russian).
8. **Gorbunov N.I., Mogila V.I., Kravchenko E.A., Prosvirova O.V., Skornyakov S.S., 2011.:** Brake disk, Application for Utility Model № u 2011 15061 from 19.12.2011, 5. (in Ukrainian).
9. **Grachev M.V., 2007.:** Risk analysis of the investment project, M: UNITY, 38-52. (in Russian).
10. **Isaev I.P., 1973.:** Condition of maximum use of force of coupling of wheels with the rails of the rolling stock, Some problems of mechanics of high speed rail transport, Kiev: Naukova Dumka, 17-26. (in Russian).
11. **Ivanovtseva N.V., 2007.:** Optimization adhesion of the wheels with the rails by improving the efficiency of the brake system of freight wagons, Avtoref. dis. cand.: 05.22.06, Almaty, 24. (in Russian).
12. **Kazarinov A.V., 1984.:** Improving the effectiveness of the braking means of freight trains with the optimal use of coupling of wheels with the rails, Dis. doct.: 05.22.07, M., 5-168. (in Russian).
13. **Kazarinov V.M., Vukolov L.A., 1961.:** Coupling coefficients of wheel pairs with the rails when braking, M.: Transport, Vol. 212, 5-28. (in Russian).
14. **Lisitsyn A.L., Potapov A.S., 1976.:** Choice estimated value of the coefficient of adhesion of locomotives, Electric and diesel traction, №4, 42-44. (in Russian)
15. **Lukasiewicz I.I., 2004.:** Analysis of financial operations, M.: UNITY, 28-87. (in Russian).
16. **Luzhnov J.M., 2003.:** Adhesion of the wheels with the rails, The nature and regularities, M.: Intext, 144. (in Russian).
17. **Malkov I., Sirovoy G., Kashkarov S., Nepran I., 2012.:** The analysis of adhesion effect on

properties of the modified polymeric nano composites TEKA. Commission of motorization and energetics in agriculture - Vol. 12, No.4, 131-134.

18. **Marchenko D., 2012.:** Investigation of the kinetics of the development of the distribution TEKA. Commission of motorization and energetics in agriculture – 2012, Vol. 12, No.4, 135-139.
19. **Meli E., Auciello J., Malvezzi M., Papini S., Pugi L., Rindi A., 2008.:** Determination of wheel rail contact points with semi analytic methods, Multibody System Dynamics, Vol. 20, 327-358.
20. **Mogila V.I., Nozhenko Y.S., 2007.:** Using wasted energy used for braking of the locomotive efficiency diesel engines, Collected scient. proceedings, Kharkov, UkrDAZT, Vol. 82, 153-157. (in Ukrainian).
21. **Mogila V.I., Nozhenko Y.S., 2010.:** Disposal of energy electrodynamic braking, Bulletin of the East-Ukrainian National University named after Volodymyr Dahl, № 3 (145), 237-243. (in Ukrainian).
22. **Moore. D., 1976.:** Fundamentals and applications of tribonics, M.: Nauka, 386. (in Russian).
23. **Popov V.A., 1984.:** Influence of the friction processes on the implementation of the clutch of wheel pairs of locomotives with rails: dis. cand.: 05.22.07, M., 206. (in Russian).
24. **Robb C. W., Zbigniew J. K., Ayyub B. M., 1996.:** Methodology for Risk-Based Technology Applications to Marine System Safety, Ship Structure Symposium ’96, November 18-20, Virginia, USA, 1-6.
25. **Shackleton P., Iwnicki S.D., 2008.:** Comparison of wheel–rail contact codes for railway vehicle simulation: an introduction to the Manchester Contact Benchmark and initial results, Vehicle System Dynamics, vol.46(1), 129–149.
26. **Smolyak S.A., 2008.:** Estimation of efficiency of investment projects in conditions of risk and uncertainty, M.: Nauka, 86-98. (in Russian).
27. **Stolyarenko G.S., 2000.:** Theoretical foundations of heterophase ozone processes and technology denitrification gas fluxes, Diss. doct., Kiev: NTU, 440. (in Ukrainian).
28. **Turkov A., 1982.:** The study, the choice of parameters and the development of the principles of designing a pair of disc brake friction of rolling stock, Dis. doct: 05.05.01, Khabarovsk, 349. (in Russian).
29. **Vetoshkin A.G., 2003.:** Reliability of technical systems and technogenic risk: Tutorial, Penza, 154. (in Russian).
30. **Vilensky P.L., 2007.:** Estimation of efficiency of investment projects, M.: Delo, 186. (in Russian).
31. **Zili Li, 2002.:** Wheel-Rail Rolling Contact and Its Application to Wear Simulation, Delft: University Press, 67-76.

АНАЛИЗ ПРОЦЕССА ТОРМОЖЕНИЯ ЖЕЛЕЗНОДОРОЖНОГО ТРАНСПОРТНОГО СРЕДСТВА и оценка показателей эффективности технических решений МЕТОДАМИ ТЕОРИИ РИСКОВ ТЕХНИЧЕСКИХ СИСТЕМ

Николай Горбунов, Ольга Просвирова, Екатерина Кравченко

А н н о т а ц и я**.** В статье приводится анализ факторов, влияющих на вероятность возникновения юза и снижения тормозной эффективности транспортного средства. Рассматривается возможность применения теории рисков для анализа процесса торможения железнодорожного транспортного средства с целью определения вероятности выполнения условия безъюзного торможения и принятия дальнейших конструктивных и эксплуатационных решений. На основе анализа методов оценки риска предоставлены практические рекомендации по ее использованию в области железнодорожного транспорта.

К л ю ч е в ы е с л о в а**.** Торможение, теория рисков, надёжность, юз, сцепление.

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Researches of influence of electric current on tribounit "Wheel-rail"

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Summary In-process studies of influence of electric current passing through the contact of two interactive rollers on their wear at varying of size of strength of current and attached loading are undertaken in and experimentally theory, and also the coefficient of friction is certain at the different friction states of surface of rail.
Experimental studies are undertaken an on the machine of proof-of-concept SMC-2 on PAT "Luganskteplovoz", and also on the automated instrumentation-designing stand setting "Machine of friction" in a laboratory on the department of railway transport of the Volodymyr Dahl East Ukrainian National University. The mechanism of influence of electric current is educed on tribounit, what application of this method allows to ground for the increase of coupling in the system "wheel-rail".
Key words: electric current, coupling, heat, electric wear, mechanical wear, coefficient of friction.

INTRODUCTION

From processes what be going on in the contact of interactive inter wheels and rail, efficiency of hauling rolling stock depends on the whole [1-5]. The size of coefficient of friction renders large influence on the terms of co-operation in the system "wheel-rail" and, in the end, on the running expenses of railways [6, 7, 14].

For the improvement of coupling internals of locomotives on a railway transport apply a method that consists in the serve of sand in the zone of contact of wheels with rails. Depending on the state of contacting surfaces of wheels and rails, such method can provide 30% increase of coefficient of rolling friction [2, 8, 12]. In spite of obvious dignities, application over of sand his use brings and to the negative consequences: contamination sand of ballast prism, to 20% to the increase of resistance of motion [9, 10, 11, 13], in addition, sand is the strongest abrasive and considerably influences on the wear of wheel and rail increasing an adhesion and abrasive wear, that in turn effects on safety of motion of rolling stock. In accordance with the programs of Ukrzaliznytsia introduction of high-speed motion requires the search of energy effective methods and methods of increase of coupling with the least affecting environment.

Analyzing the existent methods of improvement of friction co-operation of wheel it is set with a rail (Fig. 1), that providing stably of high coefficient of rolling friction in the zone of contact of wheel with a rail can be attained by two methods - cleaning of contacting surfaces from contaminations or introduction to the zone of contact of different substances (activators).

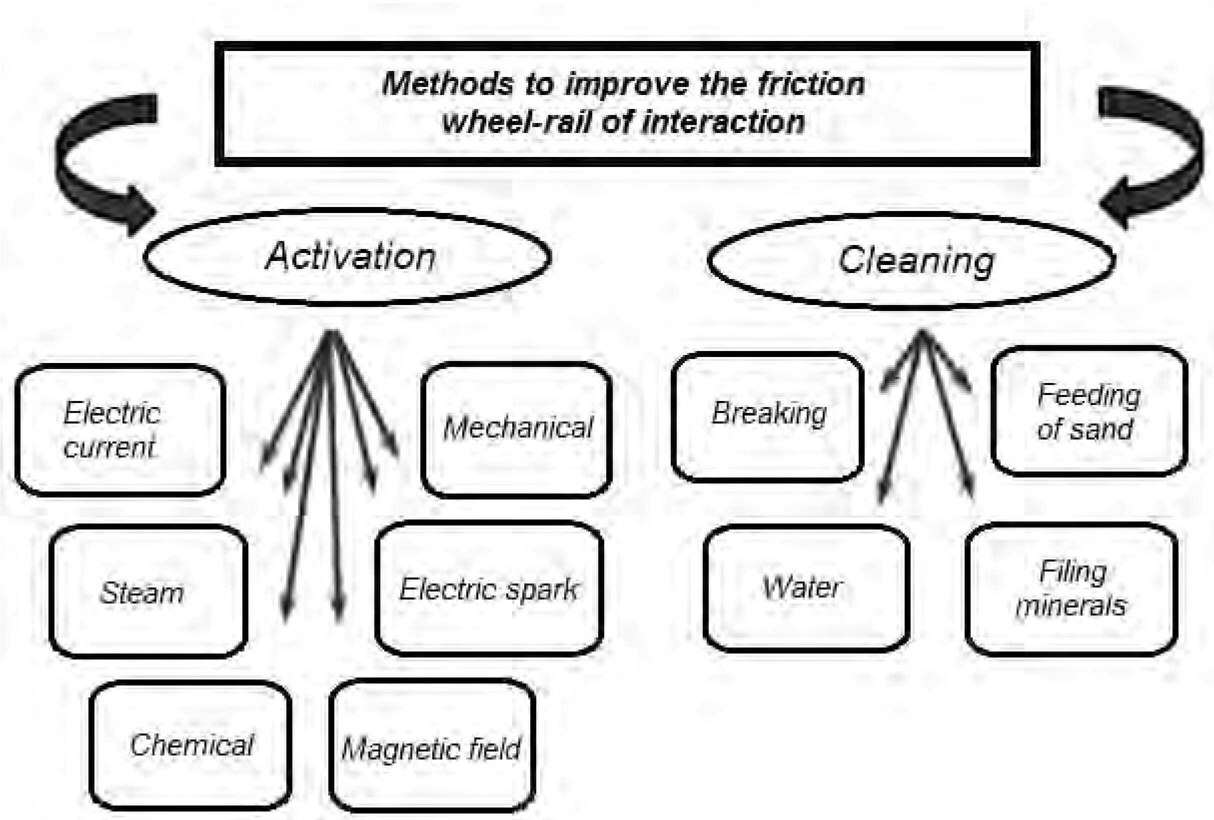

Fig. 1. Methods of improvement of friction cooperation of wheel with a rail

Researches are known sent to the search and development alternative to sand of methods of increase of coefficient of rolling friction is the use of modifiers of friction [15, 16, 17, 18], surfactants substances [19, 20], activators of friction [21, 22].

In-process [23], influence of electric current passing through a contact is investigational, on his tribology properties. The prospect of this method by implication is confirmed by the data got during exploitation of electric locomotives. It is set that their maximum coefficient of rolling friction higher on 8% at diesel engines that is probably related to the key-in of electric current through the contact of wheel with a rail [14]. However, conducted analysis of literary sources as in our country so showed abroad, that research on determination of influence of electric current on worn down of pin pair "wheel-rail" not conducted.

Aim of the article: Determination of influence of electric current on friction properties of contact "wheel-rail".

Materials and research results.

For research of processes a leak in a contact "wheel-rail" at flowing of electric current it is necessary to conduct their detailed analysis. One of parameters, characterizing the process of contact of wheel with a rail is warm, distinguished here.

In ground of tribounit, warm, distinguished at a friction is the result of friction of skidding that results in a mechanical wear. At a key-in through the pin pair of electric current additionally distinguished warm, that heats tribounit also. It is related to that the real contact of wheel with a rail will be realized not on all surface of interface, and only in a few points total area of that, and is the real surface, because of what at the key-in of electric current, there is transitional resistance or resistance of narrowing. Flowing of electric current through a contact, possessing transitional resistance, causes his heating. As a result of heating of pin zone there are current bridges appearing between contiguous rollers are melted, material evaporates or burns down. As a result there is an electric wear.

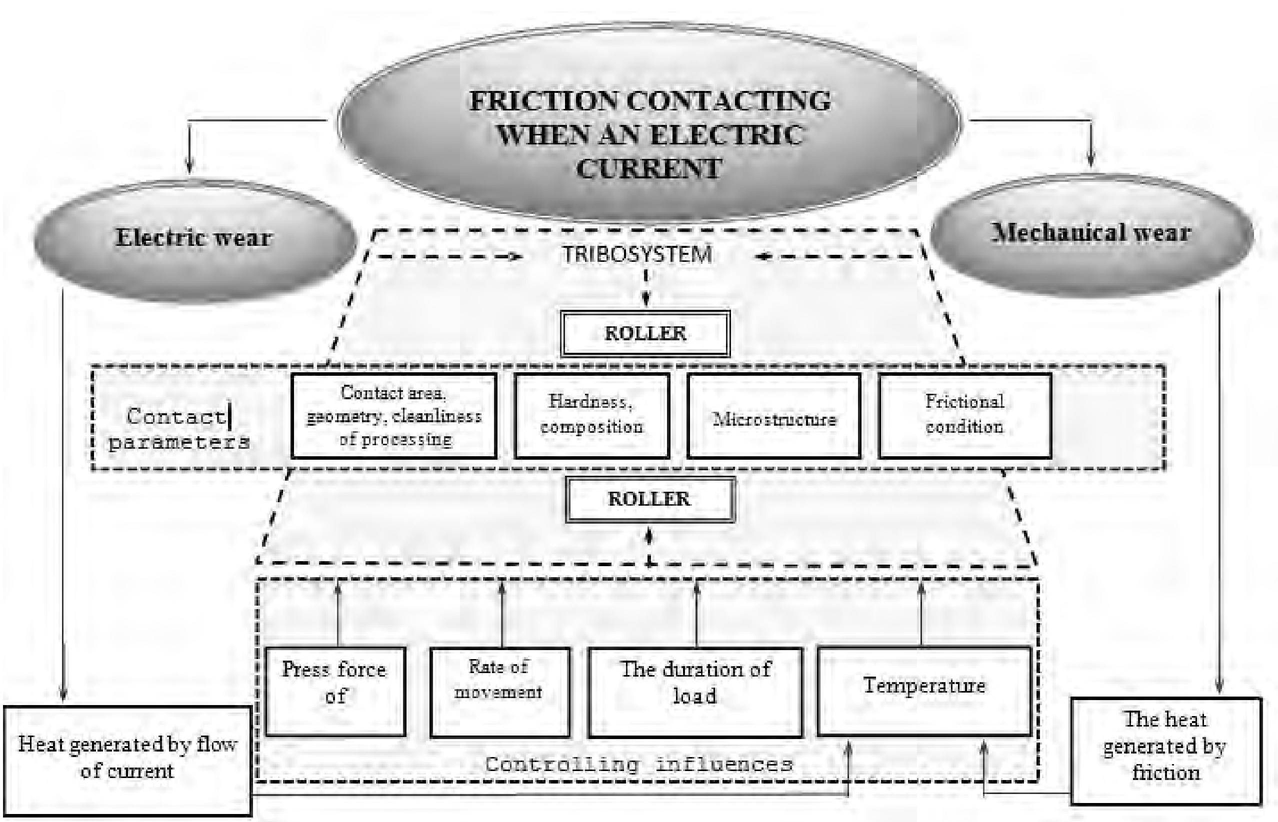

Fig. 2. Block diagram of processes in the contact under the influence of electric current

Thus, at the key-in of electric current in tribounit except a mechanical wear observed electric wear (Fig. 2), size and character of that is in a great deal determined by efficiency and perspective of this method of increase of coupling.

Theoretical pre-conditions of influence of electric current on the size of wear of tribounit were fixed in basis undertaken studies presented below.

Basic data at the design of mechanical wear it was been: loading on the standard of P, H; radius of spherical surface of r, m; speed of skidding of v, m/s; time of test, t, s; hardness of contacting materials of H1 and H2; heat conductivity of material of pin element λ1, W; specific heat capacity of material s, J/K [8, 9]. That allowed to define the size of mechanical wear of tribounit:

$$i_м = P \cdot \left[e^{\alpha} \cdot \left(\frac{P \cdot t \cdot c}{r^2 \cdot \lambda_1} \right)^{\beta} \cdot \left(\frac{v \cdot t}{r} \right)^{\gamma} \cdot \left(\frac{H1}{H2} \right)^{\varepsilon} \right],$$

where $\alpha, \beta, \gamma, \varepsilon$ – coefficients determined experimentally.

Influence of electric constituent is examined, as an additional external parameter of tribounit, that affects descriptions of contact. A general electric wear is determined by dependence [25]:

$$W = sP\left(W_0 + W_1 \sqrt{I/10} \right).$$

Taking into account higher expounded an electric wear is equal:

$$i_Э = \left[\gamma Q + \frac{sP}{9.81} \cdot \left(W_0 + \frac{k1}{P^{k2}} \cdot \left(\sqrt{\frac{I}{10}} + k3 \cdot \sqrt{\frac{Q}{s}} \right) \right) \right] \cdot \rho \cdot 10^{-6},$$

where: k1, k2, k3 – coefficients chosen from tables [23],

Q – amount of heat, J,

P – pin pressure, H,

ρ – density of material, kg/m3.

The results of design of mechanical and electric wear are presented on a Figure 3.

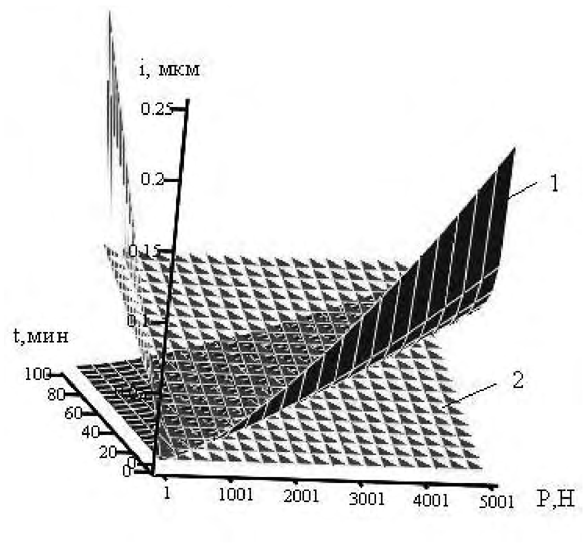

Fig. 3. Dependence of the attached loading (P, H) and wear (i, mkm) in time (t, s) at passing of electric current through a contact "roller-roller; 1 – electrical wear (ie), 2 – mechanical wear (im)

At a design influence of electric current is certain in time on the wear of the investigated standards (Fig. 3). An electric wear (surface 2) prevails at the small vertical loading that is investigation of presence in the pin pair of the undestroyed contaminations possessing high transitional resistance. With the increase of loading and destruction of contaminations transitional resistance falls, amounts of heat of distinguished in a contact diminishes, and an electric wear goes (surface 2 (Fig.3)) down.

A mechanical wear (surface 1 (Fig.3)) increases with the increase of loading, that confirmed by researches [26, 27].

For confirmation of basic conformities to law of influence of electric current on a wear tribounit "roller-roller" experimental studies are undertaken on the proof-of-concept machine of SMC-2 (Fig. 4).

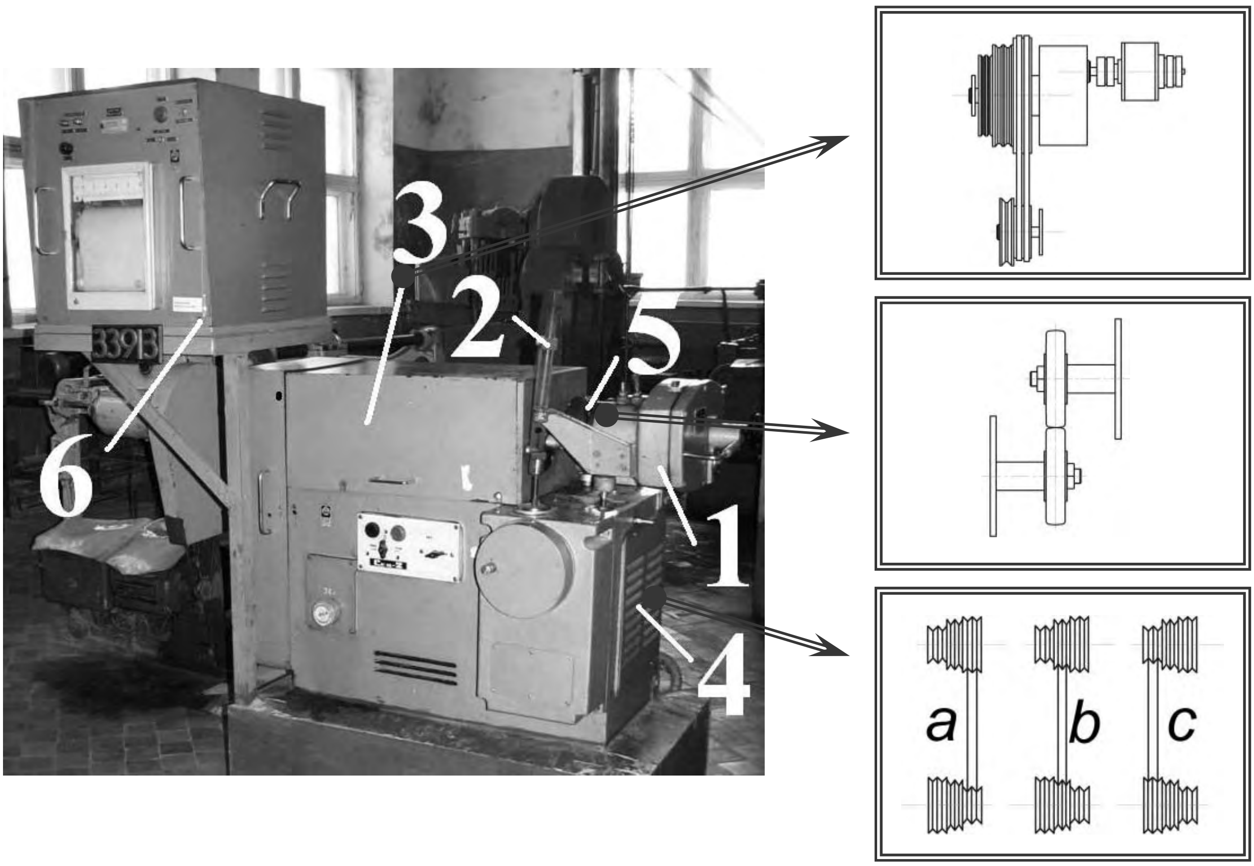

Fig. 4. test machine SMC-2
1 – carriage 2 – loading mechanism 3 – wheel drive, 4 – belt transmission (a – 300, b – 500, c – 1000 rev/min), 5 – system "movie-movie"; 6 – electronic unit

The machine of model of SMC-2 (Fig. 4) is intended for the tests of materials on a wear and determinations of their friction properties at a friction skidding and wobbling in the conditions of normal temperature in the pair of friction "roller-roller" and additionally equipped by the system of serve of electric current (Fig. 5), that includes:

- a transformer TDM–500,
- a transformer of current,
- an ammeter.

Turn-downs of parameters of work of SMC-2 here were in next limits:

- frequency of rotation - 300, 500, 1000 turn/mines,
- a coefficient of slipping of round standards with identical diameters – 0, 5, 10, 20%,
- a range of measuring of loading – 0...5 кН.

As experimental standards the rollers made from collotype bracer steel were used. Overhead and lower rollers have an outward diameter a $40{\cdot}10^{-3}$ m, internal diameter a $16{\cdot}10^{3}$ m and breadthways a $10{\cdot}10^{-3}$ m, hardness of surfaces makes according to 269 HB and 350 HB, the cleanness of treatment corresponds 7 to the class concordantly GOST 2785-75.

The aim of experimental researches was determination of work of forces of friction in a contact "roller-roller" at a leak through him electric current on conditions of close to the real contact "wheel-rail".

The way of friction was determined on dependence:

$$S = 2b \cdot \frac{V_1 - V_2}{V_1} \cdot n \cdot t \ ,$$

where: b – semi width of plane of contact:

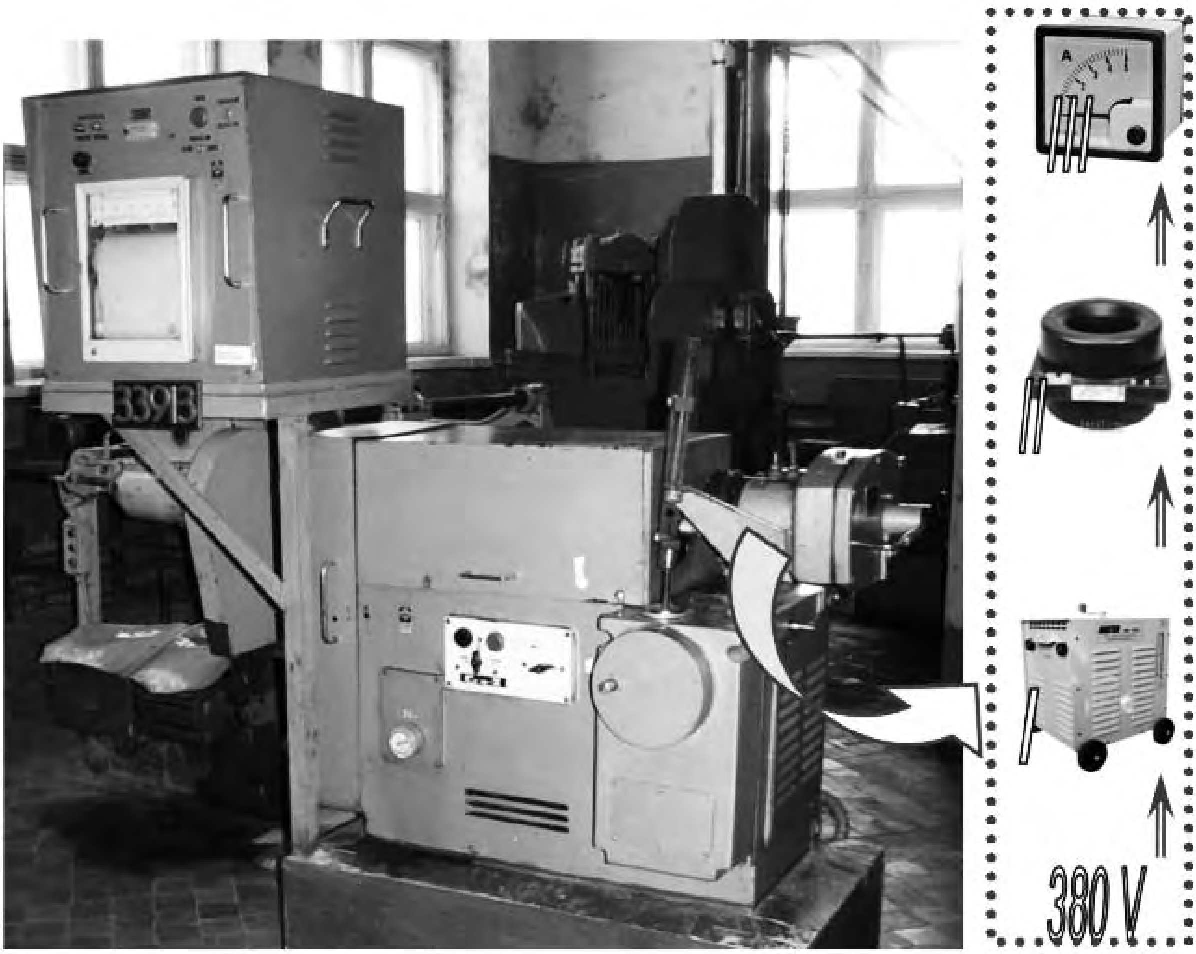

Fig. 5. Machine proof-of-concept SMC – 2 with the system of serve of electric current : 1 – transformer TMD-500, 2 – transformer of current, 3 – ammeter

$$b = 1{,}522 \cdot \sqrt{\frac{k_d \cdot F \cdot R_{np}}{l \cdot E_{np}}},$$

where: Kd = 1 – dynamic coefficient, for an unstressed cyclic laddering,

R_{np} – brought radius over, m:

$$R_{np} = \frac{r_1 \cdot r_2}{r_1 \pm r_2},$$

here: r1 and r2 – radiuses of examinee standards, m,

E_{np} – brought module over, MPa:

$$E_{np} = \frac{2 \cdot E_1 \cdot E_2}{E_1 + E_2},$$

here: E1 and E2 – modules of normal resiliency of examinee materials, MPa.

V1 and V2 – linear speeds of standards, m/s :

$$V_1 = \frac{p \cdot n}{30} \cdot \frac{D_1}{2},$$

$$V_2 = V_1 \cdot s,$$

here: s – coefficient of slipping.

Work of friction:

$$W = F_{mp} \cdot S,$$

where: $F_{mp} = P \cdot f$,

P – normal force, H,

f – coefficient of friction.

Time of wear of standards:

$$t = \frac{N}{n},$$

where: N – number of cycles of laddering,

n – frequency of rotation of standard.

Results of series of experiments on determination of influence of the skipped electric current through a contact "roller-roller" on friction properties presented on a Fig. 6.

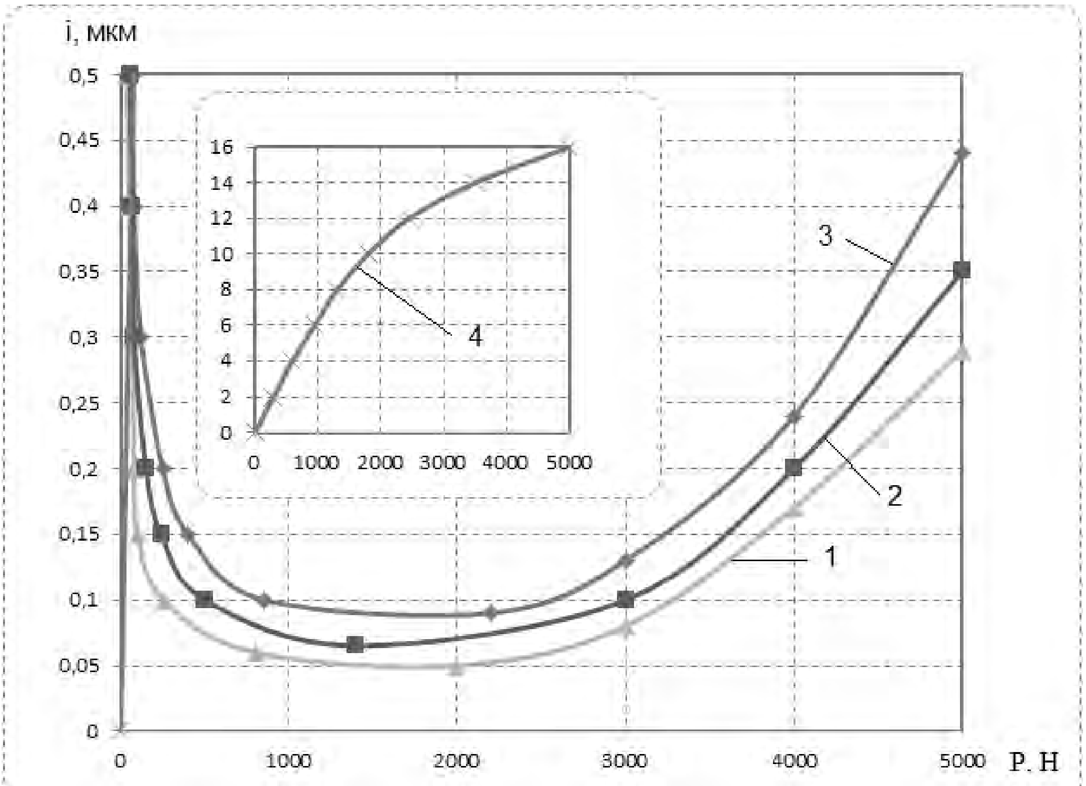

Fig. 6. Dependence of wear of rollers on loading at presence of electric current: 1 – strength of current of 100A, 2 – strength of current 200A, 3 – strength of current of 300A, 4 – wear under act of sand [12]

The experimental researches presented on a Fig. 5 confirm the results of the design given above. On graphic arts a curve is presented 4, that characterizes the wear of surface of detail under act of sand with different speed of his serve, according to researches [28]. At comparison of curves 1-3 and 4 evidently, that a wear from influence of sand in several times exceeds a wear from influence of electric current.

Actuality of problem of wear of railway wheels and rails stands especially sharply in connection with the running expenses related to the regrind of wheel pairs and influence of him on hauling-economic descriptions of rolling stock. The model of wear of tribounit supposes proportional dependence between the worn down volume V_B and work of friction of Ar :

$$V_B = kAr,$$

where: k – index of wear that is determined experimentally.

And the size of wear at the contact of surfaces is straight proportional to work of forces of friction. A friction determines a coupling size, as taking into account the resiliency of wheel and rail their co-operation takes place on some pin surface (spot of contact), where and tangent force of friction, that, is formed, as well as, coefficient of friction, depend on the great number of system and casual factors, basic from that are normal pressure, speed and temperature [13].

Consequently, except determination of influence of electric current on a wear a tribounit "wheel-rail" it is expedient to define degree of his affecting coefficient of friction.

For determination of influence of electric current on the coefficient of friction on the department of railway transport of Volodymyr Dahl East Ukrainian University experimental studies are undertaken on the automated instrumentation-designing stand setting "Machine of friction" [2, 8, 29]. Stand setting "Machine of friction" is equipped by the device of serve of electric current in a contact "roller-rail" chart of that, presented on a picture 1.

Measureable parameters on the stand setting it are: vertical effort on a working roller, force of friction of roller at a rail, frequency of rotation of engines. The signals, taken off from the sensors set on the stand setting of I (Fig. 7), are given through the block of processing of data of II (Fig. 7) on computer - III (Fig. 7), that allows jointly with a control stand to manage the hauling roller of V (Fig. 7) by a working roller and to destroy these experimental sizes of coefficient of friction from a temperature in real time. The smooth set of speed of rotation of working roller is provided by the worked out - IV (Fig. 7) on a microcontroller ATMEGA8, that is managed computer of III (Fig. 7) also.

Power is tricked into to setting of I (Fig. 6) regulated by means of transformer TDM-500 – VI (Fig. 7).

Results of experimental researches on determination of influence of electric current on a friction pair "roller-rail" of the stand setting "Machine of friction" presented on a Fig. 8.

On results experimental researches the increase of maximal coefficient of friction is set in a contact "wheel-rail" at the serve of electric current :

- to 23% rails covered by a blight at influence of current 375 A, here meaningful influence on the coefficient of friction renders the current of 100A and higher (1 Fig. 8),
- to 30% clean rails at influence of current of 375A, meaningful influence on the coefficient of friction renders the current of 100A and higher (2 Fig. 8),
- to 28% rails covered by water at influence of current of 375A (3 Fig. 8).
- to 27% rails covered by exhaust oil (4 Fig. 8).

The got results can be interpreted taking into account the theoretical pre-conditions described in [30],it mean supposition about the flowage of superficial layer explains increase of spot of contact in tribounit and, as a result, results in the increase of coefficient of rolling friction, what was observed during realization of experimental researches.

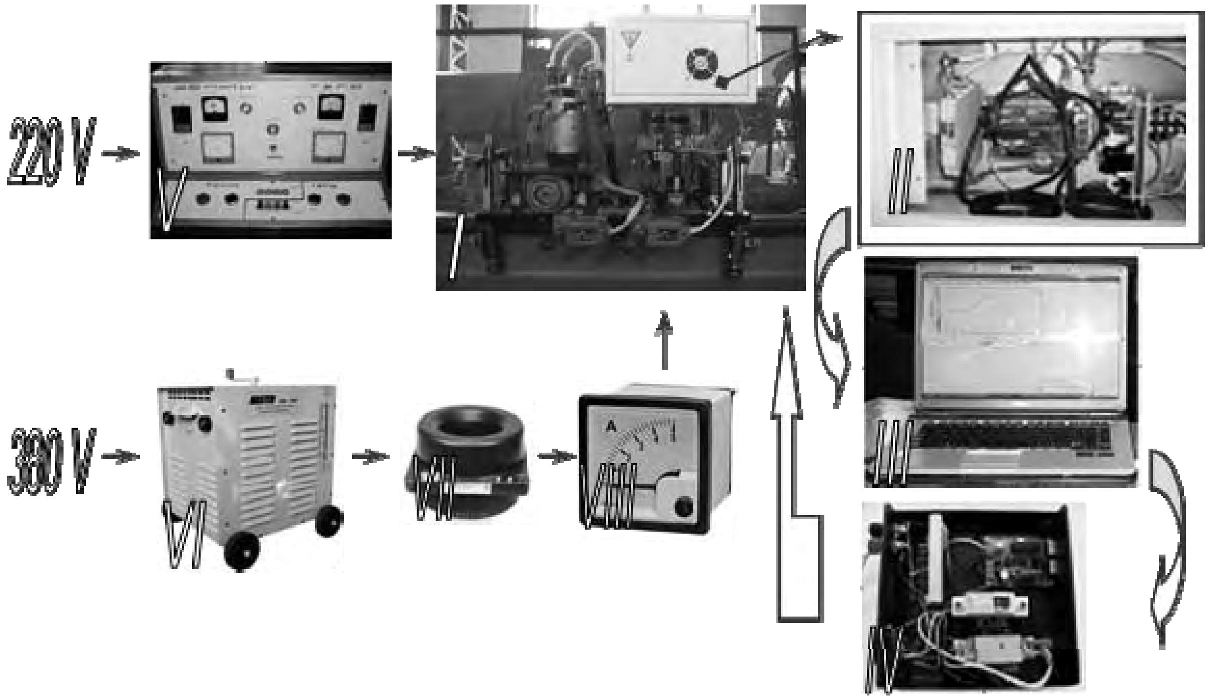

Fig.7. Chart of the automated instrumentation-designing stand setting "Machine of friction" with a device for the serve of electric current in a tribounit "roller-rail"
I – general view of the automated instrumentation-designing stand setting "Machine of friction"; II – block of processing of the obtained data, III – computer; IV – regulator of smooth tension; V – control stand by a hauling roller; VI – transformer TDM-500; VII – transformer of current, VII – ammeter

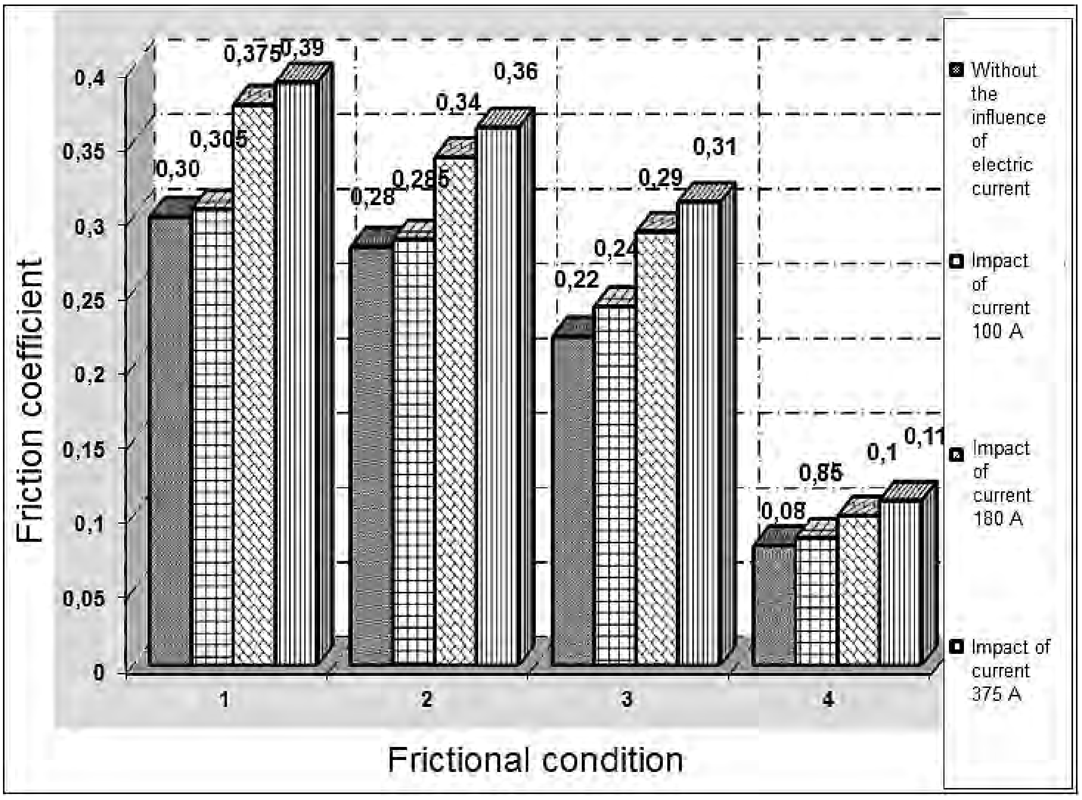

Fig. 8. Dependence of coefficient of friction on influence of electric current at presence of superficial contaminations and to different strength of current, coefficient of friction at:
1 – rail is covered by a blight, 2 – clean rail, 3 – rail is covered by water, 4 – rail is covered by exhaust oil

In addition, experiments are conducted on research of influence of electric current of high-density on a friction contact at presence of in him sand. Quartz sand, as is generally known, is a dielectric and, consequently, a dielectric barrier appears in a contact. At the key-in of electric current there is a hasp in a contact, bridges that heat and melt lances of roughness's of superficial layer appear, that results in an erosive wear [31], evidently presented on a Fig.9, where a roller is represented after undertaken experimental studies with a presence in the contact of sand.

Fig. 9. Erosive wear of roller at affecting of electric current of high-density tribounit of "roller-rail" at presence of sand

CONCLUSION

1. Applied in exploitation of rolling stock the method of increase of coupling by the serve of sand in the zone of contact of wheel with a rail considerably wears down the ground surfaces, and his basic defects (resistance to motion is an obstruction of rail grate and pointer translations, that results in the decline of safety of motion) require the search of new ways of decision.

2. The method of increase of coupling by the serve of electric current in the contact of wheel with a rail is able partly to replace the serve of sand in the pair of friction "wheel-rail".

3. The mechanism of influence of electric current on tribounit is based on that an additional heat is introduced in the system, there are flowages, increasing the spot of contact of wheel with a rail that assists the increase of coupling [32]. The size of wear depends on the attached loading and temperature in tribounit.

4. It is set that the increase of coefficient of friction on clean rails makes a to 30% dependence on the closeness of the skipped current, on rails covered by water to 28% rails covered by exhaust oil to 27% on rails covered by a blight on 23%.

5. Influence of electric current does not cause the wear of raceway unlike the wheel given in a contact with the rail of sand.

6. Undertaken studies showed that influence of electric current is parallel with sand on tribounit of interactive surfaces of wheel with a rail results in the erosive wear of contacting to the solid.

REFERENCES

1. **Ahmatov A.S., 1973.:** Molecular physics of boundary frictionativ. – M. – 427. (in Russian).
2. **Braun J.D., 1982.:** Modelling of friction and wear in machines. – M. – 191. (in Russian).
3. **Cherneckaya N., Kolodyazhnaya L., 2010.:** Technical and economic calculations in organization of railway transportations. // TEKA Commission of Motorization and Power Industry in Agriculture. – Vol. X. Poland. – 32-37. (in Russian).
4. **Derjagin B. V., 1984.:** Molecular theory of slip. // Journal fiz. Himija. – T.5. – 116-119. (in Russian).
5. **Garkunov D.N., 1989.:** Tribotechnics. – M. – 328. (in Russian).
6. **Golubenko O.L., 1999.:** Clutch wheel and rail: **-** 2 edition. Revised and supplemented. Lugansk, V. Dahl East-Ukrainian National University. 476. (in Russian).
7. **Holm, R., 1981.:** Electrical contacts. – M. – 480. (in Russian).
8. **Ishlinskij A.J., 1976**.: About slippage in the contact area with the rolling friction. // Department of Technical Sciences. – №6. – 3-15. (in Russian).
9. **Ivanov I. A., Zhukov D.A., 1998**.: The surface layer of the wheel rim, its characteristics, PGUPS, g. Sank-Peterburg. – 315. (in Russian).
10. **Jilbert G.H., Field J.E., 2000**.: Synergistic effects of rain and sand erosion. // PCS, Wear 243. – 6-17. (in Germany).
11. **Kamenev N.N., 1988.:** Effective use of sand for traction trains. // Transport №3. – 87. (in Russian).
12. **Kragelskij I.V., 1962.:** Friction and wear. – M. – 259. (in Russian).
13. **Kragelskij I.V., Dobychin M.N., Kombalov V.S., 1977.:** Basics calculations on friction and wear. – M. – 526 (in Russian).
14. **Kragelskij I.V., Mihin N.M., 1984.:** Friction units of machines. – M. – 260. (in Russian).

15. **Kostjukevich A.I., 1991.:** Kind of experimental and numerical identification process traction locomotive rails, synopsis candidate of technical sciences // Vesnik V. Dahl East - Ukrainian National University. – №1. – 12-19. (in Russian).
16. **Kulagin M.I., Kac J.I., Tjurikov V.N., 1980.:** Undulating rail wear. – M. – 144. (in Russian).
17. **Kulbikajan R.V., 2003.:** Development of management principles state frictional contact tribological system: Dissertation candidate of technical sciences. – Rostov n/D. – 17. (in Russian).
18. **Kuznecov V.D., 1997.:** Solid state physics. – Tomsk. – 539. (in Russian).
19. **Luzhnov J.M., 1978.:** Physical bases and laws traction locomotives and rails: Dis. … dr technical. sciences. – M. – 35. (in Russian).
20. **Luzhnov J.M., 2003.:** Coupling of wheels rails. – M. – 144. (in Russian).
21. **Luzhnov J.M., Popov V.A., Studentova V.F., 1985.:** Energy loss and their role in the implementation of traction rails: Dis. … aspt. technical. sciences. – Tashkent. – 19. (in Russian).
22. **Mogilevskij V.A., 2001.:** Increase the coefficient of friction wheels of locomotives and rails by applying activator friction: Dis. … aspt. technical. sciences. – Rostov- n/D. – 20. (in Russian).
23. **Osenin J.I., Marchenko D.M., Shvedchikova I.O., 1997.:** Frictional interaction wheel and rail. // Vesnik V. Dahl East - Ukrainian National University. – №2. – 28-32. (in Russian).
24. **Rebinder P.A., Shhukin E.D., 1998.:** Surface phenomena in solids and processes, and deformation and fracture. – M. – 3-42. (in Russian).
25. **Roscoe R.. 1998.:** Plastic deformation of crystals. – M. – 399-406. (in Russian).
26. **Sakalo V., Kossov V., 2004.:** Contact problems of railway transport. – M. – 254. (in Russian).
27. **Sapronova S., 2010.:** Modeling of locomotive wheel profile form. // TEKA Commission of Motorization and Power Industry in Agriculture. – Vol. X. – Poland. – 270-278. (in Russian).
28. **Sulima A.M., Shulov V.A., Jagodkin J.D., 1988,:** The surface layer and the performance of the machine parts. – M. – 240. (in Russian).
29. **Suslov A.G., 2000.:** Quality of the surface layer of machine parts. – M. – 320. (in Russian).
30. **Vorobev D.V., 2005.:** Improving Performance in the friction pair friction wheel-rail due to exposure to electric currents and magnetic fields: Dis. … aspt. technical. sciences. – Brjansk., – 20. (in Russian).

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ЭЛЕКТРИЧЕСКОГО ТОКА НА ТРИБОСОПРЯЖЕНИЕ «КОЛЕСО-РЕЛЬС»

Николай Горбунов, Владимир Ноженко,
Елена Ноженко, Сергей Клюев, Анна Бондаренко

Аннотация: В работе теоретически и экспериментально проведены исследования влияния электрического тока, проходящего через контакт двух взаимодействующих роликов на их износ при варьировании величины силы тока и приложенной нагрузки, а также определен коэффициент трения при различных фрикционных состояниях поверхности рельса. Экспериментальные исследования проведены на машине испытательной СМЦ-2 на ПАТ «Луганскутепловоз», а также на автоматизированной измерительно-моделирующей стендовой установке «Машина трения» в лаборатории на кафедре железнодорожного транспорта Восточноукраинского национального университета им. В. Даля. Выявлен механизм воздействия электрического тока на трибосопряжение, что позволяет обосновать применение данного способа для повышения сцепления в системе «колесо-рельс».

Ключевые слова: электрический ток, сцепление, температура, электрический износ, механический износ, коэффициент трения.

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New hopper-cars with one-sided self-unloading

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Summary. The prospects of use of the modernized hopper-cars with one-sided self-unloading were considered. The basic parameters of structure of the car body were determined. The investigations of loading and unloading process of bulk freight of the hopper-car were conducted. The study allowed to determine the loads upon external and internal rails for the purpose to provide the stability of the car.

Key words: hopper-car, structure, traffic safety, modeling.

INTRODUCTION

In the modern world the important direction of development of transport in the industry is modernization and re-equipment of the rolling stock for the purpose of providing the minimum expenses for transportation of freights, reductions of time on loading - unloading operations, ensuring reliability and convenience in operation of the rolling stock, decrease in prime cost of the finished products delivered to consumers.

The metallurgical and mining branches of production with the open cast or closed way of mining with removal of rock into spoil bank occupy the special role in the industry. The questions of development and perfection of the quarry transport and metallurgical industry transport are the most important as these branches are one of the most profitable [20].

Transport of the enterprises in the coal-mining industry represents difficult system of the interconnected transport links located both inside the enterprise, and out of it. The uninterrupted work of all links of technological process of the enterprise depends on the accurate organization of transport process. In this connection not only reliability of transport and efficiency of its use but also expenses on the equipment, materials and resources are of great importance in operation of transport. The purpose of transport in mining industry is to provide delivery of all volume of coal output from the extraction place to the destination point, removing the rock into a dump and transportation of materials with the maximum speed, with the minimum expenses and with taking into account the traffic safety. And the problem of decrease in expenses for transportation of dead rock to a mine dump is very actual in a mining industry [16, 18, 21].

So, in metallurgical industry the problem demanding its direct solution is reduction of transport expenses in transit of mass bulk freights, idle time shortening under loading-unloading operations, rational use of transport vehicles and loading factor of a rolling stock.

MATERIALS AND METHODS

In recent years the intensive searches of new most acceptable ways of development of transport of coal-mining and metallurgical industry for transportation of mass bulk freights are carried out. The modern vehicle is to be convenient in operation, powerful and economic. Therefore in modern conditions the industrial railway transport continues to remain one of main types of technological transport at the large industrial enterprises. Long-term economic experience confirms efficiency of use of the electrified railway transport not only at the enterprises which are producing the finished goods, but also in deep open pits.

The analysis of scientific-technical and design solutions allows to claim that the electrified railway transport will remain one of basic technological transport in the long term perspective both on operating, and on newly developed coal-mining deposits [1, 4, 12, 16]. The main advantages of the electrified railway transport are the following:

•high average operational efficiency,

•profitability (rather low prime cost of transportation of mining mass) and reliability in operation,

•possibility of a considerable overload of electric locomotives,

•simplicity of control, maintenance and repair of transport [4, 16].

All these advantages are a consequence of the centralized power supply of electric locomotives It should be noted, however, that the centralized power supply requires the creation of quite large infrastructure (traction substations, a contact network, etc.) that along with the high cost of locomotives and considerable volumes of a rating of boards of pits for placement of communications causes a high capital intensity of railway transport.

The essential advantages of the electrified railway transport are also the economy of not filled liquid fuel, almost total absence of a gas contamination of the territory by exhaust gases, insignificant dependence on climatic conditions. Along with it there is the problem of modernization of carriage yard, improvement of structures of cars for the purpose of reduction of metal consumption, reduction of time for their processing and feeding the cars in cargo fronts for loading and unloading. The worn-out and outdated park of cars demands new rationalization solutions which will improve technical and economic indicators of transportation of freights at the enterprises [2, 5, 13, 22].

Dump trucks, dump cars play a huge role in the organization of transportations of mass bulk freights in the industry [17]. However use of this rolling stock is not effectively in connection with its high metal consumption, considerable wear of all its parts, complexity of a structure of the car and the mechanism of overturning of a body, big efforts for self-loading.

Thus, the purpose of this study is modernization of carriage yard for transportation of bulk mass freights in industry.

The special role in the solution of this problem is assigned to creation of new structures of specialized cars for transportation of bulk freights. The problem of perfection of methods a choice of rational parameters of cars of this type is extremely becoming important at creation of specialized hopper-cars of new generation for transportation of bulk freights (the mining, mass, crushed rock, granulated slag, etc.). It will allow to reveal the perspective options of structures of cars and their separate functional units at early stages of their designing too [6, 19].

RESEARCH OBJECT

In this work creation of the rolling stock of new generation for transportation of bulk freights - the modernized hopper-car with unilateral self-unloading (on one side of a railway track) is offered [7, 8, 9].

The main feature of hopper-cars is their ability to self-unloading. This feature also determines the conceptual constructive scheme of the unloading device and the hopper-car body. The choice of rational parameters of hopper-car unloading system determines one of the major commercial indicators for cars of this type, namely, idle time on final operations.

The hopper-car of open type of model 20-40-15 for transportation of hot pellets and agglomerate [14] is enough known. The structure of the car provides the mechanized loading through an open body and the automated unloading on two sides from a railway track through two lateral hatches. The car is equipped with the unloading mechanism with the pneumatic drive and the automatic blocking, providing reliable locking of covers of hatches and automation of unloading process. The open hopper-car has the remote automated system of unloading of freight on both sides of the railway track, controlled by means of the compressed air fed from the power plant of the locomotive. Essential lack of the hopper-car is incomplete self-unloading of bulk freights which demands additional manual unloading,as well as impossibility of the mechanized formation of one-sided flat dump of bulk freights at unloading.

Researches of scientists of V. Dahl East-Ukrainian National University (EUNU) [6, 8, 9, 10] showed that it is possible to provide full unloading of bulk freight on the right side of a railway track concerning car movement by modernization of the known hopper-car of model 20-471 with a loading capacity of 65 t thanks to constructive changes of the shape of the body and the self-unloading mechanism (Fig. 1, Fig. 2) [7, 8, 9].

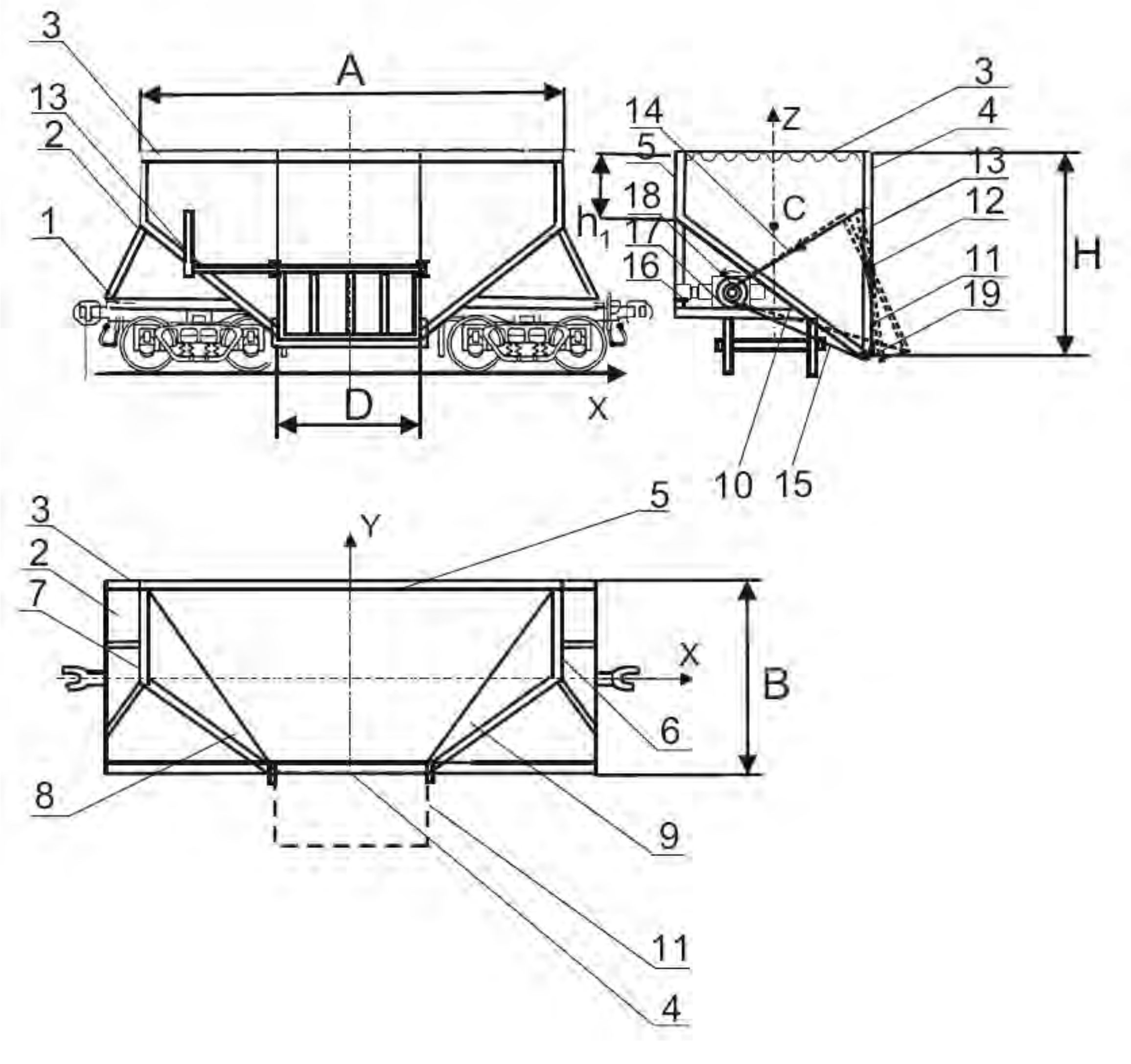

Fig. 1. The hopper-car with one-sided self-unloading

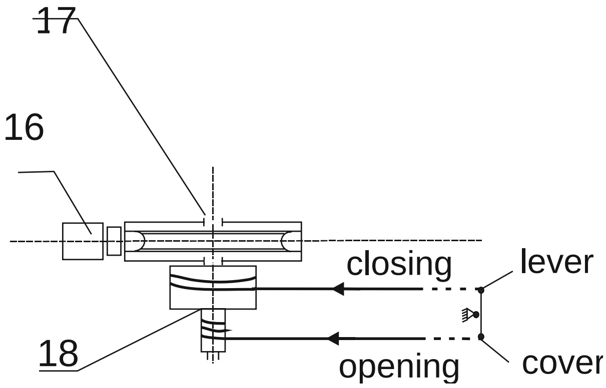

Fig. 2. Scheme of equipment for unloading of the hopper-car

The structure of the hopper-car is shown in Fig. 1. (three-view arrangement: front view, top view and side view). The hopper-car consists of a frame 1, a framework 2, the all-metal body 3 consisting of lateral walls 4 and 5, end face walls 6 and 7, transitional walls 8, 9. The part of a lateral wall 5 is transformed to an inclined floor 10 of the body 3.

The equipment for unloading is presented by rope system for opening, closing and fixing of a cover 11 of an unloading hatch, attached in hinges 12 to a lateral wall 4. The rope system consists of the lever 13 attached to a cover 11of the unloading hatch, ropes 14 and 15, the electric motor 16, a worm reduction gear17, the step drum 18 and locks 19.

The transitional walls 8, 9 provide increase in net volume of the body 3 and improvement of indexes of loading of the hopper-car through the open body 3.

In the hopper-car one unloading hatch is kept with the cover 11 suspended in hinges on a forward vertical lateral wall 4 from the unloading side, all other walls are executed obliquely.

In the place of formation of the dump through the electric motor 16, the torque is transferred by the worm reducer 17 to the step drum 18 (Fig. 2), then the tension of ropes 14 and 15 is carried out, position of the lever attached to the unloading hatch cover changes, the unloading cover of the hopper-car is opened and self-unloading of the hopper-car is executed on one side from railway track (on the right concerning movement). The ropes 14 and 15 which are reeled up on different steps of the drum 18, and the worm reducer 17 (Fig. 2) provide fixing of the cover of the hatch. The locks 19 are provided for reliable fixing of the cover 11 of the unloading hatch in a closed position that is especially important for transportation process [8, 9].

In the place of formation of the dump, the hopper-car unloading hatch cover, suspended in hinges to the lateral wall, is opened by means of the lever mechanism with driving pneumatic cylinders and self-unloading is carried out under the action of own freight weight through the hopper-car hatch on one side of railway track (on the right side concerning movement).

In operating conditions of railway transport, for example, in a mining industry, providing stability and reliability of the rolling stock as well as of traffic safety] is especially important [2, 5]. The offered asymmetrical body of the hopper-car developed by scientists of V. Dahl EUNU [6, 7, 8, 9] conforms to such requirements. It provides an arrangement of the center C of masses (Fig. 1) on the central vertical CZ axis at full loading of bulk freight. It is provided by the structure of the body and creates conditions for identical loads from the static forces on all eight wheels and, as result, promotes improvement of technical data (specifications) during movement and self-unloading.

RESULTS OF RESEARCH

1. Input data for research

The determination of loads to external and internal rails is very important in investigation of process of loading and unloading of the asymmetrical body of the hopper-car. We will note that loading is carried out with tthe bucket excavator 1 through an open body of the car. But unloading is executed through the unloading hatch 2 (Fig. 3).

The input data for research are:

- portion of loaded freight, m_1, t,
- weight of the empty car, t,
- height of falling h of freight on an inclined surface of the body floor, m,
- α – an inclination angle of a surface of a floor of the hopper-car body.

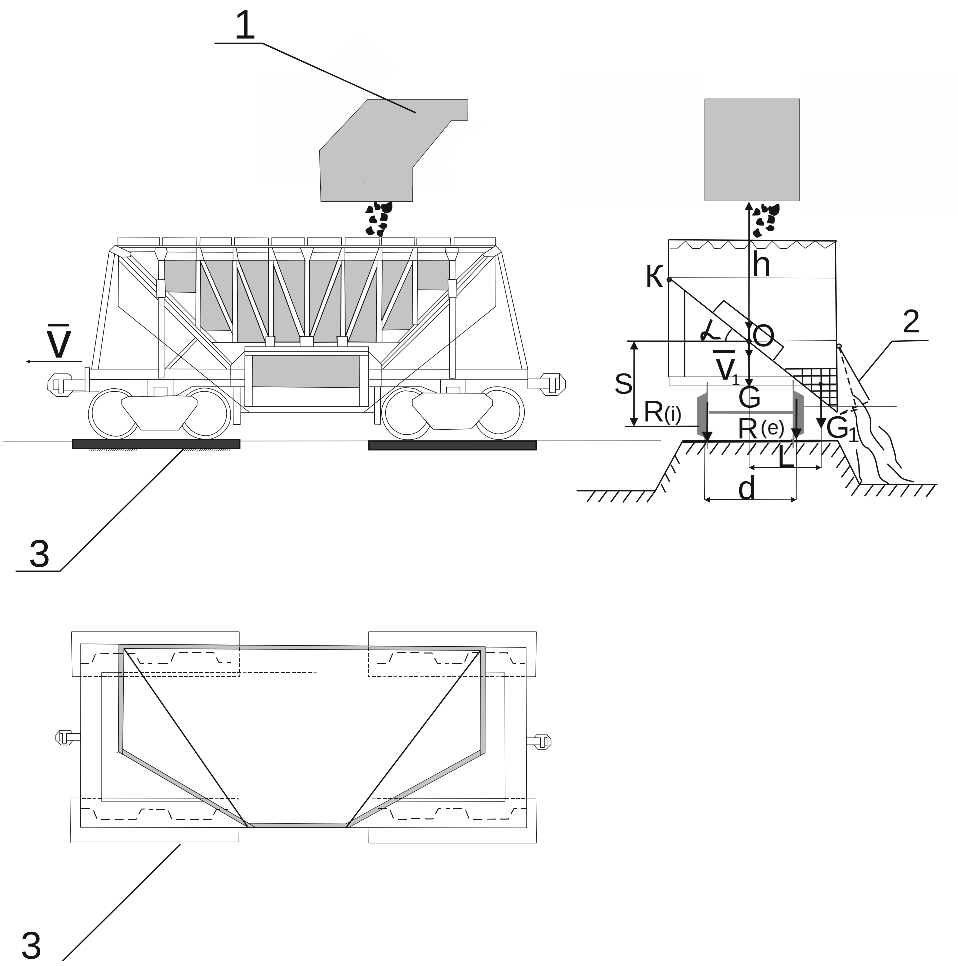

Fig. 3. Loading and unloading of the hopper-car:
1 – loading bunker (hopper), 2 – cover of the unloading hatch, 3 – scales

For calculations we take the hopper-car design with the following parameters [6]: body width B = 3154 mm, the hopper-car body length A = 9300 mm, height of one lateral wall according to vehicle gauge H = 3100 mm, width of the unloading hatch D = 3500 mm. Weight of the empty car G = 23 t.

At these parameters (width of the unloading hatch of the hopper-car D = 3500 mm) the height of the second lateral wall h_1, an inclination angle of the body floor of the hopper-car α are determined (Fig. 1) from relationships (Eg. 1) and (Eg. 2) [3, 12]:

$$h_1 = H\frac{(A+7D)}{(9A-D)}, \tag{1}$$

$$tg\alpha = \frac{H-h_1}{B}. \tag{2}$$

They will be respectively equal h_1=1300 mm, α = 30^0.

Thus, the total volume of the hopper-car body will make V_1 = 49,48 m^3 [6]. For the hopper-car this volume is considerable in comparison, for example, with the hopper-car of model 20-471 with a loading capacity of 65t. It is used for transportation of hot pellets and agglomerate and has the total volume of 42 m^3. The center of gravity is located on the central vertical axis that is provided with a structure of the car body.

The design of offered modernized hopper-car provides the mechanized loading through an open body with the bucket excavator or the conveyor. Besides the hopper-car also executes the automated unloading on one side from a railway track through the lateral unloading hatch.

2. Mathematical simulation of static weighing process of portion loading of the hopper-car asymmetrical body

Mathematical simulation of loading operation of the hopper-car asymmetrical body is carried out in the following order and to some stages:

2.1. Determination of force of action upon the left and right rail at the top loading.

The loads upon the external $R_{(e)}$ and the internal rail $R_{(i)}$ in the moment of freight blow about a surface are determined from relations (Eg. 3) and (Eg. 4) [3, 12]:

$$R_{(e)} = \sqrt{\frac{m_1 * g * h * c}{8}}(\cos^2\alpha - \frac{S}{d}\sin 2\alpha) + \frac{G}{2}, \quad (3)$$

$$R_{(i)} = \sqrt{\frac{m_1 * g * h * c}{8}}(\cos^2\alpha + \frac{S}{d}\sin 2\alpha) + \frac{G}{2}, \quad (4)$$

where: S – height from a rail head to the middle of an inclined surface, m,

m_1 – the mass of a portion of freight, t,

h – the height of falling of freight on an inclined surface of a body floor, m,

c - rigidity, N/m,

α – an inclination angle of a surface of the car body floor, ^{0},

d – the width of wheel pair, m,

G – the weight of the empty car, kg.

Investigating the loading process of the hopper-car we obtain the dependences of loads upon the external $R_{(e)}$ and internal rail $R_{(i)}$ in the moment of freight blow about an inclined body floor on the mass of falling freight and to give to recommendation on loading of hopper-car in initial moment of time.

On the basis of the conducted research it is possible to draw a conclusion that stability of the car from overturning will be provided due to positive values of loads, however it is possible to make the recommendations to carry out loading process by small portions at the initial moment of loading of the car.

2.2. Determination of redistribution of loads $R_{(i)}$ and $R_{(e)}$ upon the sides of wheel pairs.

We will consider the freight displacement under the action of gravity G_1 and potential energy of springs (Fig. 3) to the unloading hatch on distance L from the central axis.

This movement leads to redistribution of loads on the sides of wheel pairs. The loads are determined from relations (Eg. 5) and (Eg. 6) [3, 12]:

$$R^*_{(e)} = \frac{G}{2} + G_1(\frac{1}{2} + \frac{L}{d}), \quad (5)$$

$$R^*_{(i)} = \frac{G}{2} + G_1(\frac{1}{2} - \frac{L}{d}), \quad (6)$$

where: L – distance of the center of a triangle of freight from the central vertical axis, m.

2.3. Determination of force of action upon the left and right rail at the loading to a point O.

At the third stage the loads upon rails $R^*_{(i)}$ and $R^*_{(e)}$ are determined at the moment of filling of the hopper-car body with freight up to a point O (Fig. 3).

After that a half of freight portion which is loaded into the hopper-car body, falls on the inclined surface, the second part – on a horizontal surface, thus the loads upon rails at the moment of blow decrease almost twice that provides stability of the car.

2.4. Determination of force of action upon the left and right rail at the loading to a point K.

At the fourth stage, taking into account the features of the construction of the car hopper body, we determine the calculated loads upon rails when filling body to a point K (Fig. 3).

2.5. Determination of force of action upon the left and right rail at full filling of the hopper-car body.

At the fifth stage we define the calculated loads upon rails at full filling of the hopper-car body.

Dependences of loads upon the external $R^*_{(e)}$ and internal $R^*_{(i)}$ rails on the mass of loaded freight are shown in Fig. 4.

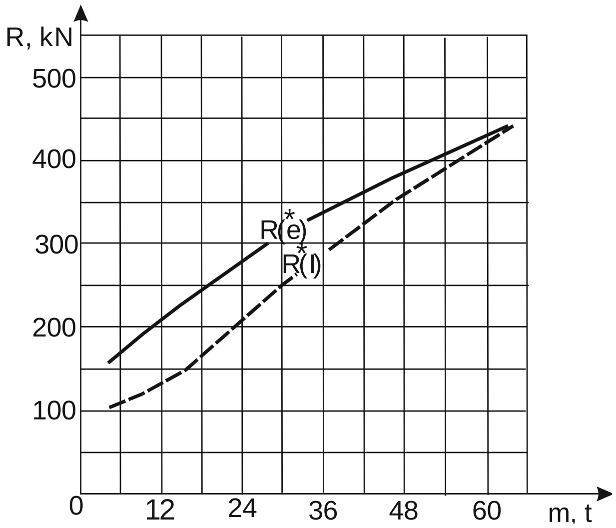

Fig. 4. Dependence of loads upon the external $R^*_{(e)}$ and internal $R^*_{(i)}$ rails on the mass of loaded freight *m*

The analysis of the dependences given on fig. 4 shows that at a full loading of the hopper-car the loads upon external $R^*_{(e)}$ and internal $R^*_{(i)}$ rails will be equal.

3. Experimental studies and their results

In the experimental study the physical modeling of loading and unloading process of the car hopper was applied to determine the relations of loads upon the external and internal rails. The plastic balls with a diameter of 5-6 mm were used as a bulk material. The hopper-car was manufactured from wood (timber) on the scale of 1:20. The coefficient of friction accepted on indications of friction gauge (tribometer) is equal to f = 0,48.

Model installation is presented in Fig. 5, a and 5b. Two operations respectively had been carried out at the model installation: Fig. 5, a – car loading and determination of the loads upon rails by means of scales, Fig. 5, b – car self-unloading through the unloading hatch.

The loads upon the internal $R^*_{(i)}$ and external $R^*_{(e)}$ rails were determined by the indications of scales (Fig. 3, Fig. 5, b) which were installed under each wheel of the car.

Dependence of the loads upon the external $R^*_{(e)}$ and internal $R^*_{(i)}$ rails on the portions of loaded freight is shown in Fig. 6.

a

b

Fig. 5. Loading and unloading of thehopper-car:
a– car loading and determination of the loads upon rails by means of scales,
b – car self-unloading through the unloading hatch

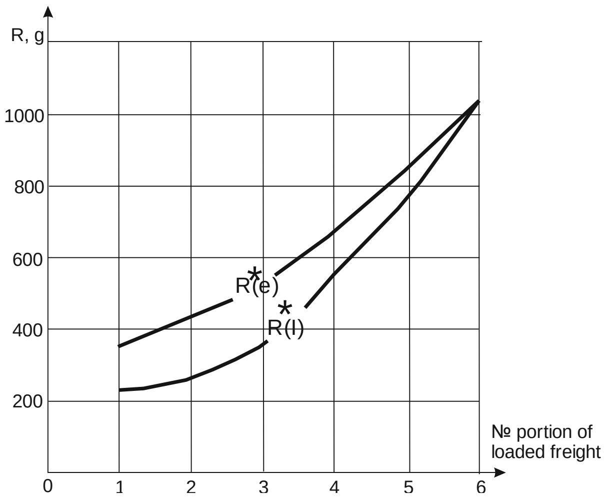

Fig. 6. Dependence of the loads upon the external and internal rails on the portion of loaded freight

The loads upon the external and internal rails will be equal at a full loading of the hopper-car. Thus, use of this car is expedient for transportations at various distances and at various trajectory of the route.

4. Investigation of the process of freight unloading from the hopper-car

As it was already noted in [6] time of unloading is in inverse proportionality to width D of the unloading hatch.

Proceeding from the accepted values of size of the unloading hatch of 3500 mm and the taken inclination angle of the main rolling-down surface 30^0, we investigate change of time of unloading of the car depending on an angle of opening of the hatch cover (on the hopper-car which has been executed on the scale of 1:20). Possibility of opening of the hatch cover in several provisions gives the chance of freight weighing in the course of unloading. Experimentally we obtain dependences of time of freight unloading on an angle of opening of the hatch cover (Fig. 7). We investigate the process of freight unloading in four positions: of completely filled body, filled for 50%, 30% and 25%. The results of research depend on type of the freight which is in the car, on its physical and chemical properties and density.

The dependence of unloading time of the hopper-car on an angle of opening of the unloading hatch cove, investigated on the model installation, is shown in Fig. 7.

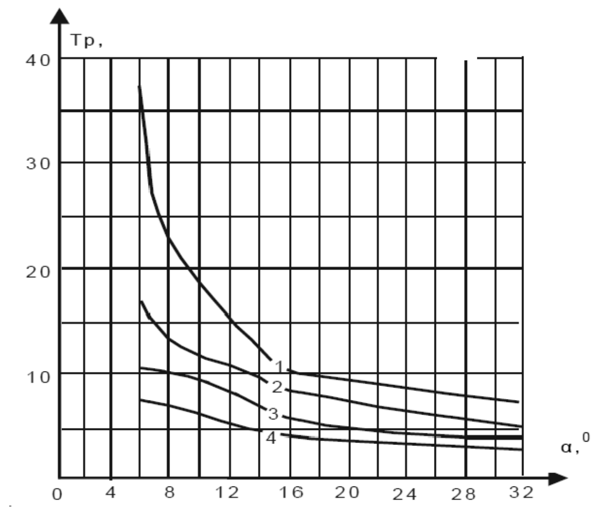

Fig. 7. Dependence of unloading time of the hopper-car on an angle of opening of the unloading hatch cover: 1 – 100% filling, 2 – 50%, 3 – 30%, 4 – 25%

CONCLUSIONS

1. Full unloading of freight on the right side of railway track concerning car movement is provided thanks to constructive changes in the shapes of the body and the mechanism of self-unloading of the hopper-car. Modernization of the hopper-car body is executed so that its net volume in comparison with initial variant (model 20-471 with a loading capacity of 65 t) should not be decreased.

2. The loading-unloading process of the hopper-car was investigated and the important calculated and experimental values were obtained. Thus, it is possible to draw a conclusion that stability of the hopper-car in the course of loading-unloading and transportation will be provided.

3. The use of the modernized hopper-car with the changed asymmetrical structure of the body and the mechanism of self-unloading is expedient for transportation of mass bulk freights in various branches of industry.

REFERENCES

1. **Anistratov K.Yu., 2011.:** Justification of structure of park of dump trucks of a class of the loading capacity of 40-100 tons. Open mining operations in the XXI eyelid / Collection of materials of the international scientific and practical conference. Krasnoyarsk. MVDTs "Siberia", 105-111. (in Russian).
2. **Basov G., Kireev A., Lysak D., 2010.:** Improvement of testiong operations during diagnosing of wheelpair tires of railway vehicles. TEKA Commission of Motorization and Power Industry in Agriculture. XC, 12-18.
3. **Vilke V.G., 2003.:** Theoretical mechanics. Moscow State University publishing house. (in Russian).
4. **Golubenko A.L., Gubacheva L.A., Andreyev A.A., 2010.:** Prospects of creation and use of narrow-gage traction units//Visnyk V.Dahl EUNU. Scientific Journal №10 [152], Part 1, 32-39. (in Russian).
5. **Gorbunov N., Kostyukevich A., Kravchenko K., Kovtanets M., 2011.:** Influence of operatonal factors on redistribution of wheel pairs vertical loads upon rails. TEKA Commission of Motorization and Power Industry in Agriculture. XIA, 30-32.
6. **Gubacheva L.O., Andreev O.O., Leonova S.O., 2012.:** The hopper-car with one-sided self-unloading. Visnyk V.Dahl EUNU. Scientific Journal № 4 [175], 69-74. (in Russian).
7. **Gubacheva L.O., Andreev O.O., Leonova S.O., 2012.:** The hopper-car for transportation of bulk

freights. Patent of Ukraine № 75199, B61D 7/02, issued 26.11., Bull № 22. (in Ukrainian).

8. **Gubacheva L.O., Andreev O.O., Leonova S.O., Mokrousov S.D., Scherbakov V.P., 2013.:** The hopper-car. Patent of Ukraine № 83182, B61D 7/02, issued 27.08., Bull № 16. (in Ukrainian).
9. **Gubacheva L.O., Andreev O.O., Leonova S.O., Kutnyakhov S.V., 2013.:** The hopper-car for transportation of bulk freights. Patent of Ukraine № 82575, B61D 7/02, issued 12.08., Bull № 15. (in Ukrainian).
10. **Gubacheva L.O., Leonova S.O., 2013.:** Assessment of economic efficiency of use of the modernized hopper-cars with the electric equipment for self-unloading. Visnyk V.Dahl EUNU. Scientific Journal №9 [198], Part 1, 36-40. (in Russian).
11. **Debeliy B., Debeliy L., Melnikov S., 2006.:** The main trends of mine locomotive transportation. Coal of Ukraine. Scientific Journal №6, 30-31. (in Russian).
12. **Dobronravov V.V., Nikitin N.N., 1971.:** Course of theoretical mechanics, p.1 and 2. M., the Higher school. (in Russian).
13. **Kulichkin P.S., Konopelko S.A., Biryukov A.N., 2011.:** Operating experience of TEREX TRI 00 dump trucks of Kuzbass. Mining industry. № 4 (98), 30-34. (in Russian).
14. **Kuzmich L.D, 1978.:** Cars.: M, "Mechanical engineering", 204-207. (in Russian).
15. **Melnikov N.N., Reshetnyak S.P., 1994.:** Prospects of solving scientific issues at working off powerful deep pits. Mining: IGD SO RAS. – Yakutsk, 14–23. (in Russian).
16. **Parunakyan V.E., 1966.:** To a question of improvement of railway transport//Equipment and technology of development of minerals: works / NIIOGR. – M, – V. 5. (in Russian).
17. **Parunakyan V.E., Yasyuchenya V.V., 1960.:** Operating experience motorized dump cars on Korkinsky coal pits.// Mining industry. Scientific Journal № 11, 157-162. (in Russian).
18. **Popov M.S., Kaplunov V.Y., 2010.:** The problem of environmental and economic decision-making on the use of of dumps and heaps in the coal industry in Russia. Mining informational-analytical bulletin. №7, 241-254. (in Russian).
19. **Savushkin R.A., 2003.:** Improving the design of self-unloading hopper cars for the transportation of bulk cargo: the dissertation of the candidate of technical sciences: 05.22.07.- St. Petersburg, 100-134. (in Russian).
20. **Yakovlev V.L., Bahturin Y.A., Stolyarov V.F., 2002.:** Some promising research areas in the field of quarry transportation. Proceedings of the International Scientific and Technical Conference on Quarry Transport. – Yekaterinburg, 15–20. (in Russian).
21. **Yakovlev V.L., Vitiazev O.V., 2004.:** Guidelines on Energy Conservation on the quarry railway transport //Mining Journal. № 10, 66–68. (in Russian).
22. **Yakovlev V.L., Popov V.Y., Kotyashev A.A., Kosnarev E.S., 2002.:** Improving safety and operational efficiency of rail transport in open cast mining / / Problems of pit transport: International Scientific Technical Conf. **-** Yekaterinburg: RAS., 94–97. (in Russian).

НОВЫЕ ВАГОНЫ-ХОППЕРЫ С ОДНОСТОРОННЕЙ САМОРАЗГРУЗКОЙ

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Аннотация. Рассмотрены перспективы использования модернизированных вагонов-хопперов с односторонней саморазгрузкой. Определены основные параметры кузова вагона. Проведены исследования процесса погрузки и выгрузки сыпучего груза из вагона-хоппера, которые позволили определить нагрузки на наружный и внутренний рельсы и обеспечить устойчивость вагона.

Ключевые слова. Вагон-хоппер, конструкция, безопасность, моделирование.

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Dimensioning and tolerancing of coated parts

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Summary. One of the most important problem in process planning for manufacturing of coated parts is the selection of the optimal relationship between the requirements for precision shaping of blanks for coating deposition and finally coated part. The processes of coatings machining differs from the machining processes of monolithic materials. One of the reasons of low workability of some coatings, especially wear-resistant, is a consequence of strong abrasivity coatings which contain hard particles. Therefore, establishment of rational dimensional tolerances in manufacturing operations is important and has a significant impact on the quality of the technological processes and the cost of manufacturing parts. This paper provides an integrated methodology for geometric dimensioning and tolerancing in manufacturing of coated parts.

Key words: allowance, coating, geometric dimensioning, tolerance analysis.

INTRODUCTION

In the problem of machinery quality control is of great importance to establish its optimal level at which the difference between the savings in consumption and cost of development and manufacturing of products will be maximized. For solving this problem an important role playing the application of protective and functional coatings and surface modification of machine parts and production tools to facilitate resources and energy savings in the manufacturing and long-term performance of machines. Coatings and surface modification technologies allow the engineer to improve the performance, extend the life, and enhance the appearance of materials used for engineering components. These technologies have been developed because the interactions of manufactured components with other components, liquid, and/or gaseous environments can result in component degradation and failure. Additionally, coating technologies enhance the performance of components by selectively applying coatings that perform specific tasks without compromising the benefits of the substrate material [2-4,27].

Coatings are no longer limited to the traditional applications associated with wear and corrosion [9,13,14]. The use of coatings for decorative effects, implant prostheses, and electrical isolation/conduction is increasing daily. As the technological needs of a society become more complex, the implementation of surface modification and coatings will assume an increasing role in meeting those needs.

Coatings often are treated after deposition to establish final dimensions or to improve or change the coating microstructure, thus avoiding some or all of the shortcomings of deposited coatings. Methods used to obtain these results include chemical/physical treatments, thermal treatments, and mechanical treatments, including machining, grinding, shot peening, hot isostatic pressing, and polishing [3,15,19,21].

In the process of repairing, the worn surface is usually coated with the layer, which thickness exceeds magnitude of wear. After the surface is coated it is machined by one of the available methods [20,21].

Preproduction planning is a fairly complex set of design and calculation work. Development of process plan (PP) involves the selection the most appropriate manufacturing processes and the order in which they should be performed to produce a given part specified by design engineer. The process sequence should be the production method that satisfies all of the design and quality requirements and also achieves the lowest possible product cost. The common goal of process planning is the creation of an optimal PP on any (mostly economic) optimality criterion. But none of the possible PP can not be considered absolutely optimal, as always there is a possibility to improve it according to the accepted criteria of optimality [17]. In process planning of coated parts there are the specific requirements that must be satisfied by PP: 1) the quality of functional coating should be stable for a long time. The process can prevent the risk of obtaining of some parts with deviations of coating thickness as its other parameters from the specified by part drawing. For some parts it is important to control not only final surface dimensions but simultaneously the specified value of coating thickness with specified tolerance limits, 2) in some cases can be specified special objectives for surface processing before coating deposition, which define surface integrity, for example, residual stresses in subsurface layer, hardness variations, etc. There are the various types of surface and subsurface alterations that are attributable to the different forms of energy applied in processing of work-piece. There may be metallurgical or other changes in the material immediately beneath the surface that can have a significant effect on part mechanical properties, coating bond strength and others.

LITERATURE REVIEW

Tolerance assignment is fundamental for successful mechanical assembly, conformance with functional requirements and component interchangeability, since manufacturing with perfect geometry is virtually unrealistic. In engineering drawings Geometric Dimensioning and Tolerancing (GD&T) correlates size, form, orientation and location of the geometric elements of the design model with the design intent, therefore it has a profound impact on the manufacturability, ease of assembly, performance and ultimate cost of the component [12,16]. High geometrical and dimensional accuracy leads to high quality, however, tight tolerances lead to an exponential increase of the manufacturing cost. Though the importance of tolerance design is well understood in the engineering community it still remains an engineering task that largely depends on experimental data, industrial databases and guidelines, past experience and individual expertise [23,24].

Geometrical and dimensional tolerances are of particular importance, on the other hand, not only in industrial production but also in product development, equipment upgrading and maintenance. The last three activities include, inevitably, RE tasks which go along with the reconstruction of an object CAD model from measured data and have to do with the assignment of dimensional and geometrical manufacturing tolerances to this object. In that context, tolerancing of RE components address a wide range of industrial applications and real-world manufacturing problems such as tolerance allocation in terms of the actual functionality of a prototype assembly, mapping of component experimental design modifications, spare part tolerancing for machines that are out of production or need improvements and no drawings are available, damage repair, engineering maintenance etc.

Process planning for parts involves the large complex of works and related details and required decisions making. The selection of operational dimensions, allowances, tolerances of work part, as well as evaluation of the accuracy of TP as a whole is one of the key task in part design and process planning as it affects both the product's functional requirements and manufacturing cost [17]. Traditionally, this important phase of product development is accomplished intuitively to satisfy design constraints, based on handbooks' data and /or skill and experience of the designers. Tolerance design carried out in this manner does not necessarily lead to an optimum design. The dimensional analysis of process plan for coated part manufacturing has three varieties: 1) analysis of newly designed PP when only drawing of coated part is available, route and operational sheets and documentation are not available, 2) analysis of newly designed PP when drawing of coated part, route sheet and drawing of work part, partially treated before coating deposition are available. This is typical situation when using concurrent engineering, and 3) analysis of the current PP which not provide required parameters for quality, consumption of materials and other resources and total part costs. In such cases it is necessary to reveal the dimensional links of machining operations before coating deposition, coating deposition process and subsequent finishing operations, and then by solving of dimensional chains and to find actual value of allowances disposed of in all stages of the processing of the coated surface and determine possible ways for improving of PP of coated part. Dimensional analysis enables to accomplish the following objectives: 1) to establish science-based operating sizes and technical requirements for all stages and operations and the manufacture of coated parts, which would require the minimum of PP correction, and 2) to establish the design of rational dimensions of workpieces with the minimum necessary allowances for processing of the workpiece to be coated and dimensioning of finishing coating operations.

Understanding the causes and effects of dimensional and geometric variations is a major concern in the design and manufacture of mechanical products [7]. However, effective tools for assisting designers in allocating tolerances and identifying trade-offs during the design process do not exist today.

CAD models, as one of the key inputs of many automated manufacturing and production systems, should include all the relevant and essential information on each and every feature of the component so it can be manufactured [11]. For instance, a particular part working surface surface feature in a CAD model can be manufactured once the coating type, position, diameter, thickness, surface finish requirement, including the tolerance on all of the parameters and constraints are known. It is understood that the initial dimension placed on the features in any drawing or CAD model should be the exact dimension that would be used if it was possible to work without tolerances. However, the tolerancing is required to make the part cost effective and feasible to manufacture. In the case of sensitive parts or features, the tolerance should be defined in more detail including geometrical features such as waviness, cylindricity, perpendicularity.

The accuracy cost of a part dimension depends on the process and resources required for the production of this dimension within its tolerance limits. This cost is thus primarily determined by the part material, geometry and tolerances. Given the material, geometrical part characteristics such as shape, size, shape complexity, existence of internal surfaces and feature details has a direct impact on the accuracy cost as they are taken into consideration for the process planning and the required machines and tools [22]. In a concurrent design environment, a robust optimum method is presented to directly determine the process tolerances from multiple correlated critical tolerances in an assembly.

Etienne et.al. deals with tolerance allocation driven by an activity based approach. Its main objective is to rationally give a good indicator of the relevance of tolerances values fixed by designers [8].

The majority of the published articles on tolerance synthesis are based on optimization, most of which use the cost-tolerance models

Tolerance modelling involves the modelling of the relationship between the tolerance information associated with part features and their effect on assembly functionality. The relationship captured by the tolerance model is referred to as the assembly response function [18].

Quality control (QC) plan is an important component of manufacturing planning for mass customization [26]. QC planning is to determine the operational tolerances and the way to control process variation for assuring the production quality against design tolerances. It includes four phases, i.e., tolerance stack-up analysis, tolerance assignment, in-process inspection design, and the procedure of error source diagnosis & process control. Based on the tolerance stack-up model and process capability analysis, a tolerance assignment method is developed to determine the operation tolerance specifications in each setup.

In conclusion, we note that the available literature does not address the definition of the dimensions and tolerances for surface preparation before coating deposition. The objective of this paper is to analyze the dimensional relationships between the three main stages of the manufacture of coated parts, and, namely, surface preparation for coating deposition, coating deposition and subsequent dimensional processing of the coating.

DIMENSIONAL TOLERANCING OF COATED PARTS

Tolerance analysis is a key element in industry for improving product quality and decreasing the manufacturing cost. In addition, it participates to an eco-aware attitude since it allows industrials to manage and reduce scrap in production. Tolerance analysis concerns the verification of the value of functional requirements after tolerance has been specified on each component [6].

Dimensional tolerances are required to be sensibly defined and presented in a way to guarantee the functionality of the part while minimising the manufacturing cost. In reverse engineering the design information including the overall geometry, surface finish and dimensional tolerances is extracted from scanning and analysing the existing part [11]. However the tolerance accommodation is one of the challenging problems that is conventionally dealt with by design initiatives of the reverse engineering expert in a rather “redesigning” approach. In this work the existing information from the part machining and surface finish measurement result is used to estimate the surface finish and dimensional tolerance information. This method can be integrated into a reverse engineering system for further automation and user flexibility. A wear factor can be added in the tolerance approximation process in the further development of the system, by involving a correction ratio to the initial estimation. Assembly analysis can also be included to better estimate the dimensional and surface tolerances for higher sensitivity components.

Campatelli introduces a new approach based on Axiomatic Design to simplify the process of Tolerance Synthesis. The main advantage of this approach is that all of the information needed for the Tolerance Synthesis is easily included in the classical AD framework [5]. The information that must be stored in the design matrices is mainly related to the production cost vs. tolerance curves and the tolerance chain needed for the synthesis phase.

In some cases of real manufacturing of coated parts the calculation of dimension chains can have the certain singularities. For example, the typical case is operation of coating finishing with removal of preselected coating allowances. It takes place in manufacturing of parts with wide dimensional tolerances of the coated surface and stringent requirements for the surface texture and therefore it is necessary to use finishing operations as superfinishing, honing, lapping, polishing, etc. In such cases the value of removed coating layer is regulated and for the calculation of technological dimensions it is possible to take allowance for coating processing as chain link, and the final dimension of coated surface as the closing dimension of dimension chain.

Assignment of rational dimensional tolerances for manufacturing operations is very important and has a significant impact on the quality of the PP and on the cost of part manufacturing. The extension of design tolerances is promoted to reduction of cost of processing operations. The wider tolerances enable performing operations at higher operational parameters, decrease time to set up the machine, less frequent corrective maintenance of machinery, etc. However, the expansion of tolerances on any operation increases the average allowances and, as a consequence, in the general case is promoted to increase the dimensions of the workpiece and its cost. In the manufacturing of coated parts increasing the tolerances on the surfaces to be coated results on an increase of the required thickness of the coating and on increase of allowance for the coating processing. In most cases, protective and functional coatings are characterized by a poor workability [15,21], which is consequence of their specific properties: high brittleness, nonuniform hardness, inhomogeneous chemical composition over the cross section, a large number of components of the microstructure (carbides, borides, and other intermetallic components with a high hardness) , substantially porous structures, etc. Therefore, the machining of coatings differs from the machining of monolithic materials. Low workability coatings is also a consequence of their large abrading ability because they contain hard particles.

Besides, the excessive coating thickness is an additional source of them internal tensile stresses have a negative impact on the bond strength and performance of the coatings.

Selection of tolerances and ISO accuracy degrees in design of machine parts traditionally are based on the principles of ensuring the operational and structural requirements for parts and assembly machine as a whole. Moreover, in some cases for improvement of reliability, durability and accuracy of machines designers tend to approximate the dimensions of parts to their calculated values of nominal dimensions. However, these design requirements are limited by technological capabilities and possibilities of technical measurements. In most cases this leads to increased complexity and cost of manufacturing and part control. For the processing of parts for more high accuracy requires increasing labor and material costs for equipment, fixtures, tools and control. The decreasing of tolerances results on increase of the probability of rejects. Relative cost of part manufacturing in these cases is decreasing when the tolerance increases by hyperbole, that is $C\delta$ = const, where C - cost of surface processing, δ - tolerance of the surface dimension.

The making of functional part surfaces with higher accuracy provides high precision couplings and permanence of their character in the large lots and their higher operational performance in general. Manufacturing of parts with extended tolerances are easier and does not require precise finishing equipment and technological operations, but reduces the accuracy, and hence the reliability of the machines. This contradiction between the operational requirements and technological capabilities is solved on the basis of technical and economic calculations based primarily of operational requirements. Application of protective and functional coatings on mating parts complicates the problem of selecting the optimum tolerances and allowances for processing operations. In this case it is necessary to consider three main process steps: surface preparation prior to coating deposition, coating deposition, and, coating processing.

Before coating deposition surfaces need to be shaped in order to meet their dimensional specifications. Some base material has to be removed in the places where the coating is to be deposited. Therefore it is necessary to develop and apply the principles of rational choice surface tolerances of parts prepared for coating deposition. Linear operating dimensions of parts subjected to thermal spraying or other methods of coating deposition must be chosen from the condition not only provide the desired thickness of the coating, but the minimum cost of its preparation and post-deposition dimensional processing. We assume that given on the part drawing the coating thickness on the given surface of the finished part is the original dimension of the drawing with a relatively small tolerances. However, in many cases, the tolerance of coatings thickness currently in the drawings are often not specified. Deposition of the coating effect on change of part shape and dimensions of it surfaces. The desired coating thickness in the drawing is provided not directly but indirectly via the machining dimensions. So promising is the use of technological dimensional chains that need to be solved to determine the linear operating size machining and coating thickness and which have a close parallel communication [1,10].

The solving of system of dimensional chains can simultaneously accomplish two conditions: remove the asperities and defective layer on the coating surface and achieve a desired thickness of the applied coating accordance with finished part drawing. The first condition is satisfied when choosing the value of the minimum allowance $z_{on}^{\min}$ for equations given in [1,10], the second – the choice of tolerances on components of the chain links on the equation:

$$\sum_{m+n} \delta_i \leq \delta_k ,$$

where: m – the number of enlarging chain links, n – the number of diminishing chain links of dimensional chain, δ_k – coating thickness tolerance of the finished part.

COST - EFFECTIVE TOLERANCE ASSIGNMENT

The matter of selection of the minimum allowance for coating processing is very essential requirement to process plan of coated parts. From the geometrical point of view it may seem that the absolute value of the thickness of removed coating layer during finishing operation is not important, and it is necessary mainly to secure coating thickness fluctuation after finishing operations within specified by part drawing. Also from this point of view there are two equivalent alternatives of proportion between thickness of deposited coating and allowance for this coating finishing. For example, first variant is thickness of deposited coating as t_{dep} = 0,5…0,6 mm and finishing allowance $Z_{fin}^{\min}$ = 0,2 mm, and for other variant t_{dep} = 0,8…0,9 mm and $Z_{fin}^{\min}$ = 0,5 mm. However, from the technical and economic points of view these options completely are ambiguous. First of all, increase of deposited coating thickness results on sharp rising of adverse internal stress reducing bonding strength between coating and substrate, which sometimes cause cracking and detaching of coatings. In this regard, it is necessary to strive for the smallest possible thickness values of deposited coatings. Furthermore, for many types of coating, for example, obtained by surfacing, their properties (hardness, structure, residual stresses, etc.) are changing in direction from outer surface to the bottom surface. Therefore, in such cases it is necessary to strive for the smallest possible values of allowances $Z_{fin}^{\min}$. For this purpose, it is necessary that for the processes of coating deposition and finishing processing were preceded by such pretreatment methods in which minimum values by the constituent elements of the allowances are provided. Practically, this problem can be solved by applying a surface processing before coating deposition with an accuracy greater than the accuracy required of the coated surface of the finished part accordance with the part drawing.

The reduction of the thickness of deposited layer and allowances for finishing processing of coatings is advisable from the economic point of view. Even a slight increase of the thickness of the deposited layer requires the increase of consumption of expensive coating material and operational time of coating deposition and, hence, the appropriate cost of the coating obtaining. In addition, usually coatings have poor machinability, which results on increase of cost of coating dimensional processing.

Furthermore, there is a need for careful approach to the selection processes of coating deposition based on accounting of design features and details of the technological features of the coating. Insufficiently rigid parts should be coated by processes with the lowest possible heat input to avoid warping and other geometrical distortions of form and dimensions of the coated part.

Comparison and selection of more suitable process plan (PP) for manufacturing of coated part is necessary to execute by whereas accuracy of PP, which has a significant impact on material consumption rate for coating obtaining:

$$H_{cm} = S_c\left(t_{\min} + \delta_w^{\pm} + Z_{fin}^{\min} + 0,5\delta_c\right)\times$$
$$\times\rho_c\left(1 - P/100\right)\eta_{dep}\eta_p,$$

where: S_c – coating surface area, $t_{\min}$ – minimum required coating thickness on the finished part, $\delta_w^{\pm}$ – tolerance of surface dimension after preparation for coating deposition, $Z_{fin}^{\min}$ – the minimum allowance for processing of deposited coating, δ_c – tolerance of deposited coating thickness, ρ_c – the density of the coating material, P – porosity of the coating, η_{dep} – utilization of coating material associated with its loss during the deposition process, η_p – the same associated with the kinematics of the deposition process and part geometry.

As it is known, that the tolerance for any ISO accuracy degree:

$$\delta = ia,$$

where: i – unit of allowance, a – a factor equal to the number of units of tolerance.

In the ISO system unit of tolerance is [25]:

$$i = 0,45\sqrt[3]{d_{av}} + 0,001d_{av},$$

where: d_{av} – average dimension for a given range of dimensions.

The allowance unit i, reflecting the influence of technology, part design and metrological factors, expresses the dependence of the tolerance for the nominal value of the dimension is a measure of precision. It allows the development of tolerance system for a wide range of design parameter values. To normalize levels of accuracy classes (degrees) it is assigned degrees of accuracy of manufacturing. For each class (degree) of accuracy exists naturally built a number of fields tolerances in which different sizes of similar dimensions surfaces of the parts have the same relative accuracy, defined roughly the same value of the coefficient a. In an ISO number of units tolerance when switching from one to another quality class accuracy ranging from 5th varies approximately exponentially (for example, 7, 10, 16, 25, 40, 64, etc.) with common ratio $\sqrt[3]{10} \approx 1,6$.

Analysis of dependence of tolerances from the magnitude of the dimension for the main accuracy degrees shows that with the dimension increase and decrease the accuracy requirements of their performance, the tolerance can approach or even exceed the thickness of some deposited coatings. In these cases it is necessary to increase of deposited coating thickness to achieve the desired value of allowance for finishing operations.

The coating thickness is usually a function parameter which specifies the availability of coated part. The ratio of coating thickness t to the allowable amount of wear should be greater than 1. Since the thickness of the coating is usually much less than the nominal dimension of the surface ($t << d$), the tolerance on the value of the unit thickness of the coating will be much less than the tolerance values for the units of the dimensions of finished coated part and the workpiece which prepared for coating deposition:

$$i_c << i_p; i_c << i_{wp},$$

because the dimensions of part and workpiece are belong to various dimension ranges.

From the theory of dimensional chains it is follow that tolerance of coating thickness is equal to the sum of tolerances for dimensions of the workpiece to be coated δ_{wp} and after coating deposition δ_{cp}:

$$\delta_c = \delta_{cp} + \delta_{wp}.$$

From the definition of tolerance value for a certain ISO accuracy degree the last expression can be written as:

$$\delta_c = i_{p(wp)}(a_p + a_{wp}) = i_c a_c .$$

It is assumed here that $i_p = i_{wp}$, as they, as a rule, from the same dimension range. In case of surfacing of thick layers it is possible that $i_p \neq i_{wp}$. Then:

$$\delta_c = i_p a_p + i_{wp} a_{wp} .$$

For thin films or coatings, for example, obtained by methods of thermal spraying, will be used the first expression.

In view of the relative smallness of the coating thickness it is possible to neglect by value of $0,001 d_{cav}$. Then we can write:

$$a_c = \frac{i_{p(wp)}}{i_c}(a_p + a_{wp}) =$$
$$= \left(\sqrt[3]{\frac{d_{wpav}}{t_{cav}}} + \frac{0,001}{0,45} \frac{d_{wpav}}{\sqrt[3]{t_{cav}}} \right) \left(a_p + a_{wp} \right).$$

As the thickness of coatings usually is included in the dimension range of up to 3 mm as the dimensions of surfaces of machine elements to be coated are predominantly in the dimension range above 18 mm (d_{wpav} = 24, 40, 65, 100 mm, etc.), the ratio $i_{p(wp)}$ / i_c is typically of the order of 3 or more. Therefore, the number of ISO accuracy degrees for tolerance of the coating thickness is many times higher than the corresponding number for the dimensions of the part and the workpiece to be coated, and therefore accuracy of thickness of dimensionally treated coating below compared to the surface dimension for several ISO accuracy degrees. As it is known, the number of units in ISO during the transition from one degree to another varies approximately in a geometric progression with ratio 1,6.

With the increase of the relative value of the allowance for coating processing increases the relative cost of dimensional processing of coatings is growing. One of the ways of reducing the allowance value for finishing of coatings is the reduction of dimension tolerance of the workpiece before coating deposition. Therefore, it is recommended to prepare surfaces for coating deposition with accuracy of average ISO accuracy degree with conditions of compliance of required tolerance values throughout the dimension range of surfaces with coatings.

It is possible to determine the average ISO accuracy degree by computational-graphical manner using the graphic dependencies or calculation formula:

$$JT_{av} = JT_a + (ab / ac),$$

where: JT_a – nearest ISO accuracy degree, having a value of tolerance for a given dimension is below than predetermined, *ab* – the difference between the value of a given (received) tolerance and tolerance for ISO accuracy degree, *ac* – the difference between the values of the nearest less precise degree and given degree JT_a.

CONCLUSION

1. The technology of the manufacturing of coated parts is the integration of traditional manufacturing technology and various engineering technologies for coatings deposition as surfacing and related welding processes, powder metallurgy, electroplating, thermal spraying, PVD and CVD, etc.). This is unique trend providing production of high quality and cost-engineering patrs, which could not be developing successfully without analysis of the accuracy of coated parts, including the stages of surface preparation and coating deposition.

2. For more wide adoption of coatings technology and other methods of surface engineering it is extremely necessary to develop standards for the accuracy parameters of coated parts and processes for coating deposition.

REFERENCES

1. **Balakshin B.S., 1969:** Fundamentals of engineering technology. – M.: Mechanical Engineering. – 560.
2. **Boguslaev V.O., Dolmatov A.I., Zhemanyuk P.D., et.al., 1996:** Detonation coating of aircraft engines and parts, jigs and fixtures, followed by magnetic abrasive treatment, Zaporozhye: Deca, 366. (in Russian).
3. **Borisov Y.S., Kharlamov Y.A., Sidorenko S.L., Ardatovskayu E.N., 1987:** Thermal Sprayed Coatings from Powder Materials: Handbook. – Kiev: publishing house of the Ukraine Academy of Sciences "Naukova dumka", 1987. – 544. (in Russian).
4. **Bunshah R.F. (ed.), 2001:** Handbook of hard coatings. Deposition Technologies, Properties and Applications. Noyes Publications. – 550.
5. **Campatelli G., 2011:** Tolerance synthesis using axiomatic design // Proceedings of ICAD2011. The Sixth International Conference on Axiomatic Design, Daejeon – March 30-31. 152-157.
6. **Dantan J.-Y., Gayton N., Dumas A., Etienne A., Qureshi A.J., 2012:** Mathematical issues in mechanical tolerance analysis // 13e Colloque National AIP PRIMECA, Le Mont Dore – du 27 au 30 Mars 2012.
7. **Davidson Joseph K., Shah Jami J., 2004:** Mathematical model to formalize tolerance specifications and enable full 3D tolerance analysis // 2004 NSF Design, Service and Manufacturing Grantees and Research Conference/SMU - Dallas, Texas.
8. **Etienne A., Dantan J.-Y., Siadat A., Martin P., 2009:** Activity Based Tolerance Allocation (ABTA) – Driving tolerance synthesis by evaluating its global cost // Laboratoire de Conception Fabrication Commande (LCFC). – 37. http://hdl.handle.net/10985/6294
9. **Groover Mikell P., 2007:** Fundamentals of Modern Manufacturing. Materials, Processes, and Systems, 3td ed., John Wiley & Sons, Inc.
10. **Ivashchenko I.A., 1975:** Technological dimension calculations and methods of automation. - M.: Mechanical Engineering. – 222. (in Russian).
11. **Jamshidi J., A. R. Mileham A.R., Owen G.W., 2006:** Dimensional tolerance approximation for reverse engineering applications // INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006. – Dubrovnik - Croatia, May 15 - 18. 855-862.
12. **Kaisarlis George J., 2012:** A Systematic Approach for Geometrical and Dimensional Tolerancing in Reverse Engineering // Reverse Engineering – Recent Advances and Applications, InTech. 133-160.
13. **Kalashnikov V.V., Demoretskii D.A., Nenashev M.V., Trokhin O.V., Rogojin P.V., et.al., 2011:** The detonation method and technology of multilayer facing charges of cumulative punches, Herald of the Samara State Technical University. Ser.: Technics, N 3, 213-219. (in Russian).
14. **Kharlamov Y.A., 1987:** Detonation Spraying of Protective Coatings, Materials Science and Engineering, Vol. 93, 1-37.
15. **Klimenko S.A., Mukovoz Y.A., Polonsky L.G., Melnychuk P.P., 1997:** Turning of wear-resistant coatings. - K.: Tekhnika. 146. (in Russian).
16. **Mandil G., Desrochers A., Rivière A., 2009:** Computational Methodology for the Prediction of Functional Requirement Variations Across the Product Life-Cycle // Proc. Of the 11th Int. Conf. on Computer Aided Tolerancing, CIRPCAT, Annecy (France). http://arxiv.org/pdf/0905.0775.pdf
17. **Matveev V., Tver M.M., Strikers F.I., et.al.: 1982:** Dimensional analysis of technological processes. M.: Engineering. 264. (in Russian).
18. **Mazur M., 2013:** Tolerance analysis and synthesis of assemblies subject to loading with process integration and design optimization tools: PhD thesis, School of Aerospace, Mechanical and Manufacturing Engineering,RMIT University, Melbourne, Australia. 258.
19. **Nenashev M.V., Ibatullin I.D., Utyankin A.V., Zhuravlev A.N., Usachev V.V., Karjakin D.J., Djakonov A.S., 2011:** Application of detonation coatings to create a new metal-working tools, Herald of the Sergei Korolev Samara State Aerospace University, № 3, Part 1, 204-210. (in Russian).
20. **Ptak P., Zloto T., 2011:** Application of an inductive conventer for measuring the thickness of anti-corrosion coatings in machines // TEKA Kom. Mot. Energ. Roln. – OL PAN, 11, 297-302.
21. **Ryzhov E.V., Klimenko S.A., Gutsalenko O.G., 1994:** Technological support quality parts with coatings . – K.: Science. Dumka. 181. (in Russian).
22. **Sampath kumar R., Alagumurthi N., Ramesh R., 2009:** Optimization of design tolerance and asymmetric quality loss cost using pattern search algorithm // International Journal of Physical Sciences Vol. 4 (11), 629-637.
23. **Shringi D., Purohit K., 2013:** Simultaneous Optimization of Tolerances for Prismatic Part Assembly in Different Stack up Conditions // International Journal of Mining, Metallurgy & Mechanical Engineering (IJMMME) Volume 1, Issue 2, 183-186.
24. **Weiss P., 1993:** A Discussion of Scientific Methods for Setting Manufacturing Tolerances. Report No. 98. University of Wisconsin. Center for Quality and Productivity Improvement. – 13.
25. **Yakushev A.I., 1975:** Interchangeability, standardization and technical measurements. - M.: Mechanical Engineering. 471. (in Russian).
26. **Yang Y., 2007:** Integrated quality control planning in computeraided manufacturing planning. PhD thesis. Worcester polytechnic institute. – 159.

27. **Zhizhkina N., 2012:** The researches of influence of thermal treatment to structure and properties of core of rolls with layer of high alloyed cast iron // TEKA. COMMISSION OF MOTORIZATION AND ENERGETICS IN AGRICULTURE, Vol. 12, No.3, 169-173. (in Russian).

ОПРЕДЕЛЕНИЕ РАЗМЕРОВ И ДОПУСКОВ ДЕТАЛЕЙ С ПОКРЫТИЯМИ

Юрий Харламов, Али Аднан Мансур Ал-Джавахери

А н н о т а ц и я . Одной из самых важных и трудных проблем в разработке технологических процессов изготовления деталей с покрытием является выбор оптимального соотношения между требованиями к точности формирования заготовок под нанесение покрытий и окончательно обработанной детали с покрытием. Процессы обработки покрытий резанием отличаются от процессов обработки традиционных материалов. Одной из причин низкой обрабатываемости некоторых покрытий, особенно износостойких, является сильная абразивность покрытий, которые содержат твердые частицы. Таким образом, установление рациональных допусков размеров на операциях изготовления деталей с покрытиями является важным и оказывает значительное влияние на качество технологических процессов и стоимости изготовления детали. В данной статья представлена интегрированная методика определения геометрических размеров и допусков на межоперационные размеры изделий с покрытиями.

К л ю ч е в ы е с л о в а . Припуск, покрытие, определение геометрических размеров, анализ допусков.

Computer-integrated system of decision-making support of control of tires operation of trucks

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Summary. The question of computer-integrated system of decision-making support of control of tires operation of trucks is considered. The software of the program is based on an accumulation and use of databases: norms of tires life from producers data and state recommendations, basic and specified correction coefficients of tires life with a glance actual real-time use, statistical indicator of tires operation, their life, results of control the residual height of the tread pattern.
Key words: tires life, software, prognostication tires life, correction coefficient, control of tires use.

INTRODUCTION

Daily runs and load trucks has substantially grown in the last year. The management of technical maintenance of tires of trucks complicates under the circumstances, what to calls for development of system, necessary for cost decrease on their service.

ANALISIS OF LAST REASEACHES AND PUBLICATIONS

Analysing works by [24], tire power consumption [4], rubber chemistry technology [2, 3, 21], Theory of Viscoelastic properties to Undiluted Linear polymers [5], tire design [29], factors on tire wear [9, 13, 17, 18], research of tire wear [1, 6, 8, 10, 30] can observed that researches of the condition of tires of trucks has linked to safeguarding of road safety, economy and comfort and in many respects depends on running conditions.

Tires life sets definitely specific in each country, based on operating experience, quality of produced tires, the intensity of their operation, weather and road conditions.

Tire plants in different countries keep established and warranty norm of run. So for truck tires is 53-77 thousand km (manufacture Russia, Belarus) and 90-175 thousand km (EU production).

Operating norm of run establishes what the minimum run for economic reasons must perform tire and it uses automobile enterprises.

Operating norms of tires life are intended for the requirements planning automobile enterprises in tires and rational use of material resources, determine the level of rates and calculation business taxation.

MATERIALS AND RESULTS OF RESEARCHES

Forecasting and work capacity of tires at an appointed instant of time is used to determine the tires life by calculation method. Since treadwear is the only phasing degradation failure of tires then this characteristic is used to establish the norms of operational run.

Wearing-out is a process of destruction and separation of material from the surface of the tire tread and the accumulation it permanent set by friction, which is manifestative in a gradual change in its size and shape. Wear - final result of wearing-out in units of length, volume or weight.

Among scientists of our country had the idea that there are three types of tire wear: fatigue, by rolling, abrasive.

When operating tires on macadam roads is observed abrasive wear. Outward manifestation of this kind is score marks, slight tears, cuts, etc.

The tires wear occurs on a mixed mechanism in actual operation at that correlation of various kinds and total failure rate changes depending on the environmental effects.

Wear intensity is the speed of the wear process.

Wear intensity determines moment of offensive blow limiting condition of the tire on treadwear.

Run up removal from service (tire life) *L* is running time of tire in kilometers until moment of reaching the limit state.

Taking into account importance and actuality of problem, it needs to decide the followings tasks: to specify determination of norm of tires life of trucks with a glance actual conditions their operation, to forecast an actual life and service life of tires with fixing of time for tire kit changing, to make a administrative decisions connected with operational process of tires. Any actions for management of a resource have to begin with creation of full-volume system of the record. It creates effective levers of influence on production for elimination of revealed defects. When carrying out maintenance and repair of trucks (Fig. 1).

The record has to be reduced to data acquisition for management of process of use of tires for the purpose of it optimization. The main total index is cost per unit in grn/1000 km of run in further to a realized tires life (run). There are situations when tires it is expedient to place out of service earlier, than there will come their limiting state by the main technical criterion - wear of a tread up to the limiting value.

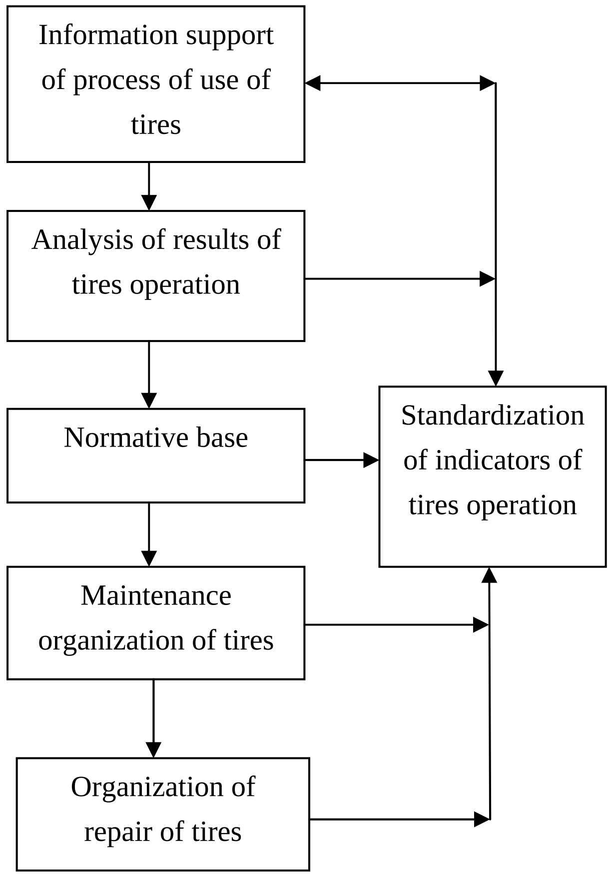

Fig. 1. Actions for optimization of a tires life

All these tasks are commutated and their decision is possible by special the developed computer-integrated system of decision support – complex program.

The initial stage is the creation of a database of trucks and tires. Database [25, 26] is renewed (daily operation) when tires is dismantled, tires life is exhausted and new tires is installed. Technical condition and character of treadwear is estimated as it is a measure of grade of service of trucks and tires in automobile enterprises.

Each accounting system must be well organized and function. This is no easy task. This is complexity of the organization of proper collection of data about laid-up tires. But the necessity of these actions determines the economy. The losses of life tires constitute

10-25 percent depending on the type of vehicles in any automobile enterprises.

So for tires of tippers are characterized by small average annual runs and according to prolonged service life. This suggests that the change in performance also depends on the time during which the running time is carried out notably the operation rate.

Physical aging causes increased wear of tire tread, increases occurrence probability of traumatic failure.

Thus, the input to the system is time and operating conditions. The transition intensity from operable state to a failed state depends from them, and then what process will prevail. Output system - a tires life failed.

The methodical, normative and programmatic support of the system is developed with a glance specifics of motor transport enterprise. The normative support is developed individually for every model of truck and for every tires model. Developed system keeps the structure and working-capacity by modification and adaptation to the conditions of concrete enterprise (Fig. 2).

The software of the control system of technical state of tires is built by module principle and it is an application package, it is bound up with the methodical, normative and documentary support of the system [12]. The bond between the relatively self-contained program modules realizes by management of the main program – device executive and through the data flow.

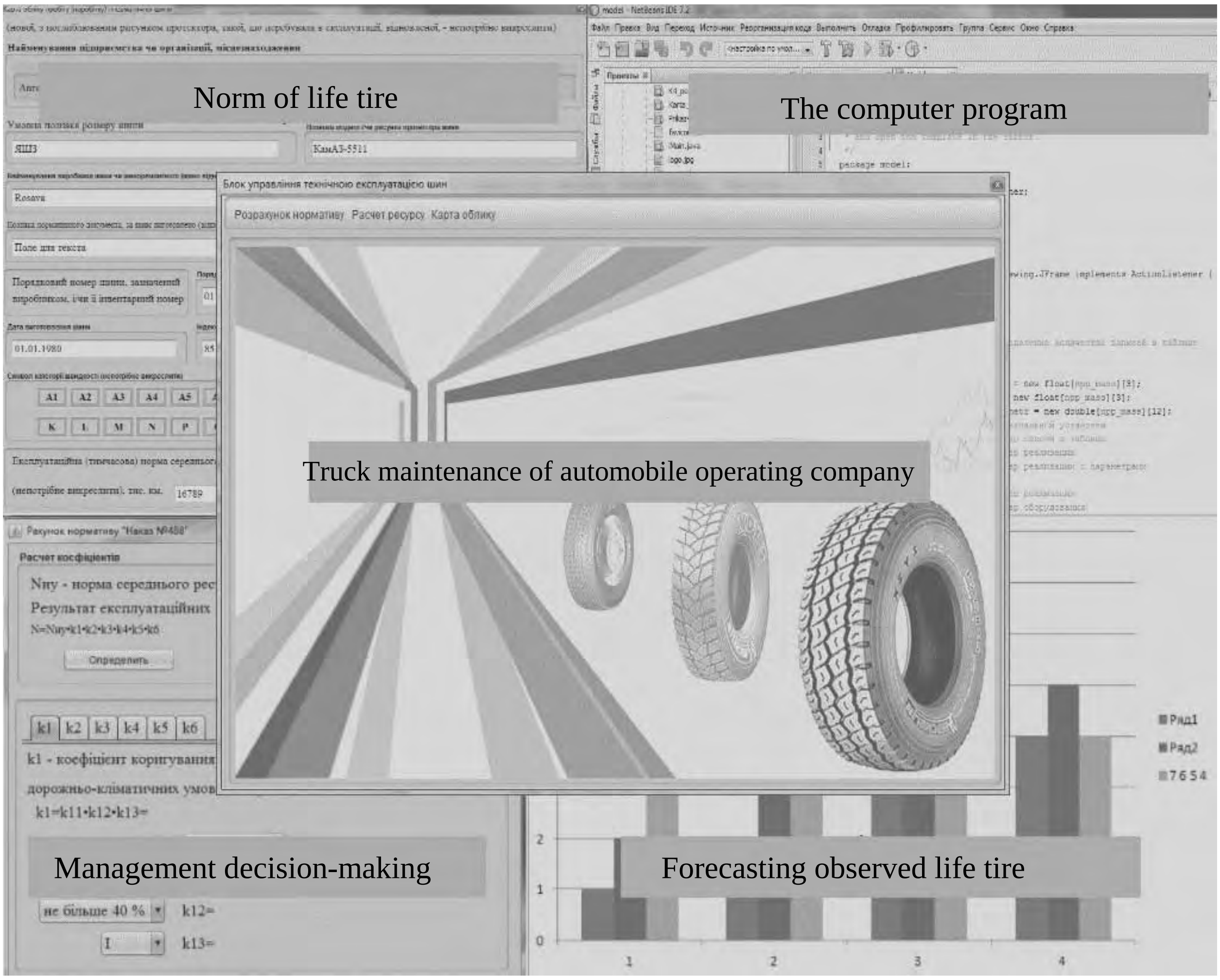

Fig. 2. General view of software

The program of organization of module interface is built on the basis of the documentary providing of control system. The created interface behaves to active, that provides work of operator in the conversationally, that conforms to the requirements which are produced to the information systems of the last generation.

Operation of the program is based on an accumulation and use of databases: norms of tires life from producers data and state recommendations, basic and specified correction coefficients of tires life with a glance actual real-time use, statistical indicator of tires operation, their life, results of control the residual height of the tread pattern in the cards of accounting.

The front pages of electronic card include total technical characteristic about a car tire and columns about damage and types of treadwear. The contextual menu is used for filling of the card, speeded up the input of information (Fig. 3, a).

Predictable tire life can view on the other tabs of the program after entering the data.

The program takes account of the wear rate of tires, and it is adjusted after the introduction of all the necessary data.

The program has a handbook on which model of tire is selected and you can update data on the tires.

All data for the program is changed simply by editing the appropriate ranges.

The next is the pages of calculations of tires life on the correction coefficients under order № 488 [16] (Fig. 3, b) on general computer-integrated system of control by technical maintenance of tires (Fig. 4).

The program is determined statistical indicators: mathematical expectation, roof-mean-square deviation, etc. Installs the percent of safe operation during the specified life (for stable operating conditions 95 percent is recommended, for variable operating conditions – 90% percent [7, 23, 27, 28]), following which the recommended prognosis of tires life fixes, which asserts by order on motor transport enterprise.

Modeling of manufacturing processes in the enterprise becomes possible on basis of the use of banks and information databases, as well as the technical condition of vehicles and their components that will use application package and automate the management of the technical influence.

Organization of accounting and control tires on automobile enterprises allows to identify the causes of increased tire wear. This set of measures and means a subsystem of information, including the provision of appropriate component (documentary, condition-monitoring, etc.). On the basis of information supplied by this subsystem manages the technical impact on tires and spare parts, affecting their wear.

The program allows to analyze the causes of failing of tires and set differentiated norm of life tires for various vehicle.

The norm of tires life is estimated as follows:

- for a 90 percent safe operation:

$$l_{norm} = \overline{l} - 1{,}28 \cdot \sigma \,, \tag{1}$$

- for a 95 percent safe operation:

$$l_{norm} = \overline{l} - 1{,}645 \cdot \sigma \,, \tag{2}$$

where: $\overline{l}$ – mathematical expectation of run to writing off, thousand km, σ – roof-mean-square deviation, thousand km.

The process of prognostication of tires life on results control the residual height of the tread patter of tires following.

The forecast of the tire life:

$$L_{i(o,d)} = 10^3 \cdot \left[(0.85...0.90) \cdot H_{in} - H_{\lim} \right] \Big/ \left[\frac{\overline{h}_1 - \overline{h}_i}{L_{act,i} - L_1} \right], \tag{3}$$

where: H_{in} – the initial height of a new track, mm, 0.85...0.90 – the coefficient, which considers the heightened wear rate in the process of wearing-in, $H_{\lim}$ – the limiting value of the remaining-tread depths (it is defined by road regulations), mm, $\overline{h}_1$, L_1 – the height of the tread and tire life at the first measurement which is carried out in 8,000…10,000 km after the process of wearing-in ends, mm, thousand km respectively, $L_{act,i}$ – the actual tire life at the moment of the measurement, thousand km.

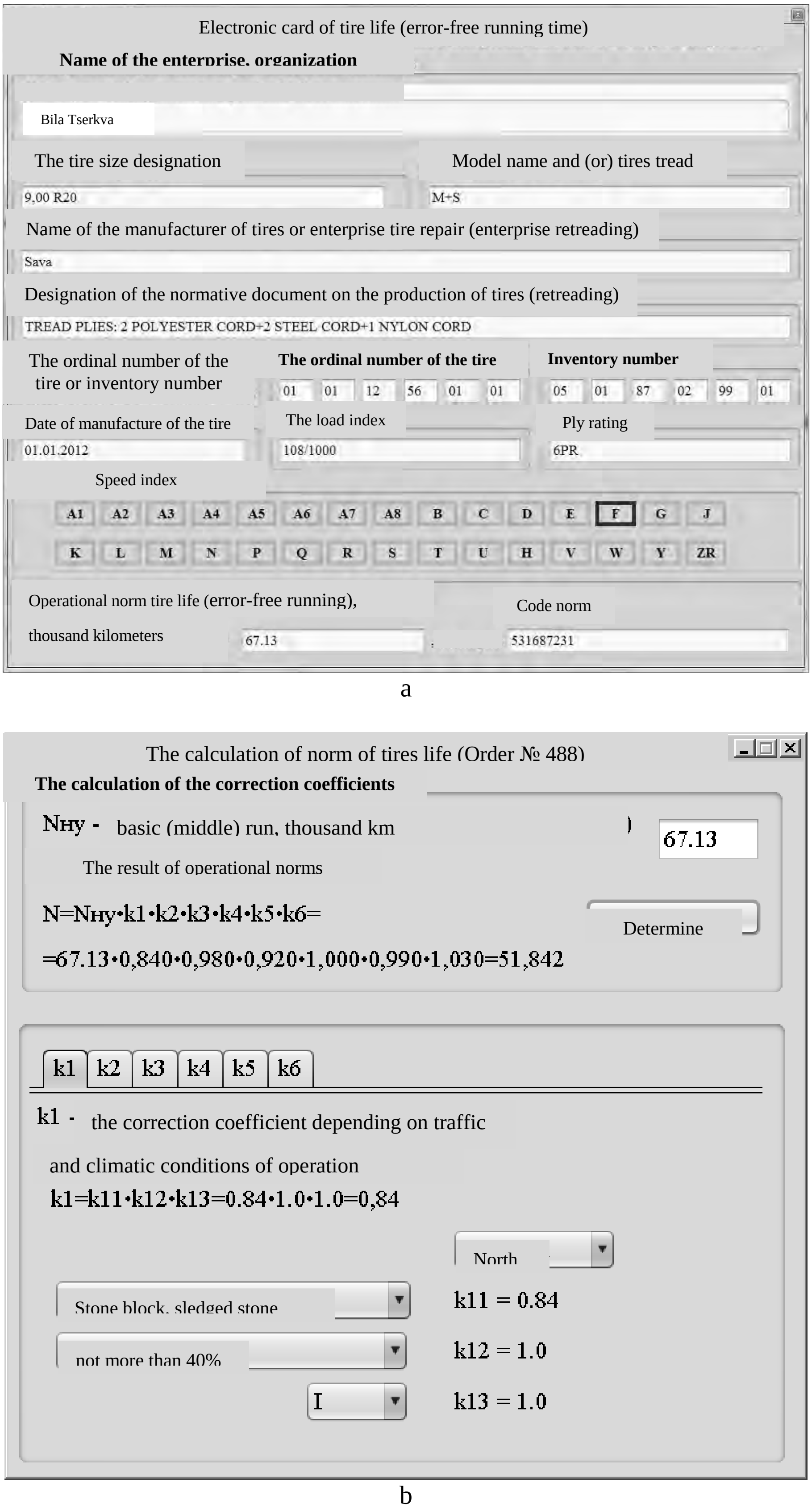

Fig. 3. Software: a – table of information about tire, b – result of calculation tires life

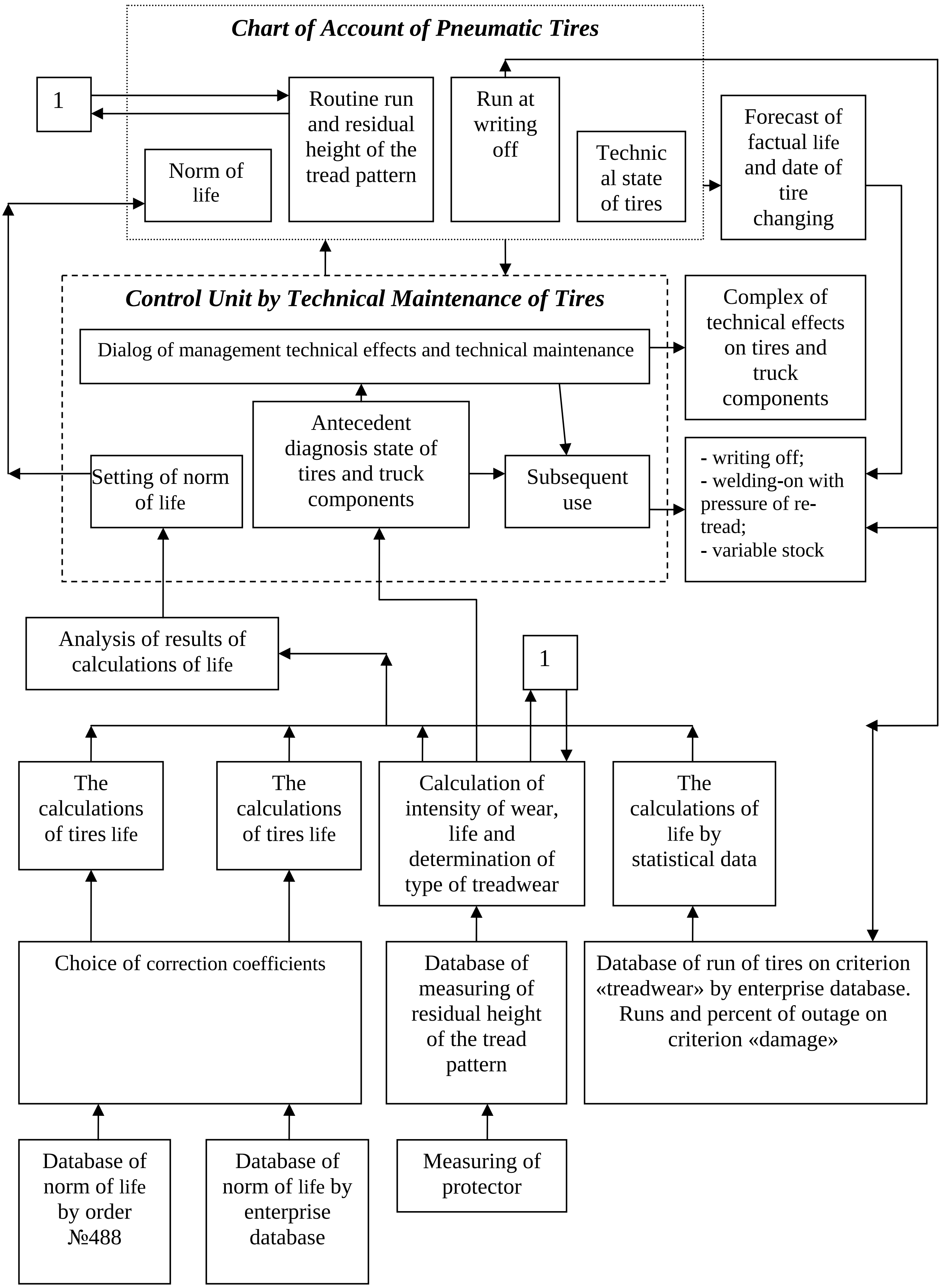

Fig. 4. The plan of computer-integrated system of control of tires operation

The minimum necessary number of measurements for each tire is nine. The average remaining-tread depths are calculated for each tire and pair of tires (at the use of the doubled tires) for the operated and driving axle of tires severally by dependence:

$$\bar{h}_i = \frac{\sum h_i}{9},$$
$$\bar{h}_{i\kappa} = \frac{\sum \bar{h}_i}{m}, \qquad (4)$$
$$\bar{h}_{i\text{в}} = \frac{\sum \bar{h}_i}{\text{n}},$$

where: h_i – the value of the i-measurement of the remaining-tread depths, mm, $\bar{h}_i, \bar{h}_{iop}, \bar{h}_{idr}$ – the average remaining-tread depths of each tire, the operated tires of the trucks, the driving tires of the trucks, mm, *m*, *n* – the quantity of the operated and driving tires of the trucks, unit.

Bundle of different factors influence on tires life [11, 14, 15, 19]. A calculated technique is based on the method of correction coefficients of base run which is determined by producer, for the tires of foreign producers base middle – in concordance with [16, 20] for the tires of production of the Union Independent State.

Tires life *N* of trucks is estimated by equation:

$$N = N \cdot k_1 \cdot k_2 \cdot k_3 \cdot k_4 \cdot k_5 \cdot k_6 \cdot k_7, \qquad (5)$$

where: $N_{ну}$ – basic (middle) run, thousand km, k_1 – the correction coefficient depending on traffic and climatic conditions of operation and it takes into account the type road carpet, longitudinal tilt of road and chemical pollution rate (values of coefficient k_1 are borrowed from a state technique), k_2 – the correction coefficient takes into account the run of truck in the special conditions (site areas, excavations), k_3 – the correction coefficient depending on locations of tire on a truck, k_4 – the correction coefficient depending on the high-speed of tires of trucks, k_5 – the correction coefficient depending on deflection of the internal pressure in tires from normative values, k_6 – the correction coefficient depending on the ratio of kilometers traveled in the city limits to total that allows to take into account intensity of wear at the expense of accelerations and braking, (values are borrowed from a state technique), k_7 – the correction coefficient depending on load-carrying capacity use k_c relative to optimum load-carrying capacity trucks.

The calculation of tires life of truck which are proposed in comparison with the factual data shows that the deviation is 4-5% (the difference between the calculation data on the orders of the Ministry of transport and communications of Ukraine from 20.05.2006, №488 and the actual run of tires is up to 30-40%).

Tire life is determined by cards of tires as the number of days since the installation of the tires before the date off.

In the analysis of experimental data is calculated type of vehicle. Analysis of the results of experimental studies made it possible to the following conclusions:

1. 96% of the empirical distribution of the tire life obeys the normal law.

2. Distribution described by the Weibull law, implemented in research units.

3. Average wearing life for different types of vehicles is significantly different.

The software enables to the normative tires life of trucks on the basis of the gamma-percent actual tires life that includes:

a) validation for the previous sample data (full or truncated),

b) determination of distribution law of tires life,

c) calculation of resource characteristics of tires,

d) to establish normative tires life at a level of given percent of no-failure operation, which depends on it dispersion, and is characterized by the coefficient of variation. If we assume that the distribution of the actual tires life is subject to the normal law, the norm may be assigned to on addictions taking into account the functions of the Laplace (for 95%, 90%, 80%, 70% and 60% no-failure operation).

The software enables to forecast the tires life on data of the constant control of residual height of tread pattern and to identify the intensity of wear. The measurement data are entered in the registration cards of tires, the forecast of their actual tires life to be specified after each measurement, since the intensity of wear changes constantly in the process of exploitation. The average residual height of tread pattern is calculated both for each tires and for managed and leading and dual tires separately.

Hence, normative tires life is assigned several ways, depending on the level of production processes on auto enterprise.

The software enables to compare calculated values. Comparison of the designated normative tires life with the actual data includes:

1) appointment of the normative tires life (L_{norm}),

2) on hand to database of actual tires life (L_i),

3) calculation of resource characteristics of tires,

4) determination (ΔL) deviation of the average tires life ($\overline{L}$) from normative (L_{norm}),

5) determination of the argument (z) for functions of the Laplace (ratio ΔL to σ),

6) the choice of the values of the normalized normal distribution function ($\Phi(z)$),

7) the calculation of the levels of reliability,

8) assessment of the calculated level of reliability,

9) decision making about the fixing normative tires life which is corrected.

For the assessment of accordance of the actual tires life in conditions of real operation requires data on the dynamics of wear of tread and dispersion of wear on different running time.

Abrasion tire occurs in various gases and in some cases corroding liquids. Studies have shown that these environments affect the abradability of rubbers, and especially on the abradability of rubbers based on unsaturated rubbers.

General environment for tires is air, oxygen is chemically-active medium towards all rubbers, accelerates the destruction and structuralization of rubber from them.

During the operation, as well as during storage of rubber products is observed deterioration in their physical and mechanical properties: rubber cracks, becomes brittle and less strong.

Aging - feedback on the rubber oxygen, heat, light and especially ozone.

Therefore, management of tires life of means of transport provides:

a) fixing of normative tires life on the basis of experimental data of control residual height of tread pattern,

b) forecasting gamma-percent tires life according to statistical data valid sample and data constant process control of their wear with the definition of intensity,

c) increase the tires life of tires through the improvement of maintenance system of element of running gear on the actual technical condition,

d) reduction in the percentage of early failures of tires for the criterion «damage» due to their retirement from operation at accessible of a zone of critical wear,

e) efficient use of the tires life due to the constant control of residual height of the tread pattern.

In the process of studying the dynamics of the tire wear was found that for tires of tippers depending on the operation rate is prevails one of the processes either wear or aging and aging-related increase in the probability of chance failure.

The operating conditions and the specific use of trucks render material effect on the operation rate.

Run of tire depends on operation rate.

The developed measures of management by technical condition of tires allow to improve indicators of efficiency of technical operation of trucks by optimization $\alpha_{TT} \to opt$ at the expense of expected positive increment of components of technical readiness coefficient which provides economic efficiency

$$\Delta\alpha_{TR}^{incr} = \Delta\alpha_{h}^{incr} + \Delta\alpha_{TA}^{incr} + \Delta\alpha_{t}^{incr} + \Delta\alpha_{TL}^{incr}, \quad (6)$$

where: $\Delta\alpha_{h}^{incr}$ – increment at the expense of effective use of a tires life with regard to constant control of residual height of tread pattern ($\bar{h}$), $\Delta\alpha_{TR}^{incr}$ – increment at the expense of management volumes of technical actions that determined the proposed layout of technical condition of element of running gear of trucks (Fig. 4), $\Delta\alpha_{t}^{incr}$ – increment at the expense of stock management of tires by forecasting the tires life, $\Delta\alpha_{TL}^{incr}$ – increment at the expense of management of tires life.

Effective solution complexes planning management and optimization problem in managing technical effects possible on the basis of operational updates on the state of internal and external factors control system (vehicle and it components, the system keeping it technical condition, or the whole enterprise). It becomes especially important in the development and implementation of new systems (strategies) technical influences. The best option is to use an individual objective information on each vehicle. Diagnosis and prognosis are tool supplying such data. However, when using such a system there is the problem of storing and processing large volumes of information containing current, valid and limit values of diagnostic and structural parameters, mean-time-between-failures, actual run of vehicle and their. To solve this problem can be used data warehouse or data bases. According to the operation automation to reduce labor costs to perform statistical operations by 70-90 %.

CONCLUSIONS

The developed system allows to assort, choose, necessary information displays and printer.

The complex of the application programs completes creation of informative and instrumental parts of the component support of control system by the technical state of trucks on the basis of information about intensity and character of treadwear of tires.

The program allows:

- to calculate and fix the normative tires life of trucks in concordance with running conditions (by system of correction coefficients or from own statistical data),
- to forecast the observed tires life and their service life (from statistical data or from data of control the residual height of the tread pattern),
- to make decision about purchase new tires, their retention cycle, setting of replacement age of tire kits, forming of temporal variables of tire kits, repeated their use after welding-on with pressure of re-tread.

The program gives the complete and objective picture of tires operation, provides support of acceptance of administrative decisions during tires operation, that is important with a glance their price.

Based on the analysis of complex research and different works forms the following types of tasks on the automobile enterprises:

1. Accounting and analytical types are design work orders and reports costs and maintenance and running repair, analysis of running time and running costs on vehicles and its individual components.
2. The planning and management types are planning and control of the vehicles for maintenance and repair, accounting and inventory control, the formation of a complex of the technical effects, etc.
3. Reference types are the creation and use of data banks in construction, operation and properties of reliability vehicles and aggregates, standards and maintenance and running repair.
4. Optimization types are the detection of a rational periodicity maintenance and planned unit replacement, resource vehicles and its systems.

REFERENCES

1. **Biderman V.L., Levin Yu.s., Slyudikov L.D., 1970.:** Influence of structural and operating factors on a wear, coupling and resistance to woobling of motor-car tires – M.: TSNIITeneftekhim. – 93. (in Russian).

2. **Bulgin D., Walters M.H., 1968.:** In: Proc. Intern. Rubb. Conf. Brighton. London, McLaren and Sons Ltd. – 445-469.
3. **Cox W.L., 1981.:** Rubber Chemistry Technology, №2. – 103.
4. **Elliot D.R., Klamp W.K., Kraemer W.I., 1978.**: Passenger tire power consumption // SAE Preprint. – 26.
5. **Ferry J.D., Landel R.F., Williams M.L., 1955.:** Extensions of the Rouse Theory of Viscoelastic properties to Undiluted Linear polymers. J. Applied Physics. – Vol. 26, №4. – 359-362.
6. **French T., 1960.:** Construction and behaviour characteristics of tyres / Automobile Division. – Februar. – 75-77.
7. **Glagolev N.I., Stankevich Z.B., 1974.:** About the approximate analysis of wear of motor-car tires. Motor industry, № 8. – 12-3.
8. **Govorushchenko N.Y., Volkov V.P., ShashA I.K., 2007.:** Providing of safety of motion on a motor transport. - Kh.: KHNADU. – 361. (in Ukrainian).
9. **He J.F., Jin X.X., Hou C.Y., Wang Jianzhong, Qi Jingang, 2011.:** Simulation Analysis and Research of Tire Wear / Advanced materials research. Materials and Manufacturing: selected peer reviewed papers from the 2011 International Conference on Material and Manufacturing September 7-9, 2011, Jinzhou, P.R. China. – 1212-1216.
10. **Jianmin G., Gall R., Zuomin W., 2001.:** Dynamic Damping and Stiffness Characteristics of the Rolling Tire / Tire Science and Technology. – Vol. 29. – 120-129.
11. **Karpenko V.A., Barannik I.M., 2011.:** Influence of operating descriptions of tires on the amplitude-response curves of vibroaccelerations of car / Announcer of the Kharkov national technical university of agriculture the name of P. of Vasilenko: Sb. Labours. it is Kharkov: Virovets a.p. «Apostrophe». – № 109. – 171-177. (in Ukrainian).
12. **Kravchenko A., Sakno O., Lukichov A., 2012.:** Research of Dynamics of Tire Wear of Trucks and Prognostication of Their Service Life // Transport Problems. – Katowice: Silesian University of Technology. – Vol. 7, issue 4. – 85-94.
13. **Li Y., Zuo S., Lei L., Yang X., Wu X., 2012.:** Analysis of impact factors of tire wear / Journal of vibration and control : JVC. – Vol. 18, №6. – SAGE SCIENCE PRESS. – 833-840.
14. **Lorenz O.M., Parks C.R., 1983.:** Rubber Chemistry Technology, №1. – 137.
15. **Mares A.A., 1978.:** Constance pneumatic // Praha. – 53-57.
16. Norms of fuel consumption for cars, norms of tire life and accumulators, 2009 / [has made Kuznetsov]. – 528. (in Ukrainian).
17. **Pacejka H.B., Bakker E., 1993.:** The magic formula tyre modell / Prog. lstCollog. Models for Vehicle Dynamics Analysis Delft, Amsterdam: Swits and Zeitlinger. – 1-18.
18. **Peng X.-d., Guo K.-h., 2003.:** Effective factors on tire wear, Xiang jiao gong ye. – Vol. 50. – 619-624.
19. **Peregon V.A., Karpenko V.A., Koryak A.A., Barannik I.M., 2009.:** Influence of operating descriptions of tires on vibro stress loading of driver and car / Mechanics and engineer: Scientific and technical magazine, Kharkov, NTU «KHPI», № 2. – 37-44. (in Ukrainian).
20. Position about technical service and repair of travelling transport vehicles of motor transport, ratified by an order Ministry of transport of Ukraine from 30.03.98 year. № 102. (in Ukrainian).
21. **Reznikovsky M.M., Brodsky G.I., 1962.:** Proc. 4th Rubb. Technol. Conf. London. – 34-42.
22. **Veksel'man I.V., Slyudikov l.D., 1966.:** About exactness of measuring of treadwear of motor-car tires, Rubber and rubber, №1. – 38-41.
23. **Shtorm P., 1970.:** Probability theory. Mathematical statistics. Statistical quality control, Moskow. – 368. (in Russian).
24. **Tredgold T.A., 1925.:** Practical Treaties on Railroads and Carriages / E. Bliss&E. White, New York. – 114.
25. **Ulchin V., Klimchuk S., 2011.:** Case-based reasoning method for diagnostic decision support system of bridge cranes // TEKA Kom. Mot. i Roln. – OL PAN. – Vol. XIA. – 266-275.
26. **Ulchin V., Yurkov D., 2010.:** Decision support system bridge cranes diagnostics on the basis of cases // TEKA Kom. Mot. i Roln. – OL PAN. – Vol. XD. – 5-14.
27. **Veksel'man I.V., Slyudikov l.D., 1966.:** About exactness of measuring of treadwear of motor-car tires, Rubber and rubber, №1. – 38-41.
28. **Velikanov D.P., 1962.:** functional quality of cars, Moskow, Avtotransizdat. – 395. (in Russian).
29. **Woods E., 1972.:** Pneumatic tire design. Cambridge. – 117-132.
30. **Yurchenko A.N., Kostyurin A.V., 1988.:** Influence of operating factors on the wear of tires. «Motor transport», Kiev, № 25. – 48-52. (in Ukrainian).

КОМПЬЮТЕРНО-ИНТЕГРИРОВАННАЯ СИСТЕМА ПОДДЕРЖКИ ПРИНЯТИЯ РЕШЕНИЙ УПРАВЛЕНИЯ ЭКСПЛУАТАЦИЕЙ ШИН ГРУЗОВЫХ АВТОМОБИЛЕЙ

Александр Кравченко, Ольга Сакно

А н н о т а ц и я . Рассмотрен вопрос о компьютерно-интегрированной системе поддержки принятия решений управления эксплуатацией шин грузовых автомобилей. Компьютерное обеспечение программы основано на накоплении и использовании баз данных: нормативы ресурса шин по данным производителей и государственных рекомендаций, базовые и уточненные коэффициенты корректирования ресурса шин с учетом фактических условий эксплуатации, статистические показатели эксплуатации шин, их ресурс, результаты контроля остаточной высоты рисунка протектора. Программа учитывает интенсивность износа шин и корректируется после введения всех необходимых данных. В программе имеется справочник, по которому выбирается модель шины и можно самому обновлять данные по шине. Все данные для программы изменяются простым редактированием соответствующих полей.

Ключевые слова: ресурс шин, программное обеспечение, прогнозирование ресурса, коэффициент корректирования, управление эксплуатацией шин.

3D-modeling of the rotary table for tool SVM1F4 with non - clearance worm gearing

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Summary. Procedure of the building 3D- models of the rotary table for feed's drive the tool SVM1F4 with vertical and horizontal axis's of the rotation in system KOMPAS - 3D is realized.
The offered design non - clearance worm gearing with zeroizing lateral clearance and is completed its calculation in module APM Trans. Complex calculation tense-deformed conditions worm by method final element is executed in module APM FEM, integrated in CAD KOMPAS - 3D.
Key words: rotary table, worm gearing, non – clearance, 3D-model, equivalent stress.

INTRODUCTION

For automated manipulation workpiece and cutting instrument of the different sizes and the forms in machining centre with NC use the additional elements, supplied mounting base: pallets, device satellite, rotary and pulsing tables [3, 4, 15].

In condition production all greater amount standard size tool and constant change to configuration of the processed details perspective is a designing and production of the table range of the rotary tables, equipped hydro mechanical drive [16, 17].

PUBLICATION AND METHOD ANALYSIS

The rotary table renders the significant influence upon softness and accuracy of the positioning tool [1, 21]. The calculation of the balance to relative softness of the carrier system (NS) tool SVM1F4 has shown that workpiece and its springy relationship with rotary table form before 22% (from the general softness NS) under loading power of the weight of the nodes and loading in zone of the processing equal 10000 N on all three coordinates (X, Y, Z) [21]. Relative softness of the table rotary before 36%, but springy relationship of the table rotary with crusade table before 10% under the same condition loading.

Accuracy of the positioning the table is connected with reduction clearance in worm gearing of the drive of the table, caused by their wear-out in process of the usages.

The questions to geometries, kinematics, strenght of the worm gearing with cylindrical worm have found the reflections in multiple publication. So, in work [9, 13, 22] are stated general questions to geometries and kinematics of the worm gearing. The contact lines, curvatures worker surfaces and localization of the contact were considered in works [14, 19, 20, 23]. The problems of increasing to load rating capacity and efficiency worm gearing discussed in study [2, 7, 10, 12]. The problem of the exception of the disadvantage zones of the gear-tooth is dedicated to work [11].

However specified studies pertained to worm gearing with specified lateral and radial clearance in gear-tooth. In persisting article are stated some results of the study non clearance worm gearing with reference to metalcutting tool, where is required synchronizing the rotations worm and wheel, including, at reversing.

Together with that for realization complex calculation main element of the drive of the rotary table necessary using developed toolbox of the modern systems by designing with use the final element method for full belief about field of the stress and displacement in space 3D [18, 24].

OBJECTS AND PROBLEMS

The purpose of the work is an improvement of the process of the designing the rotary tables with non clearance worm gearing on the base 3D-modeling and increasing level accounting procedures at estimation stress-deformed conditions.

THE MAIN SECTION

The most important requirements to unit, realizing moving the presenting in multi-objective tool is [15]:

- high (before 2 nm) accuracy positioning the rotary table when use the systems to correction,
- accuracy of the reversing, for ensuring the dynamic compensation of inaccuracy,
- a realization minimum (before 5 nm) of the pulsed displacement,
- a reduction outraging influence from drive, including source to energy, before possible value.

In specialized vertical multi-objective tool with NC models SVM1F4, the instrument equiped by automatic change and rotary table is realized performing the large number different technological operation without reset up of the processed details.

The table rotary operated executed in the manner of independent node, set up on table tool in two positions with vertical and horizontal axis, depending on locations processed to surfaces. In CAD KOMPAS [5, 6] is built by 3D-model of the rotary table consisting of more than 300 details (Fig.1).

The table consists of housing, in which is found worm pair, sending motion from high torque of the engine on executive organ – face plate. Table rotary management is realized by means of NC through circular detector (indutoksin). Rotating face plate on given corner is checked by optical sensor, set up on vertical axis of the rotary table. Fastening the details to table rotary is produced on T-slot. Change worker’s velocities face plate table rotary is produced is smoothness within from 0,1 before 3,5 min^{-1}, speed displacement forms 6,5 min^{-1}. In the event of location of the table rotary with horizontal axis for maintenance console located detail is used tailstock.

For increasing of accuracy of the basing worm wheel about in drive of the rotary table it is not enough to use only one cone-shaped fit surface. Necessary also to provide basing on face. For ensuring the synchronizing worm and worm’s wheel about necessary to realize the design an non clearance worm gearing. The article is offered one of the variant of the decision of this problem.

Zeroizing lateral clearance in worm tooth gearing by possible by offsets worm toward, parallel axis’s worm wheel (Fig. 2).

Herewith in contact will be simultaneously both sides of the wrap of worm with surface two nearby teeth worm’s wheel. We shall consider got thereby non clearance worm gearing in two aspects - geometric and power. For determination of the value of the shift of worm - U, is used accounting scheme, submitted for Fig. 3.

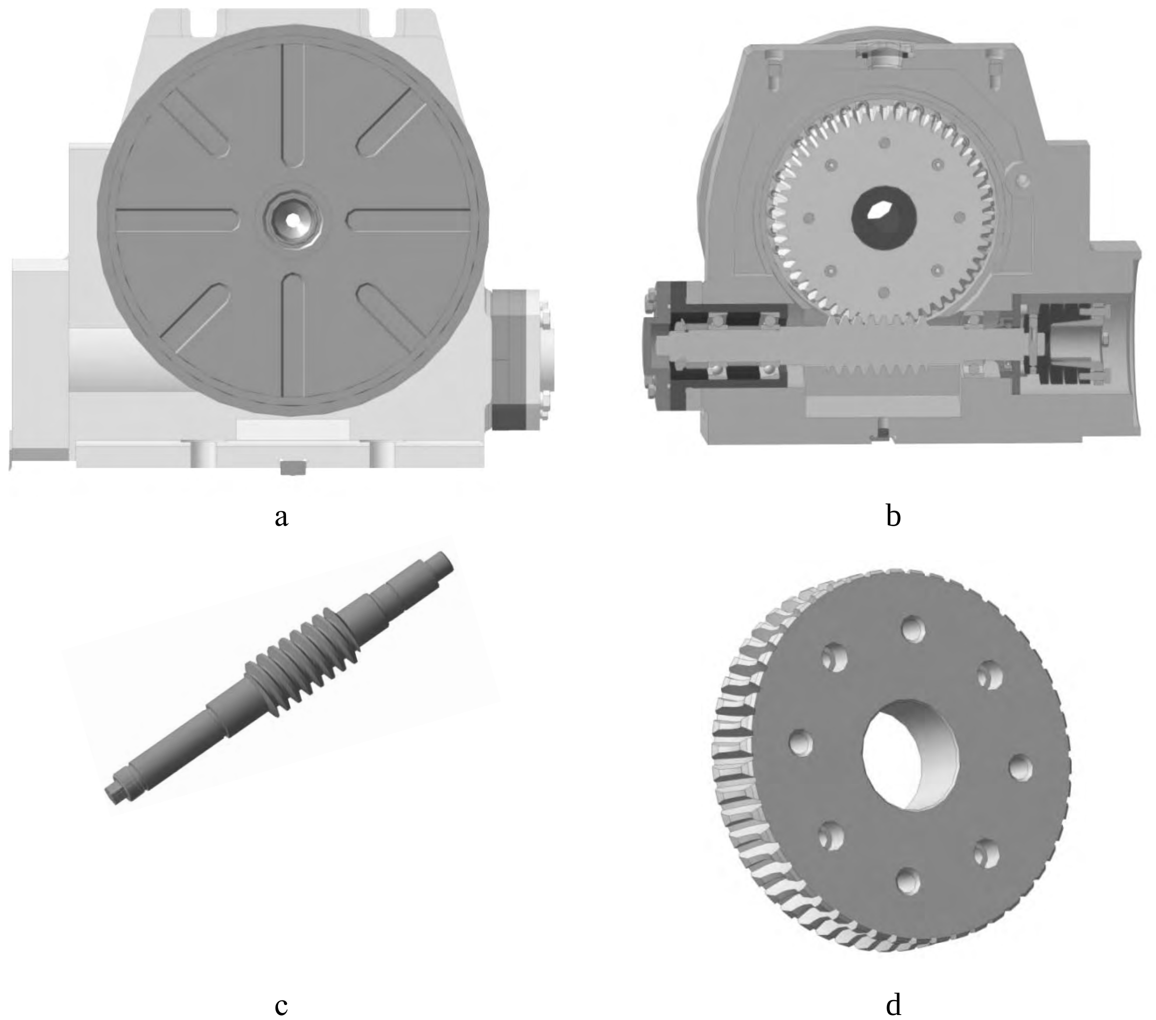


Fig. 1. 3D-model rotary table:
a – principal view, b-sectional view of table,
c – worm shaft, d – worm wheel

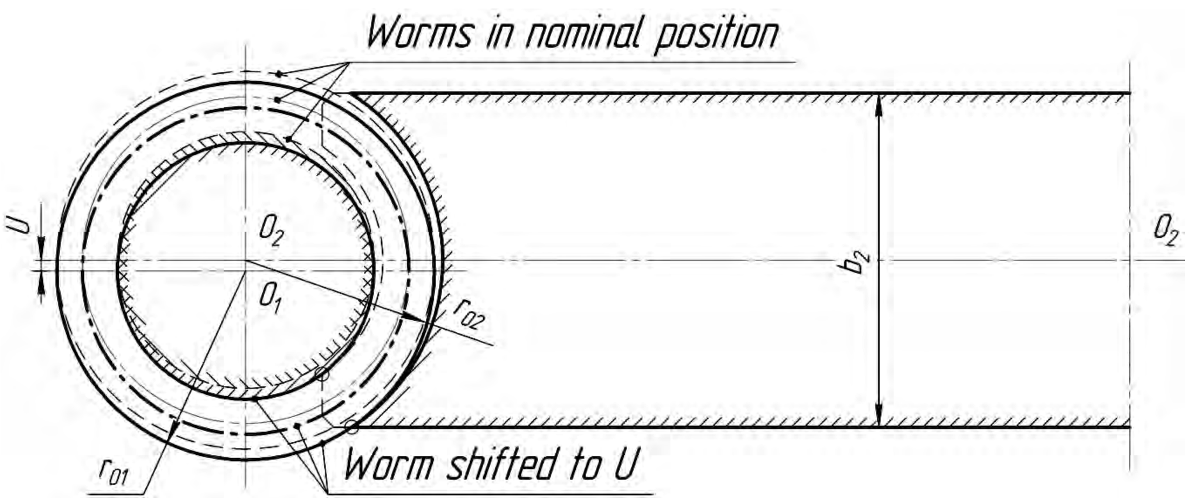


Fig. 2. Design gearing with zeroizing lateral clearance

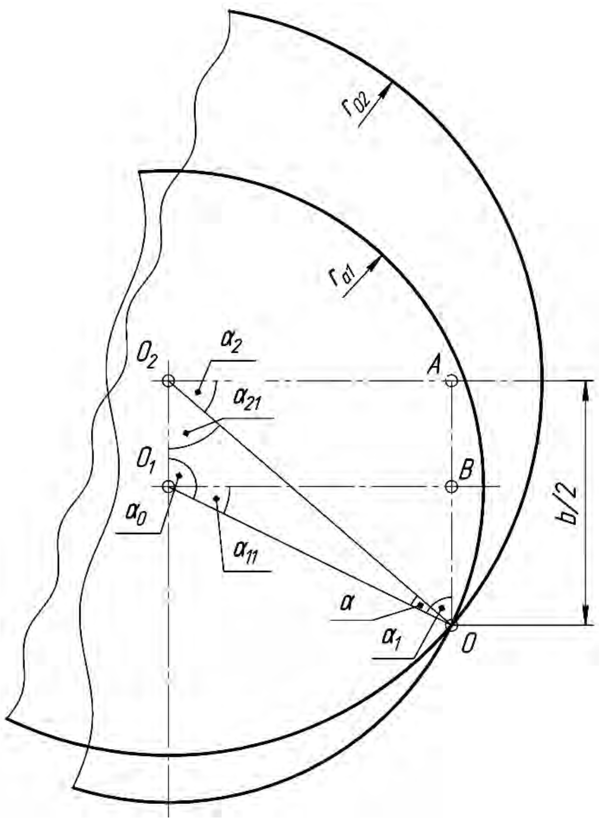


Fig. 3. To determination of the shift of worm

For clarity elements gearing - a correlation between radius r_{a1} and $r_{02} = r_{a1} + \Delta$, ($\Delta = 0{,}2 \cdot m$ – a radial clearance), are given not in that proportion, which exist in real gearing (the values u and α_1 on fig. 3, were practically not discernible). The known are: $r_{a1} = 0{,}5 \cdot m \cdot (q+2)$ – a radius of the tops whorl worm, $r_{02} = r_{a1} + \Delta = m \cdot [0{,}5 \cdot (q+2) + 0{,}2]$ – a radius of the arc to circumferences, outlining tops teeth wheel about in axis section, $b_2 \le 1{,}5 \cdot r_{a1} = 0{,}75 \cdot m \cdot (q+2)$ – a width ring worm wheel, (m and q – a module and coefficient of the diameter worm). From ΔO_2OA follows that:

$$\alpha = \arcsin\left(\frac{b_2/2}{r_{02}}\right).$$

From ΔO_1BO:

$$\alpha_1 = \arccos\left[\frac{\sqrt{r_{02}^2 - (b_2/2)^2}}{r_{a1}}\right], \quad \alpha_{11} = \pi/2 - \alpha_1.$$

follows that

$$\alpha_0 = \pi/2 + \alpha_{11} = \pi - \alpha_1, \quad \alpha_{21} = \pi/2 - \alpha_2.$$

From ΔO_2O_1O:

$$\alpha = \pi - (\alpha_0 + \alpha_{21}) = \alpha_1 + \alpha_2 - \pi/2.$$

As a result, from ΔO_2O_1O, where known two sides – r_{a1} и r_{02}, as well as corner between them α, is found sought shift worm:

$$u = \sqrt{r_{a1}^2 + r_{02}^2 - 2 \cdot r_{a1} \cdot r_{02} \cdot \cos\alpha}. \qquad (1)$$

Calculations on dependencies (1) for worm gearing with different parameter of the tooth system have shown that

$$u/d_1 \approx 0{,}02...0{,}03,$$

that is to say, for forming non clearance gearing it is enough to provide the possibility of the shift worm parallel axis wheel on value , equal 2… 3% from its reference diameter.

Naturally that worm must be in displaced position at action of the external loads. Under determined direction of tangential force on worm F_{t1} worm will try to return in non shift position (the dotted scene on Fig. 2). This will bring about appearance clearance in gearing that break accuracy to synchronizing the rotation worm and wheel. Counteract such shift can springs of the compression, installed in plain support of the worm's shaft. The efforts of the springs $F_П$ calculate from condition of the balance of the system of power, expressed on Fig. 4.

On condition of the balance of force: $2 \cdot F_П + G = F_{t1}$, whence

$$F_П \ge (F_{t1} - G)/2, \text{ N.}$$

After transformations, shall get

$$F_П \ge T_2 \cdot \frac{tg(\gamma + \varphi')}{d_2} - \frac{G}{2}, \text{ N,} \qquad (2)$$

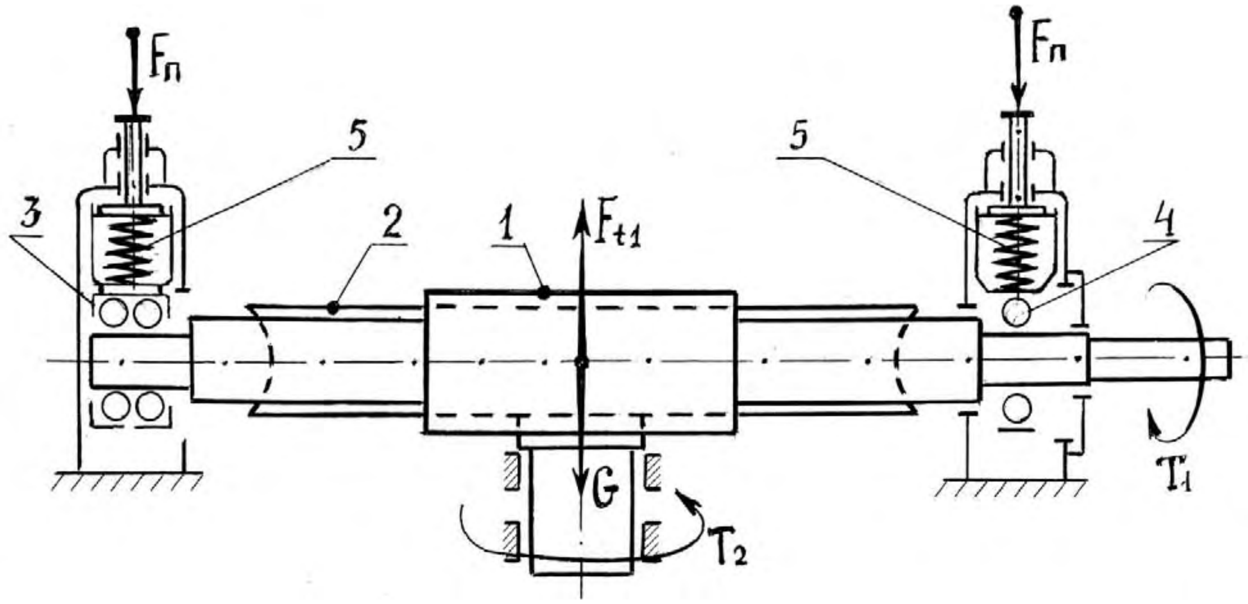


Fig. 4. To calculation of power of the compression of the springs: 1 – worm, 2 – worm wheel, 3 and 4 – a bearings in plain supports of the shaft of worm, which compression the spring 5, T_1 *and* T_2 – a rotating moments on shaft of worm and wheel, G – a weight of the shaft of worm in assembly

$d_2 = m \cdot z_2$ – reference diameter worm wheel, m, $\gamma = arctg(z_1 / q)$ – reference corner of the ascent wrap worm, grad,

φ' – adduction corner of friction in tooth system, grad.

$$\eta \approx tg\gamma / tg(\gamma + \varphi').$$

$$F_\Pi \geq T_2 \cdot \frac{tg\gamma}{d_2 \cdot \eta} - \frac{G}{2}. \qquad (3)$$

At conclusion of the correlation (2) is used approximate variant calculation efficiency worm pair:

$$\eta = \frac{tg\gamma}{tg(\gamma + \varphi')} - \frac{\pi}{2} \cdot f_{np} \cdot \frac{\varepsilon_S}{z_2},$$

here: $f_{np} = B - C \cdot V_S$ – adduction factor of friction at swing teeth on wrap, B and C – on [1],

$$\varepsilon_S = \sqrt{[0{,}17 \cdot z_2 + 0{,}34 \cdot (x+1)]^2 - (0{,}16 \cdot z_2)^2} - 0{,}058 \cdot z_2 + 1{,}01 \cdot (1 - x),$$

- a factor of the overlapping of the worm gearing in average face of the planes wheel, (x – a factor of the shift worm).

The calculations show that elaborated variant (3) differs from drawn near variant (2) not more, than on 5… 6%.

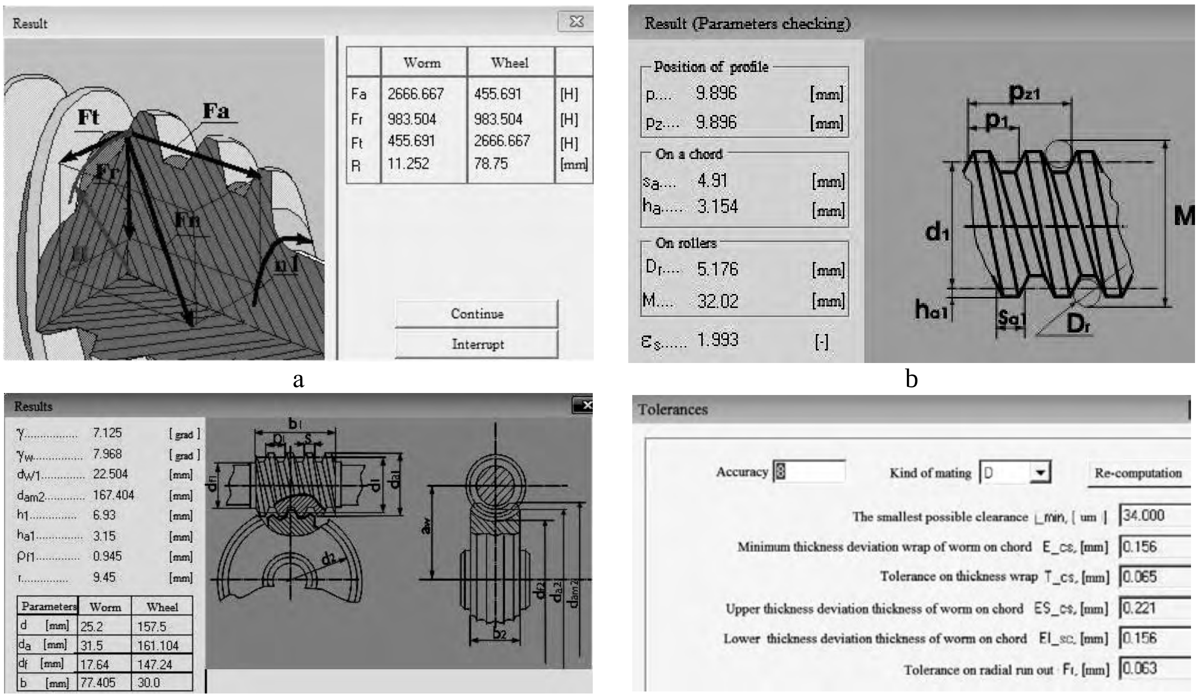
For tool SVM1F4, where rotation of the table is realized by worm gearing with parameter:

$$a_W = 98\ mm,\ m = 3{,}15\ mm,\ q = 12{,}5,$$
$$z_1 / z_2 = 1/50,\ x = 0,\ b_2 = 34\ mm,$$

shift u and required power of the spring take value:

$$u = 0{,}824\,mm,\ accounts\ \ for$$
$$2{,}1\%\ \ from\ d_1 = 39{,}375\ mm,$$
$$F_\Pi \approx 156\ H.$$

Extended design calculation of the worm gearing (WG) shall realize in module of the designing the mechanical gearing of the rotation APM Trans [8, 24]. Under given external load, material worm and wheel, type thermal treatment shall define the main geometric parameters of the gearing: power, acting in her, parameters of the checking the position of the lateral surfaces, as well as tolerances and fit in tooth system (Fig. 5).

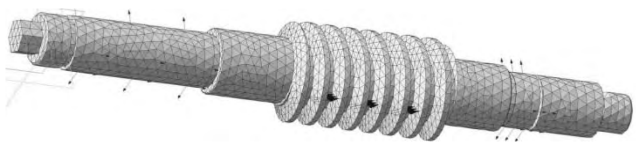


a b

c d

Fig. 5. The results of the calculation WG in module APM Trans: a – force in tooth system, b – a parameters of the checking, c – a geometric parameters, d – a tolerances in tooth system

Name	Value
Maximum length sides element, mm	5
Maximum factor thickenings on surfaces	1
Factor rarefy in volume	1,5
Quantity final element	11515
Quantity nodes	3430



a b

c d

Fig. 6. Result of FEM-analysis: a – characteristic separate into final element, b – finite element grid, c – field of stress, d – field of displacement

For more full description to geometries to designs of the worm gearing, kind, attached to her loads and characteristic of the material to designs is used finite element method. Herewith continuum medium of the under investigation object is prototyped by partition it on final elements, in each of which behavior of this medium is described by means of separate set chosen function (satisfying condition to continuity), presenting itself displacement in specified area.

At study of the designs worm facility APM FEM [24] and buildings finite-element grid (Fig. 6,b), number finite element has formed 11515, and number of the nodes for rod element more than 3000 (Fig. 6, a).

In system APM WinMachine as finite element is used rod element, each of two nodes which has 6 degrees of freedom. The interaction finite element is with each other realized through their nodes on determined law, with provision for which is formed matrix to stiffness, which is reduced to system of the algebraic equations, both separate finite element, and designs as a whole. The joint decision of the got systems of the equations is realized searching for of the values of displacement (Fig. 6, d) and values of the stress (Fig. 6, c) , which will exist in each of final element of the designs. The most further summation result from separate finite element is defined and the general deformation to designs in different directions, and deformation separate its element, and appearing internal stress in separate its parts.

CONCLUSION

1. Complex research to designs rotary table specialized vertical multi-objective tool with NC models SVM1F4 with use 3D modeling CAD KOMPAS and engineering analysis of the construction with use finite element method are realize.

2. 3D-model of the rotary table with non clearance in system KOMPAS-3D, giving real belief about designs is built.

3. By means of module APM FEM is realized calculation of the values of the stress and deformation in any point of the designs, as with provision for influences external load, so and with provision for own weight each of element.

4. Calculation rod element to lead with provision for all concentrator of the stress that allows more exactly define the values acting stress. The broad spectrum of the possibilities of the module APM FEM allows greatly to perfect the quality of the designing element drive tool, vastly reduce the weight to designs, consequently and reduce its cost. With use of this module possible to design near-by to equal strength on criterion of strength and stiffness.

REFERENCES

1. **Averyanov O.I., 1987.:** Module principle of the building tool with NC. – M.: Machine building, 232. (in Russian).
2. **Bernackiy I.P., 1965.:** The Study of the worm gearing raised load rating with convolute worm to new variety //Tr. Leningr. politehn. in-t. – Leningrad: 42-53. (in Russian).
3. **Bushuev V.V., 1992.:** Bases of design tools. M.: , Stankin, 520. (in Russian).
4. **Bushuev V.V., Eremin A.A., Kakoilo A.A., 2012.:** Machine tool: Book. Is.1. – M.: , Machine building, 608. (in Russian).
5. **Ganin N.B., 2011.:** Designing and calculation of strength in system KOMPAS-3D V13. – M.: DMK, 320. (in Russian).
6. **Ganin N.B., 2012.:** Three-dimensional designing in KOMPAS-3D. – M.: DMK, 776. (in Russian).
7. **Gerasimov B.K., Komkov V.N., 1983.:** Load ability and efficiency worm gearing with localized by tooth-contact pattern // Tr. Leningr. politehn. in-ta. – Ltningrad: 41-44. (in Russian).
8. **Krol O.S., Shevchenko S.V., Sokolov V.I., 2012.:** Designing machine tool in surrounding APM WinMachine: Book. Lugansk,. The East-Ukrainian National University named after V.Dahl, 400. (in Russian).
9. **Litvin F.L., 1962.:** New types cylindrical worm gearing. – Moscow -Leningrad: Mashgiz, 103. (in Russian).
10. **Litvin F.L., 1968.:** Theory tooth system. – M.: Science, 584. (in Russian).
11. **Litvin F.L., Bernackiy I.P.,1976.:** The determination and exception of the disadvantage zones of the tooth system in cylindrical worm gearing //Vestn. Mashinostroeniya: 14-16. (in Russian).
12. **Maznev E.A., 2010.:** Increasing load abilities of the cylindrical worm gearing by using convexocon profile wrap// dis. Cand. tehn. sciences: 05.02.02, Lugansk: 289. (in Russian).
13. **Niemann G., Heyer E., 1953.:** Untersuchungen an Schneckengetrieben, VDI, № 6, 1953.
14. **Parubec V.I., 1985.:**The Analysis and syntheses of the worm gearing with operated by contact, localized in given zone //dis. kand. tehn. Sciences: 05.02.02, Kiev: 233. (in Russian).
15. **Pronikov A.S., Borisov E. I., 1995.:** Designing machine tool and machine systems: Reference book-textbook. In 3-h part. Is. 2. P. 1. Calculation and Designing nodes and element tool. – M.: Machine building, 371. (in Russian).
16. **Sokolov V., Azarenko N., Sokolova Ya., 2012.:** Simulation of the power unit of the automatic electrohydraulic drive with volume regulation // TEKA Commisionof Motorization and Energetic in Agriculture. – Vol.12. – № 4. – Lublin, Poland: 268-273. (in Russian).
17. **SokolovaYa., Tavanuk T., Greshnoy D., Sokolov V., 2011.:** Linear modeling of the electrohydraulic watching drive // TEKA Kom. Mot.I Energ.Roln. – OL PAN, XIB, Lublin, Poland: 167-176. (in Russian).
18. **Shelofast V.V., 2004.:** Bases of the designing machine. – M.: APM, 472. (in Russian).

19. **Shevchenko S.V., 1974.:** To choice parameter concave profile worm //Izv. Vuzov. Mashinostroenie. № 2. – M.: 79-83. (in Russian).
20. **Shevchenko S.V., 2010.:** The localization of the contact in worm tooth system on the base standard element gearing // Lifting-transport technique. – Dnepropetrovsk: 49-55. (in Russian).
21. **Taratynov O.V., 2002.:** Designing and calculation machine tool on computer. – M.: MGIU, 384. (in Russian).
22. **Ufert O., 1961.:** Dynamische Drefhehler-messungen an Walzerfrasmaschinen undihr Einfluss auf die Genauigkeit gefraster Grobgetrieberader, VDI, № 103.
23. **Verhovskiy A.V., 1978.:** The Study of the conditions of the working the worm gearing with cloused line of the contact //dis. kand. tehn. Science. – M.: 269. (in Russian).
24. **Zamriy A.A., 2008.:** Practical scholastic course CAD/CAE systems APM WinMachine. –M.: APM, 144. (in Russian).

3D-МОДЕЛИРОВАНИЕ ПОВОРОТНОГО СТОЛА СТАНКА МОДЕЛИ СВМ1Ф4 С БЕЗЗАЗОРНОЙ ЧЕРВЯЧНОЙ ПЕРЕДАЧЕЙ

Олег Кроль, Святослав Шевченко,
Иван Сухорутченко, Андрей Лысенко

Аннотация. Реализована процедура построения 3D- модели поворотного стола привода подач станка СВМ1Ф4 с вертикальной и горизонтальной осями вращения в системе КОМПАС - 3D.
Предложена конструкция беззазорной червячной передачи с обнулением боковых зазоров и осуществлен ее расчет в модуле APM Trans. Выполнен комплексный расчет напряженно-деформированного состояния червяка методом конечных элементов в модуле APM FEM, интегрированного в САПР КОМПАС - 3D.
Ключевые слова: поворотный стол, беззазорная передача, эквивалентное напряжение, 3D-моделирование.

Information security of critical application data processing systems

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S u m m a r y . The results of researches, allowing to raise the level of protection of the automated data processing systems of critical applications (ADPS CA) and intellectual information systems of enterprises are presented in the article. The mathematical models and results of vulnerability estimation of information systems which have Internet connection through various communication channels are resulted in this work. The system approach to solving problems of information security, proposed in this work provides for the integration of mathematical models of the processing and protection of information. The method of modeling the security policy (SP) to provide a highly reliable information processing (HRIP) has been developed. The mathematical models of synthesis of policy safe interaction of information processes, allowing SP to consider separately the various structural components of network with the ability to its further interlinkages have been developed. Using the new mathematical models of flexible reliability, availability, confidentiality and integrity of information processed, allowing mathematically describe the mechanisms to ensure the availability and confidentiality of the information and take into account the quantitative requirements for data integrity.

K e y w o r d s : Protection of Information, the data processing system, security policy, mathematical models.

INTRODUCTION

The modern approach to ensure the reliability of information processes (IP) and its protection from unauthorized access (UA) is supported at the international level by standard ISO/IEC 15408. According to this approach, a reliable IP successfully counteracts to the specified threats of security at the given external conditions of its operation. This leads to continuous improvement as ways and means of information protection (MIP) as well as ways and means of implementation of threats to information security (IS), resulting that appearance of new MIP leads to its bypassing by means of attack [1, 2, 4, 25].

This, in its turn leads to the need for a new interpretation of the term "reliability of IP" that should be understand as lack of security vulnerabilities, which can be a consequence of the implementation of the various unintentional and intentional threats [3, 9, 13, 27].

The sophistication and effectiveness of cyberattacks have steadily advanced. These attacks often take advantage of flaws in software code, use exploits that can circumvent signature-based tools that commonly identify and prevent known threats, and social engineering techniques designed to trick the unsuspecting user into divulging sensitive information or propagating attacks [16, 24, 30, 31]. These attacks are becoming increasingly automated with the use of botnets

- compromised computers that can be remotely controlled by attackers to automatically launch attacks. Bots (short for robots) have become a key automation tool to speed the infection of vulnerable systems [5, 11, 14, 23].

Analysis of existing methods of HRIP modeling that affect the security of information conducted in this research has revealed the impossibility of ensuring for the level of models of invulnerability of processing technology and information transfer using flexible protective mechanisms, due to the lack of integration of mathematical models of the processing and protection of information [8, 12, 17, 20].

MATERIALS AND METHODS

Any model of the security policy (SP) to ensure the HRIP necessarily support the global SP characterizing the desired properties of IP (access syntax), and can support the local SP, which characterizes the transition rules of IP between the neighboring states (the semantics of access). Availability of support the local SP means dynamics of the appropriate model, and absence means the static. The dynamic model of SP, as opposed to static, imposes constraints on the state of IP [6, 10, 15, 22].

If the set of possible states of the automated data processing systems of critical applications (ADPS CA) can be represented as a finite set, then the model of SP refers to the class of finite state models. The theoretical basis of the fundamental security of such models of SP is the so-called fundamental theorem of security, which is stated and proved separately for every model [7, 19, 28, 29]. According to it if at the initial time the global SP is performed and all the transitions of IP from state to state fulfill the corresponding local SP, then at any time thereafter, the global SP will also be performed. Therefore, vulnerabilities of IP of this type are not directly incorporated into the model of SP, but must occur only in practical realization [18, 21].

The discretionary model, setting access permissions of users, in general, acting in certain roles, to objects, no operating with transitions between IP, most perfectly supports the global SP. However, not be referring to the model of the final states, it is not fundamentally safe.

In this regard, the topical problem is the development of models of SP complexes, which are models of the final states in substance and discretionary in form. The formalism of such models should integrate graph-theoretic basis of discretionary formalism, static in nature, and convenient to describe the information processes, network formalism, having a dynamic character. As a result, it should describe by uniform way the dynamic and static access to information, structured to ensure the unity of the local and global SP review.

In terms of confidentiality and availability of information protection mechanisms flexibility refers to the flexibility of differentiation of access and the vulnerability is embedded in the model used by SP and its practical implementation. The only truly flexible is discretionary model of SP, which inevitably creates vulnerabilities. On the other side, the only intrinsically safe is the class of models of the final states, originating from the mandatory access control method. However, the application of existing models of the final states is very limited due to their principal inflexibility [17, 25, 26]. This disadvantage of this class of models can be eliminated, brought closer together this class of models with the discretionary model. Nevertheless, it is hampered by the conventional independent review of processes to protect information from its processing, and retreat from this principle requires new research, the results of which are presented in this work.

The reason lies in the fundamental theoretical difficulties of modeling technologies ensuring the reliability and protection of IP in automated data processing systems of critical applications (ADPS CA) occurring when you try to connect a promising approach to ensure the safety and protection of IP from UA with the flexibility of the protective mechanisms [3, 8, 14, 29].

RESULTS OF RESEARCH

The analysis of existing methods of modeling processes HRIP in ADPS affecting the security of the information has allowed to choose basic graph-theoretic modeling unit of IP protection from UA in ADPS SP - E-networks unit.

The automated systems on transport vary in technologies applied, from basic management systems such as car navigation, traffic signal control systems, container management systems, variable message signs, automatic number plate recognition or speed cameras to monitor applications, such as security CCTV systems, and to more advanced applications that integrate live data and feedback from a number of other sources, such as parking guidance and information systems, weather information, and the like.

A Transportation Management System (TMS) is a software system designed to manage transportation operations. TMS are one of the systems managing the supply chain. They belong to a sub-group called Supply chain execution (SCE). TMS, whether it is part of an Enterprise Level ERP System and has become a critical part of any (SCE).

The block diagram of a typical control system for transport is shown in Fig. 1.

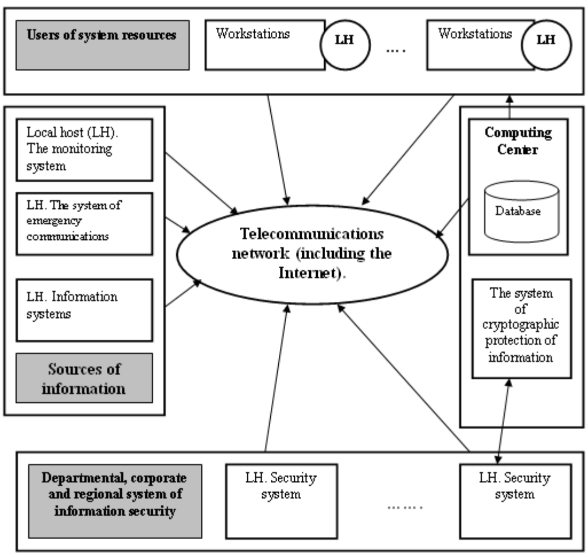


Fig. 1. The block diagram of control system for transport

Rapidly changing external and internal business environment, necessity to adapt oneself very quickly and take adequate management decisions in time make the effective use of corporate information to be a pre-requisite for business success.

Based on the analysis in the works [14, 17, 29], the purpose and objectives of the research are defined. According to the proposed system approach, the main result of the formation of methodological bases of safety and reliability of IP in ADPS SP is a reference model of secure automated system (RMSAS) as an idealized model of ADPS SP implementing fundamentally safe technology of information circulation. Such model allows standardization of unified architectural appearance of different classes of ADPS SP by developing and registering for the regulation of safety standards. Regulated reference models of secure automated system (RMSAS models) of complexes of SP, joining the existing model of the final states with discretionary form, provide that any discretionary access can be realized only by uniquely defined sequence of transitions between the end states for which one can guarantee its safety.

However, due to the specificity of IP in the reference ADPS, the direct use for it such general formalisms inherent for E-networks is little effective [14]. Therefore, based on the E-networks unit has been built a new graph-theoretic unit of problem-oriented nature – RMSAS networks. Relying of an equivalent E-network representation, a proper specific syntactic representation of RMSAS networks by minimizing the descriptive means has been found – the canonical form of RMSAS network.

The composition of RMSAS network is defined as follows:

L – number of RMSAS network levels (usually L=13), $k=\overline{1,L}$, $l=\overline{1,L}$, $k \neq l$, S – positions quantity, $S = Q \cup P \neq \varnothing$, $Q \cap P = \varnothing$, $|S| < \infty$, $|Q| = |P|$, Q, P – quantities of simple and permissive positions, $|Q| < \infty$, $|P| < \infty$, $Q = \bigcup_{l=1}^{L} Q_l \neq \varnothing$, $Q_k \cap Q_l = \varnothing$,

$P = \bigcup_{l=1}^{L} P_l \neq \varnothing$, $P_k \cap P_l = \varnothing$, Q_l, P_l – quantities of simple and permissive positions of the l-st level, $|Q_l| = |P_l| \neq 0$, U – quantity of modules, $U = \bigcup_{l=1}^{L} U_l \neq \varnothing$, $|U| < \infty$, $U_k \cap U_l = \varnothing$, U_l – quantity of modules of the l-st level, $I(u) = i_1.i_2.....i_{L-l}$ – index module $u \in U_l$ and unit, which this module is the upper (№ 0 in the unit), particularly, $I(u) = 0$ when $l = L$, $K[I]$ – number of the lower modules in unit with index I, $I.j$ – index of the lowest module with number $j = \overline{1,K[I]}$ in the unit with index I, if I, J – module indexes, than:

$$(J \subset I) \Leftrightarrow (I \supset J) \Leftrightarrow (I = J.i_1.i_2....i_k),$$

$$(J \subseteq I) \Leftrightarrow (I \supseteq J) \Leftrightarrow ((J \subset I) \vee (I = J)).$$

To specify the structure of the RMSAS network we introduce the notation: N – quantity of number of authorization, $\alpha = \overline{1,N}$ – number of authorization, $r = r[I,\alpha]$ – Boolean attribute of the admissibility of authorization α in the module with index I, $M_{in} = M_{in}[I,\alpha]$, $M_{\text{out}} = M_{\text{out}}[I,\alpha]$ – input and output functions of marking defining marking of input and output modules positions in form of a Boolean variable (indicate whether the position of the chip, and each item can contain no more than one chip).

The formal presentation of the RMSAS network module of given structure looks like:

$$u = \langle I, q = q[I,\alpha], p = p[I,\alpha] \rangle \in U_l, \qquad (1)$$

where: $I = I(u)$ – index of module, $q = q[I,\alpha] \in Q_l$, $p = p[I,\alpha] \in P_l$.

Moreover, the formal representation of the structure of the network RMSAS is the next:

$$\varepsilon = \left\langle \begin{matrix} N, K = K[I], r = r[I,\alpha], \\ M_{in} = M_{in}[I,\alpha], M_{\text{out}} = M_{\text{out}}[I,\alpha] \end{matrix} \right\rangle. \qquad (2)$$

Bringing into service of RMSAS networks opens the way for a systematic research of its mathematical properties as a development tool of ADPS CA based on the RMSAS. A fundamental step in this direction is the construction of using the unit of RMSAS networks modeling approach complex SP of the reference ADPS in the form of SP of RMSAS network.

Global (g) SP and discretionary of the l-st level are given as set of allowed positions: $\Psi_g \subseteq P_I$, $\Psi_{dl} \subseteq P_l$, and leveled structure (l) looks like:

$$\Psi_{ll} = \left\{ \begin{matrix} \langle I(u), \alpha, r[I(u),\alpha] \rangle \mid u \in \\ U_l, \alpha = \overline{1,N} \end{matrix} \right\}. \qquad (3)$$

Block SP (b) is given by the installation of admissibility of evidence of various authorizations in all modules of the block, agreed to the following rules ($\alpha = \overline{1,N}$, $I = I(u)$, $u \in U \setminus U_1$):

$$\begin{aligned} &(\exists_j \in \overline{1,K[I]})(r[I.j,\alpha] = 1) \Rightarrow \\ &\Rightarrow (r[I,\alpha] = 1), \end{aligned} \qquad (4)$$

$$\begin{aligned} &(r[I,\alpha] = 0) \Rightarrow \\ &\Rightarrow (\forall_j \in \overline{1,K[I]})(r[I.j,\alpha] = 0). \end{aligned} \qquad (5)$$

Local SP is given as follows:

$$\Psi_1 = \bigcup_{l=1}^{L} \Psi_{ll} = \left\{ \begin{matrix} \langle I(u), \alpha, r[I(u),\alpha] \rangle \mid u \in \\ U, \alpha = \overline{1,N} \end{matrix} \right\}, \qquad (6)$$

where: all $r[I(u),\alpha]$ are mutually agreed to all blocks in accordance with the rules:

$$(\alpha = \overline{1,N},\ I - I(u)):$$

$$\begin{aligned} &(r[I,\alpha] = 1) \Rightarrow (\forall J \subset I)(r[J,\alpha] = 1), \\ &u \in U \setminus U_L, \end{aligned} \qquad (7)$$

$$(r[I,\alpha]=0)\Rightarrow(\forall J\supset I)(r[J,\alpha]=0),\quad u\in U\setminus U_1. \tag{8}$$

Discretionary SP is given by its permissive $\Psi_{\partial p}$ or globalized $\Psi_{\partial g}$ representation:

$$(p[I,\alpha]\in\Psi_{\partial g})\Leftrightarrow((p[I,\alpha]\in\Psi_{\partial p})\wedge \wedge(\forall J\supset I)(p[J,\alpha]\notin\Psi_{\partial p}));$$

$$\Psi_{\partial p}=\bigcup_{l=1}^{L}\Psi_{\partial l}\subseteq P,\ \Psi_{\partial g}\subseteq\Psi_{\partial p},\ \alpha=\overline{1,N},\quad I=I(u),\ u\in U, \tag{9}$$

besides the quantities $\Psi_{\partial l}$ are agreed to rule ($\alpha=\overline{1,N}$):

$$(p[I,\alpha]\in\Psi_{\partial p})\Rightarrow \Rightarrow(\forall J\subset I)(p[J,\alpha]\in\Psi_{\partial p}),\quad I=I(u),\ u\in U\setminus U_L, \tag{10}$$

$$(p[I,\alpha]\notin\Psi_{\partial p})\Rightarrow \Rightarrow(\forall J\supset I)(p[J,\alpha]\notin\Psi_{\partial p}),\quad I=I(u),\ u\in U\setminus U_1. \tag{11}$$

The induction of discretionary global security policy means $\Psi_g=\Psi_{\partial g}$, and the local security policy of discretionary means –

$$(\forall p=p[I,\alpha]\in P)((p\in\Psi_{\partial p})\Leftrightarrow \Leftrightarrow(r[I,\alpha]=1)). \tag{12}$$

During researches have been developed mathematical models of the synthesis of secure communications policy interaction of the reference ADPS that can consider SP of some IP (at different structural components RMSAS-network) with the possibility of further interlinkages (a layered synthesis of SP on RMSAS network). As the basic structural components have been defined in a network interpretation (as part of RMSAS network) and systemic treatment (as appropriate system quantities) layers and concepts of superblock of RMSAS network. The layer $S_{lH\ldots lb}$ of the level l_b with the lowest level l_H of RMSAS network $B_0=S_{1\ldots L}$ is (in the network interpretation) part of RMSAS network related to the levels of RMSAS with numbers $l=\overline{l_H,l_в}$.

Superblock $S_{lH\ldots lb}(I)$ of the level l_H with the index I (given superblock of RMSAS network $S_{lH\ldots lb}$) of RMSAS network $B_0=B_{1\ldots L}(0)$ is a part of layer $S_{lH\ldots lb}$ with moduls index $J\subseteq I$. The ways setting various SP on individual structural components of RMSAS network, in particular, its layers and superblocks, by analogy with the task SP in all RMSAS network are identified.

For the account of the possibility of SP interlinkages given on the various structural components of RMSAS network, the concept of SP compatibility in two different senses is formally defined for all pairs of types of SP. Weak compatibility of random SP Ψ_1 and Ψ_2, denoted as $\Psi_1\sim\Psi_2$ is the lack of direct conflict between them. Strong compatibility of random SP Ψ_1 and Ψ_2, denoted as $\Psi_1\approx\Psi_2$ is the inability of a conflict between them, even in distributing of SP to all RMSAS network.

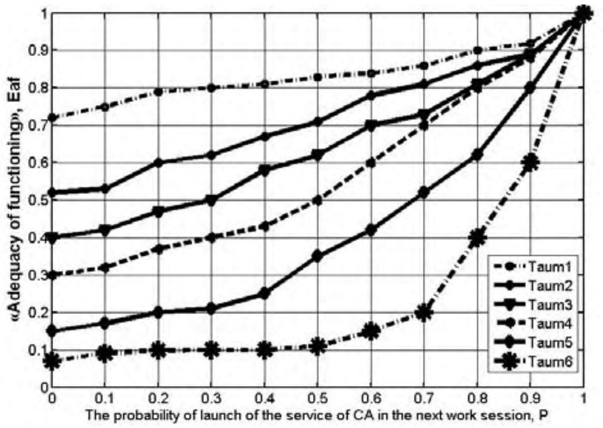
A set of criteria quality of service operation of CA as a control object has been substantiated:

1) dynamic – «adequacy of functioning» E_{af}, «temporary aggressiveness of functioning» E_{ta},

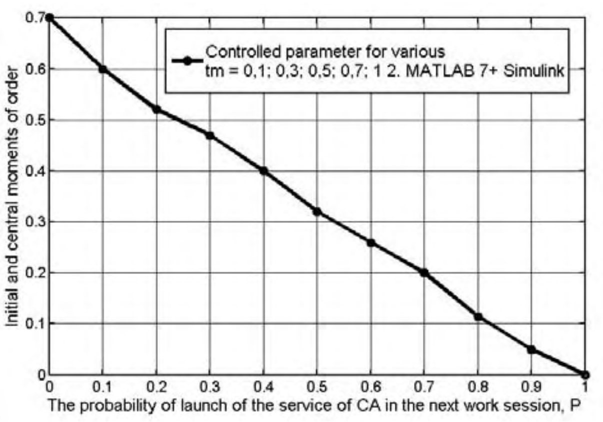
2) static (Boolean) – «functionality» E_f, «resource aggressiveness of functioning» E_{ra}, «functional aggressiveness of functioning» E_{fa}, «usability» E_{yu}.

In the MatLab and DELPHI programming environment we created a complex of problem-oriented software for modeling service management of CA of information processed as in conventional so in reference ADPS. It, in particular, allows us to construct graphic dependences of dynamic criteria, regardless of the variable parameters. Using these graphics choosing the optimal values of the controlled parameters and evaluate the attainable level of targets is visualized.

With the help of the developed software has been conducted a comprehensive research of the quality of the functioning of typical SIP as applied to the operation of workstations based on computers as part of ADPS and the criteria of efficiency and dynamic characteristics of the lifetime of the FSP (time of CA using discretionary access) in the reference ADPS (Fig. 2).



a



b

Fig. 2. The results of the calculations for the reference ADPS:
a – criteria of dynamic efficiency,
b – mathematical expectation.

For the reference ADPS the results of calculations were presented in the form of dependencies of output variables from the single (unique for each method), regardless of the varied managed parameter by different $\tau_m = 0{,}1;0{,}3;0{,}5;0{,}7;1;2$ (curves *taum*$_i$, $i = \overline{1,6}$) and a different number of controlled levels $l_{\max} = 1;3;6;9;12;15$ (curves *lmaxa*$_i$, $i = \overline{1,6}$).

The data mining process effectively reduces the size of the data that needs to be retained for future comparisons. The network data processor (NDP) prepares counts and other statistical measures from the mined data and stores them to disk. Since FIRE is an anomaly detection system, the measures are chosen such that anomalies in network data can be ascertained easily.

Typical summaries include:

1. The number of total packets observed in the data collection interval.

2. The number of unique sdp's observed in the interval.

3. The number of sdp's that are new in this data collection interval.

4. The number of sdp's that are new in the longerterm data retention interval (i.e. have never been seen before).

5. The number of well-known ports used in an interval.

6. The variance of the count of packets seen against the sdp's.

7. The number of sdp's that include foreign hosts (hosts outside the local network domain).

8. The number of successfully established TCP connections in a time interval.

Analytical model of membership function of variable ϕ (ϕ – controlled input variables) to an arbitrary fuzzy term T can be expressed as

$$\mu^T(\phi) = \frac{1}{1 + \left(\frac{\phi - \alpha}{\beta}\right)^2}, \qquad (13)$$

where: α – coordinate of the maximum function, β – the coefficient functions.

Function of the controlled parameter ϕ_i fuzzy set of values conducive to the realization of the *j*-th option, describe the function (*S*-*Q*)-type:

$$\mu_j(\phi_i) = \begin{cases} S\left(\dfrac{\overset{0\,j}{\phi_i} - \phi_i}{\varsigma_{ij}}\right), \phi_i \le \overset{0\,j}{\phi_i}, \\ Q\left(\dfrac{\phi_i - \overset{0\,j}{\phi_i}}{\xi_{ij}}\right), \phi_i > \overset{0\,j}{\phi_i}, \end{cases} \quad (14)$$

where: S and Q arbitrary functions that do not grow on the set of positive real numbers, $\varsigma > 0$, $\xi > 0$ (Options ς and ξ are respectively the left and right fuzziness coefficients),

Membership function in terms of (S-Q) correlation functions will be described:

$$\mu(\phi) = \begin{cases} \dfrac{1}{1 + \left(\dfrac{\alpha - \phi}{\beta}\right)^2}, & \phi \le \alpha, \\ \dfrac{1}{1 + \left(\dfrac{\phi - \alpha}{\beta}\right)^2}, & \phi > \alpha. \end{cases} \quad (15)$$

FIRE consists of the three types of components: network data collector (NDC), network data processor (NDP), Fuzzy Threat Analyzer (FTA). The network data collector (NDC) is a promiscuous network data sniffer and recorder. It reads raw network packets off the wire and stores them on disk. The next component, the network data processor (NDP), summarizes and tabulates the raw packet data in carefully selected categories. In a sense, an NDP performs a kind of data mining on the collected packets. The NDP merges these summaries and tables with past data and stores them on disk. Next, the NDP compares the current data with the historical mined data to create values that reflect how the new data differs from what was observed in the past. These values are “fuzzified” to produce the fuzzy inputs needed by the Fuzzy Threat Analyzer (FTA). The resulting fuzzy inputs from the NDPs are called “fuzzy alerts” because they represent an alert condition to a degree.

Example list of factors that affect the productivity of information systems under the threat of DDoS attacks, presented in the form of linguistic variables, for which the selected set and universal terms. According constructed fuzzy knowledge base, representing a set of fuzzy rules "IF-THEN" that define the relationship between input and output variables. For fuzzy knowledge bases composed logical equation:

$$\mu^{d_j}(D) = \bigvee_{p=1}^{h_j} \begin{bmatrix} \mu^{y_3^{jp}}(y_3) \wedge \mu^{y_4^{jp}}(y_4) \wedge \ldots \\ \wedge\, \mu^{\phi_z^{jp}}(\phi_z) \end{bmatrix}, \quad (16)$$

$$p = \overline{1, h_j}\,, \; j = \overline{1, U}.$$

Once the NDP completes the data mining phase, it produces fuzzy sets based on past input data. FIRE uses the historical and statistical data for each element of matrix (Eq. 17). We have arbitrarily chosen five fuzzy sets for each data element: low, medium-low, medium, medium-high, and high (Table 1). By standardizing the number of sets, we can apply the same fuzzy rules against the data from each NDP, regardless of the differences in the local input domain.

$$H = \begin{pmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1i} & \cdots & \phi_{1n} \\ \phi_{21} & \phi_{22} & \cdots & \phi_{2i} & \cdots & \phi_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \phi_{l1} & \phi_{l2} & \cdots & \phi_{li} & \cdots & \phi_{ln} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \phi_{N1} & \phi_{N2} & \cdots & \phi_{Ni} & \cdots & \phi_{Nn} \end{pmatrix}. \quad (17)$$

In a common intrusion scenario, an attacker conducts a port scan of a network, sending packets to several well-known ports (FTP, HTTP, etc.) looking for systems that might be running those services. The presence of those services on a system gives a hint as to what vulnerabilities the attacker might try to exploit to penetrate the system. Additionally, the attacker may use scanners that can accurately identify the operating system on the target machine by examining the response of the TCP stack to carefully crafted TCP control messages.

Table 1. Factors affecting the productivity of information systems for DDoS and DoS attacks

A partial state variable of the information system and Network	**Univer-sum**	Terms for lingu-istic asses-sment
ϕ_1 – indicator of current risks [10]	[0,1], arbitrary units (A.U.).	*low*, *medium-low*, *medium*, *medium-high*, and *high*
ϕ_2 – acceptable level of risk information	[0,1], A.U.	-
ϕ_3 – intensity of flow rate (requests) coming to servers	[10,6000], frame / s	-
ϕ_4 – nominal capacity of the environment data	[10,100], Mbit / s	-
ϕ_5 – number of attempts to access to environmental data generated by an attacker to view	$[0, N_a]$	-
ϕ_6 – the service transaction	[0,001-0,01], s	-
ϕ_7 – IP pocket length	[1 -65529], byte	-
ϕ_8 – large number of IP packets with the type of attack Ping of Death	[0,1], A.U.	-
ϕ_9 – number of http-requests to the object of attack	[0,1], A.U.	-
ϕ_{10} – presence of TCP packets	[0,1], A.U.	-
ϕ_{11} – presence of UDP packets	[0,1], A.U.	-
ϕ_{12} – presence of ICMP packets	[0,1], A.U.	-
ϕ_{13} – availability of SQL injection	[0,1], A.U.	-
ϕ_{14} – interval between frames	[10-100], bit	-
…		-
ϕ_z – other factors		-

Knowledge of the services running and the host operating system is extremely valuable to the attacker because it helps to narrow the types of vulnerabilities the attacker can exploit on the systems. Port and operating system detection scanning may be a strong indicator that a more serious attack may be occurring in the future.

With the fuzzy input sets defined, the security administrator can then construct the rules of the fuzzy system. Fuzzy rules are written using common sense experiences by the security administrator. The rules designer seeks to define rules that cover as much of the input space as possible Using tools such as the Matlab Fuzzy Toolbox, the designer can check the input rule space to ensure that the fuzzy rules cover the input space and that all output responses are defined (Fig. 3).

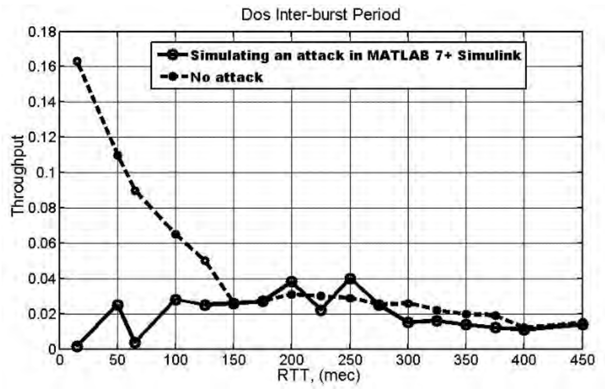


Fig. 3. Dos Inter-burst Period

DISCUSSION

Analysis of the results of calculations, part of which is shown in Fig. 2, 3 allows you to identify patterns of governance. They do not contradict the known data and show the opportunities of modeling.

A task-oriented graph-theoretic unit of RMSAS networks, allowing to model invulnerable processing and transmission of information with flexible protective mechanisms, providing a formalization and research of RMSAS SP is developed. It uses not only the details of the transfer process, but the data within the proposed hierarchical structuring of RMSAS resources for unified modeling of dynamic and static information access based on the integration of E-network and discretionary formalisms.

A method for modeling RMSAS networks regulated RMSAS SP for HRIP, allowing combining the flexibility of discretionary models with security of models of the final SP states is developed.

CONCLUSION

Thus, studies with the following results.

1. A task-oriented graph-theoretic unit of RMSAS networks, allowing to model invulnerable processing and transmission of information with flexible protective mechanisms, providing a formalization and research of RMSAS SP is developed. It uses not only the details of the transfer process, but the data within the proposed hierarchical structuring of RMSAS resources for unified modeling of dynamic and static information access based on the integration of E-network and discretionary formalisms.

2. Mathematical models and algorithms of optimal control of the integrity of information processed, while maintaining the effectiveness of this treatment, allowing us to find a compromise between ensuring the integrity and the efficiency of information processing are developed.

3. Exact analytical method for evaluating and analysis of the complex criteria for assessing the quality service operation of CA of information uses semi-Markov matrix formalism, integrating matrix formalism of finite Markov chains and operator formalism of random processes in a single review of continuous-time and discrete states.

REFERENCES

1. **Ahmad D., Dubrovskiy A., Flinn X., 2005.:** Defense from the hackers of corporate networks. Trudged. with angl. – 2th izd. M.: Companies AyTi, DMK - Press. 864. (in Russian).
2. **Atighetchi M., Pal P., Webber F., Schantz R., Jones C., Loyall J., 2004.:** Adaptive Cyberdefense for Survival and Intrusion Tolerance // Internet Computing. Vol. 8, No.6. – 25-33.
3. **Atighetchi M., Pal P.P., Jones C.C., Rubel P., Schantz R.E., Loyall J.P., Zinky J.A., 2003.:** Building Auto-Adaptive Distributed Applications: The QuO-APOD Experience // Proceedings of 3rd International Workshop Distributed Auto-adaptive and Reconfigurable Systems (DARES). Providence, Rhode Island, USA. 74-84.
4. **Chapman C., Ward S., 2003.:** Project Risk Management: processes, techniques and insights. Chichester, John Wiley. Vol. 1210.
5. **Chertov R., Fahmy S., Shroff N., 2006.:** Emulation versus simulation: A case study of TCP-targeted denial of service attacks. In Proc. of the 2nd International conference on Testbeds and Research Infrastructures for the Development of Networks and Communities.
6. **Chi S., Park J., Jung K., Lee J., 2001.:** Network Security Modeling and Cyber At-tack Simulation Methodology//LNCS. Vol. 2119.
7. **Goldman R., 2002.:** A Stochastic Model for Intrusions//LNCS. Vol. 2516.
8. **Gorodetski V., Kotenko I., 2002.:** Attacks against Computer Network: Formal Grammar-based Framework and Simulation Tool. RAID 2000//LNCS. Vol. 2516.
9. **Harel D. Statecharts: A., 1987.:** Visual Formalism for Complex Systems, Science of Computer Programming.
10. **Hariri S., Qu G., Dharmagadda T., Ramkishore M., Raghavendra C., 2003.:** Impact Analysis of Faults and Attacks in Large-Scale Networks//IEEE Security & Privacy. 456-459.
11. **Hatley D., Pirbhai I., 1988.:** Strategies for Real-Time System Specification, Dorset House Publishing Co., Inc., NY.
12. **Keromytis A., Parekh J., Gross P., Kaiser G., Misra V., Nieh J., Rubensteiny D., Stolfo S., 2003.:** A Holistic Approach to Service Survivability // Proceedings of ACM Workshop on Survivable and Self-Regenerative Systems. Fairfax, VA. 11-22.
13. **Larson D.R., Field W.E., Farahmand F., Jeffries J.L., 2006.:** Foundations in Homeland Security Studies. Purdue University.
14. **Larson D.R., Field W.E., F. Farahmand, Aaltonen P.M., 2007.:** Managing Resources and Applications for Homeland Security. Purdue University.
15. **Lufar V., 2012.:** Database of hazardous substances properties. TEKA Commission of Motorization and Power Industry in Agriculture, V. XII, No. 3, 90-93.
16. **Marcus K., Mcquade S. 2011.:** Internet Addiction and Online Gaming (Cybersafety). Chelsea House Pub.
17. **Marcus K., Mcquade S. 2011.:** Living With the Internet (Cybersafety). Chelsea House Pub.
18. **McNab C., 2004.:** Network Security Assessment. O'Reilly Media, Inc.
19. **Mirkovic J., Dietrich S., Dittrich D., Reiher P., 2004.:** Internet Denial of Service: Attack and Defense Mechanisms. Prentice Hall PTR, 400.
20. **Moitra S. D., Konda S. L., 2000.:** A Simulation Model for Managing Survivability of Net-worked Information Systems, Technical Report CMU/SEI-2000-TR-020.
21. **Negoita M., Neagu D., Palade V., 2005.:** Computational Intelligence Engineering of Hybrid Systems. Springer Verlag. 213.
22. **Piszcz A., Orlans N., Eyler-Walker Z., Moore D., 2001.:** Engineering Issues for an Adaptive Defense Network. MITRE Technical Report.

23. **Rohse M., 2003.:** Vulnerability naming schemes and description languages: CVE, Bugtraq, AVDL and VulnXML. SANS GSEC PRACTICAL.
24. **Smirniy M., Lahno V., Petrov A., 2009.:** The research of the conflict request threads in the data protection systems. Proceedings of Lugansk branch of the International Academy of Informatization. № 2(20). V 2. 2009. – 23-30.
25. **Shun-Chieh Lin & Shian-Shyong Tseng. 2004.:** Constructing detection knowledge for DDoS intrusion tolerance // Expert Systems with Applications. – 2004. – Vol. 27. – 379-390
26. **Templeton S., Levitt K., 2000.:** A Requires/Provides Model for Computer Attacks. Proc. of the New Security Paradigms Workshop. 274-280.
27. **Xiang Y., Zhou W., Chowdhury M., 2004.:** A Survey of Active and Passive Defence Mechanisms against DDoS Attacks. Technical Report, TR C04/02, School of Information Technology, Deakin University, Australia. 38-43.
28. **Slobodyanuk M., Nechaev G., 2010.:** The evaluation technique of logistics system cargo ransportation efficiency development.TEKA Kom. Mot I Energ. Roln. – OL PAN, 10B. Lublin, 162-170.
29. **Urgen M.W. Pan and S. Stolfo., 2002.:** Ensemble-based adaptive intrusion detection. In Proceeding of 2002 SIAM International Conference on Data Mining, Arlington, VA.
30. **White D., Alijani G., 2003.:** Identifying requirements for network security software. SAM ’03. International Conference, 539-543.
31. **Zou C.C., Duffield N., Towsley D., Gong W., 2006.:** Adaptive Defense against Various Network Attacks // IEEE Journal on Selected Areas in Communications: High-Speed Network Security (J-SAC). Vol.24, №.10. – 44 -51.

ИНФОРМАЦИОННАЯ БЕЗОПАСНОСТЬ КРИТИЧЕСКИ ВАЖНЫХ СИСТЕМ ОБРАБОТКИ ИНФОРМАЦИИ

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Аннотация. Статья содержит результаты исследований, позволяющие повысить уровень защиты автоматизированных и интеллектуальных информационных систем предприятий и компаний. В статье предложен проблемно-ориентированный теоретико-графовый аппарат эталонных моделей защиты автоматизированных систем, позволяющий моделировать неуязвимые технологии обработки и передачи информации. Предлагаемый в работе системный подход для решения задач информационной безопасности, предусматривает интеграцию математических моделей обработки и защиты информации, соединяющий неуязвимость и гибкость по каждому из трех аспектов защищенности (конфиденциальность, доступность и целостность) информации на основе конструктивной унификации указанных противоречий. Разработан метод моделирования политики безопасности (ПБ) для обеспечения высоконадежной обработки информации (ВНОИ), отличающийся использованием нового проблемно-ориентированного теоретико - графового аппарата эталонной модели защищенной автоматизированной системы для соединения гибкости дискреционной модели с принципиальной безопасностью моделей конечных состояний ПБ.

Ключевые слова: информационная безопасность, автоматизированная система, политика безопасности, математические модели.

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Study of multi-layer flow in coextrusion processes

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S u m m a r y : The article presents a research of the process of flow multilayer coextrusion. It analyzes the method of regulation of a multilayer structure by volumetric metering of each layer. It presents the data of the calculation of the flow based on slip on the channel wall.

K e y w o r d s : coextrusion, multilayer flow, slip on the wall, gravimetric dosing.

INTRODUCTION

The main task of coextrusion technology is the control of multi-layer structure. This means prediction of the distribution of layers depending on the given technological regimes. Modern gravimetric control systems provide the given percentage of layers by controlling the productivity of each extruder to the required level [4, 12].

Usually set proportional relationship between a given layer thickness and volumetric productivity of the conform extruder. Regulation is independent from the position of the layer a channel dies and / or design of the dies. This method contradicts the popular theoretical description of the multilayer flow, but gives high accuracy by controlling the thickness of each layer.

According to the existing approaches for the calculation of multilayer flows on the border of two immiscible liquids, the following conditions must be met: the continuity of the tangential and normal components of the velocity (this means no slip at the interface), the continuity of the shear stress, balance difference of normal stresses at the surface to surface forces [7, 11, 15].

The boundary condition is also equal to zero velocity at the channel walls [5, 14, 16, 17, 19, 21].

Under such conditions, for example, a three-layer material LDPE-LDPE-LDPE at the percentage layers 33.3/33.3/33.3, the theoretical velocity profile shows that the productivity of the middle layer extruder has to be approximately 2 times higher than extruder external and internal layers. In fact, for equal thickness of three layers of extrusion speeds must be identical.

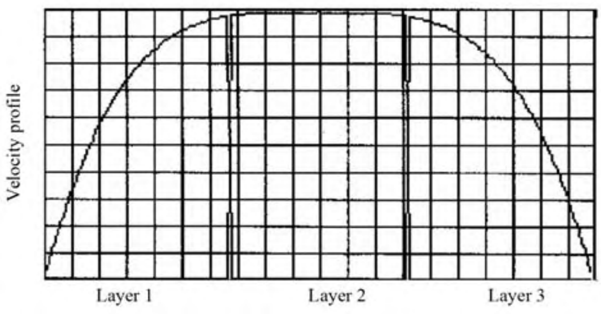


Fig. 1. The theoretical velocity profile of the multilayer flow calculated on the basis of the power law

During the coextrusion, the layer thickness is directly proportional to the productivity of the respective extruders. The varying viscosity, the quantity of the filler, the flow index have no appreciable effect on the distribution layers. These experimental data contradict the theoretical results of modeling the multi-layer flow based on the power law.

According to Figure 1, it requires increased productivity of extruders of the central layer (the layer productivity Q2≈2*Q1, Q2≈2*Q3 with the layer thickness H2=H1, H2=H3), which is never observed in practice.

Thus, you must have adequate models of the multilayer flow. Conduct a study of the characteristics of the multilayer polymer melt flow in the coextrusion processes. Identify the basic parameters and the regularities of the process to control the multilayer structure.

Common description of the melt using the assumption that the velocity on the channel wall is zero. It is believed that on the channel wall, a layer of molecules fixed on which then flows the polymer melt.

At the same time, the individual polymers LLDPE and PVDC this statement is not consistent with experimental studies [11]. Practical exploitation of the extrusion equipment resulting in actual production conditions shows that the rate on the channel wall is not zero for the polyamide (PA) and the polyethylene (LDPE), a mixture of plasticized polyvinyl alcohol (PVA) and polyamide-6 (PA6).

During the processing of polyamide, when the line is stopped at the included heating for 1 hour and at the same time the screw speed is equal to zero - the degradation of the polymer takes place. But if you install the screw speed 1rev/min, no degradation is observed during 10 hours from the stop line.

Therefore, a slight movement of the melt in the extruder ensures that there is no degradation of the polymer melt. On the other hand, a small stop time of the screw rotation leads to the degradation of materials. This discrepancy can not be explained with the help of melt flow models which have an assumption that the linear velocity of the polymer on the wall of the channel is zero [1, 6, 18].

Practical observations show a direct relationship between the time of operation of the head and washing time during the changeover. That is, the channel surface cleanliness and corrosion resistance affect the flushing time.

OBJECTS AND RESEARCH

The study was conducted by a coextrusion line equipped with a gravimetric system. The flow rate was measured with discreteness – 0,01kg (for all extruders).

The distribution of melt along the circumference in the dies is accomplished by a spiral mandrel. The melt temperature at the exit of the dies (control using a pyrometer) 230-250^{o}C. The gravimetric based on the current value of the parameter α=Q/N (the ratio of output to the speed of the rotation) calculates the necessary output of each extruder, and automatically sets it. Then every 0,5min the throughput of the extruder is measured and, if necessary, the screw speed is corrected. The set extruder output is in the range ±0,5%, according to the monitoring gravimetric control system of the coextrusion line. The main technological regimes are shown in Table 1.

Table 1. Technological parameters of the process

Characteristic/ Five-layer structure	A (external)	B	C	D	E (internal)
Screw diameter, mm	45	25	45	25	30
Performance range, kg/h	2-30	0,5-5	2-30	0,5-5	1-20
Drive power in kW	30	15	30	15	20
The maximum rotational speed, r/min	160	150	160	150	160
Material	PA	EVA	LDPE	EVA	PA
Flow index (190^{o}C, 2,16kg) The basic material (80-100%) Masterbatches (0-20%)			2,0-4,0 1,2-11,7		
Flow index (230^{o}C, 2,16kg) The basic material (80-100%) Masterbatches (0-20%)	2,5-5,5 8,0-22,0	2,0-3,0	5,0-7,0	2,0-3,0	2,5-5,5 8,0-22,0

Research of accuracy of control multi-layer structure for different recipes

Five-layer structure of the film material thickness of 35-45 micron measure passed on the system of video microscope SVC. The absolute error of measurement of the layer thickness Δ=0,4 micron. The film thickness 40 microns, it is 100% of the thickness of the system for gravimetric dosing, the absolute error (in the analysis of the percentage of layers) is Δ=1%.

We studied the effect of the following factors: MFI layer, set layer thickness on gravimetry, structure on the final thickness of the film. Range of MFI varied according to the Table 1. Main characteristics of recipes are shown in Table 2. The period of study 1 month. N - number of samples.

Table 2. Main characteristics of recipes

recipe number	characteristics of some recipes
Recipe № 1	in a layer of "C" masterbatches 10%
Recipe№2	in the layer "C" masterbatches 3%, in the layer "E" masterbatches 15%
Recipe№3	in the layer "C" masterbatches 3%, in the layer "E" masterbatches 15%
Recipe№4	in the layer "C" masterbatches 20%, in layer "E" masterbatches 3%
Recipe№8	without masterbatches

The data analysis of Table 3 shows that the final thickness of the layer does not influence the viscosity, the layer position in the dies. The main factor - the volume extruder output.

There is a high standard deviation from the set thickness. It affects significant measurement error, since the film is very thin and difficult to determine the interphase boundary between the layers.

Research of accuracy of control multi-layer structure for a single recipe

The following experiment was carried out as follows: to set different percentages in a multilayer structure (PA/EVA/LDPE/ EVA/PA), the total productivity of the plant has not changed. We measured the same cross-section. The error of measurement of the layer thickness (compared with the first study) was Δ=0,1%, because the analyzed primary tube thickness of 350 microns. We used the recipe №8 without masterbatches.

Regression analysis of the data of Table 4 shows that the correlation coefficient is 0.95, the calculated value of the Fisher Fp=1411 much more than the table value Ft=7,04, the significance level α=0,01. The number of data points n=65, k - the number of factors studied, k=1, the degree of freedom v1=1, and v2=63, therefore there is a statistical relationship between the parameters of the volume extruder output and thickness of the layer. In the Figure 2, we see a good correlation parameters.

The study of the values indicates that the middle layer is thinner by 0,5-3,0% from the given by gravimetry, at the same time, the outer and the inner layers are thicker on the 0,5-3,0%.

Table 3. Summary table of the results of measurement

Characteristic		Setting gravimetry, Δ±0,5%					Measurement of the layer thickness by SVC, Δ=1%				
material	N	E	D	C	B	A	E	D	C	B	A
Recipe № 1-10	53	20	2	31	2	45	20,4±2,0	3,3±0,7	31,2±3,2	3,1±0,8	42,0±3,1
Recipe№ 11-15	10	20	2	40	2	36	20,4±2,0	4,2±1,0	33,6±2,6	4,2±0,3	37,6±2,4
Recipe№16-18	5	10	2	21	2	65	10,5±1,2	4,0±1,3	19,7±1,9	3,1±0,9	62,6±2,4
Recipe№19-25	31	20	2	50	2	26	21,7±2,1	3,4±0,9	47,3±3,2	3,3±0,7	24,3±2,2
Recipe №1	11	20	2	31	2	45	20,5±1,6	3,6±1,0	32,7±2,0	3,7±1,0	39,6±2,3
Recipe№2	8	20	2	31	2	45	19,2±2,0	3,3±0,3	30,8±2,9	3,2±0,7	43,6±4,3
Recipe№3	6	20	2	31	2	45	19,1±1,7	2,8±0,7	31,8±4,5	2,7±1,0	43,6±4,0
Recipe№4	8	20	2	31	2	45	21,0±2,7	3,6±1,1	33,0±3,9	3,6±0,8	38,9±2,9
Recipe№8	5	20	2	31	2	45	20,6±1,9	3,7±1,2	31,2±3,0	3,2±1,4	41,3±1,4

Table 4. Comparative results of set and actual thickness

	Setting gravimetry, Δ±0,5%					Measurement of the layer thickness by SVC, Δ=0,1%				
№	A	B	C	D	E	A	B	C	D	E
1	18,5	2,5	36,6	2,8	39,6	15,8	3,75	32,7	2,41	45,3
2	18,5	2,5	36,6	2,8	39,6	15,8	3,75	32,7	2,41	45,3
3	18,5	2,5	36,6	2,8	39,6	19,2	2,82	32,1	3,38	42,5
4	18,5	2,5	36,6	2,8	39,6	19,2	2,78	31,1	3,33	43,6
5	17,6	2,4	34,9	2,7	42,4	18,0	4,0	36,6	4,57	36,9
6	17,6	2,4	34,9	2,7	42,4	20,1	2,83	41,1	2,83	33,1
7	17,5	2,4	30,3	2,7	47,1	17,6	2,85	24,7	2,3	52,6
8	39,9	2,6	30,3	2,9	24,2	47,1	1,63	30	2,45	18,8
9	20,0	2,5	38,5	2,5	36,0	23,8	2,58	35,4	2,58	35,7
10	45,0	2,5	30,0	2,5	20,0	45,2	1,69	25,7	1,69	25,7
11	39,6	2,8	36,7	2,5	18,5	43,2	5,09	31,9	2,95	16,9
12	47,1	2,7	30,3	2,4	17,5	51,6	2,02	23,9	2,27	20,2
13	39,9	2,5	30,5	2,8	24,2	46,2	1,36	29,9	1,63	20,9
average	27,6	2,52	34,1	2,68	33,1	29,4	2,86	31,4	2,68	33,7

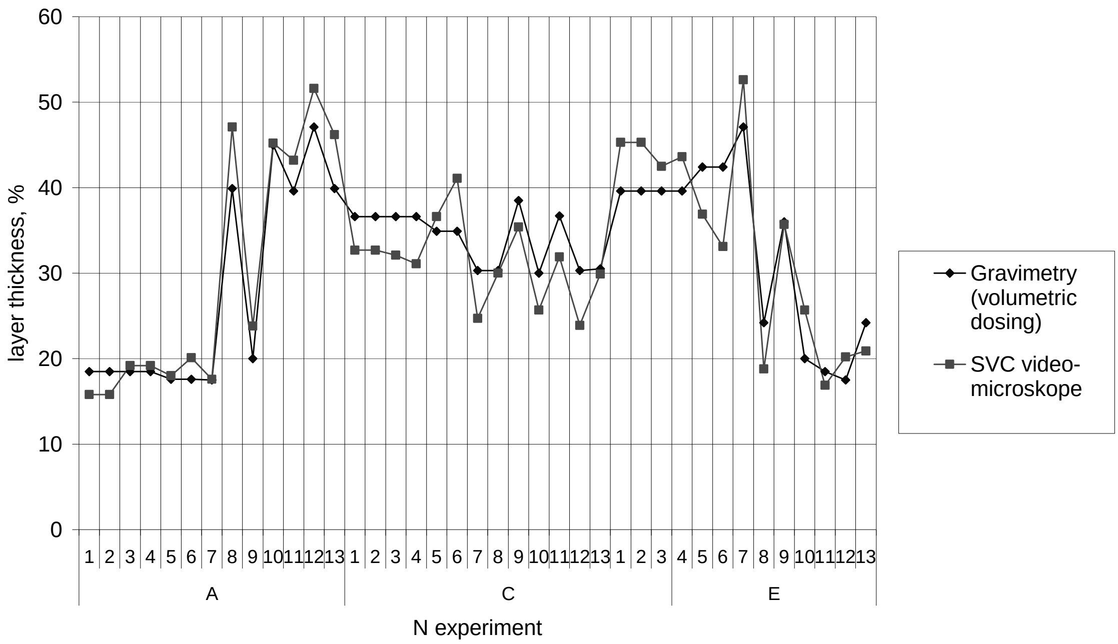


Fig. 2. Comparison of gravimetric data control system and measuring the thickness of the layer with the using video-microscope

Data analysis gravimetric dosing system and the resulting distribution layers.

For refinements on the conclusions the previous experiment, the research was conducted by distribution of each layer in the die. The main technological regimes are shown in Table 5. That is, for one section the thickness of the layers measured in a circle in different parts of the section. The primary tube thickness of 350 microns. Layers B, C and D were measured together because adhesive is more visually similar to polyethylene, and the border with the polyamide is more visible.

The results of the analysis of the data of Tables 6, 7 show, as in the second experiment, that the thickness of the middle layer is 2,6% less than the set on gravity, accordingly on the outer layers it is much thicker.

A detailed study of the cross sections using the video-microscope indicates, that everywhere there the boundary layer thickness is 0.5-5% which is formed because the slip of the melt on the surface of the channel dies. That is, the outer and inner layers have a double layer structure as though (Fig. 4).

Table 5. Technological regimes of the primary molding in the manufacture of sample on prescription number 8 (colorless)

Parameter	A	B	C	D	E	in total
N, rpm/min	49	19	113	19	44	
Q, kg/h	19,9	1,1	17	1,1	11,1	50,2
Q/N kg/60rpm	0,450	0,056	0,150	0,058	0,251	
Percent, %	36	2,5	39	2,5	20	100
P, g/cm^3	1,14	0,9	0,9	0,9	1,14	
I, A	27	2,4	15	2,1	8,1	

Table 6. Summary data on the distribution of layers

Recipe №8	layer		
parameter	A	B+C+D	E
The structure given by gravity, %	36,0	44,0	20,0
Productivity, kg/h	19,9	19,2	11,1
The structure, measuring video microscope, the results of a 7-measurements on one section, %	37,3±0,78	41,4±4,38	21,3±4,16

Table 7. Summary data on the distribution of layers

Recipe№1	layer		
parameter	A	B+C+D	E
The structure given by gravity, %	45,0	25,0	30,0
Productivity, kg/h	12,7	5,6	8,4
The structure, measuring video microscope, the results of a 3-measurements on one section, %	46±1,35	22,4±1,68	31,6±0,5

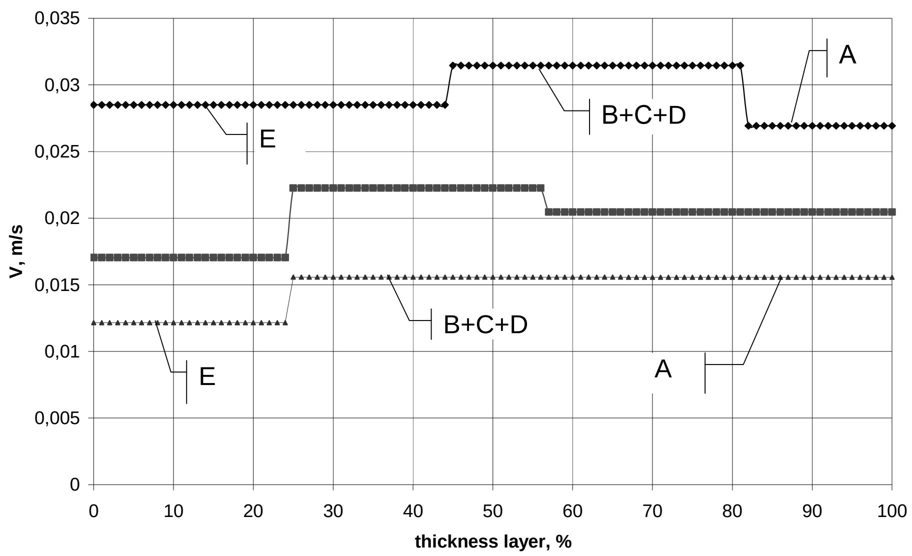
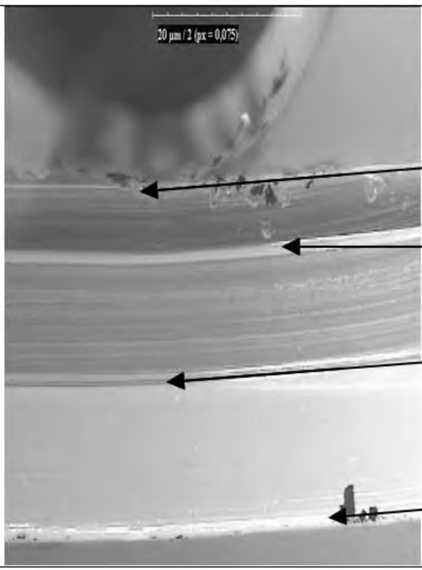


Fig. 3. Multi-flow velocity profile obtained from the experimental data from Tables 6,7.



5 layered structure material (PA / EVA / LDPE / EVA / PA) Thickness 350 micron	Q kg/h	The structure given by gravity
Connect Wall W2 layer PA 3,0%	9,5	18,5%
The outer layer of the PA 16,1%		
Adhesive EVA 2,8%	1,02	2,5%
Middle layer LDPE 31,1%	14,9	36,6%
Adhesive EVA 3,3%	1,14	2,8%
The inner layer of the PA 40%	22,9	39,6%
Connect Wall W2 layer PA 3,6%		

Fig. 4. The analytical description of a typical multilayer structure (the touch of a ballpoint pen can be seen at the top)

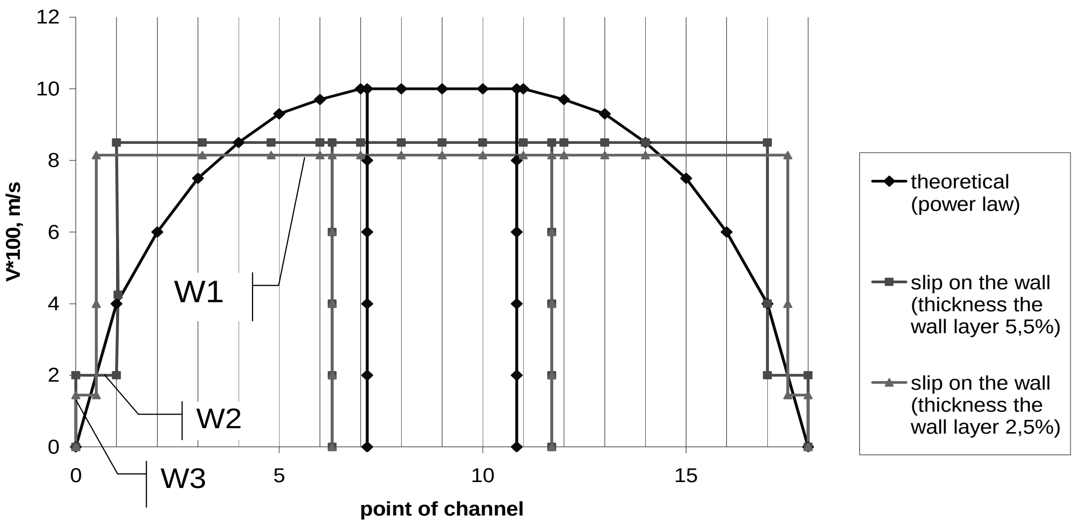


Fig. 5. The velocity profile flow of the three- layer PE/PE/PE is installed equal to the productivity all extruders

For the calculation of the velocity profile with the wall slip and the equality of the rates at the interface layers, as well as data gravimetric dosing system and the test results of the multilayer structure, a method allowing to predict the speed and thickness of boundary-layer of low viscosity was developed. The result of the calculation is given in Figure 5.

"Corky" character of the flow in the channels of the extrusion equipment repeatedly confirmed [2, 8, 9, 20], but its theoretical description has been little studied, no calculations and models to help you analyze interaction near-wall low-viscosity layer W2 and the central layer W1, and the wall layer W3 which is directly contacted with the metal wall of the channel.

Polymer extrusion processes are severely limited by flow instabilities and product distortions. At the same time, many problematic phenomena in extrusion associated with the near-wall flow, phenomena on the surface of the extrudate - is “sharkskin” (fragmentation of the extrudate surface) [3], "die droop" (adhesion of the melt, degradation products directly at the exit of the dies) [13].

The processes of near-wall flow influence on technological parameters of extrusion and coextrusion. Their analysis and control required when replacing recipe, during stopping and starting the extruder, for quick changeover equipment. This is important when implementing the principles of lean manufacturing.

The nature of the boundary layer formation is also interesting. It is understood that there is its dependence on the coefficient of friction of the polymer melt by the metal and heat resistance polymer.

Dies temperature affects in two ways, on the one hand the increase of the in temperature reduces the viscosity on the channel wall and boundary layer W2 becomes thinner and faster. On the other hand increasing the melt degradation and increasing thickness W3 on the walls.

As the temperature decreases the reverse process, increase of the in viscosity takes place, boundary layer W2 increases, but the destruction of the melt is reduced it improves the stability of the boundary layer. With a significant reduction of temperature effects occur that are associated with defects in the surface of the melt, reaching the level of the critical shear stress.

The model of polymer melt flow

Consider the following mechanism (model) the flow of non-Newtonian fluid. Since the polymer chains are in mutual meshing, steady state flow cork is always evolving the nature of the flow. Adhesion macromolecules block the development of a smooth velocity profile from zero at the wall of the channel to a maximum at the center, the diagram has a telescopic character [10]. In any case, it concerns the size of the channels of modern extrusion equipment and rheometers.

We can distinguish the wall layer W3 whose molecules are compressed and practically no relax and central layer W1 (cork) which slides on the wall layer. The central layer is compressible and can have an elastic.

Interaction occurs macroroughness and segments of molecules that protrude from the tangles and interact (showing adhesion) with the molecules of the wall layer. Area where there is an interaction, can be called low-viscosity layer W2.

Macroroughness (molecular clumps), is characterized by the height H and the angle of inclination α. Microroughnesses - protruding segments of molecules, this model does not take into account, but it is assumed their presence and influence on the flow parameters. Flow scheme is presented in Figure 6.

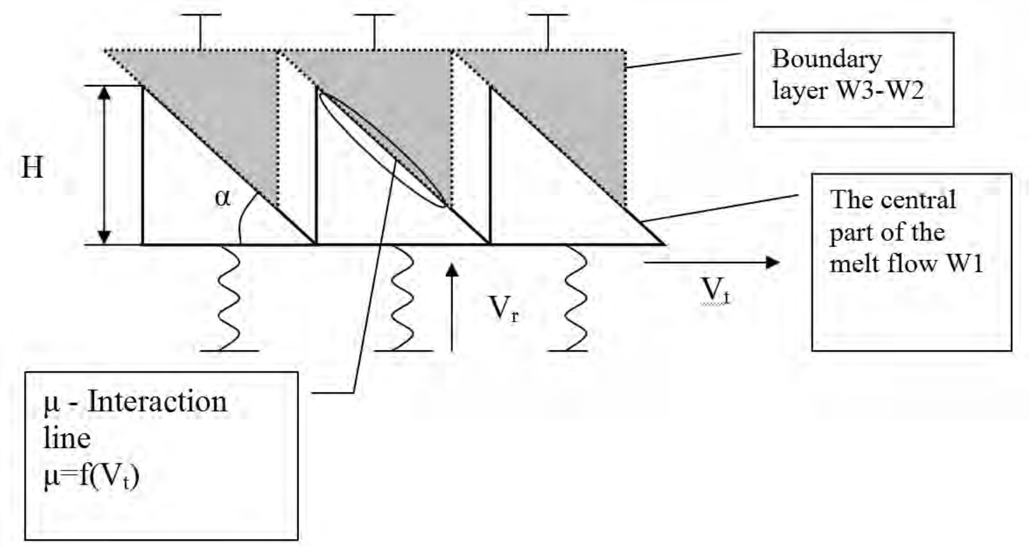


Fig. 6. The model of polymer melt flow

For interaction and is as follows

1. Newtonian region of high viscosity - speed Vt small and macroroughness segments and the central layer of molecules have a time to almost completely relax, cohesion is fully restored, so there is no noticeable decrease in viscosity/

2. Non-Newtonian region where the relaxation rate Vr and flow velocity Vt comparable, that is macroroughness has no time to relax, but has moved to a new area, here it decreases rapidly μ - length of the line, where the central molecule in contact and wall layers, therefore a decrease in viscosity.

3. Newtonian region of low viscosity - speed increases so that the molecules do not have time to relax and increase adhesion. That is the interaction takes place on upper part macroroughness, thus the viscosity is stabilized.

The structure of the melt surface, that is the geometry of the interacting macroroughness, may be visible at the output from the head, as rectangular velocity profile is saved when exiting the melt from the mold channel.

The analysis of the movement of the central layer received the equation:

$$\mu = \frac{H}{\sin\alpha} - \frac{H}{\dfrac{V_r}{V_t * tg\alpha} + 1}, \qquad (1)$$

It should be noted that the transition from planar to volumetric flow model, the parameter μ can be regarded as the viscosity.

At an angle α≈0 modeled Newtonian flow, that is realized shear layers without relaxation.

The model connects the stress relaxation in the polymer with the flow characteristics.

The equation allows us to calculate the constant viscosity at low and high shear rate:

$$\mu_0 = \frac{H}{\sin\alpha}, \qquad (2)$$

$$\mu_\infty = \frac{H}{\sin\alpha} - H, \qquad (3)$$

Table 8. The model parameters for the rheological characteristics of the LDPE at various temperatures

Parameter	α, deg.	V_r, m/s	H, Pa*s	μ_o Pa*s	μ_∞ Pa*s
Model1 (170°C)	82	0,05	5000	5049	49
Model2 (230°C)	70	0,07	700	745	45

As a result of the periodic relaxation, macroroughness melt oscillations appear, and their frequency increases with increasing the flow velocity. It can be assumed, if they are equal with the frequency of temperature fluctuations of molecules, resonance occurs and the phenomenon of fragmentation surface of the extrudate is observed.

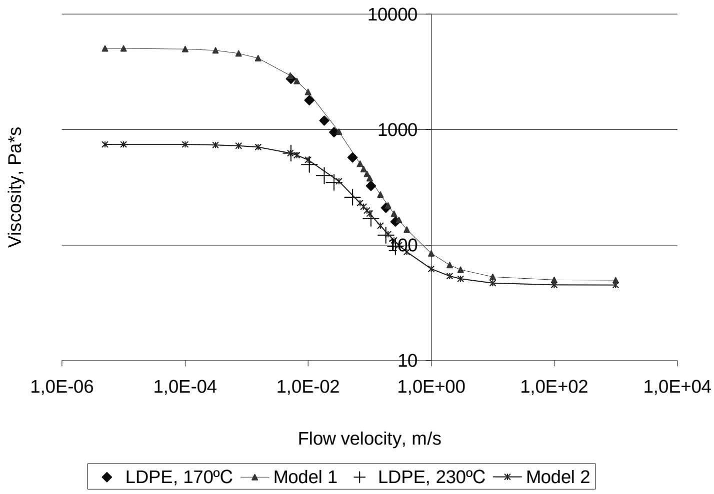


Fig. 7. The rheological characteristics of LDPE at various temperatures and the approximation by equation (1) with the parameters according to Table 8

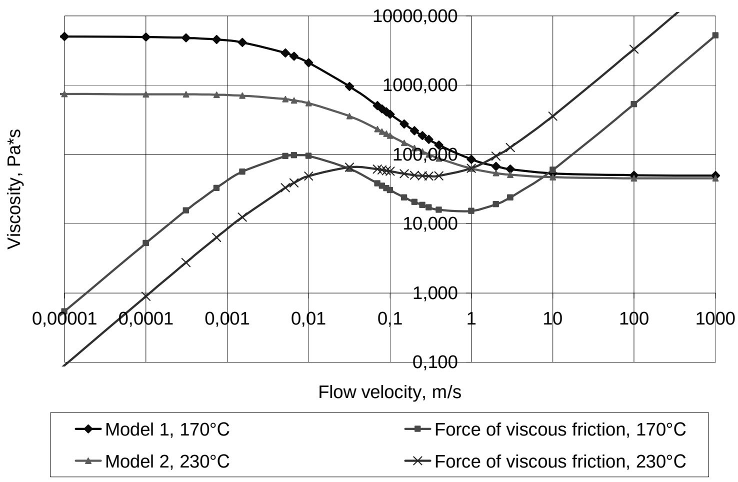


Fig. 8. Reducing the viscous friction forces in the field of non-Newtonian flow

The change is known in the effective area of interaction and rheological curve, possible to calculate the force of viscous friction. The analysis shows that in the region reduction viscosity decrease in the effective contact area occurs faster than increased shear stress so the force of viscous friction decreases (Fig. 8).

The model requires further development. Parameters H and α characterize the strength of the interaction between the layers and depend on the intermolecular interaction, temperature, branching of the polymer, molecular weight, segment sizes of macromolecules.

Therefore, it is required a search for the relationship model and molecular characteristics of the polymer.

CONCLUSIONS

1. Modern coextrusion equipment together with gravimetric dosing systems allow us to study the flow properties of melts for a wide range of polymeric materials.
2. The study of multilayer structures and modes of their production indicates that there is almost "corky" nature of the flow. The deviation from the "cork" character indicates set and actual redistribution of the layer thickness. The thickness of the outer and inner layers is higher by 0.5-3% from the setting (control layer thickness proportional to the volumetric dosing).
3. Low viscous boundary layer W2 has enough stable thickness which is 0.5-5%. The tendency thickness increases the boundary layer with increasing thickness (productivity) corresponding to the outermost layer.
4. Improving coextrusion technology, especially for single and small batch production, requires the development of models of multi-layer flow with the wall slip and the formation of the wall region of the melt flow.
5. The first obtained full flow curve equation of non-Newtonian liquid based on a physical model.

REFERENCES

1. **Altınkaynak M., Gupta M., Spalding S., Crabtree., 2011.:** Melting in a Single Screw Extruder: Experiments and 3D Finite Element Simulations. Magazine International Polymer Processing XXVI (2), 182-196.
2. **Basov N., Broy W., 1985.:** Engineering plastics. – M.: Chemistry. - 528. (in Russian)
3. **Brian Black W., 2000.:** Wall slip and boundary effects in polymer shear flows, A dissertation at the University of Wisconsin – Madison, [Electronic resource] http://grahamgroup.che. wisc.edu / pub/ black_dissert.pdf
4. **Dyadichev V., Tereshenko T., Dyadychev A., 2010.:** Problems of specified quality polymer mixture preparation when utilizing waste in coextrusion equipment, TEKA Commission of motorization and power industry in agriculture, Vol. Xa, 113–118.
5. **Dyadichev V., Levanichev V., Tereshtchenko T., 2003.:** Method description rheology of the

polymer melt in a wide range of shear rates. Resource-saving technologies of production and fabrication of materials in mechanical engineering: Coll. Science. etc. Part 2. - Lugansk: publ EUNU. Dal, 68-72. (in Russian)

6. **Dyadichev V., Tereshenko T., Dyadycheva I., 2011.:** Methods of choice of melt filtration system in the process of secondary polymer material extrusion, TEKA Commission of motorization and power industry in agriculture, Vol. XIa, 56–62.
7. **Han C., 1979.:** Rheology in polymer processing. tr. from Eng. ed. Vinogradov, G.V. Fridman, M.L. – M.: Chemistry. - 368. (in Russian)
8. **Hatzikiriakos S., Dealy J., 1991.:** Wall slip of molten high density polyethylene. [Electronic resource] Department of Chemical Engineering, McGill University// Access mode http://www.chem.mtu.edu/~fmorriso/cm4655/Hazikiriakos_Dealy.pdf.
9. **Kosarev A., 2003.:** The unity of the dynamics and mechanisms of turbulence eddies and vortices Benard, [Electronic resource] / Agency for Science and Technology Information / / Access mode http://www.sciteclibrary.ru/rus/catalog/pages/4917.html. (in Russian)
10. **Levanichev V., 2013.:** Model of the polymer melt flow, Eastern-European journal of enterprise technologies, Vol 4, No 7(64), 39-41. (in Russian)
11. **Michaeli W., 1992.:** Extrusion dies for plastics and rubber: design and engineering computations. Hanser Publishers. Munich, 340.
12. **Rauwendaal C., 2008.:** Polymer extrusion . tr. from english. ed. A.J. Malkin - St. Petersburg. Profession. - 768. (in Russian)
13. **Rauwendaal C., 2008.:** Identification and elimination of problems in extrusion. tr. from english. ed. Volodin, V. - St. Petersburg.: Profession, 328. (in Russian)
14. **Tadmor Z., Gogos C., 1984.:** Theoretical Foundations of polymer processing. tr. from english. – M.: Chemistry. - 632. (in Russian)
15. **Tager A., 2007.:** Physical chemistry of polymers. 4th edition. – M.: Scientific World. - 576. (in Russian)
16. **Torner R., Akutin M., 1986.:** Equipment for plastics processing plants. – M.: Chemistry. - 400. (in Russian)
17. **Torner R., 1977.:** Theoretical foundations of polymer processing (mechanical processes). . – M.: Chemistry. - 464. (in Russian)
18. **Ulshin V., Levanichev V., Tereshenko T., 2011.:** Research of process flow of the polymer melt in the channels coextrusion equipment, Lugansk: publ EUNU. Dal, No 3(157). (in Russian)
19. **Vinogradov G., Malkin A., 1977.:** Rheology of polymers. – M.: Chemistry. - 434. (in Russian)
20. **Wei C., Yaqiang S., Chunqian L., Qian L., Changyu S., 2011.:** Effect of micro-viscosity and wall slip on polymer melt rheology inside micro-channel. [Electronic resource]/ Materials conference ANTEC 2011. Access mode http://www.plasticsengineering.org/polymeric/node/4897.
21. **Yakovlev A., 1972.:** The manufacturing of products from plastics. Leningrad, Chemistry, 344. (in Russian)

ИССЛЕДОВАНИЕ МНОГОСЛОЙНОГО ТЕЧЕНИЯ В ПРОЦЕССАХ СОЭКСТРУЗИИ

Виталий Леваничев

Аннотация: В статье представлены результаты исследования многослойного течения в процессе соэкструзии. Проведен анализ метода регулирования многослойной структуры путем объемного дозирования каждого слоя. Приведены данные по расчету многослойного потока с учетом скольжения на стенке канала.

Ключевые слова: соэкструзия, многослойное течение, скольжение на стенке, гравиметрическое дозирование.

An obtaining of nanoheteroepitaxial structures with quantum dots for high effective photovoltaic devices, investigation of their properties

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S u m m a r y . Experimental results showing of a possibility of an obtaining by a method of liquid phase epitaxy with a pulse cooling of a substrate nanoheteroepitaxial structures with quantum dots for a manufacturing of an one-junction concentrate sun elements are presented. For this purpose an installation and a graphite cassette allowing to obtain many layer structures of high quality have been made. Experiments for an obtaining of structures and complex of investigations of materials under various stages of a technological process have been carried out. Morphology of a structures surface has been learned by a microscope MII-4. Sizes of quantum dots have been found by methods of probe microscopy. Measurements and analysis of photoluminescence spectra of structures have been carried out.

K e y w o r d s : nanoheteroepitaxial structures, quantum dots, liquid phase epitaxy, substrate, growing.

INTRODUCTION.

Due to the development of modern technologies, investigations in a region of an obtaining of nanoheteroepitaxial structures (NHES) with quantum dots (QD) with a purpose of a creating based on them various devices with improvement properties induce a great interest. One of the important areas for a wide application of those structures is a photovoltaic with a possibility of a creating 3-d generation solar cells with efficiency above 50 % [6]. The creation of such devices will allow better use of electric motors, replacing their internal-combustion engines, which have a number of negative factors [10, 20].

Optimal semiconductor materials for manufacturing one-junction solar cells with maximal efficiency are wide band semiconductor such as gallium phosphide and gallium arsenide. Solar cells, manufactured for example on a base of gallium phosphide, have the efficiency up to 33% whereas maximal efficiency of silicon solar cells does not exceed 27 %. There are theoretical calculations showing that introduction of narrow-band semiconductor QDs in a wide-band solar cell allows to rich the efficiency above 70% due to a summing of an energy of two long-wave light quanta that does not absorbing in wide-band semiconductor material and absorbing by a QD material [2, 7, 18, 23].

At present time QDs basically are obtained by methods of molecular-beam epitaxy and MOCVD. In this case substrates with a lattice constants that significantly different from the lattice constants of materials for QD are used [11]. Despite advances in technology of an obtaining of QD by these methods there are some problems connected with a high cost of technical equipment and specific defects in obtained by these methods materials. All these require a search for alternative methods that can be used for growing of NHES with QD. Such methods must be economically viable and competitive in comparison with applicable today. As such alternative for an obtaining of NHES with QD we use method of a liquid-phase epitaxy (LPE) with pulse cooling of substrate (PCS) [1, 19, 25]. A manufacturing of quantum-sized structures requires not only high technological equipment for their obtaining but a creating new procedures and equipment for a preparation of main and auxiliary materials and also an inspection of raw materials and making structures on various stages of their manufacturing. For a purpose of inspection of morphology of a quantum-sized objects surface at present time it is widely used methods of electron and scanning probe microscopy [8, 12]. Optical properties are investigated by a learning of spectral dependencies of an absorbing, reflection and photoluminescence [11].

PURPOSE

Main purposes of the paper are the description of investigations connecting: with a developing of technological equipment and installations, studying processes of growing and obtaining many layers NGES with QD with reproduced characteristics; with a developing and a justification laboratory technical scheme of a carrying out processes of growing of NGES with QD; with an investigation of a morphology of the surface of obtained structures and structures with open QD by methods of optical and probe microscopy; with an investigation of optical properties of obtained samples.

MAIN MATERIAL

For a carrying out of experiments for the growing of many-layer NGES with QD the laboratory equipment of horizontal type including a heating furnace, a quartz quasi hermetical reactor with a working cassette and installations, a block for a temperature control, a gas distribution system and a vacuum post has been developed, manufactured and established. Constructive features of the equipment provide a possibility of a heating and cooling charged into the reactor of the materials with a velocity up to 30 and 10 grades per minute respectively with a maximal shelf temperature up to 1200°C [4, 14, 15].

The quasi hermetical reactor is provided with a closing device as a flange. For supply and discharge from the quartz reactor working gases and vacuum the flange has technological input and output as well as hermetically sealed holes for inputs of molybdenum or quartz manipulators for a moving of cassette sliders under a process of a growing and shifting of a water-cooled heat sink with built-in thermocouple.

An obtaining of NGES with QD from solution-melt has been carried out by a designed and manufactured graphite cassette that allows to grow high quality NGES with QD by the method of pulse cooling of a substrate on substrates of various diameters and thickness.

One of the purposes of this work was the obtaining of NGES with QD for a manufacturing photoelectrical converter on a base of A^3B^5compounds using as substrates silicon wafers in order to reduce their cost.

For an obtaining NGES with QD by the method LFE with PCS has been developed and justified a laboratory technological scheme of a carrying out of a process. Conventionally, the scheme can be divided into three process steps: a preparing of main materials, technological equipment and installations to the process of the obtaining NGES with QD; the carrying out the process of the obtaining NGES with QD; management of quality and parameters of source materials and grown NGES with QD.

After the preparing main materials with a purpose of a degreasing, a clearing dirt from the surface and a removing oxide and broken (defective) material layer samples was been prepared for a cooking solutions-melts [21, 3, 9, 22, 13, 24]. That subsequently was been loaded to a prepared to the process the cassette. A components mass needing to a cooking saturated solution melts has been calculated on a base of state diagrams of systems Sn-Ga-As, In-Ga-As, Sn-In-As, In-Al-Ga-As, Al-Ga-As, Ga-P-Sn, Sn-Yb for temperature of a carrying out of process of 480°C. A weighing of components has been carried out by a microanalytical scales with a precision of 0,1 mg.

The growing of NGES with QD for solar cells on substrates GaAs or Si of n-type conductivity has been carried out as follows:

1. The growing of a metallic layer of ytterbium of a thickness 10 nm for a case of Si substrate.
2. The growing of a buffer layer of GaAs or GaP of a thickness 100 nm of a n-type conductivity on a substrate GaAs or Si n-type conductivity.
3. The growing of a many layers structure consisting from layers of QD arrays (InAs), seeded by spacer layers from a array materials GaAs or GaP of a n-type conuctivity.
4. The growing of a thick (100 nm) layer GaAs or GaP of n-type conductivity.
5. The growing of a thick (100 nm) layer GaAs or GaP of p-type conductivity.
6. The growing of a many layers structure consisting from layers of QD arrays (InAs), seeded by spaces layers of array materalsGaAs or GaP of p-type conductivity.
7. The Growing of a layer $Al_{0,7}Ga_{0,3}As$ or GaP of p-type conductivity of a thickness of 10-30 nm for an optical window.
8. The growing of under contuct layer GaAs or GaP of p-type conductivity of 100 nm thickness.
9. An infliction of a cooling solution-melt containing over 10 at. % Al for a forming of a quality surface of the under contact layer for a case of GaAs.

Analogical stages are used for a obtaining of NGES with QD on substrates of p-type conductivity.

A main method for management and characterization of parameters of manufacturing NGES are spectral dependence of an absorbing, reflection and photoluminescence. A morphology of grown structures surfaces was been evaluated by methods of an optical microscopy, and morphology of plates surfaces with grown open QD was been evaluated by methods of a probe microscopy.

RESULTS OF RESEARCH

The morphology of surfaces of obtained epitaxial structures and thickness of bulk epitaxial layers (ES) was been measured on a structures cleavage and was been studied by a MII-4 microscope after a treating in etchant HNO_3:HF:H_20=2:1:5 and illuminating for 1 minute.

On a Fig.1 a transverse cleavage of gallium arsenide substrate with NGES with QD is represented. A thickness of a layer is approximately 1,5 mkm. ES have an mirror surface morphology. A thickness of microuniformity the surface is not over 0,18 mkm. An investigation of the cleavage has showed an absence of vestige of the corroding: an ES-substrate boundary is planar, ES is solid, inclusions of a solvent on a heteroboundary was not been observed.

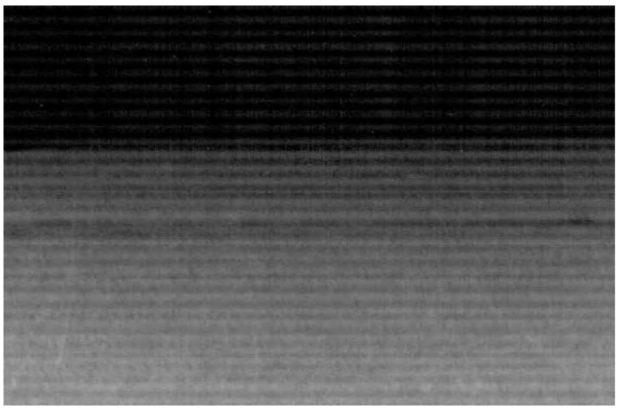

Fig. 1. Transverse cleavage of NGES with QD on a gallium arsenide substrate

A typical morphology of an ES surface grown on a substrate gallium arsenide under growing on substrates (111) and epitaxy temperature 450-500°C are showed on Fig.2.

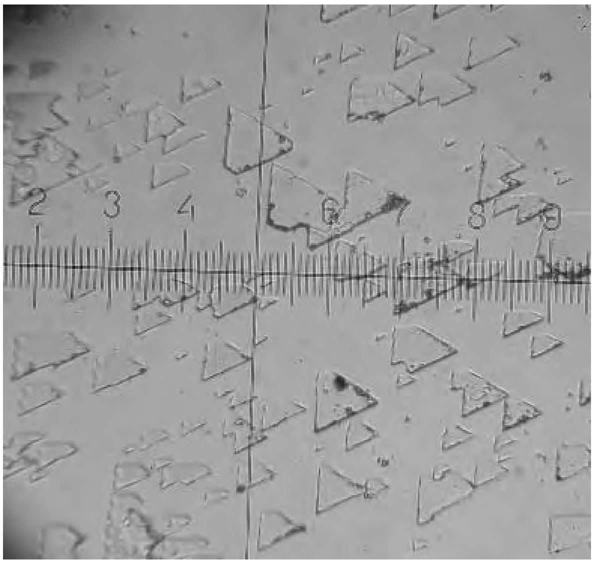

Fig. 2. The morphology of surface of ES grown on gallium arsenide substrates with orientation (111)

On the microscope the silicon and gallium arsenide substrates was been investigated before chemical and dynamical polishing and after it. Before polishing the substrate surface was looked as mirror smooth but under magnification here and there were noticeable roughness in the form of tiny grooves sanding, roughness was R_Z=0,1mkm. After a carrying out of the chemical and dynamical polishing by a method [22] we have seen that scratches disappeared and on the surface the shell etching has been seen, roughness was R_Z=0,08mkm

On Fig.3 grown indium arsenide QD in matrix (buffer layer) gallium phosphide on a silicon substrate with crystallographic orientation (111) picture is shown. The process has been carried out under a temperature 480°C and $\Delta T_F=5$°C under 10 pulse of cooling. A magnification is 500, and scale division ~ 3 mkm. A sample has shells that was been created after chemical and dynamical surface preparation.

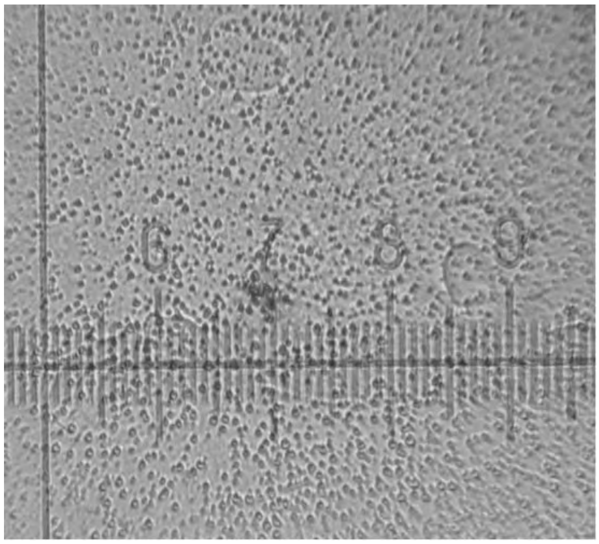

Fig. 3. A seeding of grown QD of indium arsenide in a matrix of gallium phosphide, a surface orientation is (111)

Obtained samples was been investigated also by the probe microscopy methods on a multimicroscope SMM-2000 in a regime of atomic and force microscopy [12]. An investigated sample was been put out from plates under investigation. By the method we investigated plates with obtained by LPE with PCS structures with not seeded QD, and plates of source materials before and after chemical treating. Chipped sample was been attached by two-side scotch on a sample holder of the microscope [16, 5, 17].

A scanning was been carried out by soft cantilevers of MSCT mark of Veeco, USA, firm by a highest console with smallest rigidity with a nominal pressure of 20 units with a speed of approximately 4 mkm per second and with a number of averages in point 16, that allows to us to obtain acceptable results with enough high speed of the scanning.

On Fig.4 a primary frame of the source substrate of silicon before chemical and dynamical preparation to epitaxy process is shown. There are scratches left by grinding grain on the silicon substrate after chemical and mechanical polishing on the picture. The presentation of the frame in 3D (Fig.5) contrast visualize the structure. It shows that deep of scratches in some places riches 40 nm and a length is over 400 nm.

Fig. 4. A primary frame of a source silicon substrate

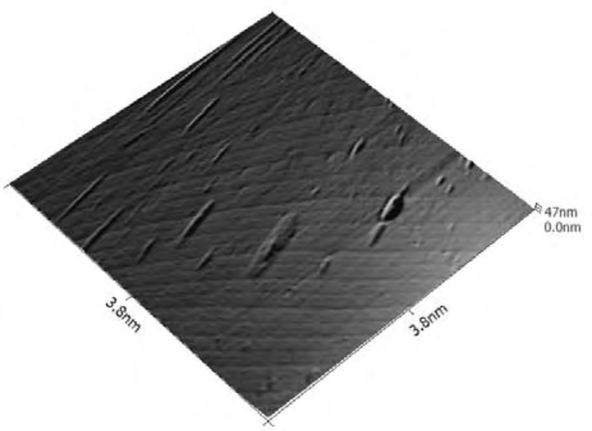

Fig. 5. 3D frame of source silicon substrate

On a Fig.6 a source silicon substrate that was held a chemical and dynamical polishing by method described in [22] is shown. The polishing of plates has the following goals: a degreasing, a cleaning the surface from contaminations and a removing an oxide and defect layer of the material. One can see an absence of scratches from a grinding grain and a presence of small pits that was been formed in process of treatment of the material. A maximal size of pits is over 300 nm and depth is 8 nm. A processing of plates was been carried out immediately prior to the process of epitaxy and a cassette layout.

On Fig. 7 and Fig. 8 primary and 3D frames of grown QD of gallium arsenide in a matrix (buffer layer) of gallium phosphide on a silicon substrate with crystallographic orientation (111) is shown. The process was been carried out under temperature of 480°C and ΔT_F=5°C under 10 pulses where ΔT_F is temperature difference between substrate and heat absorber (cooling pulse).

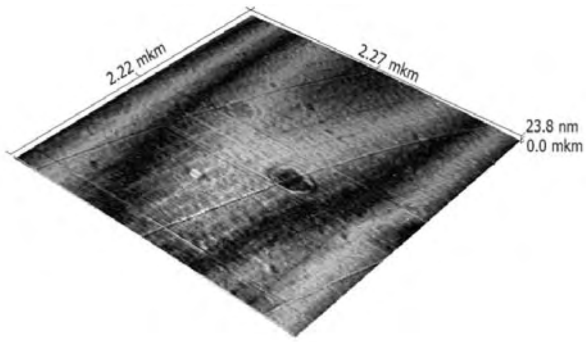

Fig. 6. 3D frame of a source silicon substrate after chemical dynamical treatment

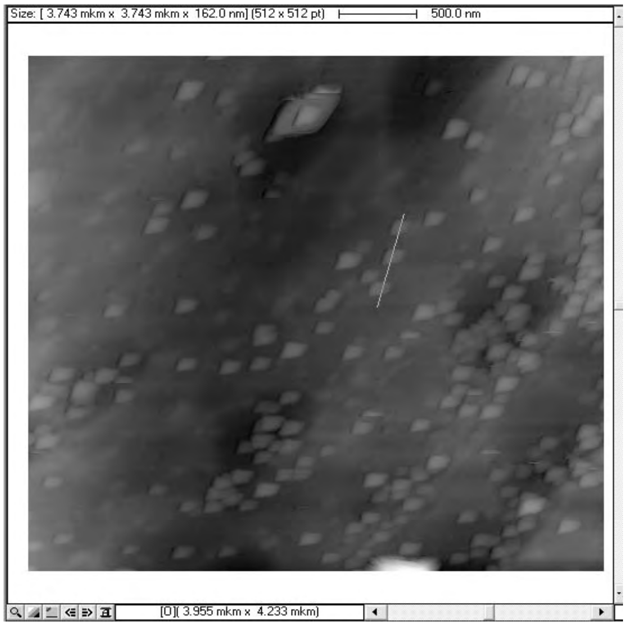

Fig. 7. Source frame of grown QD of gallium arsenide in a matrix of phosphide gallium, substrate orientations (111)

On Fig. 9 a profile of QD emphasized by a line on Fig.7 is shown. As one can see from the profile the average size of QD grown under presented above technological parameters is in width of the order 100 nm and in height of the order 20 nm.

On Fig. 10-12 primary, 3D and profile of QD of indium arsenide in a matrix (buffer layer) gallium phosphide on a silicon substrate with crystallographic orientation (111) with a disorientation of 4-angle grades are shown. The process was been carried out under temperature of 480^{o}C and ΔT_F=5° C under 10 pulses. As one can see from pictures, a density of the seeding of QD is higher that is connected with a presence of stairs on a disoriented substrate. The same is caused by the presence of various size QD: a big ones with a size approximately 150 nm in width and up to 70 in height and small ones (that is occupied on stairs situated under an angle) with size up to 120 nm in width and 40 nm in height.

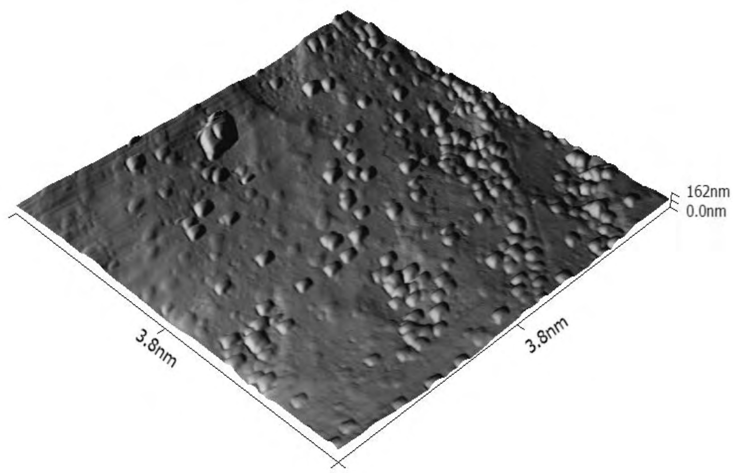

Fig. 8. 3D frame of grown QD of indium arsenide in matrix of gallium phosphide, a substrate orientation is (111)

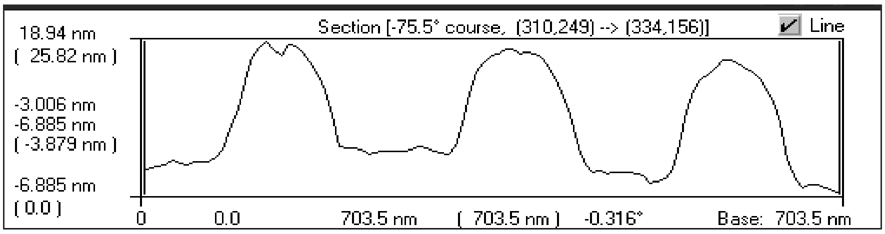

Fig. 9 A profile of QD of indium arsenide in a matrix of gallium phosphide under emphasizing on the Fig. 7

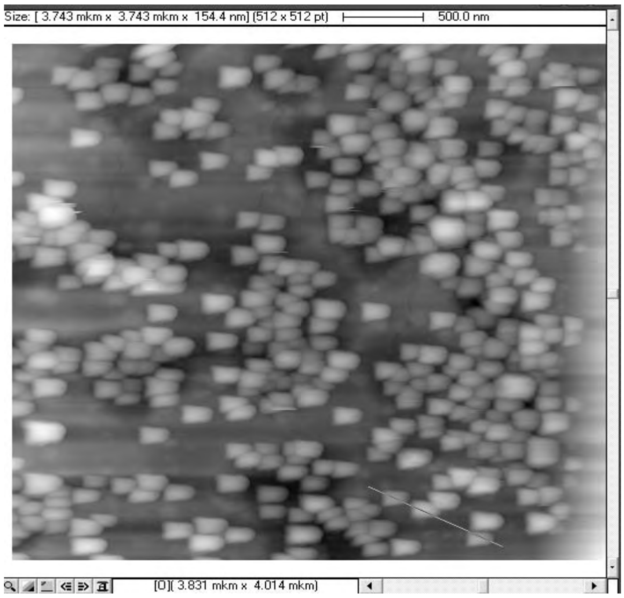

Fig. 10. A primary frame of grown QD of indium arsenide in a matrix of gallium phosphide, a substrate orientation is (111) with a disorientation in 4^o

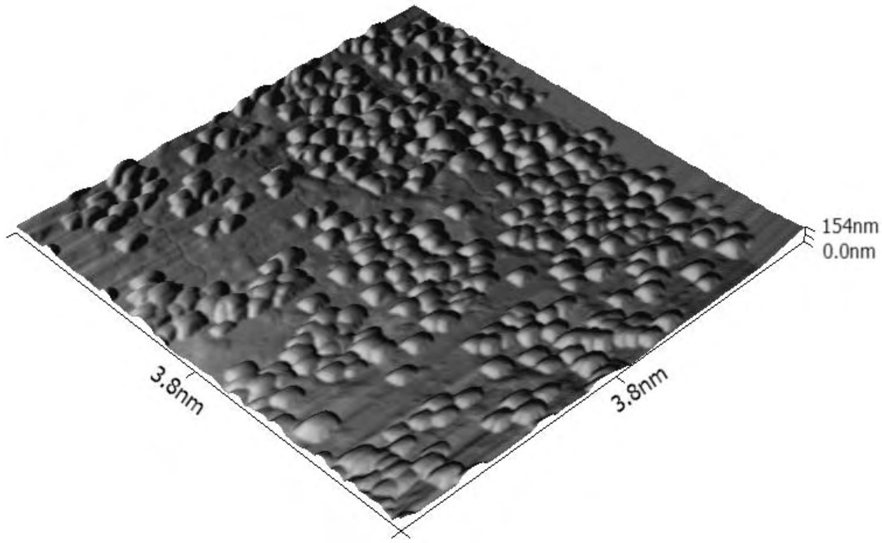

Fig. 11. 3Dframeof grown QD of indium arsenide in a matrix of gallium phosphide, a substrate orientation is (111) with a disorientation in 4^{o}

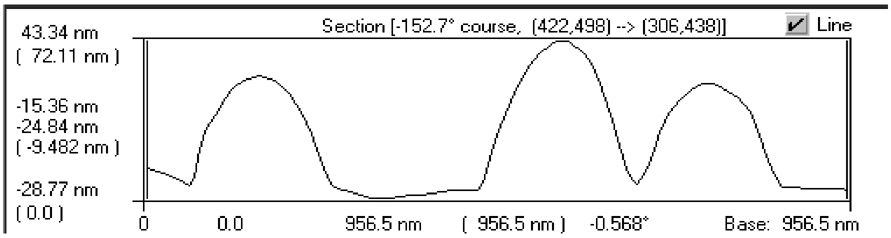

Fig. 12. A profile of QD of gallium arsenide in a matrix of gallium phosphide under a emphasizing on a Fig. 10

A studying of spectral dependencies of an absorption, a reflection and a photoluminescence was been carried out by a set of spectral apparatus on a base of monochromators MDR-41.

In photoluminescence spectra of samples, obtained by a mentioned above method, an investigated radiation of the photoluminescence was been led out both from the sample surface as from a butt of the sample. Emission bands in intervals 1,05-1,35 eV was been observed in photoluminescence spectra of all investigated samples. We connect this fact with a radiation of QD of indium arsenide in a matrix of gallium arsenide.

On Fig. 13 and Fig. 14 typical photoluminescence spectra under a RT obtained from butts of samples of NGES with QD in a system InAs-GaAs that have been grown under 480^{o}C (sample 1) and 500^{o}C (sample 2) respectively on a substrates of gallium arsenide with orientation (111) is presented. The first sample differs from the second sample by less quantity of layers with QD. Remain parameters of technological process of an obtaining of samples is the same. From the investigation of the obtained spectra, we believe that short wave bands under $h\nu \geq 1,4$ eV are connected with a radiation of the substrate of gallium arsenide, and long wave bands is connected with a radiation of QD of indium arsenide.

A shift to a long wave region of a radiation band of sample 2 versus band of sample 1 that one can see from pictures, can be connected with the difference of the temperature under the obtaining of structures (a difference of QD sizes), or, maybe, with a difference of quantity of QD layers. In work [11] it is shown that with an increasing of quantity of QD layers photoluminescence spectra shift to long wave region that is connected with a forming of a system of vertically connected QD. The same phenomenon we observe in our photoluminescence spectra.

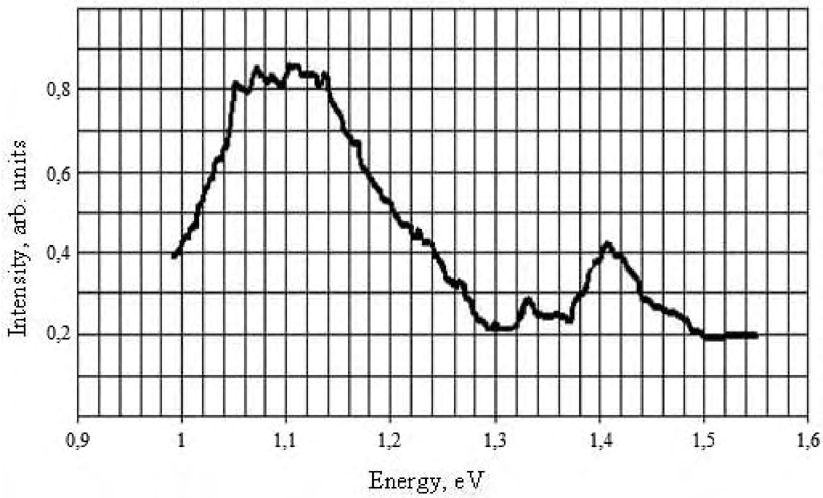

Fig. 13. A photoluminescence spectrum under RT obtained from a butt of sample with NGES with QD in s system InAs-GaAs, grown under 480°C on substrates of gallium arsenide with orientation (111)

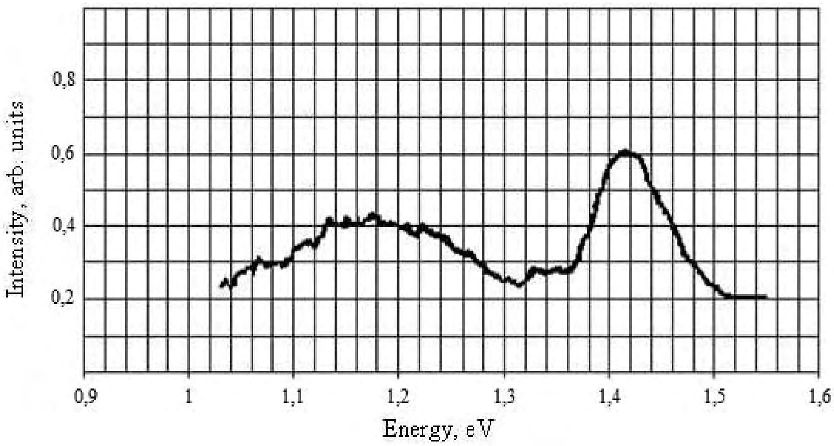

Fig. 14. A photoluminescence spectrum under RT obtained from a butt of sample with NGES with QD in system InAs-GaAs, grown under 500°C on substrates of gallium arsenide with orientation (111)

CONCLUSIONS

In progress of project performance, we obtain the follow main results.

1. A special installation of horizontal type has been developed, manufactured and tuned.
2. A graphite cassette for a growing of nanoheterostructures of semiconductor compounds from solutions-melts has been developed and manufactured. It allows to obtain many layers NGES with QD by the method of PCS of higher quality and on substrates of various diameters and thickness.
3. A laboratory technology for an obtaining of NGES with QD on a base A^3B^5 compounds has been developed. Experimental samples have been obtained.
4. A complex of investigations of materials under various stages of technological process has been carried out. A morphology of surface has been studied by an interference microscope MII-4. Investigations of obtained structures with open QD have been carried out by a methods of atomic and force microscopy. Sizes of QD is detected. Measurements and analysis of photoluminescence spectra of obtained samples has been carried out on a set spectral equipment on a base of monochromators MDR-41.

REFERENCES

1. AS 1566807 USSR. MKI3 A23. A method for producing epitaxial layers A3B5 / Maronchuk I.E, Over-Garyants M.N, Maronchuk I.Y, Kulyutkina T.F, VS Polishchuk (USSR) - declared 04/01/88 publ. 01.22.90, Byul. № 24 (in Russian).
2. **Asai M., Ueba H., Tatsuyama C., 1985.:** Heteropitaxial growth of Ge films on the Si(100)-2 P. 1 surface // J. Appl. Phys. – Vol. 58. – 2577-2585.
3. **Andronov A.**, **2001.:** Tehnoloiya obtain GaSb pn structures of the liquid phase termofotovoltaicheskih converters // Herald KHGTU. – № 4 (13). – 438-440. (in Russian).
4. **Bondarets S., Bikovskiy S., Dovgalenko V., Maronchuk I., 2013.:** Preparation of silicon substrates for growing quantum structures by LPE. // Collection of scientific works SNUNEI. – Sevastopol. – Vol. 2(46) – 153-161. (in Ukrainian).
5. **Bondarets S.**, **Bikovskiy S., Guseva E., Maronchuk I., 2013.:** Assessing the quality of the surface morphology of epitaxial structures by atomic force microscopy // Theses of reports IV Scientifically-practical conference young scientists "Methods and expedients of not destroying control of the process equipment". – Ivano-Frankivsk. – 18-19. (in Russian).
6. **Cuadra L., Lopez N., Luque A., 2003.:** Intermediate Band Photovoltaic Overview // 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan. May 11-18. PCD IPL-B2-01.
7. **Dubrovsky V., 2009.:** Theory of formation of epitaxial structures // FIZMATLIT. – M. – 350 (in Russian).
8. **Hoks P., 1974.:** Electron optics and electron microscopy // Mir. – M. – 320. (in Russian).
9. **Gatos H., 1960.:** The reaction of semiconductors with aqueous solutions in the surface chemical of metal and semiconductors // Wiley. – N. – Y.– 381.
10. **Kuranc A.**, **2005.:** A continuous measurement of CO, CO_2, HC and NO_X at the work of a combustion engine fed with petrol in nstable thermal conditions, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 5, 107-115.
11. **Ledentsov N., Alferov G., Bimberg D., Kop'ev P., Shukin V., 1998.:** Heterostructures with quantum dots: preparation, properties, lasers. Overview. // Semiconductor Physics and Technology. – Vol. 32. – № 4. – 385-410. (in Russian).
12. **Loginov B., 2006.:** Scanning tunneling and the atomic-force microscopy: a guide to work on the microscope SMM-2000 // GOUMIFI (GU). – M. – 92 (in Russian).
13. **Lunin L.**, **2008.:** Tech gradient epitaxy of semiconductor structures electronics. // Don SKNTS VS SFU. – Rostov. – 160. (in Russian).
14. **Maronchuk I., 2013.:** Getting nanogetero epitaxial structures with quantum dots for highly efficient solar cells, used to follow their properties. // EUNU them. Volodymyr Dahl – Lugansk. – № 4 (193) – Part 2. – 122-130. (in Russian).
15. **Maronchuk I,. Petrash A., Sanikovich D., Smirnov S., 2013.:** Structures with quantum dots obtained by LPE, investigation of their properties. // VIII International school-conference "Actual problems of physics of semiconductors". – Drogobich. – 183-184. (in Ukrainian).
16. **Maronchuk I., Petrash A., 2013.:** Evaluating the quality and morphology of the initial substrates non-overgrown structures with quantum dots by atomic force microscopy. // Collection of scientific works SNUNEI. –Sevastopol. – Vol. 1(45) – 144-150. (in Ukrainian).
17. **Maronchuk I., Petrash A., Sanikovich D., Bondarec S., Bykovsky S., 2013.:** Investigation of the surface morphology of structures with open quantum dots grown by liquid phase epitaxy. // Materials of the international conference Physics and technology of thin films and nano-systems ICPTTFN XIV-XIV. – Ivano-Frankovsk. May 20-25. – 209. (in Ukrainian).
18. **Марйе P., Nakagawa K., Mulders F., Van der Veen J., Kavanagh K., 1987.:** Thin epitaxial Ge-Si(111) films: study and control of morphology // Surf. Sci. – Vol. 191. – 305-328.
19. Patent Ukraine UA № 94699 Cl. C 30V 19/00, C 30V 29/00, H 01L 21/20 method epitaxy growing for nanoheterostructure array of quantum dots / Maronchuk I.E., Kulyutkina T.F., Maronchuk I.I., Customer and holder Maronchuk I.E., Kulyutkina T.F., Maronchuk I.I.; Orders. 20.09.2010, Publ. 10.06.2011, Bull. №5 (in Ukrainian).
20. **Roszkowski A., 2006.:** Agriculture and fuels of the future. TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 6, 131-134.
21. **Sangwan K., 1990.:** Etching of crystals: theory, experiment. // Wiley. – N – Y. – 496.
22. **Shwartz B., Robbins H.**, **1976.:** The production technology of semi-conductor structures. // Electrochem. Soc. – Vol. 1906. – 123.
23. **Snyder C., Orr B., Kessler D., Sander L., 1991.:** Effect of strain on surface morphology in highly strained InGaAs films. // Phys. Rev. Lett. – Vol. 66. – 3032-3035.
24. **Strelchenko S., Lbedev V., 1984.:** Compounds A3B5. // Metallurgy. – M. – 144. (in Russian).
25. United States Patent US 7,422,632 B2 Int. Cl. C30B 19/02 Epitaxial growth of structures with nano-dimensional features from liquid phase by pulse cooling of substrate / Kulyutkina T.F., Maronchuk I.E., Maronchuk A.I., Naidencova M.V.; provisional application № 60/688,769 Jun.8, 2005; date of patent sep. 9, 2008.

ПОЛУЧЕНИЕ НАНОГЕТЕРОЭПИТАКСИАЛЬНЫХ СТРУКТУР С КВАНТОВЫМИ ТОЧКАМИ ДЛЯ ВЫСОКОЭФФЕКТИВНЫХ СОЛНЕЧНЫХ ЭЛЕМЕНТОВ, ИССЛЕДОВАНИЕ ИХ СВОЙСТВ

Игорь Марончук, Сергей Быковский, Степан Бондарец, Анна Вельченко

Аннотация: В работе представлены экспериментальные результаты, показывающие возможность получения методом жидкофазной эпитаксии с импульсным охлаждением подложки наногетероэпитаксиальных структур с квантовыми точками для изготовления однопереходных концентраторных солнечных элементов. С этой целью была изготовлена установка и графитовая кассета, позволяющая получать многослойные структуры высокого качества. Проведены эксперименты по получению структур и комплекс исследований материалов при различных стадиях технологического процесса. Морфологию поверхности структур изучали на микроскопе МИИ-4. Размеры квантовых точек, определяли методами зондовой микроскопии при исследованием образцов структур с открытыми квантовыми точками. Проведены измерения и анализ спектров фотолюминесценции структур.

Ключевые слова: наногетероэпитаксиальные структуры, квантовые точки, жидкофазная эпитаксия, подложка, выращивание.

The integration of ontologically oriented technologies in model of knowledge processing

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Summary. The paper discusses the model of knowledge representation, including now the most common models in the computer processing of knowledge ontology. Computer ontologies are used in medicine, biology, diagnosis, e-learning. On the example of e-learning shows the specific logical-mathematical software applications ontologically oriented technologies.

Key words: knowledge models, computer ontology, the subject area, information technology, subject discipline, e-course.

INTRODUCTION

Under the influence of the process of information now emerging new social structure – the information society. It is characterized by a high level of information technology, infrastructure development, ensuring the production of information resources and access to information, processes, accelerated automation and robotics all sectors of production and management, changes in social structures, the consequence of which is the expansion of the scope of information activities.

The process of information is logical and objective process, characteristic of the entire world community. It manifests itself in all spheres of human activity, including e-learning. Informatization included as an important component of e-learning, involves improving the quality of educational services in e-learning [19].

Formulation and investigation of problems of integration of information technology in e-learning is due to the need of their application in various stages of training in accordance with the modern concept of lifelong education.

Development of e-learning, as a branch of learning is not possible without the development of models of knowledge processing, based on which it is implemented. Available current research on the theory of information make a significant contribution to knowledge processing techniques, however, are now studies on systems approaches to solving the problems of integration of information technology in the ontological e-learning, not so much. This is due to the fact that the complexity of the problems arising here is so high that the creation of e-learning courses (EC) should be considered as subject to the complex process of high-tech design.

The introduction of new information technologies in the development of EC complexity and ambiguity caused by the objective and subjective factors:

a) the lack of evidence-based concepts and programs of e-learning,

b) an underdeveloped physical infrastructure, lack of adequate educational environment in most universities,

c) the lack of specific software that allows applications to solve specific problems,

d) inadequate level of information culture and technology training.

Specificity of e-learning technology is that it is designed and implemented a training process to ensure the achievement of the goals. New information technologies have great potential and can enhance the effect of human actions than through their individual elements, and by combining them into a single system. Their implementation, especially the rational integration with e-learning technologies will help create the conditions intensification of e-learning and techniques focused on self extraction and presentation of knowledge, skills formation.

MATERIALS AND METHODS

Known production systems of describe concepts, the shape of which in something inherit syllogisms [6].

Designing electronic courses involves the formation of sets of concepts, their descriptions.

Basic principles of the paradigm of computer ontologies have been formulated in [7].

In contrast to the knowledges encoded in the algorithms [1-3, 4, 11], an ontology provides a unified and their re-use in different research groups on different computer platforms for solving various problems [12].

Subset of the concepts of the ontology database [14].

RESEARCH OBJECT

With the integration of information technology in the processing model of knowledge necessary to choose a formal representation of knowledge. Processing model of knowledge is now being implemented in many industries and technologies. They have the greatest development in medicine, biology, diagnosis, e-learning. This paper analyzes the model of choice for knowledge representation, it is proposed to use the capabilities of the formal description ontologically oriented processing model of knowledge, on the example of the application in e-learning shows the features of logical-mathematical apparatus for processing models of knowledge.

RESULTS OF RESEARCH

The automated system of training of electronic courses are one of the components of the integration of e-learning and information technology. Designing electronic courses involves the formation of sets of concepts, their descriptions. The construction of these sets by hand is a tedious process, both in time and in the number involved in the design process of highly qualified specialists. Set EC should ensure the professional activities of an engineer to solve problems in a variety of subject areas (SA) (Fig. 1).

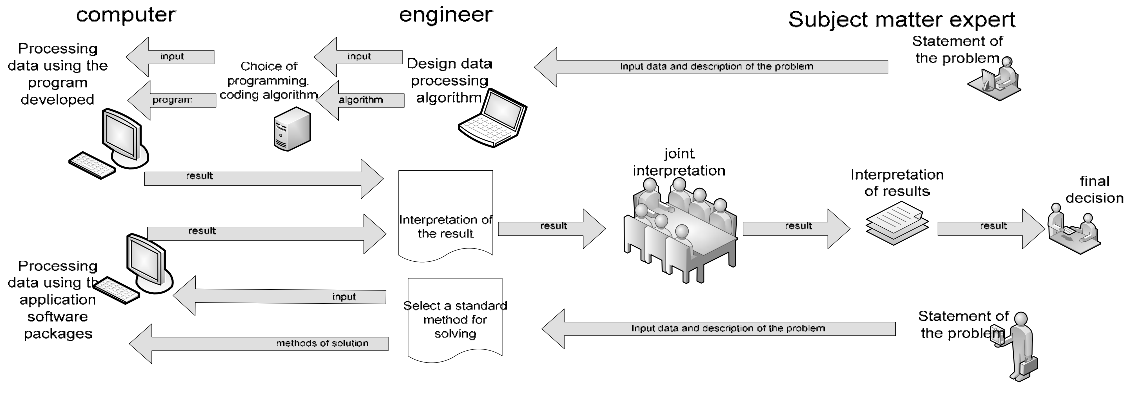

Fig. 1. The scheme of professional problem solving activity in a variety of subject areas

Based on this information model of the electronic courses must be based on a model of knowledge processing SA, on the basis of which it is implemented. To implement the model, you must identify the relationships between the concepts of SA. In implementing the model, you must use the representation of knowledge in an easy to use form. Below is a brief analysis of the formal-logical representation of knowledge [13].

The logical model (the symbolic notation of mathematical expressions using predicate logic), which can use various logical aspects of knowledge representation [11, 14]. Propositional logic is a complete, a system of iterative construction and parsing logic statements, which is the atomic structure for the components of which it is impossible to establish the truth.

Predicate calculus. The main characters are the language of predicate logic variables, individual constants, predicate constants, ligaments $(\neg, \wedge, \vee, \rightarrow, \leftrightarrow)$, quantifiers $\forall$ (for all) and the existence $\exists$ (there) [13].

In the language of the predicate is contained language statements, as saying – neither more nor less than a predicate constant no arguments or, more precisely, a predicate constant with zero seats. Convenient to replace the concept of individual constants a more general concept of functional constants. Functional constant with a certain number of seats – exactly the same as the predicate constant. Individual constant – just ary functional constant.

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Use the default payment method for reasoning about the relationship to the language of predicate logic. It represents the following sequence of steps:

1) replace the unit and common names of individual constants and predicates, respectively,

2) replace the quantifier words quantifiers and write quantifiers with their associated variables in the order quantifier occurrences of words in the sentence that expresses the proposition,

3) write out a formula that replaces the first (within the meaning of) the predicate by preceding the left bracket, and if an individual variable formula, which replaces the first predicate associated quantifier, then put it after the implication sign after sign implication or sign conjunction to put a left parenthesis,

4) if the individual variable formula, replacing the second (within the meaning of) the predicate is associated quantifier, then write it and put it after the implication sign, but if it involves an existential quantifier, then write it and put it after the conjunction sign, after sign implication or sign conjunction to put a left bracket (if translated judgment of more than double sense), and so on,

5) write a formula that replaces the last predicate,

6) after the formula, which replaces last predicate to supply the required number of right brackets (if detected logical form of negative judgments, the predicate before the last to put the negation sign).

Existentially - conjunctive logic.

Her name is associated with a logical operator conjunction and existential quantifier, which are used in it. The widespread use of EC logic gained from the development and implementation of relational databases. Thus, each database is used to fix the presence of an object (the existential quantifier) and the list of its inherent properties (connected by a conjunction). All that is not included in the database, is considered from a logical point of view as nonexistent. This restriction has created one of the most commonly used query languages SQL.

Frame model (systematization and structuring of information in the form of tables, matrices, etc.).

Frame – an abstract image to represent a stereotype perception. In general, the frame can be formally described as a structure that includes the name of the frame, a plurality of slots with their names and a host of associated procedures associated with the frame or the slots. Such frames are called frames-prototypes. Frames-examples are frames-prototypical with the values of slots and must display certain real-world objects, situations, and so on. Notion of frames was the concept of object-oriented systems, which have narrowed the interpretation of the frames of the prototype to the classes, and the frame-examples to class objects, preserving fully the structure and capabilities of frames.

Production model (a set of rules or regulations for the submission of algorithmic procedures for solving).

Production systems. The shape of the production systems in something inherit syllogisms: The system consists of rules Productions $A \supset B$ (if A, then B), which in general terms in place A and B can appear arbitrary Boolean expressions without implication. However, the automatic systems of productions as a B share a single fact or reference to a simple implementation of the Direct Output (from antecedent to consequent) [5].

Horn clauses. Production systems with the opposite conclusion in their majority are Horn systems. The reason for this is the use of Horn clauses – implicative formula $A \supset B$, where B is an atomic predicate.

Semantic model (knowledge representation using graphs, flow charts, drawings, etc.).

Semantic networks and conceptual graphs. Semantic network is a directed graph with named nodes that represent objects and arcs – relationships between objects. As the graph semantic networks use at least two measurements for its notation. The first was a semantic network of concepts with a small tree genus-species relationships, built on the categories of Aristotle. Later repeatedly builds a tree of categories, but they used a very limited set of relations. Semantic networks were developed in connection with the possibility of automatic processing on a computer, use a lot of expanding relations: linguistic (declensional, attribute), logic (conjunction, disjunction, negation, implication), quantified (all, some). Logical basis of semantic networks is the full first-order predicate logic – every relationship can be viewed as a predicate of adjacent to it (relative) peaks – objects. From the variety of semantic networks deserve special attention conceptual graphs (CG). This is evidenced by at least the fact that for the CG Committee NCITS T2 on the exchange of information and interpretations have been adopted by ANSI-standard. CG designed to represent knowledge at the level of the man-machine, although there is a form recording CG designed to manipulate graphs between machines. For CG defines the basic universal primitives for building semantic networks with arbitrary relationships. They have the ability to include images, audio information and other CG as objects (top graph)

Conceptual graph is a bipartite labeled directed graph $G = (V_1 \cup V_2, E)$, where $V_1 \cap V_2 = 0$ the vertices of V_1 the marked predicate names, and the top V_2 of the – argument names, E – set of arcs (directed edges). The arcs connecting the vertices of the graph, labeled with the name of predicates, with vertices labeled by the names of the arguments. The tops of the plurality V_1 called nodes - predicates, the tops of V_2 – nodes-concepts and predicates themselves – conceptual predicates.

From this definition, it follows that the conceptual graph must satisfy the following conditions:

1) the number of arcs that connect nodes to nodes predicate - concepts, as well arity of the predicate (i.e., the number of its arguments),

2) all nodes predicates marked with the same concept of the predicate have the same arity,

3) all the arcs that connect nodes and predicate nodes concepts in the CG, ranked from 1 to n, where n – the arity of the predicate.

Graphically nodes predicates are indicated by ellipses, and the nodes of the concepts – rectangles. If your logic is typed language, i.e., its objects are assigned certain styles, with each conceptual predicate symbol associated tuple <a, b,…, c>, called the signature of the predicate. Or in other words, the signature of the predicate describes the semantic model of correct use of arguments in the syntactic structure of a natural language, offers a maximum expressive power. Under full expressive power of understanding the motorcade without blank cells.

CG does not accidentally chosen as the data structures for the representation of predicates and their arguments. These structures were tested in long-term knowledge base systems and have proven to be the best side. This is manifested primarily in the efficiency of operations on such data structures. The operations are performed on a set of CG in order to effectively build a more complex structure – the semantic web.

The ontological model (knowledge representation using the concepts, relationships, functions, interpretation of axioms). Basic principles of the paradigm of computer ontologies have been formulated in [7].

1. **Clarity**. The terms (and concepts) of the ontology must reflect reality. Their graphic symbols (signs) should be formed on the basis of the standard rules of semiotics and to express the conventional sense of real objects. In turn, these meanings are extracted from the generally accepted definitions of terms (concepts), recorded in the dictionaries, glossaries of different. The judgments included in the definition are formalized through a formal conventional apparatus in the form of identically true logical axioms.

2. **Coherency**. Formation of the initial set of ontology concepts and their addition should be reasonable, determined, first of all, the requirements of the proposed set of tasks. Logical axioms of the initial set of concepts must be consistent. To this must be provided inference which including checks on the consistency added axioms in the ontology and output approval.

3. **Extensibility**. The core ontology are initially introduced (designed) the concepts and describing their axioms. In the ontology should be a mechanism extension (restriction) shared vocabularies of concepts without compromising the integrity of the system.

4. **Minimal encoding bias**. In the ontological system should be implemented the principle of shared ontologies, which includes: the specification of the ontology at a complete picture, not a character encoding, recording a specification for conventional and platform-independent language for defining ontologies can be transferred for use by any software agent.

5. **Minimal ontological commitment**. This principle resonates with the principles of reasonableness and extensibility / restrictions. It is important that a lot of the concepts of the ontology displayed the conceptual structure of a SA, a relatively stable throughout the “life cycle”. And the latter would offer the possibility of expanding or specialization of individual branches of the ontology graph. Department of conceptual knowledge from the knowledge expressed by facts, is the strategy of building an ontological system, or more precisely – the ontological knowledge base.

Under the ontology of the domain objects is understood Four:

$$O^{O} = < X, R, F, A(D, Rs) >, \qquad (1)$$

where: $X = \{ x_1, x_2, ..., x_i, ..., x_n \}$,

$i = \overline{1, n}, n = Card\ X$ - finite set of concepts (concepts-objects) of a given subject area,

$R = \{ R_1, R_2, ..., R_k, ..., R_m \}, R \subseteq X_1 \times X_2 \times ... \times X_n$,

$k = \overline{1, m},\ m = Card\ R,$ – finite set of semantically meaningful relationship between the concepts subject area. They define the type of relationship between concepts. In general, the relationship is divided into general significance (of which the release is usually the partial order) and specific relationship given subject area,

$F : X \times R$ – Finite set of interpretation functions defined on the concepts of objects and relationships,

A – Finite set of axioms, which consists of a set of definitions D_i^l and a set of constraints Rs_i^t for the concept X_i. Definitions are written in the form of identically true statements that can be taken, in particular, of the dictionaries subject area. They can specify additional relationships X_i with the notion X_j. In the set of constraints Rs_i can be specified limitations on the interpretation of the relevant concepts X_i.

An ontology defines a common, semantically meaningful "conceptual unity of knowledge", operated by the researchers and developers of knowledge-oriented information systems. It separates the "static" and "dynamic" component of knowledge from the operational knowledge. In contrast to the knowledge encoded in the algorithms, an ontology provides a unified and their re-use in different research groups on different computer platforms for solving various problems [1-3, 4, 18].

The latter view is now most common in models of knowledge processing. Computer ontologies are used in medicine, biology, diagnosis, e-learning [5, 9]. One of the reasons for such an extension is a good-quality tool support for the development and application of ontology. Now known more than a tool or software systems ontology editors with a wide range of features and functionalities.

The model of knowledge processing for use in the EC proposed to present knowledge in the form of computer ontologies.

In ontological model of EC uses a domain ontology, corresponding to the subject discipline of EC. Ontology SA is the result of using the original tool kit ontological purpose and library reference information.

The library of reference information (LRI) include: encyclopedias, thesauruses and explanatory dictionaries. Contains a library of concepts and their descriptions in Russian, Ukrainian and English languages, divided into thematic dictionaries from one (or more) domains.

LRI generally contains several definitions for each concept based on shades of meaning and focused on a wide range of consumer information. Such knowledge representation with the fundamental principles of constructing formal ontology, and their semantic interpretation is the main source of the SA for ontology knowledge engineer.

LRI module developed in object-oriented programming language Java. For Storage dictionaries used Redis - document-oriented, networked, data store of type "key-value" open source. The system keeps a database in RAM, equipped with logging mechanisms to ensure permanent storage.

The main purpose of LRI is to support the processes of transdisciplinary research.

The main functions provided by LRI.

1. Viewing entries for an arbitrary concepts.

2. View mode of a concepts and definitions (the default).

3. Representation for concepts multiple definitions of.

4. With the context menu can be called up point – "Other definitions" (of concrete concepts).

5. View mode of ontological description of concepts.

6. Authorization of users. There are two types of authentication: for "User Mode" – without password and "edit mode and filling" - requires an account on the server (username and password).

7. Search term by LRI (all Components).

8. Entering a new concept and its definition from the keyboard or with the digitized source.

LRI module consists of three subsystems, and combines information resource, software and hardware that allow the interaction with natural intelligence.

Subsystem Clearinghouse consists of a specialized database Redis. The database contains a digitized encyclopedia, thesauruses and dictionaries, as presented in the form of domains of knowledge, which in turn are divided into sections - dictionaries domains. For example, domain "Computer" includes dictionaries "Programming", "Databases", "Cryptography". Each dictionary of domain in turn contains a set of concepts and their definitions.

Subsystem of resource of software-hardware includes a block of connection to the database (information resource) and includes a control GUI with the help of which carried the interaction between a user and a knowledge engineer to be able to work with LRI.

Subsystem Natural intellect fills content dictionaries LRI, provides control and validate the contents of an information resource in case of errors or inconsistencies performs editing.

Development of a methodology ontologize EC involves the use of sets of concepts, relations, functions, axioms and interpretation. The use of ontologies in the beginning of the relevant EC design ensures its quality factor validity.

The problem of finding, reporting, understanding and knowledge of computer processing is one of the most difficult problems in the light of the relevant tasks of artificial intelligence.

If a detailed analysis of the significant types of relations by which built the hierarchy of concepts (concepts) in the representation of knowledge, we can see that they are associated primarily with the ratio of the partial order. A relationship of this type constitute a distributive lattice, which has a number of useful properties, and these properties can be used to generate the corresponding consequences, that is, to find the (generation) of new knowledge.

Thus, with the integration of information technology ontologize useful logical-mathematical description of the ontology-managed systems.

Consider a fragment of such a description relating to the partial order.

Cartesian product of $A_1 \times A_2 \times ... \times A_n$ sets A_1, $A_1, A_2, ..., A_n$ is the set of sequences (i.e., a set of ordered n-tuples of elements) of the form $(a_1, a_2, ..., a_n)$, where $a_i \in A_i$, $1 \le i \le n$.

The elements of the Cartesian product is also called tuples. Arbitrary subset R of the set $A_1 \times A_2 \times ... \times A_n$ is called a relation defined or defined on the sets $A_1, A_2, ..., A_n$. If $A_1 = A_2 = ... = A_n = A$, then the Cartesian product of $A_1 \times A_2 \times ... \times A_n$ is called the Cartesian product of the n-th degree of the set A (A^n), and the ratio R, defined on the sets $A_1, A_2, ..., A_n$, – n-ary relation on the set A.

When $(a_1, a_2, ..., a_n) \in R$, we say that the elements $a_i \in (a_1, a_2, ..., a_n)$, (i = 1, 2,..., n) are against each other R, or the ratio R of a true for $a_1, a_2, ..., a_n$. If $(a_1, a_2, ..., a_n) \notin R$, it is considered that R is false for $a_1, a_2, ..., a_n$. For n = 1 the ratio is called unary if n = 2 – binary, for n = 3 – Ternary, etc.

As the relationship defined by $A_1, A_2, ..., A_n$ – subsets $A_1 \times A_2 \times ... \times A_n$, then they define operations of union, intersection, difference, and additions:

$$(a_1, a_2, ..., a_n) \in R \cup R_1 \Leftrightarrow (a_1, a_2, ..., a_n) \in R \text{ or } (a_1, a_2, ..., a_n) \in R_1,$$

$$(a_1, a_2, ..., a_n) \in R \cap R_1 \Leftrightarrow (a_1, a_2, ..., a_n) \in R \text{ and } (a_1, a_2, ..., a_n) \in R_1,$$

$$(a_1, a_2, ..., a_n) \in R \setminus R_1 \Leftrightarrow (a_1, a_2, ..., a_n) \in R, \ (a_1, a_2, ..., a_n) \notin R_1,$$

$$(a_1, a_2, ..., a_n) \in R' \text{ в } A_1 \times A_2 \times ... \times A_n \Leftrightarrow (a_1, a_2, ..., a_n) \notin R.$$

We introduce a nested relationship between the concepts of ontology.

Suppose there is a finite set of concepts Z:

$$Z = (Z_1, Z_2, ..., Z_k),$$

where: k – the number of concepts. We call ratio R_z between the concept and the concept $Z_i \subset Z, Z_j \subset Z$ ratio of nesting, if the concept of Z_j is lower in the hierarchy concept Z_i: $Z_i \, R_z \, Z_j$. For example, we construct the set $Z' = (Z_1, Z_2, ..., Z_8)$ (a subset of the concepts of the ontology database [14] – Figure 2), a plurality of pairs satisfying the relation R_z.

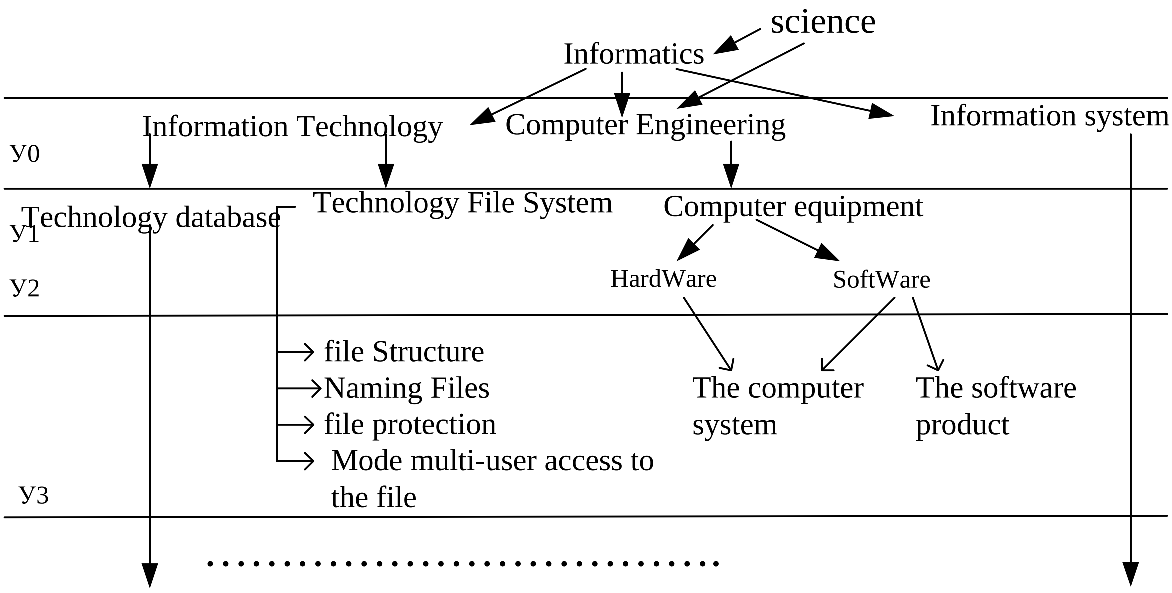

Fig. 2. Fragment of ontograf ontology “Databases”

here:

Z_1 – the concept of “Informatics”,

Z_2 – the concept of “Information Technology”,

Z_3 – the concept of “Computer Engineering”,

Z_4 – concept “Information system”,

Z_5 – concept “Technology database”,

Z_6 – concept “Technology File System”,

Z_7 – concept “Computer equipment”,

Z_8 – concept “Hardware”.

You can imagine the relationship to Z' in the form of a matrix description (Fig. 3).

	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8
Z_1	1	1	1	1	0	0	0	0
Z_2	0	1	0	0	1	1	0	0
Z_3	0	0	1	0	0	0	1	0
Z_4	0	0	0	1	0	0	0	0
Z_5	0	0	0	0	1	0	0	0
Z_6	0	0	0	0	0	1	0	0
Z_7	0	0	0	0	0	0	1	1
Z_8	0	0	0	0	0	0	0	1

Fig. 3. A binary relation R_z

By the finiteness of the set matrix relations R_z will have a precise meaning and allows algorithmic implementation relations. The matrix pair of concepts that satisfy the relation R_z, will be denoted by 1, and do not satisfy the relation – 0.

For the concept Z_1 the ratio $Z_1 R_z Z_1$ obviously, as for all other concepts $Z_1, Z_2, ..., Z_8$. That is, each concept in relation to itself satisfies the relation R_z: $Z_1 R_z Z_1$, $Z_2 R_z Z_2$,..., $Z_8 R_z Z_8$.

As can be seen from figure 3, unit depicting these pairs are diagonal matrices.

Concept Z_2 takes place in the hierarchy of the ontology concept after one, and it is the component, hence we have:

$Z_1 R_z Z_2$.

Similarly, reasoning, and considering the links between concepts, we can construct a binary relation nested R_z, and show that it has the following properties:

1. $\forall Z_i \in Z'$, i=1,…,8

$$Z_i R_z Z_i \tag{2}$$

that is, property of reflexivity.

2. $Z_i R_z Z_k, Z_k R_z Z_j \Leftrightarrow Z_i R_z Z_j$ (3)

that is, has the property of transitivity.

3. $Z_i\, R_z\, Z_j \bigcap Z_j\, R_z\, Z_i \Leftrightarrow Z_i = Z_j$ (4)
that is, property antisymmetry.

By definition, the relationship with the properties (2) - (4) is a partial order.

Take the concept (Fig. 2), which can be called a structured natural language definitions. The following are examples of such definitions, taken from an encyclopedic dictionary.

The definitions of the concept "SCIENCE".

$K(a) = \{p_1, p_2, p_3, p_4, p_5, p_6\}$ – The equivalence class (different definitions of the concept 'is one of the forms of social consciousness').

The definitions of the concept "Computer Engineering".

$K(c) = \{r_1, r_2, r_3\}$ – The equivalence class (different definitions of the concept "discipline, studying computers"…).

The definitions of the concept "informatics":

$$K(b) = \{q_1, q_2, q_3, q_4, q_5\}.$$

Introduced formalization defines a partial order as follows

$K(a) \leq K(b) \Leftrightarrow (\exists p_i(a))(\exists q_j(b))(q_j(b) \leq p_i(a))$, $(q_j(b) \leq p_i(a))$ means $q_j(b)$ is as conjunctive terms in $p_i(a)$.

Permission thus a partial order naturally requires a predicate-object relational view of equivalence classes and within these classes (Fig. 4) [15].

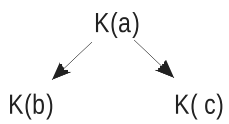

Fig. 4. Partial order K(a), K(b), K(c)

CONCLUSION

1. The paper discusses the model of knowledge representation, including now the most common models in the computer processing of knowledge ontology.

2. The model of knowledge processing for use in the EC proposed to present knowledge in the form of computer ontologies. The use of ontologies in the beginning of the relevant EC design ensures its quality factor validity. Examined the relationship between the concepts of ontology nesting SA and show that it is a partial order.

REFERENCES

1. **Bechhofer S., Horrocks I., Goble C., Stevens R., 2001.:** OilEd: A Reason-able Ontology Editor for the Semantic Web // Joint German/Austrian conf. on Artificial Intelligence (KI'01). Lecture Notes in Artificial Intelligence LNAI 2174, Springer-Verlag, Berlin, 396-408.
2. **Chaudhri V., 1998.:** OKBC: A Programmatic Foundation for Knowledge Base Interoperability. V. Chaudhri, A. Farquhar, R. Fikes P. Karp J. Rice // Fifteenth National Conf. on Artificial Intelligence. AAAIPres/The MIT Press, Madison, 600-607.
3. **Domingue J., 1998.:** Tadzebao and WebOnto: Discussing, Browsing, and Editing Ontologies on the Web // Proc. of the Eleventh Workshop on Knowledge Acquisition, Modeling and Management, KAW'98, Banff, Canada.
4. **Farquhar A., Fikes R., Rice J., 1997.:** The Ontolingua server: A tool for collaborative ontology construction // International Journal of Human-Computer Studies, 46(6), 707-728.
5. **Fernandez M, Gomez-Perez A., Pazos J., 1999.:** A Building a Chemical Ontology Using Methondology and the Ontology Design Environment // IEEE Intelligent Systems, Jan./Feb. 37-46.
6. **Gavrilov A.V., 2004.:** Artificial intelligence system: methodological instructions for students of correspondence courses / A.V. Gavrilov. - AVTF. - Novosibirsk, Novosibirsk State Technical University, 59.
7. **Gruber T.R., 1993.:** A translation approach to portable ontology specifications / Gruber T. R. – Knowledge Acquisition, 5 (2), 199-220.
8. **Guc A.K., 2003.:** Mathematical logic and the theory of algorithms: a training manual A.K. Guc- Omsk: Publisher of "Heritage". Dialog-Siberia, 108,
9. MacGregor R., 1991.: Inside the LOOM classifier // SIGART bulletin, Vol.3, No.2, 70-76.
10. **Motta E., 1997.:** Reusable Components for Knowledge Modelling // Ph.D. Thesis. The Open University.
11. **Musen M., 1998.:** Domain Ontologies in Software Engineering: Use of Protege with the EON Architecture // Methods of Inform. in Medicine, 540-550.

12. **Noy N., 2001.:** Creating Semantic Web Contents with Protege-2000. N. Noy, M. Sintek, S. Decker, M. Crubezy, R. Fergerson, M. Musen // IEEE Intelligent Systems, March/April, 60-71.
13. **Novikov F.A., 2000.:** Discrete mathematics for computer programmers / F.A. Novikov. - St. Petersburg.: Peter, 304.
14. **Palagin A.V., 2010.:** On the automated construction of ontology for the discipline of electronic courses II / [Palagin A. Petrenko, N. Tikhonov, Y., Velichko VY]. - publisher VNU named. Dahl. - № 4 (150). – 171-178.
15. **Palagin A.V., 2012.:** Ontological methods and means of processing of subject knowledge A.V. Palagin, S.L. Kryvyj, N.G. Petrenko- [Monograph] - Lugansk: publisher VNU named. Dahl, 323.
16. **Robinson J., 1988.:** Logic Programming - Past, Present and Future / J.Robinson. - In the book.: Logic programming. M.: Mir.
17. **Sowa J.F., 2000.:** Knowledge Representation: Logical, Philosophical, and Computational Foundations / J. F. Sowa – Brooks Cole Publishing Co., Pacific Grove, CA, – 594.
18. **Sure Y., 2002.:** OntoEdit: Collaborative ontology development for the Semantic Web. Y. Sure, M. Erdmann, J. Angele, S. Staab, R. Studer, D. Wenke // In Proc. of the Inter. Semantic Web Conference (ISWC 2002), Sardinia, Italia.
19. **Zharikov E., 2010.:** Topical questions of implementation of information services in a network of University, TEKA Kom. Mot. I Energ. Roln. – OL PAN, 10B, 331.

ВОПРОСЫ ИНТЕГРАЦИИ ИНФОРМАЦИОННЫХ ОНТОЛОГИЗИРОВАННЫХ ТЕХНОЛОГИЙ В МОДЕЛИ ОБРАБОТКИ ЗНАНИЙ

Геннадий Могильный, Виталий Семенков, Юрий Тихонов

Аннотация. В статье рассматриваются модели представления знаний, в т.ч. наиболее распространенные сейчас в моделях обработки знаний компьютерные онтологии. Компьютерные онтологии находят применение в медицине, биологии, диагностике, e-learning. В онтологизированной модели электронного курса (ЭК) используется онтология предметной области (ПдО), соответствующая предметной дисциплине (ПдД) ЭК. Онтология ПдО является результатом использования оригинального Инструментального комплекса онтологического назначения. На примере e-learning показано специфическое логико-математическое обеспечение для приложений онтологизированных технологий. Рассмотрено отношения вложенности между концептами онтологии ПдО и показано, что оно является отношением частичного порядка.

Ключевые слова: модели знаний, компьютерная онтология, предметная область, информационная технология, предметная дисциплина, электронный курс.

Modelling of vibrating machine-tool with improved construction

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S u m m a r y The work presents the mathematical modeling of the motion of the U-shaped container of the vibration of the machine, with the aim of finding the optimum position vibration exciter with respect to the container and an improved design of the machine. Fig.: 6. Bibliogr.: 23 titles.
K e y w o r d s : vibration processing circular motion, vibrating machine, optimal design, productivity.

INTRODUCTION

One of major tasks of modern engineer is an improvement of quality, increase of reliability and longevity of the produced machines and wares. Perspective direction in providing of these indexes is mastering of progressive technological processes.

Vibration processing has received wide distribution as a promising method of treatment of parts, especially of complex shapes.It runs on vibration machine tools of different types.[1, 17,18]

The analysis and classification of vibration equipment were repeatedly carried out during the existence of the vibratory processing. The aim of analysis was finding a rational design of vibrating machine, providing for intensification of the process of treatment and improving the quality of the machined surfaces. [15, 21, 22].

THE PURPOSE OF THE WORK

The purpose of the work is a modelling of the relationship between the vibrating equipment parameters, its structural elements and the corresponding characteristics of technological processes. Also a development, through research, the advanced design of the vibrating machine, that provides productivity of vibrating processing.

MATHEMATICAL MODELING

Mathematical modeling of the process of vibrating treatment is a quite difficult task. First of all it is connected with the fact that the working environment is a granular medium, which characteristics vary significantly not only from the properties of its elements, but also from the operation modes and parameters of vibrating machine construction (Fig. 1). [5, 12, 13] Such properties as the ability of a medium to transmit the force impulse into the processing zone, transportation of working environment, the appearance in container zones with varying processing intensity may be changed. [6, 7, 14]

1. The movement of the container vibration machine
Input parameters: the parameters of the design and operation of the machine, tool options.
Output parameters: the trajectory and frequency movement of the container.

↓↑

2. Power transmission and processing zone
Input parameters: the trajectory and frequency of movement of the container, the parameters of the working environment.
Output parameters: power momentum transferred in a zone of contact of granules of the working environment and parts, usable horsepower for processing, the settings for the entire download (circulation speed, trajectory).
[2, 3, 4]

↓↑

3. Exposure to the elements of the working environment on the workpiece
Input parameters: speed of movement of the elements, parameters of elements of the working environment (geometric parameters of granules, weight, hardness) and the workpiece.
Output parameters: the metal removal or the degree of hardening. [11, 19]

Fig. 1. Classification of basic processes what be going on at vibrating processing

Modeling of a container movement is an indispensable link between the parameters and design of vibrating machine and the end result - energy of power momentum transferred from container walls to the working environment and to the processing zone, allowance removal or the depth of superficial layer hardening depending on the treatment aim. [20]

Description of the container motion with its loading (media, parts and solution) it is an important task. This is the only way to perform further analysis of movement of the working environment (media and solution).

A mathematical model of movement of the vibrating machine container was developed. It takes into account the influence of the loading mass and changing the rheological parameters of oscillatory systems. Its calculation scheme is shown on Fig. 2 .

For solution of such problems is used Lagrange equation of the second kind:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)-\frac{\partial T}{\partial q}+\frac{\partial U}{\partial q}=F_q\,, \qquad (1)$$

where q – is the generalized coordinate ($q \in \{X, Y, \varphi\}$);

T – is the kinetic energy of the system,

U – is the potential energy of the system,

F_q – external generalized force for the model are defined as:

$$F_q = Q_q - \frac{\partial D}{\partial \dot{q}}\,, \qquad (2)$$

where: Q_q – disturbances force,

D – Rayleigh dissipative function.

Change the angle of the φ accepted quite small for the observance of the conditions of $\sin\varphi \approx \varphi$, $\cos\varphi \approx 1$. Shoulders projections of elastic forces are constant.

For this case the kinetic energy of the system can be expressed as:

$$T=\frac{1}{2}\left((M+m_d)\dot{x}^2+(M+m_d)\dot{y}^2+J\dot{\varphi}^2+m_r\dot{x}_r^2+m_r\dot{y}_r^2\right) \qquad (3)$$

Potential energy is expressed as the total energy of deformation of elastic elements of the system on the corresponding generalized coordinates and energy associated with the elastic properties of the working environment:

$$U=\frac{1}{2}\left[2C_x(x-L_y\varphi)^2+C_y(y-L_x\varphi)^2+C_y(y+L_x\varphi)^2+C_r(x_{cr}-x)^2+C_r(y_{cr}-y)^2\right] \qquad (4)$$

This characteristic is expressed with Rayleigh function:

$$D=\frac{1}{2}\int_F \dot{q}^T B\dot{q}\,dF\,, \qquad (5)$$

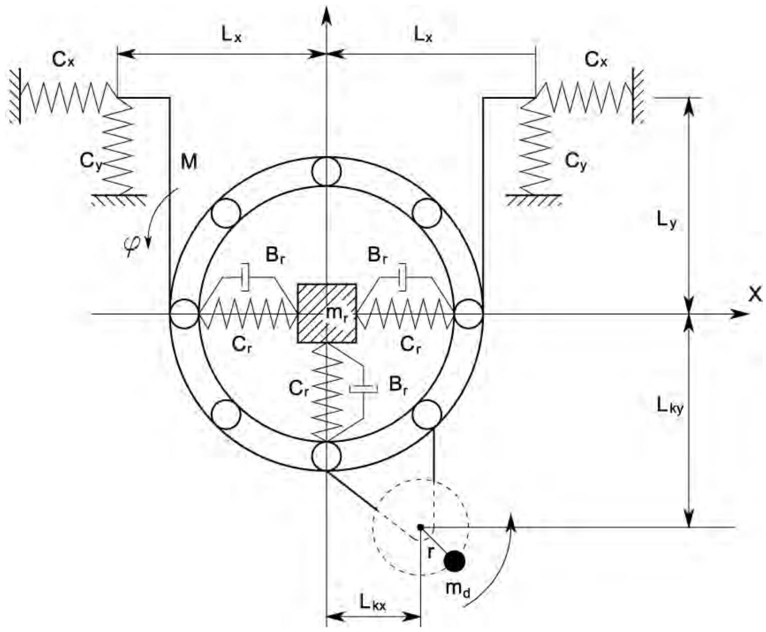

Fig. 2. A calculation scheme of the proposed mathematical model of work of vibrating machine, where: C_x,C_y – the coefficient of elasticity of suspensions, L_x,L_y – distance along the X,Y from the centre of mass of fastening points of left and right suspensions, C_r – coefficient of elasticity of the working environment, B_r – damping factor of the working environment, L_{kx},L_{ky} – distance along the X,Y from the center of mass to the point of application of the disturbing force, M – mass of the container and part of attached loading, m_r – loading weight (according to the scheme located in the center of the container and moving under the influence of the layer that is in contact with the walls), m_d – unbalanced mass of unbalance cargoes; J – is the moment of inertia of the system (total container and debalance) about the center of mass, r – eccentricity of mass debalance relative to its axis of rotation, ω – angular velocity of rotation of unbalanced shaft of vibroexciter, φ – rotation angle of the container about the system center of mass counterclockwise, X,Y – axes are conducted through the center of mass of the container

where: $\dot{q}$ – is the column of the generalized velocities of the friction surfaces,

B – is a nonnegative matrix of the coefficients of viscous friction, and the integration is performed by the internal frame running gear surfaces F.

Physically D function expresses the power of surface friction dissipative forces. For this calculation scheme and the corresponding generalized coordinates D can be written as:

$$D = \frac{1}{2}\left[B_r(\dot{x}_r - \dot{x})^2 + B_r(\dot{y}_r + \dot{y})^2\right]. \qquad (6)$$

The force exerted Q_q for the corresponding generalized coordinates defined as:

$$\begin{gathered} Q_x = m_d r\omega^2 \cos(\omega t), \\ Q_y = m_d r\omega^2 \sin(\omega t), \\ Q_\varphi = m_d r\omega^2\left(L_x \sin(\omega t) - L_y \cos(\omega t)\right). \end{gathered} \qquad (7)$$

Substituting D, T, U in equation (1) for the corresponding generalized coordinates, we will receive a system of five ordinary linear differential equations (8):

$$\begin{cases} (M+m_d)\ddot{x} + (2C_x + C_r)x - 2C_x L_y\varphi - C_r x_r + B_r\dot{x} - \\ -B_r\dot{x}_r = \omega^2 r\,cos(\omega t)m_d\,, \\ (M+m_d)\ddot{y} + (2C_y + C_r)y - C_r y_r + B_r\dot{y} - B_r\dot{y}_r = \\ = \omega^2 r\,sin(\omega t)m_d\,, \\ J\ddot{\varphi} + \left(2C_x L_y^2 + 2C_y L_x^2\right)\varphi - 2C_x L_y x = \\ = L_{kx}\left(\omega^2 r\,sin(\omega t)m_d\right) - L_{ky}\left(\omega^2 r\,cos(\omega t)m_d\right), \\ m_r\ddot{x}_r + C_r x_r - C_r x + B_r\dot{x}_r - B_r\dot{x} = 0, \\ m_r\ddot{y}_r + C_r y_r - C_r y + B_r\dot{y}_r - B_r\dot{y} = 0. \end{cases}$$

Research of dependence of the productivity of vibrating treatment from the location of vibroexciter. At treatment in identical terms the power expended on a process can simply characterize his productivity, because she is a general parameter for all variety of his technological operations, characterized by different technological end-point which in turn depend on combination of great number of factors also different for every operation [16, 23].

We will define intercommunications between power, expended on the process of treatment, and productivity of this process.

After the decision of equalization (8), coming from the dissipative Rayleigh function, the worked out mathematical model allows to determine middle useful power for period depending on parameters vibrating machine-tool:

$$N = \frac{1}{2T}\int_0^T \left[B_r\left(\dot{x}_r(\omega,r,t) - \dot{x}(\omega,r,t)\right)^2 + B_r\left(\dot{y}_r(\omega,r,t) + \dot{y}(\omega,r,t)\right)^2\right]dt$$

The results of calculations of power that can be transferred into working environment depending on the location of vibroexciter , are presented on a fig. 3.

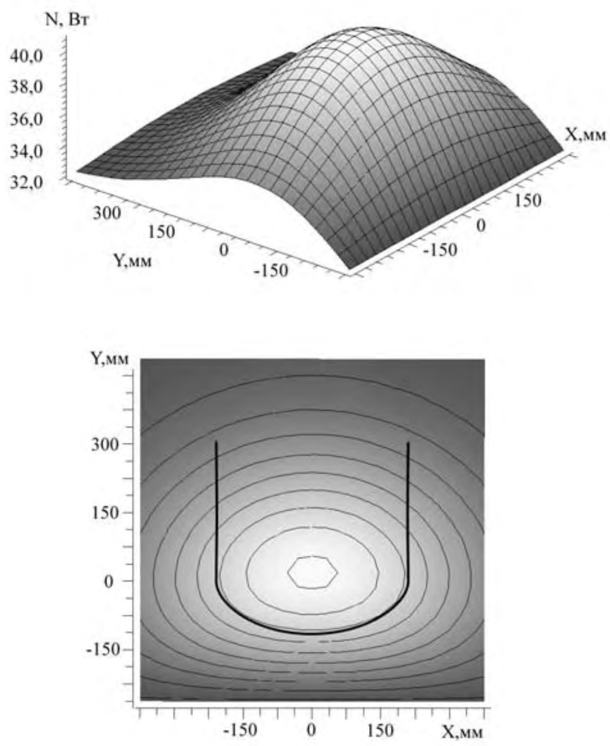

Fig. 3. Calculation of middle useful power, that can be transfered from the walls of container to the working environment for period (a, b image – in the three- and two-dimensional system of co-ordinates accordingly)

The got results are confirmed by works [2, 6].

From charts evidently, that most productive is a location of vibroexciter in the center of container of oscillation machine-tool (co-ordinates – 0;0). Accordingly, with approaching to this point useful power increases. Advantage of application of circular trajectory, and also trajectory, being a prolate on a vertical line ellipse, were resulted in-process [6], that confirms the rightness of the chosen direction.

THE RESULTS OF THEORETICAL RESEARCH

The system (8) has been solved numerically using a modified Runge-Kutta method, which allows to achieve the following aims:

- to study the dependence of trajectory of the vibrating machine container movement from the location of the vibroexciter,

- to assess the circular motion of the loading mass,

-to study the dependence of vibrating processing productivity from the location of the vibroexciter relatively to the U-shaped container.

The proposed model allows to calculate the trajectory of container movement, as well as the power expended on details treatment depending on conditions and place of the vibroexciter relatively to the container of the vibrating machine.

A methodic of precise definition of the working environment circulation speed and a method of determining of the stability of circulation flow motion were suggest based on the developed model.

The developed model allowed to determine the efficiency of vibrating processing depending on the coordinates of vibroexciter location relatively to the longitudinal axis of the container, ensuring the circulation flow and improving the process productivity without introduction of additional energy consumption.

The results of mathematical modeling were confirmed with the experimental studies. They showed that changes in the design of vibrating machine, a choice of location of vibroexciter relatively to the container, namely its location 45º to the vertical axis is perpendicular to the longitudinal axis passing through the center of mass of the container for the machine, with the volume of container to 100 dm^3 provides increase of productivity of vibrating processing 20...30 % upon reaching the necessary technological results.

IMPROVEMENT OF MACHINE-TOOL CONSTRUCTION

Based on the above studies of a modified vibration machine VNU 100 was designed, with the possibility of changing the location of vibroexciter relatively to the container (Fig. 4) intended to perform the following operations: clean the surface of the parts from scale, corrosion, moulding materials; removal of burrs and rounding of sharp edges, waste removal; grinding and polishing of surfaces of details in the preparation of their under protective and decorative galvanic and other coverings; improving the quality of the surface layer, ensuring the required geometrical and physical-mechanical characteristics.

The difference of this machine is in possibility to modify the location of the source of vibrations - the vibroexciter relatively to the container. It can be achieved by attaching a vibroexciter rigidly on a bracket with the possibility of changing in the regulations relatively to the container and attaching to it.

Machine for vibrating processing of the parts contains a U-shaped container 1, vibroexciter 2, rigidly mounted on the bracket 3, attached to the container using washers 4 and 5 bolt, with the ability to change the position of the bracket relatively to the container, defined on a scale of 6 and the subsequent fastening to him bolts 7.

A three-dimensional model of the vibrating machine of modified designs, was developed in the program Compass 3D (Fig. 5), which allowed to conduct computer analisys of the got design of machine. [8, 9, 10]

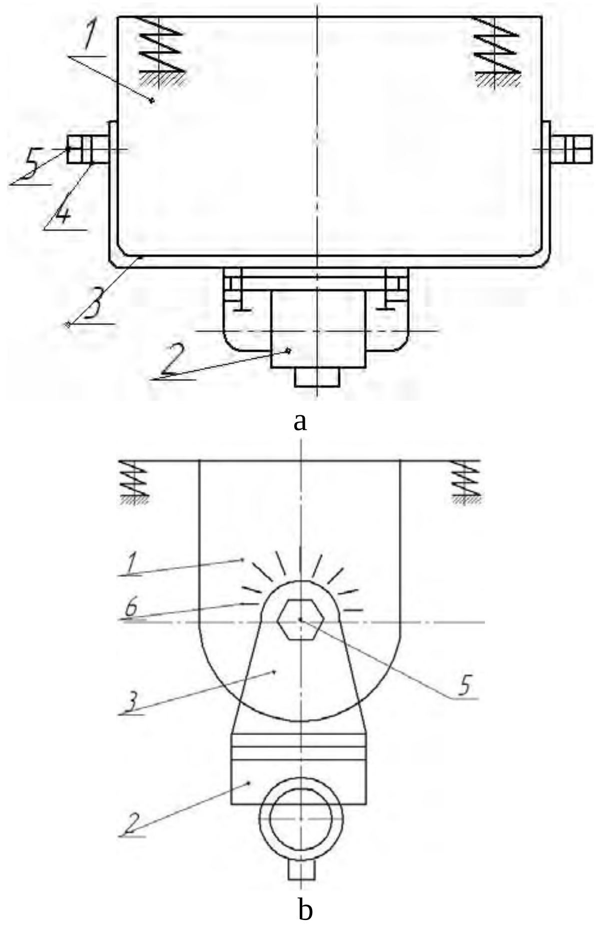

Fig. 4. Schematic diagram of the modified vibrating machine VNU-100: a – a general view; b – side view

Technical characteristics of the machine VNU-100: container volume V – 100 dm^3; the amplitude of oscillation A – 0,2...3,2 mm; oscillation frequency f – 50 Hz, power N – 7,0 kW, weight m – 2400 kg, size – 2100x950x1200 mm

A work of machine for vibrating processing of parts is carried out as follows. Container 1, mounted on resilient suspension and availability to fluctuate in different directions, are reported oscillating motion with the help of the inertial vibroexciter 2. Vibroexciter 2 is set at a certain angle relatively to the container 1, determined on a scale of 6. Depending on the angle brackets 3, which rigidly fixed the vibroexciter, set its position, providing stable circular motion, which promotes the achievement of the quality process. The motion of the vibroexciter shaft is opposite to the movement of the working environment.

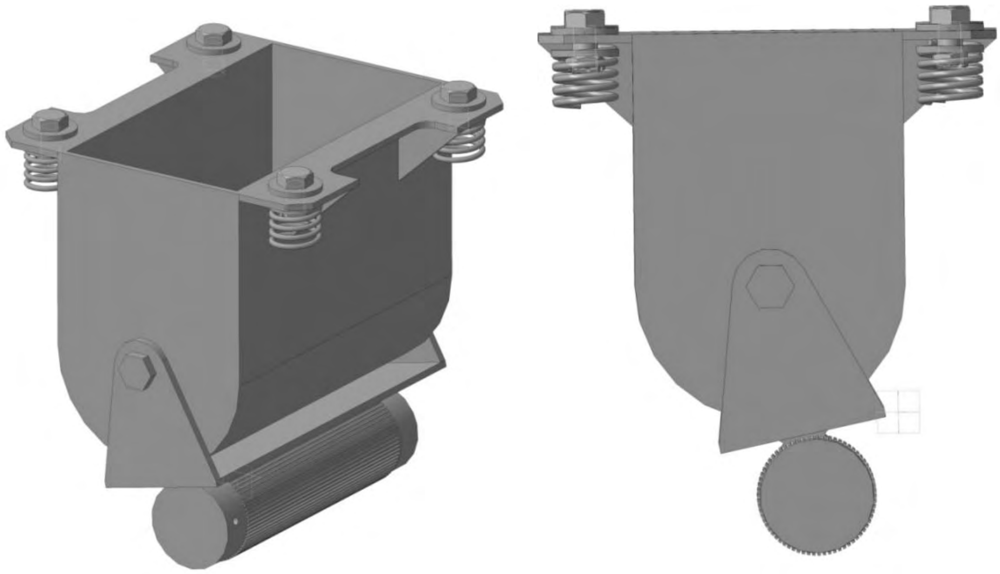

Fig. 5. Three-dimensional model of the vibrating machine modified designs, developed in the program Compass 3D

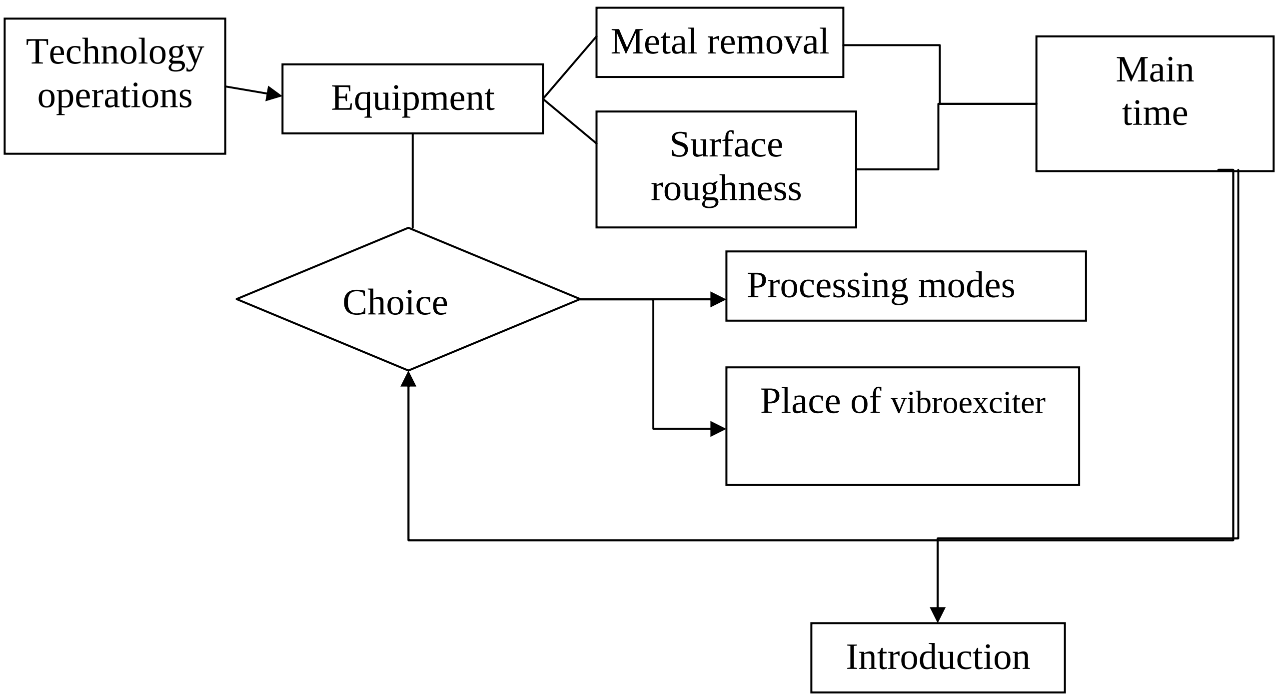

Fig. 6. Scheme of the selection of equipment for the operation of vibrating processing

The choice of the location of vibroexciter was conducted as follows (Fig. 6). On the basis of earlier studies were set initial parameters, namely, the frequency and amplitude, loaded the working environment and the specified amount of fluid. Then an initial coordinate of the location of vibroexciter were installed. After the launch of the machine, measurement of the circulation speed of the working environment flow was carried out, and, if its value matches the required downloaded details. Then the circulation speed of the working environment and loaded into the container parts was re-measurement, if this value was close to the first, that the treatment was carried out at the given position of vibroexciter. So, when moving the bracket with vibroexciter relative to the container, using the scale and measuring the circulation speed of load mass, you can choose an optimal location of vibroexciter.

Due to vibration details and working environment continuously have variables in sign of acceleration and are in an inertial relative movement, making two kinds of motion: oscillatory with a frequency depending on the frequency of oscillations of the container and the rotation of the whole load mass (circulatory).

The direction of the relative movements of the parts and media is changing, resulting in the processing. In the process parts occupy different positions in the working environment that provides a relatively uniform treatment of all surfaces in contact with the working environment.

CONCLUSIONS

1. The developed model allowed to determine the efficiency of vibrating processing depending on the coordinates of vibroexciter location relatively to the longitudinal axis of the container, ensuring the circulation flow and improving the process productivity without introduction of additional energy consumption.
2. With the ability to provide rational location of a vibroexciter relatively to container increases the efficiency of vibrating treatment process, reduces the time required for processing of products without increasing power consumption of the process.

REFERENCES

1. **D'yachenko E.A., 2005.:** Increase of efficiency of oscillation treatment taking into account ecological limitations: diss. doctor. of technical. sciences: 05.02.08 / D'yachenko E.A.. –Rostov-on-Don. – 156. (in Russian).
2. **Kalmykov M.A., 2005.:** Increase of efficiency of process of oscillation treatment of large wares: diss. doctor. of technical. sciences / Kalmykov M.A.. Lugansk. – 223. (in Russian)
3. **Kharlamov Yu.A., 2000.:** Physics, chemistry and mechanics of surface of solid: train aid / Kharlamov Yu.A., Budag'yants N.A. Lugansk: VUGU. – 624. (in Russian).
4. **Kharlamov Yu.A., Kharlamov M.Yu., 2013.:** Design concepts of gaseous detonation guns for thermal spraying TEKA Kom. Mot. I Energ. Roln. – OL PAN, Vol.13, No 4, Lublin, Poland. – 82-91.
5. **Kopylov A.Yu., 2004.:** Decline of error of roughness, peening and remaining tensions at vibroshock treatment of details: diss. doctor. of technical. sciences: 05.03.01 / Kopylov Andrey Yuri. Voronezh. – 187. (in Russian).
6. **Kopylov Yu.R., 1999.:** Vibroshock work-hardening / Yu.R. Kopylov. Voronezh: VIMVD. – 384. (in Russian).
7. **Kopylov Yu.R., 1990.:** Dynamics of process and technology of the vibroshock work-hardening of details of difficult form: diss. doctor. of technical. sciences / Yu.r. Kopylov. Voronezh. – 387. (in Russian).
8. **Krol O.S., Osipov V.I., 2013.:** Modeling of construction spindle’s nodes machining centre TEKA Com. Mot. and Energ. in Agriculture. – OL PAN, 2013, Vol.13, No 3, Lublin, Poland. – 108-113.
9. **Krol O.S., Sukhorutchenko I.A., 2013.:** 3D-modeling and optimization spindle’s nodes machining centre SVM1F4 TEKA Com. Mot. and Energ. in Agriculture. – OL PAN, Vol.13, No 3, Lublin, Poland. – 114-119.
10. **Krol O.S., Szuravlev V.V., 2013.:** Modeling of spindle for turret of the specialized tool type SF16MF3 TEKA Com. Mot. and Energ. in Agriculture. – OL PAN, Vol.13, No 4, Lublin, Poland. – 141 – 147.
11. **Mamalis A.G., Mitsyk A.V., Grabchenko A.I., 2013.:** Mathematical simulation of motion of working medium at finishing–grinding treatment in the oscillating reservoir The International Journal of Advanced Manufacturing Technology. – .Vol. 68. № 1 – 4. – 1 – 14 Springer-Verlag, London
12. **Mitsyk A.V., Fedorovich V.A., 2014.:** Mathematical simulation of kinematics of vibrating boiling granular medium at treatment in the oscillating reservoir Key Engineering Materials. – Switzerland,. – Vol. 581 (Precision Machining VII). – 456-461 Trans Tech Publications Inc., Switzerland.
13. **Mitsyk A.V., Fedorovich V.A., Fadeev V.A., 2012.:** Development of the problems of cinematics and dynamics of finishing-grinding treatment in vibrating reservoir //Cutting & tool in technological system: International Scientific-Technical Collection. Kharkov NTU «KhPI». – Vol 82. – 171-182. (in Russian).
14. **Podol'skiy M.A., 2005:** Estimation of efficiency of work-hardening of details the dynamic methods of SPD on the basis of power criterion: diss. doctor. of technical. sciences: 05.02.08 / Podol'skiy Maxim Aleksandrovich. Rostov-on-Don. – 146. (in Russian).
15. **Shainskiy M.E., 1965:** The oscillation polishing and polishing of details / M.E. Shainskiy //

Announcer of engineer. – №9. – 64 – 68. (in Russian).
16. **Sokolov V.I., Azarenko N.G., Sokolova Ya.V., 2012.:** Simulation of the power unit of the automatic electrohydraulic drive with volume regulation TEKA, Vol.12. – N4. – 268 – 273.
17. Technological providing and increase of operating properties of details of machines and their connections / Suslov A.G., Fedorov V.P., Gorlenko O.A. and other – M.: Engineer, 2006. – 448. (in Russian).
18. Technological providing of operating descriptions of details of GTD. Shoulder-blades of compressor of ventilator. Part I / Boguslaev V.A., Muravchenko F.I. , ZhemanyuK P.d. – Zaporozhia: LTD. «Motor of Sich», 2003. – 396 (in Russian)
19. **Vlasova T.A., 2006.:** Influence of descriptions of instrument – abrasive granules on efficiency of process of oscillation treatment / T.A. Vlasova, L.M. Lubenskaya // Progressive technologies and systems of engineer. – Vyp. 31. – 186-191. (in Russian).
20. **Volkov I.V., 2006.:** Oscillation treatment and its possibilities / I.V. Volkov, A.P. Nikolaenko // Physical and computer technologies: theses. – Kharkov. – 266-268. (in Russian).
21. **Volkov I.V., 2008.:** Increase of the productivity of process of oscillation treatment of details on finishings and consolidating operations: diss. doctor. of technical. sciences: 05.02.08 / Volkov I. V. Lugansk. – 164. (in Russian).
22. **Yasunik S.N., 2003.:** Increase of efficiency of process of treatment of details in vibrating containers: diss. doctor. of technical. sciences: 05.03.01 / Yasunik S. N. Lugansk. – 215. (in Russian).
23. **Zhu ZQ, Chen LG, Rao DL. 2005.:** Relieving welding; residuals stresses by applying vibratory weld conditioning;.Mater Sci Forum 490-491: 475-80.

МОДЕЛИРОВАНИЕ ВИБРАЦИОННОГО СТАНКА УСОВЕРШЕНСТВОВАННОЙ КОНСТРУКЦИИ

Анна Николаенко, Алсаяд Тага Хуссейн

Аннотация: В работе представлено математическая модель движения U-образного контейнера вибрационного станка для определения оптимального положения вибровозбудителя относительно контейнера и создания усовершенствованной конструкции вибрацилонного станка.

Ключевые слова**:** вибрационная обработка, циркуляционное движение, вибрационный станко, совершенствование констуркции, производитель-ность.

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Helical gear train load capacity criterion

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Summary: In the article, the results of the study on helical gear load capacity increase are represented, and one of the most important criteria of transmission performance is introduced – it is the contact tightness coefficient of active lateral surfaces of gear teeth. The coefficient characterizes the stressed state of helical gear teeth. To build a mathematical model of the teeth stressed state, analytical dependences were derived that uniquely identify the theoretical initial surfaces of helical gears.
The results of the comparative analysis confirm the direct dependence of gear train load capacity on the contact tightness coefficient.
Key words: helical gear, contact tightness coefficient, load capacity criterion, stressed state, objective function, optimization, synthesis.

INTRODUCTION

During the design of crossed-axis helical gears, a forced deviation from the hyperboloid base of initial surfaces affected operating characteristics of such transmissions, as compared to their theoretical potential [11]. Substantial improvement of technical characteristics and transmission competitiveness are possible in case of the hyperbolical axoid as initial surfaces, or surfaces that are less deviated from hyperbolic axoids [16, 11, 10, 8]. The important task arising during the gear design is the defining of geometric parameters values of original profile that could ensure the best value of the objective function, taking into account the qualitative parameters of the performance and load capacity of gear [17, 18, 26]. During the helical gear design, the load distribution in tooth flank and the size of contact area have to be studied for defining the allowable contacting, bending and shearing stresses in tooth.

In machine science, the gear train performance is assessed using quality indicators [11, 15] – the criteria characterizing local kinematic and hydrodynamic phenomena in the teeth contact patch, as well as the load capacity of transmissions.

Contact stress eventually results in tooth fatigue breakdown in the contact patch. This destruction becomes apparent in surface chipping.

We introduce a contact tightness coefficient (K_p) [11, 20, 23], which characterizes the stress state of helical gear tooth:

$$K_p = \frac{S}{S_z}, \qquad (1)$$

where: S – surface area of instant contact, S_z – area of the lateral surface of helical hyperboloid gear tooth, K_p coefficient is, to a certain extent, an analogue of K_S coefficient of a comparative stressed state of gear teeth [11].

The physical meaning of the contact tightness coefficient: increase (decrease) of K_p means an increase (decrease) of teeth load capacity and contact strength and, consequently, increase (decrease) in the entire gear durability.

Theoretical initial surfaces of helical gears are one-sheeted hyperboloid of revolution the equations of which are the following:

$$x_m^2 + y_m^2 - tg^2\beta_m z_m^2 = r_m^2, \ \left(m = \overline{1,2}\right). \quad (2)$$

Necessary and sufficient set of constraints is applied to geometric parameters of surfaces defined by equation (2):

$$\begin{cases} r_1 + r_2 = a_w, \\ \beta_1 + \beta_2 = \gamma, \\ r_1 ctg\beta_1 = r_2 ctg\beta_2, \\ u_0 = \dfrac{r_1 \cos\beta_1}{r_2 \cos\beta_2}, \end{cases} \quad (3)$$

where: a_w is the distance between axes, γ is crossing angle of gears, u_0 is reduction ratio, r_1, r_2 are radiuses of the neck of initial hyperboloids, β_1, β_2 are angles of slope of hyperboloid generating lines (Fig. 1).

Solving the system (3) with respect to the geometric parameters of one-sheeted hyperboloids β_1, β_2, r_1, r_2, the following dependences uniquely defining the theoretical initial surfaces of helical gears:

$$\begin{aligned} \beta_1 &= arctg\frac{u_0 \sin\gamma}{1 + u_0 \cos\gamma}, \\ \beta_2 &= \gamma - arctg\frac{u_0 \sin\gamma}{1 + u_0 \cos\gamma}, \\ r_1 &= a_w \frac{(u_0 + \cos\gamma)u_0}{u_0^2 + 2u_0 \cos\gamma + 1}, \\ r_2 &= a_w \frac{1 + u_0 \cos\gamma}{u_0^2 + 2u_0 \cos\gamma + 1}. \end{aligned} \quad (4)$$

In this paper, the hypothesis is assumed that a real contact patch of helical gears, with sufficient accuracy for solving practical problems, can be represented by an ellipse (Fig. 2, a). This hypothesis is supported by recent studies [11, 7, 13]. The size of an elliptical contact patch depends on the geometrical parameters of the contacting surfaces, the resilience moduli of gear material and normal load on gear teeth.

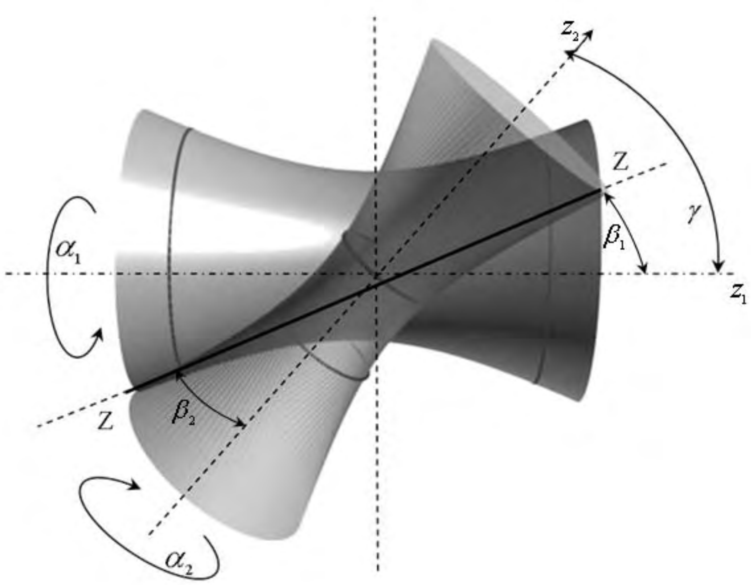

Fig. 1. Surfaces of an one-sheeted hyperboloid of revolution

Normal load P_n is distributed over the entire ellipse area – area of instantaneous contact (Fig. 2, a), that has an area defined according to the formula:

$$S = \pi ab\,, \tag{5}$$

where: a is a major semiaxis of the contact ellipse, b is a minor semiaxis of the contact ellipse.

The equation of the ellipse is

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1\,. \tag{6}$$

Pressure at any point of elliptical area is proportional to the z – applicate of the stressed state semi-ellipsoid (Fig. 2, b):

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1\,, \tag{7}$$

where: a, b, c are semi-axes of the stressed state ellipsoid.

On the other hand, the area S_z of a helical tooth flank of a hyperboloid gear is defined by the formula:

$$S_z = LL_a\,, \tag{8}$$

where: L is a tooth length (length of a one-sheet hyperboloid generating line), L_a is an arc length of the lateral surface tooth profile.

Tooth length L is defined by the formula (Fig. 3, a)

$$L = \frac{H}{cos\,\beta_n}\,. \tag{9}$$

Since the equation of a one-sheet hyperboloid of rotation looks as follows (2), the height of the hyperboloid (gear rim width) will be equal to:

$$H = 2ctg\beta_n\sqrt{r_t^2 - r_1^2}\,, \tag{10}$$

where: H is a rim width, r_1 is the radius of hyperboloid neck, r_t is the radius of the hyperboloid in the butt, β_n is the slope angle to rotation axis (Fig. 3, a).

The arc length L_a depends on the radius of the profile and the tooth height (Fig. 3, b)

$$L_a = \rho_a\left(arcsin\left(\frac{h_a + y_a}{\rho_a}\right) - arcsin\left(\frac{y_a}{\rho_a}\right)\right). \tag{11}$$

Thereby, the contact tightness coefficient can be defined according to the formula:

$$K_p = \frac{S}{S_z} =$$

$$= \frac{\pi ab\cos\beta_n}{2ctg\beta_n\sqrt{r_t^2 - r_1^2}\,\rho_a\left(arcsin\left(\frac{h_a + y_a}{\rho_a}\right) - arcsin\left(\frac{y_a}{\rho_a}\right)\right)} =$$

$$= \frac{\pi ab\sin\beta_n}{2\rho_a\sqrt{r_t^2 - r_1^2}\left(arcsin\left(\frac{h_a + y_a}{\rho_a}\right) - arcsin\left(\frac{y_a}{\rho_a}\right)\right)}\,. \tag{12}$$

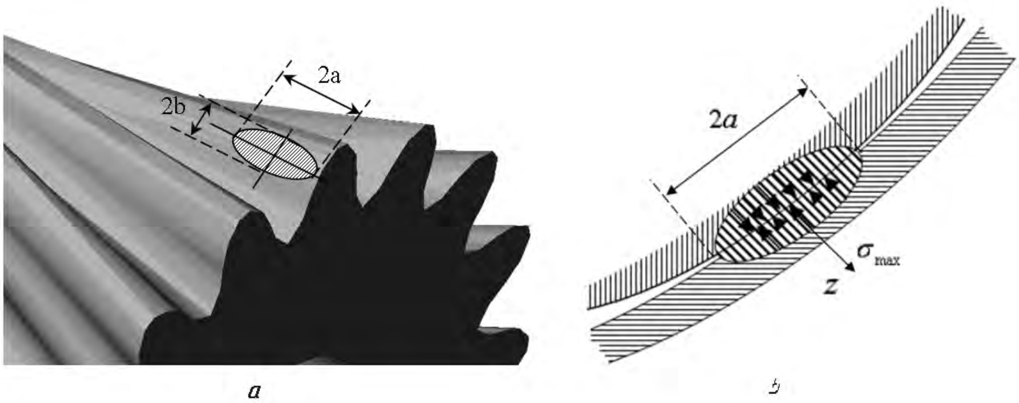

Fig. 2. The elliptical contact patch of lateral surface of a helical gear (***a***), stress distribution on Hertz's diagram at the pitch point of helical pair (***b***)

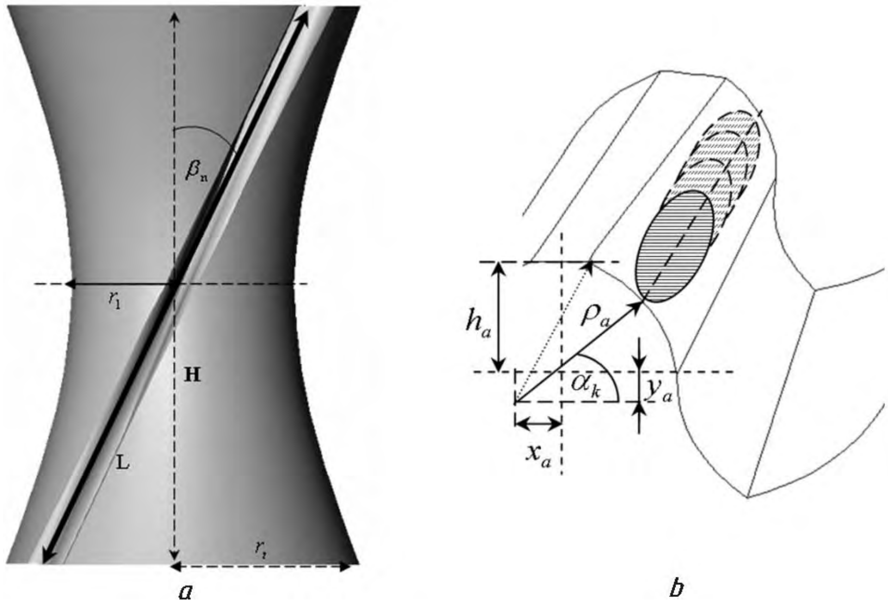

Fig. 3. For the definition of tooth length L (***a***) and arc length L_a (***b***)

For the purpose of defining major and minor semiaxes of the instantaneous contact ellipse (Fig. 2.a), generalized Hooke's law and Winkler's hypothesis are used [21, 1]. Therefore, the function of contact deformations is defined as follows:

$$D(x,y) = B(x,y)\sigma_H(x,y), \tag{13}$$

where: $B(x,y)$ is a resilience coefficient of the mating pair of teeth, mm^3/N (variable), $\sigma_H(x,y)$ is a contact stress function.

The contact stress function of helical gear teeth will be defined below.

Using (7), the contact stress at any point within the elliptical contour is defined through the maximum (normal) stress in the area center:

$$\sigma_H = P = P_{max}\frac{z}{c} = P_{max}\sqrt{1-\left(\frac{x}{a}\right)^2-\left(\frac{y}{b}\right)^2}. \tag{14}$$

The contact deformation function will look as follows:

$$D(x,y) = \frac{a^2}{2\rho}\sqrt{1-\left(\frac{x}{a}\right)^2-\left(\frac{y}{b}\right)^2} = \frac{b^2}{2R}\sqrt{1-\left(\frac{x}{a}\right)^2-\left(\frac{y}{b}\right)^2}. \tag{15}$$

Normal stress P_n will be defined through the stress P at any interior point of an elliptical contour as follows:

$$P_n = \int_S PdS = \frac{P_{max}}{c}\int_S zdS, \tag{16}$$

where: the volume of semi-ellipsoidal compression is the following:

$$\int_S zdS = \frac{2}{3}\pi\, a\, b\, c. \tag{17}$$

Substituting the value of the integral (17) into (16), the expression for the maximum normal contact stress in the area center will look as follows:

$$P_{max} = \sigma_{max} = \frac{3P_n}{2\pi a b} = \frac{1{,}5P_n}{S}. \tag{18}$$

It is evident from (18) that the maximum stress σ_{max} in the elliptical area center of resilient contact is 1.5 times greater than the average stress set by the formula:

$$\sigma_s = \frac{P_n}{\pi ab} = \frac{P_n}{S}. \tag{19}$$

Contact stress is not a linear function of the normal load P_n, and with an increase of P_n it grows slower. This can be explained by the fact that under the load P_n, the local resilient deformation of a small volume of metal takes place in the contact zone. As a result, the contacting teeth approach each other. The convergence occurs so that the teeth points, which lie outside the deformation zone, move by a certain value along the z-axis. Therefore, with increase of P_n, a and b increase and the area of instantaneous contact patch also grows (5), and hence contact stresses reduce.

For the purpose of defining the coefficient B as constant in equation (13), the actual diagram of stresses distribution $\sigma_H(x,y)$ over the elliptical contact patch (Fig. 2, b) will be replaced with diagram of mean stresses σ_s (20) equally distributed over the given contact patch.

Then, (18) takes the following form:

$$\sigma_{max} = \frac{3P_n}{2\pi a b} = \frac{3}{2}\sigma_s . \tag{20}$$

After replacing the variable resilience coefficient B (x, y) in equation (13) with constant B, the equation looks as follows:

$$D(x,y) = B\sigma(x,y) . \tag{21}$$

For the purpose of using the function (21), it is necessary to define the expression of resilience coefficient B. Therefore, first we will use the dependence which characterizes the relationship between the resilient movements (deformations) D of teeth and stresses arising in them, namely:

$$D_m = K_m \sigma_s{}^n , \tag{22}$$

where: K_m is dimensional parameter, mm/MPa, n is a power exponent, equal to 0,7...0,8 [13, 24] (with regard to the point contact of objects we should proceed from the exponent n = 0,7).

Applied to the mating pair of teeth of gear and wheel, contact stress equation, based on the generalized Hooke's law, will look as follows [1]:

$$\begin{cases} \sigma_1 = \dfrac{(\varepsilon_{zy} + \nu_1 \varepsilon_{zx})E_1}{1-\nu_1^2}, \\ \sigma_2 = \dfrac{(\varepsilon_{zy} + \nu_2 \varepsilon_{zx})E_2}{1-\nu_2^2}, \end{cases} \tag{23}$$

where: $\varepsilon_{zx} = \dfrac{\Delta L_{zx}}{L_x}$, $\varepsilon_{zy} = \dfrac{\Delta L_{zy}}{L_y}$ is relative deformations, ΔL_{zx}, ΔL_{zy} are absolute deformations, $L_x = 2a$, $L_y = 2b$ are lengths of contact ellipse axes, ν_1, ν_2 are Poisson coefficients, E_1, E_2 are resilience moduli of teeth materials.

Taking into account the equality $\Delta L_{zx} = \Delta L_{zy}$, we obtain the expression $\varepsilon_{zx} L_x = \varepsilon_{zy} L_y$, basing on which, in case of $L_x = 2a$, $L_y = 2b$, $\dfrac{a}{b} = \alpha$ (α is an ellipticity coefficient [6]), the next formulas will be obtained:

$$\frac{\varepsilon_{zy}}{\varepsilon_{zx}} = \frac{L_x}{L_y} = \frac{2a}{2b} = \frac{a}{b} = \alpha; \quad \varepsilon_{zy} = \alpha \varepsilon_{zx} .$$

Taking into account that $\Delta L_{zx} = \dfrac{a^2}{2\rho}$, then $\varepsilon_{zy} = \varepsilon_{zx}\alpha = \dfrac{\Delta L_{zx}}{L_x}\alpha = \dfrac{a^2}{2\rho 2a}\alpha = \dfrac{a}{4\rho}\alpha$, where $\rho = \dfrac{\rho_a \rho_f}{\rho_a + \rho_f}$ is a reduced radius of curvature of the lateral tooth profiles.

After placing the right side of the dependence $\varepsilon_{zy} = \alpha \varepsilon_{zx} = \dfrac{a}{4\rho}\alpha$ into the equations (23), they will look as follows:

$$\begin{cases} \sigma_1 = \dfrac{\varepsilon_{zx}(\alpha + \nu_1)E_1}{1-\nu_1^2} = \dfrac{a(\alpha + \nu_1)E_1}{4\rho(1-\nu_1^2)}, \\ \sigma_2 = \dfrac{\varepsilon_{zx}(\alpha + \nu_2)E_2}{1-\nu_2^2} = \dfrac{a(\alpha + \nu_2)E_2}{4\rho(1-\nu_2^2)}. \end{cases} \tag{24}$$

Based on the dependence (22), when $n = 0.7$ and taking into account the expression

(24), two equations of resilient displacements of teeth mating pair will be defined as follows:

$$\begin{cases} D_1 = K_1\sigma_1^{0.7} = K_1\left(\dfrac{a(\alpha+\nu_1)E_1}{4\rho(1-\nu_1^2)}\right)^{0.7}, \\ D_2 = K_2\sigma_2^{0.7} = K_2\left(\dfrac{a(\alpha+\nu_2)E_2}{4\rho(1-\nu_2^2)}\right)^{0.7}. \end{cases} \quad (25)$$

From (25) and taking into account that $D = \Delta L_{zx} = a^2/(2\rho)$, the dependence of dimensional parameters will be defined as follows:

$$\begin{cases} K_1 = D_1\left(\dfrac{4\rho}{a}\dfrac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0.7} = \\ = \dfrac{a^2}{2\rho}\left(\dfrac{4\rho}{a}\right)^{0.7}\left(\dfrac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0.7} = \\ = 2^{0.4}\dfrac{a^{1.3}}{\rho^{0.3}}\left(\dfrac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0.7}, \\ K_2 = D_2\left(\dfrac{4\rho}{a}\dfrac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0.7} = \\ = \dfrac{a^2}{2\rho}\left(\dfrac{4\rho}{a}\right)^{0.7}\left(\dfrac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0.7} = \\ = 2^{0.4}\dfrac{a^{1.3}}{\rho^{0.3}}\left(\dfrac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0.7}. \end{cases} \quad (26)$$

Next, based on the relation (19) and expressions (26), the equations of contact resilience of gear and wheel teeth will be defined as follows:

$$\begin{cases} \delta_1 = \dfrac{D_1}{P_n} = \dfrac{K_1\sigma_s^{0.7}}{P_n} = \dfrac{2^{0.4}a^{1.3}}{\rho^{0.3}P_n}\left(\dfrac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0.7}\left(\dfrac{P_n\alpha}{\pi a^2}\right)^{0.7} = \\ = \dfrac{2^{0.4}}{\pi^{0.7}a^{0.1}(\rho P_n)^{0.3}}\left(\dfrac{\alpha(1-\nu_1^2)}{(\alpha+\nu_1)E_1}\right)^{0.7}, \\ \delta_2 = \dfrac{D_2}{P_n} = \dfrac{K_2\sigma_s^{0.7}}{P_n} = \dfrac{2^{0.4}a^{1.3}}{\rho^{0.3}P_n}\left(\dfrac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0.7}\left(\dfrac{P_n\alpha}{\pi a^2}\right)^{0.7} = \\ = \dfrac{2^{0.4}}{\pi^{0.7}a^{0.1}(\rho P_n)^{0.3}}\left(\dfrac{\alpha(1-\nu_2^2)}{(\alpha+\nu_2)E_2}\right)^{0.7}. \end{cases} \quad (27)$$

Taking into account the size of elliptical contact patch (5), equal to $S = \pi ab$, and relations (27). The resilience coefficient will be defined as follows:

$$B = S(\delta_1+\delta_2) = \pi a b(\delta_1+\delta_2) = \pi\frac{a^2}{\alpha}(\delta_1+\delta_2) =$$

$$= \pi\frac{a^2}{\alpha}\cdot\frac{2^{0.8}}{\pi^{0.7}a^{0.1}(\rho P_n)^{0.3}}\times$$

$$\times\left(\left(\frac{\alpha(1-\nu_1^2)}{(\alpha+\nu_1)E_1}\right)^{0,7} + \left(\frac{\alpha(1-\nu_2^2)}{(\alpha+\nu_2)E_2}\right)^{0,7}\right) = \frac{2^{0,8}a^{1,9}\pi^{0,7}}{(\alpha\rho P_n)^{0,3}}\times$$

$$\times\left(\left(\frac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0,7} + \left(\frac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0,7}\right). \quad (28)$$

According to the expression (28), the function (21) of teeth contact deformation will take the final form:

$$D(x,y) = \frac{2^{0,8}a^{1,9}\pi^{0,7}}{(\alpha\cdot\rho\cdot P_n)^{0,3}}\times$$

$$\times\left(\left(\frac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0,7} + \left(\frac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0,7}\right)\sigma(x,y). \quad (29)$$

On the basis of (16) and (29), taking into account (15), the equation that characterizes the stressed deformed state of the teeth mating pair will look as follows:

$$BP_n = B\int_S P\,dS = B\int_{-b}^{b}\int_{-a}^{a}\sigma(x,y)dxdy =$$

$$= \frac{2^{0.8}a^{1.9}\pi^{0.7}P_n}{(\alpha\cdot\rho\cdot P_n)^{0.3}}\left(\left(\frac{1-\nu_1^2}{(\alpha+\nu_1)E_1}\right)^{0,7} + \left(\frac{1-\nu_2^2}{(\alpha+\nu_2)E_2}\right)^{0,7}\right) =$$

$$= \frac{a^2}{2\rho}\int_{-b}^{b}\int_{-a}^{a}\sqrt{1-\left(\frac{x}{a}\right)^2-\left(\frac{y}{b}\right)^2}\,dxdy =$$

$$= \frac{a^2}{2\rho}\cdot\frac{2}{3}\pi ab = \frac{\pi a^3 b}{3\rho} = \frac{\pi a^4}{3\alpha\rho}. \quad (30)$$

This equation will be transformed to the following:

$$a^{2,1} = 2^{0,8} \cdot 3 \cdot \frac{(\alpha\rho P_n)^{0,7}}{\pi^{0,3}} \times$$

$$\times \left(\left(\frac{1-\nu_1^2}{(\alpha+\nu_1)E_1} \right)^{0,7} + \left(\frac{1-\nu_2^2}{(\alpha+\nu_2)E_2} \right)^{0,7} \right). \quad (31)$$

Exponentiating the left and right parts of the last equation to power 10/21, the small semiaxis of the ellipse will be defined:

$$a = 1{,}8658 \times$$

$$\times \sqrt[3]{\left(\left(\frac{\alpha\rho P_n(1-\nu_1^2)}{(\alpha+\nu_1)E_1} \right)^{0,7} + \left(\frac{\alpha\rho P_n(1-\nu_2^2)}{(\alpha+\nu_2)E_2} \right)^{0,7} \right)^{\frac{10}{7}}}. \quad (32)$$

Based on dependence (32), the major semiaxis of the elliptical contact patch will be defined as follows:

$$b = \frac{a}{\alpha} = \frac{1{,}8658}{\alpha} \times$$

$$\times \sqrt[3]{\left(\left(\frac{\alpha\rho P_n(1-\nu_1^2)}{(\alpha+\nu_1)E_1} \right)^{0,7} + \left(\frac{\alpha\rho P_n(1-\nu_2^2)}{(\alpha+\nu_2)E_2} \right)^{0,7} \right)^{\frac{10}{7}}}. \quad (33)$$

Then, (5) will be transformed to:

$$S = \pi \frac{3{,}478}{\alpha} \times$$

$$\times \sqrt[3]{\left(\left(\frac{\alpha\rho P_n(1-\nu_1^2)}{(\alpha+\nu_1)E_1} \right)^{0,7} + \left(\frac{\alpha\rho P_n(1-\nu_2^2)}{(\alpha+\nu_2)E_2} \right)^{0,7} \right)^{\frac{20}{7}}}. \quad (34)$$

And finally, taking into account (34), the contact tightness coefficient (12) will look as follows:

$$K_p = \frac{S}{S_z} = \frac{\pi ab \sin\beta_n}{2\rho_a \sqrt{r_t^2 - r_1^2} \left(arcsin\left(\frac{h_a + y_a}{\rho_a} \right) - arcsin\left(\frac{y_a}{\rho_a} \right) \right)} =$$

$$= \frac{3{,}478 \cdot \pi \sin\beta_n \sqrt[3]{\left(\left(\frac{\alpha\rho P_n(1-\nu_1^2)}{(\alpha+\nu_1)E_1} \right)^{0,7} + \left(\frac{\alpha\rho P_n(1-\nu_2^2)}{(\alpha+\nu_2)E_2} \right)^{0,7} \right)^{\frac{20}{7}}}}{\alpha\rho_a \sqrt{r_t^2 - r_1^2} \left(arcsin\left(\frac{h_a + y_a}{\rho_a} \right) - arcsin\left(\frac{y_a}{\rho_a} \right) \right)}. \quad (35)$$

As a matter of practice, in the calculations: $\nu_1 = \nu_2 = \nu = 0{,}3$, and $E_1 = E_2 = E$. Based on this, the equation (32) will be simplified:

$$K_p = \frac{6{,}73 \cdot \pi \sin\beta_n \sqrt[3]{\left(\frac{\alpha\rho P_n(1-\nu^2)}{(\alpha+\nu)E} \right)^2}}{\alpha\rho_a \sqrt{r_t^2 - r_1^2} \left(arcsin\left(\frac{h_a + y_a}{\rho_a} \right) - arcsin\left(\frac{y_a}{\rho_a} \right) \right)}. \quad (36)$$

Next, the influence of gear parameters on contact tightness coefficient (36) will be studied (Fig. 4 – Fig. 7).

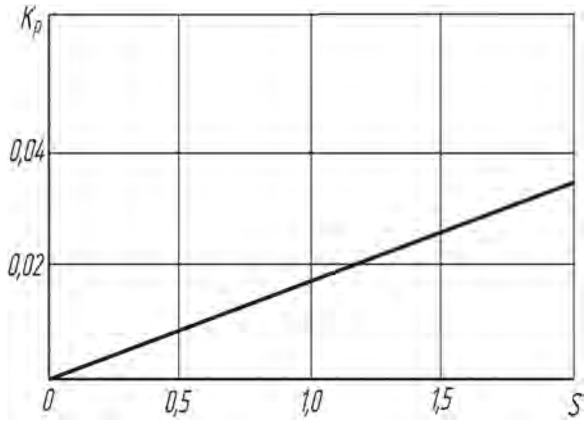

Fig. 4. Dependency K_p (contact tightness coefficient) on S (contact area of the lateral tooth surface)

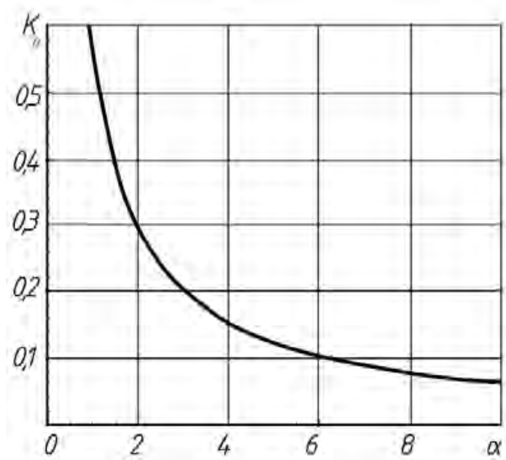

Fig. 5. Dependency K_p (contact tightness coefficient) on α (ellipticity)

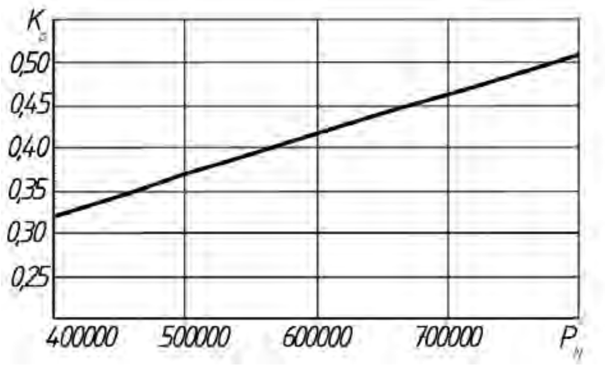

Fig. 6. Dependency K_p (contact tightness coefficient) on P_N (normal stress in nominal contact point)

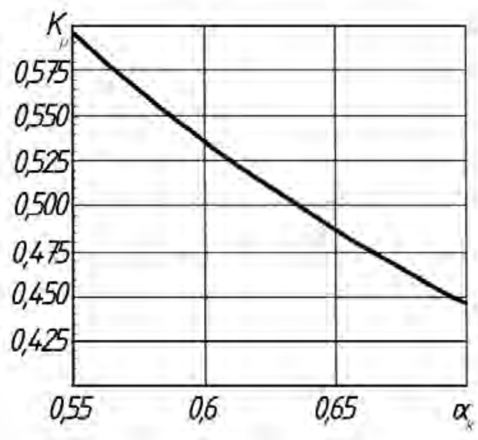

Fig. 7. Dependency K_p (contact tightness coefficient) on α_k (pressure angle in nominal contact point)

In Fig. 4–7, it is evident that increasing P_N (normal stress in nominal contact point) or increasing S (instantaneous contact patch area), which can be the consequence of increasing in P_N, the value of contact tightness coefficient is increased and, therefore, the load capacity increases, and the conditions of oil-film wedge formation are improved, friction decreases, transmission performance improves, contact and bending stress decreases.

Therefore, it can be justly concluded that gear load capability is in direct dependence on the contact tightness coefficient, which should be classified as the criterion for selecting of tooth rim parameters from the point of view of the best durability characteristics.

CONCLUSIONS

1. The main factors affecting the performance and competitiveness of crossed-axis helical gear were studied. Theoretical research on building up a mathematical model of helical gear teeth loaded state was conducted.

2. Analytical dependences of contact tightness coefficient on load factors and geometric parameters of original profile and original hyperboloid surfaces were defined. The considered factor belongs to the main group of criteria included in the objective function that is used for the multi-criteria synthesis of a new initial gear profile.

3. Analytical dependences were derived that uniquely identify the theoretical initial surfaces of helical gears.

4. With the aim of defining a correlation dependence between performance criteria, a multiple correlation analysis of qualitative variable was conducted. This will enable setting up a close correlation between the contact tightness coefficient and load capacity and teeth contact strength. The obtained results of the comparative analysis confirmed the accuracy of the developed theory and the adequacy of the proposed mathematical models.

REFERENCES

1. **Andreev A.V., 1981.:** Calculation of details under complex stress state. – M.: Mashinostroenie, , 215. (in Russian).
2. **Belodedov V., Nosko P., Fil P., 2010.:** Selection of optimal parameters dosator with horizontal dick in the general criterion. – Lublin, "Teka", V. XC, 19-27.
3. **Belodedov V., Nosko P., Fil P., Mazneva M., Boyko G., 2010.:** Selection of batchen with horizontal dick parameters while maize sowing. – Lublin, "Teka", V. XA, 33-40.
4. **Belodedov V., Nosko P., Fil P., Stavicky V., 2007.:** Parameter optimization using coefficient of variation of intervals for one-seed sowing apparatus with horizontal disc during maize seeding. – Lublin, "Teka". vol.7, 31-37.
5. **Belodedov V., Velichko N., Fil P., Breshev V., Mazneva M.. 2008.:** "Simulation of influence of seeding conditions on closed to calculated quantity". – Lublin, "Teka", V. 10A, 11-17.
6. **Demidov S., 1979.:** The theory of elasticity. – M., «Higher school». 432.

7. Design of bevel and hypoid gears. – “Glisson” company instructions (USA). – M. – 2001, 274. (in Russian).
8. **Gribanov V.M., Medintseva Y.V., Ratov D.V., 2010.:** Novikov’s gears. Accuracy problems. – Lugansk “Knowledge”, 252.
9. **Gribanov V.M., Medintseva Y.V., Ratov D.V., 2010.:** On production of quasi-hyperboloid gears. – Bulletin of Volodymyr Dahl East Ukrainian National University. Lugansk, 12 (154), Vol. 2, 236 – 239. (in Russian).
10. **Gribanov V., Ratov D., Balitskaya T., 2009.:** Imitating modeling hyperboloid gears. – Lublin, "Teka", V. XC, 54-61.
11. **Grybanov V.M., 2003.:** Theory of hyperboloid gears. – Lugansk, Volodymyr Dahl East Ukrainian National University, 272. (in Russian).
12. **Ivanov M., 1981.:** Wave gearings. – M.: Higher school. 184.
13. **Levina Z.M., Reshetov D.N., 1971.:** Contact stiffness of machines. – M.: Mashinostroenie, 264. (in Russian).
14. **Litvin F., 1968.:** Theory of gearings. – M: Science. 584.
15. **Medintseva Y.V., Ratov D.V.** On the accelerated sliding rate of helical gear trains. – Lugansk. Bulletin of Lugansk National Agricultural University. Engineering Sciences, 76 (99), 55-61. (in Russian).
16. **Medintseva Y.V., Ratov D.V., Balytska T.Y.** 2007.: Numerical multicriteria synthesis of Novikov gears with two lines coupling. // Bulletin of Volodymyr Dahl East Ukrainian National University, No. 12 (118), Vol. 1, 52-56. (in Russian).
17. **Nosko P., Shishov V., Fil P., Muhovatiy A., Sklyar U., 2008.:** Parametrical optimization of worm gears on losses in gearing. TEKA Commission of Motorization and Power Industry in Agriculture. – Lublin. – V. VIII. 213-221.
18. **Nosko P., Shishov V., Tkach P., Sklyar U., 2010.:** Gearing with increased teeth wear. TEKA Commission of Motorization and Power Industry in Agriculture. – Lublin. – V. XB. 87-94.
19. **Novikov M.L., 1958.:** Gear trains with new coupling engagement. – M.: Zhukovsky AFEA, 186. (in Russian).
20. **Pavlenko A.V., Fediakin R.V., Chesnokov V.A., 1978.:** Gear train with Novikov’s gearing. – Kiev: “Tehnika”, 144. (in Russian).
21. **Popov A.P., 2008.:** Contact strength of gear mechanisms. – Nikolaev.: NUK. (in Russian).
22. **Popov A.P., Selivanovskyi V.Y., 2003.:** New method for calculating contact stresses in Novikov’s gearing. – Kharkov, Bulletin of National Technical University “KhPI”, (8), 82-87. (in Russian).
23. **Pysarenko G.S., 1979.:** Strength of materials. Textbook for high schools. Edit. by Pysarenko. – Kiev, 696 (in Russian).
24. **Ryzhov E.V., 1946.:** Contact stiffness of machine parts. CNIITMASH. – M. (in Russian).
25. **Shyshov V.P., Nosko P.L., Velychko N.I., Karpov A.P., 2009.:** Highly loaded helical gears. – Lugansk. Volodymyr Dahl East Ukrainian National University, 240. (in Russian).
26. **Strelnikov V., 2000.:** Determination of forces acting on flexible gear on wave generator side // Bulletin of Kharkov National Pedagogical University. - Kharkov. – Issue 109. 154-158.
27. **Strelnikov V., 2000.:** Interaction between wave generator and flexible gear // Advanced technologies and engineering systems. International edited volume – Donetsk: Donetsk State Technical University. – Issue 13. 191 – 199.
28. **Strelnikov V., Sevostyanov S., 1998.:** About energy losses in wave gearing meshing // Protection of metallurgical machines against failures. – Issue No.3. 237 – 241.
29. **Strelnikov V., Sevostyanov S., 1999.:** Determination of energy losses in wave-type gear reducers for metallurgical and mining equipment// Metallurgy and mining industry. – No.5. 102-105.
30. **Strelnikov V., Sevostyanov S., 1999.:** Determination of energy losses in wave-type gear reducers for metallurgical and mining equipment// Metallurgy and mining industry. – No.5. 102-105.
31. **Strelnikov V., Sevostyanov S., 2000.:** Determination of axial forces on wave gearing flexible gear // Bulletin of Kharkov National Pedagogical University. - Kharkov. – Issue 109. 159-172.

КРИТЕРИЙ НАГРУЗОЧНОЙ СПОСОБНОСТИ ЗУБЧАТЫХ ВИНТОВЫХ ПЕРЕДАЧ

Павел Носко, Валентин Шишов, Денис Ратов, Павел Филь, Андрей Лысенко

Аннотация. Представлены результаты исследований повышения нагрузочной способности и введен в рассмотрение один из важных критериев работоспособности передач — коэффициент плотности прилегания активных боковых поверхностей зубьев винтовых передач, характеризующий напряженное состояние зубьев винтовой передачи. Получены аналитические зависимости, однозначно определяющие теоретические начальные поверхности винтовых передач.
Результатами сравнительного анализа подтверждена прямая зависимость несущей способности зубчатой передачи от рассмотренного коэффициента плотности прилегания.
Ключевые слова: винтовая передача, коэффициент плотности прилегания, критерий нагрузочной способности, целевая функция, оптимизация, синтез, начальные поверхности, аксоиды.

The research of application and working process of fluid-jet elements and devices in planting techniques

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S u m m a r y. It is set on the basis of results of researches, that for the increase of the productivity and quality, declines of power - hungryness of work of sowing machines the association of seedmeter and system of synchronization (controls) is needed on one principle – discrete action, and rational basis for them is application of managing and power stream elements, and also active pneumatic distributive devices and pneumatic system of feed. On this basis fluid-jet is developed sowing systems for the ordinary and one seed sowing, allowing also to make the differentiated distributing of seed at sowing on technologies of exact agriculture.

K e y w o r d s : pneumonics, stream element, sowing system.

INTRODUCTION

The analysis of development of agro industrial complex branches testifies that further intensification of agricultural production, strengthening and perfection of material and technical base of agriculture, is impossible without the decision of on principle new technical tasks, which are allowing doing a high-quality transition in the increase of efficiency of production.

The traditional methods of agricultural technique production do not provide the increase of the labor productivity in proportion to expenses already, and also return of capital investments, and, at the same time, reduce efficiency of agricultural production. The state of Science and Technique presently allows finding on principle new technical decisions.

Therefore hunting of the new technological and technical decisions, based on modern achievements of Science and Technique and proper socio-economic requirements is required.

For a present times sharp expansion of researches is characteristic on creation of the complex systems of mechanization, control and operation in different fields of human activity. Investigation of it is stormy development of technique, applied at the construction of the systems of mechanization, control and automation.

Required at the same time, that some systems of mechanization, control and automation worked under trying conditions exploitations (at temperatures, different from normal, high accelerations, intensive oscillation and shock loadings, in the conditions of dust-ladenness, in the areas of radiation-damages etc.). New direction, getting the name, conforms to the put requirements «fluid-jet techniques».

Fluid-jet techniques or pneumatic automation is an area of automation, based on the use of operation of gas streams. A stream technique is analogical electronics in regard to both basic principles of construction and practical application. Devices and systems of stream technique do not have mobile details and utilized in computers, pumps of heart-lungs, control the system rockets, submarine boats, metal-cutting machine-tools etc. Fluid-jet elements works on in relation to small overfalls of pressure.

ANALYSIS OF PUBLICATIONS, MATERIALS AND METHODS

Fluid-jet techniques has a number of advantages before electronic. Its technique are maximum simple, lasting, cheap and reliable [7, 10, 13, 15, 19]. It is more reliable at high and low temperatures, and also at the high levels of radiation and more steady to the mechanical loadings and vibrations, that very important in a mobile technique [8, 9, 17, 26, 27].

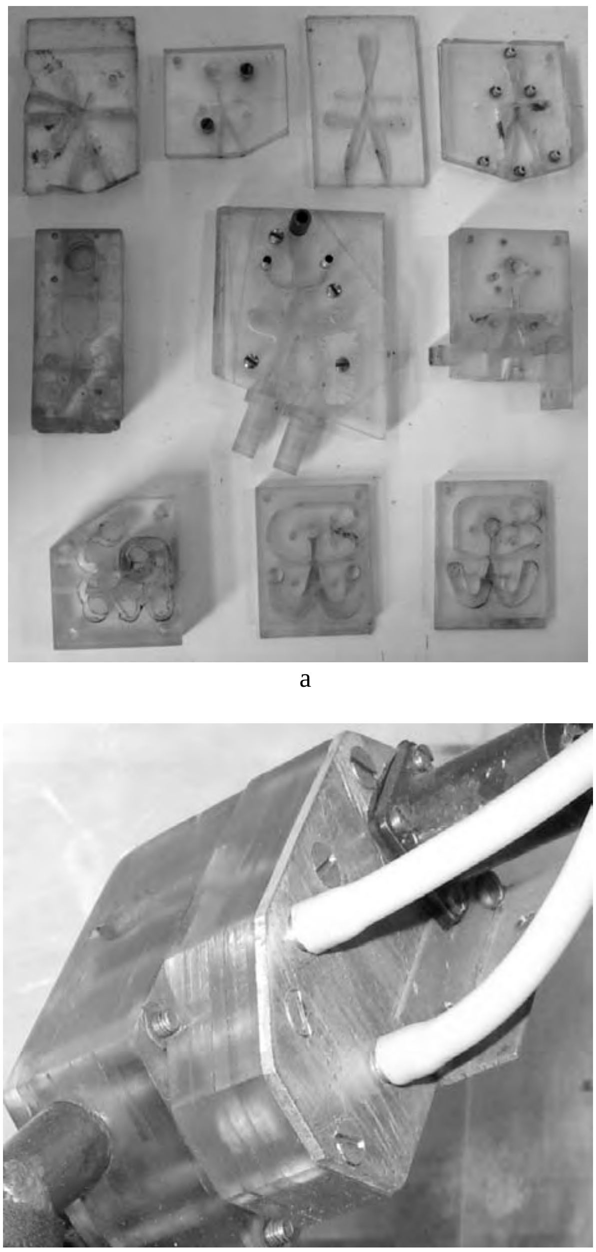
Fluid-jet techniques is comparative new direction of automation, but perspective of its application is in industrial, now already and in an agricultural engineer great enough. In this connection there are many interesting questions yet not found out to the end, namely – possibilities of more wideuse of fluid-jet elements and devices [28].

In this article possibilities of construction of not only control and calculable devices are examined from fluid-jet elements. The effects of co-operation of streams and streams can with success be used, for example, at the construction of different sensors, and also executive devices on the basis of power fluid-jet elements. However processes, what be going on in fluid-jet elements difficult and yet it is not enough studied [26, 28].

PURPOSE AND OBJECTIVES OF RESEARCH

Therefore the purpose of researches is development and application of power fluid-jet elements in relation to linear largenesses, and also construction on their basis of fluid-jet devices for the technique of AIK.

In agriculture information of fluid-jet device on the basis of power fluid-jet elements (Fig. 1) can be used on sowing of seed, the on principle new sowing systems are created as a result.



a

b

Fig.1. Power fluid-jet elements for sowing devices:
a – non-assembled, b - assembled

Hereupon, the task of researches is research of possibility of application of power fluid-jet elements in devices for sowing of seed of different crops.

Here take a place also the special tasks, related to the area of aeromechanics, in raising of which the use of fluid-jet elements resulted on sowing. It is a task of research of influence of scale effect and modes of motion of running environment on descriptions of fluid-jet elements, intended for work in the specialized sowing devices. For optimization of workings descriptions of stream elements of this type it is necessary not only, that were rational appearance correlations of sizes of chambers and ductings are taken, but must be optimum and correlations of sizes of pressure and expense in a tricking into channel and in the channel of management.

In addition, application of power stream elements restrains a temper in a number of reasons - by their insufficient efficiency, by absence of the developed model standards as dimension type rows etc. Therefore for the removal of these retentive factors additional researches are required.

THE MAIN SECTION. ANALYSIS OF RESULTS

As is generally known, the mortgage of high harvest at the low expenses of labour and facilities is timely and high-quality implementation of technological operations on till of agricultural crops in accordance with agrotechnical requirements, in particular case sowing. For this purpose the reliable, productive, high-quality workings sets of technique are needed for all of operations in technologies of till.

It is set at the study of the general state and prospects of development of the technical providing of production of food stuffs, that extensive approach in relation to traditional facilities and processes of mechanization is unable rationally to provide the increase of amount and quality of products and works in future, and also to the capacity requirement, adequate making progress capital investments, circulating cost and power expenses. The scopes of extensive growth are already obvious in the processes of traditional mechanization [1].

It is set in relation to a sowing technique, that as a result of work of scientific and inventor thought, directed mainly, on upgrading implementation of process of sowing, in different original principles of work and construction of the sowing systems and methods of their application were the past stopped up. Lately all more frequent began to appear decision on automation of process of sowing and to his control. However, analysing the algorithmic models of technological processes of existent constructions of seedmeters and systems for the different types of sowing and sorts of seed, it is possible to draw a conclusion, that stand the algorithm of work of these constructions requires in relation to heavy tolls energy, details and materials directed on overcoming of friction, although to energy, to necessary for realization of all of elementary operations of process of sowing, required far fewer.

Specific steel intensity, and, consequently, and incarnate energy of existent constructions of sowing machines also unjustified high. It entails a high cost, insufficient reliability of machines, relatively large labour intensiveness of tuning, adjusting and maintenance of machines, and also restrains creation and applying in industry of new kinds and constructions of machines.

Analogical position – with automation of technique in agriculture. The stake of the automated agricultural machines in the general volume of their output does not exceed 30%, the simplest controls and management separate workings organs are thus used, with the use of hydraulic, mechanical and mixed devices. Application, for example, of microelectronics in the systems of automation of separate groups of agricultural machinery is within the limits of 16% [21].

Further development of agriculture, its concentration, and consequently, and possibility of his intensification was put on an order-paper by on principle new requirements to forming of material and technical base and constructions of machines.

Therefore presently actual is a question of development and applying in industry of new, universal agricultural machines, including sowing, with minimum energy of production and exploitation, high reliability, automation of working process and possibility of its dirigibility on every area of moving of machine.

For realization of the put tasks new direction is offered is creation of seedmeters and devices on the basis of fluid-jet elements. It in an equal measure belongs both for the ordinary sowing and for sowing of vegetable crops, and also for the one seed sowing of the cultivated crops.

Fluid-jet sowing system plugs in itself fluid-jet seedmeter and device of synchronization of sowing at a speed of motion of machine.

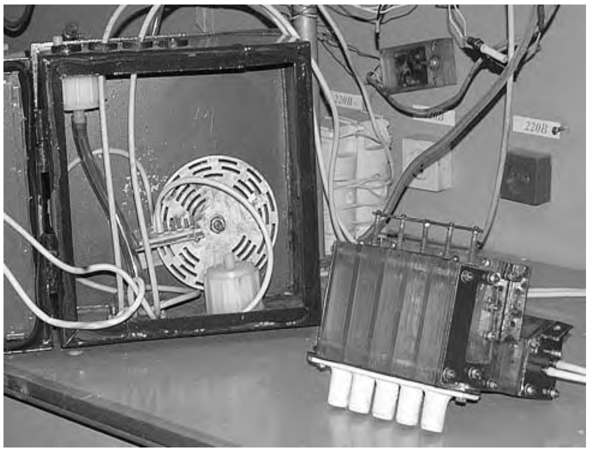
Notably here that a stream technique here can work both in the power mode and in the mode of management.

Development of the offered direction gives positive results presently. The standards of seedmeters are created without mobile details on the basis of power elements and devices of stream pneumatic automation for sowing of ordinary crops (Fig. 2, a, b).

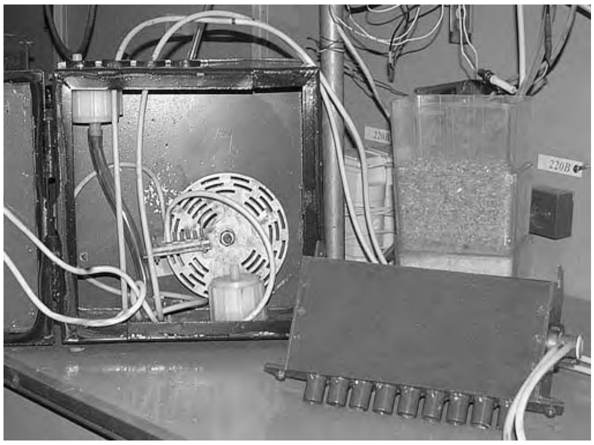
It is also set [6] on the basis of results of the conducted analysis of the systems**,** that for the high-quality sowing of seed of ordinary and cultivated crops the association of seedmeter and system of synchronization is needed on one principle – discrete action, and rational basis for them is the pneumatic system of feed. On this basis developed also fluid-jet sowing system, including a seedmeter with the drive of sowing drum (Fig. 3, a, b).

At comparative tests developed (ATV-7.02) and serial (N126.13.000) one seed seedmeters it is set that at the developed apparatus equitability seed better and injuring of sowing material absents. Laboratory-stand tests and field approbation of the sowing system rotined high quality of distributing of seed, proper agrotechnical requirements on seeder of seed-spacing.

Comparison of quality of work of apparatuss rotined that advantage on evenness of seed distribution ($\Delta\sigma$) - 2,7cm (for the seed of sunflower) and 4cm (for the seed of sugar beet, Fig. 4). Exactness of intervals at the developed and serial apparatuss accordingly compose: for the seed of beet - 100 and 83%, for the seed of sunflower - 100 and 85,4%. In addition, in times of researches at the developed apparatus, unlike serial, there was not injuring of sowing material, as air stream fully purged suckers from seeds.



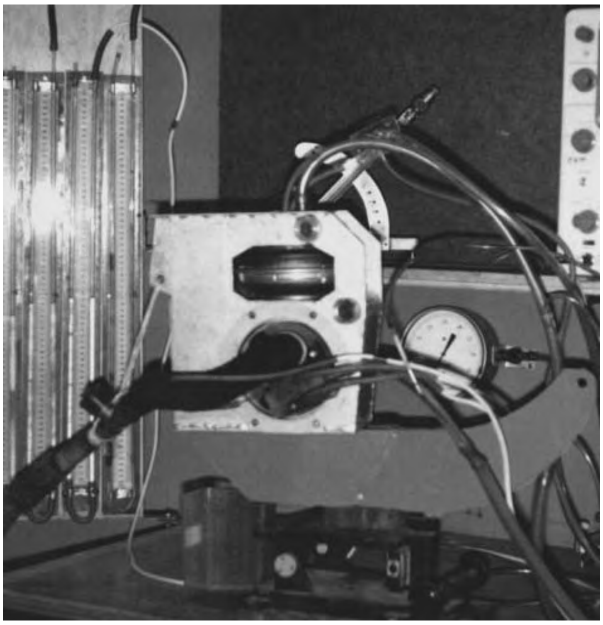
a



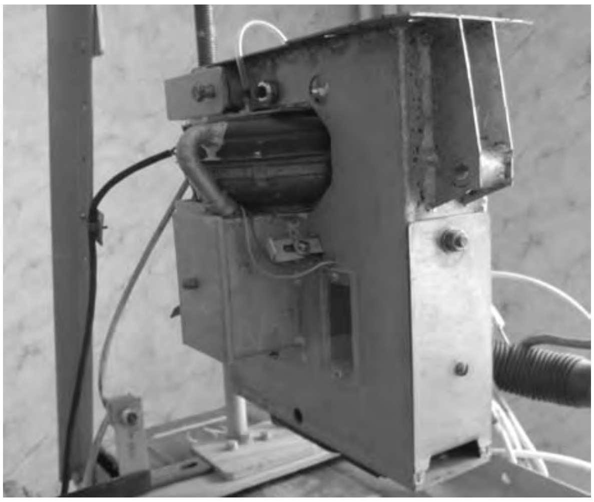
b

Fig. 2. Seedmeters on the basis of elements of pneumatic automation for sowing of ordinary crops: a - without moving details, for application in the systems of the centralized sowing (look at Fig. 6), b - for a layout chart there is a «apparatus - plowshare».

Laboratory-stand and production testing shows high quality of seed distribution (coefficient of variation 18,2-25,4% and exactness of intervals between plants growth 86,7-85%), which conform to the agrotechnical requirements to seeding-machine of precision sowing [4, 5].



a



b

Fig. 3. Seedmeters on the basis of elements of pneumatic automation for the one seed sowing: a – an apparatus is tested on stability of sowing, b – an apparatus is tested on evenness of sowing on a ribbon.

The sowing systems allow also to carry out the differentiated sowing and distributing of seed on an area in technologies of exact agriculture.

In agriculture sowing devices on the basis of fluid-jet elements can be also used on sowing of seed and mineral fertilizers, possibility of creation of on principle new universal planters appears as a result.

Seedmeters and sensor-based systems on the basis of elements of stream pneumatic automation can work in the laboured external environments (at high accelerations, intensive oscillation and shock loadings).

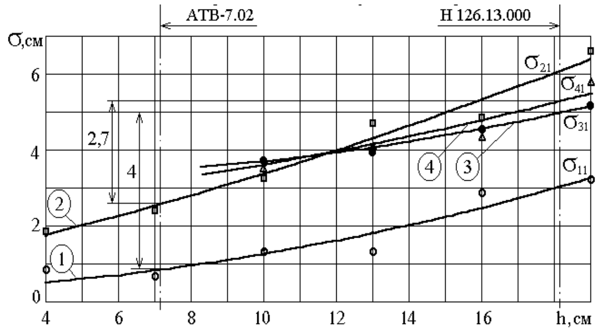


Fig. 4. Dependence of rejection σ of intervals from the height “h” upcast of seeds: 1 and 2 – sugar beet and sunflower for the developed apparatus, 3 and 4 – sugar beet and sunflower for a serial apparatus

Take a place and other advantages of the sowing systems on the basis of elements and devices of stream pneumatic automation, namely:

– high reliability and longevity,

– low enough cost of stuff details,

– simplicity of technology of making (casting, unsealing on a 3D-printer),

– firmness to aggressive influences of environment,

– small resource-demanding, diminutiveness and fast-acting,

– a minimum of mobile mechanical and ground details,

– absence of individual regulations during setting of norms of sowing,

– absence of mechanisms of drives and boxes of change of transmissions,

– absence of points of greasing,

– simplicity of tuning on the required norm of sowing,

– simplicity of alteration on different norms and charts of sowing,

– high quality of sowing is in all of range of norms and rates of movement,

– relatively small watts-in by the sowing system,

– possibility of complete automation and control of working process.

In more detail will be stopped for indexes, related to energy of process, namely on power, necessary for realization of working process. The comparative power analysis of work of seedmeters and systems shows that on driving to the action and working process of fluid-jet of seedmeters far less power expenses are required (Table 1). Comparison was made for the sowing machine of the ordinary sowing with the width of capture B=3m and number of plowshares n_p = 24.

Table 1. Power indexes of work of seedmeters (systems) with fluid-jet elements

Type of the sowing system	Brought power, Watt	
	specific (per plowshare)	per machine
Spool-type	125	3000
Pneumatic centralized	94,0	2256
Fluid-jet sowing apparatus (Fig.2,a)	25,0	600,0
Fluid-jet sowing apparatus (Fig.2,b)	12,0	290,0

It is known that for till of the proper culture, not including harvesters, it is necessary to have, at least, four separate machines, which have considerable steel intensity and cost, although work during a year the limited period. For example, the annual load of different planters makes 50…160 hours, cultivators - 270…350 hours etc. It is thus set [23] that there is 116,1MJ of the materialized energy per one kilogram of mass of agricultural machine, that corresponds a heating value approximately four litres of petrol.

Obviously, that is paid far of the materialized energy, which does not accomplish work. The search of ways and possibilities is therefore required if not avoidances, minimizations such of non-productive expenses of labour and facilities.

Also one of possible directions in researches is creation of universal machines, due to the stream sowing systems considered higher.

A machine (Fig. 5) can have a frame of cultivator with add-on sections, pneumatic station a drive of which can be hydraulic or mechanical from a tractor, general control the system sowing of seed or fertilizers and removable workings knots, set on it: capacities with seedmeters, and also closers: plowshares, cultivation paws and rolling up wheels, set on the add-on sections of cultivator [20].

Fig. 5. Universal machine «seeder - cultivator» on till of buckwheat.

Thus, effectiveness of circulating costs, consisting in the decline of power-hungryness of process of sowing, takes a place. Also as a result of replacement of two machines to one, universal, possibility of decline of expenses of the materialized energy or fixed assets is got.

It is necessary to mark that it only one of variants of application of fluid-jet of seedmeters and systems. There are other possibilities of development to this direction:

– application in «exact» agriculture is easy enough adaptation to the line change of norms of sowing,

– possibility of creation of not only universal machines of type «seeder - cultivator» but also universal module facilities of mechanization of till of corn and cultivated crops.

Also one of perspective directions there is development of the pneumatic centralized sowing systems (PCSS). Their application allows to promote the labour productivity on sowing and reduce resource-demanding of sowing machines. But in quality of sowing, in particular on the unevenness of sowing between plowshares they not always conform to the agrotechnical requirements [2, 14, 24].

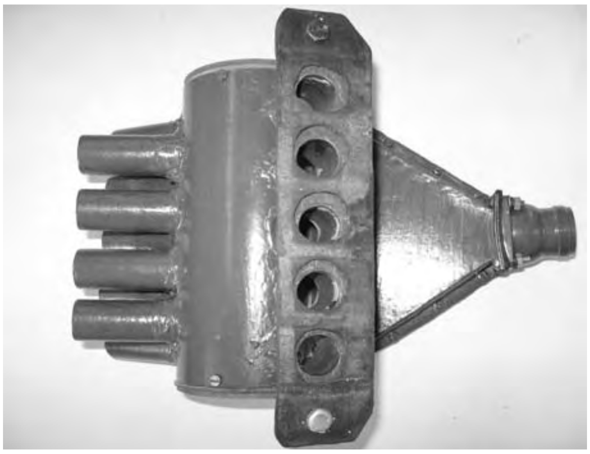
One of reasons of such position is that the делительные devices of known PCSS do not provide the required equitability the sown material. At inclinations and vibrations of sowing machine in the field terms there is displacement of stream of seed from the ax of symmetry of divizor and an unevenness yet more increases as a result, and the productivity of plants largely depends on an equitability seed on an area at sowing. It is known that on this reason a to 20% potential harvest is lost. The said higher belongs in an equal degree and to the mechanical sowing machines with spool-type seedmeters which do not provide the high-quality sowing and distributing of seed also, in particular case during work on slopes from - after moving of sowing material in the bunker of drills and as a result - uneven distributing on plowshares [18, 25].

It is set at a review and analysis of literary sources [3, 11, 12, 22], that the most applied distributors - both vertical and horizontal type - are passive, that negative affecting of gravity, aerodynamic and inertia forces seed in them not compensated no appearance. From here their high technological “sensitiveness” flows out on external and internal influences. It is inclinations, vibrations, pressure of air in the system, serve of seed, concentration of mixture et cetera. Besides the distributors of horizontal type possess failing, arising up from the known effect of “board of Galton” initially, that a bulk of the distributed seed is on the center of distributor (on an even area). It is therefore necessary to create and perfect distributive devices, providing a high equitability seed on plowshares and possessing a sufficient technological “rudeness”, eliminating in considerable a measure negative influence of external and internal factors.

It is set that this requirement can be executed, applying the active distributing of seed on сошникам. Constructions, where the active mechanical distributing, untwisting of stream of seed is used on sending, influence of centrifugal forces already known [16, 22]. But in them there are failings - presence of mobile details and regulations, considerable resource-demanding, complication in making.

Therefore for fluid-jet of seedmeters of the ordinary sowing a divider pneumo-jet device is offered, the process of distributing of seed in which takes a place at the rotation of materials - current of air with permanent speed into a cylinder under act of air-blast (Fig. 6).

On the lateral surfaces of cylinder, along his ax, ductings of input of seed, cart of pressure of feed and output ductings are located. Such chart of distributor does his active, compact and without locomotive parts. Thus the particles of material under the action of centrifugal force cuddle to the midwall of cylinder (vortical chamber) and move on it to the output. For normal work of distributor centrifugal forces must be more making gravity, displacing seed at inclinations, that reduces the degree of redistribution of sowing material because of inclinations and vibrations.



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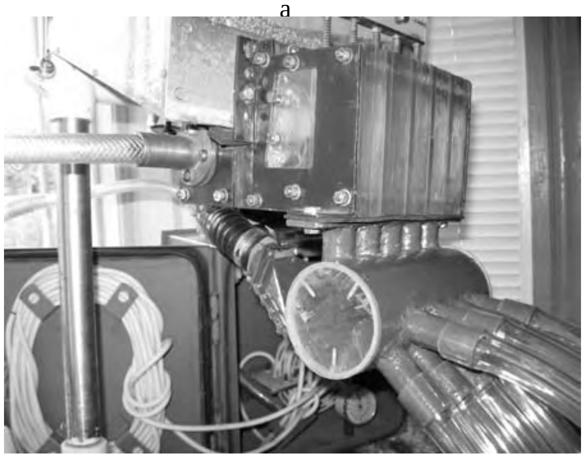

b

Fig. 6. Fluid-jet sowing apparatus with the fluid-jet distributor for the systems of the centralized sowing: a - distributor assembly, b - mounted on sowing apparatus

CONCLUSIONS

1. The new seeding system sowing machines and their components can be built on entirely new principles, the basics of which are laid in fundamental research in hydraulics, pneumatics and aerodynamics.

2. The elements of stream technique by comparison to the element base of electronics are more cheap, reliable and

simple. Therefore mechanization and automation of production processes on the basis of element base of fluid-jet technique topical in such areas of national economy, which are characterized the complicated and non-stationary terms of work (enhanceable gassed, humidity, vibrations, presence of aggressive environments), – namely in agriculture, to light and food industry et al.

3. Efficiency of technological process of sowing of seed rises with the use of seedmeters on the basis of executive and managing elements of stream pneumatic automation, and also stream distributive devices.

4. On the basis of the use of force and controls the pneumatic jet automatic seeding is possible to build devices and systems for both ordinary seed crops, and for seeding row cultivated crops.

5. Evenness of sowing of distributing of seed and plants is thus improved on an area at a simultaneous decline energy - and to resource-demanding of sowing machines.

6. The use of the new sowing systems on the basis of elements and devices of fluid-jet technique opens possibility of creation of universal multi-purpose machines, and also universal module facilities of mechanization of till of corn and cultivated crops.

REFERENCES

1. **Antoniuc L., 1983.:** National task. – M.: Young guard. – 191. (in Russian).
2. **Astakhov V., 1997.:** Pneumatic systems of centralized seed // Tractors and farm machinery. – №9. – 12-15. (in Russian).
3. **Astakhov V., 1999.:** Analysis dividers for pneumatic seed drills // Tractors and farm machinery. – №5. – 31-34. (in Russian).
4. **Belodedov V., Nosko P., Fil P., Stavitskiy V., 2007.:** Parameter optimization using coefficient of variation of intervals for one-seed sowing apparatus with horizontal disk during maize seeding. TEKA Commission of Motorization and Power Industry in Agriculture, Vol.VII, 31-37.
5. **Belodedov V., Nosko P., Boyko G., Fil P., Mazneva M., 2013.:** Parameter optization of dosator for technique cultures on the quantity intervals, close by to calculation // TEKA, Commission of Motorization and Power Industry in Agriculture, Vol.13, № 4, Lublin, 18-24.
6. **Burkov Y., Goryunov V., Diachkov E., 2009.:** Use of inkjet technology for seed drills // Sensors and Systems. – №3. – 30-32. (in Russian).
7. **Chernyshev V., 1966.:** Fluids pnevmogidroavtomatik. – M.: Mir. – 384. (in Russian).
8. **Chulkov G., 1983.:** Achievements pnevmoavtomatik – for agriculture // Mechanization and electrification of agriculture. – №1. – 3-39. (in Russian).
9. **Chulkov G., 1985.:** Scientific – technological advances - practical use // Mechanization and electrification of agriculture. – №3. – 23. (in Russian).
10. **Denisov A.**, **Nagornij B., 1978.:** Pneumatic and hydraulic equipment automation. – M.: High school. – 214. (in Russian).
11. **Eikel G., 1995.:** Three air seeders compared // Profi. Journal of Agricultural Technology. – №7. – 22-27.
12. **Eikel G., 1997.:** Pneumatics in green // Profi. Journal of Agricultural Technology. – №9. –30-34.
13. **Elimelech**, I., **Sidorkin Y., 1972.:** Inkjet automatic (pnevmonika). – L.: Lenizdat. – 212. (in Russian).
14. **Gainanov H., Zemdihanov M., 1991.:** Design and rationale of parameters flow dividers seed material // The study of machines and workers to cultivate and harvest of potatoes, vegetables and grains. Collection of scientific papers. – Nizhny Novgorod. – 58-62. (in Russian).
15. **Kassimov A., 2010.:** The development of pneumatic automation // Proceedings of the conference "Hardware and software systems management, control and measurement" of the Institute of Control Sciences RAN. – M. – 640-652. (in Russian).
16. **Khegai P., 1983.:** Justification of the concept of centralized seed corn planter // Improving the process of combining soil and crop. Collection of scientific papers. – №99. – M. – 35-42. (in Russian).
17. **Kolbikov L., 1972.:** Automatic control of the amount of funds jet logic // Tractors and farm machinery. – №12. – 37-38. (in Russian).
18. **Korolenko K., Donets** S., **Skorodumov A., 1971.:** The mechanization of planting crops on slopes // Mechanization and electrification of agriculture. – №2. – 15-17. (in Russian).
19. **Korotkov F., 1972.:** Elements and devices fluidics. – M.: Energija. – 98. (in Russian).
20. **Koval V., 1998.:** The basic patterns of development and methods to improve agricultural technology // Scientific bulletin LNAU. Series Technical sciences. – Lugansk. – №2/4. – 23-29. (in Russian).
21. **Ksenevich I., 1989.:** Automation and electronization - the way of intensification of agricultural production // Tractors and farm machinery. – №6. – 9-11. (in Russian).
22. **Lyubushko N., Zvolinskyi W., 1999.:** The development of structures of distribution systems for

central air drill seeding // Tractors and farm machinery. – №2. – 20-23. (in Russian).

23. **Mindrin A., 1996.:** The energy equivalent of food production // International Journal of Agriculture. – №2. – 42-45. (in Russian).
24. **Nasonov V., 1984.:** Justification process of planting and dosing parameters of working bodies wide field of grain sowing drills with a centralized system. - The Abstract. – Glevaha. – 17. (in Russian).
25. **Sysolin P., Lykkei**, A., **Ivanitsa K.**, **Shilo A., 1973.:** The study sowing drills SZ-3,6 // Design and technology of production of agricultural machinery. – №3. – Technika. – 47-51. (in Russian).
26. **Zalmanzon L., 1978.:** Specialized aerohydrodynamic automatic control system. – M. – Science. – 464. (in Russian).
27. **Zalmanzon L., 1985.:** Conversations about automation and cybernetics. – M.: Science. – 416. (in Russian).
28. **Zalmanzon L., Danko Y., 1974.:** Jet models of the elements and devices of automation systems. – 5th “Jablonna”, Fluidics Conference, Preprint, Budapest. – 57-88. (in Russian).

ИССЛЕДОВАНИЕ ПРИМЕНЕНИЯ И РАБОЧЕГО ПРОЦЕССА ПНЕВМОСТРУЙНЫХ ЭЛЕМЕНТОВ И УСТРОЙСТВ В ПОСЕВНОЙ ТЕХНИКЕ

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Аннотация. На основании результатов исследований установлено, что для повышения производительности и качества, снижения энергоемкости работы посевных машин необходимо объединение высевающего аппарата и системы синхронизации (управления) на одном принципе – дискретного действия, а рациональной основой для них является применение управляющих и силовых струйных элементов, а также активных пневматических распределительных устройств и пневматической системы питания. Исходя из этого разработаны пневмоструйные высевающие системы для рядового и однозернового посева, позволяющие также производить дифференцированное распределение семян при посеве по технологиям точного земледелия.

Ключевые слова: пневмоника, струйный элемент, высевающая система.

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Investigation of the process of vibrorheology of cement concrete solutions with the external source of dynamic effect

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Summary. In the article in the frames of the semi-phenomenological approach there have been formulated the main requirements to the mathematical model of movement of the mortar and its interaction with the filler in the planar case, when the external variable force field of the excitation has a turbulent component. It is given the strict interpretation of the influence of the parameters of the model under investigation on the process of vibrorheology of cement concrete solutions and was formulated the criterion of its effectiveness.

Key words: vibrorheology of cement concrete solutions, turbulence, swirling, tensors of the first and second viscosity.

INTRODUCTION

The modern mathematical constructions as according to the theory of vibrorheology of cement concrete solutions [2-5, 7, 8, 11, 15, 17-20] are based on the one and the same unique approach the initial position of which is the consideration of some concrete form with fixed geometry filled with multi component media in the type of visco-plastic fluid with the filler which is under the conditions of periodic vibro excitation within the certain period of time [0, T]. The description of the movement of working material is a contact problem taking into account the boundary conditions [12, 13]. It is easy to see that the exact solution of the problem of compression of cement solution provides its deterministic nature, which is a consequence of the complete task of the behavior of working environment of shuttering form on its boundary. But it is not possible for even the simplest geometric configuration of the border. Thus, the creation of the theory of the vibrorheology in a separately taken shuttering form does not lead to the description of the general laws of interaction of cement solution with the filler which would bring the research process to certain technological solutions and recommendations, including the ability to control the compaction process based on the combination of the values of the constructive parameters of the problem. We cannot count on a clear prospect of application research based on effective technology without a new consequent systematic approach to the theory vibrorheology. This situation underlines the chronic weakness of the previously mentioned concept of the vibrorheology (and in some cases the use of research schemes which unacceptable), improving the design of the shuttering form when done as the result of analysis of numerous experimental data by the method of trials and errors without stringent performance criteria and in the absence of theoretical results of a general character.

STATEMENT OF THE PROBLEM

Let's consider a plane task associated with the description of the process of the medium of cement solution filling at the initial time t = 0 in the state of the rest all Euclidean plane R2 with Cartesian rectangular coordinate system X0У. At time t = 0 in the cement solution starts hydration and hydrolysis of the constituents of cement clinker – tricalcium silicate and tricalcium aluminate with the formation respectively dicalcium hydrosilicate, calcium hydroxide and tricalcium hydroaluminate:

$$3CaO\cdot SiO_2+nH_2O=2CaO\cdot SiO_2\,(n-1)H_2O+Ca(OH)_2, \quad (1.1)$$

$$3CaO\cdot A\ell_2O_3 + 6H_2O = 3CaO\cdot A\ell_2O_3\cdot 6H_2O, \quad (1.2)$$

which are gradually moving from one colloidal state to the state of crystallization and, henceforth, to the state of cement stone.

Here and further we define two states of working media: a-state (a priori state of rest) and e-state (state of excitation). It should be marked that the medium of cement solution as visco-plastic fluid transfers from homogeneous and isotropic a-state into e-state («a – e» transfer) with the help of external variable plane-parallel field $\vec{F}(N,t)$, $N(x,y)\in R^2$ which is switched on at the moment of time t = 0 and which is a general model of vibro excitation that is the formation of colloidal medium and as the consequence of chemical reactions (1.1) and (1.2), and e-state begins at the moment of time t = 0.

The term general model should be understood in the sense that at the special task of vibro field $\vec{F}(N,t)$ can be studied the plane task and in restricted simply connected field $G\subset R^2$. a-state and e-state will be characterized by their sets of the parameters which we'll fix by the indexes correspondingly «a» and «e». For example, the mass surface density of the cement solution (without filler) let's denote by the symbol $\rho_a = m_{1a}n_{1a} + \rho'_a$, where m_{1a} – mass of a separate cement lobe, n_{1a} – surface density of the particles of cement, ρ'_a – surface density of water in the solution etc.

The statement of the problem «a – e» of transfer of the medium of cement solution is reduced to the following:

- to explore the response of the system under consideration at the model level viscous-plastic fluid to an external alternating field $\vec{F}(N,t)$,
- and to consider the process of the interaction of massive flows appearing and filled as the main theoretical and technological working mechanism with the aim of definition of effective viscosity of concrete solution and optimal parameters of the external field of excitation for obtaining maximum density of modified concrete.

It should be marked that full description of the response of working medium to the effect of force vibro field $\vec{F}(N,t)$ should be conducted in the terms of indexes $\{\rho_e(N,t), \vec{\pi}_e(N,t), \varepsilon_e(N,t)\}$, where $\rho_e(N,t)$ – surface density of a mass, $\vec{\pi}_e(N,t)$ – surface density of impulse, $e_e(N,t)$ – surface density of an energy. In this case the main parameter is the mass density $\rho_e(N,t)$, through which are easily expressed the other parameters. This is due to the fact that the movement of the cement solution in the presence of an external field $\vec{F}(N,t)$ is compulsory and, therefore, is not the nature of the relaxation. Moreover, dissipative processes in the moving working medium are due only to mechanical sticking of the particles during the two-, three-, and, in general, n-particle sticking with the formation of aggregated particles as the centers of the further relaxation process (crystallization) are already in the absence of an external excitation field. This is so-called – internal friction which is the effect of intermolecular interaction and is associated with the classical transport phenomena in liquids and gases, which can be interpreted by the language of the laws of conservation of mass, impulse and energy, and induced by swirling properties of the force field $\vec{F}(N, t)$. It should be noted that the presence of turbulence in the working medium leads to a tensor-like distribution of the velocities of two components of cement solution: viscous-plastic liquid of cement particles and liquid vortex flows.

MATERIALS AND RESULTS OF RESEARCH

1. Now we formulate the basic terms and principles (system of axioms) of construction of model of the process under research.

A1. Cement solution with the filler in a-state fills the entire Euclidean plane R2: cement solution and k-component filler have surface density of a mass correspondingly:

$$\rho_a = \rho_{1a} + \rho'_a, \quad \rho_{1a} = m_{1a} n_{1a} \qquad (1.3)$$

and

$$\tilde{\rho}_a = \sum_{i=2}^{k+1} m_{ia} n_{ia}, \qquad (1.4)$$

where: m_{ia}, n_{ia} – mean mass of a particle and surface density of i-components correspondingly, i = 2, 3,... .

A2. At the moment of time t = 0 switches on the external variable plane parallel force field providing «a – e» transfer and having surface density of type

$$\vec{F}(N, t) = \vec{F}_{s.p.}(N, t) + \vec{F}_{r.d.}(N, t), \qquad (1.5)$$

where: $\vec{F}_{s.p}(N, t)$ – solenoidal potential field, for which, with the exception of not more than the estimated number of points, $\operatorname{div}\vec{F}_{s.p}(N, t) = 0$ and $\operatorname{rot}\vec{F}_{s.p}(N, t) = 0$, and $\vec{F}_{r.d.}(N, t)$ is a component of the turbulent with $\operatorname{rot}\vec{F}_{r.d.}(N, t) \neq 0$ and $\operatorname{div}\vec{F}_{r.d.}(N, t) \neq 0$.

It is easy to see that the surface density of forces $\vec{F}_{r.d.}(N, t)$ – is the vector random variable defined on some initial probable space {Ω, U, P}, where Ω = {ω} space of elementary events ω, U = {A} – algebra (or σ-algebra) of some event A и P = P (A) – probability function. Choosing the probability space is associated with the features of the mechanism of vibro excitation and will not be explored in this work. The action of vibro field (1.5) defines only dynamic properties of cement concrete solution and does not affect the physical chemical processes of its modification.

A3. The presence of external force field in the structure (1.5) of turbulent component $\vec{F}_{r.d.}(N, t)$ contributes to the emergence of vortex flows in the cement mass $\overline{m}_e(t)$ and surface density $\overline{n}_e(N, t)$, which is random function. Surface density of a mass of vortex flows and the density of flow of mass of vortex flows are respectively:

$$\overline{\rho}_e(N, t) = \overline{m}_e(t)\, \overline{n}_e(N, t), \qquad (1.6)$$

$$\vec{\overline{\pi}}_e = \overline{m}_e(t)\, \overline{n}_e(N, t)\, \vec{w}_e(N, t), \qquad (1.7)$$

where: $\overline{n}_e(N, t)$ – density of the number of vortex flows in the point N = N(x, y),

$\vec{w}_e(N, t)$ – the rate of the flow of vortex flows in the point N = N(x, y).

Let's define the average index of the density $\overline{n}_e(N, t)$ using dynamic limiting transition:

$$\overline{n}_e(t) \equiv \langle \overline{n}_e(N, t) \rangle \overset{\text{def}}{=} \lim_{S\to\infty} \frac{1}{\mu(S)} \iint_S \overline{n}_e(N, t)\, d\sigma_N, \qquad (1.8)$$

where: $d\sigma_N = dxdy$,

$\mu(S)$ – the square of simply connected field $S \subset R^2$.

Thus, the dynamic density of vortex flows $\overline{n}_e(t)$ can be considered as a random process with the discrete or continuous parameter t, $t \geq 0$. Let's note that here the meaning of the transition boundary (1.8) is to eliminate the influence of the boundary and thereby meet the requirements of the basic problem.

A4. The vortex flow is the unification at one point $M_0(x_0, y_0) \in R^2$ of the vortex flow with the intensity E(t) and virtual flow with the intensity H(t), so that:

$$H(t) = \lambda\, E(t), \quad t \geq 0, \quad 0 < \lambda < 1, \qquad (1.9)$$

where: λ – coefficient of a mass dispersion in the ordinary liquid vortex flow.

The ratio (1.9) defines the specifics of the vortex flow: if $\mathrm{rot}\,\vec{F}_{r.d}(M_0, t) \neq 0$, then the circulation of the vector field $\vec{F}_{r.d.}(N, t)$ leads with the effect of inner friction in the cement solution to the dispersion of the mass in the ordinary liquid with the intensity H(t), which is equivalent to the action of the flow at the point $M_0(x_0, y_0)$. The point $M_0(x_0, y_0)$ moves in the cement solution along the line of the flow of the function $\vec{F}_{s.p.}(N, t)$, coinciding with the line of the break of the function $\vec{F}_{r.d.}(N, t)$, on the pass:

$$x_0 = x_0(t), \quad y_0 = y_0(t), \quad t \geq 0. \qquad (1.10)$$

A5. In e-state the cement solution is considered as two liquid medium with the qualitatively different components.

The first component is the cement liquid consisting of cement particles with the mass $m_{1e}(t)$ and the ordinary liquid and has the surface density of a mass $\rho_e(N, t)$ and the density of the flow of a mass $\vec{\pi}_e(N, t)$ as:

$$\rho_e(N, t) = \rho_{1e}(N, t) + \rho'_e(N, t), \qquad (1.11)$$

$$\vec{\pi}_e(N, t) = [\rho_{1e}(N, t) + \rho'_e(N, t)]\,\vec{v}_{1e}(N, t), \qquad (1.12)$$

where: $\rho_{1a}(N, t) = m_{1e}(t)\, n_{1e}(N, t)$ – the surface density of a mass of cement particles,

$n_{1e}(N, t)$ – the surface density of the number of cement particles,

$\rho'_e(N, t)$ – the surface density of the ordinary liquid,

$\vec{v}_{1e}(N, t)$ – the rate of cement liquid at the point $N = N(x, y)$.

And the second component is the liquid of vortex flows with the surface density of a mass (1.6) and surface density of the flow of a mass (1.7). It should be noted that the presence of the turbulence in the working medium leads to the tensor type of the distribution of the rates of two component cement solution: viscous plastic liquid of cement particles and the liquid of vortex flows. The dependence between the rates $\vec{v}_{1e}(N, t)$, $\vec{w}_e(N, t)$ and the external force field $\vec{F}(N,t)$ will be defined below.

A6. The action of solenoidal potential field $\vec{F}_{r.d.}(N, t)$ promotes the emergence of two virtual force solenoidal potential vector fields in this model $\vec{G}^{(1)}_{s.p.}(N, t)$ и $\vec{G}^{(2)}_{s.p.}(N, t)$, which accordingly define the dynamics of the first and the second components correspondingly that is viscous plastic liquid and the liquid of vortex flows.

A7. The transfer of the mass of two components cement liquid in the presence of the external force field $\vec{F}(N, t)$ (1.5) with turbulent constituent $\vec{F}_{r.d.}(N, t)$ takes place along the lines of the flow of force solenoidal potential field $\vec{F}_{s.p.}(N, t)$ with the rate:

for the first component with the rate:

$$v_{1ei}(N,t) = \int_0^t \iint_{R^2} \varepsilon^{(1)}_{ik}(N - P, t - \tau) F_{s.p.k}(P, \tau)\, d\tau d\sigma_P, \qquad (1.13)$$

for the second component moving along the line of the flow of the field $\vec{G}^{(2)}_{s.p.}(N, t)$ or $\vec{F}_{s.p.}(N, t)$ on the pass (1.10) of the line of turbulence for which $\mathrm{rot}\,\vec{F}_{r.d}(N, t) \neq 0$, with the rate:

$$w_{ei}(N,t) = \int_0^t \iint_{R^2} \varepsilon_{ik}(N - P, t - \tau) F_{s.p.k}(P, \tau)\, d\tau d\sigma_P. \qquad (1.14)$$

Bivalent tensors $\varepsilon^{(1)}_{ik}(N, t)$ и $\varepsilon_{ik}(N, t)$, which are in the formulas (1.13) and (1.14), should be considered as the coefficients of effective viscosity in two component cement solution.

A8. Let's consider that the radius (r) of vortex flow is distributed according to normal law with expectation function α = 0 and root-mean-square deviation σ = σ(t), which is the function of the parameter (t), that is the density of the probability of random variable (r) is equal:

$$p_{0;\sigma}(r) = \frac{r}{\sigma^2(t)} \cdot e^{-\frac{r^2}{2\sigma^2(t)}} . \qquad (1.15)$$

The action of vibro field $\vec{F}(N,t)$ takes place in the time intervale [0, T], where T – the time of technological functionality of colloidal medium when the dispersion of the mass of ordinary liquid stops and starts the process of crystallization of gel with dicalcium hydrosilicate, calcium hydroxide and tricalcium aluminate hydrate. If the critical mass of colloidal cement particle is equal to $m_{1kp} = \beta_1 m_{1a}$, $\beta_1 > 1$, then the index of the parameter τ_{tec} – technological time of modification of cement solution in the presence of vibro field $\vec{F}(N,t)$ is in equations

$$m_{1kp} \equiv m_{1e}(\tau_{tec}) = \beta_1 m_{1a} . \qquad (1.16)$$

Then the criterion of the effectiveness of the process of the modification of cement solution in the presence of vibro field $\vec{F}(N,t)$, is:

$$\tau_{tec} \le T, \qquad (1.17)$$

where: τ_{tec} – solution of equations (1.16).

A9. The presence of the filler does not affect the mechanical, physical and chemical technological parameters of vibrorheologic process of conversion of cement solution into the state of cement stone.

2. Let's consider further the semi-phenomenological model of vibrorheology of cement concrete solution.

We'll form based on the axioms A1-A9 formulated in the previous item, the mathematical mechanism of the research of the contact task of mutual movement of the medium of cement solution and the filler in the presence of the external vibro field $\vec{F}(N,t)$. First of all, let's find the actual expression of the surface density of a mass of cement solution (1.3) in a-state. For a mass m_{1a} of a separate cement particle we'll have:

$$m_{1a} = \frac{4}{3}\pi r_{1a}^3 \gamma_{1a} , \qquad (2.1)$$

where: r_{1a} – average radius of cement particle,

γ_{1a} – volume mass density of cement lobe.

Thus, the surface density of a mass ρ_{1a} of cement particles in в a-state is equal to:

$$\rho_{1a} = m_{1a} n_{1a} = \frac{4}{3}\pi r_{1a}^3 \gamma_{1a} n_{1a} . \qquad (2.2)$$

Taking into account (2.2) for the surface density of a mass ρ'_a of ordinary liquid in a-state we get:

$$\rho'_a = \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{1a}^3 \right) \gamma'_a n_{1a} , \qquad (2.3)$$

where: γ'_a – volume density of a mass of ordinary liquid in a-state.

On the base of the formulas (2.2) and (2.3) the surface density of a mass of cement solution (1.3) in a-state will be:

$$\rho_a = \rho_{1a} + \rho'_a = \\ = \frac{4}{3}\pi r_{1a}^3 \gamma_{1a} n_{1a} + \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{1a}^3 \right) \gamma'_a n_{1a} . \qquad (2.4)$$

Further in e-state the surface density of a mass of cement solution $\rho_e(N,t)$, taking into account the formulas (1.6) and (1.11), is defined by the equity:

$$\rho_e(N,t) = \rho_e(N,t) + \overline{\rho}_e(N,t) = \\ = \overline{m}_e(t)\, \overline{n}_e(N,t) + m_{1e}(t)\, n_{1e}(N,t) + \rho'_e(N,t). \qquad (2.5)$$

Making (2.5) dynamic boundary transfer (1.8), we get:

$$\langle \rho_e(N,t) \rangle = \langle \rho_e(N,t) \rangle + \langle \overline{\rho}_e(N,t) \rangle , \qquad (2.6)$$

or

$$\rho_e(t) = \rho_e(t) + \overline{\rho}_e(t) = \\ = m_{1e}(t)\, n_{1e}(t) + \rho'_e(t) + \overline{m}_e(t)\, \overline{n}_e(t). \qquad (2.7)$$

If in (1.5) is absent the turbulent component $\vec{F}_{r.d.}(N,t)$, that is $\vec{F}_{r.d.}(N,t) \equiv 0$, then the formula (2.7) will be:

$$\rho_e(t) \equiv \rho_e(t) = m_{1e}(t)\, n_{1e}(t) + \rho'_e(t)\,. \qquad (2.7')$$

Let's mark that in the formula (2.5) the indexes $m_{1e}(t)$, $n_{1e}(N,t)$, $\rho'_e(N,t)$, have determined character and the index $\overline{n}_e(N,t)$ is the random function. First we find the mass $\Delta\rho'(t)$ of ordinary liquid dispersed by the vortex flow. As the geometric features of the vortex flow do not depend on its state on the plane R^2, then for the simplicity of subsequent constructions we place the vortex flow into center of coordinates $O(0,0)$, supposing its radial symmetry. We find with the help of the formula (1.15) the average radius $\bar{r}$ of vortex flow:

$$\begin{aligned} \bar{r} = \bar{r}(t) &= \int_0^\infty r p_{0;\sigma}(r)\, dr = \\ &= \frac{1}{\sigma^2(t)} = \int_0^\infty r^2\, e^{-\frac{r^2}{2\sigma^2(t)}}\, dr = \sqrt{\frac{\pi}{2}}\, \sigma(t). \end{aligned} \qquad (2.8)$$

We calculate the circulation of vortex point (Fig. 1):

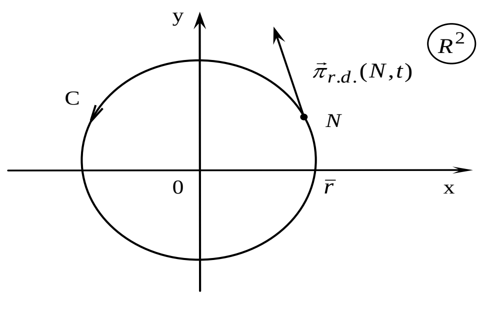

Fig. 1. Vortex flow is in the center of coordinates and average radius $\bar{r}$

$$E(t) = \oint_C \left(\vec{\pi}_{r.d.}(N,t), d\vec{s}_\tau\right), \quad C: \quad x^2 + y^2 = \bar{r}^2\,, \qquad (2.9)$$

where: $\vec{\pi}_{r.d.}(N,t)$ – the density of the flow of mass of vortex is equal to:

$$\begin{aligned} \vec{\pi}_{r.d.}(N,t) &= \left[m_{1e}(t)\, n_{1a} + \rho''_e(t)\right] \vec{v}(N,t), \\ \vec{v}(N,t) &= K(N,t)\, \vec{F}_{r.d.}(N,t), \end{aligned} \qquad (2.10)$$

where: $K(N,t)$ – coefficient of turbulence of field $\vec{F}_{r.d.}(N,t)$,

$\rho''_e(t)$ – surface density of a mass of ordinary liquid supposing that $\overline{n}_e(t)$ is equal to zero.

Inserting (2.10) into (2.9), we get:

$$\begin{aligned} E(t) = m_{1e}(t) \oint_C n_{1a}\, K(N,t) \left(\vec{F}_{r.d.}(N,t), d\vec{s}_\tau\right) + \\ + \oint_C \rho''_e(t)\, K(N,t) \left(\vec{F}_{r.d.}(N,t), d\vec{s}_\tau\right). \end{aligned} \qquad (2.11)$$

Taking into account that $d\vec{s}_\tau = \vec{s}_0\, ds$,

where: $\vec{s}_0$ – unit vector of tangent line to the wire circuit C in the point N, $\vec{F}_{r.d.}(N,t) \parallel \vec{s}_0$, on the base of (2.11) we get:

$$\begin{aligned} E(t) = m_{1e}(t)\, \bar{r}(t) \int_0^{2\pi} n_{1a}\, K(N,t) \left| \vec{F}_{r.d.}(N,t) \right| d\varphi + \\ + \bar{r}(t) \int_0^{2\pi} \rho''_e(t)\, K(N,t) \left| \vec{F}_{r.d.}(N,t) \right| d\varphi. \end{aligned} \qquad (2.12)$$

Thus, mass $\Delta\rho'(t)$ of ordinary liquid dispersed by the vortex flow is equal to:

$$\begin{aligned} \Delta\rho'(t) &= \lambda \int_0^t E(\tau) d\tau = \\ &= \lambda \int_0^t \int_0^{2\pi} \left[m_{1e}(\tau)\, \bar{r}(\tau)\, n_{1a} + \bar{r}(\tau)\, \rho''_e(tm)\right] K(N,\tau) \times \\ &\times \left| \vec{F}_{r.d.}(N,\tau) \right| d\tau\, d\varphi, \end{aligned} \qquad (2.13)$$

$$\bar{r}(t) = \sqrt{\frac{\pi}{2}}\, \sigma(t), \quad t \in [0, T]. \qquad (2.14)$$

Let's formulate the analytical scheme for finding indexes $m_{1e}(t)$ and $n_{1e}(t)$. It should be noted that the index $m_{1e}(t)$ has two constituents: colloidal particle and residual (relict) initial cement particle.

Further we give the following definition. *Coefficient of the initial hydration* $k_{i.g.}$ is called the index which is equal to the relative volume of cement lobe which comes into reaction of hydration with the ordinary liquid (water) that is:

$$k_{i.g.}=\frac{\frac{4}{3}\pi r_{1a}^3-\frac{4}{3}\pi r_{rem}^3}{\frac{4}{3}\pi r_{1a}^3}=1-\frac{r_{rem}^3}{r_{1a}^3}, \qquad (2.15)$$

where: r_{rem} – radius of relict cement particle.

If the coefficient of initial hydration $k_{i.g.}$ stated *a priori*, the radius r_{rem} of relict cement particle on the base of (2.15) is defined by the equation:

$$r_{rem}=r_{1a}\sqrt[3]{1-k_{i.g.}}\,. \qquad (2.16)$$

Coming back to the equation (1.16), we make the following refinement regarding the interpretation of the parameter τ_{tec} – technological time of modification of cement solution in the presence of vibro field: the parameter τ_{tec} defines time interval within which takes place the modification of initial cement lobe till relict state with the account of the criterion of the effectiveness (1.17).

In this connection we introduce the index $m_{1e}(t)$ as:

$$\begin{aligned}m_{1e}(t)=&\frac{4}{3}\pi\left[r_{col}^3(t)-r_{1e}^3(t)\,\eta(\tau_{tec}-t)-\right.\\&\left.-r_{1e}^3(\tau_{tec})\,\eta(t-\tau_{tec})\right]\gamma'_a+\frac{4}{3}\pi\, r_{1a}^3\,\gamma_{1a},\end{aligned} \qquad (2.17)$$

where: $r_{col}(t)$ – radius of colloidal cement particle,

$r_{1e}(t)$ – radius of residual primary cement particle at the moment of time t, $t\in[0,T]$,

$\eta(t)$ – Heaviside function.

The obvious expression of the indexes $r_{col}(t)$ and $r_{1e}(t)$ in (2.17) can be found taking into account the following concepts. The formation of colloidal cement particle takes place as the sequence of chemical reactions of hydrolysis (1.1) and (1.2), thus, it is correct the statement that the indexes $r_{col}(t)$ and $r_{1e}(t)$ conform correspondingly the differentiation equations of hydrolysis and hydration:

$$\frac{dr_{col}(t)}{dt}=\alpha\, r_{col}(t),\; r_{col}(0)=r_{1a},\; \alpha>0,\; t\in[0,T] \qquad (2.18)$$

and

$$\frac{dr_{1e}(t)}{dt}=-\alpha\, r_{1e}(t),\; r_{1e}(0)=r_{1a},\; \alpha>0,\; t\in[0,T]. \qquad (2.19)$$

The solution of equations (2.18) and (2.19) are:

$$r_{col}(t)=r_{1a}\exp(\alpha t),\quad \alpha>0,\quad t\in[0,T], \qquad (2.20)$$

$$r_{1e}(t)=r_{1a}\exp(-\alpha t),\quad \alpha>0,\quad t\in[0,T_{tec}]. \qquad (2.21)$$

Let's make some notes regarding the quantitative index of the parameter α in formulas (2.20), (2.21). The magnification of the radius $r_{col}(t)$ (2.20) stops at the moment of time $t=T$, when starts the sticking of adjoining colloidal cement particles (moment of setting). In this connection it is necessary to define the upper boundary r_{sup} of index $r_{col}(t)$. It is easy to see that the parameter r_{sup} should meet the requirement:

$$\frac{4}{3}\pi\, r_{sup}^3=\frac{1}{n_{1a}\sqrt{n_{1a}}}\,. \qquad (2.22)$$

On the base of (2.22) we finally find:

$$r_{sup}=\sqrt[3]{\frac{3}{4\pi}\frac{1}{\sqrt{n_{1a}}}}\,. \qquad (2.23)$$

Taking into account the formula (2.23), and the circumstance that the function $r_{col}(t)$ (2.20) is monotonous increasing at the intervale $[0,T]$, we have:

$$r_{col}(T)=r_{1a}\exp(\alpha T)\le r_{sup}=\sqrt[3]{\frac{3}{4\pi}\frac{1}{\sqrt{n_{1a}}}}\,. \qquad (2.24)$$

The solution of the inequation (2.24) regarding the index α we find as:

$$\alpha\le\frac{1}{T}\ln\frac{1}{r_{1a}}\sqrt[3]{\frac{3}{4\pi}\frac{1}{\sqrt{n_{1a}}}}\,. \qquad (2.25)$$

Using formulas (2.21), (2.16), we get the ratio:

$$r_{1e}(\tau_{tec}) \equiv r_{1a}\exp(-\alpha\tau_{tec}) = r_{rem} \equiv r_{1a}\sqrt[3]{1-k_{i.g.}}\,. \quad (2.26)$$

From the equation (2.26) follows the expression for the index α:

$$\alpha = \frac{1}{\tau_{tec}}\ln\frac{1}{\sqrt[3]{1-k_{i.g.}}}\,. \quad (2.27)$$

For the surface density $n_{1e}(t)$ of colloidal cement particles is the expression:

$$n_{1e}(t) = n_{1a}\left[1-\pi\,\bar{r}^2(t)\,\bar{n}_e(t)\right]. \quad (2.28)$$

If $\vec{F}_{r.d.}(N,t) \equiv 0$, then the formula (2.28) is simplified to:

$$n_{1e}(t) \equiv n_{1a}\,. \quad (2.28')$$

Random function $\bar{n}_e(t)$, which in the formula (2.28), can be introduced as:

$$\bar{n}_e(t) = \bar{n}_e^{(+)}(t) + \bar{n}_e^{(-)}(t)\,, \quad (2.29)$$

where: $\bar{n}_e^{(+)}(t)$ and $\bar{n}_e^{(-)}(t)$ mean accordingly the surface density of vortexes oriented in the opposite directions.

If suppose that at even impactions the vortexes with the equal orientation repel and with the opposite orientation disappear with the formation of the first component then indexes $\bar{n}_e^{(+)}(t)$ and $\bar{n}_e^{(-)}(t)$ will conform the system of differential equations as:

$$\begin{cases} \dfrac{d\bar{n}_e^{(+)}(t)}{dt} = -\beta\bar{n}_e^{(-)}(t), \\ \dfrac{d\bar{n}_e^{(-)}(t)}{dt} = -\beta\bar{n}_e^{(+)}(t), \quad \beta > 0, \quad t \in [0,T], \end{cases} \quad (2.30)$$
$$\bar{n}_e^{(+)}(0) = \bar{n}^{(+)}, \qquad \bar{n}_e^{(-)}(0) = \bar{n}^{(-)}.$$

The system of differential equations (2.30) is the normal system which is brought into one linear homogeneous differential equation of the form:

$$\frac{d^2\bar{n}_e^{(+)}(t)}{dt^2} - \beta^2\bar{n}_e^{(+)}(t) = 0\,. \quad (2.31)$$

As the characteristic equation for differential equation (2.31) is defined by equity:

$$k^2 - \beta^2 = 0\,, \quad (2.32)$$

then its general solution is:

$$\bar{n}_e^{(+)}(t) = C_1\exp(\beta t) + C_2\exp(-\beta t)\,. \quad (2.33)$$

For the function $\bar{n}_e^{(-)}(t)$, taking into account (2.30) and (2.33), we have:

$$\bar{n}_e^{(-)}(t) = -C_1\exp(\beta t) + C_2\exp(-\beta t)\,. \quad (2.34)$$

The usage of initial data for the system (2.30) allow us to find easily arbitrary constants in the formulas (2.33) and (2.34):

$$C_1 = \frac{1}{2}(\bar{n}^{(+)} - \bar{n}^{(-)}), \quad C_2 = \frac{1}{2}(\bar{n}^{(+)} + \bar{n}^{(-)})\,. \quad (2.35)$$

Thus, for the function $\bar{n}_e(t)$ (2.29), taking into account the equities (2.33) - (2.35), we finally get:

$$\bar{n}_e(t) = \bar{n}\exp(-\beta t), \quad \bar{n} = \bar{n}^{(+)} + \bar{n}^{(-)}, \quad t \in [0,T]\,. \quad (2.36)$$

Let’s note that in (2.36) should be followed the terms of coordination:

$$\bar{n}_e(t) \le \bar{n} \le \bar{n}^{max} = \frac{1}{\pi\bar{r}^2(0)}\,. \quad (2.36')$$

Thus, on the base of (2.28) and (2.36), the surface density $n_{1e}(t)$ of colloidal cement particles is defined by the equity:

$$n_{1e}(t) = n_{1a}\left[1-\pi\bar{n}\bar{r}^2(t)\exp(-\beta t)\right], \quad t \in [0,T]\,. \quad (2.37)$$

Now let’s find the surface density of a mass of cement solution (2.7) at the moment of time $t = T$, that is at the moment of time when the reactions of hydrolysis and hydration have been finished. Thus, on the base of e (2.7), we have:

$$\rho_e(T) = \rho_e(T) + \overline{\rho}_e(T) = \\ = m_{1e}(T)\, n_{1e}(T) + \rho'_e(T) + \overline{m}_e(T)\, \overline{n}_e(T). \tag{2.38}$$

In case (2.7′), when $\vec{F}_{r.d.}(N,t) \equiv 0$, formula (2.38) will be:

$$\rho_e(T) \equiv \rho_e(T) = m_{1e}(T)\, n_{1\alpha} + \rho''_e(T)\,. \tag{2.38′}$$

In the formula (2.38) the values $\rho'_e(T)$ and $\overline{m}_e(T)$ are undetermined. For the surface density of a mass $\rho'_e(T)$ of residual ordinary liquid we get:

$$\rho'_e(T) = \left[\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{col}^3(T)\right]\gamma'_a\; n_{1e}(T)\,. \tag{2.39}$$

Further according to equity (2.14), the vortex flow does not contain the residual ordinary liquid and, thus, its mass $\overline{m}_e(t)$ is defined by the formula:

$$\overline{m}_e(t) = 4\pi\bar{r}^2(t)\, n_{1a} m_{1e}(t), \qquad t \in [0,T]\,. \tag{2.40}$$

For t = T, on the base of (2.40), we get:

$$\overline{m}_e(T) = 4\pi\bar{r}^2(T)\, n_{1a} m_{1e}(T)\,. \tag{2.40′}$$

Using the evident expression (2.8) and (2.17) regarding the values $\bar{r}(t)$ and $m_{1e}(t)$ for the moment of time t = T, on the base (2.40), we have:

$$\overline{m}_e(T) = \frac{1}{2}\pi^2\sigma^2(T) n_{1a} \times \\ \times\left\{\frac{4}{3}\pi\left[r_{col}^3(T) - r_{1e}^3(T_{tec})\right]\gamma'_a + \frac{4}{3}\pi r_{1a}^3\,\gamma_{1a}\right\}. \tag{2.41}$$

In connection with getting the formula (2.41) for the calculation of the mass $\overline{m}_e(T)$ of vortex flow we'll make some details regarding the equity (2.13), which defines the quantity $\Delta\rho'(t)$ of ordinary liquid dispersed by the vortex flow for the interval of time $[0,t], t \in [0,T]$. The value $\Delta\rho'(t)$ at t = T can be also defined on the basis of the following concepts. As the number of colloidal cement particles connected with the system of vortex flows at t = T is equal to $\pi\bar{r}^2(T)\,\overline{n}_e(T)\, n_{1a}$, then can be easily found considering that (2.39), the value $\Delta\rho'(T)$ is defined by the equity:

$$\Delta\rho'(T) = \pi\bar{r}^2(T)\overline{n}_e(T) n_{1a}\left[\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{col}^3(T)\right]\gamma'_a\,. \tag{2.42}$$

Comparing the formulas (2.13) and (2.42), for the parameter λ we get:

$$\lambda = \pi\bar{r}^2(T)\,\overline{n}_e(T)\, n_{1a}\left[\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{col}^3(T)\right]\gamma'_a \times \\ \times\left[\int_0^T\int_0^{2\pi}\left[m_{1e}(\tau)\,\bar{r}(\tau)\, n_{1a} + \bar{r}(\tau)\,\rho''_e(\tau)\right]\times \right. \\ \left. \times K(N,\tau)\left|\vec{F}_{r.d.}(N,\tau)\right| d\tau\, d\varphi\right]^{-1}. \tag{2.43}$$

In the ratio (2.43) the value $\rho''_e(t)$ is equal to:

$$\rho''_e(t) = \left[\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r_{col}^3(t)\right]\gamma'_a n_{1a}\,. \tag{2.44}$$

For the quantitative valuation of the degree of impaction of cement solution we add series of the technological parameters λ_1, λ_2, λ_3. The degree of impaction λ_1 of the first level is defined by the formula:

$$\lambda_1 = \frac{\rho_e(T)}{\rho_a}\,. \tag{2.45}$$

On the base of (2.4), (2.17), (2.38′) can be easily written for (2.45):

$$\lambda_1 = \left[\left\{\frac{4}{3}\pi\left[r_{col}^3(T) - r_{1e}^3(\tau_{tec})\right]\gamma'_a + \frac{4}{3}\pi r_{1a}^3\gamma_{1a}\right\} n_{1a} + \right. \\ \left. + \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi\, r_{col}^3(T)\right)\gamma'_a n_{1a}\right]\times \\ \times\left[\frac{4}{3}\pi\, r_{1a}^3\,\gamma_{1a}\, n_{1a} + \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi\, r_{1a}^3\right)\gamma'_a n_{1a}\right]^{-1}. \tag{2.46}$$

The degree of impaction λ_2 of the second level is defined by the ratio:

$$\lambda_2 = \frac{\rho_e(T)}{\rho_a}. \qquad (2.47)$$

Using (2.4), (2.17), (2.38), (2.39), (2.41), we modify the expression (2.47) as:

$$\lambda_2 = \Bigg[\Bigg\{\frac{4}{3}\pi\Big[r^3_{col}(T) - r^3_{1e}(\tau_{tec})\Big]\gamma'_a + \frac{4}{3}\pi r^3_{1a}\,\gamma_{1a}\Bigg\} n_{1e}(T) + \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r^3_{col}(T)\right)\gamma'_a\, n_{1e}(T) + \overline{m}_e(T)\,\overline{n}_e(T)\Bigg] \times \left[\frac{4}{3}\pi r^3_{1a}\,\gamma_{1a}\,n_{1a} + \left(\frac{1}{n_{1a}^{3/2}} - \frac{4}{3}\pi r^3_{1a}\right)\gamma'_a\,n_{1a}\right]^{-1}. \qquad (2.48)$$

The degree of impaction λ_3 of the third level is defined by:

$$\lambda_3 = \frac{\lambda_2}{\lambda_1}, \qquad (2.49)$$

where: λ_1, λ_2, are defined by the equities (2.46) and (2.48).

Now let's describe the interaction of the structured two-component cement solution with the filler (1.4), taking into account axiom A9. The optional particle of the filler is introduced as restricted simple connected field $\Sigma \subset R^2$, with the center of masses at the point P, has sectionally smooth border L, mass M, rate $\vec{u}(N, t)$ at the point N and unit vector of external normal line $\vec{n}$ at the point N (Fig. 2).

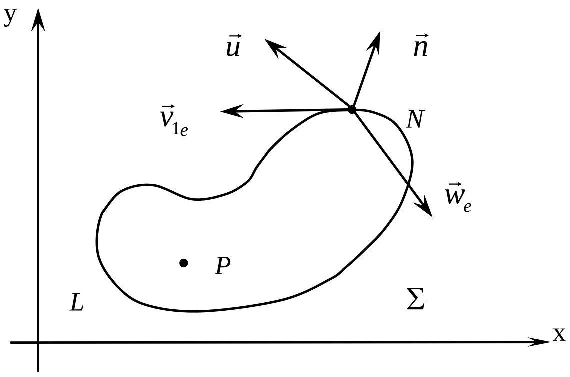

Fig. 2. Scheme of interaction of two-component cement solution with the optional particle Σ of the filler at the point N

The interaction of two-component cement solution with the particle Σ along the border L at the time interval $[0, t]$, $t \in [0, T]$ leads to sticking of colloidal mass ΔM, which is defined by the formula:

$$\begin{gathered}\Delta M(t) = \chi_1 \int_0^t d\tau \int_L dl[m_{1e}(\tau)\, n_{1e}(\tau) + \rho'_e(\tau)] \times \\ \times \left|(\vec{v}_{1e}(N,\tau) - \vec{u}(N,\tau), \vec{n}(N,\tau))\right| + \\ + \chi_2 \int_0^t d\tau \int_L dl\, \overline{m}_e(\tau)\, \overline{n}_e(\tau) \times \\ \times \left|(\vec{w}_{2e}(N,\tau) - \vec{u}(N,\tau), \vec{n}(N,\tau))\right|, \\ \chi_1, \chi_2 > 0.\end{gathered} \qquad (2.50)$$

In the equity (2.50) χ_1 and χ_2 mean coefficients of sticking of colloidal medium on the optional particle Σ.

CONCLUSIONS

On the ground of the results of experimental theoretic researches:

1. It is shown that mathematical constructions stated above have general character and determine the direction in the largest degree in which the theory of vibrorheology of cement concrete solutions must develop.

2. It is proved that the detailed study of the geometry of the grid vector $\vec{F}(N, t)$ leads to the specific technological recommendations related to the parameters and the structure of shuttering forms which are used in the practice of vibro excitation.

3. It is argued that the results obtained in the article can be also used in the study:

- firstly, the process of corrosion of concrete blocks under the influence both of aggressive media solutions of inorganic substances[1, 9, 10], and biologically active habitat of some bacterial species (particularly sulfur-oxidizing thione bacteria) [6],

- secondly, the technologies of chemical treatment of especially dense concretes by the method of fluosilicate treatment [14].

REFERENCES

1. **Alekseev S., Rosenthal N., 1976.:** Corrosion rigidy of ferroconcrete structures in aggressive industrial environments: monograph. – M.: Stroyizdat. – 205. (in Russian).
2. **Bazhenov Yu., 1987.:** Technology of concretes: monograph. – M.: Higher school. – 415. (in Russian).
3. **Bratchun V., Zolotarev V., Pakter M., Bespalov V., 2011.:** Physical chemical mechanics of building materials: the textbook for the students of higher schools. Edit. 2, rev. and add. – Makiivka-Kharkiv: Donnbas. – 336. (in Ukrainian).
4. **Cherny L, 1988.:** Relative models of continuous media. - M.: Nauka. – 288. (in Russian).
5. **Chernyavsky V., 2002.:** Adaptation of concrete: monograph. – Dniepropetrovsk: New ideology. – 115. (in Ukrainian).
6. **Dmitrieva E., 2013.:** Microorganisms - Biodestructors of underground sewerage facilities. Water and ecology. Problems and solutions, № 1, 20-39. (in Russian).
7. **Gusev B., Kondrashchenko V., Maslov B., Faivusovich A., 2006.:** Structure formation of composites and their properties. – M.: Nauchnyi mir, ill. – 560. (in Russian).
8. **Loitsiansky L. 2003.:** Mechanics of liquid and gas. – M.: Drofa. – 900. (in Russian).
9. **Lubarskaya G., Rubetskaya T., 1984.:** Effect of the concentration of corrosive substances on the rate of corrosion of concrete type II. Researches in the field of protection of concrete and reinforced concrete from corrosion in aggressive environments. – M.: Stroyizdat. – 23-26. (in Russian).
10. **Moskvin V., Ivanov F., Alekseev S., Gusev Eu., 1980.:** Corrosion of concrete and reinforced concrete, methods of their protection: monograph. – M.: Stroyizdat. – 536. (in Russian).
11. **Nigmatulin R., 1987.:** Dynamics of multiphase medium, part 1. – M.: Nauka. – 414. (in Russian).
12. **Pilipenko V., 2012.:** Mathematical model-building of reological and hermodynamical processes in modified concrete mix at vibro impact compact method of comression. TEKA Commission of Motorization and energetics in agriculture – Vol. 12, № 4, 204-209.
13. **Pilipenko V., 2013.:** Mathematical model-building of relax processes taking place in concrete mix at vibro impact compact deformation. TEKA Commission of Motorization and energetics in agriculture – Vol. 13, № 3, 175-181.
14. **Pukhnarenko Y., 2008.:** Current status and prospects of usage of fulleroid nanostructures in cement compositions. Siberian Industrialist. № 3, 30-31. (in Russian).
15. **Punagin V., 2010.:** Properties and technology of beton for high altitude monolithic construction. TEKA Commission of Motorization and Power Industry in Agriculture. V. XB, p. 114-119.
16. **Rudenko N.N., 2010.:** The development of conception of new generation concretes. TEKA Commission of Motorization and Power Industry in Agriculture. V. XB, p. 128-133.
17. **Sheikin A., Chekhovsky Yu., Brusser M., 1979.:** Structure and properties of cement concretes. – M.: Stroyizdat. 343. (in Russian)/
18. **Trambovetskiy V., 2008.:** Prospects for concrete improving. Technologies of concretes, № 7, 8-10. (in Russian).
19. **Wollis G., 1982.:** One-dimensional two-phase flow. M.: Mir. 456. (in Russian).
20. **Ziegler G., 1976.:** Extremal principles of thermodynamics of irreversible processes and mechanics of continuous medium. – M.: Mir. – 315. (in Russian).

ИССЛЕДОВАНИЕ ПРОЦЕССА ВИБРОРЕОЛОГИИ ЦЕМЕНТНО-БЕТОННЫХ РАСТВОРОВ С ВНЕШНИМ ИСТОЧНИКОМ ДИНАМИЧЕСКОГО ВОЗДЕЙСТВИЯ

Владимир Пилипенко

А н н о т а ц и я. В статье, в рамках полуфеноменологического подхода сформулированы основные требования к математической модели движения среды цементного раствора и его взаимодействия с наполнителем в плоском случае, когда внешнее переменное силовое поле возбуждения имеет турбулентную составляющую. Дана строгая трактовка влияния параметров исследуемой модели на процесс виброреологии цементно-бетонных растворов и сформулирован критерий её эффективности.

К л ю ч е в ы е с л о в а. Виброреология цементно-бетонного раствора, турбулентность, вихросток, тензоры первой и второй вязкости.

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NPV simulation as a way to reduce uncertainty in the project

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Summary: *The purpose of the study is* to develop an approach for the simulation of the net present value of the project in terms of uncertainty and incomplete information. To achieve this goal. *The methodological basis* of the study consists of the graphic modeling methods, comparative analysis, the method of analogy, scientific methods of analysis and synthesis, discounting method, method of computer simulation. *The main results of the study.* The lack of studies devoted to the profile of the cash flow effect for the project specification was shown. The concept of uncertainty as the decision maker's state in terms of information insufficiency was clarified. The coefficient of underdeterminess of the cash flow as the value that characterizes the knowledge of the decision maker in comparison with the actual flow profile in the future was introduced. For its calculation the model of displaying of the project cash flow profile in the operational phase in the form of five zones of the sectionally-broken line was proposed. By analyzing the results of the computer simulation it was proved that the value of the coefficient of underdeterminess has functional dependency with the shape of the cash flow of the profile and reflects its features. The procedure of the information preparation for the decision maker was developed. This procedure reduces the rate of the coefficient of underdeterminess of the cash flow.

Keywords: project, uncertainty, simulation, modeling, simulation modeling, underdeterminess coefficient, cash flow profile

INTRODUCTION

The last two decades of the civilization existence refer to the implementation (not the origin) of transition to the knowledge society. Many facts confirm this. Thus, in 2000 the Lisbon program [35] entered into force. This program identified key strategic areas of economic and social innovations in Europe in the beginning of the XXI century. The program says that Europe must revise the strategies for fuller manifestation of a new society that is focused on knowledge. The main goal, which identified future policy actions, became "the creation of special, dynamic and knowledge-oriented economy".

In 2005 UNESCO published the world report "Towards knowledge societies". It contains the following: "it is generally accepted that knowledge has become a subject of enormous economic, political and cultural interests as much so that can determine the qualitative state of society, the outlines of which are just beginning to emerge in front of us. Knowledge society, … , there are no any doubts concerning the importance of its concept, whereas the state of things concerning its intension is not so good" [37]. The last statement indicates that the uncertainty is increasing in society about many aspects of life.

However, the presentation of the modern society as a knowledge society is only one of the metrics of processes vision that are taking place in civilization. Other metrics (visions) also exist. For example, the study [32] indicates that the modern society is characterized by the following diverse indicative terms, such as post-industrial, network, creative, innovative, service, information, science intensive, knowledgeable, risk society and so on. But, as the study [15] states, “despite the interpretation differences, every definition contains unity of views, which is that the transformation of the modern world is inseparably linked with the key role of information flow, advanced technologies and theoretical knowledge”.

As we can see, from the point of view of one of the metrics the modern society appears as a risk society. Ulrich Beck has invented this term on the basis of the established fact that in the modern society "risk involves industrial, i.e. technical and economic decisions (feasibility), and utility evaluation. As opposed to “war losses” risk differs in its “normal birth” or, more precisely, in its “peaceful origin” n the world centers of rationality and prosperity under the cover of law and order” [3].

Therefore, “our society of ultimate risk has become the society without guarantees, it is not insured, and the paradox is that security decreases with the growth of dangers” [3]. And the essence of "risk society" can be defined through the logic of production of industrial society (the accumulation and distribution of wealth), which transforms into the logic of production of mass distribution of risks that are generated by scientific and technical systems [4]. Ulrich Beck believes that the development of civilization provides us with risk and it becomes the backbone principle of society that makes its essence. Unlike past eras’ hazards, risks are a direct result which is connected to threatening power of modernization and global instability and uncertainty generated by modernization. In the risk society the unknown and unexpected effects become dominant forces [4]. In the risk society avalanche-like socio-economic process (such as panic, agiotage) appear very often and they characterize society as unstable and crisis [7].

The overview report of the World Bank World Development 2014 “Risk and Opportunity: Managing Risk for Development” points, “The changes that are taking place in the world are accompanied by the rise of variety of new opportunities. However, both new and old risk factors arise.” [39]. But risks are only the way of how uncertainty comes out while uncertainty itself is an essential characteristic [11]. Uncertainty is the state of ambiguity of future events and impossibility to predict them and it is caused by informational incompleteness and incorrectness [17].

New opportunities open new horizons for the implementation of new innovations especially process innovations at the first place. Process innovation is the implementation of a new and dramatically improved production or delivery method. This includes significant changes in technology, production equipment and/or software [27]. To implement innovations in the terms of uncertainty and risk is impossible without the use of project management tools.

BACKGROUND

Project management is now seen as the process of making competent decisions regarding effective and efficient coordination of actions as an integrated system to produce a product with unique features of performance value, quality, time, cost and satisfaction of stakeholders [29]. This process takes place under conditions of uncertainty. When creating an innovative product uncertainty always increases due to the change of technological processes. According to many researchers uncertainty is primarily associated with insufficiency [13], incompleteness [10], unreliability [6], and deficiency [23, 31] of information. It is possible to receive information either by force of prediction or by simulation modeling of the future. Simulation modeling allows establishing the presence and the type of cause-and-effect relations, to identify their nature, to find the most rational parameter values of the simulated system, etc. Owing to this fact insufficiency, incompleteness, underdeterminess (rus. недоопределенность) and other non-factors reduce [24], as well as integrally they determine the essence and the extent of uncertainty. Nowadays the modeling of uncertainty and risks is satisfactory developed for technical systems [16]. At the same time it is considerably worse developed for socio-technical and social systems. The evidences from the study [38] confirm this. It shows, for example, that risk management takes one of the last places among the techniques and methods of management functions implementation for all types of projects (social, economic, organizational and technical). The study [18] cites data that confirm a sustainable growth of the number of publications which are devoted to “uncertainty”. However, most of them do not apply modeling techniques to reduce uncertainty. The largest amount of studies in this direction is connected to the simulation modeling of investment processes [5, 14], investment strategies [22, 36], net cash flows [8], in the terms of uncertainty. The studies [19, 20] and other researches describe the results of simulation modeling of various factors on the NPV value which is net present value of a project. In particular, there were some impacts of project risks simulated through the changes of discount rates, various response events and others. However, the author is not aware of the studies that take into account the nature of cash flows of a project as an indicator of uncertainty of a project. This problem arises in practice when choosing one of several projects with approximately equal values of NPV, but with different types of cash flows. In addition, in the phase of doing feasibility studies the task of finding an indefinite cash flow with the desired NPV value can arise. Besides, doing feasibility studies may challenge the selection of uncertain cash flow with the desired NPV value. This task is relevant in the absence of reliable information about the volume and possible price characteristics of goods (services), which will be implemented during the operational phase of the project product.

PURPOSE AND RESEARCH PROBLEM STATEMENT

The purpose of this study is to develop an approach for simulation modeling of project activities in the terms of insufficiency and incomplete information about the characteristics of cash flows at the operational phase of the project product. The information received as the result of modeling should have some value for the decision maker of a project. Only in this case it will be a means of reducing of uncertainty. Thereby, the approach should take into account the peculiarities of decision maker’s perception of instability and uncertainty of the environment in which the project product will be operated.

METHODS

The methodological basis of the study consists of the graphic modeling methods, comparative analysis, the method of analogy, scientific methods of analysis and synthesis, discounting method, method of computer simulation.

FINDINGS AND THEIR ANALYSIS

Let’s define the terminology platform of the research more precisely. There is a need to do this for the following reasons. Firstly, the terminological system formalizes the object and the subject of the study. Notably, it is the basis of an idealized descriptive model of the subject field (phenomenon, process) which will be explored. Therefore, the terminological system always reflects a certain degree of abstraction in the description of the study area [9]. The subject of the study and research is the object’s essential part which is allocated in terms in the form of distinguishers that are fixed in verbal definitions. Besides verbal definitions allow to expose dishonest sources of information (messages) that contain meaninglessness of some proposals (sentences) [28].

Secondly, the fidelity of verbally formulated definitions will depend on the understanding of its constituent terms that are defined ostensive, i.e. using sensory perceptions. This determines the degree of ambiguity, and hence the uncertainty for the person who will use the terms and information about the results of modeling for making a decision. Therefore, for different people, the same information will reduce uncertainty in varying degrees.

Based on analysis of more than 30 definitions (idealizations) of the term "uncertainty", we propose the following version of its definition. Uncertainty is a state of a person that is determined by his/her knowledge system concerning the impossibility/possibility of decision making as to further activity in a particular situation on the assumption of insufficiency/sufficiency, inaccuracy/accuracy, incorrectness/correctness and other information about events that are associated with future activity and their impact and effects on the expected values (planned output).

Any decision making involves evaluation (of the situation, parameters, etc.). Therefore, a decision maker always operates qualitative or quantitative data, which are expressed in numeric characters, even if it is fuzzy input. Based on this definition of uncertainty it is possible to say that a decision maker uses underdetermined data values (non-values). Underdeterminess means that some kind of data (member object/instance variable) is inherently more accurate in comparison with what currently available information about the object allows to set [24]. Underdeterminess reflects not only data properties but also knowledge properties that are defined as a partial knowledge of the content x and that is limited by the information that *x* belongs to some specific set *X* [25]. Therefore, in the future in order to distinguish the concept of the term "uncertainty" as a condition of a value taker’s state from the characteristic of this state we will use the term "underdeterminess".

Based on the proposed definition, the main task of simulation modeling is providing a decision maker as with specific, unambiguous information about project performances, as with information of how it was obtained and on what assumptions (idealizations) of a particular situation it was based. Such representation has some advantages.

In the first place, the decision maker of a project receives information data and then, after having realized it, chooses an alternate solution independently and in accordance to his/her priorities.

In the second place, such type of informational presentation gives an opportunity to assess the degree of underdeterminess, the complexity of a project, and helps to refer a project to one of the four groups proposed in the study [21]. This by-turn helps to define a basic set of operational procedures that are "almost sufficient" to begin the execution of a specific project.

In the third place, in the implementation phase of the selected variant of the project persons who will do that will be able to take some underdeterminess off in assumption that underdeterminess always occurs and is associated with an alternative choice of the project. At the same time, these persons perceive decision making in their own way, as well as they will be able to implement an adopted decision in their way in real situation which will take place at the moment of decision’s implementation but not in an idealized one. To do this, depending on the complexity and underdeterminess of the local situation they independently choose additional procedures that were not in the core set. In such situations socio-normative models of individual behavior occur [12].

Carrying out an investment analysis in the initialization phase the project parameter NPV is often used as a basic one [30]. To model this parameter it is necessary to fix a few characteristics that are included in the formula for calculating:

$$NPV = \sum_{i=1}^{n} \frac{C_i}{(1+r)^i} - IC_o \,, \qquad (1)$$

where: C_i - is the integral value of the cash flow in i th year of the operational phase of the project product,

IC_o - is the cost of creating the project product,

r - is the discount rate,

n - is the duration of the operational phase of the project product.

As we can see there are three parameters. They are the cash flow which is in the operational phase of the project product, the cost of creating the project product, and the third and the most important parameter is the discount rate. It should reflect the peculiarities of decision maker's perception of the complexity and underdeterminess degree as well as project complicacy not only in the initialization phase of a project but in the operational phase as well.

To simulate cash flow in the operational phase let's assign it in the form of a chain line (sectionally-broken line) which has five sections (or six characteristic points) (Fig. 1).

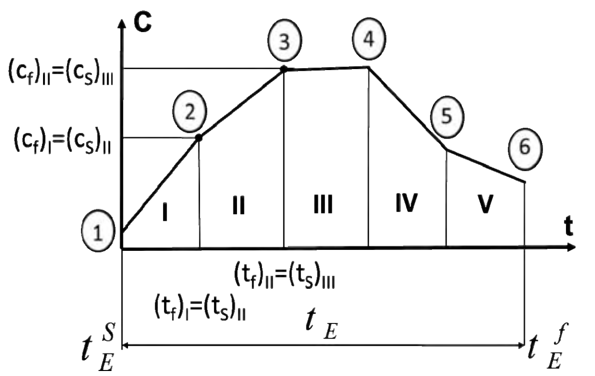


Fig.1. The cash flow representation in the operational phase of the project product

This is not a generally accepted way of cash flow representation. But it allows representing of any cash flow with an accuracy that is adequate for the initial phase (15-20% [34]) where the indicator NPV is calculated (Fig. 2).

In addition, it fully meets the recommendations of project risk management that are developed in the study [26]. It says, "Special attention should be paid on the conceptual risks and not to follow the technologies of detailed development in methodological researches spending limited resources on small problems and forgetting the fundamental strategic risks". The representation of cash flow in the form of a chain line allows conceptual reproducing of the zones of capacity expansion (product ramp-up), stabilization and recession.

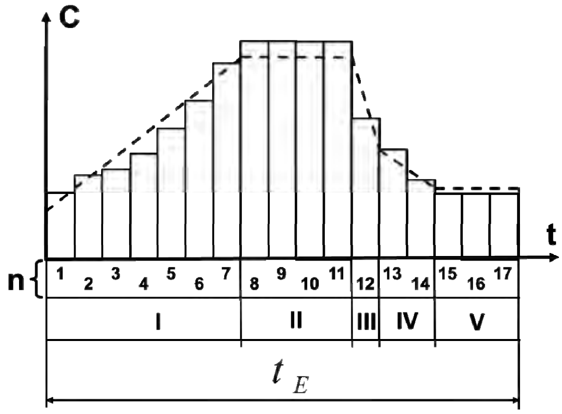


Fig. 2. The replacement of the traditional way of cash flow representation when the operational phase duration is 17 time periods into chain line with five zones (sections)

Every zone can be set as the following tuple $\{t_S, c_S, t_f, c_f\}_i$, where the index s means the beginning of a leg (section), f is its end, and i is the number of a leg of a chain line. Moreover, parameter values should be equal for the adjacent sections:

$$(t_S)_i = (t_f)_{i-1},\ (c_S)_i = (c_f)_{i-1},\ t_E = \sum_{i=I}^{V} t_i. \quad (2)$$

Such cash flow representation allows considering of it's changing within the period. For example, Fig. 2 shows that during the period II cash flow has not changed, and in the period III it has sharply declined. This reflects the business strategy which is laid when it is created on the basis of the project's product.

Due to this fact it is possible to simulate alternative strategies, thereby reducing the degree of uncertainty about the operational phase of the project product.

In regard to IC_o which is the cost in the initial phase of the project product, it is usually given as one indicator of a fuzzy number [2]. This assumes that in the operational phase the modeling results are also fuzzy represented.

In order to make the discount rate reflect decision maker's peculiarities of perception the degree of underdetermines and the complexity of the project as in the initialization phase of the project as in the operational phase the following approach is being proposed. Let's consider two projects with idealized versions of cash flows. The first project has the largest annual cash flow in the initial period of the operation phase and then project's cash flow is uniformly decreasing till the phase ends (Fig. 3 a). And the second project has the largest annual cash flow in the closing phase (Fig. 3 b). If the NPV for both of these projects will be the same, then obviously the first project should be chosen as far as the possibility of its full is much higher than for the second project. So we can say that the decision maker has lower underdeterminess relative to the first project than to the second one. However, in the real world such choice is practically not possible when the cash flows have compound forms.

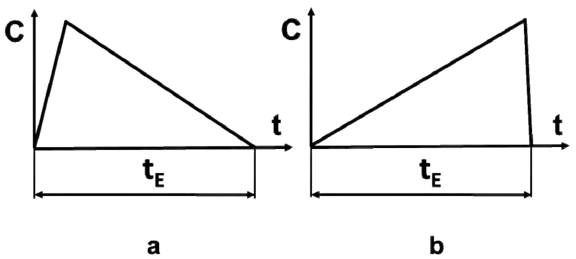


Fig. 3. Alternative form types of cash flows

Therefore, the following problem arises. How to take into account the different types of the cash flow of the project? The solution requires the decision makers to initially express their degree of underdetermines in regards to the project as to a holistic phenomenon in the form enlargement factor of the standard discount rate K_b. The more we have initial information about the project, options (scenarios) of its implementation, the possible events that can affect both positively and negatively on the value of the project the more awareness becomes and, therefore, the less the value of K_b coefficient should be. The value of this coefficient also affects the complexity of the project.

The second parameter is the K_f coefficient. The decision maker specifies it. It is associated with underdetermines compensation regarding the reliability of refund, which should arrive in the last period of operational phase of the project, compared to the degree of underdeterminess regarding to the initial period. This coefficient should affect the discount rate and vary from 0 to 1. It is logical to assume that if the projected income's return year lies after the start of the operational phase of the project then the discount rate should be higher. Then, on this basis, for the cash flow of each period of the phase we must consider its discount rate. At the present time we know the studies where the discount rate is taken on different values in different periods of the operational phase of the project (for example, [1]). However, such studies do not consider its representation with an allowance of a decision maker.

Taking a linear subjection of variation of K_f coefficient for the current year of operation in the first approximation it can be calculated as:

$$\beta_i = \frac{i - t_E^S + 1}{t_E^f - t_E^S + 1} \cdot K_f, \qquad (3)$$

where: i – is the current year of the operational phase starting from the beginning of the project,

t_E^S, t_E^f – are the years of the beginning and the end of the operational phase starting from the beginning of the project.

On this basis the discount rate for the current year can be calculated by the formula:

$$r_i = (1 + \beta_i) \times K_b \times r_b. \qquad (4)$$

From the viewpoint of reducing of the underdeterminess of the project it is reasonable to enter a coefficient of reduction for underdeterminess of the cash flow's type. Let's represent the cash flows of the project in relative units. To do this, we divide each average value of C_i on the sum of all flows of operational phase $\sum C_i$. We denote the obtained values through αi.

In this case $\sum \alpha_i = 1$. I.e. we obtain the normalized cash flow for a specific project. Thus we can calculate the net present value for a project which has the amount of the discounted cash flow equal 1:

$$NPV = \sum_{i=t_E^S}^{t_E^f} \frac{\alpha_i}{(1+(1+\beta_i)\times K_b \times r_b)^i} \ . \quad (5)$$

This value is not normalized, i.e. does not vary from 0 to 1. To disclose its content we will do normalization. Then we will calculate npv for two projects. The first project has not discounted unit flow in the first year of the operational phase, and the second project has it the last year:

$$npv_S = \frac{1}{(1+K_b \times r_b)^{t_E^S}}, \quad (6)$$

$$npv_f = \frac{1}{(1+(1+K_f)\times K_b \times r_b)^{t_E^f}}. \quad (7)$$

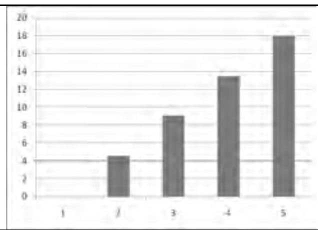
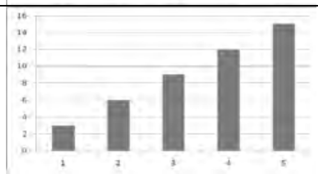
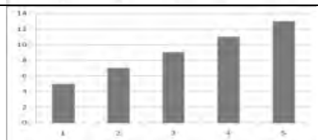
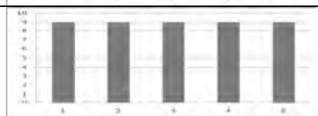
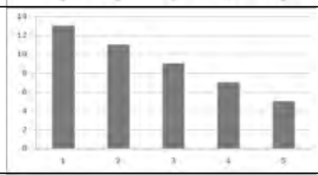
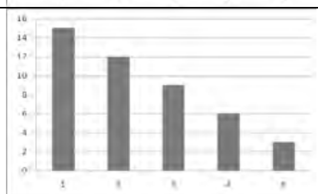
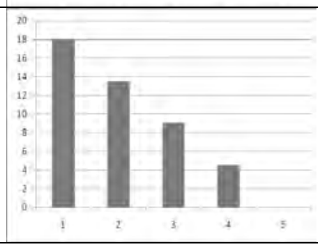
Thus for any kind of cash flow in the implementation phase the underdeterminess's reduction coefficient of the cash flow's type can be calculated as:

$$K_{dv} = \frac{npv_S - nnv}{npv_S - npv_f}. \quad (8)$$

Let's do the calculation for the K_{dv} coefficient's variation for different cash flow profiles. The simulation method of various forms of profiles is widely and successfully applied in the study of technical systems [33]. We will assume identical initial conditions for all profiles' options. Let r_b =0,2, I_o =15 monetary units, $\sum C_i$ =45 monetary units, K_b = 0,5, t_E^S, is the second year of the project, t_E^f is the sixth year of the project. Table 1 shows various cash flow profiles, NPV and K_{dv} values.

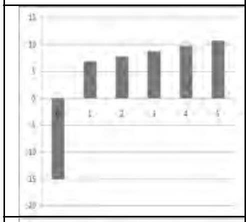
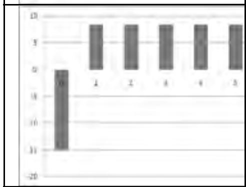
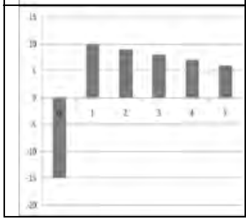
The correlation coefficient calculations between NPV and K_{dv} show that it equals -1. This indicates that the proposed coefficient has a functional relation to the form of the cash flow profile which linearly varies from «min - max» kind to «max - min» kind. For that reason it will properly reflect its peculiarities for any form of cash flow profile. To confirm this assertion we carried out additional calculations. We considered three projects that had equal values $\sum C_i$ = 15 monetary units and NPV =10 monetary units, while the forms of cash flow profiles are different (Table 2).

Table 1. Calculating results for project performance

№	Cash flow profiles	NPV	K_{dv}
1		7,1	0,8
2		8,7	0,71
3		9,8	0,66
4		11,9	0,55
5		14,1	0,44
6		15,1	0,39
7		16,8	0,31

As one can see even with a relatively small flow increasing/decreasing by 8-10% during the five-year term of the project operation, the coefficient varies by 20-25%.

Table 2. The influence of the form of the cash flow profile on the value of the reduction coefficient of the underdeterminess of the cash flow K_{dv} type

Cash flow profiles	The base discount rate K_b increasing coefficient				
	0	0,25	0,5	0,75	1
	0,6	0,6	0,61	0,61	0,62
	0,55	0,55	0,55	0,56	0,57
	0,48	0,48	0,49	0,5	0,51

In addition, all other things being equal, K_b increasing makes K_{dv} increasing and makes its difference to decrease for different flow profiles.

The obtained simulation results allow us to recommend the following procedure as to information preparation in the initialization phase of the project for the decision maker concerning the further project implementation.

1. Preliminary cost information as for project product creation (I_o), base discount rate for this class and complexity of the project (r_b), possible operational term of the project product (t_E^S), intended type (profile) and the value of the cash flow in the operational phase (C_i).

2. To calculate the coefficient NPV the traditional method.

3. To presentat the cash flow profile as a sectionally-broken line with the anticipated operating conditions of the project product which determine sectionally-broken line's type.

4. To make the decision maker acquainted with the prepared information. To get his/her opinion in regards to the discount rate increasing (K_b) and the heterogeneity compensation coefficient relating to the reliability and the refunds which should come in the last period of the operational phase (K_f).

5. The simulation of at least six cash flow's forms that have identical sums of undiscounted flow $\sum C_i$ and that is equal the one that was used in the implementation of paragraph 3. These forms are the following:

- when $\sum C_i$ returns in the first year of project product operation,
- when $\sum C_i$ returns in the last year of project product operation,
- linearly increasing flow for which $NPV_{\min-\max} = NPV$,
- linearly homogeneous flow for which $NPV_{\min=\max} = NPV$,
- linearly decreasing flow for which $NPV_{\max-\min} = NPV$,
- linearly- increasing-decreasing flow for which $NPV_{\min-\max-\min} = NPV$.

6. To calculate the value of the heterogeneity reduction coefficient K_{dv} for all forms of the cash flow including the initial one.

7. The final representation of the information in the form of a table for the decision maker. This table must contain the type of flow forms and the value NPV and K_{dv} of each of them.

The implementation of the proposed procedure will reduce the underdeterminess of the decision maker concerning the project owing to the representation of results obtained during the simulation.

CONCLUSIONS

1. Based on the analysis of publications in the field of uncertainty and risk management it was shown that there is a lack of studies that would have been devoted to the effect of cash flow forms variation as one of the

characteristics that defines the uncertainty of the project.

2. It has become possible to identify the main reasons why this study is relevant after we have considered the need to clarify the research terminology base associated with uncertainty. These reasons are the need to describe an idealized model of the field of study through the separation of distinctive features in terms, subjective interpretation of the terms that are defined ostensive. This study proposes to understand the uncertainty as a decision maker’s condition to make solutions in regards to further activity in a particular situation with the lack of information.

3. To characterize the heterogeneity it was proposed to apply the coefficient of underdeterminess which means the fact that the properties of the data and knowledge are inherently more accurate comparing to what currently available information allows us to discover.

4. Based on the nature of the proposed uncertainty definition the main task of the simulation in the project was formulated.

5. For the purpose to reduce the uncertainty in the project we propose the model of how to represent operational phase’s cash flow in the form of a sectionally-broken line. It has made possible to introduce the notion of uncertainty reduction coefficient about the type of cash flow and develop an approach to its definition.

6. Based on the simulation results of various forms of cash flow it was proved that the proposed coefficient reflects its peculiarities due to the nature of the functional dependence with the cash flow.

7. On the basis of new scientific results we have developed the procedure of how to prepare the information for the decision-maker in the initialization phase of the project.

REFERENCES

1. **Aftanjuk O.V., 2000.:** Calculation and optimization of net present value of the investment project in unstable economic conditions. Project management and development of production. 2(2). 57-60. (in Russian).
2. **Aftanjuk O.V., 2010.:** Account of unstable economic conditions at calculation and optimization of the project NPV. Project management and development of production. 1(33). 68-71. (in Russian).
3. **Bek Ul'rih., 1994.:** From industrial society to society of risk. Thesis. Vol. 5. 161-168. (in Russian).
4. **Bek U., 2000.:** Society of risk. On a way to other modern. Moscow: Progress-Tradition. 384. (in Russian).
5. **Chirkova S., Chernov V., 2004.:** Modelling of investment processes in the conditions of uncertainty: proc. of interinstitutional scientific-technical conference. Saint Petersburg, SPbGPU, Part VII, 49-50. (in Russian).
6. **Creating of administrative decision in conditions of uncertainty and risk, 2010.:** Essence of uncertainty and risk. Available at: http://elearn.oknemuan.ru/?id=9&p=1. (in Russian).
7. **Danich V., 2010.:** Modelling of avalanche-like socioeconomic processes. TEKA. Comission of motorization and energetics in agriculture. 10A, 78-90.
8. **Dimova D., 2004.:** Modelling of future net cash-flows by the Monte Carlo method in the condition of the environment uncertainty. Management of organization: diagnostics, strategy, efficiency: proc. of XII international scientific and practical conference. Moscow, 195-196. Available at: http://www.creativeconomy.ru/articles/20648/. (in Russian).
9. **Donchenko V., 2008.:** Structures, uncertainty: mathematical modelling. Information science and computing: International book series. Book 7. Artificial Intelligence and Decision Making. ITHEA, Sofia, 243-253. Available at: www.foibg.com/ibs_isc/ibs-07/IBS-07-p35.pdf. (in Russian).
10. **Efimovskih V., 2009.:** Risk in modern society: socially-philosophical analysis. Abstract of thesis of dissertation of candidate of philosophy sciences: 09.00.11. Bashkir state university. Ufa. 18 (in Russian).
11. **Ermasova N.B., 2009.:** Risk management of organization. Moscow: Dashkov and Co. 380. (in Russian).
12. **Garkavet’s S., 2010.:** Phenomenological aspects of psychological displays of individual social-normative behavior. TEKA. Comission of motorization and energetics in agriculture. 10A, 145-151.
13. **GOST R ISO 31000-2010. 2010.:** National standard. Risk management. Principles and guidances. Moscow: Standartinform. 21. (in Russian).
14. **Guzairov M., Orlova E., 2012.:** Modelling of innovative processes of regional systems in the conditions of risk. Announcer UGATU. Vol.16, No1(46), 226-232. (in Russian).

15. **Kalinina N., 2012.:** Comprehension of knowledge society transformation in society of risk in modern socially-humanitarian idea. Innovations in science: proc. of X international scientific and practical conference in absentia. Available at: http://sibac.info/index.php/2009-07-01-10-21-16/3370-2012-07-24-17-10-57. (in Russian).
16. **Krasheninin A., Osenin J., Matvienko S., 2013.:** Improving efficiency of train traction operational standards: an approach with usage of simulation. TEKA. Comission of motorization and energetics in agriculture. Vol.13, No.3, 98-102.
17. **Kulikova E.E., 2008.:** Risk management: innovative aspect. Moscow: Berator-Publishing. 112. (in Russian).
18. **Kuz'min E., 2012.:** Uncertainty in economy: concepts and positions. Poins of management. No4(21). Available at: http://vestnik.uapa.ru/ru-ru/issue/2012/04/10/. (in Russian).
19. **Latkin M., Efremova A., Chumachenko I., 2005.:** Risk identification during the project life cycle. Air-space technique and technology. No5(21), 62-65. (in Russian).
20. **Latkin M., Chumachenko I., 2008.:** Estimation of the project efficiency considering negative influence of risks and indemnification of losses. Project management and development of production. 1(25), 46-53. (in Russian).
21. **Littl Todd, 2005.:** Flexibility in a fight against complication and uncertainty. Open systems. No10.
22. **Melihov D., 2012.:** Modelling of the firm investment strategies in the conditions of uncertainty. Abstract of thesis of dissertation of candidate of economy sciences: 08.00.13. Volgograd state technical university. Volgograd. 20 (in Russian).
23. **Mohor V.V., Bogdanov A.M., 2011.:** Each section interpretation of ISO GUIDE 73:2009 “Risk management – Vocabulary”. Announcer of IPME NAN of Ukraine. Kiev. Iss. 59. 173-199. (in Russian).
24. **Narin'jani A., 1998.:** No-factors: inaccuracy and not-fully-uncertainty - distinction and intercom-munication. Available at: http://viperson.ru/wind.php?ID=514361. (in Russian).
25. **Narin'jani A., Telerman V., Ushakov D., Shvecov I., 1998.:** Programming in limitations and not-fully-determined models. Information technologies, No7, Moscow, 13-22. Available at: www.raai.org/about/persons/nariniani/N-MODEL2.doc. (in Russian).
26. **Neizvestnyj S.I., 2007.:** The project’s brain. Moscow: Russian Science Publisher. 400. (in Russian).
27. **Oslo Manual., 2006.:** Guidelines for collecting and interpreting innovation data. 3d ed. A joint publication of OECD and Eurostat. Organisation for economic co_operation and development. Statistical office of the european communities. Moscow. 192. (in Russian).
28. **Pogorelov O., 2012.:** Outline of a theory of semantic information and misinformation. TEKA. Comission of motorization and energetics in agriculture. Vol.12, No.4, 210-217.
29. **Rach V.A., Rossoshanskaya O.V., Medvedeva E.M., 2010.:** Project management: practical aspects of regional development strategies realization. Kiev: “K.I.S.”. 276 (in Ukrainian).
30. **Rach V., Borzenko-Miroshnichenko A., 2012.:** Features of project analysis of the portfolio of regional educational space. TEKA. Comission of motorization and energetics in agriculture. Vol.12, No.4, 235-239.
31. **Risk management professional standard, 2012.:** Risk management of organization. Qualification level 6, 7, 8. Moscow: RusRisk. 60. (in Russian).
32. **Rossoshanskaya O., Scherbatyuk A., 2013.:** Innovative labour as a tool of ensuring the strategic economic security for innovative project-oriented enterprises**.** Project management and development of production. 3(47), 5-18. (in Ukrainian).
33. **Sapronova S., 2010.:** Modelling of locomotive wheel profile form. TEKA. Comission of motorization and energetics in agriculture. 10C, 270-278.
34. **Terner J. Rodney, 2007.:** Guidance on the project-oriented management. Moscow: Publ. house of Grebennikov. 552 (in Russian).
35. **The Lisbon European council – an agenda of economic and social renewal for europe. 2000.:** Brussels. Feb. 28. Available at: http://www.ec.europa.eu/growthanjobs/pdf/lisbon_en.pdf
36. **Tkachenko D. 2011.:** Modelling and optimization of investment strategies in the conditions of uncertainty considering the project realization dead-line. Management of economic systems. No12. Available at: http://www.uecs.ru/instrumentalnii-metody-ekonomiki/item/886-2011-12-22-06-55-57. (in Russian).
37. **To societies of knowledge, 2005.:** JuNESKO. 239. (in Russian).
38. **Voropaev V., 1995.:** Project management in Russia. Moscow: Allans. 225. (in Russian).
39. **World bank of reconstruction and development, 2013.:** Risks and possibilities. Risk management in interests of development. Report about world development 2014. 66.

МОДЕЛИРОВАНИЕ NPV КАК СПОСОБ СНИЖЕНИЯ НЕОПРЕДЕЛЕННОСТИ О ПРОЕКТЕ

Денис Рач

Резюме. Изложен подход к моделированию показателя чистой приведенной стоимости проекта в условиях неопределенности. Уточнено понятие неопределенности как состояния лица, которое принимает решение в условиях недостаточности информации. Введено понятие коэффициента недоопределенности потока. Для его расчета предложена модель отображения профиля денежного потока по проекту на фазе эксплуатации в виде пяти зонной кусочно-ломаной прямой. Разработана процедура подготовки информации для лица принимающего решение которая снижает коэффициент недоопределенности потока.

Ключевые слова. проект, неопределенность, моделирование, коэффициент недоопределенности, профиль денежного потока.

Technology of shotcreting based on activated binder

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S u m m a r y . The article presents the main peculiarities of the developed shotcreting technology wherein fine grained concrete mixes based on activated binder are used. This technology is applied in the repair and rebuild of transport and hydrotechnical constructions. It is shown that introduction of cement suspension into the activation technological process allows increasing concrete repair coat operating abilities, reducing the production process time along with the minimum binder consumption.
K e y w o r d s : shotcrete, cement system, activation.

INTRODUCTION

Shotcreting is a process of coating a surface with concrete mixture or mortar in the compressed air jet [3, 5, 7, 13, 31]. Shotcreting is used when it’s impossible to use traditional ways of concrete placement, for example, in thin-walled structural elements fabrication, for the production of high-performance material, as well as for the repair of various constructions, where the high-scale adhesion between the new concrete and the repaired surface is required [8, 10, 11].

A dry shotcreting process was first introduced in 1910 by “Cement gun Company”, which exhibited a specially designed equipment in New York [11].

Shotcreting became widely used in hillside flanking, in tunnel lining, in capping on the surface of a preload tank, for masonry enforcement, enforcement of metal structures, for butt joint grouting, for the production of thin-walled structures of complex shape [1, 2, 4, 14].

Technology of shotcreting is based on the following operations: loading of a prepared mixture into pneumatic transporter, batching of a dry mix to a loader-dozer with the simultaneous compressed air admission, hose handling of a dry mix in the compressed air jet to an edge nozzle atomizer, dosed supply of compressed water into the nozzle atomizer, as it allows mix blending inside the nozzle, coating the shotcrete surface with prepared combined jet, which comes out of the nozzle atomizer at high speed [6, 12, 17-19].

PURPOSE

Solution of the mentioned problems is possible due to the air jet concreting procedure performed with activated cement system. A considerable increase of the strength of shotcrete based on the activated cement system is explained by several reasons. It should be pointed out that the initial set occurs almost instantly due to the activation effect which also contributes to the increased adhesion to the shotcrete surface. At the same time the reduction of the rebound amount up to 6…7% is possible on the vertical surfaces, and up to 8…9% on the ceiling surfaces.

RESEARCH DATA

There are a number of imperfections in this technology. Uneven flow of the dry mix into the nozzle as a consequence of the alternating resistance inside the hoses caused by various bends and obstructions, leads to the necessity of constant water flow control. When dry mix consumption decreases then water washes out previously applied layer of shotcrete, and when it increases then dusting occurs. The prepared mixture contacts water in the spray gun nozzle only for a few seconds, so cement particles are not able to adsorb water in corpora, and it leads to underutilization of cement binding potential. For the same reason aggregate rebound from the shotcrete surface increases, its value makes 10…30%. The actual cement content in the applied dry mixtures shotcrete with the increase of the rebound makes 600…800 kg/m^3, this results in overexpenditure of the expensive component.

In order to remove shortcomings of a dry shotcreting process in the middle 60's of the twentieth century a wet shotcreting process was developed, it has made it possible to monitor the applied mixture composition. The principle of the wet shotcreting process consists of the following. Concrete mixture or a mortar is prepared in a separate mixer, and then it is loaded in a compressor gun, wherefrom it moves through the hoses to the nozzle. Simultaneously, compressed air is pumped to the nozzle, it ejects the incoming mixture to increase its nozzle exit velocity [15, 16, 20, 22]. Then the shotcrete surface is covered with prepared combined jet.

In spite of some advantages of the wet shotcreting process, the aggregate rebound reduction was not achieved, on the contrary, when the coarse aggregate is used then the rebound increases only. One of the disadvantages of the wet shotcreting process is an air blocking tendency, which leads to the irregularities in the shotcreting procedure [21, 23, 25]. The aggregate rebound is one of the peculiarities of the processes considered above, in many ways it establishes shotcrete materials requirements, requirements for its composition, works execution rules and it directly affects the hardened shotcrete properties [24, 26-28]. The rebound is a material reflected from the shotcrete surface due to the elastic energy of the applied material jet blow. The amount of the rebound is determined by the shotcrete surface elasticity and the applied material elasticity. At the beginning of shotcreting when the gun mixture jet strikes sufficiently rigid surface, rock or concrete, the amount of the reflected material is more than in the next phase of work when the jet strikes a much less elastic layer of a freshly placed shotcrete.

The composition of the rebound is mainly determined by the elasticity of the particles of the applied material. Cement paste makes 10…40% of the initial mixture in the composition of the rebound. The actual cement content in the applied dry mixtures shotcrete with the increase of the rebound makes 600…800 kg/m^3, this results in overexpenditure of the expensive component. The increase of the amount of sand in the initial mixture elevates its content in the rebound. Rebound increases at bar mat reinforcement shotcreting due to the vibration of the latter during the process of application of the mixture. The rebound material is considered to be a loss [29, 30].

The hardeners are admixed to the ready mixes to reduce the setting time and the amount of the rebound. However, the use of the powdered admixes becomes complicated because of their high hygroscopity, which leads to sticking to the feeder walls and impossibility of a precise components batching.

It is obvious that existing shotcrete technologies, fundamentally different from each other, dry shotcreting process and wet shotcreting process, cannot solve all the listed problems.

The disadvantages of the modern shotcrete technology significantly impair its properties and at the same time increase the cost price. As it is well known, the strength of rocks, out of which the cement is obtained by grinding or kilning, comes up to 200 MPa. The strength of the cement stone of the same mineralogical composition is 6…8 times less, the concrete strength is even much less. This is mainly caused by low bulk concentration of hydrated newgrowths in a material volume unit due to under-utilization of cement binding potential.

E. Freyssinet showed that the increase of the level of compaction concurrent with hydration activation make it possible to increase concrete strength in 3…4 times, up to 100 MPa. At the same time concentration of solid in the cement stone was about 80% and if it is increased to 100% the strength may rise up to 170…180 MPa.

Modern technology even by maximum possible reduction of W/C ratio cannot essentially increase bulk concentration of a solid. Not only quantitative factor has a significant effect on the shotcrete strength enhancement, but, to a greater extent, qualitative composition of newgrowths, that’s why there’s no need to bring up the concentration of solid to 100%.

The attempts to get a higher density of the cement stone resulted in the reduction of shotcrete density due to the rebound increase. Consequently, a paradox emerged - low-density shotcrete contains high-density cement stone. Therefore, nowadays high-strength shotcrete coatings are produced with the application of mixes with extremely low W/C ratio. However, this resulted in the requirement of a considerable cement consumption increase in a cement volume unit (up to 600 kg and more) with a simultaneous increase of the amount of the rebound. Surplus of the most expensive and scarce component, which serves as a plasticizer, reduces construction properties of shotcrete, and this is especially dangerous in extreme conditions, as it causes considerable bulk deformations of concrete, increases inherent stresses, accompanied by crack formation and reduction of product life and structural durability.

The modern concrete technology is, in essence, not able to overcome the existing contradiction between the concrete strength and concrete mix viscosity. The application of different admixtures, including complex admixtures, only partially improves the situation. As is known, when the degree of plastification increases the concrete strength decreases. Consequently, the application of chemical additives, progressive from the point of view of improvement of hydration processes and binder structure formation, doesn’t contribute to the comprehensive solution of the technological problem of high-tensile and high-density products manufacture.

Unfortunately, in modern technology the system “binder-water-aggregates” never attains equilibrium, as chemicals desorbing, accumulation and reforming never stop in this system, especially in the conditions of the direct influence of the environment.

Thus, modern methods of improving shotcrete properties by increasing cement consumption, application of chemical additives are not able neither in a complex, nor individually resolve the main contradictions of concrete technology. At the same time it is important to note the well-known phenomenon of underutilization of cement binding properties. Experiments have shown that in traditionally prepared shotcrete mix cement particles with a diameter of about 20μm can hydrate not more than 60% of the initial volume.

When the degree of grinding of cement clinker increases and its particles grow smaller, the degree of hydration of cement increases very slowly. Moreover, author [8] showed that the increase of the specific surface area of cement over 600m2/kg leads to its flocculation and, consequently, to the reduction of the degree of hydration. The degree of hydration also reduces due to significant precasting process duration in the modern technology and due to the concrete dehydration caused by environmental effect. Therefore, it can be asserted that even when favourable conditions are established not more than 60% of cement participates in the “cement glue” formation. Rest of the cement volume is only inert filler of the concrete. This phenomenon of “microconcrete” [14] is theoretically based and is known as a concrete “clinker stock”.

According to some researchers, the content of unhydrated cement grains in the binder is conductive to rehydration when concrete is remoistened [7]. However, the phenomenon of crack bridging presents great difficulties, considering that almost 40% of cement doesn't show their binding properties in the initial period of concrete structure formation [8, 9].

The developed method of applying the shotcrete based on the activated binder allows repairing drowned hydrotechnical constructions and transport constructions. As is known, such types of work are difficult and expensive as a result of a requirement to apply special types of a binder, polymer and other. The air jet way of applying a protective layer on a damaged surface is defined by a relatively low cost and high quality factors.

Shotcrete technology in the repair and rebuild of transport and hydrotechnical constructions makes it possible to enhance their operating abilities using minimum amount of a binder and reducing the production processes.

The technology is based on physicochemical activation of a binder which takes place in an activation reactor. The activation reactor is a cylindrical vessel with a closed loop line [12]. Cement and warm water are conveyed to the activation reactor at the rate of 60…70% of the estimated amount. Thorough mixing of the cement paste is performed with the compressed air. Organo-mineral complex (OMC) based on the rest amount of the water is prepared in a separate vessel. OMC is loaded in the activation reactor at a certain time [20]. Activated cement glue is conveyed by the compressed air to the mixing gun nozzle. The estimated amount of the fine aggregate is conveyed to another nozzle of the mixing gun.

The direction of components movement is chosen in a way to intersect the jets of the activated binder and aggregate at a certain angle. This way aggregate is mixed with the binder and the surface of aggregate particles is shotcreted with the cement glue.

The generated aggregate and activated cement system mix is pushed out by compressed air jet from the mixing chamber and directed to the application surface area. For shotcreting with mixtures based on activated binder a plunger straight-flow pump of batch action with pneumatic adaptor was used to form an air-mortar mixture.

Experimental shotcrete compositions based on activated binder are presented in Table 1.

Table 1. Experimental shotcrete compositions based on activated binder

Grade of cement	Shotcrete composition, kg/m^3					Compressive strength, MPa
	cement	sand	OMC	water	W/C	
400	374	1058	71,13	161	0,43	67,8
	348	1044	66,12	143	0,41	64,2
	332	1006	63,20	159	0,48	66,4
500	357	1027	71,42	157	0,44	72,9
	330	1032	66,08	155	0,47	74,6
	315	1015	63,11	132	0,42	72,1

Field studies of the restored area showed good adhesion of the shotcrete based on activated binder and the application surface. At the same time the amount of the rebound didn't exceed 6,5%. Economic effectiveness of the developed shotcrete consists in the possibility of cement consumption reduction, decrease of the rebound and improvement of the surface operating abilities.

The process of the concrete and reinforced concrete products technology is connected with the solution of the following main questions:

- preparation of the cement glue saturated with solid phase (minimal W/C ratio) to the limit and with the most complete cement particles hydration regardless of their strength,
- physicochemical activation in optimal terms,
- applying of the activated cement paste layer on the aggregate grains should provide filling of their surface microrelief and, consequently, a high degree of adhesion between the glue and the aggregate,
- the concrete strength is adjusted by compaction of the aggregate particles with cementing coating to a given density,
- reduction of cement consumption to the level required for the formation of the cement glue volume with optimal amount of water enough to coat aggregate grains with minimum thickness layer.

On this basis an extra strong concrete and reinforced concrete products advanced technology was developed, it allows manufacturing concrete products of a tailored composition with minimum binder consumption and allows reducing production processes.

Cement-water suspension activation starts from the moment of organo-mineral complex introduction, being accompanied by the super plasticization effects and having a special impact on spatial structure formation.

The aftereffect of the activation treatment is being observed in the composite material for a long time of its life due to the phenomena of structural heredity and maintenance of a certain orientation of hydration which was specified in the initial stages of binder transformation in a ductile cement-water suspension.

The activated cement system at the bottom of the activation reactor is pumped into the closed loop line and is ejected at high speed in the middle part of the reactor from two opposite nozzles. Conditions for the cavitation effect are created at the jet impact, this contributes to the activation of cement and micro filler particles chemical interaction in the activated system in the environment of a structural formation chemical optimizer. Particles of the mineral component of the organo-mineral complex are the cavitation nucleus carriers.

The generated aggregate and activated cement system mix is pushed out by compressed air jet from the mixing chamber and directed to the precast-concrete mould. The mould and the jet device are able to move relative to each other that allow molding products of any shape. After casting the products are sent to the thermos maturing chamber. The mixture in the form consolidates intensively due to the use of the flow kinetic energy which allows excluding vibration from the technological process. Physicochemical activation of the binding mix effects the temperature of the products. Products manufacturing process is intensified due to the directed structure formation of the activated cement system.

The table 2 lists the equivalent compositions of the activated binder concrete. The design strength of concrete is 70 MPa, Portland cement M 500, W/C = 0,45. A composition with minimal cement consumption was chosen, it equals to 317 kg/m^3 of concrete.

Table 2. Equivalent compositions of the activated binder concrete

x	Cement, kg	Water, l	Sand, kg	Crushed stone, kg	$\gamma_{concrete}$, kg/m^3
1,6	335	150	536	1370	2391
1,7	329	148	559	1357	2393
1,8	325	146	585	1345	2404
1,9	323	145	614	1321	2403
2,0	317	142	634	1310	2402
2,1	318	143	668	1276	2404
2,2	318	143	700	1244	2405
2,3	321	144	738	1203	2406
2,4	325	146	780	1156	2407

From a practical point of view it is reasonable to make not one composition, but a set of equivalent compositions of the given materials which comply with two requirements: the necessary concrete strength and specified concrete workability. For this it's necessary to work out sand-cement ratio values and to calculate the compositions with specified workability and strength.

Concrete mechanical characteristics are presented in Table 3.

Table 3. Strain characteristics of concrete samples

Prism code	R_{cube}, MPa	R_{prism}, MPa	E_0, MPa	Ultimate strains, 10^{-3}		μ
				ε_1	ε_2	
N-4-3	41,4	33,3	43200	1,14	0,357	0,29
N-4-4	42,2	34,8	42700	1,24	0,386	0,34
N-5-7	50,6	42,7	49500	1,46	0,437	0,30
N-5-9	56,8	47,5	37000	1,74	0,493	0,28
N-5-11	54,7	45,2	42800	1,67	0,702	0,42
A-5-7	84,2	73,3	64900	1,70	0,391	0,23
A-5-9	89,7	78,0	65000	1,90	0,475	0,25
A-6-5	103,4	90,0	67000	2,39	0,573	0,24
A-6-7	118,7	104,5	67100	2,40	0,552	0,23
A-6-8	112,6	98,0	67000	2,40	0,624	0,26

Continue table 3

Prism code	Plasticity coefficient λ	E of total strains, MPa	Coefficient β, 10^6	Microcrack formation boundaries		Prism strength coefficient
				Bottom	Upper	
N-4-3	0,322	29200	6,14	0,62	0,83	0,80
N-4-4	0,337	28000	5,93	0,63	0,86	0,82
N-5-7	0,409	29200	10,57	0,68	0,81	0,84
N-5-9	0,262	27300	2,79	0,71	0,82	0,84
N-5-11	0,388	27100	4,70	-	-	0,83
A-5-7	0,336	43000	6,44	0,76	0,91	0,87
A-5-9	0,368	41000	6,30	0,82	0,90	0,87
A-6-5	0,438	37600	6,15	0,85	0,93	0,87
A-6-7	0,351	43500	4,92	-	-	0,88
A-6-8	0,390	40800	5,46	0,87	0,91	0,87

The developed air jet way can be also applied for the manufacturing of extra strong concrete and reinforced concrete products based on a coarse aggregate. In this case products molding is made by prepacked concreting. The cement-sand mortar is prepared according to the considered scheme. The prepacked coarse aggregate is shotcreted with the activated cement system from the nozzle atomizer. A considerable mixture kinetic energy provides penetration of the cement glue into the coarse aggregate voids, which results in the further formation of a dense and strong spatial structure.

CONCLUSIONS

1. The developed shotcrete technology makes it possible to raise efficiency of the commercial concrete guns, to cut down the maintenance staff, to cut down on transportation and processing expenditures, to maintain reliability and safety during the concrete gun work, to mechanize fine aggregate loading, to provide engine driven batching of cement and organo-mineral complex, to improve shotcrete works quality, to enhance shotcrete operating abilities.

2. An extra strong concrete and reinforced concrete products advanced technology was developed, it allows manufacturing concrete products of a tailored composition with minimum binder consumption and allows reducing production processes.

3. The introduced air jet way of extra strong concrete and reinforced concrete products manufacturing makes it possible to save about 40% of cement, to increase the density of concrete and, hence, to debulk products.

REFERENCES

1. **Cervera Miguel, Oliver Javier, Prato T., 1999:** Thermo-Chemo-Mechanical Model for Concrete. Hydration and Aging // Journal of Engineering Mechanics. – Vol. 125. – No. 9. – 1018-1027.
2. **Collepardi M., 2003:** Innovative Concretes for Civil Engineering Structures: SCC, HPC and RPC / M. Collepardi // Workshop on New Technologies and Materials in Civil Engineering. – Proc. – Milan. – 1-8.
3. **Hanehara S., 2008:** Rheology and early age properties of cement systems / Shun-suke Hanehara, Kazuo Yamada//Cement and Concrete Research. – Vol. 38, No l. – 175-195.
4. **Hogan F.J., Meusel J.W., 1991:** Evaluation for Durability and Strength Development off a Ground Granulated Blast-Furnace Slag//Cem., Concr. and Aggreg. – V. 3. – N 1. – 40-52.
5. **Gjorv O.E., 2007:** High Strength Concrete. Advanced in Concrete Technology. – Canada. – 21-79.
6. **Jawed Inam, 1988:** Hydration of Portland cement. //Cem. Res. Progr., Surv. sci. lit. cem., publ. /Cem. Div. Amer. Ceram. Soc. – Westerville (Ohio). – 39-81.
7. **John M. Hooks, 1999:** HPS bridges for the 21-st century // Bridge Views. – Issue N 6. - 1-3.
8. **Lea's, 1998:** Chemistry of Cement and Concrete, ed. by Peter C. Hewlett. – 1008.
9. **Lu P., Yong I.F**., 1993: Slag-Portland Cement Based DSP Paste. J. Am. Ceram. Soc. – Vol. 76. – №5. – 329-334.
10. **Mehta P.K., 1990:** Principlts Underlying Production of High Performance Concrete. /P.C. Aitcin // Cement, Concrete and Aggregates. – Vol.12. – №2. – 70-78.
11. **Meguid S.A., 1989:** Engineering fracture mechanics. – London and New York: Elsevier applied science. – 397 p.
12. **Middendorf B., 2006:** Nanoscience and nanotechnology in cementitious materials / Middendorf B., Singh N. B. // Cement International. – № 4. – 80-86.
13. **Neville A.M., 2000:** Wlasciwosci betonu, wydanie 4, Kakow. – 874.
14. Powers T.C., 1957: The physical structure of Cement and Concrete / T.C. Powers // TSJ-ACI. – Vol. 17. – № 5-6. – 189-202.

15. **Punagin V., 2010:** Properties and Technology of Concrete for high altitude monolithic construction//TEKA Kom. Mot. I Energ. Roln. – Lublin: OL PAN. – Vol. XB. – 114-119.
16. **Punagin V., 2012:** Physicochemical Characteristics of Bond and Friction between the Modified Concrete and Sliding Formwork for the Construction of High-rise Buildings//TEKA Kom. Mot. I Energ. Roln. – Lublin: OL PAN. – Vol. 12. – No. 4. – 229-234.
17. **Reading T.J., 1987:** Shotcrete as a construction material / T. J. Reading // Shotcreting. – Publication SP-14. – ACI. – 98-118.
18. **Rohling Stefan, Niether Manfred, 1989:** A model to describe the kinetics of structure formation and strength development: [Pap.] Expert Meet. Microstruct. and Prep. Concr., Espoo //VTT Symp. – №115. – 5-51.
19. **Roy D.M., 1992:** Advanced Cement Systems Including CBS, DSP, MDF/ 9-th ICCC, vol. 1 – 357-380.
20. **Rudenko N., 2010:** The Development of Conception of New Generation Concretes//TEKA Kom. Mot. I Energ. Roln. – Lublin: OL PAN. – Vol. XB. – 128-133.
21. **Sakai E., Sugita J., 1995:** Composite Mechanism of Polymer Modified Cement. Cem. Concr. Res., vol. 29. – 127-135.
22. **Sawaide M., Iketani J., 1992,** Rheological Analysis of the Behavior of Bleed Water from Freshly Cast Mortar and Concrete //ACI Materials Journal. – Vol. 89. – No. 4. – 323-328.
23. **Schiller K.K., 1991:** Mechanical Properties of Non-Metallic Brittle Materials / K. K. Schiller // Cement and Concrete Research. – Vol. 2. – 35-42.
24. **Shah S.P., McGarry F.J., 1991:** Griffith Fracture Criterion and Concrete//J. Eng. Mech. Div. Proc. Amer. Soc. Civ. Eng. – V. 97. – N 6. – 1663-1670.
25. Singh B.G., 1998: Specific surface of aggregates related to compressive and flexural of concrete//J.A.C.I. – Vo1. 29. – № 10. – 897-907.
26. **Sujata K., Jennings Hamlin M., 1992:** Formation of a protective layer during the hydration of cement. //J. Amer. Ceram. Soc. – №6. – 669-1673.
27. **Tank Rajesh C., Carino Nicholas J., 1991:** Rate constant functions for strength development of concrete //ACI Mater. J. – №1. – 74-83.
28. **Thomas M.D.A., 1998:** Development and field applications of silica fume concrete in Canada / K. Cail, R.D. Hooton // Canadian Journal of Engineering. – Vol. 25. №3. – 391-400.
29. **Ulm Franz-Josef, Coussy Olivier, 1996:** Strength Growth as Chemo-Plastic Hardening in Early Age Concrete // Journal of Engineering Mechanics. – Vol. 122. – No. 12. –1123-1132.
30. **Wrihgt James, Frohnsdorf G., 1985:** Durability of building materials: durability research in the United States and the influrnce of RILEM on durability research //Mater. and Constr. – Vol. 18. – No 105. – 205-214.
31. **Zollo R.F., 1997:** Fiber-reinforced Concrete: an Overview after 30 year of Development / R. F. Zollo // Cem. Concr. Com. – Vol. 19. – 107-122.

ТЕХНОЛОГИЯ ТОРКРЕТИРОВАНИЯ НА АКТИВИРОВАННОМ ВЯЖУЩЕМ

Наталья Руденко

Аннотация. В статье приведены основные особенности разработанной технологии торкретирования мелкозернистыми бетонными смесями на активированном вяжущем, применяемой при ремонте и восстановлении транспортных и гидротехнических сооружений. Показано, что введение в технологический процесс активации цементной суспензии позволяет повысить эксплуатационные свойства ремонтного слоя бетона при сокращении продолжительности производственных процессов наряду с минимальным расходом вяжущего.

Ключевые слова: торкрет-бетон, цементная система, активация.

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Implementation of automated informational interactions as a part of integrated information-processing system

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Summary. This paper investigates the implementation of information-analytical system component based on modern IT infrastructure to automate information interactions as an example of state power and local self-government with citizens and business entities, using digital signatures.
Keywords. Automation, information interaction, integrated information-processing system, it infrastructure, information infrastructure, electronic services, reporting, digital signature.

INTRODUCTION

Nowadays in Ukraine there are no universal standards and mechanisms of electronic interaction between state authorities and local self-government with citizens and business entities. However, they are the main source of state (including social) budget and make the most of the information resources of public bodies to support the basic functionalities of these processes with the submission of electronic reporting. The lack of technological sophistication and uniformity of reporting operating systems, including ones in electronic form, provide full requirements neither to business reporting nor to state supervisory bodies, to which it is handed in. The submitting process of the majority of reports has not been automated. There is no single methodological guidance and coordination of electronic reporting on the state level.

Insufficient attention has been paid to establishing a productive and secure IT infrastructure that is the basis of information services. One of the problems is the use of different software and hardware platforms for web-based services of public authorities. This leads to increased operating costs and the need to involve specialists and administrators for various products and systems.

Nearly 1 million taxpayer’s entities and more than 3 million individual entrepreneurs have been registered as taxpayers by 1 January 2014 in Ukraine. Almost all working-age population can be potential users of information resources of public authorities. There are various examples of electronic interaction between individuals and the state, using digital signatures: State Registration of Legal Entities and Individual Entrepreneurs [14, 17, 18], reporting, obtaining information and so on.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS, WHICH DISCUSS THIS ISSUE

Practical application of electronic reporting has long roots in the United States and Europe and continues to win new positions. In countries of the CIS as Russia and Kazakhstan, the transition to the new report filing system gave positive results. Nowadays the taxpayers of these countries have completely switched to this reporting system. Every day electronic reporting is becoming more and more popular [5, 20].

The laws on digital signature has been implemented in Germany, Austria, France, India, Ireland, the Republic of Korea, Lithuania, Poland, Finland, Estonia, Russia, Thailand, etc. Similar laws have been applied even in countries where there was a steady tradition of contractual jurisdiction to regulate discretionary economic activities between contractors, such as the UK and the U.S. The law on electronic document has been adopted in Belarus.

Electronic signatures are widely used in the Republic of Estonia, which introduced ID-card program that involves near 75 percent of the population. By means of an electronic signature in March 2007, elections had been held for the local parliament - the Riigikogu. 400 thousand citizens used electronic signature while they were voting. In addition, by using digital signatures one may send a tax or a customs declaration and other forms to different local governments and state agencies. In large cities, using ID-card, citizens can purchase month bus tickets. This is done through a central civil portal. Estonian ID-card is mandatory for all citizens who are 15 years old residing temporarily or permanently in Estonia [2].

Of course, each state has established a more or less liberal approach to regulating the use of cryptographic (technological) resources [3].

In addition, in modern publications the possibility of using cloud services for public information services has been analyzed. It is necessary to analyze the security problems of client data, as well as to ensure the acceptable response time from information services side. Mobile devices are surpassing desktops and notebooks. There is a need to reduce operating costs and optimize the use of computing resources [21].

The issues that are considered in this article are relevant, as evidenced by the publication of professionals who work directly in the industry, at conferences at various levels [8, 15, 16, 19].

ASPECTS OF UNSOLVED PROBLEM

However, Nowadays along with the obligatory performance of statutory regulations problematic issues regarding the use of digital signatures of state and local governments to citizens and business entities remain unsolved. The lack of a unified submission process standard as for processing, use and report storage, the legislative, methodological, organizational and technical interoperability of stakeholders who are submitting electronic reports. Formulation of article goals (problem).

We believe that finding the ways to perform statutory norms in electronic document organization of state institutions and local self-government authorities with citizens and business entities using digital signatures in accordance with the current legislation is relevant and timely.

THE MAIN MATERIAL OF RESEARCH AND EXPLANATION OF SCIENTIFIC RESULTS

For the first time the idea of receiving reports electronically in Ukraine originated on the verge of XX-XXI centuries. At that time, it was about the formation of electronic copies on magnetic or other media, and presenting them to the public authorities along with paper copies of reports. One of the prerequisites for the operation of this system provided that it should maintain the means of digital signature of all Certification Authorities operating in Ukraine in accordance to applicable law.

Composing and submission of electronic documents, electronic documents and digital signature overlay regulated by the Law of Ukraine "On electronic documents and document flow" dated 22.05.2003 № 851 "On electronic digital signature" from 22.05.2009 № 852 [12, 13].

Every day there are more and more reports submitted to the state electronically. For example, thousands of Ukrainian taxpayers, who have chosen this path, have already understood the convenience and efficiency of reporting electronically. First, the possibility of tax reports electronically will significantly reduce the time, and secondly, minimize the possibility of errors in reporting, and, thirdly, decidedly reduce paper-based operations. Also, there will be fewer documentary and counter checks as tax officers attention will be concentrated primarily on those taxpayers who avoid paying taxes.

The system allow to automate the process of submission and acceptance of tax returns, avoiding queues and direct contacts between tax inspectors and officials of taxpayers, preventing malpractice in the process. In addition, it eliminates the possibility of error while transferring data from paper to electronic media report.

2013 was the year of large-scale implementation of electronic services for the Ministry of Revenue and Duties of Ukraine (Ministry). As a result, today tax returns are handed in on-line by over 92% of taxpayers. 82% of economic agents use features of electronic declaration of goods.

During 2013, economic operators drew up 2.3 million electronic customs declarations. Compared with 2012 the number of electronic customs declarations had increased almost 4 times. According to Ministry statistics, in 2012 the number of electronic customs declarations constituted only 20% of the submitted documents. In 2013, this figure rose to 70% already. Taxpayers spent fulfilling their tax obligations for 100 hours this year less than the previous year.

The unified social tax has also shifted to an electronic format to communicate with the public revenue and fees because all conditions have created. As a result, only in November-December 2013 the number of electronic reports has increased from 38% to 60%. Moreover, this is not the limit.

Citizens were able to declare income and assets over the Internet in 2013 for the first time. Largely due to this the number of handed in files has increased compared to the previous year by 7%, the amount of reported income - 27%.

Implementing of e-office of the payer was completed in 2013. This is a massive project that will not only enable to report on-line, but also give users the ability to check payments to the budget remotely, to remember, when and which taxes must be paid. This is the first step to build a national One-stop shop system of electronic reporting, which will include other authorities.

All this improvements were possible because of the Certification Authority of the Information Reference Department in the Ministry (hereinafter - CA IRD).

For obtaining digital signatures one should apply to the offices of User Registration Center. There are 104 such points that operate in Ukraine today.

868 thousand taxpayers who formed around 1333 thousand reinforced certificates are customers of CA IRD today.

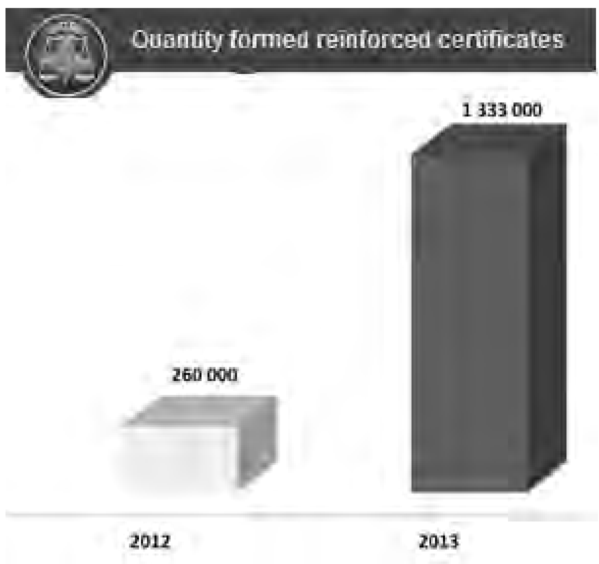

Fig. 1. Quantity of formed reinforced certificates

Over 50 thousand of payers turn to the Ministry to get free keys monthly that is twice more than last year. The most numerous category of the clients are individuals, the number of which is 73%.

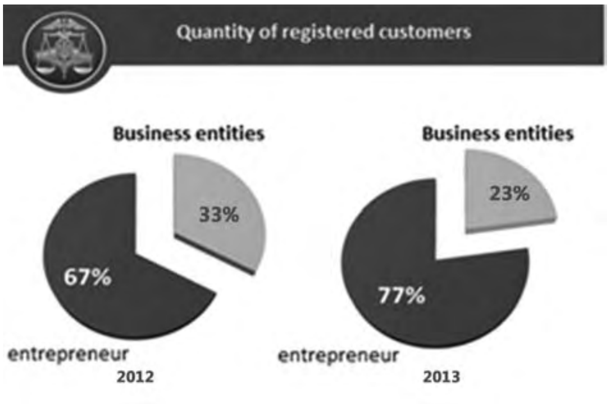

Fig. 2. Quantity of registered customers

For 634 000 registered individuals and citizens in the center have issued 763,600 signatures during 2013. Among the Customer Center entities there were 234,000 people who have ordered 569,400 keys at this period.

Also, pay attention to the fact that Public Key Certificates on Ministry are formed for the period of two years since November 1, 2013. This possibility of Certification Authority, which operates under the Ministry, received after the procedure of accreditation. It formed a new technology certificates and servers Center, which helped extend the digital signature. All reinforced certificates that were formed before the effective date of this order should be served to the end of their validity. That is, the certificates received by 01.01.2014, are valid and will apply from the date of reception for 2 years.

Key digital signature issued by CA IRD enable to report on-line not only to the Ministry, but also to the State statistics of Ukraine and the Pension Fund of Ukraine.

From January 1, 2014 CA IRD switching to two Public Key Certificates. According to experts of the Center, a cryptographic message format will enhance the protection and safety of filing reports electronically using digital signature and provide a high level of security to protect confidential information. The digital signature implies that each user has its secret key which is used to create a signature (for data encryption) and private key corresponding to this public key that matches the public key certificate that is designed to decrypt the digital signature when obtaining report. Thus, on January 1 2014 to encrypt and decrypt information used by experts and customers Ministry need to use two separate certificates to prevent counterfeiting of keys and enhance the protection of information from unauthorized modification by unauthorized persons.

These innovations have been provided by the Order of the State Service for Special Communication and Information Protection of Ukraine from 18.12.2012, № 739 "On Approval Requirements for Cryptographic Message Formats", registered with the Ministry of Justice of Ukraine 14.01.2013, №108/22640.

Due to CA IRD innovations new forms of documents registration was developed, it can be downloaded from the official information resource http://acskidd.gov.ua.

We emphasize that ACA IDD MD also provides free certificates to users and Uniform State Register of the Ministry of Justice of Ukraine.

Accountability in electronic form includes already 224 thousand cash registers. That is the number of payment transactions on January 1, 2014 which was obtained from cash registers connected to the storage system and collected Cash and settlement operations data to Ministry. Less than 10% of vehicles remained disconnected among the total cash appliances. During retrofitting techniques people can use the State Register of transactions, where there are 86 certified devices. These cash registers meet current requirements and can transfer control and reporting information about income and charges in electronic form. A complete list of payment transactions that are included in the State Register, is available on the Ministry website http://minrd.gov.ua/dovidniki--reestri--perelik/reestri/94957.html

With key digital signatures, a taxpayer has an opportunity not only to submit reports electronically but also to use a variety of additional services. The following are some of them:

- the updated website of the State Tax Service of Ukraine,
- ministry Databases (Databases VAT payers, Cancelled Certificate of VAT, Address mass registration of taxpayers and others),
- service "Information message about debts, dues",
- the project "Electronic office".

This service launched in beta in July 2013. Large number of taxpayers had the first view of the services level, and since December 2013 it is available for all categories of taxpayers.

Electronic Office project – is a personal service a payer works with and he can access it from any computer connected to the Internet, after authorization. The advantage of the new service is filing tax reporting in real time. The payer will immediately see how the performance of his statements affected his settlement with the state budget. Tax report can be submitting as a package including declaration and all attachments. For each document received, a receipt of acceptance of the declaration will be issued. Electronic office will be expanded in the nearest future. For example, taxpayers will be able to view documents issued by Ministry, to fill out vouchers to pay taxes, to calculate penalties, to apply for registration of individual tax payer, to receive counseling services and more.

Electronic office can be accessing at the Ministry portal http://knp.minrd.gov.ua/ Publish /PublishedApp.aspx or on the Ministry portal with authorization by digital signatures.

System "E-card".

A payer will be able to conduct certain transactions electronically with a personal cabinet online using digital signature: Submission of data, filing, reporting, getting information about the status of payments to the budget and so on. Implementation of the system will last in 2012-2016 years.

Realizing the importance of the tax system in society, TAX Ukraine for the first time among the state executive bodies identified strategic mission of the activity - the transformation of the tax service in a fiscal instrument of fiscal revenue in highly skilled customer service with taxpayer service by implementing electronic services that may be obtaining by using the key digital signatures.

All reports to the central government will be submitted through a special "One-Stop Shop" on-line and a single unified standard soon. A concept of creation and operation of automated system "One-Stop Shop filing electronic filing" has approved in August 2013 by the Government. The concept implies that citizens and businesses will be able to apply accounting data once and remotely instead of making a large number of identical accounting data for different authorities and different standards. Information exchange will adjusted automatically between the central government bodies for quick access to the accounting data necessary to perform their duties.

According to Ministry experts, which acted as the initiator of this issue, the implementation of "One-Stop Shop" will allow citizens and businesses to save time and reduce material costs for the preparation and filing, and governments - to its acceptance and processing. In addition, just as importantly, this will abandon paper-based operations and reduce the role of the human factor: the presence of errors in reports, subjectivity, corruption and so on.

Generally, a "One-Stop Shop" - is an important component of e-government, the implementation of which will improve the business environment and investment climate. It has expected that this concept will be implemented in three stages: the first - the unification of electronic reports to be submitting to central government in electronic form, the second - the introduction of common standards for the formation and filing electronically, the third - the introduction of commercial operation. Implementation of the system will provide some benefits.

1. For subjects reporting:

- simplification of procedures for preparing and submitting reports electronically (especially for businesses that are reported in a large number of regulatory bodies),

including reducing the time and cost of preparing and submitting reports,
- possibility of remote submission of all reports to any supervisory authorities through a single point,
- operational feedback from regulatory authorities, implementation of related services that provide a new quality of relations between these authorities and reporting entities,
- simplification in general business conditions and economic activity.

2. For supervisory authorities and the state as a whole:

- reporting to regulatory authorities process optimization and systematization, including the introduction of a single unified regulatory Default information and interagency information exchange,
- reduce the time for processing statements, reducing the associated errors, subjective effects of "human factor",
- gradual costs reduction associated with the administration of the process of reporting to regulatory authorities,
- improving the efficiency of the tax system, the system of compulsory social insurance, other public institutions, increase revenues to the budgets of all levels and social funds.

Recall Concept creation and operation of automated systems "One-Stop Shop filing electronic filing" developed by the Ministry of income and fees pursuant to the National Action Plan for 2013 to implement the program of economic reforms for 2010-2014 years "Prosperous Society, Competitive Economy, Effective State", approved Decree of the President of Ukraine on 12 March 2013.

In the implementation of the Cabinet of Ministers of Ukraine № 809 [2] to enable the formation of reporting to the Pension Fund of Ukraine, the State Statistics Service of Ukraine and the Ministry of the proceeds and fees of Ukraine, as well as the imposition of digital signature and encryption of electronic documents, the Ministry of Ukraine of income and charges introduced into trial operation complemented software "Specialized client software for the development and submission of reports to the "One-Stop Shop of electronic submission of reports". In this formation the software implements reporting to the State Statistics Service of Ukraine and the Ministry of income and charges of Ukraine, as well as the imposition of digital signature and encryption of electronic records.

According to the Limited Liability Company "Sihnis" from September 17, 2013 in software "SONATA" (hereinafter - Software "SONATA") the support is reliable by means of digital signature of Ministry CA IRD. Thus, customers of Ministry CA IRD can use software "SONATA" for submitting reports electronically to the Ministry authorities (228 forms), the Pension Fund of Ukraine (8 reports and 29 forms) and the State Statistics Service of Ukraine (28 forms). Forms are automatically updating. Their number is constantly increasing. More information regarding the software "SONATA" is available on the website http://sonata.biz.ua

Online service allows customers of iFinZvit CA IRD to sign and submit to the regulatory agencies electronic reporting of Ministry, the Pension Fund and the State Statistics Service of Ukraine free of charge. More information regarding the online service iFinZvit is available on the website https://zvit.ifin.ua.

PERFORMANCE AND SECURITY ASPECTS

To implement "One-Stop Shop" system governmental agency must follow the recommendations of ITIL providing a proper service strategy, service design, service transitions, service operations and continual service improvement, which comes in support. Users of the system create thousands of transactions per second, so you need to ensure a sufficient level of performance. Also, please note that the load varies over a wide range and at nighttime, the resources will be uncalled. In such circumstances, it is preferable to use of hybrid cloud services that reduce operating costs and provide a good level of scalability, efficient use of allocated resources. By creating a private cloud, we can effectively eliminate the provisioning bottleneck present in the datacenter virtualization model while preserving cost savings as the same many-to-one relationship exists between VMs and physical hosts.

There are several areas of consideration that should guide system architect evaluate hybrid cloud for "One-Stop Shop" system needs:

- workload and infrastructure interaction,
- security compliance,
- reduced network latencies,
- resources cost and bandwidth consumption.

Current trends are that users are increasingly using their personal devices in the workplace, which increases the efficiency in solving enterprise tasks. The growing number of consumer gadgets is changing the system architecture, creating not only important opportunities but also massive risks for customers. Mobile trend has defined by several factors.

Modern smartphones and tablets can perform workplace IT-operations and customers are demanding to use them for work and play. Smartphone and tablet sales have already surpassed PC sales. But these mobile devices were built for the consumer world and lack enterprise-grade security capabilities.

Customers want to use their mobile devices for solving different work and personal tasks. Many researches indicate that over 80 percent of workers use a personal device for work-related functions and more than 60 percent of organizations enable "Bring Your Own Device" (BYOD) policy.

Mobile computing is becoming central to the way people interact, work, learn and communicate. The benefits of using consumer mobile technologies for the tax paying are very important, including increased agility, improved productivity, and reduced costs.

Governmental agency should encourage their users to follow certain rules of use with mobile devices. This concerns use protocols, password policies and additional software installation. According to AOL Government Mobility Study security is the greatest barrier to supporting mobile technology especially to defense employees.

CONCLUSIONS

1. Using digital signatures to automate information interaction of state and local governments with citizens and business entities is an important segment of interrelations, the style of XXI century, which is an integrated information processing system. Still there is a lot of work in this area to develop as for natural and legal persons and state.

2. a free key digital signatures issuing by Ministry CA IRD has been established. It is the only state accredited. Practically only in our country there has been developed and is supported a free tax software, while it is not always actual and difficult to use.

3. Automated system "One-Stop Shop submission of electronic reports" should provide support to the means of digital signature of all Certification Authority operating in Ukraine in accordance with applicable law. Other formats (standards), the structure of digital documents, providing electronic submission of reports will be placed and kept up to date at no charge to users based on publicly available information resources.

4. Automated system of "One-Stop Shop submission of electronic reports" has become one of the most important elements. It has practically implemented as a nationwide system of e-government that will continue effective implementation in all spheres of public life. Taking into account the principles of construction of the system, it is advisable to provide other services ("United State Portal of administrative services" http://poslugy.gov.ua at present under development and testing).

5. Applying digital signatures will create a comfortable environment for business operation, will establish non-contact way of information interaction of state and local governments with citizens and business entities, will minimize the role of human factors, and thus avoid corruption. Moreover, this is a true European approach.

6. Governmental agency should encourage their customers to follow certain rules of mobile devices usage. This concerns the use of protocols, password policies and additional software installation. A private cloud has recommended to implement the "One-Stop Shop" system, which must meet the requirements of: workload and infrastructure interaction, security compliance, reduced network latencies, resources cost and bandwidth consumption.

REFERENCES

1. **Boguta A., 2011.:** Zastosowanie monitoringu ip w systemie nadzoru budynku. Lublin University of Technology. TEKA Commission of Motorization and Power Industry in Agriculture, Tom XIC. – 9-17.
2. Cabinet of Ministers of Ukraine "On Approval of Measures of the establishment and functioning of the automated system of "One-Stop Shop of electronic submission of reports" from 17.10.2013 № 809 [Electronic resource]. – Mode of access: http://zakon1.rada.gov.ua/laws/show/809-2013-р. (in Ukrainian).
3. Digital signatures [Electronic resource]. – Mode of access: http://www.yurpractika.com/article.php?id=0000979. (in Russian).
4. Digital signatures [Electronic resource]. – Mode of access: http://конференция.com.ua/pages/view/656. (in Ukrainian).
5. **Ivahnenkov S., 2006.:** Information technology in accounting and auditing: Training guidances. – 3 ed., Rev. and add. – K.: Knowledge. – 350. (in Russian).
6. **Konovalenko M.K., 2006.:** Regional aspects of the promotion of innovative activity in Ukraine / M.K. Konovalenko, R.A. Koval // Actual problems of governance : Coll. sciences works. – Kharkov: Type of KRI NAPA "Master" , 2006. – № 1 (27). – 353-360. (in Ukrainian).
7. **Koval R.A., 2007.:** Elements of information-analytical system of state and local government // Actual problems and prospects of development of the economy of Ukraine: Materials VI Internat. sciences -practical. conf., Alushta, 4-6 oct. 2007 – Simferopol. – 226. (in Ukrainian).
8. **Koval R.A., 2007.:** Information-analytical system of management of the regional authorities: current approaches to their development / R. Koval // Actual problems of governance: Coll. sciences works. – Kharkov: Type of KRI NAPA "Master", 2007. – № 1. (31). – 349-358. (in Ukrainian).
9. **Koval R.A., 2006.:** Information and analytical support of public authorities / Koval R.A. // Theory and Practice of Public Administration: Coll. sciences. works. – Kharkov: Type of KRI NAPA "Master", 2006. – № 1 (113). – 223-226. (in Ukrainian).
10. **Koval R.A., 2008.:** Public Administration in the Information Society: perspectives on e-governance / Koval R.A. // Economy and State. – 2008. – № 4. – 81-84. (in Ukrainian).
11. **Ksieniia Sieriebriak, 2012.:** Information technologies in Ukraine: problems and obstacles. TEKA Commission of Motorization and Power Industry in Agriculture, Tom XII_3. – 128-135.
12. Law of Ukraine "On electronic digital signature" from 22.05.03 №852-IV. [Electronic resource]. – Mode of access: http://zakon2.rada.gov.ua/laws/show/852-15. (in Ukrainian).
13. Law of Ukraine "On electronic documents and electronic document" from 22.05.03 №851-IV. [Electronic resource]. – Mode of access: http://zakon2.rada.gov.ua/laws/show/851-15. (in Ukrainian).
14. Law of Ukraine "On state registration of legal entities and natural persons - entrepreneurs" from 15.05.2003 №755-IV [Electronic resource]. – Mode of access: http://zakon2.rada.gov.ua/laws/show/755-15. (in Ukrainian).
15. **Kalinesku T.V., 2011.:** Mechanisms to ensure tax-sufficiency: monograph / [Authors] for science. Ed. TV. – Lugansk: publ EUNU Dal, 2011. – 247. (in Ukrainian).
16. **Okhten A., Kiselev M., 1998.:** Electronic documents and standardization // Law of Ukraine. – 1998. – № 3. – 45-48. (in Ukrainian).
17. Order of the Ministry of Justice of Ukraine of 04.01.2013 № 43/5 "On Amendments to the Procedure for the submission and circulation of electronic documents state registrar" registered with the Ministry of Justice of Ukraine on 01.08.2013 under number 69/22602. [Electronic resource]. – Mode of access: http://zakon4.rada.gov.ua/laws/show/z0069-13. (in Ukrainian).
18. Order of the Ministry of Justice of Ukraine of 19.08.2011 №2010/5 "On approval of the submission and circulation of electronic documents state registrar" registered with the Ministry of Justice of Ukraine on 23.08.2011 under №997/19735 [Electronic resource]. – Mode of access: http://zakon4.rada.gov.ua/laws/show/z0997-11. (in Ukrainian).
19. **Petrov A.S., Samozdra M.M., 2012.:** Free key digital signatures for taxpayers / Information Security number 1 (7) Lugansk: publ EUNU Dal, 2012. – 144. (in Ukrainian).
20. **Tereshchenko LA, Matienko Zubenko I.I., 2005.:** Information Systems and Technologies in Accounting : Teach. guidances. – K.: MBK, 2005. – 187. (in Ukrainian).

21. **Zharikov Eduard, 2013.:** Analysis of the theoretical and applied aspects of modern IT infrastructure TEKA Commission of Motorization and Power Industry in Agriculture – 2013, Vol. 13, No.4, 297-306.

ВНЕДРЕНИЕ АВТОМАТИЗИРОВАННОГО ИНФОРМАЦИОННОГО ВЗАИМОДЕЙСТВИЯ КАК СОСТАВЛЯЮЩЕЙ ИНТЕГРИРОВАННОЙ ИНФОРМАЦИОННО-АНАЛИТИЧЕСКОЙ СИСТЕМЫ

Михаил Самоздра, Эдуард Жариков, Оксана Самоздра

Аннотация. В статье исследована реализация информационно-аналитической системы на базе современной ИТ-инфраструктуры для автоматизированного информационного взаимодействия на примере органов государственной власти и органов местного самоуправления с гражданами и субъектами хозяйствования, в том числе с использованием электронно-цифровой подписи.

Ключевые слова. Автоматизация, информационное взаимодействие, интегрированная информационно-аналитическая система, ИТ-инфраструктура, информационная инфраструктура, электронные сервисы, отчетность, электронно-цифровая подпись.

Theoretical studies of horizontal dynamics parameters of the «wheel-rail» kinematic pair

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Summary. The article made a deep analysis of scientific publications researching horizontal dynamics performance of "wheel-rail" kinematic pairs. There has been worked out the scheme of the cohesive forces in the main crest contacts and "wheel-rail" kinematic pair by applying the theory of mechanisms and machines. There has been given calculation data pf transverse displacements of wheelsets and bogie frames, yaw angles wheelsets , angular velocities of wheel pairs at maximum speed and normal loads in the main contacts. There has been worked out the scheme for the passage of wheel wags turnout and shown the calculated dependence of rudder crest contact with racking wheel on the rail. There has been made a conclusion about the reliability of the theoretical research results.

Key words: "wheel-rail" kinematic pair, cohesive forces, horizontal dynamics, crest contact, sliding speed.

INTRODUCTION

Lack of reliable scientific data on frictional contacting of wheels and rails is an indirect cause of many problems in the "wheel-rail" kinematic pair. Among them - excessive wear of the wheels and rolling surfaces of the rails, particularly the undercut crests, increased resistance to movement of the kinematic, dynamic elevated horizontal load on the track, and others.

The main problems of horizontal dynamics and surface wear are associated with contacting the crest. In this regard, accurate simulation of the two-point contact with the rail wheels with the description of the crews kinematics direction by rail track, including the clash of the crest on the rail and wheel input turnout is crucial in the study of horizontal dynamics indicators in "wheel-rail" kinematic pair.

PUBLICATION ANALYSIS

The most important research of horizontal dynamics indicators in the "wheel-rail" kinematic pairs, forming the basis of the dynamics of railway rolling stock as a section of mechanics, are the works of the following scientists: MF Verigo [22], A.L.Golubenko [3], V.D.Danovich [2], A.I.Karmazin [4] V.G.Masliev [6], and others.

In studies conducted by scientists of the Dnepropetrovsk scientific school – E.P.Blohin, G.I.Bogomaz, Yu.V.Demin, M.L.Korotenko, V.F.Ushkalo, there was made a significant contribution to the science of the interaction of track and rolling stock composition. There have been developed fundamental methods of statistic dynamics and stability theory of railway vehicles.

In [9, 20, 1, 18, 21, 8] there have been suggested mathematical models, with varying degrees of completeness, showing the main features of the "kolesos" and allows you to examine both steady states and stability of the unperturbed motion of railway vehicles, taking into account the contact forces.

Design diagrams, mathematical models of the crew and track to a great extent reflect the physical processes that take into account the characteristics of the relationships between elements of systems, disturbing factors and mode of traffic.

The resulting system of nonlinear differential equations with right-hand sides is examined by using a computer [12, 23].

According to the nature of oscillatory processes elements crews, there are made conclusions about the stability of their motion, the amplitudes of forces and accelerations acting on them.

This method allows us to study the dynamics of the vehicles movement and get the motion characteristics of the system elements power interaction, wear characteristics.

In [13, 14] there has been suggested a fundamentally new approach to the classical problem of the wheels contact with the rails and has been used in studies of the "carriage-way."

Questions of coupling dynamics, crews rail gauge direction, kinematic frictional resistance to movement, were first investigated at a precise description of the wheels in contact with the rail, including a two-point [15].

In particular, in [16], the problem of redistribution of normal stresses in the wheel contact with the rails, was solved with contact deformations.

The considered works, depending on the level of detail modeling of contact wheels with rails, can be divided into three groups.

To first refer operation in which the wheel profile is seen in a simplified form as a conical surface.

This, above all, is a study where differential equations linearization systems are performed to study the stability of motion.

Naturally, in this case contact is considered as a single point. Same type of modeling is most often used in studies of locomotives traction qualities.

The second group consists of works in which the profiles of wheels and rails are considered to approximate the actual profiles, but the contact is considered as a single point.

It uses both linear and nonlinear friction characteristics.

It should be noted that while introducing of external friction characteristics as a depending of coefficient on the relative coupling coefficient of sliding, a precise description of the profile of the wheel and the rail is not essential, since the restriction of singleton contacting key pair - meters kinematics interaction - the radius of the rolling circle and taper wheel - changes slightly [5, 7].

The third group includes a few studies in which the contact of wheel and rail is considered as a two-point.

However, there are no works where at the same time there would be considered the following features of two-point contacting:

- the redistribution of loads between normal contacts,
- the velocity distribution of the sliding contact,
- taking into account the difference in the laws of friction on the contact surface of rolling contact and raised bed,
- describing kinematics and dynamics of the two-point contact system "wheel-rail" in a turnout with regard to the shape profile of the wheel and rail [22].

PURPOSE OF RESEARCH

Therefore, the aim of this work is to develop methods of calculating horizontal transverse crews vibrations by improving the modeling of two-point wheel contact with the rail.

The task of theoretical research is to obtain the comparative dynamics horizontal engine with extremely worn crests of wheels bandages. To check the validity of the results of theoretical research, the model debugging was performed by checking derivatives and intermediates for the parameters of robust criteria:

- transverse displacement of wheelsets and bogies frames,
- periods of wavelengths and wiggle angles in wheelsets and bogies frames,
- angular speed of wheelset, velocity slip in the main crest and contacts,
- normal stress in the core and the crest contacts of wheels with rails and turnout elements.

RESEARCH RESULTS

To calculate the contacts coupling force there has been used the method of professor V.Tkachenko [17, 18], which is based on the dependence of the longitudinal and transverse forces coupling on longitudinal and transverse velocities in sliding contacts.

Shows a diagram of adhesion forces in the main contacts K_{1jk}.

In the main contacts K_{1jk} relative movement of the wheel and the rail has rolling nature of slip or grip.

Longitudinal S_{x1jk} and transverse S_{y1jk} components of adhesion forces in the main contacts (Fig. 1) [10, 11]:

$$S_{x1jk} = -N_{1jk} \cdot \Psi_0 \cdot k_{x1jk};$$
$$S_{y1jk} = -N_{1jk} \cdot \Psi_0 \cdot k_{y1jk}, \qquad (1)$$

k_{x1jk}, k_{y1jk} – regarding the longitudinal and transverse coefficients using the clutch, which are defined by the formulas [19]:

$$k_{xjk} = \frac{\varepsilon_{xjk}}{a_x \cdot \varepsilon_{xjk}^2 + b_x \cdot \left|\varepsilon_{xjk}\right| + c_x} \cdot \frac{d_x}{e_x + \varepsilon_{yjk}^{g_x}}, \qquad (2)$$

$$k_{yjk} = \frac{\varepsilon_{yjk}}{a_y \cdot \varepsilon_{yjk}^2 + b_y \cdot \left|\varepsilon_{yjk}\right| + c_y} \cdot \frac{d_y}{e_y + \varepsilon_{xjk}^{g_y}}, \qquad (3)$$

where:

$a_x, b_x, c_x, d_x, e_x, g_x, a_y, b_y, c_y, d_y, e_y, g_y$ – empirical correlation coefficients grip [13],

ε_{xjk}, ε_{yjk} – respectively, the longitudinal and transverse sliding core in the main (first) contacts in coordinate systems for wheel profiles $O_{jk}X_{jk}Y_{jk}$:

$$\varepsilon_{xjk} = \frac{v_{x1jk}}{\dot{\varphi}_k \cdot R_{1jk}}, \quad \varepsilon_{yjk} = \frac{v_{y1jk}}{\dot{\varphi}_k \cdot R_{1jk}}, \qquad (4)$$

or, given the fact that $\bar{v}_{1jk} = \bar{V} + \bar{V}_{\varphi 1jk} + \bar{V}_{\psi 1jk} + \bar{V}_{y1k} + \bar{V}_{p1jk}$:

$$\varepsilon_{x1k} = \frac{V \cdot cos\psi_k + \dot{\psi}_k \cdot A}{\dot{\varphi}_k \cdot R_{1jk}} - 1, \qquad (5)$$

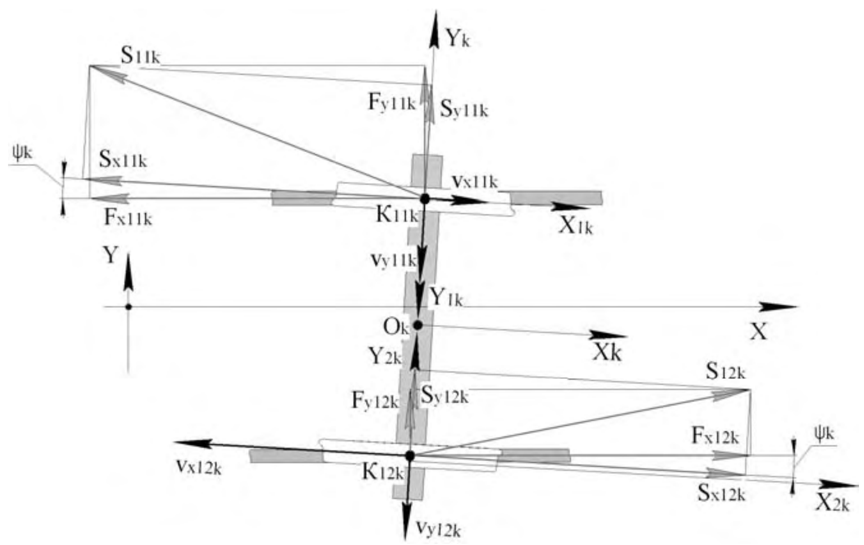


Fig. 1. Scheme of adhesion forces in the main contacts

$$\varepsilon_{x2k} = \frac{V \cdot cos\psi_k - \dot{\psi}_k \cdot A}{\dot{\varphi}_k \cdot R_{12k}} - 1, \qquad (6)$$

$$\varepsilon_{yjk} = \frac{\dot{y}_k - V \cdot sin\psi_k - \dot{y}_{pjk}}{\dot{\varphi}_k \cdot R_{1jk}}. \qquad (7)$$

Traction in key contacts in the absolute coordinate system: OXY :

$$S_{1jk} = \sqrt{S_{x1jk}^2 + S_{y1jk}^2}. \qquad (8)$$

The force of adhesion F_{x1jk} i F_{y1jk} in key kontacts of the absolute coordinate system OXY :

$$F_{x1jk} = S_{x1jk} \cdot cos\psi_k + S_{y1jk} \cdot sin\psi_k, \qquad (9)$$

$$F_{y1jk} = S_{y1jk} \cdot cos\psi_k - S_{x1jk} \cdot sin\psi_k. \qquad (10)$$

In Fig. 2 there is shown a diagram of adhesion forces in the main and crest contacts for two-point contacting of the wheel with a rail.

In the crest contacts K_{2jk} relative movement of the wheel and the rail has the character of sliding friction, so the strength of adhesion in crest contact S_{22k} can be determined by Culon's law:

$$S_{22k} = -N_{22k} \cdot f_0 \cdot sign(v_{22k}), \qquad (11)$$

where: f_0 − friction coefficient in crest contact.

Longitudinal S_{x2jk} and vertical S_{z2jk} components in the adhesion force of crest contacts systems of wheels coordinates $O_{jk}X_{jk}Y_{jk}$:

$$S_{x22k} = S_{22k} \cdot sin\zeta_{2k}, \qquad (12)$$

$$S_{z22k} = S_{22k} \cdot cos\zeta_{2k}. \qquad (13)$$

Longitudinal F_{x2jk} and transverse F_{y2jk} components of adhesion forces in crest contacts in the absolute coordinate system OXY :

$$F_{x2jk} = S_{2jk} \cdot cos\psi_k, \qquad (14)$$

$$F_{y2jk} = S_{2jk} \cdot sin\psi_k. \qquad (15)$$

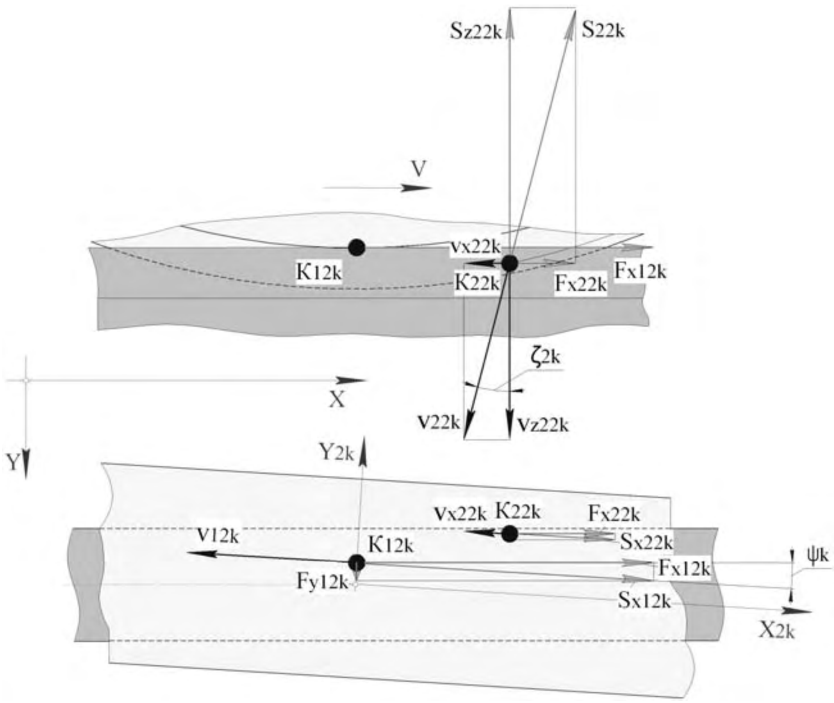


Fig. 2. Scheme of adhesion forces in the crest contacts

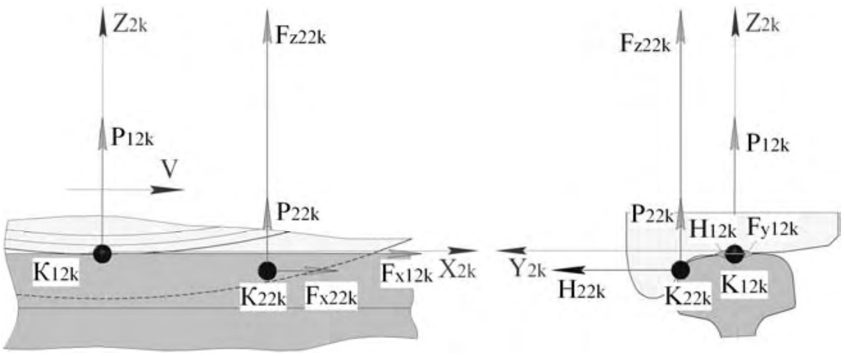


Fig. 3. The contact forces structure of two-point contact with the rail wheels

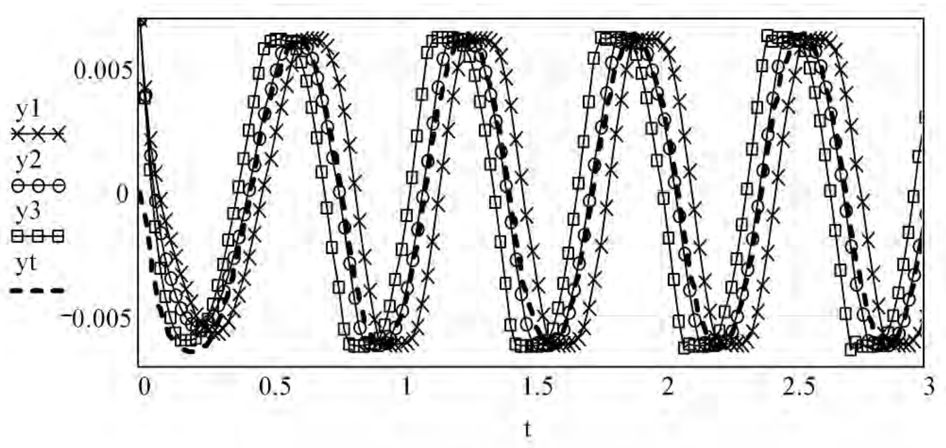


Fig. 4. Transverse displacement of wheelsets and bogies frames for velocity of 30 m/s: y1, y2, y3 – lateral movement (side assignment) of wheelsets, yt – lateral movement (side assignment) of the frame cart, t – time, s

Fig. 3 shows the structure of the contact force to the wheels that have a two-point contact with the rail.

Vector equation of contact forces acting on the wheel bogies from the rails along the axes of the absolute coordinate system, are as follows:

$$\overline{X}_{jk} = \sum_{i=1}^{2} \overline{F}_{xijk} \ , \tag{16}$$

$$\overline{Y}_{jk} = \overline{F}_{y1jk} + \sum_{i=1}^{2} \overline{H}_{ijk} \ , \tag{17}$$

$$\overline{Z}_{jk} = \overline{F}_{z2jk} + \sum_{i=1}^{2} \overline{P}_{ijk} \ . \tag{18}$$

Calculation results of deterministic dependency of kinematic and dynamic crew motion parameters in a straight section lines are shown in Fig. 4-8.

In Fig. 4 there is shown the calculation of the transverse displacements (lateral assignment) of wheelsets and bogies frames at maximum speed of movement – 30 m/s. The period of oscillation for speeds is 0,72 s, and the wavelength wiggle – 21,6 m.

The calculation of wheelset wiggle angles shown is shown in Fig. 5. The maximum wiggle angles for the speed of 30 m/s were 0,0028 rad.

In Fig. 6 shows the calculation of the angular rotation velocity of the wheelset around their rotation axes. Fluctuations in the angular velocity is associated with the wheelsets wiggle noticeable at speeds over 20 m/s.

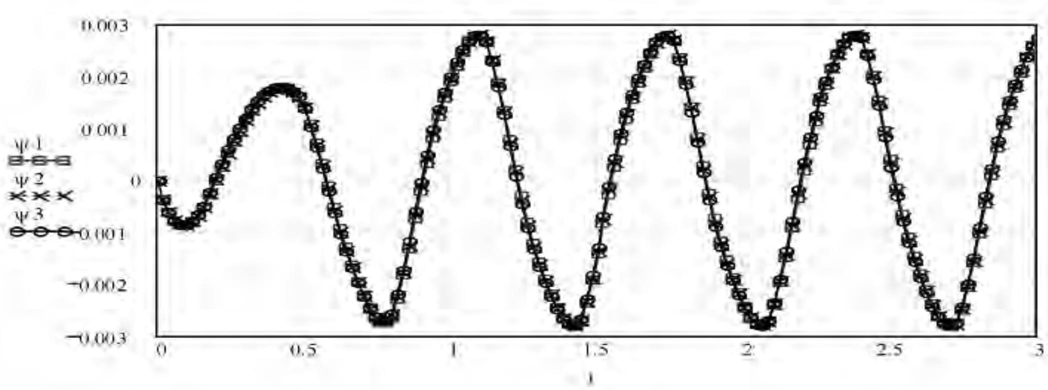


Fig. 5. Angles of wheelsets wiggle for velocity of 30 m/s, ψ1, ψ2, ψ3 – wiggle angles, respectively, 1, 2 and 3 first trolley wheelsets, t − time, s

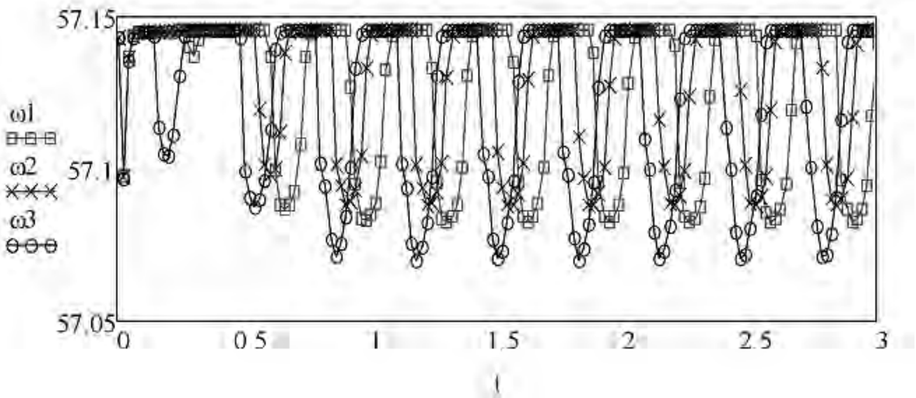


Fig. 6. Angular wheelset velocity for velocity of 30 m/s, ω1, ω2, ω3 – angular velocity of the 1, 2 and 3 wheelset, rad/s

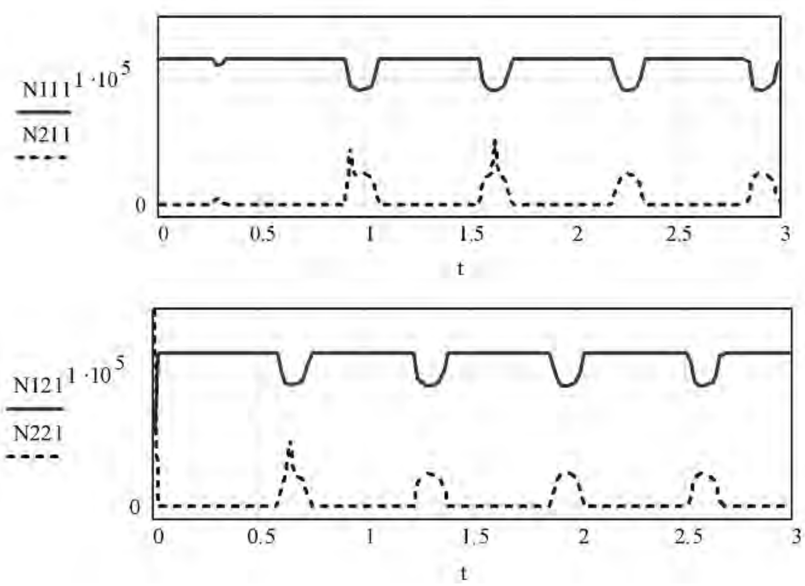


Fig. 7. Normal load on the main N1jk and crest N2jk contact wheels with the rails when driving in a straight section of track at a speed of 30 m/s

Fig. 7 shows the calculation of normal reactions in the core - N111 ... N121 and N211 ... N221 crest contacts of wheelset wheels for velocity of 30 m/s: N111, N121 - basic, N211, N221 - the crest contact of first wheelset wheels.

Sliding velocity in the main and crest contacts are considered as the velocity of the wheels crest surface under the surface of the rails, and, regardless of whether there is direct contact surfaces or not. Therefore, the rate of slip is conditional and is called the conventional sliding speed.

Fig. 8 shows an example of changes in conventional velocity sliding in crest contacts in the third wheelset wheels locomotive at a speed of 30 m/s.

Fig. 9. scheme of wheel studs passage in protysherstnomu movement in turnouts is shown in.

In Fig. 10 shows calculations of relaying the crest contact at vkochuvanni of wheel on the studs of a turnout at protysherstnomu motion for speeds of 10 m/s and 20 m/s.

Depending on the crest contact pattern there can be identified three phases hitting the wheel on studs (Fig. 11).

The first phase - hitting the rail of frame – exists on the section from point I to point II. At this phase the crest contacts with the groove of frame rail at point K_2, and between the studs and the edge of the crest there is a gap τ_1, which decreases as we approach point II. In this case, the vertical and horizontal components of the normal crest reactions depend on the angle of contact:

$$P_2 = N_2 \cdot sin\,\mu\,, \qquad H_2 = N_2 \cdot cos\,\mu\,, \quad (16)$$

where: contact angle $\mu = 90 - \gamma_2$.

The second phase – hitting on the tip studs - takes place in the area from point II to point III (Fig. 12). In this phase, the crest contacts with elements of turnout at two points: the point K_2 - with frame rail and at the point of K_3 – with studs. Changing the values of the reaction N_2, N_3 in section II-III is shifting nature: at the point of II – N_3=0, and in point III – N_2=0.

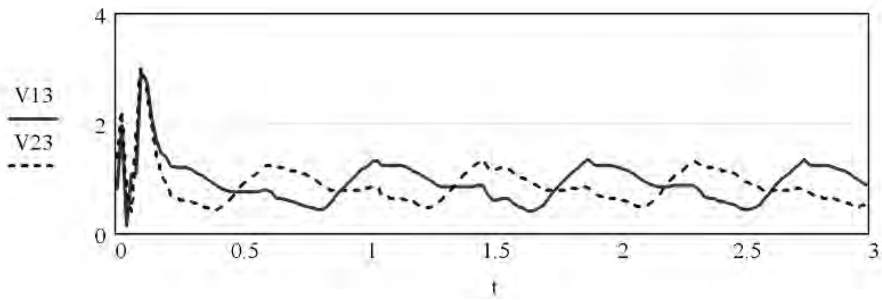


Fig. 8. Changing the conventional speed of sliding in crest contacts of wheels with tracks for velocity of 30 m/s: V13, V23 - the first and second wheel of the third wheelset

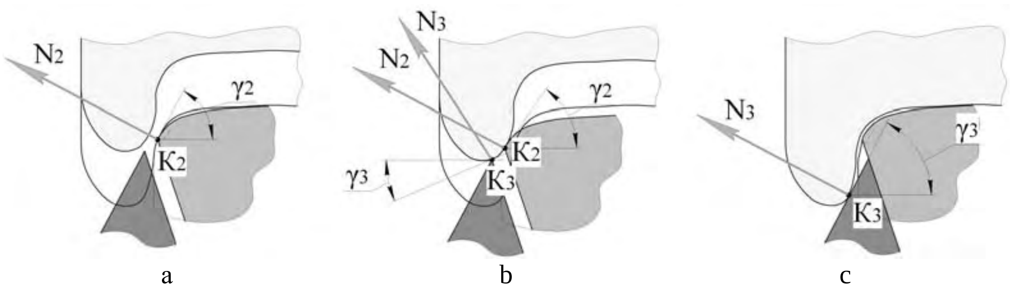
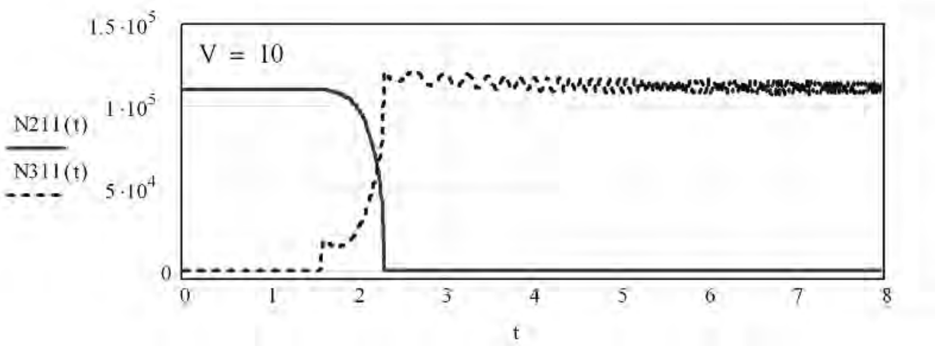
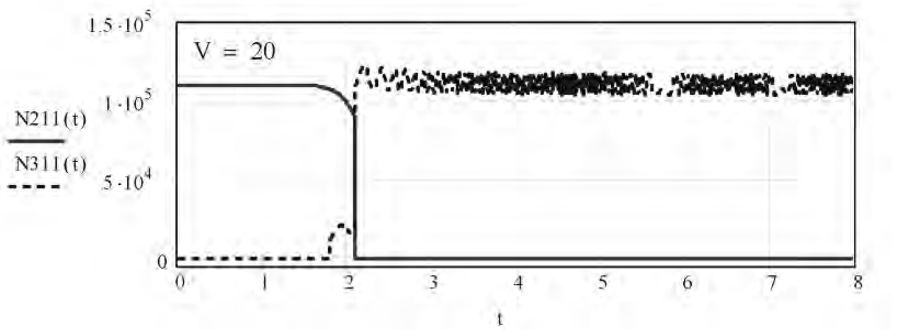


Fig. 9. Routing of wheel studs in turnout at protysherstnomu motion: a) phase in which there is contact with the crest of frame rail - point K2, b) phase of crest contact shifting from frame rails on the studs - the point K_2 and K_3, c) phase of full crest contact with the studs at the point K_3.



a



b

Fig. 10. Relaying of crest contact at wheel vkochuvanni on the studs on the turnout at protysherstnomu motion: a) speed of 10 m / s, b) 20 m/s

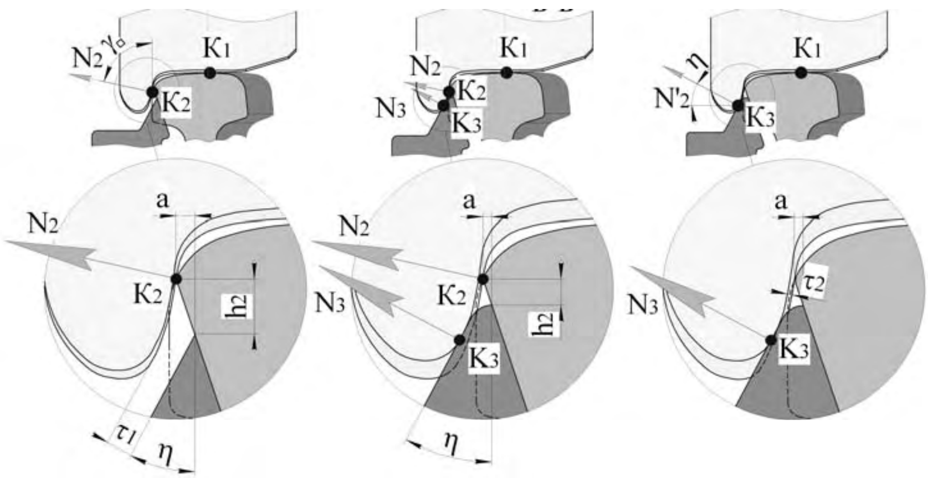


Fig. 11. Scheme of the crest hitting the maximum tie worn profile on turnout studs

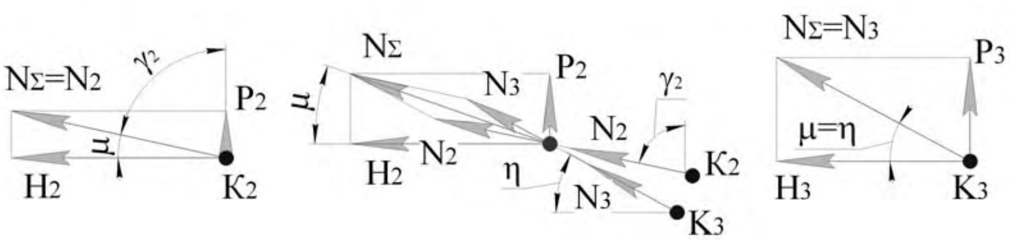


Fig. 12. Scheme of crest reactions on turnouts

Overall reaction of the crest on the turnout consists of reactions at points K_2 i K_3 ($\overline{N}_\Sigma = \overline{N}_2 + \overline{N}_3$) and is defined by the formula:

$$N_\Sigma = \sqrt{N_2^2 + N_3^2 + 2 \cdot N_2 \cdot N_3 \, sin(\gamma_2 + \eta)} \, . \quad (17)$$

The third phase – after the third point – is the movement of the wheel studs. In this phase, between the frame rail and the crest, there is a gap τ_2 and steering effort is passed through a point on the crest K_3.

$$P_3 = N_3 \cdot sin\eta \, , \qquad H_3 = N_3 \cdot cos\eta \, . \quad (18)$$

In the absence of excess wear and defects studs its geometry does not create conditions for vkochuvannya of wheels on the rail. There are manual stair cases that are usually associated with defective studs.

CONCLUSIONS

1. The results of theoretical studies suggest an adequate level of research results and the use of models for the study of the horizontal parameters dynamics of locomotive wheels with worn profiles.

2.The results of the research model are significantly affected by the redistribution of contact stress between contacts of the wheel crest and turnout elements: frame rails and studs.

REFERENCES

1. **Blokhyn E.P., Manashkyn L.A., 1982.:** Train dynamics (transient longitudinal oscillations). Transport. 222. (in Russian).
2. **Danovych V.D., Reidemeister A.G., 1999.:** Mathematical model of wheel-rail interaction. Transport: Collection of scientific works. 2, 17-22. (in Russian).
3. **Golubenko A.L., 1993.:** Clutch of wheel and rail. VIPOL. 448. (in Russian).
4. **Karmazyn A.Y., 1955.:** About wheel slip at tangential force. Railways technologies. 8,12-14. (in Russian).
5. **Kolodyazny P., 2010.:** Some problems of improvement of ultrasonic control of wheel pair axles while their diagnostics. TEKA. Commission of motorization and power industry in agriculture. XC, 132–139.
6. **Maslyev V.H., 1996.:** Study of dynamic processes in the movement of railway vehicles. East Ukraine Univ. Herald. 4, 176-178. (in Russian).
7. **Myamlin S., Neduza L., Ten A., Shvets A., 2013.:** Research of friction indices influens on the freight car dynamics. TEKA. Commission of motorization and power industry in agriculture. XIII, 4, 159-166.
8. **Mytrokhyn A.N., 1998.:** "Wheel-rail": there is required more advanced teoriya. Railway transport. 7, 41-44. (in Russian).
9. **Pevzner A.Z., 1996.:** On the problem of interaction between wheel and rail. locomotive. 9, 19-20. (in Russian).
10. **Sapronova S., Tkachenko V., 2013.:** Justification of the choice of admissible parameters wear paddlewheel locomotives. TEKA. Commission of motorization and power industry in agriculture. XIII, 4, 270-278.
11. **Sapronova S.U., 1997.:** Distribution of power and geometrical parameters for the two-point contact of the wheels of railway vehicles with rails. Herald of East Ukraine Volodymyr Dahl National University. №2(6), 205-207. (in Russian).
12. **Sapronova Svetlana., 2010.:** Modeling of Locomotive wheel profile form. TEKA. Commission of motorization and power industry in agriculture. XC, 270–278.
13. **Tkachenko V., Sapronova S., 2007.:** Steerability of railway vehicles. Transport Problems. International Scientific Journal. T.2, Z.4, 9–16.
14. Tkachenko V.P., 1996.: Kinematic resistance to movement of rail vehicles. Monograph. 200. (in Russian).
15. **Tkachenko V.P., 1996.:** Kinematic resistance to movement of rail vehicles.Herald of East Ukraine Volodymyr Dahl National University. 5(14), 200–208.
16. **Tkachenko V.P., 1997.:** Control of railway vehicles. SUDU. 92. (in Russian).
17. **Tkachenko V.P., 1999.:** Calculating and predicting road frictional resistance to movement of railway carriages. Dis. Dr. ... Engineering. sciences. 05.22.07. 371. (in Russian).
18. **Tkachenko V.P., Sapronova S.U. 1997.:** Kinematics direction crews rail track. 22. (in Russian).
19. **Tkachenko V.P., Sapronova S.U., 2009.:** Studies on the characteristics clutch wheel and rail on a special stand. Herald All-scientific.-research. and design Konstr. Inst electric locomotive. 89-99. (in Russian).
20. **Ushkalov V.F., Malyshev Y.U, 1989.:** Influence of creep model choice for joint spatial variation rail vehicle and uprugodissipativnogo inertial way. Vibrations and dynamic quality of railway rolling stock. Intercollege. Sat Nauchn. tr. Dnepropetrovsk. 266/36, 10-21. (in Russian).

21. **Ushkalov V.F., Reznykov L.M., Red'ko S.F., 1982.:** Statistical dynamics of railway vehicles. Naukova dumka. 360. (in Russian).
22. **Verigo M.F., Kogan, A.Y., 1986.:** Interaction of the way and rolling stock. Transport. 559. (in Russian).
23. **Wickens A.H., 1996.:** Fundamentals of rail vehicle dynamics: guidance and stability. International Heavy Haul Association. − Virginia Beach: 2808 Forest Hills Court (USA). 481.

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ ПОКАЗАТЕЛЕЙ ГОРИЗОНТАЛЬНОЙ ДИНАМИКИ КИНЕМАТИЧЕСКОЙ ПАРЫ «КОЛЕСО-РЕЛЬС»

Сапронова Светлана

Аннотация. В статье выполнен глубокий анализ научных публикаций по исследованию показателей горизонтальной динамики кинематической пары «колесо-рельс». Разработана схема сил сцепления в основных и гребневых контактах кинематической пары «колесо-рельс» с применением теории механизмов и машин. Представлены расчетные данные поперечных перемещений колесных пар и рам тележек, углов виляния колесных пар, угловых скоростей вращения колесных пар при максимальной скорости движения, а также нормальных нагрузок в основных контактах. Разработана схема прохождения колесом остряка стрелочного перевода и представлена расчетная зависимость перекладки гребневого контакта при вкатывании колеса на рельс. Сделан вывод о достоверности результатов теоретических исследований.

Ключевые слова: кинематическая пара «колесо-рельс», силы сцепления, горизонтальная динамика, гребневой контакт, скорости скольжения.

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METHODICS AND ALGORITHMS FOR CREATION OF INTERMODAL LOGISTICS PARK

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Summary. In this article the state and development of transport infrastructure of the transport system for border territories of Ukraine is considered. It is noted, that creation of the logistics parks on these territories will increase the appeal of international transport corridors, passing through Ukraine, will increase the scale, speed of transit for cargo flows and incomes. Method and algorithms for creation of the logistics park is suggested. The implementation of the method is considered, with regard to example of creation of the pilot project for logistics inter-modal park on Ukraine-Russia border, in Melovoe and Chertkovo regions.
Key words: international transport corridor, logistics park, project, method and algorithm, effectiveness of the investment.

OBJECTS AND PROBLEMS

The efficiency of transport system in modern conditions, depends on technical level, scale, forms of service and organization for international cargo flow. The quality and forms of the service must be adapted to maximal degree for new requirements of the modern market of transport services.

PUBLICATION AND METHOD ANALYSIS

Comparative analysis for state of MTK Ukraine, especially on the border regions, indicated that transport system, judging by quantity measurements (in particular, carrying capacity) satisfies the requirements for attracting of transit on the territory of Ukraine, but judging by quality characteristics (speed, safety of cargo, information services, state of border infrastructure, comfort and service on highways, the process of traversing the border) didn't reach the level of European standards [6, 14]. Therefore, as indicated in theoretical and practical designs [6, 15, 16], it is wise to build logistics parks on the state border or close by, near the international transport corridors, as well as making sure that these logistics park will include state structures (customs house, border veterinary and other services), post office, bank, insurance company and other. Independently, on the territory of the logistics park, service areas for vehicles and passengers, zones of storages, terminals for temporary storing and processing transit cargo and forming local cargo flow [4].

This zone can include small agricultural production centers, assembly plants for components of different parts and materials of engineering purpose. The work of these logistics park will allow to significally decrease time for transit of cargo flow through customs house, will increase the quality of service and respectively will increase attraction for this transport corridor, which is going through territory of Ukraine [19].

Currently there is no unified method and designed methods for creating such territorial and industrial structure, as logistics park in border zone. This why, the goal of this work is – design of method and algorithm for creating such logistics park.

RESULTS OF RESEARCH

Methodically development of project of logistic park can be divided into a few stages.

First stage for creating logistics park is the choice and characterizing of enterprises, which will be taking part in this project. If the logistics park is to be placed inside the country, in place of intersection for transport corridor or one of the parts for the main transport net of current region, the main participants would be regional administrations. These, by solving principal questions in possibility of creating logistics park, will delegate authority to identify and to grant land on adjacent territories to regional border administrations, which will simultaneously define the activity for this territorial-economical entity [7], depending on development perspectives [5, 18].

If logistics park is to be placed on or close by the state border with neighboring countries, the main participant will be state administrations of bordering territories, depending on international agreements. The other organization questions will be handled by corresponding subordinate state structures [8].

Second stage is the identification of investment idea and it's characteristics.

The idea is to take in consideration and valuation potential participants and customers for services of future logistics park, judging by activity, scale and investment perspectives.

The first investor must be the state or border territorial structure, which own the territory for future logistics park (region, federal district and such.) This way is needed and must be implemented, because on the dedicated area, in the process of forming the logistics park, in first place must be installed and accredited the state services (administrative, customs, border, quarantine, legal, financial, informative and other.) During start process of functioning for created structure, some financial means will be needed. Further on, given structure, as administration will decide and design technology for functioning logistics park, considering his potential customers (investors) [7, 8]. The last mentioned, judging by their scale of production and services will rent from administration the land for installing production centers, equipment, storage terminals and other buildings and will invest in construction of these units and all needed infrastructure.

The investors also will fund project designs for transport infrastructure for development and maintenance of cargo flow, which are coming through given logistics park.

It must be noted, that transport-storage processing for cargo flow such, as transit and local ones is quite expensive and may sometimes reach from 7 to 30%, and sometimes even bigger net cost of products (from delivery of raw materials or basics to products for consumers) [2, 3], this why the optimization for parameters of technological processes for transport-storage services of different cargo flows is one of the main goals in designing projects for logistics parks.

All participants and potential customers are interested in solving these problems, because in this case upgrading the technology can lead to decreased net cost of products. This why customers for logistics park, and in the same time investors, must take part in funding these projects.

Third stage must be evaluation of market environment, i.e. potential customers, who will use the services of logistics park, with analysis of their geographical and financial position with regards to future perspectives. Along with that, transport connection and communication must be analyzed, which must be considered in the process of designing the project [13]. On this stage it is possible to build and optimize transport net of regional and higher levels, which unify neighboring territory and production centers in clusters for minimizing the volume of the transport work needed for functioning of the given logistics park [12, 17, 20].

Fourth stage is consisted of marketing research and building of marketing plan for perspective development of logistics park, for assuring ever changing production line and volumes, and other transport-storage services. These researches are needed, because during the functioning of logistics park, it is inevitable, that customers, service line and volume, the type of transport and infrastructure of transport-communication network will change.

Besides, on this stage the possibility of connecting and introducing individual territorial-production structures and objects, for attracting additional cargo flows in given region and logistics park respectively, to the system of logistics park will be researched, analyzed and evaluated.

Very important and, certainly, perspective will be evaluation of possibility for connecting transport network of the given region along with the logistics park, with the international transport corridor, if it is not already in the system of given transport corridor [1, 14].

Fifth stage is consisted of designing the production plan for implementation of investment project. On this stage, the construction projects of objects for common use, objects for potential customers (assembly plants, storage terminals and separate warehouses), objects for infrastructure, service centers and other will be held in consideration, with regard to the volume of services provided. Foremost the price (investment) for construction of basic objects and objects for infrastructure of common use, which are built with the state funding, will be identified. Further on the price for objects of individual customers, who are taking part in constructing the logistics park in the beginning of implementation of the project, will be identified. Emphasis is on building system of informative service, maintenance of cargo flows and other types of activity for logistics park, using modern IT technologies. This is due to the fact that, logistics park with his functional goal is the place of birth and branching of material flows, including transit ones. This why the objects for customs tracking and transit must be equipped with modern facilities with the possibility for upgrading and development, including the use of electronic signature for unloading and contact-less control of the cargo and other.

The general evaluation of investment for constructing objects during first 12 months is made. The planned volume of provided services from different types of activity, including: loading and unloading, storing and preparing cargo for transportation to the consumers (division into groups, completion, packaging, bagging and other), processing of containers, use of the parking lots, transportation of cargo and passengers, maintenance and other services in declaration of cargo, maintenance and repair for vehicles and other, is evaluated.

On this stage the spending and profit for changing transit cargo flows is researched, and that's very important for attracting those for processing through projected logistics park.

Sixth stage covers the drafting (development) of financial plan and program for investment, basing on the results from analysis of previous stages, that is selection of potential customers – participants of the project, analysis of investment idea and possible investors, evaluation of market environment, marketing researches and volume of investments, the economical evaluation of the effectiveness for the project is made.

The economic effectiveness of the project is identified, based on the growth of pure profit from it's implementation and pure profit from canceling the project. In case, if the logistics park is created, as new territorial-production structure and there is no existing objects in it, which process the cargo flows, then it is possible to consider only the time for paying back the investment value. For each customer (investor) of the logistics park the time for paying back it's investment will be individual, because it will depend on the type of activity and the volume of the work performed (services provided). This why, on this stage, it is wise to evaluate (identify) the average value of effectiveness for logistics park in general, considering all the investments from all participants.

Besides, the value of effectiveness, aside from the time of paying back for investments, which complement given value, should include:

1. size of investments, USD,
2. discount rate, %,
3. discounted payback time – DPB, months,
4. average rate of return ARR, %,
5. net pure profit value NPV, USD,
6. discounted profitability index DPY,
7. internal rate of return IRR, %,
8. time for calculation of integral values.

Further on, depending on the volume of funding and set time for construction of the project, the time of paying back is identified, based on the income stream from the investments in each subsequent year from the start of the project. For example, if the time for implementation of the project is set for 5 years, and the time for construction is set to 12 months, then the income stream will start only from the second year, that is after the logistics park will start functioning.

After that, discount payback time and discount profitability index are identified.

Based on the calculation of economic effectiveness for the project of logistics park, the decision on expediency and perspective, from constructing objects on it's territory, is made.

Methods for evaluation effectiveness of the investment project is listed below.

International practice of evaluating investment projects uses few indexes, which allow to prepare the decision on expediency (inexpediency) for investment of money [11].

These indexes can be divided into two groups:

1. Indexes, defined by using concept of discounting (evaluation of effectiveness for investment projects):

- pure current value,
- profitability index for discounted investments,
- internal rate of return,
- payback period of investment with regards to discounting,
- maximal cash outflow with regards to discounting.

2. Indexes, which don't imply using of concept of discounting (evaluation of effectiveness for investment projects):

- simple payback period for investments,
- indexes of simple return for investments,
- pure cash flow,
- index of profitability for investments,
- maximal cash outflow.

Period payback (*PP*) – it is a period, during which the profits from investments reaches the value, which is equal to the seed money (i.e. period, needed for fully paying back all the cash invested in the project).

Net present value (*NPV*) together with internal rate of return (*IRR*) is used as an instrument in evaluation of investments.

Payback period of investments – is the index, which present to investor simple way to identify how much time it is needed for enterprise to pay back the primary cost. It has special meaning for business, situated in the countries with the unstable financial system, or business, that is lied with modern technology, where rapid aging of the product is the common practice, which transforms the fast pay back of investment funds in serious problem.

The general formula for calculating payback period for investments is:

$$T_{ok} = n, \quad \sum_{t=1}^{n} \frac{CF_t}{\left(1+k_t\right)} > I_0\,, \qquad (1)$$

where: T_{ok} – payback period for investments, n – number of periods, CF_t – cash flow in t period, I_0 – the value of seed money in zero period, k_t – inflation factor in t-period.

Depending on goal at hand, it is possible to calculate payback period for investments with different precision.

Discounted Payback Period (*DPP*), is the payback period for investments in current values (payback in terms of current cost)

The general formula for calculating *DPP*, in terms of current cost:

$$T_{ok}TC = n, \quad \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} > I_0 , \tag{2}$$

where: $T_{ok}TC$ – payback period for investments in current cost, r – hurdle rate (discounting rate), I_0 – the value of seed money of investments in zero period.

By transforming the term of payback, we can get two additional instruments for analysis of investments. Thus, payback index in terms of current cost (we will call it discounted payback period, *DPP*)), also used in identifying the number of time periods, needed for paying back investment expenses, takes in consideration the timed cost of cash. While, calculating payback yearly cash income is summed, for identifying the year, during which those will surpass seed money investment expense, calculating *DPP* the discounted cash will be summed.

Net Present Value (*NPV*) – is the difference between current cost of cash by project or investments and the current cost of cash payments for receiving investments, or for project funding, calculated with fixed discounted rate.

Method for identifying Net Present Value consists of:

1. Identifying the current cost for expense (I_0), i.e. deciding, which volume of investments is needed to reserve for the project.

2. Calculating the current cost of future cash income from the project, wherefore income for each year *CF* (cash stream) is reduced to current date.

The results of calculation shows, how much cash is currently needed for funding and receiving projected cost, if the rate of return would be equal to hurdle rate (for investor – it is a rate of alternative return, for enterprise – the cost of cumulative fund or through risks). Summing the current cost of income for all years, we will get the present value (*PV*):

$$PV = \sum_{t=0}^{n} PV_t = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} . \tag{3}$$

3. The current cost of investment expenses (I_0) is compared with Present Value (*PV*). The difference between them is the Net Present Value (*NPV*):

$$NPV = PV - I_0 . \tag{4}$$

NPV is showing pure income or pure expenses for investor from funding the project, compared to keeping money in the bank. If *NPV* is greater than 0, we can say, that this investment will multiply the cash of enterprise and it is wise to make this investment. If *NPV* is less then 0, then the profit from this investment isn't big enough to compensate for the risk within the project (or from the point of view of the cost for funding, there will not be enough cash to pay dividends and interest on the loan) and investment memorandum must be declined.

Net Present Value (*NPV*) is one of the basic indexes, used for investment analysis, but it has few flaws and cannot be the only instrument for evaluating of investment. *NPV* identifies absolute rate of return for investment, and, likely, the bigger is the investment, the bigger is Net Present Value. Hence, the comparison of few investments of different scale using this index is impossible. Besides, *NPV* don't show the time at which the investment will be payed back.

If the investment funding, lied with the implementation of the project, is made through few stages (periods), then calculating *NPV* is made using this formula:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{I_t}{(1+r)^t} , \tag{5}$$

where: I_t – the sum of investment (expenses) in t period, n – summed number of periods (spans, steps) t = 1, 2, ..., n (or investment duration).

Usually for Cf_t the value of t is situated between 1 to n, the case, when $Cf_0 > 0$, is the costly investment (for example: the funding for ecological program).

Discounted Profitability Index (*DPI*): One of the option, for understanding the term of payback period, is in summing all discounted cash streams (incomes from investments) and dividing this sum by discounted investments.

The formula for calculating the discounted index for rate of return:

$$DPI = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{I_t}{(1+r)^t}}. \tag{6}$$

Internal Rate of Return (*IRR*) – is the rate of return (hurdle rate, discounted rate) whereby *NPV* (Net Present Value) for investment is equal to zero, or it is the discounted rate, whereby discounted profits from the project are equal to investment expenses.

IRR defines maximal acceptable discounted rate, whereby it is possible to invest the funds without any loss for the owner.

$IRR = r$, whereby $NPV = f(r) = 0$.

It's value is found from this equation:

$$\mathrm{NPV}(\mathrm{IRR}) = \sum_{t=0}^{n} \frac{\mathrm{CF_t}}{(1+\mathrm{IRR})^t} - \sum_{t=0}^{n} \frac{\mathrm{I_t}}{(1+\mathrm{IRR})^t} = 0. \tag{7}$$

The economic sense for this value is that, it shows the expected rate of return (profitability for investments) or maximal acceptable level of investment expenses in the given project. *IRR* must be greater than average cost for investment resources.

If this condition is maintained, investor can accept the project, if no, then this project must be declined.

The pluses for this value of Internal Rate of Return (*IRR*) are in the fact, that besides, defining the level of profitability for investment, it is possible to compare projects of different scales and different duration.

The Internal Rate of Return (*IRR*) has three basic flaws:

1) By default, it is considered that positive cash flows are reinvested, using rate equal to Internal Rate of Return. In case, if *IRR* is close to the level of re-investments for the enterprise, then there is no problem, when *IRR*, for especially attractive investment project is equal to, approximately 80%, then it refers, that all incomes must be reinvested with rate of 80%. But it is unlikely, that enterprise has yearly investment possibilities, which insure profitability in 80%. In this case, Internal Rate of Return (*IRR*) overstates the effect from investments (in the value of *MIRR*, Modified Internal Rate of Return, this problem is solved).

2) There is no possibility to define, which profit will bring this investment in absolute values (cash).

3) In case with alternating cash flows it is possible to calculate few values for *IRR* or it is possible to define wrong value.

The method of successive approximation is also used for calculation. By selecting values for hurdle rate for finding the minimal values for *NPV* using modulo, and then we carry out approximation. Standard method – the problem with multiple definition of *IRR* still persists and there is possibility of the wrong calculations (with alternating cash flows). For solving this problem usually a graph *NPV*(*r*) (Fig. 1) is constructed.

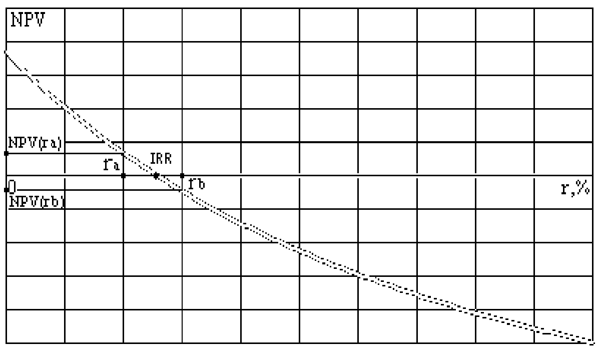

Fig. 1. Graph of changing *NPV* depending on rate of discount *r*

Defining *IRR* with method of selection. It is assumed, that in the sector from point *a* to point *b*, function of *NPV*(*r*) is rectilinear, and we are using formula for approximation in the sector of straight:

$$IRR = \frac{r_a + (r_b - r_a) \cdot NPV_a}{NPV_a - NPV_b}. \tag{8}$$

The Average rate of return (*ARR*) – is the profitability of the project, as the ratio between average yearly income from his implementation and the cost of seed money. Average rate of return is calculated using this formula:

$$ARR = \frac{\sum_{t=1}^{n} CF_t}{N \cdot I}\,. \qquad (9)$$

where: I – seed money, CF_t – pure cash flow for period i, N – project duration.

The economic sense for average rate of return – average yearly income, which can be received by implementing the project.

Thus, by calculating economic effectiveness for the project of inter-modal logistics park, we can decide, if it is expedient and perspective to build object on the chosen or given territory, or no.

Seventh stage is the analysis of the risks for implementation of the project. The most significant risks depend on general situation in the given country, lied with the political and financial instability, perspective for development of economic in general and geopolitical changes.

Political instability in the country defines and affect the stability of priority goals for developing the economic, one of those is the intensification for international economic collaboration and developing transport systems and their infrastructure. Reducing such risks can be achieved through insuring stability for economic ties through development of competitive environment for exchange of goods and services.

The influence of financial instability can be reduced with financial appeal of the project, with the support of various stabilization funds and other.

The other types of risks and their possible negative influence at the stage of preparation, investment and functioning of the logistics park are listed in the Table 1.

Decreased influence of these factors on the effectiveness for functioning of the logistics park can be achieved through additional measures, developed as they arise.

Table 1. Risks and their negative influence

Risks	Negative influence
– volatility of demand,	– reduction in demand for goods and services, reduction in profit,
– emerging of alternative enterprises,	– reduction in demand for goods and services, reduction in profit,
– insolvency of the clients,	– decline in the volume of services,
– dependency from the clients, no alternate types of activity,	– reduction in profit, also due to the price increase,
– staff qualification,	– decline in the quality of services provided,
– insufficient level of motivation for workers,	– liquidity of staff, decline in the quality of services provided,
– breaking of the equipment,	– decline in the quality of services provided, increase in service time,
– stricter requirements for ecological technology processes	– increased expenses for ecological protection of environment

On eighth stage we are considering social-economic aspects for implementation of the business-plan. The information about social-economic aspects for the investment project of the logistics park, as enterprise, is provided [9, 10].

The essence of this aspect is that any increase in cargo and passenger flow through logistics park will increase the number of jobs. It is very important for depressive regions and especially border territories. This will contribute to development of various production centers, various types of transport and infrastructure for the neighboring territories. Besides, economic development of the neighboring territories adjacent to logistics park will inevitably contribute to development of cultural ties between individual territories and countries, it will also serve as positive effect.

EXAMPLE FOR IMPLEMENTATION OF METHOD

Stage 1. Characteristics of enterprises-participants.

«Transport systems» department of Volodymyr Dahl East-Ukrainian National University and public organization «Institute of strategy for security and development of border territories» (Lugansk city) over the years are working on the project, which will ensure the creation of modern transport-logistics infrastructure for border territories of Lugansk region, which border with next regions of Russian Federation – Rostov region, Voronezh region, Belgorod region. On the current stage, in transboundary cooperation of Lugansk region, the idea for creating network of international inter-modal logistics parks, in border regions of Eastern Ukraine, is developed. The perspective of creating and developing Euro-region «Donbass» is taken into account. Since, the logistics park is to be created in border region between Ukraine and Russia (Melovoe village – Ukraine, and Chertkovo – Russia), the main participants are state administrations, i.e. Lugansk and Rostov regions, which may delegate their authority to mentioned above regional centers.

Stage 2. Characteristics and description of investment idea.

The concept for the project is the creation of international rail and road cargo-passenger checkpoint and inter-modal logistics park (ILP) in Melovoe village, Lugansk region, and Chertkovo village, Rostov region [7].

The creation of inter-modal logistics park «Melovoe-Chertkovo» will allow to form basic background for attracting local transit cargo flow, partially relieving southern part of «Moscow–Caucasus» highway. Using Melovoe region in unified Euro-Asian transport-logistics system of transit cargo flow is profitable due to few reasons. Melovoe village, Lugansk region, is situated equidistant from such regional centers as Kharkov, Donetsk, Voronezh, Rostov (aproximately 350 km). The creation of inter-modal logistics park «Melovoe-Chertkovo» will give opportunity to relieve part of railway cargo flow from Chertkovo russian railway station and will direct it on Ukrainian automobile transport with appropriate customs clearance, partially «relieving» the flow on «narrow» sector Lisky (SER) – Likhaya (NCR), which is «locked» between two overloaded gateways.

This option excludes demmurage of trains on gateways of Lisky and Likhaya for cargo destined to Lugansk region, Donestk region, Kharkov region and further on, including western regions of Ukraine.

The advantages of using Melovoe region in transit freight turnover (through, created international railway checkpoint «Melovoe – Chertkovo») are listed below:

– the cargo will go only through one customs clearance station and that will reduce the time of cargo arriving to destined station,

– the cargo will be transported by railway from the station, situated directly on the highway «Moscow – Caucasus» and does not wait his turn on the gateway for «entering» the highway from adjacent branch,

– excluding option of shipping delay due to the mistakes in customs clearance,

– assurance of high quality and fast interaction for rail and road transport during international trafficking.

The perspective for development of inter-modal logistics park «Melovoe-Chertkovo» is assured not only by effective use of change for the type of transport, from rail to road, but also by further possibility to develop transport infrastructure, which can implemented step by step:

– stage 2.1 – creation of international rail and road checkpoint «Melovoe – Chertkovo» and inter-modal logistics park «Melovoe – Chertkovo»,

– stage 2.2 – construction of railway branch line Melovoe – Starobelsk – Svatovo (approximate length 150 km), which will allow to connect railway «Moscow – Caucasus»(RF) with two railway branch lines of Ukraine: Valuiki – Lugansk and Kupyansk – Debaltsevo.

Stage 3. Evaluation of market environment.

Interacting with the system of road-transport communications of Lugansk region, the cargo owners, their providers acquire the possibility to transport transit cargo from Northern, Central and Southern Europe in direction of Southern Federal District of Russian Federation, further on to regions of Northern Caucasus, to Volgograd, in Caspian regions, countries of Central Asia and Indo-China.

It is important for Ukraine to construct and develop Ukrainian transport system, in such way, that international transport corridor Europe – Asia with the exit to Trans-Syberian highway, will be passing through Lugansk region to Volgograd. This direction gives the possibility of the shortest exit to corridor North – South, reducing the length of both corridors approximately by 900-1000 km. It is profitable for all participants of traffic. These areas currently have around 30% of all the volume for traffic, besides Russia is planning to invest huge amount of money in development of infrastructure for Transsiberian up to 2030 year, to replace sea trafficking with trafficking through Transsiberian and increase those by 4,5-5 times, reducing the expenses for transport-storage operations, in cost of products from 15-20% right now, down to 7-8%.

Recently the government of Kazakhstan is developing new transport corridor, which will go from China in the destination of Volgograd and further on, through eastern, central and western regions of Ukraine, to European countries.

The value of transit cargo flows from European countries, passing through, Lugansk region further into Russian Federation territory and back, in 2011 year according to experts opinion was more than 200 billions of UAH. The volume of transported transit cargo by road exceeded 26 million of tons [4].

However, analysis showed some negative trends in this activity. The transit trafficking through Ukraine, using all types of transport, starting from 2007 year, is diminishing.

Among basic reasons, for diminished volume of transport cargo flows, are incompatibility road-transport infrastructure with international standards. Regarding this, until 2013 year, Ukraine planned to invest 125 billions of UAH in reconstruction of roads. Wherein, it is expected to build 2500 km of new highways, to overhaul more than 5000 km and to repair around 1000 km of highways. It was planned to allocate annually around 8 billions of UAH from state budget. The rest of funding is meant to be attracted through loans and investments.

The success of organizational-administrative and economic functioning of the logistics park on regional level, is due to existence of railway highway «Moscow-Caucasus» (ITC «North-South») [1], highway of republican value P-07 «Chuguev – Melovoe», as well as existence of large number of towns with developed economic infrastructure.

The most significant social-economic infrastructure belongs to Lisichansk-Severodonetsk agglomeration (Lisichansk-Severodonestk-Rubejnoe), for which the highway P-07 logistically the most favorable, because it gives enterprises the straight exit to railway highway ITC «North-South» (length 160 km).

Lisichansk-Severodonetsk agglomeration (Lisichansk-Severodonestk-Rubejnoe):

Chemical (Severodonestk, Lisichansk, Rubejnoe) and oil-refinery industry (Lisichansk), engineering (Severodonetsk, Lisichansk) and instrumentation (Severodonetsk), coal-mining industry (Lisichansk), food processing industry (Lisichansk, Severodonetsk, Kremennaya), glass, building materials production (Severodonetsk, Rubejnoe, Lisichansk), oil and gas industry (Severodonestk, Kremennaya, Lisichansk).

Severodonetsk:

Antex-automatika, Ltd. SPE, Armoplast, JSC, GLOBUS, IPE, Resistance plant, Impulse, Severodonetskoe JSC, METROCOM, SPE, Mriya-Novaya Technology, SPF, Azot Union, industrial state enterprise of Severodonetsk, Stekloplastik Union, JSC, Pirena, enterprise specialized in firefighter equipment, nonstandard chemical equipment plant of Severodonetsk, JSC, boiler-engineering plant of Severodonetsk, JSC, ORGKHIM of Severodonetsk, Company, engineering plant Severodonetsk, JSC, chemical-metallurgical plant of Severodonetsk, SE, Ukrvneshtradeinvest, Ltd. JE, Ukrkhimenergo, JSC, Khimavtomatika, JSC, Khimpostavshik, PE, Khimtechnologiya.

Lisichansk:

Volcheyarovsk quarry, JSC, Lion, Ltd., Linos, JSC, Lisichansk soda, JSC, gelatin plant of Lisichansk, JSC, rubber technical instrument plant of Lisichansk, JSC, Lisichansknefteorgsintez, JSC, Neftekhimik, JSC, Proletariy, glass plant of Lisichansk, Company, Rare gases, JSC, Strommachina, JSC, Instrument plant, JSC.

Rubejnoe:

BKF, SPE, «Zarya», state chemical plant of Rubejnoe, «Krasitel», JSC, reinforced concrete plant of Rubejnoe, JSC, building materials plant of Rubejnoe, Ltd., paperboard mill of Rubejnoe, JSC.

Krasnorechenskoe:

Frunze machine-tool plant of Krasnorechenskoe, JSC, Stankomplekt, Ltd.

Kremennaya:

Kremenmash, JSC, Khimavtomatika, JSC.

The towns and villages, situated directly on the way of P-07 highway «Chuguev – Melovoe».

Kupyansk:

Milk cannery of Kupyansk Company, Sugar factory of Kupyansk, JSC, Meat processing plant of Kupyansk, «Torgperspetiva» (foundry of Kupyansk), Ltd., Machine-building plant of Kupyansk, JSC, cast iron foundry of Kupyansk, Ltd., Silicate plant of Kupyansk, «Bel-Ger» brewery, Company, reinforced concrete plant ZJBK-11, JE «UEFC» (Ukrainian Eastern Fishing Company), «Metiz» factory of Kupyansk, `TERMOTEKH` plant, Ltd.

Svatovo:

Merchandising Equipment Svatovo Plant, JSC.

Starobelsk:

JSC „milk substitue factory of Starobelsk” (production of skimmed milk powder, butter), Branch of JSC „Karavai” „Bakery of Starobelsk” (production of crackers, bakery and confectionary), PE „Fruit-mineral water plant „Aidar” (sparkling water, vinegar), Ltd. „Garment factory of Starobelsk”, Company „Mechanical factory of Starobelsk”.

Besides the specified enterprises, logistics park «Melovoe-Chertkovo» is territorially favorable for many agricultural enterprises of Belevod, Belokurakino, Kremen, Markov, Melovoe, Novoaidarskoe, Novosopskovskoe, Svatovo, Stanichno-Lugansk, Starobelsk, Troitsk regions in Lugansk area.

From the Russian side, logistics park «Melovoe-Cherkovo» will be profitable for JSC «Russian Railroad Highways», enterprises of agricultural-industrial union Chertkovo, Verkhnedon, Sholokhov, Bokov, Kashar, Miller regions of Rostov area, Kantemir, Boguchar, Rossoshansk, Petropavlovsk regions in Voronezh region.

Currently, the exit for the most of the enterprises to international checkpoints, situated to the north-east of Lugansk region, is limited. The status of international checkpoint have these points «Krasnaya Talovka» and «Markovka». The rights of international checkpoints for full customs clearance in northern direction, needed for enterprises of Lisichansk-Severodonestk agglomeration, have only those, which are situated in Kharkov region. In Lugansk region enterprises of the Lisichansk-Severodonestk agglomeration have exit to the international checkpoint of full customs clearance only to the south-east, and that's very uncomfortable.

Stage 4. Marketing plan.

Considering the perspective for development of inter-modal logistics park «Melovoe-Chertkovo», listed below in 2.1, 2.2 of STAGE 2, in combination with creation of international rail and road checkpoint «Melovoe – Chertkovo» on the territroy of Melovoe region, it is perspective to use a range of enterprises, which lost their relevance after the collapse of USSR.

Currently, there are more than thousands unused square meters of storage capacity in ex-inter-regional base of Lugansk regional customer union. The railway branch line was connected with this inter-regional storage base, through which trains were unloaded. While creating logistics terminal, using specified storage capacity, based on international rail and road checkpoint «Melovoe – Chertkovo», allows to exclude demmurage of automobile transport and trains during customs clearance. The cargo will go through customs clearance on the warehouse of the terminal. Using these storage capacity will allow to exclude mileage of empty transport, by loading «passing» cargo along the way.

On the territory of Melovoe village, oil base with the existing railway branch line is situated. Using oil base of Melovoe in railroad trafficking will decrease expenses in delivery of fuels and lubricant to the region.

Directly on the railroad highway, there are two grain elevators: Chertkovo elevator (RF) and Zorino elevator (Ukraine). Both elevators have working railway branch lines and possibility to load (unload) the grain by railway transport.

Unifying the specified objects in one logistics park, the existence of large rail and road highways, will allow to attract additional cargo flows in to the region, and the combination of two border, rail and road, checkpoints will assure fast customs clearance for cargo and will accelerate the transit of cargo flows.

The system of international corridors, passing through Lugansk region (Ukraine) and Rostov region (RF), includes sectors of Euro-Asian ITC “North-South” and “Transsiberian”, as well as Pan-European corridors prolonged in the direction of Russia:

– ITC «North-South» (Helsinki – St. Petersburg – Moscow – Astrakhan – Caspian Sea – Iran), with the branch lines through Rostov up to Novorossiysk, Stavropol – Kochubei –Makhachkala – Azerbaijan,

– Branch line of Transsiberian (Novorossiysk – Salsk – Volgograd – Samara – Transsiberian),

– Danube water transport corridor № 7 (Danube – Don – Volga),

– ITC № 3 (Berlin – Dresden – Kiev) is prolonged through Rostov region up to Vladikavkaz and Tbilisi, as well as through Belaya Kalitva up to Volgograd and further on, into Central Asia,

– ITC № 4 (Vienna – Budapest – Bucharest – Kishinev) – Odessa – Rostov – Astrakhan and further on, up to connection with the project TRACEKA in Kazakhstan. To create prolonged corridor rail and road highway Rostov –Odessa – Kishinev is used,

– ITC № 9-б (Klaipeda (Kaliningrad) – Kiev) – Kharkov – Rostov and further on, up to Makhachkala – Baku – Teheran. This corridor connects ports of Baltic Sea with the ports of Caspian Sea, as well as ITC “North-South” with ITC № 3.

The logistics park «Melovoe – Chertkovo» may be positioned directly within international transport corridor «North – South» (Fig. 1). Situated between three regions (Lugansk region, Rostov region and Voronezh region), two railroads (NCR and SER), logistics park will effectively take part in the system of inter-modal trans-boundary trafficking, this will allow to optimize the delivery of the cargo in all destinations of Lugansk, Kharkov and Donetsk regions (Ukraine), Rostov, Voronezh, Belgorod and Volgograd regions (Russia). The logistics park «Melovoe – Chertkovo» will become logical component for the infrastructure of highways of north-eastern part of Lugansk region with the exit to the Russian highway M-04 «Don» and railroad highway «Moscow – Caucasus».

The basic methods for promoting the services of the logistics park are:

1. Organization of themed events for potential customers (presentation, conferences, exhibitions and other).

2. Written commerce propositions for potential customers.

3. Regular visits to potential customers from representatives of the logistics park.

4. Advertisement in the Internet and media.

5. Attraction of clients is planned through affordability, high quality service, efficiency, complexity of services provided and other possible preferences.

The marketing plan also envisage the system of discounts and forming on this basis, the group of permanent solvent clients.

Fig. 2. Logistics parks «Melovoe – Chertkovo» among the international corridors system

Stage 5. Production plan for implementation of investment project.

The project suggests the construction of the logistics storage terminal (Fig. 3) to the south-east from Melovoe and Chertkovo villages, creating outdoor platforms for handling, maintenance, storing the goods and parking the automobile transport.

Using the services of the logistics park, the customer will get high quality service and will optimize the expenses, with regard to specifics of each cargo and different conditions for storing the goods to choose from. The storage complexes include – warm premises, cold premises and open platforms. All the storage complexes have comfortable driveways, regardless the size and technical characteristics of the automobile transport.

For decreasing the expenses for storing the goods and cargo, we suggest responsible warehousing. Our warehouse complexes are projected to maximally match the requirements and standards for responsible warehousing. All needed loading-unloading equipment available. The professional hourly security will ensure the safety of the stored goods and materials, privacy of the information about goods and cargo is guaranteed.

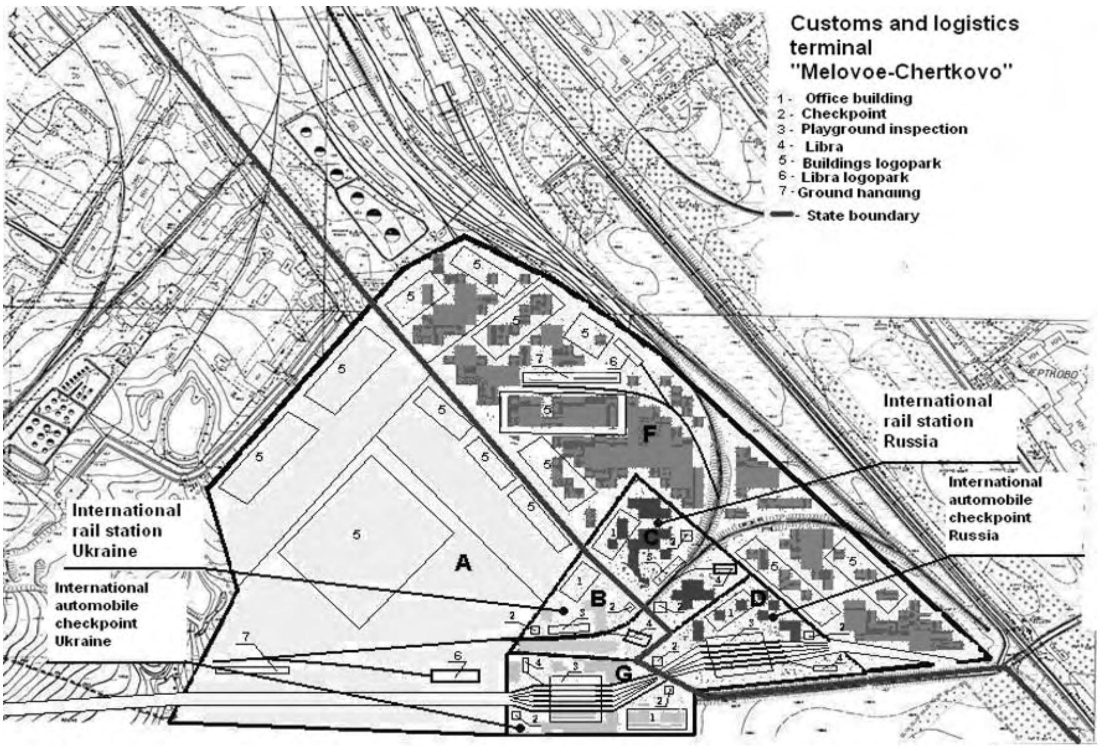

Fig. 3. The scheme of positioning for objects of logistics park

Temporary Storage Warehouse (TSW). Temporary Storage Warehouse – it is a special premise with temporary storage for various goods and transport under customs control from the moment of passing through checkpoint and up to finishing all needed customs procedures.

The comfortable transport position of TSW and it's own railroad branch line will allow, without any extra expenses and wasting the time, to primary place the cargo and the delivery to it's destination.

We may propose these for our clients:

– responsible warehousing for the goods,

– loading-unloading service,

– acceptance and issuance of the goods with the control of quality and quantity,

– regular shipping of the complex cargo through rail and road transport,

– full complex of warehouse operation of the logistics terminal: assortment of goods in groups, packing, labeling, forming sets (packs), possibility to track serial numbers, lots, storage life by request of the client, stocktaking and reports about merchandizing, remote access to information about the goods fro client,

– work with return of goods,

– monitoring the cargo flow,

– road trafficking of the cargo by logistics park’s transport,

– delivery of complex cargo after receiving customs clearance to any place in Ukraine and Russia,

– help with the customs clearance and consulting about paperwork,

– logistics control during all stages of the cargo trafficking,

– insurance, escort, security and tracking of the cargo,

– consolidation and payment of the bills for cargo trafficking.

The purpose of the warehouse terminal (10000 m^2) – to accept the cargo and combining them according to destinations (completion), warehouse storing itself, loading-unloading services and other.

The general characteristics of warehouse terminal building:

Building length	100 m.
Building width	100 m.
Building height	13 m.
Building area	10 000 m^2.
Building perimeter	400 m.
Wall area	5 730 m^2.
Roof area	10 201 m^2.
Total area	15 931 m^2.
Floor thickness	100 mm.

The cost for construction is 442 USD for 1 m^2, total of: 10000 × 442 = 4 420 000 USD.

The general characteristics for auxiliary building (Fig. 4):

The purpose of the auxiliary building (2500 m^2) – accommodation for staff, office space, garage for loading-unloading mechanisms and other.

Building length	50 m.
Building width	50 m.
Building height	13 m.
Building area	2500 m^2.
Building perimeter	200 m.
Wall area	2740 m^2.
Roof area	2601 m^2.
Total area	5341 m^2.
Floor thickness	100 mm.

Fig. 4. Auxiliary building

The cost for construction of this object is 500 USD for 1 m^2, total of: 2500 × 500 = 1 250 000 USD.

Two auxiliary buildings for logistics terminal with total area of 12 500 m^2, with total cost of 5 670 000 c.u. (Fig. 5).

Fig. 5. Logistics terminal building

Besides, it is planned to construct other objects of infrastructure:

Total area of land – 30 ha.

Total area for construction – 287 500 m^2, those are:

container platform – 40 000 m^2,

outdoor platform for storing the goods and parking lot for automobiles – 247 500 m^2.

The total cost of infrastructure is 5 700 000 USD. **The total sum of investment is 11 370 000 USD.**

In calculation of initial data for the project the types of services will be defined, which will be provided to trafficking operators, volume of their service and price characteristics (Table 2)

According to calculations made of initial data for the project, we can define yearly income from turnover in the sum of 7 758 760 USD.

The initial data for the project provide us (Table 3).

Table 2. The planned volume of services provided

№ п/п	Name of the entry	Measure	Price	Volume per 24 h.	Sum per 24 h, USD	Sum per month, USD	Sum per year, USD
1	Loading/unloading, warehousing, grouping of the cargo	thousands tons	1 600	10	16 000	480 000	5 760 000
2	Container processing	piece	6,95	31	215	6 464	77 562
3	Outdoor parking lot service	unit	3,13	685	2 144	64 322	771 858
4	Cargo trafficking	thousands of km,	20,87	3	63	1 878	22 540
5	Maintenance services	compl.	313	10	3 130	93 900	1 126 800
	Total:				21 552	646 563	7 758 760

Table 3. The project provide

Payments and income	Time period				
	1-st period*	2-nd period	3-rd period	4-th period	5-th period
1. Construction of logistics park, buying and installing equipment	11 370 000				
2. Income from services provided		7 758 760	7 758 760	7 758 760	7 758 760
3. Variable expenses		120 000	120 000	120 000	120 000
4. Permanent expenses		50 000	50 000	50 000	50 000
5. Amortization		350 000	350 000	350 000	350 000
6. The income before tax		7 238 760	7 238 760	7 238 760	7 238 760
7. Taxes (VAT and tax on profits)		3 531 138	3 531 138	3 531 138	3 531 138
8. Pure income		3 707 622	3 707 622	3 707 622	3 707 622
9. Cash stream from investments	11 370 000				
10. Cash stream from operations		4 057 622	4 057 622	4 057 622	4 057 622
11. PURE CASH STREAM	-11 370 000	4 057 622	4 057 622	4 057 622	4 057 622

Stage 6. Financial plan and program for investments.

Financial results from implementation of the project. For identifying the economic effectiveness of the project, must be defined the growth of pure income from it's implementation, i.e., we are calculating the difference between pure incomes, which we will get from implementation of the project and pure incomes in case of canceling the project. In case «without project» all the indexes will be equal to zero, because the enterprise is building the new warehouse premises.

Thus, the growth of pure income is equal to value of pure income (Table 4).

Cumulative total for pure income growth is (Table 5).

Table 4. The value of pure income

Period	USD
1-st	0
2-nd	7 758 760
3-rd	7 758 760
4-th	7 758 760
5-th	7 758 760

Table 5. Cumulative total for pure income

Period	USD
1-st	0
2-nd	7 758 760
3-rd	15 517 520
4-th	23 276 280
5-th	31 035 040

According to the project, the time for construction is equal to 12 months from the start of funding the project.

If the project will be funded for 11 370 800 USD, then the index of NPV will be 13 191 270 USD.

Internal rate of return (IRR) for the project will be 35,82%.

The profitability index from investments of the project will be 54,59%, it shows quite high profitability for investments.

Payback period for the project from the start of functioning will be 2,47 time periods, i.e. 3 years (2 years and 5 months).

According to discounting, the payback period is equal to 2,73 years, i.e., the expenses from the project with regard to changing in cost of currency, will be paid back in 3rd year of implementation of the project.

Detailed method for calculating indexes of effectiveness is shown below. Calculated time period for implementation of the project is set to 5 years.

Indexes of effectiveness of the investment are shown in Tables 6-8. Basing on the calculation of economic effectiveness for the project of logistics park «Melovoe – Chertkovo», we can decide on expediency and perspective for construction of the object on the territory of Melovoe and Chertkovo regions.

Table 6. Indexes of the investment

Index			
Sum of investment, USD			11 370 000
Discount rate, %			7
Payback Period - PB, months.			36,00
Discounted Payback Period - DPB, months.			36,00
Average Rate of Return - ARR, %			54,59
Net Present Value – NPV, USD			13 191 270
Discounted Profitability Index- DPI			2,16
Internal Rate of Return – IRR, %			35,82
Period for calculating integral values			5 years
Payback Period			
Expected sum of investments, USD			11 370 000
Year	Income stream from investments		Payback from the project
	current year	cumulative total	
1-st	0	0	doesn't occurs
2-nd	7 758 760	7 758 760	doesn't occurs
3-rd	7 758 760	15 517 520	occurs
4-th	7 758 760	23 276 280	occurs
5-th	7 758 760	31 035 040	occurs
Payback period of the project is			3 years
		Precisely	2,47 years

Table 7. Discounted payback period

Expected sum of investments, USD				11 370 000
Discount rate (discount)				0,07
Year	Income stream from investments			Payback of the project
	current year	current cost	cumulative total	
1-st	0	0	0	doesn't occurs
2-nd	7 758 760	6 776 801	6 776 801	doesn't occurs
3-rd	7 758 760	6 333 459	13 110 261	occurs
4-th	7 758 760	5 919 121	19 029 382	occurs
5-th	7 758 760	5 531 889	24 561 270	occurs
Payback Period of the project is				3 years
			Precisely	2,73 years

Stage 7. Analysis of risks for the implementation of the project.
Information about possible situation of the investment project, which have risks.

Project risks. The most significant risks for the project are due to the general situation in Ukraine, lied with political instability, perspective of economic in general and financial instability.

Table 8. Discounted profitability index

Expected sum of investments, USD	11 370 000	
Discount rate (discount)	0,07	
Year	Income stream from investments	
	current year	current cost
1-st	0	0
2-nd	7 758 760	6 776 801
3-rd	7 758 760	6 333 459
4-th	7 758 760	5 919 121
5-th	7 758 760	5 531 889
Net Present Value – NPV	**13 191 270**	
Discounted Profitability Index – DPI	**2,16**	

Political instability in Ukraine. The stability of the project with regard to this factor is due to it's attachment to foreground activity for Ukraine economy – intensification of international economic collaboration and development of transport infrastructure. Since, all the territory of Melovoe region is considered to be agricultural land, implementation of the project is directed on solving one more foreground activity – integrated development of agricultural territories.

Financial instability. The influence of this factor can be partially decreased through stabilization fund and financial appeal of the project in general.

Other types of risks and their possible negative influence on the stage of preparation, investment and implementation of the products are shown in the next chart.

The most significant (quantity defined) risks for the project will be minimized due to insurance of stored cargo, as well as various measures for decreasing the risks.

Measures for decreasing the risks. There is no analogs for this project in Ukraine, this why, risks with the significant competition from other projects, on the preparation stage is set as insignificant.

The risks on the stage of functioning can be significant. However, due to effective management, those can be minimized.

The calculations for the project were based on real-life scenario for development in the market. Significant deviations to decreased economic effectiveness are unlikely.

The general level of risk for the project is acceptable for investment.

Stage 8. Social-economic aspects of the business plan.

The practical implementation of the project, with the increasing volume of transit cargo (which according to some forecast, already in 2020 year will be more than 1 trillion of UAH worth), will allow to use transport-logistics infrastructure of Lugansk region. This will provide jobs for the thousands of the local population, as well as additionally will increase state budget income on 30-35%.

Administration center – Melovoe village and significant part of the territory of local region, are situated near the Ukraine-Russia state border, on the «crossroad» of international strategic highways, near the one of the most intense Euro-Asia transport-logistics system «North – South – West – East».

In the process of solving this question, we must consider the fact that on the territory of Melovoe region, distant from the industrial and highly populated regions, trafficking is always intense and highly active movement of rail and road transport. Russian Federation has strategy up to 2030 year to organize the fast movement of the passenger trains in direction Center -South (Moscow – Adler). This implies movement of large quantity of passengers, people of various age, characters and interests. All that will stimulate development of their activity and will positively influence local and state budget, the creation of new jobs, and will allow to exclude in the future their social-economic downturn and depression.

The creation of logistics park «Melovoe – Chertkovo» will allow to increase transit transport flow through Lugansk region, and that will increase tax income, customs duties on the checkpoints of north-eastern region, and will contribute to development of infrastructure near the highway P-07 (additional gas stations, supermarkets, hotels, maintenance centers and other).

CONCLUSIONS

1. The algorithm and method for creating the inter-modal logistics park, for processing transit and local cargo, with the regard to position, production and economic characteristics of potential customers, was designed.

2. This method provides record for all comprehensive features for all participants of the project, investment idea, evaluation of the market environment. The marketing plan and plan of implementation for the investment project allows us to define the sum for all needed investments.

3. The method for evaluating the effectiveness of the investment project, based on financial plan, with the regard to risks and social-economic aspects, in the process of the plan implementation, was suggested.

4. The example for implementation of the project, for creating logistics park on the Russia-Ukraine border, near the villages Melovoe and Chertkovo, was suggested.

REFERENCES

1. **Al'kema V.G., 2012.:** Transportnij potencial Ukraïni v umovah stalogo rozvitku // Visnik of the Volodymyr Dahl East Ukrainian National University. − № 6 (177), Vol. 1, 92-98 (in Ukrainian).
2. **Dybskaja V.V., 2005.:** Logistika skladirovanija dlja praktikov. – M.: Izdatel'stvo «Al'fa-Press», 208 (in Russian).
3. **Kichkina O.I., Kichkina Є.O., 2013.:** Modeljuvannja sklads'kih procesiv na bazi nechitkoï logiki // Visnik of the Volodymyr Dahl East Ukrainian National University. − № 5 (194), Vol. 2, 151-155 (in Ukrainian).
4. **Kichkina O.I., Shevchenko P.V., 2013.:** Pidvishhennja tranzitnogo potencialu shodu Ukraïni na bazi stvorennja logistichnogo centru ta viznachennja gnuchkih tarifiv na logistichni poslugi // Visnik of the Volodymyr Dahl East Ukrainian National University. − № 6 (195), Vol. 2, 53-58 (in Ukrainian).
5. **Khalipova N.V., 2013.:** Modeljuvannja logistichnih sistem mizhnarodnih perevezen' // Visnik of the Volodymyr Dahl East Ukrainian National University. − № 5 (194), Vol. 2, 73-79 (in Ukrainian).
6. **Nechaev G.I., Gutsalo B.P., Smalts A.I., Slobodyanyuk M.E., 2012.:** Theoretical basis for development of territorial-economic and transit potential for transport system South-East of Ukraine and city of Sverdlovsk, Study, PH East Ukrainian National University, Lugansk, 314 (in Ukrainian).
7. **Nechaev G.I., Smirniy M.F. and other., 2010.:** Regional logistics: methodic basis for creating Euro-region (basing on Lugansk region). Study. PH EUSU Volodymyr Dahl, Lugansk, 200 (in Ukrainian).
8. **Nechaev G.I., Struk V.A., Gutsalo B.P., Slobodyanyuk M.E., 2011.:** The shaping and developing of transport-communication and logistics infrastructure of Eastern Ukraine, in the context of globalization. Study, PH East Ukrainian National University, Lugansk, 288 (in Ukrainian).

9. **Nechaev G., Slobodyanyuk M., 2011.:** Development of transport infrastructure in eastern Ukraine and its interaction with the international transport corridors // Teka Kom. Mot. Energ. Roln. – OL PAN, 11B, 95-101.
10. **Nechaev G., Slobodyanyuk M., 2008.:** Tendencies, prospects and problems of transport-logistical processes dataware automation at Ukraine enterprises // International Scientific Journal “Problemy transportu” tom 3. Zeszyt 4. Gliwice, 27-32.
11. **Nepomnyashiy E.G., 2003.:** Investment design: Tutorial. Taganrog: PH State Radio University of Taganrog, 262 (in Russian).
12. **Omelchenko A.D., Kujel N.V., Slobodyanyuk M.E., 2012.:** Improvement of the processes for transport and defining performance for transport system and complexes. EUVDNU News. – № 6 (177), Vol. 2, 197-201 (in Ukrainian).
13. **Pushkar T.A., 2013.:** Transkordonni teritorial'no-virobnichi klasteri: suchasnij stan i perspektivi rozvitku // Problemi ekonomiki − № 1, 130-135 (in Ukrainian).
14. **Slobodyanyuk M.E., Lapaeva E.N., Pudrik D.V., Grishenko D.I., 2012.:** Formulation of goal for effective development of transport infrastructure, which is adjacent to transport corridor. EUVDNU News. – № 12 – Vol. 2, 288-295 (in Ukrainian).
15. **Slobodyanyuk M., Lapaeva E., 2013.:** Development of transport and socio-economical potential of eastern Ukraine on the example of Lugansk region // Teka Kom. Mot. Energ. Roln., Vol. 12, No 3, 143-147.
16. **Slobodyanyuk M.E., Lapaeva E.N., 2012.:** Analysis of external transport flows of Ukraine. EUVDNU News. – № 6 (177) – Vol. 1, 315-319 (in Ukrainian).
17. **Slobodyanyuk M., Nechaev G., 2010.:** The evaluation technique of logistics’ system cargo transportation efficiency development // Teka Kom. Mot. Energ. Roln. – OL PAN, 10 B, 162-170.
18. **Slobodyanyuk M., 2009.:** Model of transportational system for freight insurance automation based on digital signature // International Scientific Journal “Problemy transportu” tom 2. Zeszyt 4. Gliwice, 85-91.
19. **Tararychkin I., Nechaev G., Slobodyanyuk M., 2013.:** Operation of the road transport network in the presence of various options of freight shipping by automobile transport // Teka Kom. Mot. Energ. Roln., Vol. 13, No 3, 235-238.
20. **Tararychkin I.A., Slobodyanyuk M.E., 2010.:** Finding competitive ability for various transport ways, with regard to unimodal cargo trafficking. EUVDNU News. – № 4 (146) – Vol. 1, 18-22 (in Ukrainian).

МЕТОДИКА И АЛГОРИТМ СОЗДАНИЯ ИНТЕРМОДАЛЬНОГО ЛОГИСТИЧЕСКОГО ПАРКА

Максим Слободянюк, Григорий Нечаев, Александр Кислицин

Аннотация. В статье рассмотрено состояние и развитие инфраструктуры транспортных систем приграничных территорий Украины. Отмечено, что создание логистических парков на этих территориях повысит привлекательность международных транспортных коридоров, проходящих через Украину, увеличит объёмы, скорость прохождения грузопотоков и доходы. Предложена методика и алгоритм создания логистического парка. Рассмотрена реализация методики на примере создания пилотного проекта логистического интермодального парка на Украино-Российской границе в районе Меловского и Чертковского районов.

Ключевые слова: международный транспортный коридор, логистический парк, проект, методика и алгоритм, эффективность инвестиций.

Spatial contact problems for elastic layer in case of flat areas of contact

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S u m m a r y . The following spatial contact problems of the theory of elasticity of strip width 2a stamp sphere forcing in elastic layer of finite thickness h: lying without friction on the hard grounds, rigidly connected to holds its ground. In the area of contact between the die and the friction layer. The stamp is pressed into a layer of force *P*, related to the unit of length, and moments - M_x, M_y. The asymptotic expressions for determination of contact normal voltages under the stamp.

K e y w o r d s . Elastic layer elastic half-space, integral transforms, normal contact stress, hard rubber stamp.

INTRODUCTION

Contact mechanics of deformable solid body interaction is currently the most active and growing field of continuum mechanics. Contact problems of the theory of elasticity are finding more and more applications in the engineering calculations.

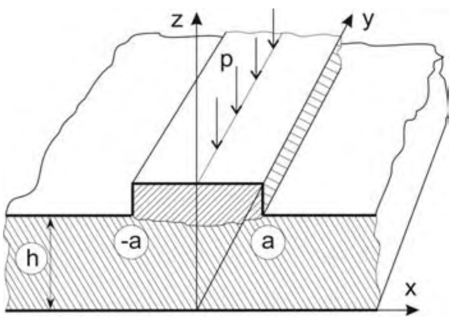

Fig.1. Design scheme

The paper considers the problem of contact interaction of spatial rigid Strip stamp with elastic layer thickness h (Fig. 1).

RESEARCH ANALYSIS

Major publications on the subject are in the works, which contain an overview of the main scientific results on the contact flat static [5, 7, 12, 14, 29], spatial static [1-4, 11], dynamic flat panel [8, 9, 19, 26, 30], spatial dynamic [6, 10, 13, 24, 28], thermo elastic [22, 25, 26, 27, 18], objectives for elastic contact problems of the theory of viscoelasticity [16, 17, 20, 21, 23].

Outlines the mathematical methods of decision of plane and space problems with various boundary conditions at the sites of the contact.

RESEARCH OBJECT

The objective of the proposed work is research of spatial contact problems for elastic layer in case of flat areas of contact and the definition of normal contact stresses under the stamp.

RESULTS OF RESEARCH

1. The task of the integral equation we obtain from these same tasks of integral equation for the free-form contact Ω derived in [1]:

$$\iint_\Omega q(\xi,\eta)d\xi d\eta \int_o^\infty\int_o^\infty \frac{L(u)}{u}\cdot\cos\frac{s}{n}(\xi-x)\cos\frac{t}{n}(\eta-y)dtds =$$

$$=\Delta h\pi^2\delta(x,y)\,,\quad (x,y)\in\Omega\,,\quad u=\sqrt{s^2+t^2}\,. \quad (1.1)$$

Here: $q(x,y)$ – contact pressure distribution function, $\delta(x,y)$ – function of the sediment surface layer points of contact Ω, $\Delta=G(1-\nu)^{-1}$, G,ν – shear modulus of the material layer and Poisson's ratio.

Function $L(u)$ for targets respectively are:

$$1 - \ L(u)=\frac{ch2u-1}{sh2u+2u}\,, \quad (1.2)$$

$$2 - \ L(u)=\frac{2k_1 sh2u-4u}{2k_1 ch2u+1+k_1^2+4u^2}\,,$$

$k_1=3-4\nu$, $\delta(x,y)=\delta+\alpha x+\beta y-f(x,y)$,

$f(x,y)$ – function of the base surface,

$\delta+\alpha x+\beta y$ – move a stamp under the action of forces *P* and moments M_x, M_y.

After solving the equation (1.1) relationship between *P*, M_x, M_y, the efforts of the stamp, and the values α,β,δ determined from the ratio of:

$$P=\iint_\Omega q(\xi,\eta)d\xi d\eta\,,\qquad M_x=\iint_\Omega \eta q(\xi,\eta)d\xi d\eta\,,$$

$$M_y=\iint_\Omega \xi q(\xi,\eta)d\xi d\eta\,. \quad (1.3)$$

Get the integral equation for contact problems of the contact area in the form of endless bands $(|x|\le a, |y|<\infty)$.

Enter into the transformanty Fourier transform functions $\delta(x,y)$, $q(\xi,\eta)$, ratios:

$$\delta(x,y)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\delta_\beta(x)e^{-i\beta y}d\beta\,,$$

$$\delta_\beta(x)=\int_{-\infty}^{\infty}\delta(x,y)e^{i\beta y}dy\,. \quad (1.4)$$

$$q(\xi,\eta)=\frac{1}{2\pi}\int_{-\infty}^{\infty}q_\beta(\xi)e^{-i\beta\eta}d\beta\,,$$

$$q(\xi)=\int_{-\infty}^{\infty}q(\xi,\eta)e^{i\beta y}d\eta\,. \quad (1.5)$$

Based on (1.4) and (1.5) integral equation (1.1) takes the form:

$$\int_{-a}^{a}q_\beta(\xi)d\xi\int_o^\infty\frac{L(u)}{u}\cos\frac{s}{h}(\xi-x)ds=\pi\Delta\delta_\beta(x),$$

$$|x|\le a\,. \quad (1.6)$$

For the case of rolled stamp (1.3) should be replaced by the following:

$$P(y)=\int_{-a}^{a}q(x,y)dx\,,\quad M(y)=\int_{-a}^{a}xq(x,y)dx\,, \quad (1.7)$$

$P(y)$, $M(y)$ – force and moment acting on the section of the stamp.

2. Properties of the core and the representation of the solution of integral equation contact problems for the layer.

We will specify some of the General properties of the kernel integral equation (1.6) into the form:

$$\int_{-a}^{a}q_\beta(\xi)k(b,s)d\xi=\pi\Delta\delta_\beta(x)\,,|x|\le a\,, \quad (2.1)$$

$$k(b,s)=\int_o^\infty\frac{L(u)}{u}\cos(\nu s)d\nu\,, \quad (2.2)$$

here: $b=\beta h$, $s=(x-\xi)h^{-1}$, $u=(\nu^2+b^2)^{1/2}$.

Transform kernel (2.2) as follows:

$$k(b,s)=K_o(b,s)-F(b,s)\,. \quad (2.3)$$

In the expression (2.3) $K_o(b,s)$ - Macdonald function:

$$F(b,s)=\int_o^\infty [1-L(u)]u^{-1}\cos(\nu s)d\nu\,. \qquad (2.4)$$

Based on the properties of functions $L(u)$, ($L(u)\to 1$ when $u\to\infty$, $L(u)\to Au$ when $u\to 0$), it is easy to show that even on the function $F(b,s)$ is continuous, together with all its derivatives at $-\infty<s<\infty$.

As regards $K_o(b,s)$, then, as it is known, the Macdonald at zero point behaves $\ln|bs|$ like the infinity decays like $|bs|^{-1/2}e^{-|bs|}$. For all other values of the argument is continuous, together with all its derivatives.

Will continue to explore the properties of the function $F(b,s)$.

Laying $\cos(\nu s)$ out under the integral of (2.4) in a number of νs, introduce $F(b,s)$ in the form:

$$F(b,s)=\sum_{i=0}^{\infty}C_i(b)s^{2i}\,, \qquad (2.5)$$

where:

$$c_i=\frac{(-1)^i}{(2i)!}\int_0^\infty\frac{[1-L(u)]}{u}\nu^{2i}d\nu,(i=0,1,2,...)\,. \qquad (2.6)$$

Let us rewrite equation (2.1) based on (2.3) in the form of

$$\int_{-a}^{a}q_\beta(\xi)K_o[\beta(\xi-x]d\xi=\pi\Delta\delta_\beta(x)+\int_{-a}^{a}q_\beta(\xi)F(b,s)d\xi\,,$$
$$|x|\le a\,. \qquad (2.7)$$

We will find the solution to the equation (2.7) in the class $L_p(-a,a)$, $1<p<2$. Then based on the properties $F(b,s)$, when $b>0$, you can easily conclude that function:

$$\varphi(x)=\int_{-a}^{a}q_\beta(\xi)F(b,s)\cdot d\xi\,, \qquad (2.8)$$

is continuing with all its derivatives on $x\in[-a,a]$.

When $\lambda_1=ha^{-\infty}$ the function (2.8) takes the form:

$$\varphi(x)=c_o(b)P_\beta\,,\quad P_\beta=\int_{-a}^{a}q_\beta(\xi)d\xi\,. \qquad (2.9)$$

If the relative thickness of the layer is so great that b – it is quite large, then given the asymptotic estimate for the numbers $c_i(b)\sim O(b^{i+3/2}e^{-2b})$ for large values b, can conclude $\varphi(x)=0$.

Therefore, when $\lambda_1=\infty$, if that fits the occasion of elastic half-space, the surface integral equation for strip stamp (2.7) will take the form of:

$$\int_{-a}^{a}q_\beta(\beta)K_o[\beta(\xi-x)]d\xi=\pi\Delta\delta_\beta(x)\,,\quad |x|\le a\,. \qquad (2.10)$$

Note now that because of the properties of the function $\varphi(x)$ at all λ_1 and b the nature and characteristics of the integral equation (2.7) is defined by equation (2.10).

3. Solution of contact problems with large values of the parameter $\lambda_1=ha^{-1}$.

Asymptotic at the big λ_1 challenges for the Strip to stamp can only be obtained based on integral equation (2.7), which, taking into account the (2.5) will be in the form:

$$\int_{-a}^{a}q_\beta(\beta)K_o[\beta(\xi-x)]d\xi=\pi\Delta\delta_\beta(x)+$$
$$+\sum_{i=0}^{\infty}\frac{c_i(b)}{h^{2i}}\cdot\int_{-a}^{a}q_\beta(\xi)(\xi-x)^{2i}d\xi\,,\ |x|\le a\,. \qquad (3.1)$$

As the formula (2.5) occurs when $|s|=|(x-\xi)h^{-1}|<2$, $\max|x-\xi|=2a$, while equation (3.1) and all the results to be obtained from it will make sense, at least when $\lambda_1>1$.

Solution of integral equation (3.1) will search in the form of the following asymptotic number of degrees h^{-1}:

$$q_\beta(\xi)=\sum_{\hat e=0}^{\infty}q_{\beta\hat e}(\xi)\cdot\frac{1}{h^{2\hat e}}\,. \qquad (3.2)$$

Substituting the expression (3.2) in equation (3.1) and equating members under the same degrees, h^{-1} we get an infinite system of integral equations for sequential definitions $q_{\beta\hat{e}}(\xi)$:

a) $$\int_{-a}^{a} q_{\beta 0}(\xi) K_o[\beta(\xi - x)] d\xi = \pi \Delta \delta_\beta(x) + $$

$$+ c_o(b) \int_{-a}^{a} q_{\beta 0}(\xi) d\xi ,$$

b) $$\int_{-a}^{a} q_{\beta 1}(\xi) K_o[\beta(\xi - x)] = c_1(b) \int_{-a}^{a} q_{\beta 0}(\xi)(\xi - x)^2 d\xi +$$

$$+ c_0(b) \int_{-a}^{a} q_{\beta 1}(\xi) d\xi ,$$

c) $$\int_{-a}^{a} q_{\beta 2}(\xi) K_o[\beta(\xi - x)] d\xi = c_2(b) \int_{-a}^{a} q_{\beta 0}(\xi) \times$$

$$\times (\xi - x)^4 d\xi + + c_1(b) \int_{-a}^{a} q_{\beta 1}(\xi)(\xi - x)^2 d\xi +$$

$$+ c_0(b) \int_{-a}^{a} q_{\beta 2}(\xi) d\xi , |x| \le a , \qquad (3.3)$$

etc.

Obviously, the equation a) system of equations (3.3) coincides with an integral equation, the occasion of very large relative layer thicknesses.

Found the approximate solution of integral equation of the contact problem for elastic half-space [1], which is different from the equation a) (3.3) the last element on the right side. Since this term has a functionality, the corresponding approximate solution of integral equation a) and can be considered notable.

3.1. Solution of integral equations (3.3) by the method of successive approximations.

We will write the system (3.3) in another form:

a) $$\int_{-a}^{a} q_{\beta 0}(\xi) \{K_o[\beta(\xi - x)] - c_o(b)\} d\xi = \pi \Delta \delta_\beta(x) ,$$

b) $$\int_{-a}^{a} q_{\beta 1}(\xi) \{K_o[\beta(\xi - x)] - c_o(b)\} d\xi =$$

$$= c_1(b) \int_{-a}^{a} q_{\beta 0}(\xi)(\xi - x)^2 d\xi , \qquad (3.4)$$

c) $$\int_{-a}^{a} q_{\beta 2}(\xi) \{K_o[\beta(\xi - x)] - c_o(b)\} d\xi =$$

$$= c_2(b) \int_{-a}^{a} q_{\beta 0}(\xi)(\xi - x)^4 d\xi + c_1(b) \int_{-a}^{a} q_{\beta 1}(\xi)(\xi - x)^2 d\xi ,$$

$$|x| \le a .$$

Further, consider the case:

$$\delta_\beta(x) = \delta_\beta = const .$$

Let's move into the equation a) system (3.4) to have variables $\xi = \xi' a$, $x = x' a$, $\delta_\beta = \delta_\beta \cdot a^{-1}$, $\varphi_o(\beta) = q_{\beta 0}(\xi' a)$ and putting down the finishing touches, we get:

$$\int_{-1}^{1} \varphi_0(\xi) k\left(b, \frac{\xi - x}{\lambda}\right) d\xi = \pi \Delta \delta_\beta ,\ |x| \le 1 ,\ \lambda = (a\beta)^{-1}, \qquad (3.5)$$

$$k(b,t) = \int_0^\infty \frac{\cos tu}{\sqrt{u^2 + 1}} du + c_0(b) . \qquad (3.6)$$

Using asymptotic representation for Macdonald $K_0(t)$ at small t, get the idea for the kernel $k(b,t)$ in the form:

$$k(b,t) = -\ln|t| + \sum_{K=0}^{\infty} a_k t^{2k} + \ln|t| \sum_{k=1}^{\infty} b_k t^{2k} - c_o(b) . \qquad (3.7)$$

Write some first coefficients of decomposition (3.7):

$$a_0 = 0.1159 + c_o(b) ,$$

$$a_1 = 0.2790, \qquad b_1 = -0.2500 ,$$

$$a_2 = 0.2525, \qquad b_2 = -0.01563 .$$

Substituting (3.7) in (3.5) and drawing the logarithmic part, here is the equation (3.5) equivalent $L_p(-1,1)$, $1 < p < 2$ to the integral equation of the second kind [2]:

$$\varphi_0(x)=\frac{1}{\pi\sqrt{1-x^2}}\left[P_{\beta 0}-\int_{-1}^{1}\frac{\psi'(\tau)\sqrt{1-\tau^2}}{\tau-x}d\tau\right], \quad (3.8)$$

$$P_{\beta 0}=\int_{-1}^{1}\varphi_0(\xi)d\beta=\int_{-1}^{1}\frac{\psi(\tau)d\tau}{\sqrt{1-\tau^2}} \quad . \qquad (3.9)$$

Here:

$$\psi(x)=\Delta\delta_\beta-\frac{1}{\pi}\int_{-1}^{1}\varphi_0(\xi)\left[\sum_{K=0}^{\infty}\lambda^{-2k}(\xi-x)^{2k}+\right.$$

$$+\,(\ln|\xi-x|-\ln\lambda)\times$$

$$\left.\times\sum_{K=1}^{\infty}b_k\lambda^{-2k}(\xi-x)^{2k}-c_0(b)\right]d\xi\,. \qquad (3.10)$$

The solution to the equation (3.8) will be looking for in the form of [3]:

$$\varphi_0(x)=\sum_{i=0}^{\infty}\sum_{j=0}^{\infty}\varphi_{ij}(x)\lambda^{-2}\ln^j\lambda\,. \qquad (3.11)$$

Substituting the expression (3.11) in (3.8) and equating members of the left and right parts with identical grades $\lambda^{-2i}\ln^j\lambda$ will have a number of relationships, of which consistently define $\varphi_{ij}(x)$. Then, from equations (3.9) to find the value $P_{\beta 0}$.

Thus, the asymptotic solution of integral equation (3.5) can be represented in the form:

$$\varphi_0(x)=\frac{P_{\beta o}}{\pi\sqrt{1-x^2}}\left[1+A_1\lambda^{-2}+A_2\lambda^{-4}-\right.$$

$$-\,(2A_1\lambda^{-2}+A_3\lambda^{-4})x^2+A_4\lambda^{-4}x^4+O(\lambda^{-6}\ln^3\lambda)\,,$$

$$P_{\beta 0}=\pi\Delta\delta_\beta\left[a_0-c_0(b)+\ln 2\lambda+\right.$$

$$+\,C_1\lambda^{-2}+C_3\lambda^{-4}+O(\lambda^{-6}\ln^3\lambda)\,,$$

$$A_1=\left(a_1+\frac{3}{2}b_1-b_1\ln 2\lambda\right), \qquad (3.12)$$

$$A_2=\frac{7}{2}a_2+\frac{103}{24}b_2+\frac{7}{2}b_2\ln 2\lambda-\frac{5}{12}b_1A_1,$$

$$A_3=4(a_2+\frac{7}{12}b_2-b_2\ln 2\lambda)-\frac{4}{3}b_1A_1\,,$$

$$A_4=-4(a_2+\frac{25}{12}b_2-b_2\ln 2\lambda)-\frac{2}{3}b_1A_1\,,$$

$$C_1=a_1+b_1-b_1\ln 2\lambda\,,$$

$$C_3=-\frac{1}{4}\left[A_1^2-9(a_2+\frac{7}{6}b_2-b_2\ln 2\lambda\right].$$

Turning to have variables in the integral equations b) and c) system (3.4) and calculating the right parts, here is the integral equations in dimensionless variables:

$$\int_{-1}^{1}\varphi_1(\xi)k(b,\frac{\xi-x}{\lambda})d\xi=\pi(\delta+A_0x^2)\,,\ |x|\le 1\,, \quad (3.13)$$

$$\int_{-1}^{1}\varphi_2(\xi)k(b,\frac{\xi-x}{\lambda})d\xi=\pi(\gamma_1+\gamma_2x^2+\gamma_3x^4)\,,$$

$$|x|\le 1\ . \qquad (3.14)$$

Here:

$$\varphi_1(\xi)=q_{\beta 1}(\xi'a)\,,\ \delta=c_1(b)a^2\pi^{-1}B_2P_{\beta 0}\,,$$

$$A_0=c_1(b)a^2\pi_{-1}P_{\beta 0}\,,\ B_2=1/2-\frac{1}{4}A_1\lambda^{-2}+B_1\lambda^{-4}\,,$$

$$B_1=-(a_2+\frac{4}{3}b_2-b_2\ln 2\lambda)+\frac{1}{12}b_1A_1\,,$$

$$\varphi_2(\xi)=q_{\beta 2}(\xi'a)\,,$$

$$\gamma_1=a^2[c_2(b)a^2S_3P_{\beta 0}+c_1(b)(P_{\beta 1}B_2+A_o\pi S_6)]\pi^{-1}\,,$$

$$\gamma_2=-\frac{33}{32}\left(a_2+\frac{179}{132}b_2-b_2\ln 2\lambda\right)+\frac{5}{64}b_1A_1\,,$$

$$S_2=-6(a_2+\frac{4}{3}b_2-b_2\ln 2\lambda)+\frac{1}{2}b_1A_1\,,$$

$$S_3=\frac{3}{8}-\frac{1}{4}A_1\lambda^{-2}+S_1\lambda^{-4}\,,\ S_4=3-\frac{3}{2}A_1\lambda^{-2}+S_2\lambda^{-4}\,,$$

$$S_5=-\frac{3}{8}a_2+\frac{39}{64}b_2+\frac{11}{384}b_1^2+\frac{3}{8}b_2\ln 2\lambda\,,$$

$$S_6=\frac{1}{4}-\frac{1}{12}b_1\lambda^{-2}+S_5\lambda^{-4}\,.$$

Applying to solve integral equations (3.13) and (3.14) the same method to the equation (3.5) we their solutions in the form of:

$$\varphi_1(x)=\frac{P_{\beta_1}}{\pi\sqrt{1-x^2}}[1-A_1\lambda^{-2}+A_2\lambda^{-4}-(2A_1\lambda^{-2}+A_3\lambda^{-4})x^2+$$
$$+A_4\lambda^{-4}x^4+O(\lambda^{-6}\ln^3\lambda)+\frac{c_1(b)a^2P_{\beta 0}}{\pi\sqrt{1-x^2}}\left\{-1+\frac{5}{12}b_1\lambda^{-2}+\right.$$
$$+A_5\lambda^{-4}+(2-\frac{4}{3}b_1\lambda^{-2}+A_6\lambda^{-4})x^2+$$
$$+\left[\frac{2}{3}b_1\lambda^{-2}-\frac{11}{5}(b_2+\frac{1}{6}b_1^2\lambda^{-4}\right]x^4+$$
$$+\frac{2}{5}(b_2+\frac{1}{6}b_1^2)\lambda^{-4}x^6+O(\lambda^{-6}\ln^3\lambda)\,, \qquad (3.15)$$

$$P_{\beta 1}=c_1(b)a^2P_{\beta 0}\left\{B_2+\frac{1}{2}+c_0(b)+C_1\lambda^{-2}+\right.$$
$$+\frac{1}{4}\left[\frac{1}{3}b_1A_1+9A_7\right]\times\left[a_0-c_0(b)+\ln 2\lambda+c_1\lambda^{-2}-\right.$$
$$\left.-\frac{1}{4}(A_1^2-9A_7)\lambda^{-4}\right]^{-1},$$

$$A_5=\frac{3}{2}a_2+\frac{89}{40}b_2-\frac{3}{20}b_1^2-\frac{3}{2}b_2\ln 2\lambda\,,$$

$$A_6=-\left(3a_2+\frac{61}{20}b_2-\frac{8}{15}b_1^2-3b_2\ln 2\lambda\right),$$

$$A_7=a_2+\frac{7}{6}b_2-b_2\ln 2\lambda\,.$$

$$\varphi_2(x)=\frac{P_{\beta 2}}{\pi\sqrt{1-x^2}}\left[1+A_1\lambda^{-2}+A_2\lambda^{-4}-(2A_1\lambda^{-2}+A_3\lambda^{-4})x^2+\right.$$
$$\left.+A_4\lambda^{-4}x^4+O(\lambda^{-6}\ln^3\lambda)\right]+\frac{1}{\sqrt{1-x^2}}\left\{-\gamma_2-\frac{1}{2}\gamma_3+\frac{1}{4}b_1\times\right.$$
$$\times\left(\frac{5}{3}\gamma_2+\frac{7}{3}\gamma_3\right)\lambda^{-2}+D_1\lambda^{-4}+\left[2(\gamma_2-\gamma_3)-4b_1(\frac{1}{3}\gamma_2+\frac{1}{5}\gamma_3)\times\right.$$
$$\left.\times\lambda^{-2}+D_2\lambda^{-4}\ \right]x^2+\left[4\gamma_3+\frac{1}{3}b_1(2\gamma_2-\frac{3}{5}\gamma_3)\lambda^{-2}-\right.$$
$$\left.-\frac{1}{5}\left(\frac{1}{6}b_1^2+b_2\right)\left(11\gamma_2+\frac{53}{7}\gamma_3\right)\lambda^{-4}\right]x^4+\left[\frac{2}{5}b_1\gamma_3\lambda^{-2}+\right.$$
$$\left.+\frac{1}{5}\left(\frac{1}{3}b_1^2+2b_2\right)\left(\gamma_2-\frac{1}{7}\gamma_3\right)\lambda^{-4}\right]x^6+\frac{2}{35}\left(\frac{1}{3}b_1^2+2b_2\right)\times$$
$$\left.\times\gamma_3\lambda^{-4}x^8+O(\lambda^{-6}\ln^3\lambda)\right\},$$

$$P_{\beta 2}=\pi\left\{\gamma_1+\frac{1}{2}\gamma_2+\frac{3}{8}\gamma_3-\frac{1}{4}A_1(\gamma_2+\gamma_3)\lambda^{-2}+\left[\frac{3}{32}b_1^2\gamma_3+\right.\right.$$
$$+\frac{1}{4}b_1A_1\cdot(\frac{1}{3}\gamma_2+\frac{1}{16}\gamma_3)-A_7(\gamma_2+\frac{33}{32}\gamma_3)-\frac{1}{2}b_2\times$$
$$\left.\left.\left(\frac{1}{3}\gamma_2+\frac{25}{64}\gamma_3\right)\lambda^{-4}\right\}\times\left[a_o-C_o(b)-\ln 2\lambda+C_1\lambda^{-4}-\right.$$
$$\left.-\frac{1}{4}(A_1^2-9A_7)\right]^{-1},$$

$$D_1=\left[-\frac{3}{20}b_1^2+\frac{1}{2}\left(\frac{111}{30}b_2+3A_8\right)\right]\gamma_2+$$
$$+\left[-\frac{61}{448}b_1^2+\frac{1}{2}\left(\frac{433}{112}b_2+3A_8)]\gamma_3\right)\right],$$
$$D_2=\left[\frac{8}{15}b_1^2-\left(\frac{23}{10}b_2+3A_8\right)\right]\gamma_2+$$
$$+\left[-\frac{16}{35}b_1^2-\left(\frac{193}{70}b_2+3A_8)]\gamma_3\right)\right],$$

$$A_8=a_2+\frac{1}{4}b_2-b_2\ln 2\lambda\,.$$

Given the equation (3.2), (3.12) - (3.16) and turning to the dimensional variables. Get the contact problems with accuracy to members $O\left(\lambda_1^{-6}\right)$:

$$q_\beta(x)=q_{\beta 0}(x)+h^{-2}q_{\beta 1}(x)+h^{-4}q_{\beta 2}(x)+O(\lambda^{-6}). \qquad (3.17)$$

Note that the parameters $\lambda_1=ha^{-1}$ and $\lambda=(a\beta)^{-1}$ are related by $\lambda_1=\lambda b$.

4. Solution of contact problems for small values of the parameter $\lambda_1=ha^{-1}$.

To construct asymptotic solutions integral equation (2.1) the scheme is applicable for small values of the method of work [4].

Function $L(u)$ depending on the required accuracy will approximate expressions of the form (2.3) - (2.5), in which instead of the constant B, C, D, V, F and G will be coefficients B(b), C(b), D(b), V(b), F(b) and G(b) depend on the b.

Consider together with equation (2.1) the auxiliary equation:

$$\int_{-\infty}^{a}q_\beta-(\xi)k(b,s)d\xi=\pi\Delta\delta_\beta(x)\,,-\infty<x\le a\,, \qquad (4.1)$$

$$\int_a^{\infty} q_\beta(\xi)k(b,s)d\xi = \pi\Delta\delta_\beta(x)\,, \quad -a \le x < \infty\,, \quad (4.2)$$

$$\int_{-\infty}^{\infty} \nu_\beta(\xi)k(b,s)d\xi = \pi\Delta\delta_\beta(x)\,, \quad |x| < \infty \ . \quad (4.3)$$

Solution of equations (4.1) and (4.2) can be produced by Wiener-Hopf, equation (4.3) - the use of theorems on the packages for the Fourier transform.

Omitting the intermediate calculations we obtain for the case $\delta_\beta(x) = \delta_\beta = const$ under (1.9) [4], the Chief member of the asymptotic of solutions of the equation (2.1).

$$q_\beta(x) = \varphi\left(b, \frac{a+x}{h}\right) + \varphi\left(b, \frac{a-x}{h}\right) - \frac{\Delta\delta_\beta}{hA(b)}\,. \quad (4.4)$$

Here:

$$\varphi(b,t) = \frac{\Delta\delta_\beta}{h\sqrt{A(b)}}\left[A^{-1/2}(b)erf\sqrt{D(b)t} + \frac{e^{-D(b)t}}{\sqrt{\pi t}}\right]. \quad (4.5)$$

Substituting (4.5) in (4.4) we get:

$$q_\beta(x) = \frac{\Delta\delta_\beta}{hA(b)}\left\{erf\sqrt{B(b)\left(\frac{1+x}{\lambda_1}\right)} + \frac{\sqrt{A(b)e^{-B(b)\left(\frac{1+x}{\lambda_1}\right)}}}{\sqrt{\pi\left(\frac{1+x}{\lambda_1}\right)}} + \right.$$

$$\left. + erf\sqrt{B(b)\left(\frac{1-x}{\lambda_1}\right)} + \frac{\sqrt{A(b)e^{-B(b)\left(\frac{1-x}{\lambda_1}\right)}}}{\sqrt{\pi\left(\frac{1-x}{\lambda_1}\right)}} - 1\right\}. \quad (4.6)$$

Using (3.5) defines P_β [4]:

$$P_\beta = \Delta\delta_\beta\left[\gamma A^{-1}(b) - \tilde{S}_1 + \tilde{S}_2 e^{-B(b)\gamma}\right],\ \gamma = \frac{2}{\lambda_1}\,, \quad (4.7)$$

$$\tilde{S}_1 = \frac{\sqrt{C(b)}\left[2B(b) - \sqrt{C(b)}\right]}{B^2(b)}, \quad \tilde{S}_2 = \frac{\left[B(b) - \sqrt{C(b)}\right]}{B^2(b)}.$$

In formulas (4.5)-(4.7) approximation has been used:

$$L(u) = \frac{\sqrt{u^2 + B^2(b)}}{u^2 + C(b)}u\,, \qquad \frac{B(b)}{C(b)} = A(b)\,. \quad (4.8)$$

Decomposing the kernel function $L(u)$ in the ranks of the small $\nu(u = \sqrt{\nu^2 + b^2})$ and equating coefficients under identical degrees ν to find the coefficients of the regression function in the kernel.

In the case of the layer, the core without friction on the hard ground will have:

$$B(b) = \left[-A^2(b) + \sqrt{A^4(b) + A(b)B_1(b)}\right]B_1^{-1}(b)\,,$$

$$C(b) = B(b)A^{-1}(b)\,,$$

$$A(b) = \frac{ch2b - 1}{b(sh2b + 2b)}\,,$$

$$B_1(b) = \frac{4b^2 sh2b - (ch2b-1)(sh2b+2b)}{b^3(sh2b+2b)^2}\,. \quad (4.9)$$

You can find these coefficients is much easier:

$$B^2(b) = b^2 + B\,,\ \ C(b) = b^2 + C\,,\ \ D(b) = b^2 + D\,,$$

$$V(b) = b^2 + V,\ F(b) = b^2 + F,\ G(b) = b^2 + G. \quad (4.10)$$

Here B, C, D, V, F, G-ratios approximating functions of flat tasks found in [4].

Table coefficients $A(b)$, $C(b)$, $B(b)$ for approximating functions (4.8) with different values of the parameter b formulas (4.9) and (4.10). Calculation formulas (4.10) B = 1, C = 2.

Table. Computation of coefficients of approximate function

b	A(b)		B(b)		C(b)	
	(4.9)	(4.10)	(4.9)	(4.10)	(4.9)	(4.10)
0.25	0.5000	0.5000	1.0066	1.0308	2.0625	2.0114
0.5	0.4993	0.4969	1.0230	1.1180	2.2500	2.1487
0.75	0.4969	0.4878	1.0539	1.1500	2.5625	2.1811
1.00	0.4909	0.4714	1.2007	1.4142	3.0000	2.2423
1.25	0.4802	0.4493	1.1667	1.6008	3.5625	2.4292
1.50	0.4644	0.4242	1.2547	1.8028	4.2500	2.7018
1.75	0.4440	0.3981	1.3673	2.0156	5.0625	3.0795
2.00	0.4204	0.3727	1.5061	2.2361	6.0000	3.5825

CONCLUSIONS

1. Received two-dimensional integral equations that describes the contact problems.
2. Investigated the properties of kernels of integral equations.
3. Found simple asymptotic expression for determination of contact normal stress for the entire range of parameter $\lambda_1 = h/a$.

REFERENCES

1. **Alexandrov V., 1971.:** Asymptotic methods in mixed problems of the theory of elasticity, Leningrad, doctoral thesis. (in Russian).
2. **Alexandrov V., Vorovich I., 1960.:** On the effects on elastic layer of finite thickness, Moscow, Applied Mathematics and Mechanics, vol. XXIV, 323-333. (in Russian).
3. **Alexandrov V., 1964.:** The same type two-dimensional integral equations, Moscow, Applied Mathematics and Mechanics, iss. 3, 579-581. (in Russian).
4. **Alexandrov V., Babeshko V., Kucherov V, 1966.:** Contact problem for an elastic layer of small thickness, Moscow, Applied Mathematics and Mechanics, vol. 30, iss. 1, 124-142. (in Russian).
5. **Alexandrov V., Babeshko V, 1965.:** Contact problems for the elastic band of small thickness, Moscow, Izv. The USSR Academy of Sciences, Mechanics, №2, 95-107. (in Russian).
6. **Alexandrov V., 1969.:** Asymptotic solution of contact problem for an elastic layer of thin, Moscow, Applied Mathematics and Mechanics, vol. 33, iss. 1, 61-73. (in Russian).
7. **Alexandrov V, 1968.:** Asymptotic methods in elasticity theory problems, contact Moscow, Applied Mathematics and Mechanics, iss. 4, 672-683. (in Russian).
8. **Alexandrov V., Buriak V, 1971.:** Dynamic mixed problem of pure shear deformation for elastic half-space, Kiev, Applied mechanics, vol. 7, ISS. 4, 16-22. (in Russian).
9. **Alexandrov V., Buriak V, 1978.:** On some dynamic mixed problems of elasticity theory, Moscow, Applied Mathematics and Mechanics, vol. 42, iss. 1, 114-121. (in Russian).
10. **Alexandrov V., Pozharsky D, 1998.:** Non-classical spatial problems of mechanics of contact interactions of elastic bodies, Moscow, Factorial, 288. (in Russian).
11. **Alexandrov V., Romalis A, 1986.:** Contact problems in mechanical engineering, Moscow, "Mechanical engineering", 176. (in Russian).
12. Alexandrov V., Chebakov M., 2005.: Introduction to mechanics of contact interactions, Rostov-na-Donu, Izd-vo «VCRU», 284. (in Russian).
13. **Arlinskii Y, Kovalev, Tsekanovskii E., 2010.:** Quasi-self-adjoin maximal accretive extensions of nonnegative symmetric operators. TEKA Commission of Motorization and Power Industry in Agriculture, vol. XA, 6-14.
14. **Babeshko V, 1975.:** Static and dynamic contact problems with clutch, Moscow, Applied Mathematics and Mechanics, vol. 39, iss. 3, 505-512. (in Russian).
15. **Belodedov V., Nosko P., Stavitskiy V., 2007.:** Parameter optimization using coefficient of Variation of intervals for one – seed sowing apparatus with horizontal disk during maize seeding. TEKA Commission of Motorization and Power industry in Agriculture. Vol. VII, 31-37.
16. **Belokon A, 1975.:** Some principles of conformity for dynamic problems of viscoelasticity, Moscow, Proceedings of the ACADEMY of SCIENCES of the USSR, the rigid body mechanics, № 6. (in Russian).
17. **Belokon A, 1973.:** Contact problems of viscoelasticity of linear theory without friction and adhesion forces, Moscow, Proceedings of the ACADEMY of SCIENCES of the USSR, the rigid body mechanics, № 6, 63-72. (in Russian).
18. **Development of the theory of contact problems in 1976**, the USSR: Moscow, science, 493. (in Russian).
19. **Galin l., 1980.:** Contact problems of the theory of elasticity and viscoelasticity, Moscow, Science, 304. (in Russian).
20. **Galin l., Shmatkova A., 1973.:** The motion hard punch on viscoelastic half-plane boundary, Moscow, Applied Mathematics and Mechanics, vol. 37, 445-453. (in Russian).
21. **Goryacheva I., 1973.:** Contact problems viscoelastic cylinder on the basis of the same material, Moscow, Applied Mathematics and Mechanics, vol. 37, 925-933. (in Russian).
22. **Goryacheva I., Dobichin M.,** 1988.: Contact problems in Tribology, Machine building, Moscow 254. (in Russian).
23. **Grinchenko V., Meleshko V., 1981.:** Harmonic oscillations and waves in elastic solids, Kiev, Naukova dumka, 284. (in Ukrainian).
24. **Kilchevsky N., 1976.:** Dynamic contact compression of solids. Blow, Kiev, Naukova dumka, 319. (in Ukrainian).
25. **Kilchinskaya G., 1967.:** The proliferation of thermo elastic waves in teploprovodom layer of constant thickness, Kiev, Applied mechanics, vol. 3, № 12, 78-83 (in Ukrainian)
26. **Novatsky V., 1970.:** Dynamic tasks of thermo elasticity, Moscow, World, 256. (in Russian).
27. **Podstrigach Ja., Shvets R., 1969.:** Kvazistaticheskaja task related thermo elasticity, Kyiv, Applied mechanics, vol. 5, and № 1, 43-45. (in Ukrainian).
28. **Starchenko V., Buriak V., 2005.:** Mixed problem of dynamic spatial shift of elastic half-space,

Lugansk, Visnik of the Volodymyr Dahl East Ukrainian National University, № 6 (88), 51-56. (in Ukrainian).

29. **Vorovich I., Alexandrov V., Babeshko V, 1974.:** Non-classical elasticity theory problems, Moscow, Science, 456. (in Russian).
30. **Vorovich I., Babeshko V, 1979.:** Dynamic mixed problem of elasticity theory for non-classical areas, Moscow, Science, 320. (in Russian).

ПРОСТРАНСТВЕННЫЕ КОНТАКТНЫЕ ЗАДАЧИ ДЛЯ УПРУГОГО СЛОЯ В СЛУЧАЕ ПОЛОСОВОЙ ОБЛАСТИ КОНТАКТА

Валерий Старченко, Вячеслав Буряк

Аннотация. В работе рассматриваются пространственные контактные задачи теории упругости о вдавливании полосового штампа ширины 2a в упругий слой конечной толщины h: лежащий без трения на жёстком основании и жёстко соединённый с недеформируемым основанием. Форма основания штампа является функцией двух переменных x и y, причём $|y| < \infty$. Штамп вдавливается в слой силой P, отнесённой к единице длины, и моментами M_x и M_y. Получены асимптотические выражения для определения контактных нормальных напряжений под штампом.

Ключевые слова: упругий слой, упругое полупространство, интегральное преобразование, нормальные контактные напряжения, жёсткий штамп.

Development of transport heating systems with cascade transformers of energy

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S u m m a r y . In article perspective schemes of heating and ventilating systems for the transport units, working at the principles of cascade and thermal compression are considered. Physical features of working process of the generator of cascade and thermal compression are revealed and analyzed, concepts of improvement of its properties are offered. Ways of increase of overall performance of heating and ventilating systems are opened and the various circuit solutions providing their maximum productivity under operating conditions are proposed.
K e y w o r d s : cascade-heating pressure, generator of gases, transports heating system, efficiency, rotor.

INTRODUCTION

In a total amount of consumption of energy by passenger train the considerable share is made by costs of providing a microclimate in cars and a cabin of the driver of the locomotive [2,3, 6, 9]. In the conditions of the increasing competition in the market of transport services the requirement for maintenance of comfortable sanitary and hygienic parameters in rooms of a rolling stock at simultaneous decrease in the energy consumed by systems of heating, airsupply and conditioning are of particular importance [8, 10, 31, 33].

The considerable reserve of increase of competitiveness of railway transport in passenger traffic is connected with increase of level of comfort in rooms of a rolling stock. Level of comfort of a trip on railway transport in many respects depends on a microclimate in salons of the rolling stock which parameters, and, first of all temperature, humidity, a dust content and a chemical composition of air, directly influence health of passengers and subjective perception of duration of journey [4, 11, 12, 22, 32].

Need of increase of efficiency of systems of heating and ventilation, search of the decisions possessing higher profitability, predetermines creation of new classes, schemes and the principles of action of heating systems. Significant progress in this direction can be made when using as a basic element of heating and ventilating systems of one of versions of cascade transformers of energy, namely – generators of cascade and thermal compression with an ejector step [7].

MATERIALS AND METHODS

The analysis of systems of heating and ventilation of cars shows that the best microclimatic conditions are provided by a multipoint supply of the warmed-up air in salons [21, 23, 24, 25]. However standard schemes of electro calorific heating have the extremely unsatisfactory power efficiency [5, 29].

Functionally the greatest ability to provide sanitary and hygienic requirements to a microclimate in rooms of a rolling stock air (calorific) heating system possesses [30]. Its advantages treats: simplicity of regulation of air temperature in car salon, reliability of a food of the heaters placed in one place, high level of safety for passengers, possibility of a combination of electric system about the steam, continuous inflow to salon of fresh air [26]. At the same time, air (electro calorific) heating is characterized by very small efficiency.

It is necessary to notice that power imperfection, as a whole, is typical for all systems of electric heating. The main reason consists in irrationality of the return transformation of the refined electric energy in the thermal. Really, warmly in essence is dissipative energy, and can serve as an indicator of imperfection or irreversibility of converting processes in transforming units and power machines.

Especially obvious inexpediency of use of the electric power as a source of warmth is shown in trains with diesel draft where on the one hand the electric power is a product of double transformation (with thermal in mechanical – in the diesel, and mechanical in the electric – in the generator), and on the other hand – branch of warmth in the power unit of a locomotive is a necessary condition of the organization of working process of a diesel cycle. Thus we will note that the warmth which is taken away in the cooling system of the diesel and with fulfilled gases, almost twice exceeds the warmth transformed to useful mechanical energy on a shaft of the engine [20, 26].

Lower value of efficiency of air systems of heating is caused by big costs of energy of heat transportation by an air stream. The compressed air is a product of the high-tech processing which receiving in the conditions of a rolling stock assumes use of the 3 or 4 units with the restrictions by efficiency of converting processes (cycles). For example, in case of diesel draft production of the compressed air is carried out according to the scheme:

- transformation of warmth of combustion of fuel to mechanical energy (diesel, η_e =0,32. 0,34),
- transformation of electric energy in electric (the generator η_g =0,84. 0,85),
- transformation of electric energy in mechanical the compressor drive (the electric motor η_{em} =0,8. 0,85),
- transformation of mechanical energy to located work of the compressed air (the compressor η_c =0,7. 0,72).

Thus, the general efficiency of transformation of thermal energy in the potential of the compressed air on condition of nominal operating modes of all units makes:

$$\eta_{general} = \eta_e \eta_g \eta_{em} \eta_c = 0{,}15 \ldots 0{,}18. \quad (1)$$

In a type of high cost intensity of process of forcing of air power expediency of decrease in the general level of pressure in the highway of an air duct of heating system that can be reached by use of the individual fans placed in close proximity to is obvious snuffled supply of heated air in warmed zones. Such decision is interfaced to unjustified increase in quantity of heating elements and the motor fans, complicating the structure of heating system and reducing its reliability. Thus very it isn't simple to suppress the noise created by operation of fans.

The analysis of systems of heating and ventilation of cars shows that the best microclimatic conditions are provided by a multipoint supply of the warmed-up air in salons. However standard schemes of electro calorific heating have the extremely unsatisfactory power efficiency [6, 11, 32, 33].

Costs of power of ensuring comfort make considerable part of power consumed by train. In Fig.1 average annual distribution of consumed energy standardized by intercity train Federal iron expensively to Switzerland (SBB) by weight 600t is shown at acceleration of 0,1 m / c^2 on lifting of 10%.

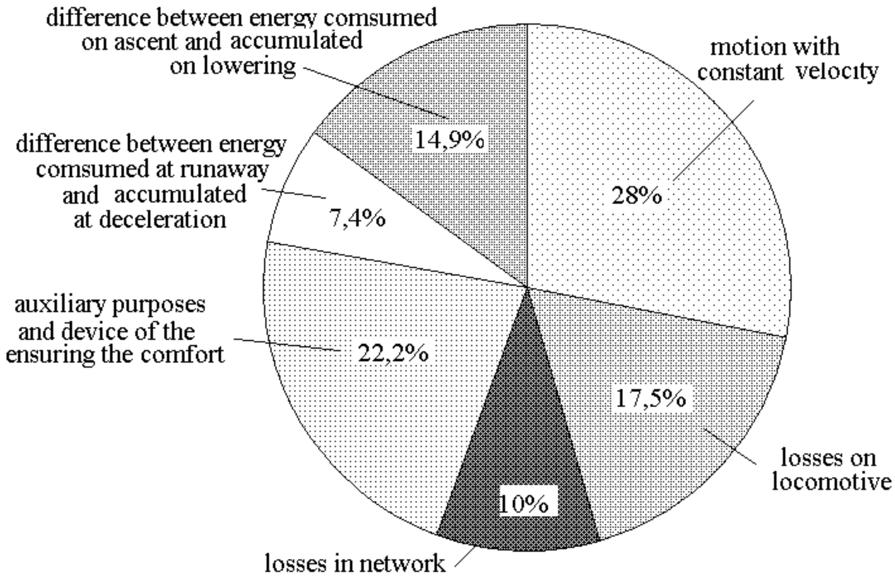

Fig. 1. Settlement distribution of annual power consumption for the standardized train

At train movement without acceleration on horizontal sites of the road, and also during stops specific costs of the auxiliary purposes and ensuring comfort increase.

ARTICLE PURPOSE

The purpose of article is identification of the major factors defining efficiency of application of the principles of cascade energy exchange in systems of heating of transport installations.

The main objectives of research was development of highly effective schemes of systems of heating on the basis of cascade transformers of energy.

RESULTS OF RESEARCH

The perspective direction of development of heating and ventilation is connected with creation of generators of the hot air based on use of effect of the cascade and thermal compression (CTC). Essence of a running cycle of CHP developed under the direction of professor Krajniuk A.I. consists in direct transformation of heat to energy of the compressed air. Thermodynamic cycle CHP can be based on a number of devices: CHP compressor [13, 20], generator of gas [20], cascade exchanger of pressure [1, 18], combustion chamber of gas-turbine installation [14, 15, 16], heater of cascade and thermal compression (HCT) [4, 7], various systems of pressurization of ICE [14, 17, 18], refrigeration machinesetc [19].

Besides simplicity and high reliability of a design, in a type of lack of mechanical displacers and mobile discretely operated gas-distributing bodies, CHP units are characterized by rather high efficiency even when using sources of warmth with rather low temperature potential that causes appeal of their application, including, as utilization systems as a part of traditional heat power plants. The principle of action and the description of the first CHP devices are opened in works [1, 26, 28].

Now on ICE chair and engineering science of the East Ukrainian University of V. Dahl efficient prototypes of the CHP unit which scheme is shown in Fig.2 are created.

The CHP unit contains a rotor 1 covering a stator 2, containing the pressure exchanged channels 3 which are in pairs connecting adjacent cells of a rotor of 1 and opposite 4 supply of low pressure (SLP) located a window and a window 6 of the supply of a high pressure (SHP). The external surface of a rotor 1 is captured by a casing including a window 5 of the branch of low pressure (BLP) and a window 7 of the branch of a high pres-

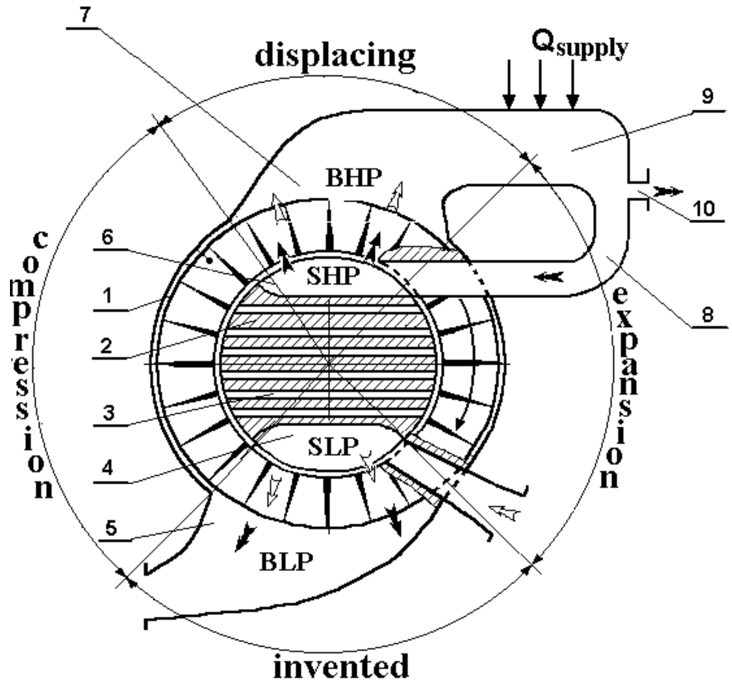

Fig. 2. Schematic diagram of the generator of cascade and thermal compression

sure (BHP), and the window 6 SHP and a window 7 are connected by a displacement path 8 to the heat exchanger 9 of a utilization contour. On a site of a displacement path 8 connecting the heat exchanger 9 and a window 7, the branch pipe of the 10 branch of the squeezed working body is located to the consumer.

In the course of rotation of a rotor 1 (clockwise) each of cells of a rotor 1 is consistently reported with pressure exchanged channels 3 stator 2 through which in it the working body from adjacent cells of a site of expansion arrives. As a result of cascade compression pressure in a cell gradually increases to the certain value depending on thermodynamic parameters of a working body at the beginning of process of expansion.

At the message of considered cells with windows of a high pressure (6 SHP and 7 BHP) displacement path under the influence of centrifugal forces or compulsory circulation replacement previously the air charge squeezed in a cell by the warmed-up source of warmth air or gases (in case of use of the camera of internal combustion) is carried out.

Thereof in a displacement path 8 and reported with it cells the maximum pressure of a cycle exceeding pressure of cascade compression is established. The part of the compressed air from a displacement path 8 is taken away to the consumer through a branch pipe 10 placed just before a source of warmth.

In the period of the subsequent message of cells with pressure exchanged channels 3 the part of a working body is taken away to adjacent cells of a site of compression that is accompanied by pressure drop in considered cells. Thus, work of expansion is spent for compression of an air charge in the course of a cascade mass exchange. Residual pressure at the end of expansion process as the indirect indicator of perfection of working process, depends on number of pressure exchanged channels, aspiring to atmospheric with increase in the last.

And, at last, the purge of cells the air charge, carried out during connection of cells to windows of low pressure of SLP and BLP, closes a running cycle of the CHP unit.

Despite uniqueness of the device, working process of the CHP unit doesn't contradict the classical principles of the organization of working process of heat power machines. Really, the running cycle in a cell of a rotor can be divided into the following processes conditionally:

- compression process at cell movement from the SLP window until its combination with the SHP window, being accompanied step increase of pressure in a cell, owing to a supply of part of a working body from adjacent cells of a rotor via stator channels,

- the process of the replacement including stages of increase of pressure in a cell with previously squeezed working body up to the maximum pressure of a cycle, during its connection to the windows SHP and BHP with simultaneous replacement from a cell and pushing through of a working body via the heat exchanger where its heating, and also branch from the displacement highway of part of the squeezed working body to the consumer with the maximum pressure of cycle CHP is carried out,

- expansion process, as a result of branch of part of a working body via stator channels in adjacent cells of a rotor,

- process of a purge of a cell by fresh air in the period of its message with the SLP and BLP blowing-off windows.

In relation to railway transport interest represents, for example, use of the generator of hot air in heating systems of a rolling stock. The obvious advantage of a heater of CHP, along with the low cost of service, autonomy in view of working capacity preservation is at a de-energization of the power supply network, also possibilities of operation on different types of fuel and from any source of warmth. Thanks to forcing of hot air directly heat carrier transportation in local zones of warmed object is carried out by the CHP unit without use of the driving compressor or the fan.

Other direction of development of devices of cascade compression is connected with creation of exchangers of pressure, for example, ICE used for pressurization.

In the cascade exchanger of pressure (CEP) air compression like the wave exchanger of pressure (WEP) is carried out as a result of direct contact with squeezing gas, however in process with significantly excellent distribution of power substances. The principle of action the CEP is opened in works [13, 27, 28].

Advantages of a running cycle the CEP concerning WEP are caused by the following. Wave character of an exchange of energy and forcing of the compressed air predetermines high sensitivity of working process of WEP to a picture of interaction of primary waves with forward edges of the gas-distributing windows, easily destroyed at a deviation of frequency of rotation of a rotor or parameters of squeezing gas from calculated values. However and on a settlement mode pulse compression of a charge is accompanied by the losses connected with dispersion of energy of formed waves as a result of their counter interaction and reflection in boundary sections of a cell.

Even more significant impact on the efficiency of the koeffitsien WED has the fullness of the displacement of compressed air through the window of high-pressure air. The increase in a share of the compressed air which has remained in a cell (after its dissociation with windows of a high pressure) causes almost proportional decrease in efficiency, to similarly negative influence of so-called "dead" volume in the piston compressor.

Given the presence of the mixing zone in the cell contraction and a compressed gas to carry out a complete replacement of the charge of compressed air, eliminating the cast of compressing gas in the windows low-pressure air is problematic. Especially much noted factors are shown at increase in a pressure of an exchanger with change of frequency of rotation of a rotor.

On a settlement operating mode the generator of cascade thermal compression forces hot air with high temperature and pressure depending on the maximum temperature of a cycle and the relative expense which is taken away to the consumer of air to components from 0,2 to 0,6 MPa. Noted thermodynamic parameters of generated air, allow to carry out transportation of heat to remote zones cars by means of an air duct with rather small section through passage with the subsequent dilution of hot air cold in the ejector cameras of mixture placed in branching of a communication network. Use of the ejector I snuffled, differing high reliability and simplicity, allows not only to reduce temperature of air arriving in salon to comfortable values, but also considerably to increase its expense.

Despite low efficiency of jet pumps their application as a part of heaters of CHP is justified as the dissipative component of an exchange of energy will be transformed to heat used directly in heating system.

The schematic diagram of the elementary system of heating with the CHP generator is shown in Fig.3.

1 hot air forced by the CHP generator is brought to an active nozzle of the ejector 2 which passive nozzle is reported with a blowing-off path 4. As a result of mixture in the ejector 5 camera, hot air is diluted with the blowing-off stream consisting of a mix of external blowing-off air and residual hot air, a rotor forced out from cells 6.

Here warmth of the residual air which is forced out from cells of a rotor remains in a contour of heating system. Thus connection of a blowing-off path 4 to the ejector 5 solves a problem of cleaning of cells 6 that promotes increase of overall performance of generatora CHP and simplification of its device.

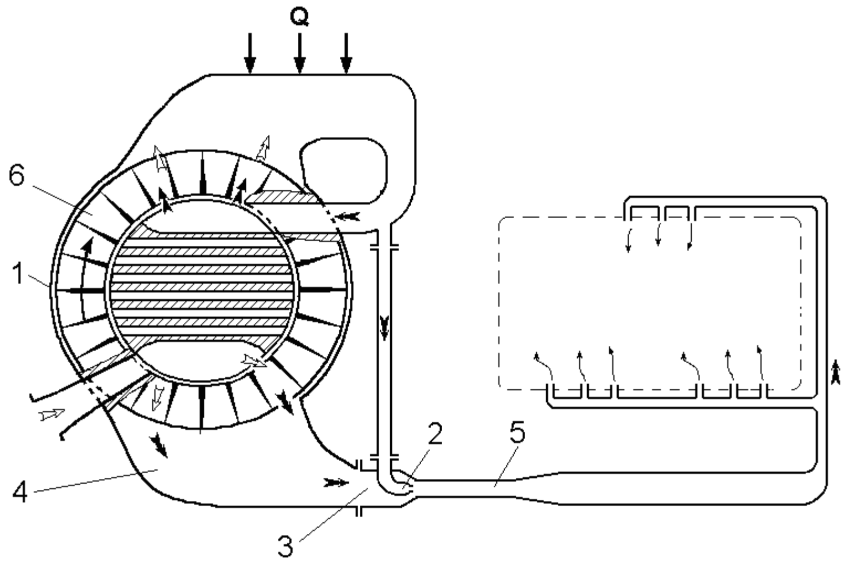

Fig. 3. Heating system with one-stage ejection of air

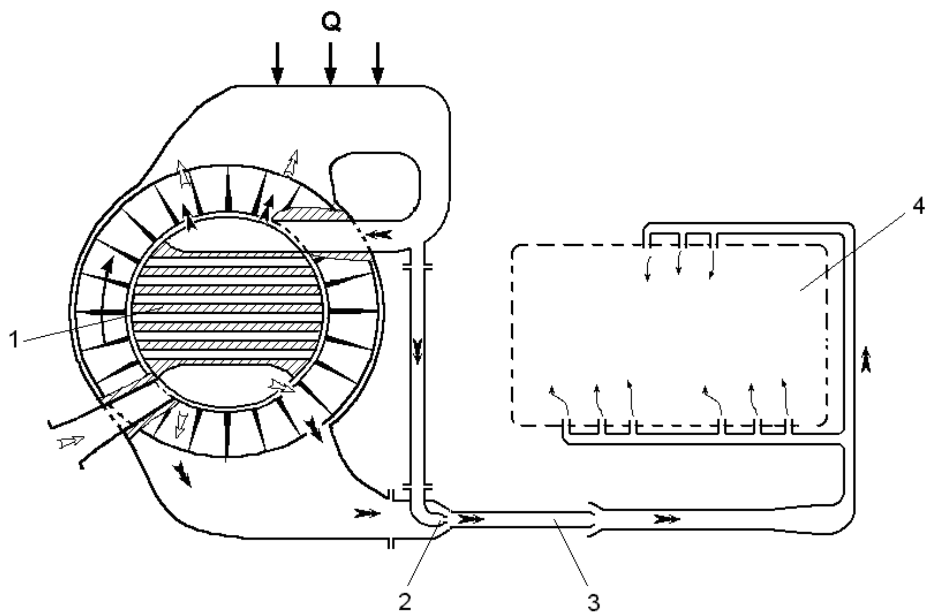

Fig. 4. Heating system with two-level ejection of air

Average temperature of a blowing-off stream in a passive nozzle 3 depends on coefficient of blowing-off air and in some cases, taking into account limited values of coefficient of ejection of one step, is high from the point of view of necessary comfortable cooling of warming air in output sections of a heating network. In case of the excessive temperature of warming air comfortable parameters of a microclimate in salon can be reached by additional dilution of calorific air in the second step of the ejector.

In the circuit shown in Fig.4 acceptable temperature of the incoming air in the interior is ensured by appropriate selection of the total ejection coefficient $n_{e_\Sigma} = (n_{e_I} + 1) \cdot (n_{eII} + 1) - 1$ two ejector stages.

At change of conditions of environment regulation of a temperature mode in salon of the car is carried out by change of power of a source of a supply of warmth in a displacement contour of generatora CHP. At the same time, for maintenance of necessary pressure in the pressure head highway of a calorific network the maximum pressure of Pz of a running cycle of generatora CHP on partial working hours of system on has to change considerably.

Noted condition is realized in adjustable systems of heating (Fig. 5) with the divided cameras of mixture of the first ejector step.

At temperature increase of environment and the corresponding reduction of a thermal stream in a displacement path of generatora CHP necessary level of the maximum pressure of Pz is provided thanks to reduction of an expense of the active environment which is taken away from a displacement contour of generatora CHP, a way of overlapping of one or several active snuffled the 1st ejector step gates 1 specially provided for this purpose.

The main differences of 5 options of adjustable systems of heating shown in fig. are connected with circuit performance of the 2nd ejector step.

When performing the second step of the ejector in the form of the ejector nozzles 2 placed directly in output sections of an air distributing network (see Fig. 5, b), secondary dilution of hot air by internal recirculation air promotes the fastest warming up of the heated room.

Shortcomings of such decision is limited removability of air in passenger salon inflow of external air. In option of execution of heating system with the antimony contours of the blowing-off and stitched highways containing consistently placed steps of the ejector (Fig.5, c) division of air streams with a various temperature is reached. Expediency of generating of air streams with a various temperature is caused by expansion of universality of heating system in cases of simultaneous heating of certain rooms, local surfaces and units of a rolling stock with various heatphysical characteristics.

When using as a source of warmth of a running cycle of generatora CHP of furnace cameras or the fulfilled gases of the diesel temperature of the gas stream leaving the heat exchanger of a displacement contour of generatora CHP, remains rather high as lower than temperature of a working body in rotor cells at the end of process of cascade compression doesn't fall.

Fuller use of thermal potential of a source of warmth possibly in the schemes (Fig.6) providing secondary utilization of a gas stream at the exit from the heat exchanger of 1 displacement contour for heating of external air in a passive nozzle of 2 first or second steps of the ejector.

Problem aspect of such way of utilization of "waste" warmth is need of dilution of a hot stream a significant amount external air that is difficult at limited number of steps of the ejector.

The most universal is the system of the mixed heating presented in Fig.7 in which residual heat of gases is taken away in a contour of water heating of the car.

Supplement heating ventilation CHP water circuit allows you to significantly increase the efficiency of the system, making best use of waste heat streams, and also solves the problem of reducing the temperature in the passenger compartment air to comfortable values by intermediate cooling flow after the first stage ejector.

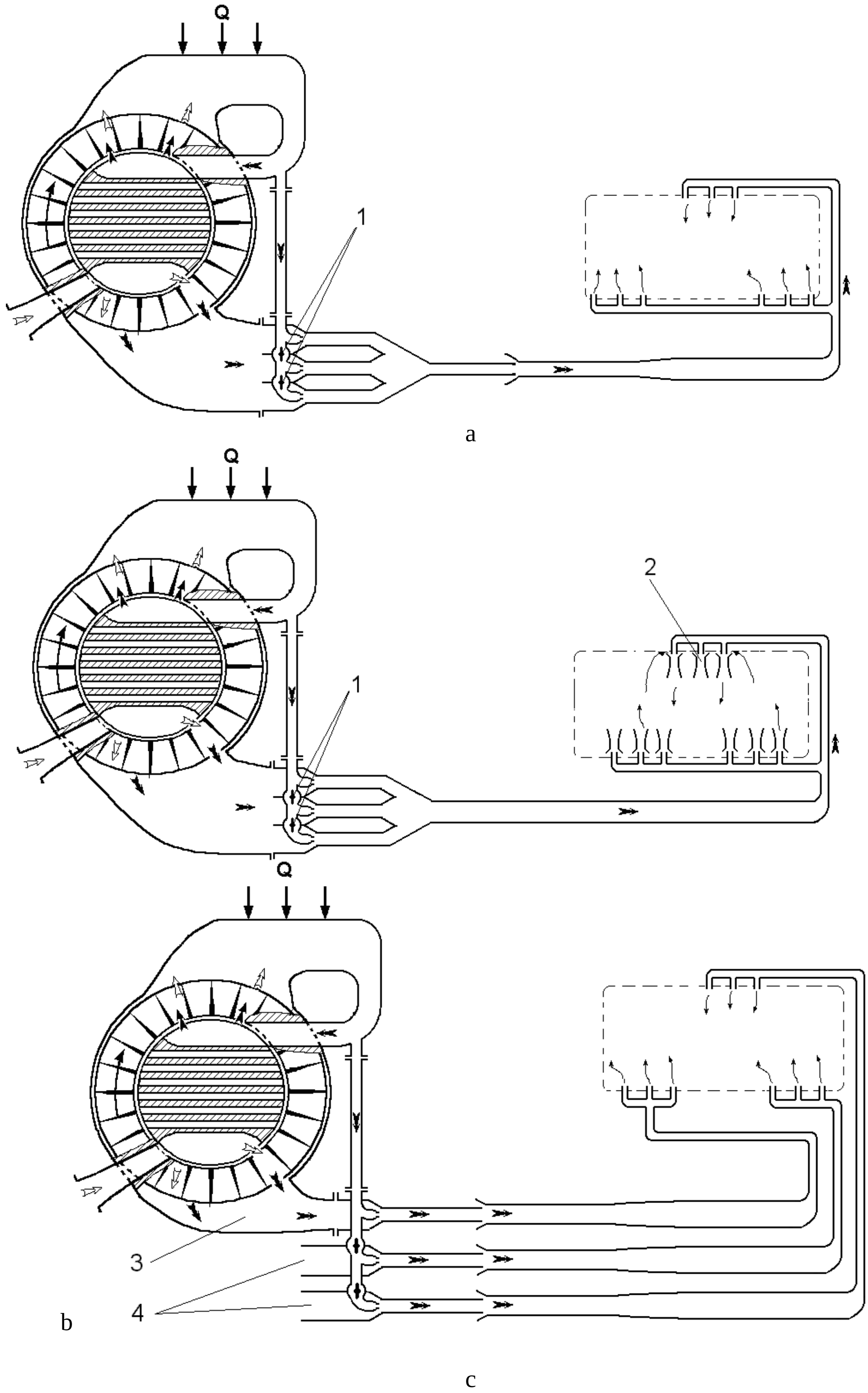

Fig. 5. Adjustable systems of heating

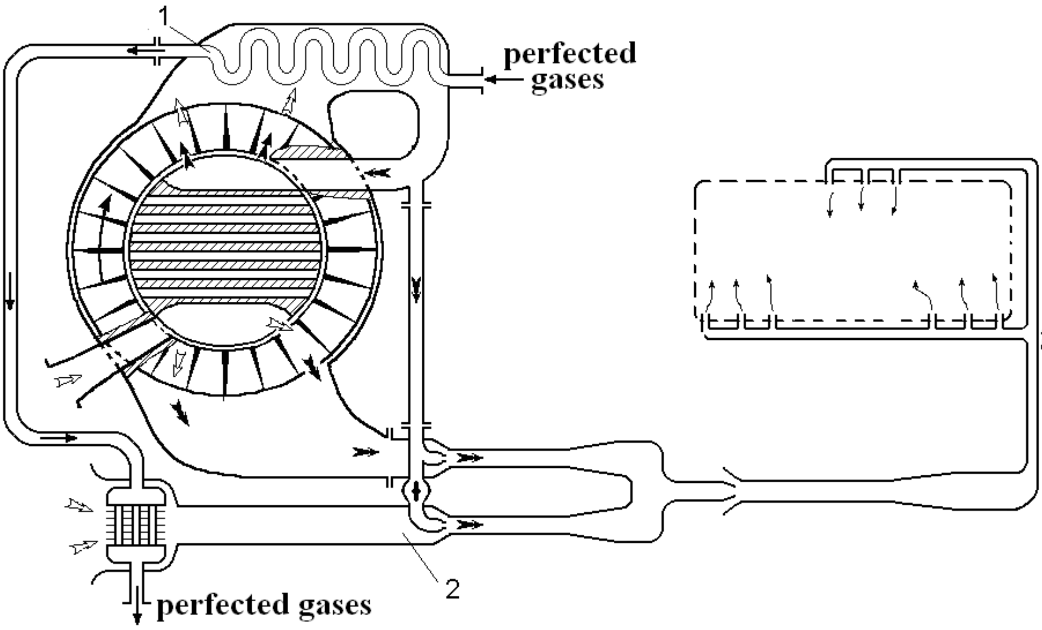

Fig. 6. Heating system with utilization of residual warmth of the gas stream leaving the heat exchanger of a displacement contour of generatora CHP

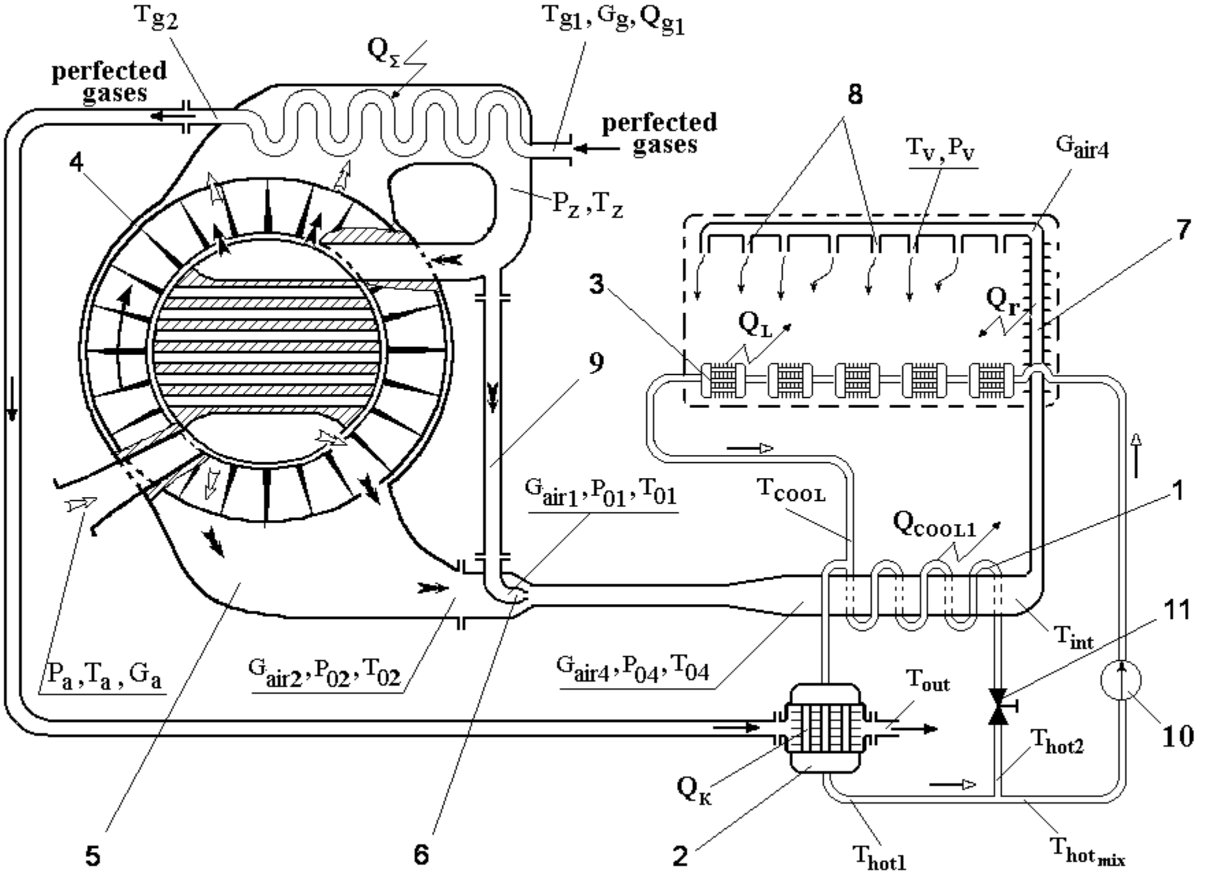

Fig. 7. System of the mixed heating with utilization of residual warmth of a gas stream in a water contour

The liquid of the water contour which is warmed up at the beginning in the heat exchanger of 1 ejector step and then in the heat exchanger of 2 utilization of "waste" warmth of fulfilled gases, are moved in the radiators 3 placed in warmed salon. Additional cooling of the air given to salon to comfortable values, is carried out on a site of the air route supplied with edges of cooling. Finned air line portion 7 is located directly in the heated compartment and thus serves as an additional convective heating radiator.

CONCLUSIONS

1. The running cycle, circuit decisions and design of essentially new structure of heating and ventilating system of the cascade and thermal compression, protected by patents of Ukraine and Russia are developed.

2. Expediency of use as a power source of heating and ventilating systems of generators cascade and thermal pressure, realizing direct transformation of warmth to energy of the compressed air in the devices which aren't containing volume displacers and discretely operated gas-distributing bodies is proved.

3. It is established that the fullest use of thermal potential of a source of warmth possibly in the schemes providing secondary utilization of a gas stream at the exit from the heat exchanger of a displacement contour for heating of external air in a passive nozzle of the ejector.

REFERENCES

1. **Alexeev S.V., Bryantsev M.A, 2006.:** Features of working process of a cascade exchanger of pressure // Internal combustion engine, NTU "HPI" Scientific and technical journal. – Kharkov, – №2, – 102-105. (in Russian).
2. **Barkalov B.V., Karpis E.E., 1971.:** Air conditioning in industrial, public and vein building, – Moscow: Stroyizdat. – 270. (in Russian).
3. **Bushuykin Y.B., 1970.:** Air conditioning in booth of the locomotive, – Moscow: Transport. – 81. (in Russian).
4. **Culicov YU.A., Kuzimenko S.V., Kuschenko A.V.1996.:** Study of the regularities and optimization parameter aerodynamic transformation to mechanical energy in heat in ecological device heating.// The messenger of the East Ukrainian national university . Lugansk: Publ. VUGU, SeriesTransport, - 102-106. (in Russian).
5. Faershteyn YU.O., 1974.: Artificial climate in passenger coach. – Moscow: Transport. – 208. (in Russian).
6. **Gogulya A.M., 2002.:** System of the heating the passenger coach with heater of the cascade type// The messenger of the East Ukrainian national university of V. Dahl, – Lugansk: Publ. EUSU, – № 3(46), - 110-115. (in Russian).
7. **Gogulya A.M., Krajniuk A.A., 2004.:** Heater of the salon of the transport facility. Patent UA №69934, International patent classification F 15 D 1/00, request №20031211690, it is declared 16.12.03, it is published 15.09.04, bulletin №9. (in Russian).
8. **Golubenko A.L., Kuzimenko S.V., Naysh N.M., 2004.:** Increasing to efficiency of the system of the heating and ventilations of the passenger coach of the suburban message Open join-stock company "Luganskteplovoz"// The messenger of the East Ukrainian national university of V. Dahl, – Lugansk: Publ. EUSU , –№ 8(78). – 204-209. (in Russian).
9. **Goryachkin N.B., 2000.:** Choice parameter systems of the provision microclimate booths of the locomotive // Abstract to thesises on competition degree kand. tehn. sciences: 05.26.01. –Moscow, – 23. (in Russian).
10. **Gribinichenko M.V., 2003.:** Improvement of the system of the heating and ventilations of the salon of the car ZAZ// Abstract disertacii. kand. tehn. sciences: 05.22.02 / Kharkovskiy national car-road university, – Kharkov. – 24. (in Russian).
11. **Kalymulin YU.M., Bluish tint I.A., 1989.:** Electric heating passenger coaches, – Moscow: Transport. – 207. (in Russian).
12. **Karnauh N.G., Karnauh L.A., Medvedeva E.F., 1978.:** Methods of the complex estimation of the heat condition of the person and parameter convections micro climate, Crivoy rog. – 365. (in Russian).
13. **Klyus O.V., Pushov V.V, Krajniuk A.A., 2010.:** Pressure exchanger. Patent RF №2382240, International patent classification F 02 B 33/00, request № 2008143154/06, it is declared 30.10.2008, it is published 20.02.2010, bulletin №5. (in Russian).
14. **Krajniuk A.I., 2010.:** Development of supercharging systems of internal combustion engines with the cascade pressure exchanger //TEKA Komisji Motoryzacji i Energetyki Rolnictwa, – OL PAN, Lublin , –№10A, 303-310.
15. **Krajniuk A.I., 2010.:** The Krajniuk’s cascade exchanger and new principles of the organization

of working process of the gas-turbine engine// TEKA Komisji Motoryzacji i Energetyki Rolnictwa, – OL PAN, Lublin, –№10C, 151-162.
16. **Krajniuk A.I., Krajniuk A.A, Bryantsev M.A, 2011.:** The cascade pressure exchange gas-turbine engine efficiency increase with fulfilled environments heat utilization// Weight nickname of engine-building, Scientific and technical journal, – Zaporozhye: OJ-SC "Motor Sich". – №2. – 91-100. (in Russian).
17. **Krajniuk A.I., Alexeev S.V., Krajniuk A. A., 2009.:** The ICE supercharge system with boosting air deep cooling // Internal combustion engine, NTU "HPI" Scientific and technical journal. – Kharkov. –№1. – 57-61. (in Russian).
18. **Krajniuk A.I., Alexeev S.V., Kovtoon A.S., 2011.:** The cascade pressure exchange supercharge system with boosting air deep cooling test results // Aerospace equipment and technology: collection of works: Thermal engines and power installations. Kharkov, – №10(87). – 168-172. (in Russian).
19. **Krajniuk A.I., Bryantsev M.A., 2010.:** Krajniuk's air refrigeration unit // Alternative kilowatt. Russia, Rybinsk, Publishing house “Media grandee”. – №5. – 40-45. (in Russian).
20. **Krajniuk A.I., Starcheous YU .V., 2012.:** Studies to physical essence of the processes to transformations to energy in a milieau of cascade-heat compression. – Lugansk: publishers "Noulidzh". – 118. (in Russian).
21. **Kuliko A.P., 2003.:** System to normalizations of the microclimate on base curl effect of the booth of the driver town and suburban bus // Abstract to thesises on competition degree kand. tehn. sciences: 05.22.10. – Volgograd. – 18. (in Russian).
22. **Kuzimenko S.V., 1999.:** Improvement of the system of the heating and ventilations of the booth of the machinist of the locomotive by by use device aerodynamic heating of the air// Abstract to thesises on competition degree kand. tehn. sciences: 05.22.07. – Lugansk. – 23. (in Russian).
23. **Mahaniko M.G., Sidorov YU.P., 1981.:** Air conditioning in passenger coach and on locomotives, – Moscow: Transport. – 254. (in Russian).
24. **Nesterenko A.V., 1971.:** Bases thermodynamic calculation to ventilations and air conditionings. – Moscow: High school. – 459. (in Russian).
25. **Pripoteni YU. K., 2001.:** Improvement of the methods of the calculation that development constructive element for systems of the heating by means of high warm-up gas gun // Thesis kand. tehn. sciences: 05.23.03 / Poltavskiy state technical university im. YUriya Kondratyuka, – Poltava. – 158. (in Russian).
26. **Starcheus, YU.V., Danileychenko A.A., 2013.:** Heating-ventilation systems for rolling stock on base cascade energy exchanger, – Lugansk: publishers "Noulidzh". – 106. (in Russian).
27. **Starcheus YU.V., 2013.:** Cascade transformers to energy, – Lugansk: publishers "Noulidzh". – 200. (in Russian).
28. **Starcheus YU.V., 2011.:** Scientific activity of the pulpit of the engines of internal combustion East Ukrainian national university im. V. Dahl // Engines of internal combustion: collection of the scientific works, NTU «HPI», – Kharkov. – №1. – 68-72. (in Russian).
29. **Timoshenkova E.V., 2002.:** Choice of the system of the ensuring the micro climate in premiseses of the rolling stock for year mode of the usages // Abstract to thesises on competition degree kand. tehn. sciences :05.14.04. – Moscow. – 24. (in Russian).
30. **Zhivnyy Karl., 1961.:** Electric heating railway compositions, – Moscow: Transport. – 154. (in Russian).
31. **Zinger N.M., Belevich A.I., Nemirova O.YU., 1989.:** State of working systems of the heating with controlled jet pump (the elevator), Teploenergetika, – №6. – 24-27. (in Russian).
32. **Zorohovich A.E., 1970.:** Electro and radio equipment passenger coaches, – Moscow: Transport. – 170. (in Russian) .
33. **Zvorykin L.R., CHerkez V.M., 1977.:** Air conditioning in passenger coach, – Moscow, "Transport". – 124. (in Russian).

РАЗВИТИЕ ТРАНСПОРТНЫХ ОТОПИТЕЛЬНЫХ СИСТЕМ С КАСКАДНЫМИ ТРАНСФОРМАТОРАМИ ЭНЕРГИИ

Юрий Сторчеус, Александр Данилейченко, Константин Лупиков

Аннотация. В статье рассмотрены перспективные схемы отопительно-вентиляционных систем для транспортных установок, работающие на принципах каскадно-теплового сжатия. Выявлены и проанализированы физические особенности рабочего процесса генератора каскадно-теплового сжатия, предложены концепции совершенствования его свойств. Раскрыты пути повышения эффективности работы отопительно-вентиляционных систем и предложены различные схемные решения, обеспечивающие их максимальную производительность в условиях эксплуатации.

Ключевые слова: каскадно-тепловое сжатие, генератор газов, транспортная отопительная система, эффективность, ротор.

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Research of interaction of disc wave generator with flexible gear of heavy loaded wave gearing

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Summary: Force processes taking place in kinematic pairs of higher degree, disc – flexible gear, cause negative developments in heavy loaded wave gearing. These are sizeable axial forces possessing dynamic characteristic as well as essential energy losses in the field of wave generator. The reported results of force analysis of disc wave generator and flexible gear interaction made it possible to give estimate of force and energy factors observed in the process of large wave gearing operation.
Key words: wave gearing, axial forces, energy losses.

INTRODUCTION

Speed reducers make the basis of heavy machines drives, the losses in which often determine total energy losses of machines and assembly units. High unit capacities of machines in heavy engineering make actual the issue of energy losses in speed reducers as it is connected not only with the increased energy consumption and financial charges but also with technical conditions: lubrication cooling, heat extraction, application of wear-resistant materials [5, 15, 16].

In theory, practice and industrialization of large wave gearings in heavy engineering, peculiarities of wave generator and flexible gear interaction are the least understood. Because of the complexity of unusual conditions of rigid parts and flexible link contact, axial forces generation mechanism is not discovered. Uncertainty of processes, proceeding in kinematic pairs of higher degree, disc – flexible gear, is conditioned by elastic deformations of flexible link and insufficiently rigid mount of wave generator discs on bearing assemblies, which causes axes deviation from the wave gearing common axis. This article will present direct conditions of axial forces generation in large wave gearings with disc wave generator as well as energy losses in kinematic pairs of higher degree, disc – flexible gear.

MATERIALS AND METHODS

In heavy engineering gearings set in the machines, transmit torques to actuators up to 10^7 *Nm* and more. Experiments with large industrial models cause known technical difficulties and big financial charges [1, 13, 23]. Parameters nonlinearity of flexible gear and mating members force interaction complicates conditions of experiments data transfer from small experimental models to large wave gearings [7, 8]. Size factor distorts not only the quantitative but also the qualitative characteristics of the sought parametric dependences of the physical quantities.

In the heavy loaded wave gearings with flexible gears diameters of more than 800mm disc wave generators are used. During load transmission interaction of discs with flexible gear breaks the initial symmetry of flexible gear force balance and causes additional reactions in the kinematic pairs. Force disturbances are conditioned by wave gearings design features and are intensified by scale factor that increases energy losses, wear and vibration, restricts application of large wave gearings [17]. It is known that large energy leakage takes place through the wave generator [3]. At the present moment reasons which influence this factor are not discovered. Mechanism of axial forces generation in the wave gearings is not determined either [24]. Derivation of analytic expressions connecting axial forces and energy losses with dimensions, deformations and conditions of flexible gear mating with elements of wave gearing kinematic pairs of higher degree is of practical interest for heavy engineering [22, 25, 26].

Method of construction of universal mathematical model of power contact of elements of higher degree kinematic pairs with flexible link is based on conditions of flexible gear permanent deformation by wave generator discs in the aggregate with possible spherical movements of the discs with respect to some centers situated on the axes of these discs.

RESULTS, DISCUSSION

The purpose of the present paper is determination of mechanism of axial forces origin and reveal of nature of energy losses in the field of disc wave generator on the basis of development of universal mathematical model of higher degree kinematic pair disc – flexible gear. Simulation of force and kinematic dependences in the wave generator as well as the solution of this multifactorial problem specifies the conditions of analytic and empirical analogs extraction with sufficient approximation of mating links interaction parameters. Such statement of the problem will allow determining force and energy characteristics of mating of higher degree kinematic pairs elements of wave gearing, design of which differs fundamentally from the rigid gear gearings [4].

Wave generator discs and flexible gear, generating kinematic pair of higher degree have different speed orders. And even slight relative positional variations can have a great impact on force and energy factors in the zone of their contact. Wave generator design admits the possibility of discs axes slight deviation from parallelism with wave gearing axis. Asymmetric load distribution on discs surfaces deflects them relative to the specified planes about some angle γ. Skewness of axes of wave generator discs generates screw friction pair: wave generator – flexible gear. Drive shaft rotation induces helical motion of wave generator which is «screwed» into the flexible gear, and generates axial forces P, which reach intolerably large values.

Generator discs deform flexible gear, located on the free end of the cylindrical shell, opposite end of which is mounted on the driven shaft and fastened by means of spline joint. On the arc of CD disc contact with flexible gear radial forces q_r (Fig. 1) effect, the influence of which is approximated by parabolic relation:

$$q_r = q_{r\max} \cdot \left(1 - \frac{\theta^2}{\theta^{*2}}\right), \tag{1}$$

where: θ - current angular coordinate, θ^* - angular coordinate which determines dimension of radial load with respect to its maximum value $q_{r\,max}$.

Forces q_r form flexible gear and balance radial forces in the gearing, carried by wave generator discs. It is due to the radial float of flexible gear, forces for generation of which in the absence of external load $(M_2 = 0)$ are weak as compared to the radial forces in the gearing. Maximum value of radial forces $q_{r\,max}$ is connected with loading torque M_2:

$$M_2 = \frac{d^2}{tg\,\alpha} \cdot \int_0^{\theta*} q_r\, d\theta, \qquad (2)$$

by the following relation:

$$q_{r\max} = \frac{3M_2 tg\,\alpha}{2d^2\theta*}, \qquad (3)$$

where: α – gearing angle, d – diameter of the circle passing through the middle of the rigid gear teeth depth.

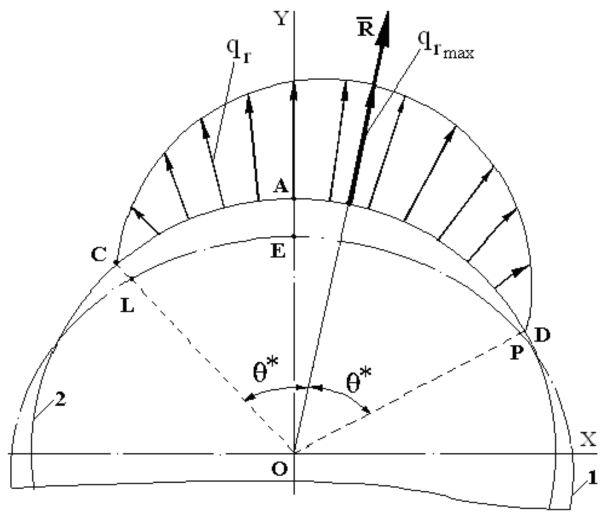

Fig. 1. Radial forces distribution on the flexible gear: 1 – before deformation, 2 – after deformation

Maximum radial load $q_{r\max}$ is deviated with respect to the major axis of the wave generator OA about the angle of χ (Fig. 2). During the flexible gear formation by wave generator discs, generators BB_1, situated in front of the major axis of wave generator OA, deviate from the initial position KB_1, before the deformation, about the angle ψ, which continuously increases and takes the maximum value $\psi_{\max}$ in the vicinity of wave generator major axis. Equivalent friction forces F_1, F_2, are determined by formula integration (Eg. 3) within relevant limits:

$$F_1 = f\, q_{r\,max}\alpha \cdot \left\{\frac{2}{3}\theta* + \chi\left(1 - \frac{\chi^2}{3\theta^2}\right)\right\}, \qquad (4)$$

$$F_2 = f\, q_{r\,max}\alpha \cdot \left\{\frac{2}{3}\theta* - \chi\left(1 - \frac{\chi^2}{3\theta^2}\right)\right\}, \qquad (5)$$

where: a – distance from drive center line to surface of disk contact with flexible gear, f – friction ratio.

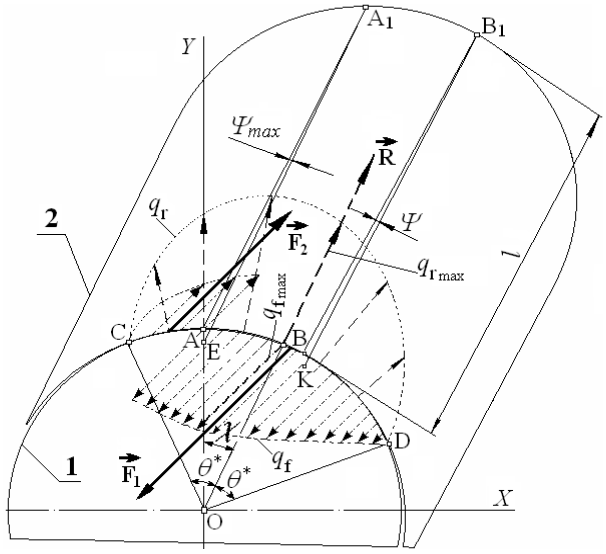

Fig. 2. Model of the disks interaction with the flexible gear: 1 – generator disk, 2 – flexible gear

Hereby, we compose the formula for friction torques along axis X and Y:

$$M_{1x} = fq_{r\,max}\, a^2 \int_{-\chi}^{\theta*} \left(1 - \frac{\theta^2}{\theta^{*2}}\right) cos(\theta - \chi)\, d\theta, \qquad (6)$$

$$M_{1v} = fq_{r\,max}\, a^2 \int_{-\chi}^{\theta*} \left(1 - \frac{\theta^2}{\theta^{*2}}\right) sin(\theta + \chi)\, d\theta, \qquad (7)$$

$$M_{2x} = fq_{r\,max}\, a^2 \int_{-0*}^{-\chi} \left(1 - \frac{\theta^2}{\theta^{*2}}\right) cos(\theta + \chi)\, d\theta, \qquad (8)$$

$$M_{2v} = fq_{r\,max}\, a^2 \int_{-0*}^{-\chi} \left(1 - \frac{\theta^2}{\theta^{*2}}\right) sin(\theta + \chi)\, d\theta. \qquad (9)$$

After formulas integration for the torques M_{1x}, M_{1v}, M_{2x}, M_{2v}, we determine point grid reference for friction torque application F_1, F_2

$$x_{c_1} = \frac{3a\{\zeta - 2[cos(\theta^* + \chi) + \theta^* sin(\theta^* + \chi)]\}}{2\theta^{*3} + \chi(3\theta^{*2} - \chi^2)}, \quad (10)$$

$$y_{c_1} = \frac{6a[sin(\theta^* + \chi) - \chi - \theta^* cos(\theta^* + \chi)]}{2\theta^3 + \chi(3\theta^{*2} - \chi^2)}, \quad (11)$$

$$x_{c_2} = \frac{3a\{\zeta - 2[cos(\theta^* - \chi) + \theta^* sin(\theta^* - \chi)]\}}{2\theta^{*3} - \chi(3\theta^{*2} - \chi^2)}, \quad (12)$$

$$y_{c_2} = \frac{6a[sin(\theta^* - \chi) - \chi - \theta^* cos(\theta^* - \chi)]}{2\theta^3 - \chi(3\theta^{*2} - \chi^2)}, \quad (13)$$

where: $\zeta = (2 + \theta^{*2} - \chi^2)$.

Friction torques q_f along wave generator large axis:

$$M = F_1 x_{c1} + F_2 x_{c2}. \quad (14)$$

Torque M gives rise to disks skewing with slewing around OA axis for an angle γ, which depends upon the type of the bearings and mounting fits. The disks can be supported in roller radial double-raw spherical bearings, admitting the twists, whereby, the axial clearances between the disks are taken up and their and their end planes are matched. The disks together with flexible gear establish friction couple with an agle γ equivalent to lead angle. The angle is linked to summarized axial clearance of the disks Δ [2]:

$$\Delta = (c_1 + c_2)(cos\gamma - cos^2\gamma) + \varepsilon \cdot tg\gamma, \quad (15)$$

where: c_1, c_2 – distance from spherical bearings center lines up to disks end planes, separated by clearance Δ, ε – eccentricity of the disks mounting position on the wave generator shaft.

Disks sliding speed V_f and power of energy losses N_f in areas of the disks contact with the flexible gear is proportional to the angle γ:

$$V_f = a \cdot \omega_1 \cdot tg\gamma, \quad (16)$$

$$N_f = 2(F_1 + F_2)V_f. \quad (17)$$

Axial force F, resulted from wave generator disks skewing and from friction forces:

$$F = F_1 + F_2. \quad (18)$$

Coordinate data as for axial force application F during the contact of wave generator disk with flexible gear:

$$X = \frac{F_1 x_{C_1} - F_2 x_{C_2}}{F_1 - F_2}; \; y = \frac{F_1 y_{C_1} - F_2 y_{C_2}}{F_1 - F_2}. \quad (19)$$

Friction forces F_1 и F_2 create friction torque M_f relative to wave generator large axis:

$$M_f = F_1 x_{C_1} - F_2 x_{C_2}. \quad (20)$$

Friction torque M_f gives rise to disks skewing, rotating them about OA major axis of wave generator at some angle γ, which depends on type of bearings and mounting clearance. In heavily loaded wave gearing, the disks are supported in roller radial double-raw spherical bearings. Such bearing assemblies assume disk skewing, where axial clearances between the disks are taken up and their end planes are matched. This allows to obtain the dependence of total axial clearance Δ between the disks from design parameters of wave generator and angle γ, which determines disk axis alignment error with general wave gearing center line:

$$\Delta = (c_1 + c_2)(1 - cos\,\gamma)cos\,\gamma + \varepsilon \cdot tg\,\gamma, \quad (21)$$

where: c_1, c_2 – corresponding distances from spherical bearings centers up to disks end planes, separated by clearance Δ, ε – mounting eccentricity of wave generator disks at high speed shaft of wave gearing.

Sliding speed V_f of wave generator disks relating to flexible gear is proportional to disks skewing angle γ:

$$V_f = a\,\omega_1\,\gamma, \quad (22)$$

where: ω_1 – angular rotational velocity of high speed shaft.

Sliding speed V_f of wave generator disks determines loss of power during friction at higher pair of kinematic elements disk – flexible gear:

$$N_f = 2\,a\,\omega_1\,\gamma\left(F_1 + F_2\right). \qquad (23)$$

Higher energy losses in deformed gear [9, 10] are mainly determined by two factors. Firstly, it is large extent of contact patch and remoteness from pitch point that increase sliding speed of the teeth. Secondly, it is the second class meshing interference resulting from flexible gear complex deformation due to wave generator and loading torque twist [14]. Small module $m = 1{,}5...4\,mm$, with flexible gear diameter $1{,}1...3{,}0\,m$, and small gear spacing of internal toothing $Z_1 - Z_2 = 2$, support meshing interference. Under higher loading torque $M_2 > M_{2nom}$, the meshing interference remarkably increases energy losses in gearing. Under higher loading torque significantly exceeding nominal values $M_2 > 1{,}2M_{2nom}$, the meshing interference can lead to binding and skipping of the teeth in large wave gearing.

To reduce energy losses, the width of toothing should be limited and gearing backlash should be increased. Contact patch range expansion, for example, during gear ratio increase, moves away extreme points of teeth entry/exit from the meshing against pitch point. Thus, the influence of teeth wedging effect is increased, along with teeth sliding speed, and energy loss does grow in toothing of wave gearing.

In a view of wave gearing multithreading, we assume average sliding speed of the teeth as equal to half of the maximum. On the basis of oscillography results as for teeth loading, the power loss in gearing can be determined P_f:

$$P_f = \frac{I \cdot f \cdot \omega_1 \cdot M_1}{\cos\alpha} \sin\frac{\beta_0}{4}, \qquad (24)$$

where: $I = 1{,}1 + 0{,}0005(u - 80)$ – is ratio, taking into account negative effect of meshing interference under higher loads, it is valid for large wave gearing with disk-type wave generator, upon condition of $b \le 40m$, where b – is width of flexible gear toothing, α – rack tooth profile angle, f – gearing friction ratio, ω_1 – wave generator rotation frequency, M_1 – rotation torque at wave generator shaft, β_0 – gearing range extent.

Main power leakage in wave gearing comes from flexible gear deformation [18]. Contact patch is expanded and, therefore, sliding speed is increased at its peripheral areas and meshing interference areas are appeared. Rigid tooth-wheel gearings do not produce meshing interference [11, 12]. In wave gearings, the meshing interference can be compensated by mechanical compliance of flexible gear, increasing power loss in gearing .Under higher load and low structure rigidity , meshing interference causes their slippage. If mechanical compliance of flexible gear [6] does not compensate meshing interference, then binding of teeth will occur. The attempts to eliminate binding of teeth with module $1{,}5\,mm$ and $2\,mm$ in large wave reducers at «NKMZ» PJSC, by means of treatment with special pastes, did not bring favorable results. However, after elimination of meshing interference areas, the wave gearings achieved specified technical characteristics [21].

The power of energy losses in gearing N_Σ comprises the losses in gearing P_f and wave generator area N_f:

$$N_\Sigma = P_f + N_f. \qquad (25)$$

Other energy losses in wave gearings are insignificant compared to those in gear engagement and wave generator area, therefore, they are not taken in consideration [19, 20].

Theoretical and experimental investigations have been performed at industrial models of wave reducers: tilt drive of mobile mixer MP – 600AC with capacity – $600\,t$ (molten metal) and drive of ore-crushing mill MGR 5500x7500 with capacity – $160\,m^3$, and charged ore weight – $220\,t$.

The power of energy losses in wave gearing engagement of the mill P_{Lf} and the mixer P_{kf} is determined according to formula (Eg. 24), where: gearing friction ratio $f_1 = 0{,}08$, $f_2 = 0{,}1$, wave generator rotation frequency $\omega_1 = 78{,}5\, s^{-1}$ and rotation torque at mill wave generator shaft $M_{L1} = 2600\, Nm$ and mixer $M_{k1} = 1880\, Nm$: $P_{kf1} = 6946\, W$; $P_{kf2} = 8683\, W$, $P_{Lf1} = 10029\, W$, $P_{Lf2} = 12536\, W$. If: $\omega_1 = 13{,}8\ s^{-1}$, $f_1 = 0{,}08$ and $f_2 = 0{,}1$, $M_{k1} = 1880\ Nm$ – power loss in wave gearing engagement of the mixer $P_{kf_1} = 1221\ W$, $P_{kf_2} = 1526\ W$.

Wave gearing engagement efficiency of the mixer η_k and the mill η_L, with different friction ratios $f_1 = 0{,}08$ and $f_2 = 0{,}1$: $\eta_{k1} = \eta_{L1} = 0{,}95$, $\eta_{k2} = \eta_{L2} = 0{,}94$. Upon the absence of meshing interference $(I = 1)$, wave gearing engagement efficiency grows: $\eta'_{k1} = \eta'_{L1} = 0{,}96$, $\eta'_{k2} = \eta'_{L2} = 0{,}95$. It is possible for low-loaded wave gearing with narrow toothing, correctly calculated and precisely executed geometrical parameters of the gearing and harmonic drive in general.

The power of energy losses in wave generator area N_f is proportional to contacting surfaces friction ratio f and disks skewing angle γ towards their motion plane. The dependence of power loss volume in contact areas of the disks with flexible gear from the angle γ, for mixer and mill reducers are determined according to formulas (Eg. 4), (Eg. 5) and (Eg. 23). The power of energy losses with reducer load torque $M_2 = 5 \cdot 10^5\ Nm$, friction ratios $f_1 = 0{,}049$ and $f_2 = 0{,}08$, mixer reducer wave generator rotation frequency: $\omega_{k1} = 13{,}8\, s^{-1}$ are shown at Fig. 3 – straight line 1 and 2, $\omega_{k2} = 78{,}5\, s^{-1}$ – straight line 5 and 6, for the mill $\omega_{L1} = 78{,}5\, s^{-1}$ – straight line 3 and 4.

Upon reduction of the friction ratio f from $0{,}08$ up to $0{,}049$, the energy losses in wave reducers under investigation are decreased. Reduction of the friction ratio and energy losses is achieved by means of bronze ring installation between the disks of wave generator and flexible gear.

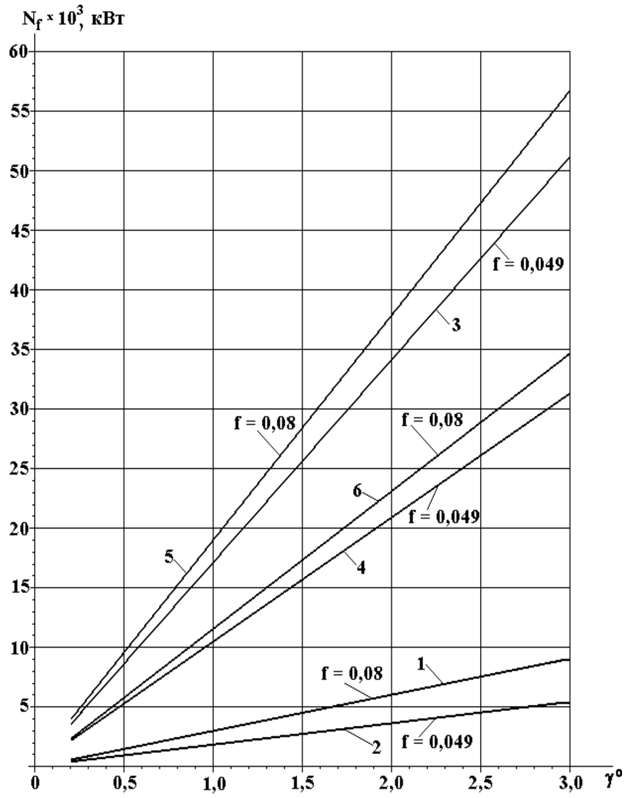

Fig. 3. Characteristic lines of energy losses power N_f, depending on disks skewing angle in flexible gear contact areas: 1, 2, 3, 4 – for mixer reducer, 5, 6 – for mill reducer

Upon growth of mixer tilt drive wave generator rotation frequency from $\omega_{k1} = 13{,}8\, s^{-1}$ (Fig. 3) (straight lines 1, 2) up to $\omega_{k2} = 78{,}5\, s^{-1}$ (straight lines 3, 4), the power of energy loss increases in $5{,}7$ times, i.e. in proportion to growth of the power transmitted by this reducer.

Upon wave generator rotation frequency $\omega_{L1} = \omega_{k2} = 78{,}5\, s^{-1}$, energy losses in mixer slewing reducer wave generator area are for 9% *less*, than in the mill reducer . It is stipulated by different values of transmitted powers and gear ratios of the reducers, as well as different correlation of geometrical parameters, effecting the load distribution in kinematic pairs. Thus, upon the same load, the mixer slewing reducer $q_{r\,max}$ is for 12% less, than in the mill reducer and, correspondently, the axial force F of the mixer reducer is less for 8%.

At Fig. 4 and Fig. 5, the efficiency characteristic lines of the mixer and mill drives wave reducers, depending on disks skewing angle γ, with different friction ratios f in flexible gear contact areas are shown. Dependence characteristic lines 1 and 2 are given without consideration of the losses in gearing. Dependence characteristic lines 3 and 4 are given with consideration of the losses in gearing and wave generator.

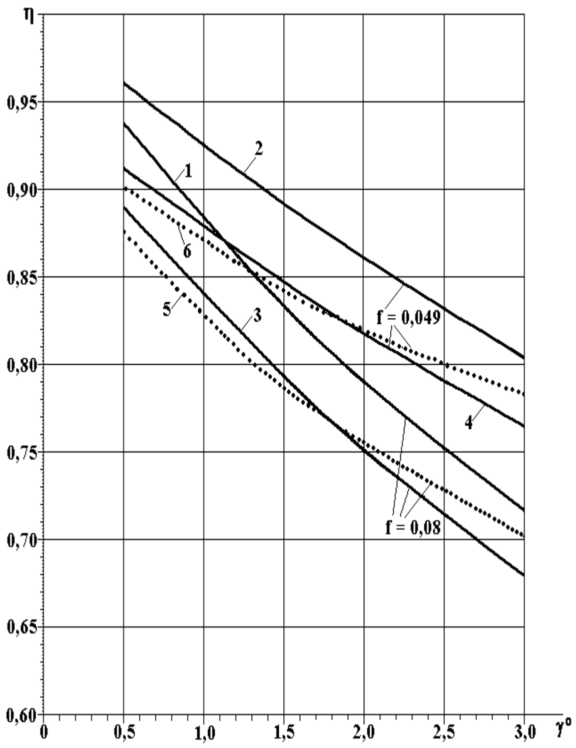

Fig. 4. Mill wave reducer efficiency depending on the angle : 1, 2 – losses in wave generator included, 3, 4 – losses in gearing and wave generator included, 5, 6 – all losses in speed reducer included, results of experiment

Dependence characteristic curves 5 and 6 were obtained experimentally and conform the general efficiency of the reducers under investigation. During experiment, the bronze or steel spacing ring was used, placed between the disks and flexible gear. Dependence characteristic lines 5 at Fig. 4 and Fig. 5 were obtained for steel spacing ring, and dependence characteristic lines 6 for bronze ring.

Upon angle γ variation from $0{,}5^\circ$ up to 3°, the efficiency of the mill wave reducer, without consideration of the losses in gearing, changes as follows: at $f = 0{,}08$, $\eta = 0{,}94 \div 0{,}72$, at $f = 0{,}049$, $\eta = 0{,}96 \div 0{,}81$ (Fig. 4) curves 1 and 2. With consideration of the losses in gearing: at $f = 0{,}08$, $\eta = 0{,}89 \div 0{,}68$, at $f = 0{,}049$, $\eta = 0{,}91 \div 0{,}77$ (curves 3 and 4). With consideration of the losses in gearing: at $f = 0{,}08$, $\eta = 0{,}89 \div 0{,}68$, at $f = 0{,}049$, $\eta = 0{,}91 \div 0{,}77$ (curves 3 and 4).

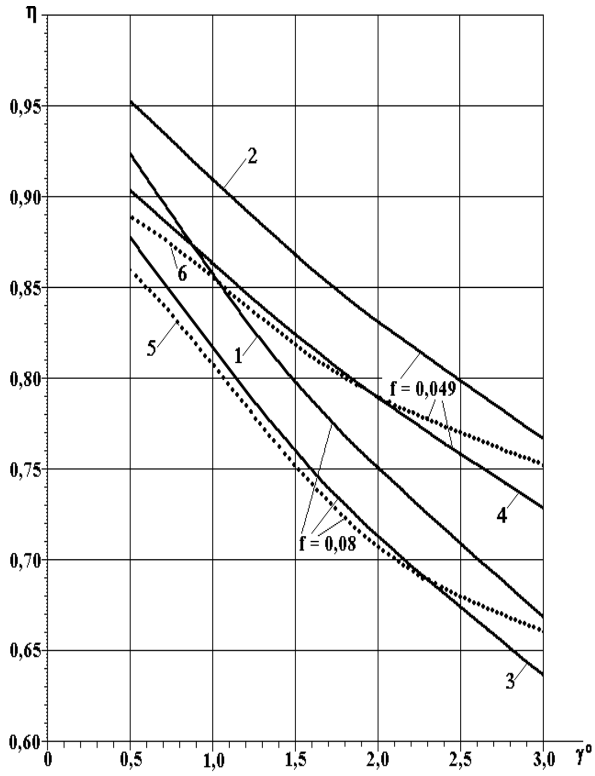

Fig. 5. Mixer wave reducer efficiency depending on the angle: 1, 2 – losses in wave generator included, 3, 4 – losses in gearing and wave generator included, 5, 6 – all losses in speed reducer included, results of experiment

The results of experimental studies of the mill speed reducer efficiency are as follows: with steel spacer ring $\eta = 0{,}88...0{,}70$; with bronze ring $\eta = 0{,}90...0{,}78$ (curves 5 and 6).

The mixer wave reducer efficiency excluding engagement losses is as follows: at $f = 0{,}08$, $\eta = 0{,}92...0{,}67$; at $f = 0{,}049$, $\eta = 0{,}95...0{,}77$ (Fig. 5) (curves 1 and 2) and the same including engagement losses is as follows: at $f = 0{,}08$, $\eta = 0{,}88...0{,}64$; at $f = 0{,}049$, $\eta = 0{,}90...0{,}73$ (curves 3 and 4). The following results of experimental studies of the mixer speed reducer efficiency are obtained: with steel spacer ring $\eta = 0{,}86 \ldots 0{,}66$; with bronze ring $\eta = 0{,}89 \ldots 0{,}75$ (curves 5 and 6).

Energy losses in the field of the wave generator are caused by friction torques in the zones of contact between the disks and the flexible gear that turn the disks orthogonal to the motion plane. Disks turning and conelike strain of the flexible gear stimulate the formation of some similarity of friction helical pair with the helix angle equivalent to the angle of disks turn γ.

Axial fixing of the disks and the flexible gear prevents their relative helical motion, the axial component of which is transformed into axial sliding of the disks relative to the flexible gear. This causes considerable energy losses in wave gearing.

Friction torques in the zones of contact between the disks and the flexible gear turn the disks in the direction of «screwing in» the flexible gear while stretching it in the axial direction by means of friction forces, the resultant value of which is equal to double the amount of forces F_1 and F_2.

For the ore-pulverizing mill relining drive speed reducer the axial stretching force $F_{\sum}$ acting on the flexible gear on the wave generator side, where $f = 0{,}08$, loading torque $M_{2max} = 5 \cdot 10^5\ Nm$, makes $F_{\sum L} = 12603\ N$, and for the mixer swing drive speed reducer at the same load $F_{\sum k} = 11619\ N$. In the presence of end plays, the action of axial friction forces becomes hazardous not only for the support between the wave generator and the flexible gear. They cause strong impacts, vibrations, noise as well as rapid wear.

CONCLUSIONS

1. The studies undertaken made it possible to reveal the mechanism of axial forces and increased energy losses generation in large wave gearings. Axial forces and basic energy losses in wave gearing are formed in the zones of contact between the disks and the flexible gear, they are proportional to the angle of deviation of the disks γ and friction factor f in the contact between the disks and the flexible gear.

2. Developed has been a new method of force analysis of kinematic pairs of higher degree including a flexible link, as applied to the wave gearing. In so doing, the influence of the flexible gear strains, design parameters of the wave generator, the amount and nature of contact forces distribution as well as the amount and directions of friction forces on the generation of axial forces and energy losses in the zones of contact between the wave generator disks and the flexible gearing has been taken into account.

3. By realizing the developed analytical method of force processes analysis in kinematic pairs of higher degree, the numerical results of the values of axial forces and energy losses in the field of the wave generator as well as the energy losses in the gearing, mechanical drives wave-type gear reducers: of tilting MP – 600AC mobile mixer with the capacity of $600\,t$ molten metal and of relining MGR 5500x7500 ore-pulverizing mill with the capacity of $160\,m^3$ and ore loading weight of $220\,t$ have been obtained.

4. On the basis of the results obtained in the course of studies a possibility has appeared to minimize the axial forces and energy losses in the large wave gear reducer kinematic pairs of higher degree at the stage of their design and to enforce high scientific and technical level of intellectual and commercial products of heavy engineering industry.

5. To restrict negative influence of flexible gear «windup» intensifying interference along the tooth length, on the increase of energy losses and in order to eliminate overshoot of teeth in meshing, it is recommended to limit the width of gear girths b depending on the teeth module m, by the following inequation $b \le 40m$.

6. To reduce the axial forces and energy losses in the field of wave generator the following means are applied: manufacture of spacer ring of bronze, minimization of the

angle of disks skewness by using more rigid bearing supports that prevent rotation of the disks relative to the predetermined positions of the process planes perpendicular to the common axis of the wave gearing as well as by using lubricant with high antifriction properties.

REFERENCES

1. **Aleksandrov V., Strelnikov V., 1989.:** Wave gearings for heavy machines // Technology, economy, organization of production and management. Ser. 8. Issue 35. – M.: Central Scientific-research institute of feasibility studies of heavy engineering (TsNIITEITyazhmash). 50. (in Russian).
2. **Beizelmann R., Tsypkin B., 1959.:** Antifriction bearings: Reference book. – M.-L.: GNTIML 608.
3. **Volkov D., Krainev A., 1976.:** Wave gearings. – K: Tekhnika. 224. (in Ukrainian).
4. **Ginzburg Ye., 1968:** Wave gearings efficiencies // Gear sets and worm gears. – L.: Machine-building industry. 192-208.
5. **Gribanov V., Ratov D., Balitskaya T., 2009.:** Imitating modeling hyperboloid gears. TEKA Commission of Motorization and Power Industry in Agriculture. – Lublin. – V. IX. 54-61.
6. **Demidov S. 1979.:** The theory of elasticity. – M., «Higher school». 432.
7. **Ivanov M., 1981.:** Wave gearings. – M.: Higher school. 184.
8. **Ivanov M., Finogenov V., 1967:** Method of experimental determination of wave gearing efficiency // Proceedings from higher educational institutions. Machine-building industry. – No. 9. 54 – 57.
9. **Ivanov M., Finogenov V., 1972.:** About wave gearing mesh efficiencies // Proceedings from higher educational institutions. Machine-building industry. – No. 1. 29-32.
10. **Kovaliov N., 1979.:** Flexible gearings. – M. Machine-building industry. 200.
11. **Kryukov A., 1959.:** Pilot study of efficiency of planetary trains with internal and external engagement // Machine-building industry reporter. – No.9. 14-19.
12. **Litvin F. 1968.:** Theory of gearings. – M: Science. 584.
13. **Gadolin V., Drozdov N., Ivanov V., 1979.:** Machines and stands for testing parts /Under the editorship of Reshetov D. – M.: Machine-building industry. 343.
14. **Mekhaev M., 1975.:** Determination of angle of wave gearing flexible gear girth gear generants rotation // Wave gearings: Edited volume – M: Stankin. P. 77 – 87.
15. **Nosko P., Shishov V., Fil P., Muhovatiy A., Sklyar U., 2008.:** Parametrical optimization of worm gears on losses in gearing. TEKA Commission of Motorization and Power Industry in Agriculture. – Lublin. – V. VIII. 213-221.
16. **Nosko P., Shishov V., Tkach P., Sklyar U. 2010:** Gearing with increased teeth wear. TEKA Commission of Motorization and Power Industry in Agriculture. – Lublin. – V. XB. 87-94.
17. **Rudenko V. 1980:** Planetary gear trains and wave gearings: Book of designs. – M.: Machine-building industry. 148.
18. **Sinkevich Yu. 1970:** Influence of wave gearing flexible gear strain on its efficiency // Wave gearings: Edited volume – M: Stankin. 272-280.
19. **Sinkevich Yu. 1970:** Analysis of wave gearing efficiency // Wave gearings: Edited volume– M.: Stankin. 272-280.
20. **Sinkevich Yu. 1967.:** Approximate analysis of losses in gear two-wave reducer // Wave and chain gearings: Edited volume – M: Stankin. 111-119.
21. **Strelnikov V., Sevostyanov S., Pankov V. 1999:** Elimination of meshing interference in wave gearing // Bulletin of Kharkov National Pedagogical University. – Kharkov. – Issue No.50. 16-25.
22. **Strelnikov V., Sevostyanov S. 1998:** About energy losses in wave gearing meshing // Protection of metallurgical machines against failures. – Issue No.3. 237-241.
23. **Strelnikov V., Sevostyanov S. 1999:** Determination of energy losses in wave-type gear reducers for metallurgical and mining equipment// Metallurgy and mining industry. – No.5. 102-105.
24. **Strelnikov V., Sevostyanov S. 2000:** Determination of axial forces on wave gearing flexible gear // Bulletin of Kharkov National Pedagogical University. – Kharkov. – Issue 109. 159-172.
25. **Strelnikov V., 2000:** Determination of forces acting on flexible gear on wave generator side // Bulletin of Kharkov National Pedagogical University. - Kharkov. – Issue 109. 154-158.
26. **Strelnikov V., 2000:** Interaction between wave generator and flexible gear // Advanced technologies and engineering systems. International edited volume – Donetsk: Donetsk State Technical University. – Issue 13. 191-199.

ИССЛЕДОВАНИЕ ВЗАИМОДЕЙСТВИЯ ДИСКОВОГО ГЕНЕРАТОРА ВОЛН С ГИБКИМ КОЛЕСОМ ТЯЖЕЛО НАГРУЖЕННОЙ ВОЛНОВОЙ ПЕРЕДАЧИ

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Аннотация: Силовые процессы в высших кинематических парах диск – гибкое колесо вызывают негативные явления в тяжело нагруженной волновой зубчатой передаче. Это значительные по величине осевые силы, обладающие динамической характеристикой, а также существенные энергетические потери в области генератора волн. Приведенные результаты силового анализа взаимодействия дискового генератора волн с гибким колесом, позволили дать оценку силовым и энергетическим факторам, наблюдающимся в процессе работы крупной волновой зубчатой передачи.

Ключевые слова: волновая передача, осевые силы, энергетические потери.

Theoretical study of the regularities of wet coal grinding in ball mills at the preparation of water-coal fuel

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Summary: Theoretical investigations of the regularities of coal grinding in ball mills are executed. The main parameters influencing the kinetics of grinding at the preparation of water-coal fuel are determined. The matrix model of grinding and dependences, allowing to conduct the classification of the process of material failure in ball mills are considered.

Key words: coal-water fuel, density of grinding bodies, grinding, kinetics of grinding, ball mills, matrix model of grinding.

INTRODUCTION

The last years in Ukraine the problem of energy carriers is becoming more and more actual and solution of this problem to a large extent determines the economic and financial security of the country. The works on the investigations of the use of alternative, renewable, non-traditional energy sources are finding in the field of promising long-term searches. At the same time, the country has significant reserves of coal which is the basic organic fuel not only in our country, but in the world. However, the traditional use of coal, that is, its direct burning in various furnace devices causes a number of problems: incomplete burning of the coal (burns to 60% of the combustible mass), necessity of the creation of systems for dust suppression, aspiration, a high degree of pollution of environment by the emissions of nitrogen oxides, sulphur , dust and soot (100-300 g/m^3 of a dust, 400-800 g/m^3 of SO_2, 250-600 g/m^3 of NO_2) [1]. The transition from direct burning coal on preparing and use of water-coal fuel (WCF), including from the waste of coal concentration, can become the fundamentally important decision for the coal power engineering.

OBJECTS AND PROBLEMS

The idea of the coal-water fuel is not new one. From the early 70-ies of the last century a number of countries, such as USA, Canada, Italy, Sweden and China are working on research and creation of pilot experiment-industrial, demonstration and commercial installations on production and use of WCF. The greatest achievements in this direction were obtained in China (the first place in the world on extraction of coal - 1.3 billion tons per year) [2, 3, 5, 19]. On these subjects in China three research centers are working, six plants are producing WCF on boiler-houses and electric power stations, burning WCF It is planned to build a large plant for preparation of water-coal fuel. Delivery of fuel is carried out in railway containers.

The technology of preparing WCF abroad, including in China, is traditional and consists of two-stepped wet grinding in ball mills with the addition of plasticizing and stabilizing chemical additives, feed of the resulting product for storage and subsequent burning in boiler furnaces. The main element in the process of preparation of water-coal fuel is the ball mills. And a matter of their downloading by coal, by certain granulated size of balls, by chemical additives as well as the time grinding for different grades of coal is not divulged. In addition, two-stepped grinding increases the cost of technological lines, preparing WCF. So the transition of the technology of preparation of WCF on one-stepped system will require conducting the theoretical and experimental researches of the processes of coal grinding, rationalization of the ball loading and modes of operation of mills that allows to lower power inputs. With the aim of significantly reducing the total cycle of grinding and producing WCF the method of one-stage wet grinding of hard coal was developed and studied. The essence of this method consists in the following. Source coal is crushed in the hammer crusher up to size 0-3 mm and loaded in the ball mill, where it undergoes directly wet grinding to obtaining WCF. Coal during grinding gradually passes from the large lump size in a state of suspension, thus the suspension density is increasing and comes nearer to a calculated. Water in the initial period of grinding in the mill is redundant, since the coal has large lumps. And as much as coal grinding, water goes on the wetting of the newly formed coal surfaces at grinding of coal. Thus, the density of the suspension during the grinding increases, and the effective density of grinding bodies, equal to the difference in the density of grinding bodies and suspension, gradually decreases, that is [20]:

$$\Delta\rho = \rho_b - \rho_s \,, \tag{1}$$

where: ρ_b – density of grinding bodies (balls), ρ_s – the density of the suspension.

In addition, when the density is increased, and therefore viscosity of the suspension, is increased [21], the impact mode at the grinding is gradually passing into abrasive.

Increasing the density of grinding bodies by downloading the balls of different diameter allows to increase grinding ability of the mills and to produce WCF composition consisting of bimodal grain-size composition of coal, which includes coarse (80-250 microns) fine milling (0-40 microns) [11, 20]. For the sedimentation stability and reducing the dynamic viscosity of WCF, the coal plasticizer (SAS) is fed into the mill by weight 1-2% of coal mass [6, 7, 15].

A number of basic factors affect the performance of wet grinding in ball mills affects, which include: rotational speed of the drum, the number, size and density of grinding bodies, the amount, size and properties of the grinded material, the amount of water and chemical additives, degree of filling the mill volume. The main values which characterize a grinding are the degree of filling the drum of the ball mill by grinding bodies and total charge. The latter refers to the ratio of the total volume of grinding bodies of the suspension to the volume of the mill drum:

$$\varphi_d = \frac{V_b + V_s}{V_d}, \tag{2}$$

where: φ_d – the degree of the total charge of the mill,

V_s – volume of the suspension in the ball mill,

V_d – volume of the mill drum,

V_b – total volume of grinding bodies, which is equal:

$$V_b = V_{b1} + V_{b2} + {} + V_{b3} + \ldots + V_n = \sum_{i=1}^{n} V_{bi}\,, \tag{3}$$

where: $\sum_{i=1}^{n} V_{bi}$ – the total volume occupied by the mill balls of the $i^{\text{-order}}$ diameter.

The ratio in loading of coal and the grinding bodies is convenient to characterize by the indicators of the active grinding zone α, corresponding to the volume of voids between the grinding bodies and suspension volume:

$$\alpha = \frac{\left(\sum \frac{G_{bi}}{\rho_{gbi}}\right) - \left(\sum \frac{G_{bi}}{\rho_{bi}}\right)}{V_s}, \quad (4)$$

where: ρ_{gbi}, ρ_{bi} – bulk and volume masses of the grinding bodies (balls) of the i^{-order} diameter,

G_{bi} – mass of the grinding bodies (balls) of the i^{-order} diameter:

$$G_{bi} = \varphi \frac{\pi \cdot D^2}{4} \cdot L \cdot \gamma_{bi}, \quad (5)$$

where: φ – permeability factor of mill volume by the balls, φ = 0,6,

D – the inner diameter of the mill, m,

L – the inside length of the mill, m.

In the case when *α =1*, all the voids between the grinding bodies should be filled with (WCF) suspension and its level corresponds to the level of grinding bodies in the mill. If the value *α<1*, the suspension not only fills the void between the grinding bodies, but there is in a certain volume of over them. With the reduction of α-index, the share of the volume of (WCF) suspension, not completed by the grinding bodies, is increased. It leads to reduction of speed of grinding.

The density of the pulp in the mill is determined by the dependence [8, 17, 18]:

$$\rho_c = \frac{\rho_c}{\rho_c - C \cdot (\rho_c - 1)}, \quad (6)$$

where: ρ_c – coal density, t/m^3,

C – the content of solids in the suspension (on mass), share of units, C ≈ 0,8.

Thus, the volume mass of load, taking into account filling the voids by the suspension, is equal, t/m^3:

$$\rho_{b.m} = 0{,}6 \cdot \rho_b + 0{,}4 \cdot \rho_m, \quad (7)$$

Mathematical analysis of the internal dynamics of ball mill was made on the basis of probability theory [14]. The basis of the hypothesis was proposed that there is a circular area of effect around the point of contact of two balls, outside which the particles are not involved in the space between the two balls. Radius of this zone action *Y* is determined by the equation, which has the form:

$$Y = \sqrt{\frac{Dd}{2}}, \quad (8)$$

where*: D* – the ball diameter, m,

d - the particle diameter, m.

The maximum number of particles N_m, which can be located in the zone of action, corresponds to the number of particles forming a ring around the point of contact.

Therefore:

$$N_m \cdot d = 2\pi \sqrt{\frac{Dd}{2}}, \quad (9)$$

or

$$N_m = 4{,}5 \sqrt{\frac{D}{d}}. \quad (10)$$

The maximum number of particles is achieved only when the system has an infinite number of particles. This number is equal zero, when there is not one particle in the system.

The probability function for the examined case in question is:

$$y = 1 - e^{-ku}. \quad (11)$$

The constant *k* is determined, subject to full filling the space between the balls, that is, when *u=1* and 40% of the maximum number of particles gets in the zone of action. From this it follows that *k=0.5*. So we can write:

$$N_p = 4{,}5 \sqrt{\frac{D}{d}} \cdot (1 - e^{-0{,}5u}). \quad (12)$$

For determination of the equilibrium number of particles in contact with the surface of the ball N_e, at the first we consider the number of particles in contact with the surface at any moment of time *t*. The rate of change of the number of particles in contact with a surface per unit of time is equal to:

$$\frac{dN}{dt} = N_i - N_o, \qquad (13)$$

where: N_i – the number of particles, which are pressed to the surface,

N_o – the number of particles destructible near the surface in a unit of time.

The number of particles, which are pressed to the surface of the ball, is proportional to the number of particles in the action zone (N_P) and is determined by the dependence:

$$N_i = k_1 \cdot N_p \cdot f \cdot P_e, \qquad (14)$$

where: P_e – probability of hit of a particle on the surface of the ball,

f – part of the surface of the ball, which is capable of receiving the particle:

$$f = 1 - \frac{N \cdot d^2}{F}, \qquad (15)$$

where: N – the number of particles, which are pressed to the ball surface,

F – the ball surface, m^2.

The probability that the particles will hit on the surface of the ball if we take the attitude of the ball hardness to the hardness of particles H of the grinding material will be equal:

$$P_e = e^{-0.7H}, \qquad (16)$$

and then:

$$N_e = K_1 \cdot \sqrt{\frac{D}{d}} \cdot (1 - e^{-0,5u}) \times \times (1 - \frac{N \cdot d^2}{F}) \cdot e^{-0,5H}. \qquad (17)$$

The number of particles which will be grinded as a result of pressing to two neighboring balls and of a collision with each other is expressed by the following dependence:

$$N_o = K_2 \cdot N \cdot R_e \cdot \alpha. \qquad (18)$$

The probability of collision of particles with each other:

$$R_e = K \cdot \left(\frac{N \cdot d^2}{F} \right)^2. \qquad (19)$$

The probability of failure of the particle:

$$\alpha = \left(1 - 2,5 \cdot H \cdot e^{-H}\right), \qquad (20)$$

then:

$$N_o = K_2 \cdot N \cdot \left(\frac{N \cdot d^2}{F} \right)^2 \cdot \left(1 - 2,5 \cdot H \cdot e^{-H}\right). \qquad (21)$$

Grinding speed $\frac{dG}{dt}$ is proportional to the number of particles in the zone of action and can be determined by the dependence:

$$\frac{dG}{dt} = K_1 d^{-\frac{1}{2}} \cdot D^{-2,5} \cdot (1 - e^{0,5u}) \times \times \{(N_e \cdot \frac{d^2}{F}) + \left[1 - (N_e \frac{d^2}{F})^2 - e^{-0,7H}\right]\} \times \times e^{-K_u N_e - 0,1u^2} \cdot \varphi \cdot V, \qquad (22)$$

where: φ – coefficient of filling the mill,

V – the volume of the mill, m^3.

Kinetics of grinding is described by the exponential equation [4, 8, 9, 13, 16]:

$$R = R_o \cdot e^{-kt^m}, \qquad (23)$$

where: *R* and R_o – masses of the material residual on the drum screen at grinding, and in the crushed product at moment *t*,

t – duration of grinding,

k and *m* – the grinding parameters.

After taking the logarithm of double the kinetics equation will be in the form:

$$\lg\lg\left(\frac{R_o}{R}\right) = m \lg t + \lg(k \lg e). \qquad (24)$$

To determine the values of parameters *m* and *k* of the line which is drawn on the experimental points, there are two points and their coordinates are determined.

The values of *m* and *k* are calculated by the formulas:

$$m=\frac{\lg\lg\left(\frac{R_o}{R_2}\right)-\lg\lg\left(\frac{R_o}{R_2}\right)}{\lg t_2-\lg t_1}, \qquad (25)$$

$$k=\frac{\lg\left(\frac{R_o}{R}\right)}{t^m\lg e}. \qquad (26)$$

Knowledge of the kinetics of grinding allows to solve theoretically a number of practical tasks: to determine the specific performance of the mill, grind ability of the material, to calculate the amount of circulating load, granulometric composition of the grinded material depending on the grinding time.

Kinetics of grinding in the mills of periodic action by O.N. Tikhonov has the following form:

$$P(y,t)=P(y,0)+ \\ +\int_0^t\int_y^{x_{max}}\left[dP_{x,t}/dx\right]\cdot S(x)\cdot B(x,y)\cdot dxdt, \qquad (27)$$

where: $P(y,t)$ – total mass portion of material with size less than *y* at time *t*,

$P(y,0)$ – mass portion of *y*-class particles in the source material,

S(x) – selection function, determined as the portion of particles of a given size *x*, selected from the whole mass of the material and destroyed in a unit of time,

B(y, x) – grinding function, determined as the portion of selected particles being ground to a size smaller than *y*, where *y<x*.

The second term of the right side of the equation (17) is mass portion *y*-class, obtained by grinding the particles with size larger than -*y* at the time from *0* to *t*.

The mechanistic approach to the construction of models of processes of reducing the size is based on identifying those physical phenomena, which composite the process. Their description can lead to obtaining the models, suitable for reproduction of the process (imitation modeling). The main principle underlying the mechanistic models is that after *n* steps of reiterative process of destruction, which can be described by means of functions of probability of destruction and distribution of the grinded material, the resulting distribution function asymptotically approaches to a log-normal law. It should be noted that just such characteristic of the distribution by size of the grinded material is often observed in practice. This principle was used in a new direction of research, which became known as the method of matrix models [9].

In the matrix model the process of crushing or grinding is considered as a sequence of cycles of destruction, and the initial material for every such act is the product of the previous one. The longer the period of grinding, then there is more the number of such cycles and higher the degree of reduction of the size [12, 16]. The models of this type are based on the following concepts and representations:

1) the probability of failure, which is named as the selection function or function of the destruction speed,

2) characteristic distribution by size after the destruction called the destruction function, or the distribution function, or a function of occurrence,

3) the difference in particle motion through a continuously acting apparatus or the rate of carrying-out the particles from the unit.

Transfer of material in apparatus is generally based on particle size and is characterized by the function that is called the classification function or function of the speed of unloading, or the diffusion coefficient dependent on the particle size. The phenomenon of reverse mixing in the mills of continuous action can be taken into account by addition of the elements characterizing the flow of material and stirring to the basic matrix determining the probability and distribution of destruction.

The probability of failure of every size class and distribution by destruction product size of every class were presented in the form of the matrix model of crushing and grinding processes, where terms of the destruction and selection functions are used for the distribution function and the probability of failure. In this model the granulometric size supply composition and the product of the process of reducing the size can be expressed by the distributions in paragraphs of *n*-classes (Table 1).

Table 1. Distribution of size supply and product grinding

Size class	Granulometric supply composition	Product of reducing the size
1	f_1	p_1
2	f_2	p_2
….	….	….
n	f_n	p_n
n+1	f_{n+1}	p_{n+1}

Number 1 on the table 1 denotes the maximum size class and number n +1 shows under-the-grate screen residual with the lowest hole of the screen.

In the process of grinding the particles of all size classes are destroyed with a certain probability, the products of destruction may fall either in the original or in any smaller size class. It should be noted that a particle can be subject to such small destruction or chipping, which is not enough for that all the resulting fragments were less than the lower boundary size of the original class. The material balance of the grinding process can be presented as table 2.

Table 2. The Material balance of the grinding process

Size class	Granulometric supply composition	Product of reducing the size					
		1	2	3	..	*n*	*n+1*
1	f_1	P_{11}	0	0	..	0	0
2	f_2	P_{21}	P_{22}	0	..	0	0
3	f_3	P_{31}	P_{32}	P_{33}	..		
…	…	…	…	…	..		
n	f_n	P_{n1}	P_{n2}	P_{n3}	..	P_{nn}	
n+1	f_{n+1}	$P_{(n+1)1}$	$P_{(n+1)2}$	$P_{(n+1)3}$	..	$P_{(n+1)n}$	$P_{(n+1)(n+1)}$

Items in columns 1, 2, 3, n+1 in the Table 2, were recorded in the form of P_{ij}, where *i* belongs to the size class, in which this element gets, and *j* - size feed class, from which it was formed.

It should be noted the following features of the submitted form of the elements table characterizing the product of grinding:

1. The granulometric composition of the product can be determined by the summation of the items in consecutive rows in the table,
2. The total amount of supply is determined by expression $\sum_{i=1}^{n+1} f_i$. The mass of the particles in the1^{-st} under- the-grate residual, i.e, in the size class n+1, can always be calculated by subtracting the total mass of the residual on the screen *n*- item from the supply F.

The item P_{ij} may be presented by: $P_{ij} = X_{ij} f_i$, where X_{ij} - mass portion of particles of the $i^{\text{-order}}$ size class of supply, transferred into the $j^{\text{-order}}$ size grade product. Taking into account the above said, the matrix of the grinding process would be:

$$\begin{bmatrix} x_{11} & 0 & 0 \ldots\ldots\ldots\ldots 0 \\ x_{21} & x_{22} & 0 \ldots\ldots\ldots\ldots 0 \\ x_{31} & x_{32} & x_{33} \ldots\ldots\ldots\ldots 0 \\ x_{41} & x_{42} & x_{43} \quad x_{44} \ldots\ldots 0 \\ \cdots & & \\ \cdots & & \\ x_{n1} & x_{n2} & x_{n3} \ldots\ldots\ldots\ldots x_{nn} \end{bmatrix} * \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ \ldots. \\ \ldots. \\ f_n \end{bmatrix} =$$

$$= \begin{bmatrix} x_{11} \cdot f_1 + 0 + \ldots + 0 \\ x_{21} \cdot f_2 + x_{22} \cdot f_2 + 0 + \ldots + 0 \\ x_{31} \cdot f_3 + x_{32} \cdot f_3 + x_{33} + 0 + \ldots. + 0 \\ x_{41} \cdot f_4 + x_{42} \cdot f_4 + x_{43} \cdot f_4 + x_{44} \cdot f_4 + 0 + \ldots + 0 \\ \ldots. \\ \ldots.. \\ x_{n1} \cdot f_n + x_{n2} \cdot f_n + x_{n3} \cdot f_n + x_{n4} \cdot f_n + \ldots + x_{nn} \cdot f_n \end{bmatrix} = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ \cdots \\ \cdots \\ p_n \end{bmatrix}$$

The matrix equation that characterizes the grinding process can be written:

$$P = X \cdot f \,. \tag{28}$$

It should be emphasized that the appropriate items *f* and *p* are relating to the same size intervals. It is convenient for calculations, if the constant geometrical relationship between successive intervals is observed.

The equation (27), although correctly characterizes the process of destruction, can be useful only if the matrix *X* is known. This matrix could not be obtained deductively, i.e., without the additional information. Consequently, it is necessary to consider how the matrix *X* can be divided into components.

The selection function. The particles of all size classes, fed in the grinding process, are destructed with a certain probability, which may depend on the particles size.

In every moment of the grinding process a certain part of the particles of every size class is taken for destruction, whereas the remaining part is not destroyed.

If *S* denotes the portion of particles of the largest class, which is selected for destruction, then the mass of ruined particles of this class will be $S_j f_j$. Similarly, the mass of particles, destroyed in the *n*- size class will be $S_{ij} f_i$, so we can write a matrix equation:

$$\begin{bmatrix} S_1 & 0 & 0 & \cdots & \cdots & \cdots 0 \\ 0 & S_2 & 0 & 0 & \cdots & \cdots 0 \\ 0 & 0 & S_3 & 0 & \cdots & \cdots 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & \cdots \cdots & S_n \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ \cdots \\ \cdots \\ f_n \end{bmatrix} = \begin{bmatrix} S_1 f_1 \\ S_2 f_2 \\ S_3 f_3 \\ \cdots \\ \cdots \\ S_n f_n \end{bmatrix}.$$

If to present the selection function as the matrix *S*, then the destroyed particles will be presented by the function *Sf*. The remaining particles during the process will be non-destructed and the mass of those indestructible particles for n- class will be $(l\text{-}S_n)f_n$. The total mass of particles, who went through the process non-destructed, can be represented by the product *(1 - S)f*.

In the case where the matrix *X* relates only to the grinded particles of feed which are really destroyed, i.e. not to the whole mass of supply, the *X* - symbol may be replaced by symbol *B*, and the equation process will obtain the form:

$$P = B \cdot S \cdot f + (1 - S) \cdot f \quad \text{or}$$
$$P = (B \cdot S + 1 - S) \cdot f\,. \tag{29}$$

The classification function. Crushing or grinding usually consists of many cycles of destruction, which can act both simultaneously and sequentially. Thus in every cycle the selection and destruction is realized. However, the process can proceed in such a way that the product of every cycle will be divided by size before some portion of this product would be subjected to the consecutive cycle of destruction. The result of classification of grinding the material can be written by the following dependencies:

$$P = (1 - c) \cdot q \quad \text{or}$$
$$P = (1 - c) \cdot (B \cdot S + 1 - S) \cdot m\,, \tag{30}$$

where: *c* - classification function,

q - supply of classifier,

m – power supply of the mill $. m = f + cq$.

After the transformation, we obtain:

$$m = f + c \cdot (B \cdot S + 1 - S) \cdot m\,,$$

$$f = [1 - c \cdot (B \cdot S + 1 - S)] \cdot m \quad \text{or}$$
$$m = [1 - c \cdot (B \cdot S + 1 - S)]^{-1} \cdot f\,. \tag{31}$$

From the equations (29) and (30) we obtain

$$\begin{aligned} P = {} & (1 - c) \cdot (B \cdot S + 1 - S) \times \\ & \times [1 - c \cdot (B \cdot S + 1 - S)]^{-1} \cdot f\,, \end{aligned} \tag{32}$$

If the classification is non-significant, then the c≈0, and the equation (31) are reduced to the equation (28).

The material having a momentary act of destruction is described in the base of all the models of crushing and grinding. This description is called a function of destruction. Research has shown that the destruction function can be approximated as stepped matrix that is the destruction nature of the material particles does not depend on the initial particle size. And then the destruction *F* and the selection *S* functions describe the grinding process of the material in the ball mill.

CONCLUSIONS

The basic parameters influencing the operation of ball mill are determined. They include: rotational speed of the drum, the number, size and density of grinding bodies, the amount, size and properties of the material, the amount of water and chemical additives, degree of filling volume of the mill, time of the grinding operation.

The question of interaction of the grinding bodies with the grinded material is considered. The imitation simulation requires the solution of the following tasks:

1. The selection of the technological scheme and size of equipment to obtain required parameter of highly concentrated coal-water suspension,
2. The provision of conditions providing for subsequent extension or modification of the grinding cycle,
3. The opportunity to minimize the capital and operational expenses

REFERENCES

1. **Andreev S.E., 1980.:** Petrov V.A, Zverevich V.V. Crushing, grinding and screening of the minerals. – M., Nedra. – 415. (in Russian).
2. **Bragin B.F., 1996.:** Kolomiets A.S., Krikunov A.P., Markuntovich F.D., Syomin Y.G. Ecologically friendly the water-coal technologies and systems. // Visnyk East-Ukrainian National University, Lugansk. Jubilee issue. – 70-76. (in Ukrainian).
3. **Bragin B.F., 1995.:** Kolomiets A.S., Pulp and suspension. (technologists, installation, calculations) Study guide. – K. ISDO. – 464. (in Ukrainian).
4. **Bilenko L.F., 1984.:** The regularition of the grinding drum mills. – M. Nedra. – 200. (in Russian).
5. **Chernetskaya N.B., 2010.:** Ecological aspects of water coal fuel transportation and application. // Teka Kom. Mot. Energ. Roln. – OL PAN, Vol. 5. – 97-104.
6. **Chernetskaya N.B., 2010.:** Shvornikova A. Kuschenko A. Choice of technology and the equipment for preparation of water-coal fuel in laboratory conditions. // Teka Kom. Mot. Energ. Roln. – OL PAN, Vol. X. – 33-38.
7. **Delyagin G.N., 1993.:** Kornilov V.V., Kuznetsov Y.D., CyernegovY.A., The improvement of the water-coal fuel and perspectives of its application. The supplement to the scientific and technical journal «The economy of the fuel and energy complex of Russia». // M., VNIIOENT. – 31. (in Russian).
8. **Golubinskaya I.V., 1989.:** Tarakanov V.M. Experimental study of high-concentrated water coal suspensions in static and dynamic conditions. // Physic-chemical fundamentals of structural-rheological properties and stability of high-concentrated water coal suspensions in the process transportation of the pipeline. The collection of scientific works. NPO «Gidrotruboprovod». – M. – 85-99. (in Russian).
9. **Hodakov G.S., 1972.:** Physics of crushing. – M., Science. – 307. (in Russian).
10. **Karmazin V.N., 1974.:** Sergo E.E., Szendrinskiy A.P. Processes and machines for enrichment of minerals. – M. Nedra. – 560. (in Russian).
11. **Kondratiev A.S., 1988.:** Ovsyannikov V.M., Oflonskiy E.P. Transportation of water coal suspensions: hydrodynamics and temperature mode. M. Nedra. – 213. (in Russian).
12. **Ling A., 1980.:** Cycle crushing and grinding: modeling, optimization, and planning (in China).
13. **Pivinskiy Y.E., 1974.:** Romashin A.G. Quartz ceramics./.– M., Metallurgy,– 264. (in Russian).
14. **Rozse Giyo., 1964.:** The problem of grinding materials and its development. - M. publishing house of literature on construction. – 112.
15. **Rukin E.I., 1976.:** Gorskaya T.P., Delyagin G.N.. Study of the properties of water coal suspensions in the presence of surfactants. – M. « Chemistry of solid fuel » №4. – 152-158. (in Russian).
16. **Regourd, M.:** Cracking and grindability of clinker. M. Regourd, H. Homain // Ciments Beton Platre Chaux. – Vol.727.
17. Regularities of grinding in ball mills: the collection of the reports international Congress on mineral processing. – L., state public library. 1968. – 6. (in Russian).
18. **Shuplyak I.A., 1972.:** The grinding of the solid materials in the chemical industry. – L. Chemical. – 64. (in Russian).
19. **Sergo E.E., 1975.:** Crushing breakage and screening minerals. – K. Higher school. – 240. (in Ukrainian).
20. The production of the water-coal fuel «Fluidcarbon» and use in Sweden. Inst. Chem. lng. Symp. Ser., №95, 1985. – 325-331.
21. The water-coal suspension of the high concentration. –Dansecoal. Translation № 3/88 - 2, institute «VNIPIGidrotruboprovod». M., 1988. The source. BWKV. 39, №5. – 246-247. (in Russian).
22. **Wang Zu-Na., 1986.:** Zang - Rong - Zeng. Research and development of coal-water fuel technology in China, International seminars on Nuclear, War – 6-th Session: International Cooperation: The Alternatives (in China).

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ ЗАКОНОМЕРНОСТЕЙ МОКРОГО ИЗМЕЛЬЧЕНИЯ УГЛЯ В ШАРОВЫХ МЕЛЬНИЦАХ ПРИ ПРИГОТОВЛЕНИЯ ВОДОУГОЛЬНОГО ТОПЛИВА

Юрий Семин, Татьяна Бондарь

Аннотация: Рассмотрены технологии приготовления водоугольного топлива (ВУТ) его параметры и гранулометрический состав, процессы измельчения и размола угля, теоретические исследования закономерностей измельчения в шаровых мельницах.
Ключевые слова: водоугольное топливо, транспорт, энергоэнтропия, шаровая мельница, термодинамическая система.

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Implementation of an information subsystem of a reference library information modern e-learning

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S u m m a r y. It is proposed further development of instrumental complex ontological destination designed to provide integrated information technology automated construction of ontologies subject area. The results are focused on the solution of practical implementation of the information subsystem, building software model of library reference information, modes of operation and its interaction with other subsystems of the complex.
K e y w o r d : library reference, the ontological description of the subject discipline

INTRODUCTION

The development of the concept of knowledge-based society, of transdisciplinary research in which information technologies unite society in the system and development of the technologies themselves affect the architecture of the knowledge-oriented information systems [8, 9, 17, 20], stimulating in turn, the development of methods of automatic construction of formalized ontology based on the analysis of natural language objects- (for extraction of knowledge) [18, 19], as well as applied aspects of ontology development, in particular for the construction of e-learning courses[13], and systems integration metaontology knowledge [4], service-oriented systems, etc.

MATERIALS AND METHODS

The paper used description of block diagram different modes of the program, a Java library.

The article emphasizes information on the development of software and models of development and improvement of e-learning [21], in particular for constructing e-learning courses oriented on ontology subject disciplines of structural units (department, faculty) University.

The paper used system-ontological domain analysis [15], ontological methods and means of processing of subject knowledge [13, 14], program model [14].

The logical model, which can use various logical aspects of knowledge representation [12]. Propositional logic is a complete [7], a system of iterative construction and parsing logic statements, which is the atomic structure for the components of which it is impossible to establish the truth.

Designing electronic course (EC) involves the formation of sets of concepts.

Basic principles of the paradigm of computer ontologies have been formulated in [6].

In contrast to the knowledges encoded in the algorithms, an ontology provides a unification [1-3]. and their re-using in different research groups on different computer platforms for solving various problems [4, 10-11].

Used subset of the concepts of the ontology database [13].

Statement of the problem. The material is the result of the continuation of research initiated in [14-16], which considered the appointment, architecture and formal models of instrumental complex ontological destination, which realizes integrated information technology of automatic construction of domain ontologies and system integration of domain-specific knowledge [16]. The article considers the problem of choosing a software platform implementation of one of the core modules of the information subsystem-library reference information (LRI), of the development of the architecture and algorithms of functioning units LRI module, as well as their interaction with other modules and implementation modes of operation.

Description of the software platform. LRI software module (hereinafter simply LRI) is developed at object-oriented programming language Java, having advantages of cross-platform and flexible security system. Java programs are translated into byte code that is interpreted (executed) on a virtual machine Java.

Redis. To store dictionaries LRI is used Redis - document- oriented network of data store such as “key-value” open source. The system keeps a database in RAM, equipped with mechanisms to preserve the database file (image) and logging in permanent storage of information. The main feature of the system is to support the Redis data values of the following types:

- string (this type allows you to store an arbitrary number or serialized object, while supported by special operations, which treat the string as an integer),
- linked list,
- set,
- assorted set,
- hash table, on which operations are performed atomically.

Redis runs on most POSIX systems such as Linux, BSD, Mac OS X without any additions.

Each of five data structures used Redis has at least a key and a value.

The key is intended to indicate the semantics of information. He is represented as follows: users: alex and contains information about a user named alex.

Value - is the data that is associated with the key. They may have different meanings - strings, numbers, or serialized objects (in the form of JSON, XML or any other format). Redis, mainly considers the value as a byte array and not the “interests” of their semantics.

Key and value - these are the basic concepts of Redis. They are treated with two teams - this team **get** and **set**. The set command takes two parameters: key, which is then saved, and the value associated with it.

To get the value for the key, use the command get, which returns a value corresponding to the key. For example, the team **get** users: alex, is to get the value for the key, which returns a value corresponding to the key.

The main functions of the program module LRI.

1. Providing two modes of operation of the module:

a) as part of a tool set of ontological appointment,

b) off-line (as a separate software system).

In standalone mode, using the control module, you can view terms and their definitions.

2. Viewing dictionaries for an arbitrary concepts.

3. Representation for concepts multiple definitions.

4. View mode of the concepts and definitions (the default).

- Other definitions (specific concepts).

-View mode of ontological description (fragment ontology) concept and its connection with the upper and lower levels.

5. Authorization of users. There are two types of authentication: for “User Mode” -

without password and “edit mode and filling” - requires an account on the server (username and password).

6. Search term by LRI (on all components).

7. Storage of concepts and of their definitions in the system Redis - document-oriented networked storage of data such as “key-value” open source.

8. Entering a new concept and its definition from the keyboard or with the digitized source.

9. Establishing links between the concepts that already in the LRI.

10. Graphical representation ontology (visualization ontology) and of fragments.

Options of autonomous mode LRI used in the application instrumental complex ontological destination (ICOD) – for automated preparation of e-learning course.

Digital libraries are significant public knowledge resources within a domain similar application area and in this sense they are invariant under the adaptation and optimization of the ontological system to the target application, in particular, in the problem of adapting to automate the development of e-courses on a particular subject discipline.

The algorithm of the program. LRI module consists of three sub-systems, and combines information resource, software and hardware subsystems and natural intellect. A generalized block diagram of the LRI module are showed in Fig. 1.

Subsystem the **information resource** consists of a specialized database Redis, which provides content ICOD. The database contains digitized encyclopedias, thesauruses and dictionaries, as presented in the form of descriptions of knowledge.

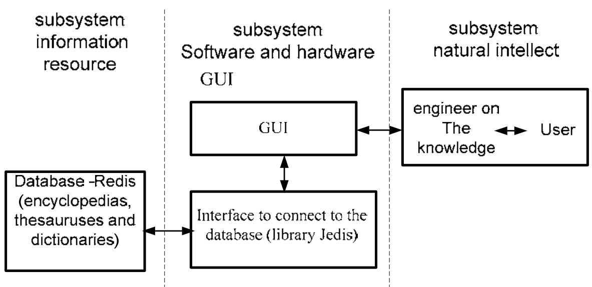

Fig. 1. Generalized block diagram of the LRI module

Subsystem software and hardware includes a block of connection to the database and graphical user interface (GUI) that allows the interaction between the user (teacher) or a knowledge engineer to work with LRI.

Subsystem **natural intellect** (knowledge engineer and / or teacher) provides content dictionaries LRI provides control and validate the contents of an information resource in case of errors or inaccuracies – edits.

Choice of modes of operation. Depending on the type of program are two modes:

- Custom mode,
- Mode filling dictionaries.

After starting the LRI module opens a window for selecting the operating mode (Fig. 2), where you can select one of the above modes and click “OK” to confirm the selection.

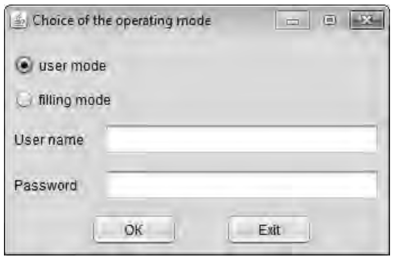

Fig. 2. Choice of the operating mode of the program

User mode. If you select “user mode” runs the main menu, shown in Fig. 3. To start working with the program, the user must select in drop-down list “Choice of SA” the desired subject area, then from the drop down menu “Choice of dictionary SA” select the desired dictionary given domain. After that a program, in the corresponding area of the window, will show the concepts corresponding to the selected domain dictionary.

For show a description of the concepts it is necessary to double-click on it to cause the corresponding description, shown in Fig. 4. By default, displays one of the most used definitions – “default definition”.

If this concept in LRI has several descriptions or definitions is in other languages to display them on the screen a button “Other definition…” (Fig. 5).

Fig. 3. Main menu

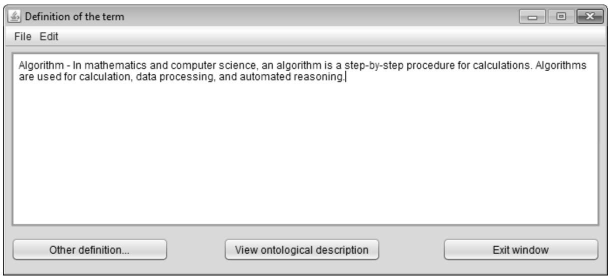

Fig. 4. Window description of the term.

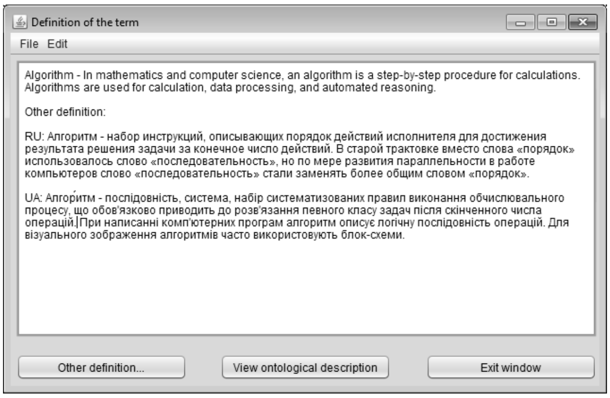

Fig. 5. Window description of the term with use additional definitions

If there is a term in describing the concepts contained in any dictionary of LRI, then the term will be highlighted in the text in a different color (Fig. 6). Thus provided a relationship between the concepts in the library LRI.

To search for concepts and their descriptions by LRI it is necessary to press "Search term…" in the main menu (Fig. 3). This will open a search window (Fig. 7), in which you must enter a word or phrase in a search string and select vocabulary of domain from the drop down list.

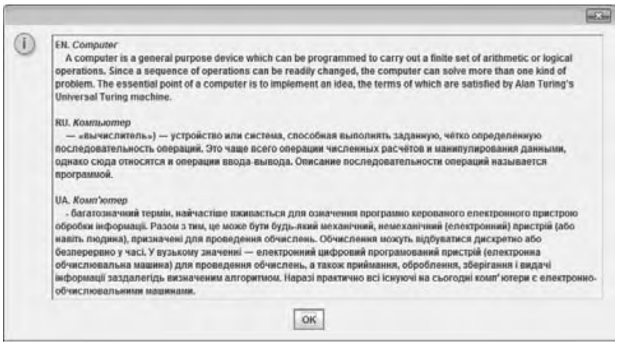

Fig. 6. Window of descriptions with backlit of related concepts

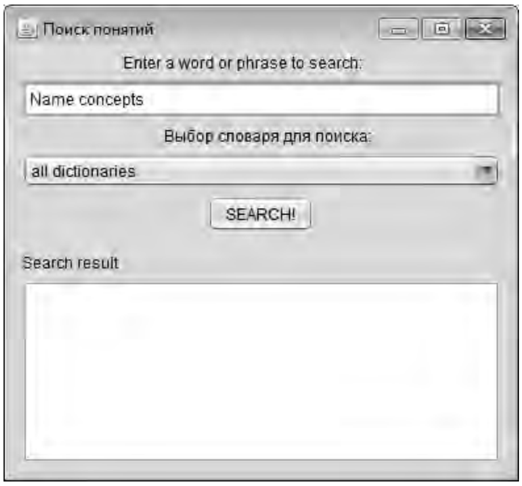

Fig. 7. Search box

To search the entire LRI need in the dropdown list leave the default choice – "all dictionary". After clicking on "Search" in the field to display the results search will be displayed concepts that found or more terms with indicating of the dictionary in which they are contained. To display a description of the terms that is found, to double click on a search results.

To display a description of the terms that is found, to double click on a search results.

Below is a general block diagram of the module LRI in user mode (Fig. 8).

Mode filling dictionaries. Selecting the edit mode. Mode filling dictionaries includes all the functionality that mode of use, as well as expanded features and content editing sections LRI. To enter to mode fill in the main menu (Fig. 3), press the button.

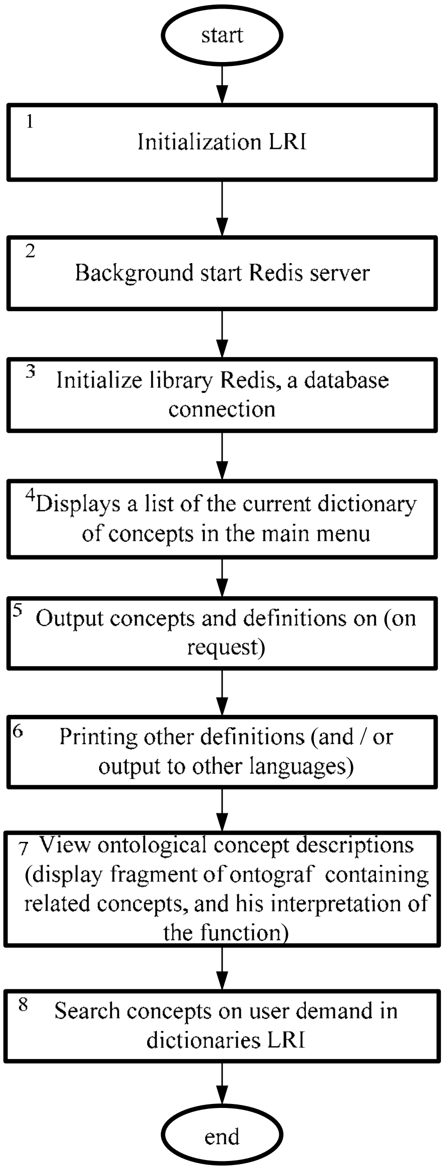

Fig. 8. General block diagram of the module LRI in user mode

“Change mode” in the window that opens, select “Filling mode” and click “OK”.

After that, in the main menu is activated button “Dictionary editor...”. For realization of mode filling dictionaries must click “Dictionary editor...”, and the dialog box will appear, shown in Fig. 9, in which you must select one of the editing modes:

- Manual editing,
- Automated edit mode.

Manual editing of dictionaries. The manual editing dictionaries LRI - editor window, shown in Fig. 10.

Fig. 9. Selecting the editing dictionaries LRI

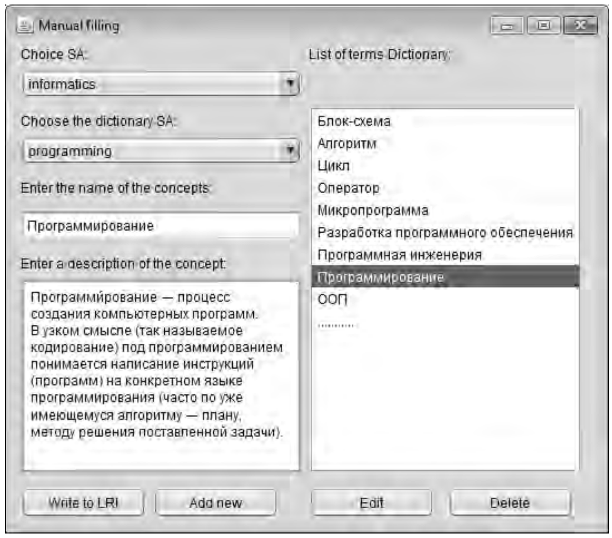

Fig. 10. Manual editing LRI

In the list drop-down left of the editor window you must select the desired subject area, and then select its dictionary. In the right pane displays a list of concepts from the dictionary.

To add a new concept into the dictionary it is necessary to press the “Add new”, then the text fields.

“Enter the name of the concepts” and “Enter a description of the concepts” will be available to fill (Fig. 11). Next, enter the name and definition of a new concept in the appropriate fields and click on “Write to LRI”. A new concept and its description will be added to the LRI.

To modify existing concepts (e.g., in case of errors or omissions in the description of the concept), select it in the display list of terms and click “Edit” and then the name and description will be displayed in the appropriate fields. When you finish editing the concept and its definition click “Write to LRI” to save the changes.

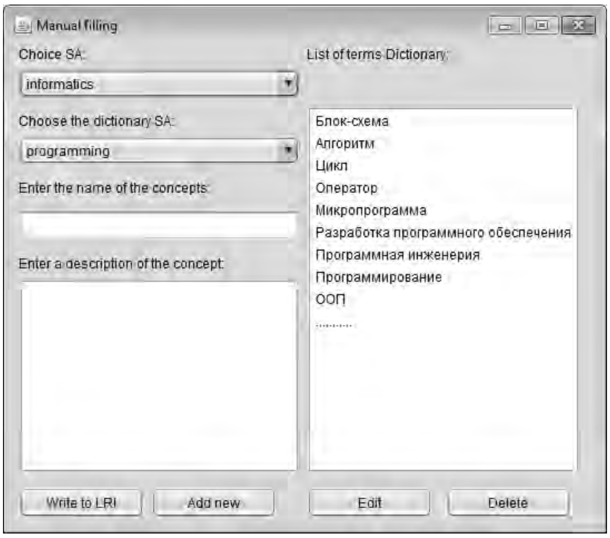

Fig. 11. Manual editing LRI - Enter a new concept

To remove concepts must select it in the list of terms and click "Delete". After this concept with its corresponding description will be removed from LRI.

Mode Automated edit dictionaries. When choosing an automated editing LRI - opens editor window, shown in Fig. 12, in which you need to click "Open..." and specify the path to the digitized source containing concepts and their descriptions. Then choose the desired subject area and its dictionary from drop-down lists that are added by the new concepts and their descriptions, and then click "Save" to complete the operation. New terms and their descriptions will be added to the selected dictionary.

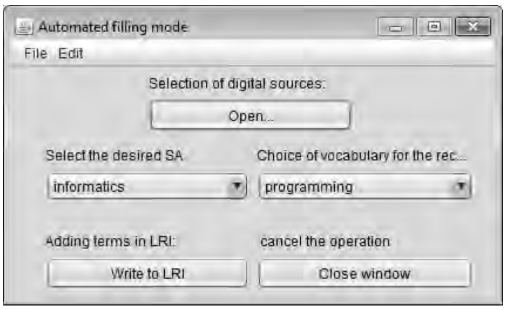

Fig. 12. Automated filling mode LRI

Fig. 13 is a general block diagram describing the algorithm of the LRI module in user mode.

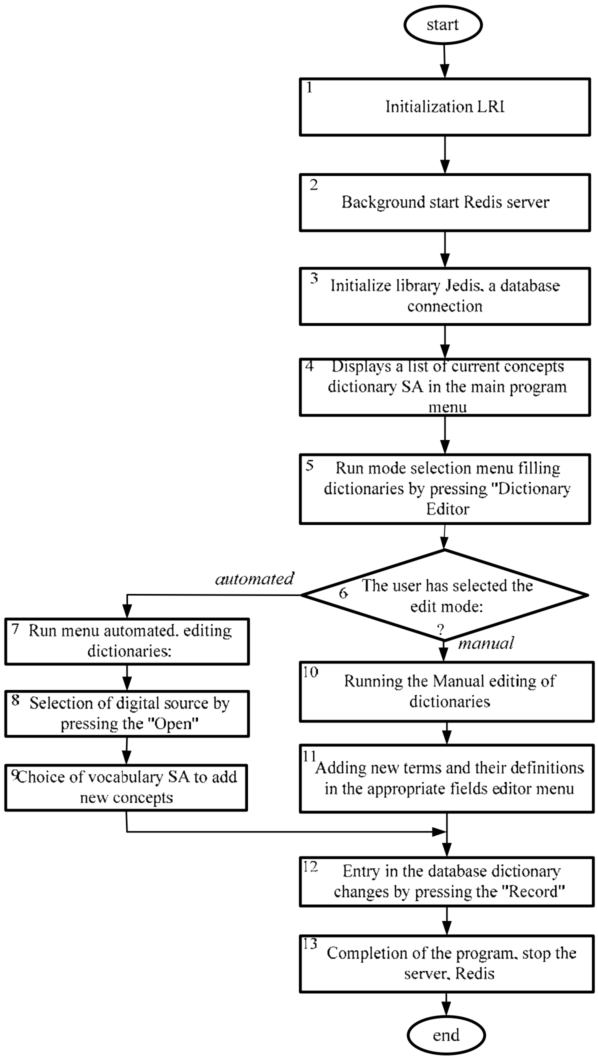

Fig. 13. Generalized algorithm of the module LRI in filling dictionaries

CONCLUSIONS

1. In this paper we proposed development of an approach to solving urgent problems of constructing formal ontologies based on the analysis of natural-language objects, developments of aspects of application of ontologies, in particular for the construction of e-learning. Described two main modes LRI, is showed windows, menus, is described purpose and as work with them. The next steps of development of the system is to implement and filling LRI by the real volumes of background information.

2. LRI as part of ICOD will improve the efficiency of applications. In particular, the solution to the problem of automatic construction of courses education will improve

the quality of content due to their significance, due to reducing the time to create and configure a specific contingent training. In addition, the problem will disappear replace the teaching staff.

REFERENCES

1. **Bechhofer S., Horrocks I., Goble C., Stevens R., 2001.:** OilEd: A Reason-able Ontology Editor for the Semantic Web // Joint German/Austrian conf. on Artificial Intelligence (KI'01). Lecture Notes in Artificial Intelligence LNAI 2174, Springer-Verlag, Berlin, 396-408.
2. **Chaudhri V., 1998.:** OKBC: A Programmatic Foundation for Knowledge Base Interoperability. V. Chaudhri, A. Farquhar, R. Fikes P. Karp J. Rice // Fifteenth National Conf. on Artificial Intelligence. AAAIPres/The MIT Press, Madison, 600-607.
3. **Domingue J., 1998.:** Tadzebao and WebOnto: Discussing, Browsing, and Editing Ontologies on the Web // Proc. of the Eleventh Workshop on Knowledge Acquisition, Modeling and Management, KAW'98, Banff, Canada.
4. **Farquhar A., Fikes R., Rice J., 1997.:** The Ontolingua server: A tool for collaborative ontology construction // International Journal of Human-Computer Studies, 46(6), 707-728.
5. **Fernandez M, Gomez-Perez A., Pazos J., 1999.:** A Building a Chemical Ontology Using Methondology and the Ontology Design Environment // IEEE Intelligent Systems, Jan./Feb. 37-46.
6. **Gruber T.R., 1993.:** A translation approach to portable ontology specifications / Gruber T. R. – Knowledge Acquisition, 5 (2),– 199-220.
7. **Guc A.K., 2003.:** Mathematical logic and the theory of algorithms: a training manual A.K. Guc-Omsk: Publisher of "Heritage". Dialog-Siberia 2003. – 108.
8. **MacGregor R., 1991.:** Inside the LOOM classifier // SIGART bulletin, Vol.3, No.2, 70-76.
9. **Motta E., 1997.:** Reusable Components for Knowledge Modelling // Ph.D. Thesis. The Open University.
10. **Musen, M., 1998.:** Domain Ontologies in Software Engineering: Use of Protege with the EON Architecture // Methods of Inform. in Medicine, 540-550.
11. **Noy N., 2001.:** Creating Semantic Web Contents with Protege-2000. N. Noy, M. Sintek, S. Decker, M. Crubezy, R. Fergerson, M. Musen // IEEE Intelligent Systems, March/April pages 60-71,
12. **Novikov F.A., 2000.:** Discrete mathematics for computer programmers / F.A. Novikov. – St. Petersburg.: Peter, 304,
13. **Palagin A.V., 2010.:** On the automated construction of ontology for the discipline of electronic courses II / [Palagin A. Petrenko, N. Tikhonov, Y., Velichko VY]. – publisher VNU named. Dahl. – 2010. – № 4 (150). – 171-178.
14. **Palagin A.V., 2012.:** Ontological methods and means of processing of subject knowledge A.V. Palagin, S.L. Kryvyj, N.G. Petrenko [Monograph] - Lugansk: publisher VNU named. Dahl, 2012. – 323,
15. **Palagin A.V., 2009.:** system-ontological domain analysis / A.V. Palagin, N.G. Petrenko. – USiM, – № 4. – 3–14. (in Russian).
16. **Palagin A.V., 2012.:** Program model ICOD: biblioteka slovarej SA / [A.V. Palagin, N.G. Petrenko, V.Ju. Velichko i dr.]. – Vestnik VNU im. V. Dalja, Lugansk: Izd. VUGU. – 2012. – № 8 (179). – 151–157. (in Russian)
17. **Robinson J., 1988.:** Logic Programming - Past, Present and Future / J.Robinson. - In the book.: Logic programming. M.: Mir, 1988.
18. **Sowa J.F., 2000.:** Knowledge Representation: Logical, Philosophical, and Computational Foundations / J. F. Sowa – Brooks Cole Publishing Co., Pacific Grove, CA, 2000. – 594,
19. **Sure Y., 2002.:** OntoEdit: Collaborative ontology development for the Semantic Web. Y. Sure, M. Erdmann, J. Angele, S. Staab, R. Studer, D. Wenke // In Proc. of the Inter. Semantic Web Conference (ISWC 2002), Sardinia, Italia, June 2002.
20. **Voronova A., 2010.:** Information technologies in public administration practice, TEKA Kom. Mot. I Energ. Roln. – OL PAN, 10D, 313-317.
21. **Zharikov E., 2010.:** Topical questions of implementation of information services in a network of University, TEKA Kom. Mot. I Energ. Roln. – OL PAN, 10B, 331-337.

РЕАЛИЗАЦИЯ ИНФОРМАЦИОННОЙ ПОДСИСТЕМЫ БИБЛИОТЕКИ СПРАВОЧНОЙ ИНФОРМАЦИИ В MODERN E-LEARNING

Александр Палагин, Николай Петренко, Виталий Величко, Геннадий Могильный, Юрий Тихонов, Виталий Семенков.

Аннотация. Предлагается дальнейшее развитие ИКОН, предназначенного для реализации интегрированной информационной технологии автоматизированного построения онтологий ПдО и ПдД. Полученные результаты ориентированы на решение задачи практической реализации информационной подсистемы, построения программной модели БСИ, режимов функционирования и ее взаимодействие с другими подсистемами комплекса.

Ключевые слова: библиотека справочной информации, онтологическое описание предметной дисциплины.

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A theoretical evaluation of locomotive wheelsets tires wear rate

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Summary A theoretical estimation of locomotive wheelset tires' wear intensity with the use of different contact models is presented in the paper. The received difference in the results of modeling varies from 40% to 100% depending on initial pre-conditions of contact model.
Key words: wheel, rail, wear

INTRODUCTION

Today with the purpose of cost effectiveness on model experiments it is expedient to create the virtual prototypes of locomotives. The so-called "multibody dynamics systems" are used for this purpose. Except solving dynamics tasks, the obtained data about position and stress state of wheel - rail contact patch can be used in a further analysis for prognostication of wear (evolution) of wheel and rail profiles and for the modeling damages caused by rolling contact fatigue .

OBJECTS AND PROBLEMS

The most reliable theoretical results can be obtained only when taking into account the complexity of locomotive wheels – railway tread contact process in real-life environment. Because of importance of this task many scientific works are devoted to it [9, 12, 14, 25 etc.]. Two approaches can be marked out for adhesion force calculation.

With the first approach adhesion forces are calculated from the approximate expressions, received by authors [17, 18, 19, 23], depending on the number of factors. Main factors are vertical load, vehicle speed, relative slippage, frictional conditions. The advantages of this approach is its simplicity and high calculation speed. The disadvantage is that it is not possible to obtain force and temperature characteristics of contact patch.

With the second approach a mathematical modeling of wheel and rail contact is performed [10, 11, 20, 21, 22]. Since in general it presents significant difficulties, some simplifying assumptions are often made, that allow to separate initial problem into two less complex problem: normal and tangential. The typical assumption are that contacting bodies' dimensions are much greater than contact zone (this assumption allows to treat contacting bodies as elastic half-spaces) and that the difference between normal elastic displacements, caused by tangential tractions in contact zone, is zero.

The aim of normal contact problem is to find a contact patch shape and normal pressure distribution within it. Then the obtained data is used as initial data for tangential contact problem, that aims to find a tangential traction distribution and creep forces.

The normal problem is usually solved analytically with a use of Hertz theory [8], but it calls for bodies to have constant curvatures in contact zone. This limitation is often violated for worn wheel and rail profiles. In this case numerical non-hertzian or semi-hertzian solution should be used, and most of them are based on Bousinesque – Cerutti solution for unit force acting on elastic – half space [9, 13, 14].

There are two different approaches for solving tangential problem.

With the first approach it is assumed that contact is separated in slip (sliding) zone and stick (adhesion) zone. The most popular solution for this approach is Kalkers' FASTSIM algorithm and it's various modifications [11, 12, 20, 30].

Since that stick zone can exist only with a very small (elastic deformation order of magnitude) relative wheel – rail slippage values [28, 31], with the second approach the possibility of it's existence is ignored and it is supposed that the whole contact area is covered by slip zone. An example of this approach is developed by Golubenko school semi-empirical method of solving the tangential problem using experimental dependence of friction coefficient on the temperature in contact zone for different frictional conditions [14]. It should be noted that unlike FASTSIM, this model provides the correct results when modeling locomotive motion in traction (breaking) regime.

According to the results [29, 32], the approximation of the contacting bodies with elastic half-spaces and separation the contact problem into normal and tangential problems for wheel-rail contact in rail gauge corner zone, where lateral curvature radius is 15 mm, can bring significant error in calculations. Besides, existing contact models do not consider the lateral bending of railhead. As it was studied by author, even 0.2 mm relative displacement between rail foot and railhead leads to significant changes in the contact patch shape, and according to JSC "VNIIZhT" (Railway Research Institute) researches, the difference between rail head and foot displacements can exceed 60 mm.

At the Railway Vehicles department of Volodymyr Dahl East Ukrainian National University a mathematical model of quasistatic contact of wheelset and track was developed, that takes into account rail lateral bending, load redistribution in case of two-point contact, increases the reliability when modeling contact in rail gauge corner zone, and takes into account the friction coefficient dependence on the contact temperature [2]. After a model discretization, a computer program called *VDEUNU CONTACT* (*Volodymyr Dahl East Ukrainian National University Contact model*) was developed to study wheel-rail contact problems. Since in problem solution the iterative algorithm is used, the program can't be used directly during the vehicle dynamics simulation. Therefore it was used for compilation of so called "contact look-up tables". Then during the vehicle dynamics simulation the data about contact patch parameters and creep forces is read directly from these pre-calculated tables. The program FASTTAB was also developed, specified for data reading from look-up tables during the dynamics simulation.

The verification of *VDEUNU CONTACT* program was carried through several steps [15].

On the first step, to compare the solution of normal problem to other existing theoretical solutions, the *VDEUNU CONTACT* program was used for passing through the Manchester contact benchmark. The aim of the test is to provide for the end user the choice of the contact model for the particular modeling situation.

Two cases are suggested for benchmark. Case A is supposed for modeling of single wheelset contact with rails with prescribed motion conditions. Case B is supposed for modeling railway vehicle (freight wagon with two bogies) for a study of its dynamical behavior. This case is now under revision.

Case A aiming to solve normal (Case A-1) and tangential (Case A-2) contact problems. In turn, case A-1 is divided on two sub-cases A-1.1 and A-1.2, that differ from each other with input parameters.

After the specification for Case A was developed, an invitation to take part in it was in open access during the 2006 year. Total 10 software packages developers confirmed their participation. The results of Cases A-1 and A-2 can be found in paper [27].

The size and form of contact patch are very important factors, influencing traction, wear and rolling contact fatigue. On Fig. 1 is shown the dependence of contact patch area from lateral displacement for right wheel-rail pair. It can be seen, that before the flange clearance is exceeded, the results for all programs are near similar. Once the flange clearance is exceeded (lateral displacement more than 6 mm) the largest contact size is four times that of the smallest. The reason for that can be the difference in contact points detection and methods of solving normal contact problem. That's why it makes sense to compare the results from VDEUNU CONTACT to experimental data using the results from [16, 24].

The experimental set- up for ultrasonic detection of wheel- rail contact parameters consists of focusing transducer, ultrasonic pulser – receiver (UPR), a digital oscilloscope, a control PC, a scanning table (automated with x, and y-stepper motors) and a load frame. Two wheel - rail pairs were used for experiments, the ne ones and the worn profiles taken from heavily worn in service components. The profiles were digitized with MiniProf device. The wheel and rail specimens were cut from actual wheel and rail sections. The rail specimen is fixed to the upper plate, and the wheel specimen to lower plate. The specimens are moving relatively to each other as in the real wheel – rail contact conditions. To fulfill this requirements a grid was marked on the lower plate, that was used to set up lateral displacement and yaw angle. The load frame consists of fixed upper plate and moving lower plate The wheel and rail specimens are loaded with hydrocylinders , and focusing transducer is located above them in the reservoir filled with distilled water. The control signal is coming from PC, and UPR brings the focusing transducer to excitation. Then focusing transducer sends ultrasonic wave and gets the reflected signal form contact area. The sent and reflected signals are then shown on the digital oscilloscope and stored in memory. After finishing the measurements in prescribed point, with the scanning table focusing transducer goes to the next point until the whole contact area is not scanned (in paper [16] 0,25 step was used in and directions).

As it can be seen from paper [15], the numerical solution from VDEUNU CONTACT and experimental data from [16, 24] has good agreement.

For case A2 (tangential problem) of Manchester Contact Benchmark the creepages are input parameters, and for VDEUNU CONTACT they are output parameters. That's why case A-2 study can't be preformed.

The verification of VDEUNU CONTACT was performed by means of comparing creepage – friction coefficient curves, built with different methods. The most common contact models (FASTSIM (J. Kalker), ADH (O. Polach), T. Muller and D.Minov) were used as alternative to VDEUNU CONTACT.

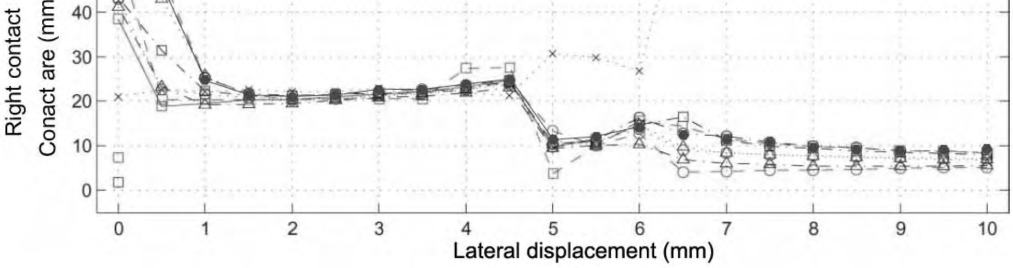

Fig. 1. The dependence of contact patch area on lateral displacement for right wheel – rail pair for different codes [15].

The next initial conditions are accepted. Wheel and rail profiles are new according to Ukrainian State Standards. Lateral displacements and yaw angles are zero. Vehicle speed is 20 m/s. Wheel vertical load - 100 kN. Two frictional cases are studied. For the first case the friction coefficient is 0.38 (clean, dry surfaces), for the second case – 0.07 (surface, coated with grease). For VDEUNU CONTACT program corresponding experimental friction coefficient dependencies on temperature were used.

For high friction coefficient values, a critical creep value, calculated with VDEUNU CONTACT, ADH, Muller and Minov is 0.02…0.025, and there is no major differences in ascending branch (no more than 7%). The results of FASTSIM, coincides with others only at very small (near 0.001) creeps. The reason is that FASTSIM was developed at the base of Kalker’s linear theory, the basic assumption of which is vanishingly small slip between wheel and rail. The falling friction branch for FASTSIM, ADH и Mullers models are absent.

The experimental studies shows the under the bad frictional conditions the critical creep is increasing. But as it was found out, the critical creep, calculated with FASTSIM, ADH и Muller, as it can be predicted, shifted to the zone of microcreep (up to 0.001), for Minov program left the same, and only for VDEUNU CONTACT increased to 0.04.

Taking into account so substantial difference in the modeling results, the questions raised about the ability of using VDEUNU CONTACT program for railway vehicle dynamics modeling. The verification was carried through the Manchester Dynamics benchmark [7].

On the international symposium «Computer Simulation of Rail Vehicle Dynamics», that took place at Manchester Metropolitan University 23 and 24 June of 1997, were agreed the etalon benchmarks for railway vehicles dynamics simulation. The aim of benchmarks is to provide for researchers, studying railway vehicles dynamics, evaluation the compatibility of different software packages. The initial results, calculated in the most popular software packages, were shown at the special meeting on 15 December, 1997. There were some corrections in the vehicle and track models, and in the results presentation to avoid misconstrues. The full description of benchmarks initial data can be found in [7]. The etalon models were chosen to cover the most common vehicle and track models, that are used in vehicle dynamics simulation. Despite the both vehicle models are simplified, they include examples of complex elements. The detailing level of models is chosen to provide every software developers to build the model. There is no restrictions in the documents about exact models usage, including wheel – rail contact model.

For modeling the «Universal Mechanism» software was used. VDEUNU CONTACT model was integrated in Universal Mechanism as dynamic link library. As alternative to VDEUNU CONTACT FASTSIMA (FASTSIM modification) was used.

As it was cleared up [15], for all cases simulation results do not depend on the chosen contact model. It can be explained with two facts. First of all, the friction coefficient for Manchester dynamics benchmarks simulations is chosen to be 0.4. Secondly, the maximal stated creep value during simulations, was 0.005. In other words, the section, called “zone of FASTSIM validity” was used on traction curve. In this zone there is no major difference which contact model is used. The influence of contact model used to be seen while modeling locomotive motion in traction regime. The choice of correct contact model is very important in prediction of wheel wear, as the wear of locomotive wheelset tires flanges is one of the main problems on ex - USSA railways [3, 26].

According to GOST 2823 – 94, the *wearing* is defined as a process of material loss from the friction surface of rigid body and (or) expansion of its residual deformation in friction conditions, shown in progressive change of body sizes, form and (or) body mass, and *wear* – as the results of wearing, expressed in prescribed units of length, volume, mass and so on. At the former USSA railways the wear rate of wheelset locomotive tires is calculated, which is measured in mm on 10000 km of haulage.

In the fundamental work of Sakalo an Kossov [25] was made a review of theoretical approaches for calculation of wheel and rail rolling surfaces wear. It is said, the most of comprehensively grounded and widespread wear models, widely adopted in railway vehicle branch, are based on the preposition, that the loss of material on the section of surface profile, is proportional to the material constant and the sum of local friction works. The wear model supposes a proportional dependence between the wear volume V_e an friction work A_r:

$$V_e = kA_r, \qquad (1)$$

where k - wear index and its value, determined with experiments, is $10^{-4} < k < 10^{-2}$ mg/ (Nm). The value of k used for calculation must be selected to satisfy the operational conditions [1, 19].

Also in the paper [25] is admitted that one of the most adverse type of wear is wear of wheel flange and rail side face of outer rail in curves. This wearing is especially intensive in case of wheel- rail two – point contact The experimental test on 2TЭ116 locomotive allowed to ascertain that lateral force can reach 62 kN.

In the book [5], which summarizes up-to-date international experience on the issues of wheel and rail interaction, is also admitted, that the wear magnitude is proportional to energy, that was dissipated during the process of overcoming the resistance to rolling with sliding of wheel on rail. The wearing of wheel and rail is determined by relative slip and pressure on contact areas. In turn, the relative slip and pressure depend on dynamical parameters of wheel and rail interaction. The wear is substantially determined by the characteristics of third body, that depend on presence of lubrication, weather conditions (humidity, rain, snow) and use of sending.

The aim of this paper is to compare the results of theoretical evaluation of locomotive wheelsets tires wear rate, received with the use of different contact models in a traction regime

RESULTS AND DISCUSSIONS

To succeed the research, the FASTSIM algorithm, original Golubenko school model and the model developed by author were integrated as contact models in mathematical model of TЭ116 locomotive motion, which was developed in Railway department of Volodymyr Dahl East Ukrainian National University [4]. The next premises were made before the construction of the model:

- All bodies of the system (locomotive body, bogies' frames, traction motor, wheelsets and wheel treads are considered perfectly rigid.
- Nonlinearities in axleboxes during the lateral run of wheelsets, in pivot units according to the lateral displacements of the bogies, in the support of the locomotive body during the yawing are considered.
- The action of the hydraulic and frictional oscillation dampers in axlebox suspension and in the bodie – bogie links.
- Train and locomotive running resistance forces are considered.
- The simulation is performed in the locomotive traction, braking and stopway regimes.
- A traction force value is determined for each wheel separately, depending on the linear velocity of the vehicle, sliding speed of the contacting bodies, frictional condition, wheel –rail profiles and their orientation.
- The longitudinal velocity of the locomotive is determined in the process of the motion differential equations integration and no limitation is put on it.
- A railway track is considered as discrete inertial beams of infinite length, which are laying on the elastic – dissipative or visco - elastic foundation and are under the influence of the vertical and lateral forces, applied at the wheel- rail contact points.
- Wheel tread and rail can have new or worn profiles.

- A wheel flange – rail friction is considered when the once flangeway clearance is exceeded.
- The electrodynamical processes in the engine action are considered.
- During the running process the longitudinal vibrations of the train are considered.
- Torsional stiffness of the wheelset axle is considered.

In the present paper, for the evaluation of wheelset tires wear was used an approach, presented in paper [6]. It is said there, that the intensity of wear can be judged by the power of friction. As during the vehicle dynamics simulation at every time point the relative slip speeds and friction forces between the whole interacting elements are known, than instant power of friction is calculated by multiplication of friction force on slip speed and is stored on PC as function of time or distance passed.

For the wear intensity determination the next expression is used in present paper:

$$I_{ij} = \frac{k_{lin}}{L} \int_0^T \iint_{S_C^{ij}} \left(V \cdot \varepsilon_x^{ij} \cdot \tau_x^{ij} + V \cdot \varepsilon_y^{ij} \cdot \tau_y^{ij} \right) dxdydt, \qquad (2)$$

where: i – wheelset number, j – wheel number (1 – left, 2 – right), T – simulation time, V – vehicle speed, ε_x^{ij}, ε_y^{ij} – slip vector projections on x, y axis correspondently, τ_x^{ij}, τ_y^{ij} – tangential tractions on x, y axis correspondently, S_C^{ij} – contact area(s) on j–s wheel of i wheelset in t time point, k_{lin} – linear wear coefficient, L – distance passed.

The locomotive motion was studied in traction regime on dry rails with vehicle speed 60 km/h in 300 m curve. The wear intensity was calculated for tread and flange separately, as the new wheel and rail profiles were used, and when flangeway clearance is exceeded, two – point contact occurs. For the tread k_{lin} is set to 10^{-6} mm/kJ [1], and for the flange - $6{,}4 \cdot 10^{-6}$ mm/kJ [19].

The modeling results are introduced in Fig. 2 and Fig. 3.

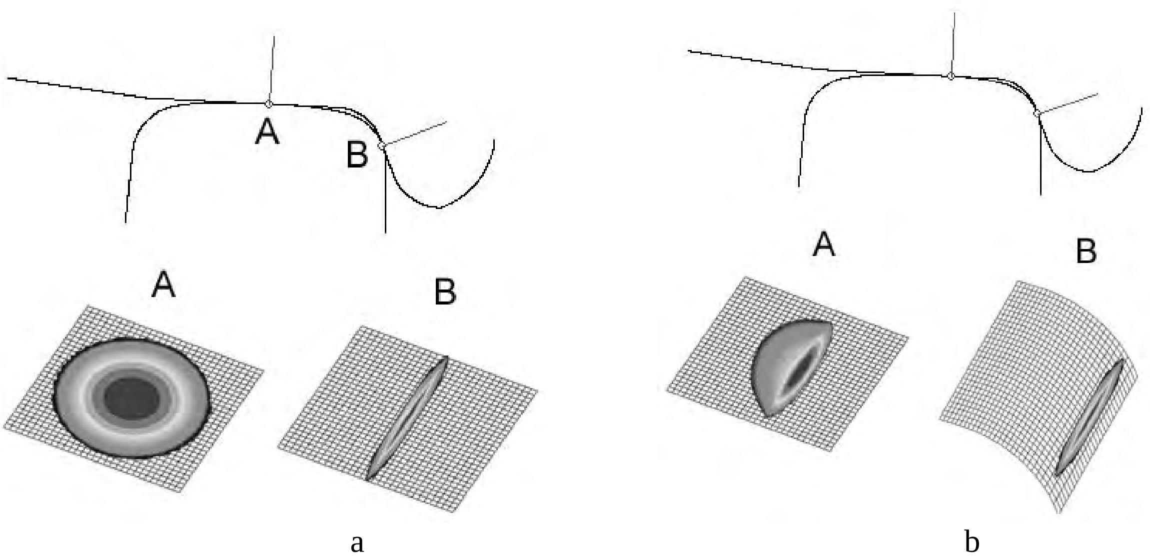

Fig. 2. Contact patches when flangeway clearance is exceeded with the use of original Golubenko school model (a) and developed model (b)

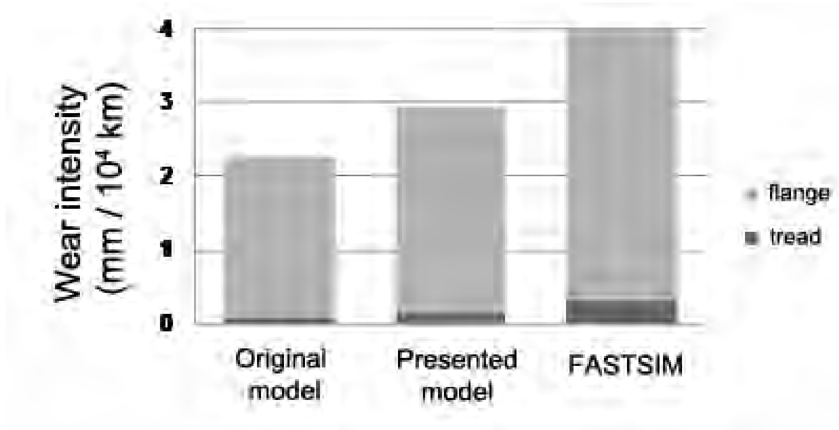

Fig. 3. The results of first wheelset tires wear intensity calculations with the use of different contact models

CONCLUSIONS

1. The difference in results obtained with the use of original model and FASTSIM is about 100% (see Fig. 2). It can be explained by the difference in definition of tribological behavior of contact.

2. The difference between the results of original model and developed model is about 40%. It can be explained by the introduction to the model additional parameters, that significantly changes the position and stress state of contact patch (see Fig.1).

3. The most reliable wheel tires wear prediction results can be obtained only with developed wheel-rail contact model, because it includes the largest number of operational conditions.

REFERENCES

1. **Braghin F., Bruni S., Resta F., 2001.:** Wear of railway wheel profiles: a comparison between experimental and a mathematical model, 17th IAVSD Symposium Dynamics of Vehicles on Road and Tracks , 43–45.
2. **Golubenko A., Kostyukevich A., Tsyganovskiy I., 2012.:** A wheel – rail frictional contact model, Bulletin of V. Dahl East - Ukrainian National University, № 5(176), 7-12. (in Russian).
4. **Golubenko A., Malohatko A., Klyuev S., Klyuev A., 2011.:** The application review on the rolling stock of devices for turn of wheel pairs in the horizontal plane, TEKA Commission of Motorization and Power Industry in Agriculture, V. XIA, 5-12.
5. **Gorbunov N., Golubenko A., Kostyukevich A., Kashura A., 2002.:** A prediction of the tractive and dynamical features of locomotives with simulation technique method. Luhanks, V. Dahl East - Ukrainian National University, 104.
6. **Harris W., Ebersöhn W., Lundgren J., Tournay H., Zakharov S., 2001.:** Guidelines To Best Practice for Heavy Haul Railway Operations (Wheel and Rail Issues), International Heavy Haul Association, USA, 408.
7. **Husidov V., Zaslavskiy L., 1995.:** Numerical modeling of coach vibrations when moving on straight and curved track. Bulletin of VNIIZT, Vol. 3, 18-25. (in Russian).
8. **Iwnicki S.,1998.:** Manchester Benchmarks for Rail Vehicle Simulation., Vehicle System Dynamics, 30:3-4, 295-313.
9. **Johnson K.L., 1985.:** Contact Mechanics. Cambridge University Press, Cambridge (UK).
10. **Kalker J.J, 1967.:** On the rolling contact of two elastic bodies in the presence of dry friction, Doct. Thes. Delft Universiti, 160.
11. **Kalker J.J., 1973.:** Simplified Theory of Rolling Contact, Delft Progress Report. University of Technology, The Netherlands, Vol. 1. 1973, 1-10.
12. **Kalker J.J., 1982.:** A fast algorithm for the simplified theory of rolling contact (FASTSIM program), Vehicle Systems Dynamics, Vol. 11, 1-13.
13. **Kalker J.J.,1990.:** Three Dimensional Elastic Bodies in Rolling Contact, Dordrecht. London.: Kluwer Academic Publishers, 314.
14. **Kalker, J.J., Piotrowski, J., 1989.:** Some new results in rolling contact, Vehicle System Dynamics, Vol. 18, 223-242.
15. **Kostyukevich A. I., 1991:** A numerical and experimental identification of the locomotive wheel – rail adhesion process, Dis. candidate of technical sciences, Luhansk, 230.
16. **Kostyukevich A., Tsyganovskiy I., 2013.:** Testing developed wheelset – track interaction model [E-resource]: http://nbuv.gov.ua/j-pdf/Nvdu_2013_10_17.pdf.

17. **Marshall M. B., Lewis R., Dwyer-Joyce R. S., 2006.:** Experimental Characterization of Wheel-Rail Contact Patch Evolution, Journal of Tribology, 128(3), 493-504.
18. **Minov D., 1965.:** The enhancement of tractions efforts of electric locomotives and diesel locomotives with electrical transmission, Moscow, 268. (in Russian).
19. **Menshutin N., 1960.:** The investigation of slippage of electric locomotives' wheelset under the tractive effort in operational conditions, Works of VNIIZT, Vol.188, 113-132. (in Russian).
20. **Masliev V., 2008.:** The dynamics of diesel trains with devices that reduce wheelset tires' wear, Kharkov, 288. (in Russian).
21. **Piotrowski J., Kik W.,2008.:** A simplified model of wheel/rail contact mechanics for non-Hertzian problems and its application in rail vehicle dynamic simulations, Vehicle System Dynamics, Vol. 46:1, 27-48.
22. **Piotrowski, J. , Chollet, H., 2005.:** Wheel-rail contact models for vehicle system dynamics including multi-point contact, Vehicle System Dynamics, Vol. 35, 361-407.
23. **Polach O., 1999.:** A fast wheel–rail forces calculation computer code, Vehicle System Dynamics, Vol.33, 728-739.
24. **Polach O., 2001.:** Influence of locomotive tractive effort on the forces between wheel and rail. Vehicle System Dynamics Supplement, Vol. 35, 7-22.
25. **Rovira A., Roda A., Marshall M.B., 2011.:** Experimental and numerical modelling of wheel–rail contact and wear, Wear 271, 911-924.
26. **Sakalo V., Kossov V., 2004.:** Contact problems of railway transport. Moscow: Mashinostroenie, (in Russian).
27. **Sapronova S., 2010.:** Modeling of locomotive wheel profile form, TEKA Commission of Motorization and Power Industry in Agriculture, V. XC, 270-278.
28. **Shackleton P., Iwnicki S.D., 2008.:** Comparison of wheel–rail contact codes for railway vehicle simulation: an introduction to the Manchester Contact Benchmark and initial results. Vehicle System Dynamics, vol.46(1), 129-149.
29. **Spiryagin M., Polach O., Cole C., 2013.:** Creep force modeling for rail traction vehicles based on the Fastsim algorithm, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility, 51:11, 1765-1783.
30. **Vollebregt E., Segal G., 2013.:** Solving conformal contact problems, Proceedings of the 23rd International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2013), Qingdao, China.
31. **Vollebregt, E., 2011.:** FASTSIM2: a second-order accurate frictional rolling contact algorithm./ Vollebregt, E., Wilders, P. // Computational Mechanics, Vol. 47, Issue 1, 105.
32. **Vollebregt E., 2013.:** Numerical modeling of measured railway creep versus creep-force curves with CONTACT. Wear, doi 10.1016 / j.wear.2013.11.030.
33. **Yakovlev V., 1963.:** About applicability of Hertz – Belyaev theory for the calculation of contact stresses in railhead gauge corner and wheel flange, Works of LIIZT, Vol. 210, 121-123 (in Russian).

ТЕОРЕТИЧЕСКАЯ ОЦЕНКА ИНТЕНСИВНОСТИ ИЗНОСА БАНДАЖЕЙ КОЛЕСНЫХ ПАР ЛОКОМОТИВОВ

Илья Цыгановский

А н н о т а ц и я : В статье при помощи различных контактных моделей проведена теоретическая оценка интенсивности износа бандажей колесных пар локомотивов. Полученная разница в результатах моделирования составляет от 40% до 100% в зависимости от того, какие исходные предпосылки заложены в контактную модель.

К л ю ч е в ы е с л о в а : колесо, контакт, износ

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The reduction in force interaction of wheel with the rail in the curves by means of the automatic control over the locomotive wheel pair position

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Summary. The paper deals with the question of reduction in force interaction of wheel with the rail in the curves by means of the automatic control system (ACS) over the locomotive wheel pair position, using an acoustic method for determining the attack angle and the navigation systems of the motion direction.
Acoustic method of control over the wheel attack angle on the rail has been chosen and investigated.
The locomotive bogie design has been improved and the simulation model of the locomotive motion with the improved bogie design with regulated axlebox with the axial formula 3o-3o has been further developed, taking into account the automatic control system dynamics with the position of wheel pair in a horizontal plane.
Automatic control system over the wheel pair position in the straight and curve sections of the track has been developed.
The theoretical research and the comparison with the experimental data of dynamic processes, occurring in the mechanical part of the serial locomotive and the improved locomotive bogie design when moving in the curve sections of the track have been done.

Key words. locomotive, attack angle, automatic control system, acoustic emission, force interaction.

INTRODUCTION

In terms of modern exploitation of the existing rolling stock there is a problem of intensive wheel flange wear of the wheel pair band related to the force interaction of a wheel with a rail [29, 11, 15, 18]. That's why a task related to the estimation of bogie design influence on the quality of motion that supposes: diminishing of the force effecting on the railway, wear of wheels and rails, environmental influence, increase of safety and stability of motion, comfort.

It has theoretically and experimentally been established that 80 % reasons of wheel pair band damage takes place because of rolling stock design imperfection and about 20 % – on reasons depending on the condition of a railway [25, 12, 4].

The solution of the given problem is connected with the creation of a basically new carriage design. The reduction in force interaction, the improvement of dynamic indicators in the curve and the diminishing of intensity of locomotive band flange and rails wear is possible by means of improving the control system of a position of wheel pair in rail track [11, 16, 9].

RESEARCH ANALYSIS

In spite of a large amount of the theoretical and experimental work on research of a motion of locomotive in the curve, the definition of the wheel attack angle on a rail is not enough studied, and the main difficulties in research of wheel attack angle on a rail lies in the absence of information about actual wheel attack angle on a rail [19, 8, 13].

The main requirements presented to the new locomotives are the increasing of motion safety and the diminishing of the level of the dynamic influence on a railway. The main influence a locomotive is on the railway when passing a curve, that is accompanied by the increased degree of wheels and rails wear [26, 1].

The perspective direction of decrease in the intensity of wear in the system a "wheel-rail" is the application of rational designs of the carriage part of the locomotives, supplemented by the system of active control of a wheel pair turn when moving at curve [18, 2, 21].

To determine the method of control of a wheel pair position in the track, it is necessary to know the characteristics of the controlled object and disturbances entering the controlling device.

A great attention is devoted to the theoretical and experimental research due to the complexity of the processes taking place in the curve [3].

RESEARCH OBJECT

The research object is the radial setting of the locomotive wheel pair when moving.

The research subject is the automatic control system of the radial setting of the wheel pair when moving in the curve sections of the track.

The main objective: a decrease of force interaction of a wheel with a rail when moving the locomotive at curve through the automatic control system of the position of a wheel pair on the basis of acoustic method for determining the angle of wheel-rail attack and the navigation system of determining the curve direction for this section of the track.

The objective mentioned above has proved the necessity to solve the followings scientific tasks:

1. The choice of the method of control over the position of the wheel pair in the rail track.
2. The choice and the research of the control method of the wheel pair angle attack on the rail.
3. The improvement of locomotive carriage design and the development of mathematical model of locomotive motion with the axial formula 3o-3o with an active control system over the position of the wheel pair in a horizontal plane on the straight and curve sections of the track.
4. Theoretical research of the dynamic processes occurring in the mechanical part of the locomotive and in the “wheel – rail” contact when moving in the curve sections of the track.
5. The development of the automatic control system of the wheel pair position in the straight and curve sections of the track.

On the basis of scientific and technical information analysis it is determined that the dynamic properties of the carriage in the horizontal plane and lateral band flange wear of the wheel and head of the rail depend on the wheel attack angle on the rail, state of the carriage part of the locomotive, on which it is possible to influence effectively by means of the rational choice of the locomotive carriage design. Carriages with the passive setting of the wheel pair tend to increase undulation in the straight sections of the track and it does not allow the radial setting of the wheel pair when moving on the curve sections of the track [7].

A turning device with the unrevolved axis has got a great distribution on the railway transport, which does not provide control on the curve sections of the track and has no control of the wheel pair turn in a horizontal plane.

One of the methods to reduce the horizontal transversal effect on the railway carriage on the curve sections of the track is the controlled wheel pair motion [15].

It has been theoretically and experimentally proved that traditional solutions and passive methods have been exhausted, and the further solution of the task to reduce the force interaction can be carried out by means of the application of active methods of control. The algorithm of work of such a control system consists in that when moving on the curve an executive device turns the wheel pair in a horizontal plane in the rail track to minimize the wheel attack angle on the rail [6].

To solve the task of reducing the resistance motion, wear of wheels and rails is possible due to the further improvement of the existing design of the locomotive carriage part with supplementing it with the active control system of the position of the wheel pair in the rail track. The controlling influence on the carriage on the curve sections of the track opens new quality possibilities of improvement of the curve dynamics, provides the reduction in the dynamic influence on the track. The existing control systems of radial setting of the wheel pair do not provide the control of the wheel attack angle on the rail, because of complex measurements and the absence of the adequacy of the obtained measurements of this parameter [15].

The lack of the existing systems of the wheel pair turn in a horizontal plane is absence of the automatic control system of the wheel pair position in the rail track.

It is reasonable to create the fast-acting system of active control over the position of the wheel pair in the rail track in the curve section of the track not from the side of the operative parameters of the motion, but taking into account the control over the wheel attack angle on the rail and the direction of moving.

The duration of the transitional process must not exceed the time of the transitional curve passing by. According to the norms of the speeds allowed on the passenger transport, the minimum time of passing transitional curve (at a_H = 0,7 m/s^2) is 0,36 seconds [28].

The automatic control system (ACS) of the position of the wheel pair in the rail track must guarantee:

- stabilization of the wheel pair motion in the rail track when it’s moving on the straight sections of the track,

- controllability and uniqueness.

A functional block of the control system over the wheel pair position in the rail track has been shown on Fig. 1.

The automatic control system over the position of the wheel pair contains a controlled object, measurement block, computing device and executive block.

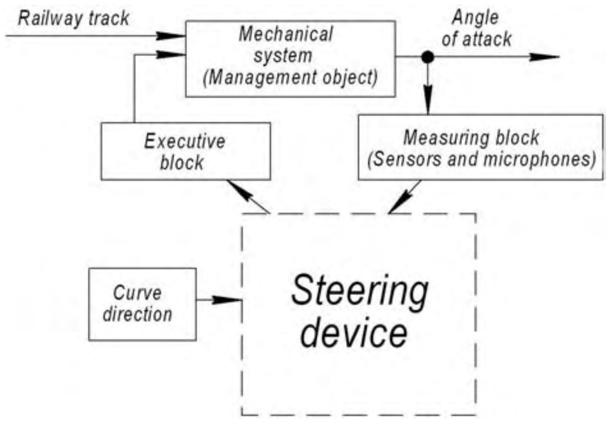

Fig. 1. A functional block of the guided motion of the wheel pair in the rail track

A measuring block contains the sensors of the wheel attack angle on the rail.

The functions of the controlling device are data processing received from sensors, formation of the controlling effect on the regulator fed to the executive mechanism.

A controlling device forms a controlling effect for the wheel pair turn in a horizontal plane in the rail track on the angle at which the reduction in the force interaction of band flange of wheel with the head of the rail is provided, which is done due to the minimization of the wheel attack angle on the rail.

A regulator must provide the required values of the transitional process time ($t \leq 0{,}36$ seconds) without overcorrection [28].

One of the difficult problems when designing the ACS is how to get information about wheel pair attack angle on the rail.

The existing methods of determination the wheel attack angle on the rail without setting a stationary sensor on the groundwork use the indirect measurements to calculate the attack angle and do not allow to measure the wheel attack angle on the rail automatically.

The investigation of the mechanism of the acoustic emission generation in a contact wheel-rail has been executed when moving the locomotive with the purpose to ground the possibility of using the acoustic emission from a contact wheel-rail to determine the wheel attack angle attack on the rail.

The scheme of acoustic emission formation has been shown on Fig. 2.

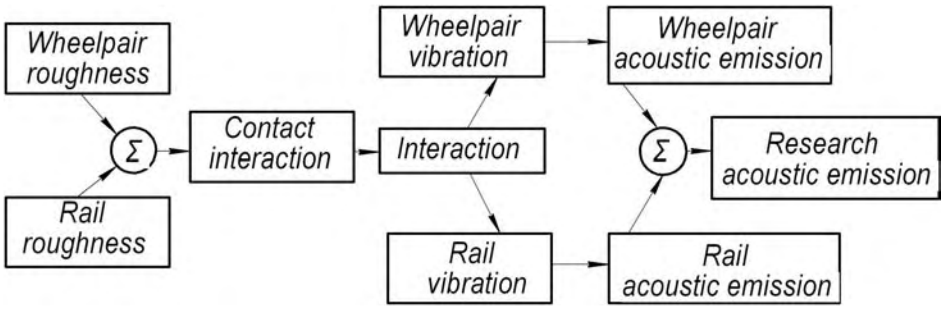

Fig. 2. Scheme of acoustic emission formation from a wheel-rail contact

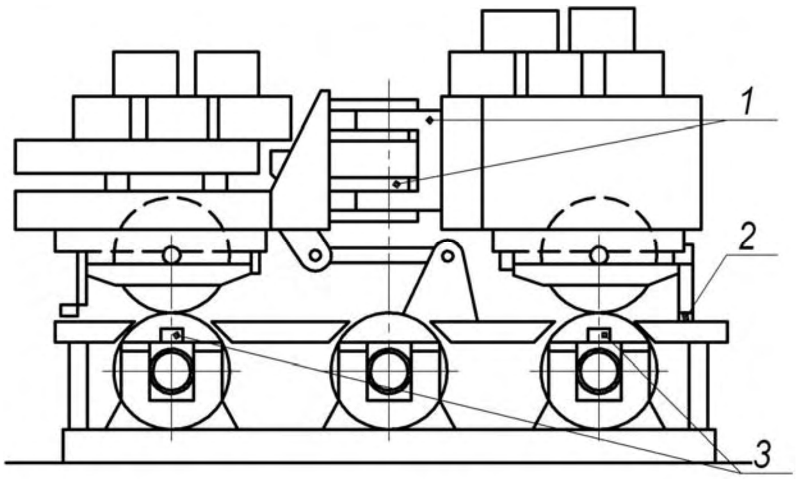

Fig. 3. Scheme of experimental carriage on the rolling bench: 1 – coupling bolt of semi-carriage, 2 – guide device with sensor of efforts, 3 – sensor of the lateral displacement

The possibility of determination the wheel attack angle on the rail has been grounded by the acoustic emission method, which was estimated by means of the experimental research.

Experimental research was conducted at the model rolling station (Fig. 3), experimental bench and diesel locomotive 2TE116.

It has been experimentally proved that the spectrum of acoustic emission is not equal, on some frequencies the level of the sound pressure exceeds the equivalent level of the sound pressure considerably.

The results of program processing of acoustic emission from a wheel-rail contact are presented on Fig. 4.

According to the experimental research data, an informative feature has been discovered on the basis of acoustic emission from a wheel-rail contact, and experimental dependence of the sound pressure level deviation has been obtained on the dominant frequency from the equivalent level of sound pressure at different wheel attack angle on the rail.

In the range of frequencies from 200 to 300 Hertzs, there is a maximal deviation of sound pressure level from the equivalent level of sound pressure. By the size of a maximal deviation from the equivalent level of sound pressure on the indicated frequencies, it is possible to measure the wheel attack angle on the rail.

The functional dependence of sound pressure level from the attack angle on the dominant frequency of acoustic emission (AE) has been used for determination the wheel attack angle on the rail when forming the controlling effect of hydrocylinder on the wheel pair of locomotive when moving on the curve section of the track.

The determination of dominant frequency of AE from a a wheel-rail contact has been executed by means of the algorithm signal processing using wavelet-transformation with the use of wavelet-

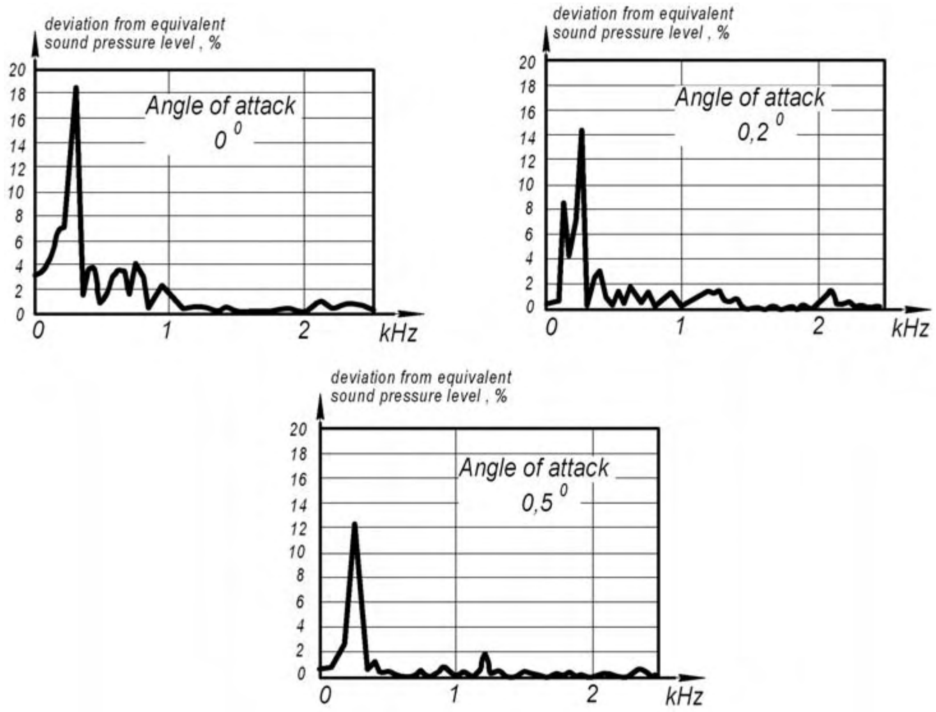

Fig. 4. Spectral analysis of acoustic emission from a wheel-rail contact at the speed of 15 m/s and different wheel attack angles on the rail

function $W_f(t,a)$ for the different moments of time t. From the statistical data of sound pressure level depending on the wheel attack angle on the rail, has been executed neuro-fuzzy adaptation on the basis of which a set of rules and a surface for determination of the wheel attack angle on the rail has been obtained [5].

To get the digital sequence, the wavelet-transformation using the wavelet-function $W_f(t,a)$ for the different moments of time t has been done [29].

Wavelet -transformation:

$$W_f(t,a) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} \Psi\left(\frac{x-t}{a}\right) \cdot f(x)dx, \quad (1)$$

where: $f(x)$ – is the research signal
$\Psi(x)$ – it is a wavelet-function,

$$\Psi(x) = (\cos x + i \cdot \sin x) \cdot e^{-\frac{x^2}{50}},$$

where: t – is the time
a – is a scale of wavelet-function.

A frequency spectrum is obtained by means of processing the acoustic emission signals according to the Furie algorithm of rapid transformation.

The determination of direction on the curve section of the track seems reasonable by sharing the satellite navigation and inertial system.

Joint processing of the calculated coordinates has been carried out by the synchronization of signals from a satellite receiver and inertial block. The increase of exactness has been provided due to the suppression of errors in the each system [24].

The scheme of complexion joint work of the satellite receiver and inertial block has been presented on Fig. 5.

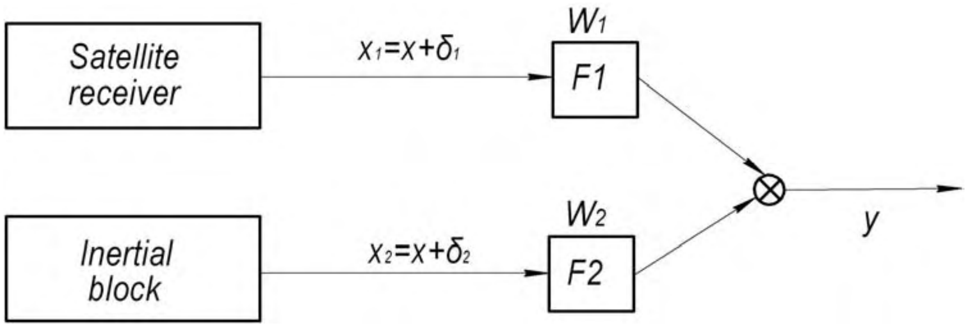

Fig. 5. Structural scheme of complexion: y – is a coordinate of the locomotive site, W1, W2 – are transmission functions of filters, F1, F2 – are filters, x1, x2 – is a representation of useful signal of x(t), ε1 and ε2 – is a representation of satellite receiver and inertial block errors

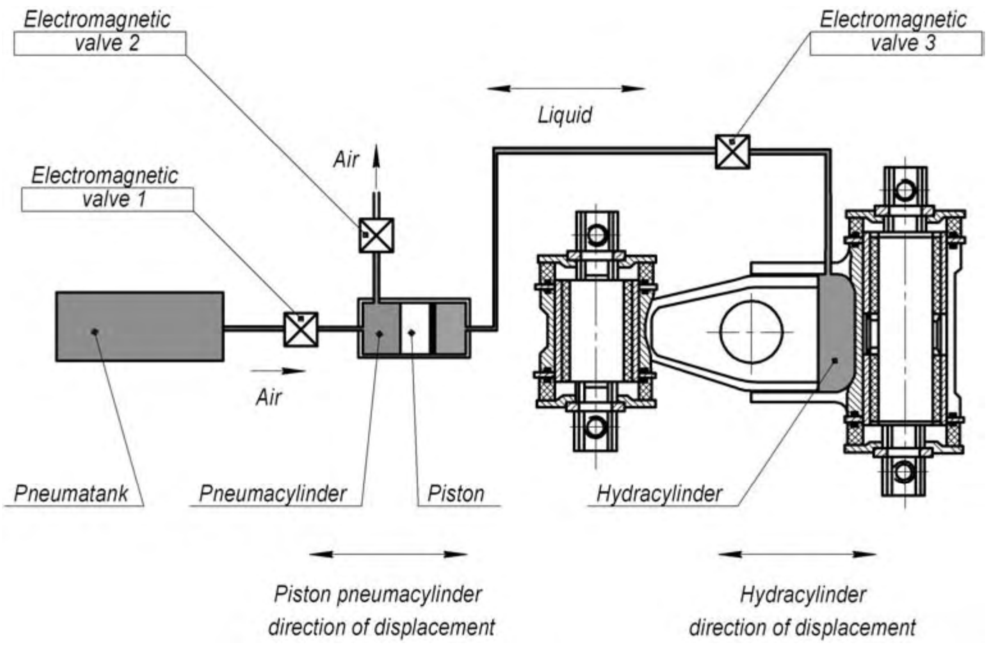

Fig. 6. Regulated length leash

$$y = (W1+W2)x + W1\varepsilon1 + W2\varepsilon2, \quad (2)$$

$$\varepsilon1(t) = b + m\cdot\sin(nt), \quad (3)$$

where: b – is a permanent part (constructive error),

m – is an amplitude of dynamic error,

m·sin(nt) – is a high-frequency constituent of error (dynamic error), n – is angular frequency of vibrations,

t – is the time

$$\varepsilon2(t) = r\cdot t. \quad (4)$$

where: r – is the average speed of inertial block drift.

Principle scheme of the executive device is shown on Fig. 6.

Hydrocylinders are set on the utmost wheel pair of the bogie.

Structural scheme of the closed loop automatic control system with the position of the wheel pair in the rail track is presented on Fig. 7.

Transmission function of the closed loop system of $W_L(p)$:

$$W_3(p) = \frac{a_1 p + 1}{a_3 p^3 + a_2 p^2 + a_1 p + 1} \quad (5)$$

where: $a_3 = \dfrac{T_1 T^2}{k_2 k_3 k_5}$, $a_2 = \dfrac{2\xi T_1 T}{k_2 k_3 k_5}$,

$$a_1 = \frac{k_4}{k_3},\ T = \sqrt{\frac{J}{c}},\ \xi = \frac{b}{2\cdot c},\ k_5 = \frac{M_H - M_C}{c}.$$

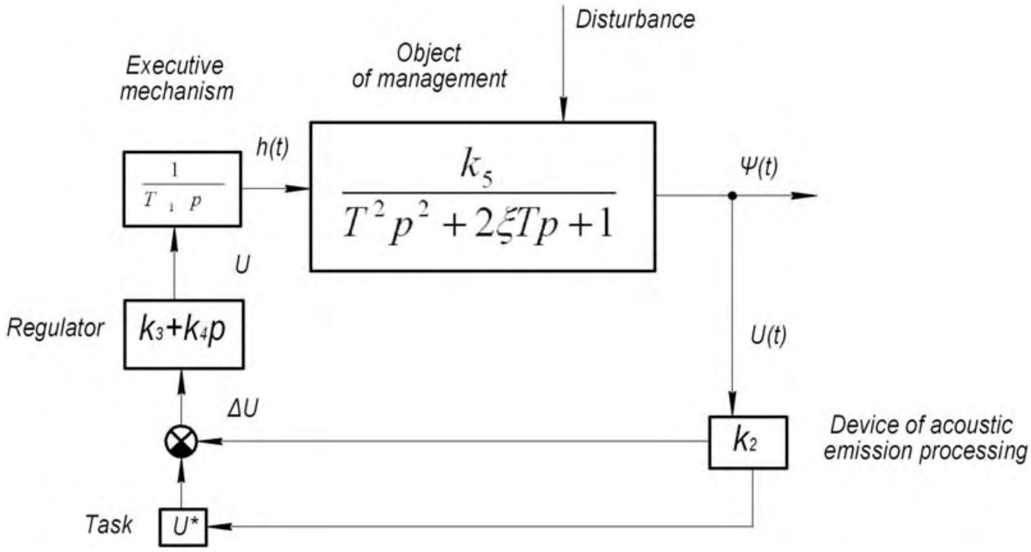

Fig. 7. Structural scheme of closed loop automatic control system of a position of wheel pair in rail track

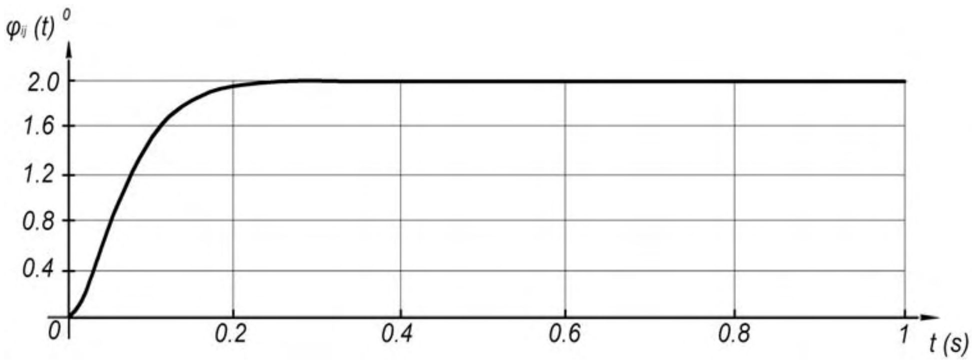

Fig. 8. Graph of transitional process of ACS when having the controlling effect

J – is a moment of inertia of the wheel pair, c, b – elastic and dissipative constituent of the spring suspension, M_C – is a friction forces moment at the turn of the wheel pair, M_H – is a moment of external loading, k_2 – is a sensor transmission ratio, k_3, k_4 – is a regulator transmission ratio.

RESULTS OF RESEARCH

With the parameters of the system: $T = 0{,}96$ with, $T_1 = 0{,}02$ with $k_2 = 2$, $k_3 = 5$, $k_4 = 4$, $k_5 = 2{,}7$, $\xi = 0{,}1$, a transitional function has been shown on Fig. 8. The analysis of the graph of transitional process shows that ACS is stable, transitional process has aperiodical character, the time of transitional process does not exceed 0,36 seconds [28].

The usage of the of automatic control system with the position of the locomotive wheel pair in a horizontal plane keeps the set attack angle of the wheel pair on the rail when moving on the curve sections of the track.

It has been experimentally proved that ACS provides the needed quality of regulation.

The attack angle of the wheel pair as to the bogie frame is determined by the differential equation [28]:

$$a_3 \frac{d^3\varphi_{ij}}{dt^3} + a_2 \frac{d^2\varphi_{ij}}{dt^2} + a_1 \frac{d\varphi_{ij}}{dt} + \varphi_{ij} = = a_1 \frac{dM(t)}{dt} + M(t) \qquad (6)$$

where: M(t) is a difference of moment of friction forces during turning of the wheelepair and moment of the external loading, φ_{ij} – is a angle attack of the wheel pair.

A model contains twenty one nonlinear differential equation with changeable ratios which are determined on every step of the integration.

The mathematical model of the mechanical system of the improved locomotive bogie design has been executed on the diesel locomotive sample 2TE116, in the program package of Matlab/Simulink.

The developed simulation model of carriage motion allows to conduct the research of dynamics when moving on the track with random curves. The verification of authenticity of the results obtained and the research of dynamic processes has been executed both at controlled and non-controlled locomotive motion in the curve section of the track.

Theoretical research of the motion on the diesel locomotive sample 2TE116 in the curve section of the track has been executed from the initial data which comply with the parameters of the experiment.

The compared results of the simulated motion of serial diesel locomotive 2TE116 and the improved locomotive with the axial formula of 3o-3o on curve section of the track with the radius of 300 m and at the speed of 70 km/h has been presented on Fig. 9.

The theoretical values of the guiding efforts on the first wheel pair of the improved locomotive at the controlled and non-controlled motion have been shown on Fig. 10.

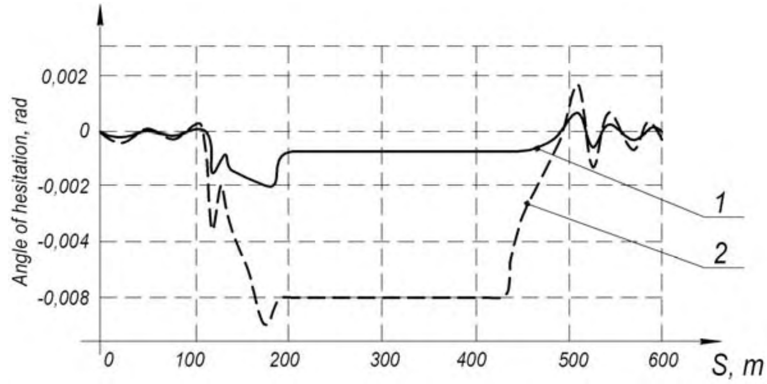

Fig. 9. Theoretical values of the wagging of the first wheel pair of diesel locomotive at controlled and non-controlled passing of the improved locomotive on the curve section of the track: 1 –controlled motion, 2 – non-controlled motion

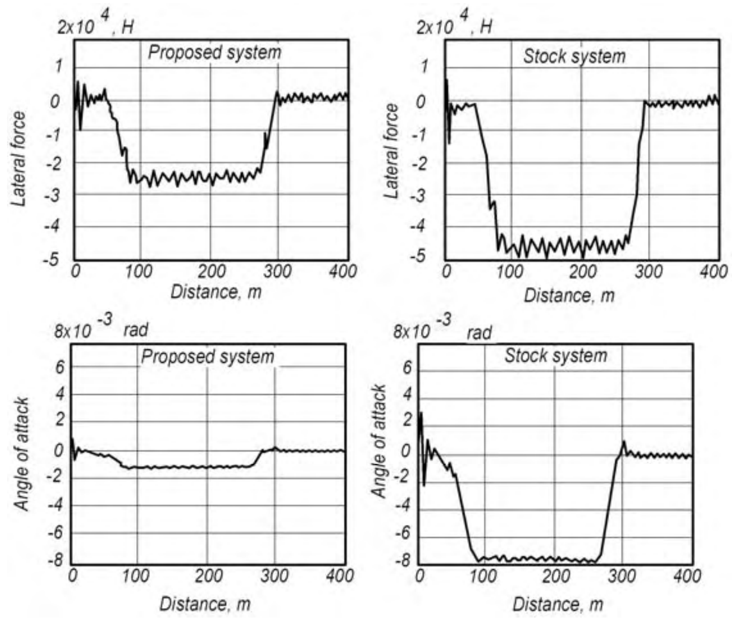

Fig. 10. Compared modeling results of carriage motion of serial locomotive 2TE116 and locomotive with the improved carriage

The fourth section represents the software and hardware choice that has been executed to realize ACS with a position of the wheel pair in the rail track, calculation of economic efficiency from applying the improved design of the locomotive carriage by means of the complemented system of the automatic control with a position of the wheel pair in rail track [22, 20, 23].

The realization of ACS with a position of the locomotive wheel pair is carried out on the diesel locomotive sample 2TE116 by a controlling computer which works in the real-time mode on the basis of the real-time operating system QNX. The control over the electromagnetic valve of EV210B has been carried out by the automatic system of pressure regulation [20, 23].

The developed microprocessor block of control is connected to the unified microprocessor control system and diagnostics through interface RS485.

The improved bogie design and automatic control system with a position of the wheel pair in the rail track has got a patent.

The application of the improved locomotive bogie design with the complemented automatic control system with a position of the wheel pair in the rail track allows to reduce:

- attack angle of the leading wheel pair in the curve by radius of 300 and 600 m accordingly in 7,5 and 3,5 times,
- level of force interaction on the track in the curve sections less than 400 m in 2-3 times,
- wear of the wheel flange band in 4,5 times,
- wear of the bands on the rolling circle up to 60%.

The net discounted income from the implantation of the system of radial wheel pair setting has made 154,5 thousand UAH per diesel locomotive, the expenses payback period is 4,2 years.

CONCLUSIONS

1. The analysis of the question showed that the dynamic properties of the carriage in a horizontal plane and the lateral wear of the wheel flange and the head of the rail depended on the wheel attack angle on the rail, state of the carriage part of a locomotive, on which it is possible to influence effectively by means of the rational choice of locomotives design.
2. It has been shown that the perspective direction when solving how to reduce the level of force interaction of wheel is the usage of rational designs of the locomotive carriage part complemented by the system of active control over the turn of the wheel pair in a horizontal plane.
3. It has been experimentally proved that ACS with a position of the wheel pair in the rail track is steady and provides the necessary quality of regulation at aperiodic character of the transitional process, which does not exceed 0,3 seconds.
4. It has been found by experimental research that the determination of the wheel attack angle on the rail is possible when using the acoustic emission method, the research of which shows that in the spectrum of acoustic emission from the contact interaction of wheel with a rail there is a range of frequencies, which is an informative indication, that allows to use it for control of wheel attack angle on the rail. An informative indication is a maximal deviation of the sound pressure level from the equivalent sound pressure level in the range of frequencies from 200 to 300 Hertzs, on the magnitude of which it is possible to measure the wheel attack angle on the rail.
5. The application of the improved design of the locomotive carriage complemented by the ACS with a position of the wheel pair in a horizontal plane, allows:

- to reduce the level of force interaction in the curve sections of the track less than 400 m in 2-3 times,
- to increase the durability of the exploited rolling stock,
- to remove the skewness of the wheel pair in the locomotive bogie when moving it in straight sections of the track.

REFERENCES

1. **Bruni S., Goodall R., Mei T., Tsunashima H., 2007.:** Control and monitoring for railway vehicle dynamics, Vehicle System Dynamics, Ed. №45, 733-779.
2. **Choi J.J., Park S.H., Kim J.S., 2007.:** Dynamic adhesion model and adaptive sliding mode brake control system for the railway rolling stocks, Proc. IMechE Part F: J. Rail and Rapid Transit, Vol. 221, 313-320.
3. **Golubenko A., 1999.:** Monograph, Tripping of wheel with a rail, Ed. 2, 476. (in Russian).
4. **Golubenko A., Kostyukevich A., Tsyganovskiy I., Nozhenko V., 2011.:** The influence of a rail lateral bending on the stress – strain state of a wheel – rail contact, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 11a, 78-84.
5. **Golubenko A., Malohatko A., Klyuyev S., Klyuyev. A., 2011.:** The application review on the rolling stock of devices for turn of wheel pairs in the horizontal plane, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 11a, 5-12.
6. **Goodall R., Bruni S., Mei T., 2006.:** Concepts and prospects for actively-controlled railway running gear, Vehicle System Dynamics, 44 (suppl), 60-70.
7. **Gus'kova M., Ruban V., 2000.:** Parameters are constructions of mobile composition and way, influencing on podrez of combs of bracers of wheelpairs of locomotives // Bulletin of Rostov State Transport University, Ed. №2, 32-35. (in Russian).
8. **Illingworth R., Pollard M.G., 1982.:** The use of steering axel suspensions to reduce wheel and rail wear in curves, Institutions of Mechanical Engineers Proceeding, 379-385.
9. **Kirichenko I., Kashura A., Kashura M., 2008.:** Design of process of friction of rolling with sliding, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 8a, 63-71.
10. **Kogan A., 1990.:** Estimation of wear of rails and bracers of wheelpairs at motion of mobile composition in the curved areas of way, Ed.№2, 36 – 40. (in Russian).
11. **Klyuyev S., Klyuyev A., 2009.:** Methods of active bogie management, Bulletin of the East Ukrainian National Dahl University, Ed. №4 (134) Part 1, 67-74. (in Russian).
12. **Kossov V., 2001.:** Decline of loadness of workings parts of locomotives and way. Thesis on doctor degree. Kolomna, 339. (in Russian).
13. **Kramar' N., Golubenko A., Tkachenko V., Gorbunov N., Mihajlov E., Kudla P, Osenin Y., Chernenko V., 1983.:** Patent, A device for determination of position of wheelpair is in claotype track. (in Russian).
14. **Lysjuk, 1997.:** Reasons and mechanism of tails of wheel from a rail. Problem of wear of wheels and rails, 188. (in Russian).
15. **Mei T., Li H., 2008.:** Control design for the active stabilization of rail wheelsets, Journal of Dynamics Systems, Measurements and Control, Vol.130, Article number 011002.
16. **N'juland D., 1969.:** Dirigibility of pliable railway bogie on the curvilinear area of way, Constructing and technology of engineer, Ed. №3, 365-375. (in Russian).
17. **Percev A., 1998.:** About reasons of wears of wheels and rails, Railway transport, Ed. №12, 13 – 31. (in Russian).
18. **Scheffel H., Tornay H., 1988.:** The mechanism of the rotable lemniscate suspension applied to bogies having selfsteering wheelsets, Vehicle System Dynamics, Ed. №17, 368-380.
19. **Shtek M., Niks M., Rozenkranc J., 1986.:** Requirement to geometrical exactness of workings parts of railway mobile composition and technician of its measuring, Works of MIIT.- Ed. 773, 35-40. (in Russian).
20. **Spiryagin M., Spiryagin V., Klyuyev S., 2007.:** The choice of where to build a model of vehicle control system, Bulletin of the East Ukrainian National Dahl University, Ed. №12(118), 203-208. (in Ukrainian).
21. **Spiryagin M., Spiryagin V., Kostenko I., 2011.:** Modelling of a controlled tractive wheelset for a bogie of a railway vehicle based on noise spectrum analysis, TEKA Commission of Motorization and Power Industry in Agriculture, Vol. 11a, 232-244.
22. **Spiryagin M., Spiryagin V., Kostenko I., Klyuyev S., 2008.:** Collaboration traction control systems and radial setting of the wheel pair of the rail vehicle, Bulletin of the East Ukrainian National Dahl University, Ed №5 (123), 68-75. (in Russian).
23. **Spiryagin M., Spiryagin V., Spiryagin K., Klyuyev S., 2008.:** Data base analysis for creation the vehicle control system, Bulletin of the East Ukrainian National Dahl University, Ed. №4 (122), 238-243.
24. **Spiryagin V., Klyuyev S., Zubar' E., 2013.:** Locomotive coordinate identification method selection for wheelpair movement control in rail track, Bulletin of the East Ukrainian National Dahl University, Ed. №5(194) Part 2, 144-146. (in Russian).
25. **Tepljakov A., 2004.:** Ways of decline of intensity of wear of combs of wheelpairs of locomotives, Thesis on candidate’s degree 05.22.07, Habarovsk, 197. (in Russian).
26. **Vasin V., Berezin V., Kokorev A., Nadeljuev V., 1990.:** Efficiency of the radial setting of wheelpairs of six axis locomotive, Problems of locomotive building development, 26. (in Russian).
27. **Verigo M.F., 1992.:** Reasons of growth of intensity of lateral wear of rails and combs of wheels:

Brochure of VNTO of railroaders and transport builders, 46. (in Russian).
28. **Ulshin V., Klyuyev S., 2012.:** The development and research of the automatic control system of the locomotive wheel pair position, Bulletin of the East Ukrainian National Dahl University, Ed. №3 (174) Part 2, 169-175. (in Russian).
29. **Ulshin V., Klyuyev S., Zybar E., 2013.:** Method of the automatic control of the wheel attack angle on the rail, Bulletin of the East Ukrainian National Dahl University, Ed. №4(193), 259-262. (in Russian).

СНИЖЕНИЕ УРОВНЯ СИЛОВОГО ВЗАИМОДЕЙСТВИЯ КОЛЕС С РЕЛЬСАМИ АВТОМАТИЧЕСКИМ УПРАВЛЕНИЕМ ПОЛОЖЕНИЕМ КОЛЕСНЫХ ПАР ЛОКОМОТИВА

Виталий Ульшин, Сергей Клюев

Аннотация. Работа посвящена вопросу снижению уровня силового взаимодействия колеса с рельсом при движении локомотива на криволинейных участках пути автоматическим управлением положением колесных пар локомотива на основе акустического метода определения угла набегания колеса на рельс и навигационной системы определения направления закругления.

Выбран и исследован акустический метод контроля угла набегания колеса на рельс.

Усовершенствована конструкция тележки локомотива и разработана математическая модель движения локомотива с усовершенствованной конструкцией тележки локомотива с регулируемым поводком с осевой формулой 3о-3о, с учетом динамики САУ положением колесных пар в горизонтальной плоскости.

Разработана система автоматического управления положением колесных пар в прямолинейных и криволинейных участках пути.

Проведены теоретические исследования и выполнено сравнение с экспериментальными значениями динамических процессов, возникающих в механической части локомотива серийного исполнения и усовершенствованной конструкции тележки локомотива с управлением и без при прохождении криволинейных участков пути.

Ключевые слова. локомотив, угол набегания, система автоматического управления, акустическая эмиссия, силовое взаимодействие.

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Speeds of movement of the point of gearing along contact lines in screw gear globoid cylindrical tooth gearing

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S u m m a r y . The mathematical model of speeds of movement of points of gearing along contact lines in a screw gear globoid cylindrical tooth gearing is stated in this article. Mathematical dependences for absolute and relative speeds of movement of points of gearing on contact lines on heads and legs of teeth of the leader and conducted wheels are received. Mathematical dependences for corners between vectors of speeds and the main coordinate lines are also received in the article.
K e y w o r d s . Tooth gearing, globoid cylindrical, screw.

INTRODUCTION

In drives of modern cars the screw tooth gearings, allowing to create a rational design of transmission gears find application, to improve smoothness of their work and to lower noise and dynamic characteristics.
Increase of load ability of tooth gearings, including screw, is an actual task.

RESERCH ANALYSIS

Screw tooth gearings with evolvent gearing [2, 4, 5, 9, 13,] have dot contact and the increased slidings in the gearing, limiting application of these transfers. In work [22] it is shown that localization of a spot of contact also have dot contact and the increased sliding. In works [8, 14, 19, 22] it is specified that it is possible to increase load ability of screw tooth gearings synthesis by their screw gearing on the method developed by M.L. Novikov [11] and added in works [12, 15, 16].

The purpose of article is increase of load ability of screw tooth gearings by synthesis of screw globoid cylindrical transfer with screw gearing. In this regard in article the task of development of mathematical model of kinematics of a globoid cylindrical tooth gearing with Novikov's gearing is solved.

RESULTS OF RESEARCH

We will write down the equations of surfaces of teeth on wheels of globoid cylindrical transfer with Novikov's gearing at which the working part of the main tool is outlined by arches of circles (an initial contour of GOST 15023-69). The equations of surfaces of teeth of leading (globoid) and conducted (cylindrical) wheels it is representable in systems of coordinates $O_1X_{11}Y_{11}Z_{11}$ and $O_2X_{22}Y_{22}Z_{22}$ respectively (Fig. 1).

Equations of surfaces of a head of tooth of a leading wheel:

$$\begin{aligned}x_{11} &= (r_1 + R_1\cos\lambda_{11})\sin(\varphi_{11}+\varphi_1) + R_1 \times \\ &\times \cos(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1,\\ y_{11} &= (r_1 + R_1\cos\lambda_{11})\cos(\varphi_{11}+\varphi_1) - R_1 \times \\ &\times \cos(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1,\\ z_{11} &= p\varphi_1 ctg\gamma - R_1\sin\lambda_{11}\sin\gamma,\end{aligned} \quad (1)$$

where: r_1 radius of an initial circle of a globoid.

$$r_1 = r_{10}\left(1 + u - u\cos\varphi_2^*\right).$$

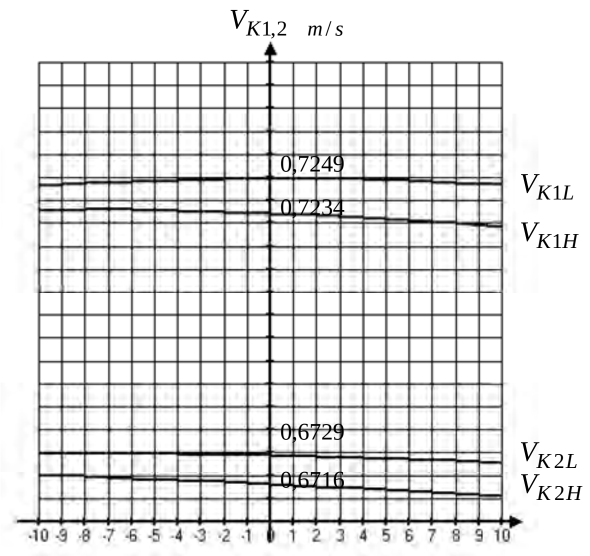

Fig. 1. Absolute speed of movement of a point of gearing along contact lines of a leading (globoid) wheel on heads V_{K1H} and on the legs V_{K1L}, a conducted (cylindrical) wheel on heads V_{K2H} and on legs V_{K2L}

In the same system of coordinates, the equations of a surface of a leg of tooth of a leading wheel has an appearance:

$$\begin{aligned}x_{12} &= (r_1 + R_2\cos\lambda_{12})\sin(\varphi_{11}+\varphi_1-\xi_1) + \\ &+ R_2\cos(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1,\\ y_{12} &= (r_1 + R_2\cos\lambda_{12})\cos(\varphi_{11}+\varphi_1-\xi_1) - \\ &- R_2 cos(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1,\\ z_{12} &= p(\varphi_1 ctg\gamma - \xi_1) - R_2\sin\lambda_{12}\sin\gamma.\end{aligned} \quad (2)$$

The equations of a surface of a head of tooth of a conducted (cylindrical) wheel in system $O_2X_{22}Y_{22}Z_{22}$ it is representable in the following look:

$$\begin{aligned}x_{21} &= (r_2 + R_1\cos\lambda_{21})\sin(\varphi_{22}+\varphi_2) + R_1 \times \\ &\times \cos(\varphi_{22}+\varphi_2)\sin\lambda_{21}\cos\beta_2,\\ y_{21} &= (r_2 + R_1\cos\lambda_{21})\cos(\varphi_{22}+\varphi_2) - R_1 \times \\ &\times \cos(\varphi_{22}+\varphi_2)\sin\lambda_{21}\cos\beta_2,\\ z_{21} &= p\varphi_1 tg\gamma - R_1\sin\lambda_{21}\sin\gamma,\end{aligned} \quad (3)$$

In the same system the equation of surfaces of legs of teeth of a conducted wheel will have an appearance:

$$\begin{aligned}x_{22} &= (r_2 + R_2\cos\lambda_{22})\sin(\varphi_{22}+\varphi_2-\xi_2) + \\ &+ R_2\cos(\varphi_{22}+\varphi_2-\xi_2)\sin\lambda_{22}\cos\beta_2,\\ y_{22} &= (r_2 + R_2\cos\lambda_{22})\cos(\varphi_{22}+\varphi_2-\xi_2) - \\ &- R_2\cos(\varphi_{22}+\varphi_2-\xi_2)\sin\lambda_{22}\cos\beta_2,\\ z_{22} &= p(\varphi_1 tg\gamma - \xi_2) - R_2\sin\lambda_{22}\sin\gamma.\end{aligned} \quad (4)$$

In the equations (1) … (4):

– φ_1 and φ_2 – corners of rotation of the leader and conducted wheels,

– R_1 and R_2 – radiuses of curvature of profiles of heads and legs of teeth respectively,

– γ –a corner of lead of the line of tooth of a globoid wheel to the face plane,

– p – the parameter of the screw of the central screw line,

– $\lambda_{11}, \lambda_{12}, \lambda_{21}, \lambda_{22}$ – independent variables, angles of rotation of radiuses of main circles,

– φ_{11} and φ_{22} – the corners defining the provision of face sections of heads of teeth with the face plane of the leader and conducted wheels,

– β_1 and β_2 – tilt corners of lines of teeth and an axis of rotation,

– ξ_1 and ξ_2 – the corners defining the provision of profiles of legs of teeth concerning profiles of heads of these teeth in the face plane of surfaces of teeth of the leader and conducted wheels respectively.

Systems (1) … (4) are the equations the screw of surfaces with a circle in the section located at a corner γ to the face plane.

Having determined the first private derivatives of the equations (1) … (4) by parameter φ_1 and having increased them by angular speeds of rotation of wheels $w_{1,2}$, we will find projections to mobile axes of coordinates $O_1X_{11}Y_{11}Z_{11}$ and $O_2X_{22}Y_{22}Z_{22}$ speeds of points of gearing at their movement on contact lines of leading globoid and conducted cylindrical wheels. These projections will be equal:

– on heads of teeth of a leading wheel:

$$\begin{aligned}
&V_{X11} = w_1[r_1' \sin(\varphi_{11}+\varphi_1) + \\
&+(r_1+R_1\cos\lambda_{11})\cos(\varphi_{11}+\varphi_1) - \\
&-R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1], \\
&V_{Y11} = w_1[r_1'\cos(\varphi_{11}+\varphi_1) - \\
&-(r_1+R_1\cos\lambda_{11})\sin(\varphi_{11}+\varphi_1) + \\
&+R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1], \\
&V_{Z11} = w_1 p\cdot tg\beta_1,
\end{aligned} \tag{5}$$

– on legs of teeth of a leading wheel:

$$\begin{aligned}
&V_{X12} = w_1[r_1'\sin(\varphi_{11}+\varphi_1-\xi_1) + \\
&+(r_1+R_2\cos\lambda_{12})\cos(\varphi_{11}+\varphi_1-\xi_1) - \\
&-R_2\sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1], \\
&V_{Y12} = w_1[r_1'\cos(\varphi_{11}+\varphi_1-\xi_1) - \\
&(r_1+R_2\cos\lambda_{12})\sin(\varphi_{11}+\varphi_1-\xi_1) + \\
&+R_2\sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1], \\
&V_{Z12} = w_1 p\cdot tg\beta_1,
\end{aligned} \tag{6}$$

– on heads of teeth of a conducted wheel:

$$\begin{aligned}
&V_{X21} = w_2\left[(r_2+R_1\cos\lambda_{21})\cos\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u} - \right. \\
&\left. -R_1\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right], \\
&V_{Y21} = w_2\left[-(r_2+R_1\cos\lambda_{21})\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u} + \right. \\
&\left. +R_1\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right], \\
&V_{Z21} = w_2 p\cdot tg\beta_2,
\end{aligned} \tag{7}$$

– on heads of teeth of a conducted wheel:

$$\begin{aligned}
&V_{X22} = w_2\left[(r_2+R_2\cos\lambda_{22})\cos\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\times \right. \\
&\left. \times\frac{1}{u} - R_2\sin\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right], \\
&V_{Y22} = w_2\left[-(r_2+R_2\cos\lambda_{22})\sin\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\times \right. \\
&\left. \times\frac{1}{u} + R_2\sin\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right], \\
&V_{Z22} = w_2 p\cdot tg\beta_2,
\end{aligned} \tag{8}$$

From expressions (5) … (8), using formulas of communication of coordinates $O_1X_1Y_1Z_1$ and $O_1X_{11}Y_{11}Z_{11}$ for a driving wheel, $O_2X_2Y_2Z_2$ and $O_2X_{22}Y_{22}Z_{22}$ for a conducted wheel, we will define projections of vectors of speeds of points of gearing to motionless axes of coordinates. For a leading globoid wheel we will receive:

– on heads of teeth of a driving wheel:

$$\begin{aligned}
&V_{X1H} = w_1[r_1'\sin(\varphi_{11}+\varphi_1) + \\
&+(r_1+R_1\cos\lambda_{11})\cos(\varphi_{11}+\varphi_1) - \\
&-R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1], \\
&V_{Y1H} = w_1[r_1'\cos(\varphi_{11}+\varphi_1) - \\
&-(r_1+R_1\cos\lambda_{11})\sin(\varphi_{11}+\varphi_1) + \\
&+R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1], \\
&V_{Z1H} = w_1 p\cdot tg\beta_1,
\end{aligned} \tag{9}$$

– on legs of teeth of a leading wheel:

$$\begin{aligned}
&V_{X1L} = w_1[r_1'\sin(\varphi_{11}+\varphi_1-\xi_1) + \\
&+(r_1+R_2\cos\lambda_{12})\cos(\varphi_{11}+\varphi_1-\xi_1) - \\
&-R_2\sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\times \\
&\times\cos\beta_1], \\
&V_{Y1L} = w_1[r_1'\cos(\varphi_{11}+\varphi_1-\xi_1) - \\
&-(r_1+R_2\cos\lambda_{12})(r_1+R_2\cos\lambda_{12}) + \\
&+R_2\sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\times \\
&\times\cos\beta_1], \\
&V_{Z1L} = w_1 p\cdot tg\beta_1,
\end{aligned} \tag{10}$$

– on heads of teeth of a conducted wheel:

$$V_{X2H} = w_2\left[(r_2 + R_1\cos\lambda_{21})\cos\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\times \frac{1}{u} - R_1\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right],$$

$$V_{Y2H} = w_2\left[-(r_2 + R_1\cos\lambda_{21})\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\times \frac{1}{u} + R_1\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right],$$

$$V_{Z2H} = w_2 p \cdot ctg\beta_1, \qquad (11)$$

– heads of teeth of a conducted wheel:

$$V_{X2L} = w_2\left[(r_2 + R_2\cos\lambda_{22})\cos\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\times \frac{1}{u} - R_2\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right],$$

$$V_{Y2L} = w_2\left[-(r_2 + R_2\cos\lambda_{22})\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\times \frac{1}{u} + R_2\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right],$$

$$V_{Z2L} = w_2 p \cdot ctg\beta_1. \qquad (12)$$

Absolute value of speed of movement of a point of gearing along contact lines of a leading (globoid) wheel:

– on heads of teeth:

$$V_{K1H} = \sqrt{V_{X1H}^2 + V_{Y1H}^2 + V_{Z1H}^2} = w_1 \cdot \sqrt{K_{VK1H}}, \qquad (13)$$

where:

$$K_{VK1H} = [r_1'\sin(\varphi_{11} + \varphi_1) + (r_1 + R_1\cos\lambda_{11})\times \cos(\varphi_{11} + \varphi_1) - R_1\sin(\varphi_{11} + \varphi_1)\sin\lambda_{11}\cos\beta_1]^2 + [r_1'\cos(\varphi_{11} + \varphi_1) - (r_1 + R_1\cos\lambda_{11})\sin(\varphi_{11} + \varphi_1) + R_1\sin(\varphi_{11} + \varphi_1)\sin\lambda_{11}\cos\beta_1]^2 + p^2 \cdot tg^2\beta_1,$$

– on legs of teeth:

$$V_{K1L} = \sqrt{V_{X1L}^2 + V_{Y1L}^2 + V_{Z1L}^2} = w_1 \cdot \sqrt{K_{VK1L}}, \qquad (14)$$

where:

$$K_{VK1H} = [r_1'\sin(\varphi_{11} + \varphi_1 - \xi_1) + (r_1 + R_2\cos\lambda_{12})\times \cos(\varphi_{11} + \varphi_1 - \xi_1) - R_2\sin(\varphi_{11} + \varphi_1 - \xi_1)\times \sin\lambda_{12}\cos\beta_1]^2 + [r_1'\cos(\varphi_{11} + \varphi_1 - \xi_1) - + [-(r_1 + R_2\cos\lambda_{12})\sin(\varphi_{11} + \varphi_1 - \xi_1) + R_2\sin(\varphi_{11} + \varphi_1 - \xi_1)\sin\lambda_{12}\cos\beta_1]^2 + p^2 \cdot tg^2\beta_1,$$

– conducted (cylindrical) wheel:

– on heads of teeth:

$$V_{K2H} = \sqrt{V_{X2H}^2 + V_{Y2H}^2 + V_{Z2H}^2} = w_2 \cdot \sqrt{K_{VK2H}}, \qquad (15)$$

where:

$$K_{VK2H} = \left[(r_2 + R_1\cos\lambda_{21})\cos\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\times \frac{1}{u} - R_1\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right]^2 + \left[-(r_2 + R_1\cos\lambda_{21})\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u} + R_1\sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right]^2 + p^2 \cdot tg^2\beta_2,$$

– on legs of teeth:

$$V_{K2L} = \sqrt{V_{X2L}^2 + V_{Y2L}^2 + V_{Z2L}^2} = w_2 \cdot \sqrt{K_{VK2L}}, \qquad (16)$$

where:

$$K_{KV2L} = \left[(r_2 + R_2\cos\lambda_{22})\cos\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u} - R_2\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right]^2 + \left[-(r_2 + R_2\cos\lambda_{22})\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u} + R_2\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right]^2 + p^2 \cdot tg^2\beta_2,$$

where: $r_1' = r_{10} u \sin \varphi_2^*$.

Directing cosines of a vector of speed of movement of a leg of gearing are equal:

− on heads of teeth of a driving wheel:

$$\cos\alpha_{K1H} = \frac{V_{X1H}}{V_{K1H}} = \frac{1}{\sqrt{K_{VK1H}}} \cdot \left[r_1' \sin(\varphi_{11}+\varphi_1) + (r_1 + R_1\cos\lambda_{11})\cos(\varphi_{11}+\varphi_1) - R_1 \sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1\right],$$

$$\cos\beta_{K1H} = \frac{V_{Y1H}}{V_{K1H}} = \frac{1}{\sqrt{K_{VK1H}}} \cdot \left[r_1' \cos(\varphi_{11}+\varphi_1) - (r_1 + R_1\cos\lambda_{11})\sin(\varphi_{11}+\varphi_1) + R_1 \sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1\right],$$

$$\cos\gamma_{K1H} = \frac{V_{Z1H}}{V_{K1H}} = \frac{p \cdot tg\beta_1}{\sqrt{K_{VK1H}}}, \qquad (17)$$

− on legs of teeth of a leading wheel:

$$\cos\alpha_{K1L} = \frac{V_{X1L}}{V_{K1L}} = \frac{1}{\sqrt{K_{VK1L}}} \times \left[r_1' \sin(\varphi_{11}+\varphi_1-\xi_1) + (r_1 + R_2\cos\lambda_{12})\cos(\varphi_{11}+\varphi_1-\xi_1) - R_2 \sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1\right],$$

$$\cos\beta_{K1L} = \frac{V_{Y1L}}{V_{K1L}} = \frac{1}{\sqrt{K_{VK1L}}} \times \left[r_1' \cos(\varphi_{11}+\varphi_1-\xi_1) - (r_1 + R_2\cos\lambda_{12})\sin(\varphi_{11}+\varphi_1-\xi_1) + R_2 \sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1\right], \qquad (18)$$

$$\cos\gamma_{K1L} = \frac{V_{Z1L}}{V_{K1L}} = \frac{p \cdot tg\beta_1}{\sqrt{K_{VK1L}}},$$

− on heads of teeth of a conducted wheel:

$$\cos\alpha_{K2H} = \frac{V_{X2H}}{V_{K2H}} = \frac{1}{\sqrt{K_{VK2H}}} \cdot \left[(r_2 + R_1\cos\lambda_{21}) \times \cos\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u} - R_1 \sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right],$$

$$\cos\beta_{K2H} = \frac{V_{Y2H}}{V_{K2H}} = \frac{1}{\sqrt{K_{VK2H}}} \times \left[-(r_2 + R_1\cos\lambda_{21}) \times \sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u} + R_1 \sin\left(\varphi_{22} + \frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21} \times \cos\beta_2\right],$$

$$\cos\gamma_{K2H} = \frac{V_{Z2H}}{V_{K2H}} = \frac{p \cdot ctg\beta_1}{\sqrt{K_{VK2H}}}, \qquad (19)$$

− on legs of tooth of a conducted wheel:

$$\cos\alpha_{K2L} = \frac{V_{X2L}}{V_{K2L}} = \frac{1}{\sqrt{K_{VK2L}}} \times \left[(r_2 + R_2\cos\lambda_{22})\cos\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u} - R_2 \sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right],$$

$$\cos\beta_{K2L} = \frac{V_{Y2L}}{V_{K2L}} = \frac{1}{\sqrt{K_{VK2L}}} \times \left[-(r_2 + R_2\cos\lambda_{22})\sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u} + R_2 \sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right], \qquad (20)$$

$$\cos\gamma_{K2L} = \frac{V_{Z2L}}{V_{K2L}} = \frac{p \cdot ctg\beta_1}{\sqrt{K_{VK2L}}}.$$

The relative speed of movement of the contact points located on contact lines of heads and legs of teeth of the leader and conducted wheels we will determine as a vector difference of speeds of movement of points of gearing along contact lines of the leader and conducted wheels:

− on heads of teeth of the leader and legs of teeth of the conducted:

$$V_{XS1} = V_{X1H} - V_{X2L} = K_{VXS1}, \qquad (21)$$

where:

$$K_{VXS1} = w_1\left[r_1' \sin(\varphi_{11}+\varphi_1) + (r_1 + R_1\cos\lambda_{11}) \times \cos(\varphi_{11}+\varphi_1) - R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1\right] - w_2\left[(r_2 + R_2\cos\lambda_{22})\cos\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u} - R_2 \sin\left(\varphi_{22} + \frac{\varphi_1}{u} - \xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right],$$

$$V_{YS1}=V_{Y1H}-V_{Y2L}=K_{VYS1}, \quad (22)$$

where:

$$K_{VYS1}=w_1\left[r_1'\cos(\varphi_{11}+\varphi_1)-(r_1+R_1\cos\lambda_{11})\times\right.$$
$$\left.\times\sin(\varphi_{11}+\varphi_1)+R_1\sin(\varphi_{11}+\varphi_1)\sin\lambda_{11}\cos\beta_1\right]-$$
$$-w_2\left[-(r_2+R_2\cos\lambda_{22})\sin\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\frac{1}{u}+\right.$$
$$\left.+R_2\sin\left(\varphi_{22}+\frac{\varphi_1}{u}-\xi_1\right)\frac{1}{u}\sin\lambda_{22}\cos\beta_2\right],$$

$$V_{ZS1}=V_{Z1H}-V_{Z2L}=K_{VZS1}, \quad (23)$$

where:

$$K_{VZS1}=p(w_1tg\beta_1-w_2tg\beta_2),$$

– on legs of teeth of a leading wheel and heads of teeth of the conducted:

$$V_{XS2}=V_{X1L}-V_{X2H}=K_{VXS2}, \quad (24)$$

where:

$$K_{VXS2}=w_1\left[r_1'\sin(\varphi_{11}+\varphi_1-\xi_1)+\right.$$
$$+(r_1+R_2\cos\lambda_{12})\cos(\varphi_{11}+\varphi_1-\xi_1)-R_2\times$$
$$\left.\times\sin(\varphi_{11}+\varphi_1-\xi_1)\cdot\sin\lambda_{12}\cos\beta_1\right]-$$
$$-w_2\left[(r_2+R_1\cos\lambda_{21})\cos\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}-\right.$$
$$\left.-R_1\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right].$$

$$V_{YS2}=V_{Y1L}-V_{Y2H}=K_{VYS2}, \quad (25)$$

where:

$$K_{VYS2}=w_1\left[r_1'\cos(\varphi_{11}+\varphi_1-\xi_1)-\cdot\right.$$
$$-(r_1+R_2\cos\lambda_{12})\sin(\varphi_{11}+\varphi_1-\xi_1)+$$
$$\left.+R_2\sin(\varphi_{11}+\varphi_1-\xi_1)\sin\lambda_{12}\cos\beta_1\right]-$$
$$-w_2\left[-(r_2+R_1\cos\lambda_{21})\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}+\right.$$
$$\left.+R_1\sin\left(\varphi_{22}+\frac{\varphi_1}{u}\right)\frac{1}{u}\sin\lambda_{21}\cos\beta_2\right],$$

$$V_{ZS2}=V_{Z1L}-V_{Z2H}=K_{VZS2}, \quad (26)$$

where:

$$K_{VZS1}=p(w_1tg\beta_1-w_2tg\beta_2).$$

The absolute value of relative speed of movement of a point of gearing will be equal:

– on heads of teeth of a leading wheel and legs of teeth of a conducted wheel:

$$V_{S1}=\sqrt{V_{XS1}^2+V_{YS1}^2+V_{ZS1}^2}=$$
$$=\sqrt{K_{VXS1}^2+K_{VYS1}^2+K_{VZS1}^2}, \quad (26)$$

– on legs of teeth of a leading wheel and heads of teeth of a conducted wheel:

$$V_{S2}=\sqrt{V_{XS2}^2+V_{YS2}^2+V_{ZS2}^2}=$$
$$=\sqrt{K_{VXS2}^2+K_{VYS2}^2+K_{VZS2}^2}, \quad (27)$$

Arrangements of vectors of speeds of points of gearing on a head and on a leg of a tooth in globoid cylindrical transfer at their movement along contact lines are defined by directing cosines of a vector of relative speed of movement of a point of gearing.

For heads of teeth of the leading and legs of teeth conducted wheels we will receive:

$$\cos\alpha_{S1}=\frac{V_{XS1}}{V_{S1}}=\frac{K_{VXS1}}{\sqrt{K_{VXS1}^2+K_{VYS1}^2+K_{VZS1}^2}},$$
$$\cos\beta_{S1}=\frac{V_{YS1}}{V_{S1}}=\frac{K_{VYS1}}{\sqrt{K_{VXS1}^2+K_{VYS1}^2+K_{VZS1}^2}}, \quad (28)$$
$$\cos\gamma_{S1}=\frac{V_{ZS1}}{V_{S1}}=\frac{K_{VZS1}}{\sqrt{K_{VXS1}^2+K_{VYS1}^2+K_{VZS1}^2}}.$$

For legs of teeth of the leading and heads of teeth conducted wheels we will receive:

$$\cos\alpha_{S2}=\frac{V_{XS2}}{V_{S2}}=\frac{K_{VXS2}}{\sqrt{K_{VXS2}^2+K_{VYS2}^2+K_{VZS2}^2}},$$
$$\cos\beta_{S2}=\frac{V_{YS2}}{V_{S2}}=\frac{K_{VYS2}}{\sqrt{K_{VXS2}^2+K_{VYS2}^2+K_{VZS2}^2}}, \quad (29)$$

$$\cos\gamma_{S2} = \frac{V_{ZS2}}{V_{S2}} = \frac{K_{VZS2}}{\sqrt{K_{VXS2}^2 + K_{VYS2}^2 + K_{VZS2}^2}}.$$

From Fig. 2 follows that the size of absolute speed of relative movement of points of gearing of screw tooth globoid cylindrical gearing a variable and changes from the maximum value on the average the section of a globoid wheel to minimum on both sides from this section for 0,28%.

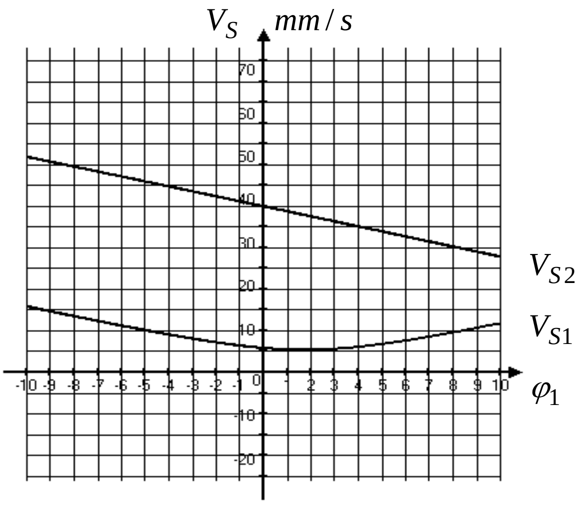

Fig. 2. The absolute value of relative speed of movement of a point of gearing of the leader V_{S1} and conducted V_{S2} wheels

CONCLUSIONS

The received mathematical dependences allowed to establish:

1. It is established that The absolute and relative speeds of movement of points of contact of teeth in a screw globoid cylindrical tooth gearing variables and which sizes change for 0,28% during removal from the plane of average (throat) section of a globoid wheel.

2. It is established that the difference of absolute speeds of movement of points of contact on a leg and a head of a leading (globoid) cogwheel makes 1,5%.

REFERENCES

1. **Egorov K.A., 1975.:** Researches on increase of load ability of screw tooth gearings. Avtoref. cand. techn. siences. Vladivostok. – 25. (in Russian).
2. **Gavrilenko V.A., 1962.:** Tooth gearings in mechanical engineering. Mashgiz. –Moscow. – 570. (in Russian).
3. **Gavrilenko V.A., Osipova S.D., 1969.:** Determination of optimum parameters of initial surfaces of wheels of evolvent hyperboloid transfers. / News of higher education institutions. Mechanical engineering, No. 1. – 5-11. (in Russian).
4. **Gribanov V.M., Gribanova Yu.V., Ratov D.V., Korobka N.V., 2011.:** About quasihyperboloid teeth transfers of Novikov. Visnik the Kharkov State Polytechnical University. Kharkov. No. 28. – 39-44. (in Russian).
5. **Korostelev L.V., 1964.:** Evolvent screw gear with a linear contact of teeth.// News higher education institutions. Mechanical engineering, No. 6. – 5-17. (in Russian).
6. **Korostelev L.V., 1964.:** Kinematic indicators of bearing ability of spatial gearings.// News higher education institutions. Mechanical engineering, No. 10. – 515. (in Russian).
7. **Krylov N.N., 1962.:** Globoid gearing with dot contact. / Tooth gearings with Novikov's gearing. VVIA of N.E. Zhukovsky, Moscow. No. 4. (in Russian).
8. **Liburkin A.Ya., Trubnyakov V.A., 1974.:** Increase of load ability screw gear.// Tooth and worm gears. Some questions of kinematics, dynamics, calculation and production. Mechanical engineering. Leningrad office. Leningrad. – 210-214. (in Russian).
9. **Litvin F.L., 1978.:** Theory of gear gearings. – M.: Science, – 584. (in Russian).
10. **Medintseva Yu.V., Balitskaya T.Yu., Ratov D.V., Korobka N.V., Pecholat T.E., 2008.:** About a contact on two points in tooth quasihyperboloid gearings of Novikov // Visnik East Ukrainian national University. Lugansk, No. 3 (121). – 293-298. (in Russian).
11. **Novikov M. L., 1958.:** Tooth gearings with new gearing. – M.: VVIA publishing house of N. E. of Zhukovsky. – 186. (in Russian).
12. **Pavlenko A.V., Fedyakin R.V., Chesnokov V.A., 1978.:** Tooth gearings with Novikov's gearing. Equipment, Kiev. – 144. (in Russian).
13. **Pavlov A.M., Trubnyakov V.A., 1972.:** Geometry and load ability of cogwheels of the hyperboloid transfer cut by a conic mill.// News of higher education institutions. Mechanical engineering, No. 7. – 46-50. (in Russian).
14. **Schultz V.V., 1963.:** Geometry and load ability of cylindrical screw wheels. – Diss. cand. techn. sciences. Leningrad. – 188. (in Russian).
15. **Sevryuk V.N., Ututov N.L., 1975.:** Some general properties screw of surfaces// The theory of mechanisms and cars. No. 19. Higher school, Kharkov: – 107-115. (in Russian).
16. **Sevryuk V.N., Ututov N.L., 1976.:** Kinematic dependences in not round cylindrical the screw

transfers// The theory of mechanisms and cars. No. 20. Higher school, Kharkov. – 141-150. (in Russian).
17. **Shishov V., 2010.:** Geometrical and kinematic criteria of arched transmissions within initial contours shift./ V. Shishov, P. Nosko, O. Revyakina, A. Muhovaty, P. Fil // TEKA Com. Mot. I Energ. Roin. – XC. – 286-293.
18. **Shishov V., 2010.:** Teeth geometry of arched transmissions within initial contours shift./ V. Shishov, P. Nosko, O. Revyakina, A. Muhovaty, A. Karpov // TEKA Com. Mot. I Energ. Roin. – XC. – 277-288.
19. **Shishov V.P., Tretiak A.E., Velichko N.I., 1978.:** To research of quality indicators of the cylindrical hyperboloid transfers, cut the shaping cutter./ Questions of design and research of mechanisms and machine guns. – Novocherkassk. – 48-55. (in Russian).
20. **Ututov N.L., Korobka N.V., 2012.:** Equations of surfaces of teeth of a globoid cylindrical tooth gearing of Novikov// Visnik the Kharkov State Polytechnical University. Kharkov. No. 35. 169-173. (in Russian).
21. **Ututov N.L., Korobka N.V., Bayun V.N., 2012.:** Screw lines and their key parameters on the aksoid of a globoid cylindrical tooth gearing// Scientific news of «University. Dahl's». No. 5. (in Russian).
22. **Velichko N.I., 1984.:** Synthesis of globoid screw gears with the localized spot of contact of teeth. Master's thesis. –Voroshilovgrad. – 202. (in Russian).
23. **Zablonsky K.I., Subbochev I.M., Popov N.L., Konigeberg A.V., 1973.:** Wear and durability globoid of transfers. News higher education institutions. Mechanical engineering, No. 10, – 46-50. (in Russian).
24. **Zak P.S., 1962.:** Globoid transfer. Mashgiz, Moscow. – 256. (in Russian).

СКОРОСТИ ДВИЖЕНИЯ ТОЧКИ ЗАЦЕПЛЕНИЯ ВДОЛЬ КОНТАКТНЫХ ЛИНИЙ В КРУГОВИНТОВОЙ ЗУБЧАТОЙ ГЛОБОИДНО-ЦИЛИНДРИЧЕСКОЙ ПЕРЕДАЧЕ

Николай Утутов, Наталья Плясуля

Аннотация. В статье изложена математическая модель скоростей движения точек зацепления вдоль контактных линий в круговинтовой глобоидно-цилиндрической зубчатой передаче. Получены математические зависимости для обсалютных и относительных скоростей движения точек зацепления по контактным линиям на головках и ножках зубьев ведущего и ведомого колес. Также получены математические зависимости для углов между векторами скоростей и основными координатными линиями.

Ключевые слова: зубчатая передача, глобоидно-цилиндрическая, круговинтовая.

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Rational design of rotor of the asynchronous motor fan for cooling units of diesel locomotives

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Summary. A comparative analysis of the design and performance of asynchronous motor fans (AMF) on the results of experimental studies of samples on the test bench. Determined rational variant for new locomotives, the frequency of which is regulated by varying the voltage on the stator winding. Identified strengths and weaknesses of rational option.

Key words: asynchronous motor fans, percentage slip, rotor design, speed control.

INTRODUCTION

Energy properties of diesel may be improved by reducing the unused directly to the traction energy consumption in auxiliary units of the locomotive. This task is important because of the relative increase in energy costs with an increase in these sectional power locomotives. For modern high-power locomotives amount of costs to drive auxiliary devices reaches 12% efficient diesel power, and the locomotive cooling devices consume up to 75% of the power consumed by the drive auxiliary devices.

One of the actual tasks in locomotive engineering is to create a system of continuous fan speed control for diesel engines, which reduces energy costs for cooling the diesel locomotive, improves thermal regulation of diesel [9, 11, 15, 16], therefore, increases the reliability of the locomotive in operation. Therefore the search for the best option for cost-effectiveness of the system of continuous thermal regulation of locomotive diesel engine [2, 10, 18, 13, 26] and the rational design of controlled asynchronous motor-fan (AMF) is very important.

The use of diesel locomotives inverted asynchronous squirrel-cage motors built into the axial fan – fan motor has reduced the weight of the fan drive for 1000 ... 2000 kg. [7] The advantage of the drive is reliability, long life, easy maintenance.

Electric fan drive on alternating current is widely used in foreign locomotives type FP-9, SD-35, SD-38, SD-45, DD-40A, DD-35, GT-16, GT-26CW (diesel power from 1470 to 4850 kW) produced by General Motors (USA) on diesel locomotives type "Kestrel" company Brush (UK) in locomotives CC2400, SS2700 firm Alstom (France) in locomotives Swedish firm Nokhab [4, 19].

A characteristic feature of the motor-fan is their low efficiency in the regulation of the relay. AMF used to power the auxiliary alternators power the locomotive. In locomotives with electric transmission AC-DC power supply for use as the main AMF traction synchronous generators [10], which provides a significant reduction in weight of the drive. In locomotives equipped with systems of electric heating of passenger cars, to power the AMF using synchronous generators heating train (locomotive TEP150).

Locomotives type 2TE116 are exploited in Ukraine and other post-Soviet Unions countries with the group asynchronous electric fan relay. Currently, it is the main diesel locomotive in Ukraine and other post-Soviet Unions countries.

Fan drive cooling device for diesel locomotive 2TE116 by four AMF rated at 24 kW (with a diameter of blades of 1100 mm, with a speed of 1960 rev / min), which are powered by the traction of the synchronous generator.

Apply the dual-circuit cooling diesel engine (cooling water and oil cooling). Each circuit is cooled by two motor-fan relay staggered way (mode short S3-S4).

A characteristic feature of the fans is the increased power consumption, their low efficiency with periodic on-off switch.. It is advisable to apply the regulation of the air flow continuous variation of speed fan motor (operating mode S6). From the graph in Fig. 1 that the total energy consumption when using the continuous fan control (curve 1) is lower than in the ladder step. Figures do not take into account losses in the drive.

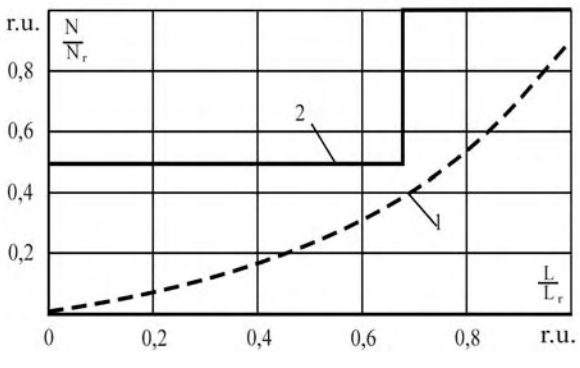

Fig. 1. Changing the shaft power of fans with continuous air flow (1) and two-stage (2) regulation $\left(L_n = 45.6\, m/c\ ,\ N_n = 112\ kW \right)$

Fig. 2 shows the modes AMF temperature heat transfer fluids and diesel locomotives 2TE116 depending on the outside temperature with the real hysteresis temperature sensors T35. In zones 1 and 1′ MF2 (water) and MF4 (oil) work in relay mode, MF1 and MF3 disabled. In zones 2 and 2′ MF2 and MF4 operated permanently. In zones 3 and 3′ are connected MF1 and MF3 running in the relay mode. In zones 4 and 4′ MF operated permanently. The dashed lines show the range of the temperature of the coolant-static error of automatic temperature control system (ATCS) taking into account the thermal inertia of the cooling unit and the diesel. Consequently, the total static uneven ATCS a change of more than 10°C.

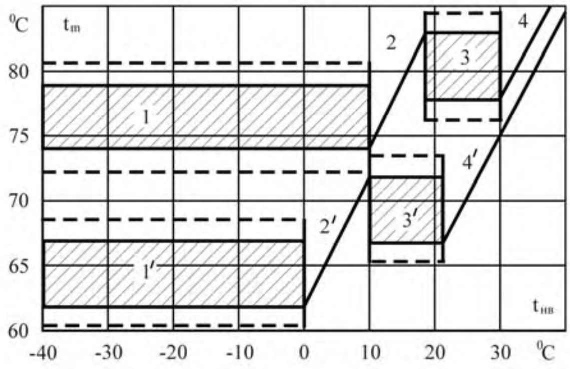

Fig. 2. Modes of motor fans on the locomotive 2TE116

Fig. 3 shows the experimental graphs of temperature of the cooling water outlet (1) and the inlet (2) diesel locomotive 2TE116 for continuous ATCS. Curve 3 is speed AMF. Tests were conducted on the rheostat in $t = +4...7\,°C$, the regulation is carried out automatically by one AMF.

From Fig. 3 it follows that when the relay ATCS diesel have been major fluctuations in water temperature, which reduces the efficiency and reliability of diesel due to thermal fluctuations, relay mode is accompanied by heavy starting AMF with frequent switch on-of (curve 3, Fig. 3), which reduces the reliability and efficiency of the drive. Smooth regulation of fan speed to cool the diesel engine is the most preferred.

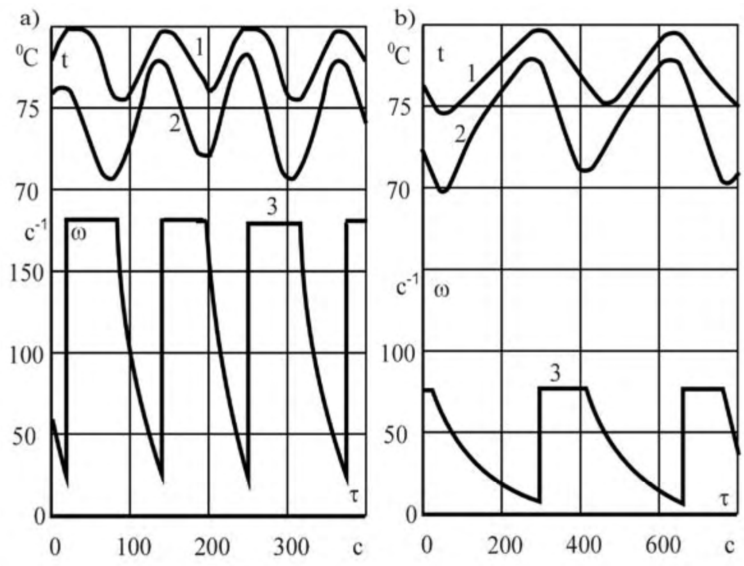

Fig. 3. Stationary processes as standard relay ATCS diesel locomotive 2TE116 at 100% (a) and 10% (b) loads

According to the PAO "LuganskTeplovoz" the results of performance tests 2TE116 locomotive number 521 in truck traffic in areas Ilovaiskaya-Volnovaha-Kamush-Zariy-Bologi Donetsk railway for 68 hours of recording to identify any significant changes in the intensity of the modes as diesel and motor-fan operating in relay mode. Over 68 hours of registration of the locomotive to operate the average number of starts per hour AMF was: № 1 - 38, № 2 - 11, № 3 - 8, № 4 - 13.

Continuous speed control of induction motor fan by varying the voltage on the stator winding can be done by using phase control thyristor voltage converter [8, 21]. The converter has six power thyristors included pairwise opposite in every phase asynchronous motor fan. By changing the angle of thyristors regulate the voltage on the stator winding, hence the speed of AMF.

Speed control by varying slip when slip power is released in form of heat in the circuit of rotor windings, accompanied by a significant decrease in efficiency At sufficiently large losses in the rotor slides predominate over other losses in the motor and efficiency determined by:

$$\eta = \frac{P_{mec}}{P_1} \approx \frac{P_{em} - s \cdot P_{e\text{м}}}{P_{em}} = 1 - s, \qquad (1)$$

where: P_{mec}, $P_{e\text{м}}$, P_1 - mechanical, electromagnetic and power consumption of induction motor, respectively.

Mechanical characteristics of the induction motor when the voltage change as shown in Fig. 4 (curves 1, 2, 3). If you change the maximum torque is proportional to the square of the voltage and the critical speed remains the same (the line in Fig. 2). With decreasing point changes stable operation of the "induction motor-fan" and changes the frequency of rotation (see Fig. 4 points a, b).

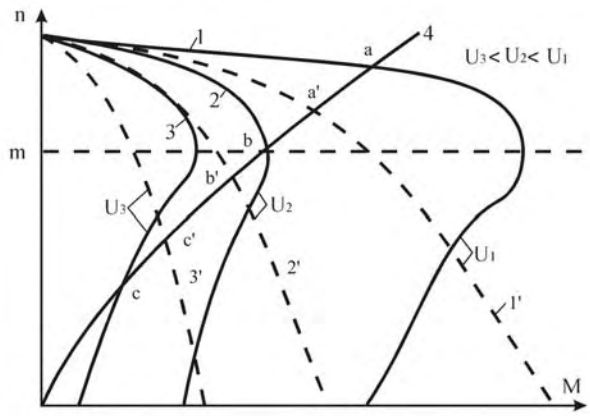

Fig. 4. The mechanical characteristics of the asynchronous motor-fan: 1-3 – serial AMF with the rotor winding alloy AK12M4, -1'-3' – regulated AMF with increased resistance of the rotor winding, 4 – fan characteristic

To expand the limits of regulation - the ratio of maximum to minimum speed $n_{\max} / n_{\min}$ you have a soft mechanical characteristics of the motor. At the same time expanding the limits of regulation (see Fig. 4, points a', b', c').

The fan load torque is proportional to the frequency of rotation of the second degree. The condition of equilibrium points for AMF:

$$M_{em} = M_n \left(\frac{n}{n_n} \right)^2 + M_o, \tag{2}$$

where: M_{em} – the electromagnetic torque of induction motor,

M_n – AMF shaft torque at nominal frequency,

n, n_n – the current and the rated speed value,

M_0 – the initial point of friction in the bearings of AMF.

The value of slip is determined by:

$$s = \frac{n_1 - n}{n_1} = \frac{\omega_1 - \omega}{\omega_1}, \tag{3}$$

where: ω_1 - the synchronous speed, rad/s, $\omega = 2\pi \cdot n$ - rotational speed of the rotor.

Shaft power of AMF

$$P_2 = M_{em} \cdot \omega. \tag{4}$$

Electromagnetic power transmitted from the stator to the rotor

$$P_{em} = M_{em} \cdot \omega_1. \tag{5}$$

The difference of power $p_p = P_{em} - P_2$ is released as heat in the circuit of rotor windings. Consequently, losses in the rotor can be:

$$p_p = M_{em}(\omega_1 - \omega) = M_{em} \cdot s \cdot \omega_1 = P_{em} \cdot s. \tag{6}$$

Part of the electromagnetic power $P_2 = P_{em}(1 - s)$ is transmitted to the rotor shaft. From the expressions (5) and (6) that the rotor losses increase is proportional to the slip, which is not economical in constant torque load and requires operating at low speeds using motors with high power reserve.

When the fan load, the expression (6), taking into account the equations (2) and (3) becomes:

$$p_p = \left[M_n \left(\frac{1-s}{1-s_n} \right)^2 + M_o \right] \cdot s \cdot \omega_1, \tag{7}$$

where: s_n – the nominal slip,

M_0 – initially torque at $s = 1$.

From (7) it follows that when the fan load compared to the load with constant torque at equal values of slip losses in the rotor is much less. Electromagnetic torque is determined by:

$$M_{em} = \frac{p \cdot m_1}{\omega_1} (I_2')^2 \cdot \frac{r_2'}{s}, \tag{8}$$

where: p – number of pole pairs,

m_1 – the number of phases of the stator winding,

I_2' – reduced secondary current (rotor current),

r_2' – the reduced resistance of the rotor to the stator winding.

According to equation (8):

$$M_{em} \equiv (I_2')^2 \cdot \frac{r_2'}{s}. \tag{9}$$

At steady state $M_{em} = M_c$. For the fan load, ignoring the point of friction and additional losses $M_c \equiv \omega^2$, accept it. From (9) with (3), neglecting the magnetizing current, we get:

$$I_1 \equiv I_2' \equiv (1 - s)\sqrt{s / r_2'}. \tag{10}$$

From the expression (10) that the stator winding current I_1 is inversely proportional to $\sqrt{r_2'}$. After differentiating expression (10) and equating it to zero, we obtain that the current has a maximum value when sliding $s = 0.33$.

Thus, for obtaining satisfactory operation modes of induction motor with a fan torque load applied to the shaft motors with increased rotor resistance, moreover, to inflate induction motor power to provide normal heating mode by sliding the rotor $s = 0.33$.

On diesel locomotives, which are produced in Ukraine for cooling heat-transfer agent uses asynchronous motor fans (AMF) inverted design with a short-circuited rotor winding "squirrel cage" [3] (Fig. 5).

AMF consists of a stator 1, which is rigidly connected to the base via the sleeve 2, which carries the support bearings 3, the shaft 4 connected to the rotor through the shield 5. The rotor consists of a fan wheel with blades 6 and 7, laminated package 8, which is filled with "squirrel cage" (rotor winding) 9 with aluminum alloy AK12M4. Rated power AMF – 24 kW, the frequency of the network, which feeds the AMF in the locomotive of 100 Hz, the phase voltage– 230V. Synchronous speed 2000 r/min. In the cooler diesel locomotive has four AMF – two: into the cooling water and oil cooling circuit. Each of AMF operates in intermittent mode, the number of starts is up to 38 per hour. This mode of operation AMF does not provide sufficient reliability of the drive fans to use and the quality of temperature control heat transfer fluids (water and oil) diesel locomotive, as well as the increased cost of power required to drive the fans.

There are three ways a more cost-effective continuous control of temperature change of locomotive diesel engine air flow through the radiator cooling device:

1) the regulation of the angle of the blades AMF [22],

2) speed control AMF frequency change of voltage on the stator winding [1, 20],

3) speed control AMF change of the supply voltage to the stator windings [5, 24, 25].

In the newly developed shunting and freight locomotives AMF supplied with an auxiliary synchronous generator, the power of which is commensurate with the power of asynchronous drive fans (150-200 kW).

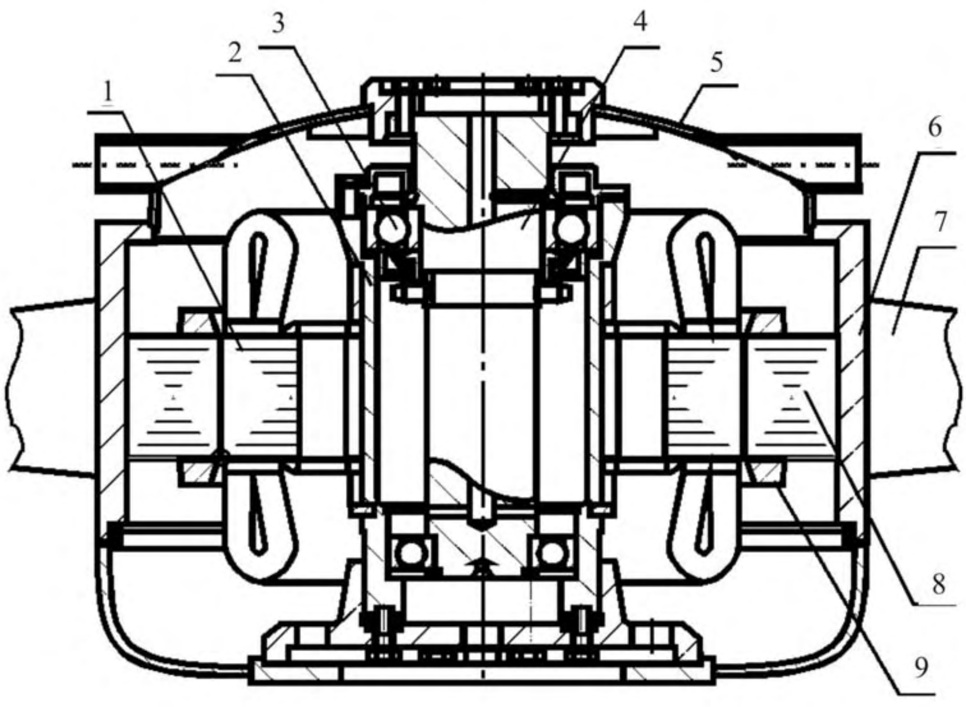

Fig. 5. The design of the serial asynchronous motor-fan for relay and frequency control

Comparative analysis of the average operating cost ways to regulate temperature diesel determined that continuous processes in 3.7-5.8 times more economical then relay method. The difference in annual fuel savings of the locomotive for continuous processes does not exceed 0.6% of the average working hours of the locomotive, so the type of drive is infinitely variable is determined largely by cost and design factors than the economy of operation that justifies the advantage of the method of regulation by varying the voltage on the stator winding AMF (change of the output voltage of the synchronous generator by changing the excitation current of the thermostat) as the most simple, cheap and reliable.

OBJECT OF RESEARCH

Object of research is asynchronous motor-fan installed on cooling units of diesel locomotives which is regulated by varying the voltage on the stator winding.

PURPOSE OF RESEARCH

The purpose of research was to determine rational variant for new locomotives. Identified strengths and weaknesses of rational option.

RESULTS OF RESEARCH

Rational embodiment of the motor-fan speed control by varying the voltage on the stator winding determined experimentally on the bench. Short-changed the design of the rotor winding 9. A laminated package of the rotor 8 by slidably inserted into fan wheel 6, which are welded to the blade 7. The tests were conducted at the same temperature in the test bench, where AMF installed to preserve the identity of the aerodynamic characteristics of the fan. Thus, the net power an asynchronous motor in bench testing of various designs of rotors was the same.

The stator of the motor-fan has the following structural data: the phase winding resistance is 0.069 ohms at t=115 ^{0}C, the number of turns of the winding phases is 60, random-wound coil of soft sections, the active length – 0.12 m, pole pitch – 0.18 m, outer diameter – 0.344 m, internal diameter – 0.164 m, the number of pole pairs – 3, backrest height of the yoke – 0.046 m, tooth height – 0.045 m, the number of slots – 72, the groove half-closed, tooth width – 0.00845 m, electrical steel – 2411. The length of the stator pack – 0.12 m outside diameter of the rotor package 0.46 m, internal – 0.346 m. Number of rotor slots – 56. The air gap between stator and rotor – 1 mm.

We investigated the following options for the design of the rotor.

Variant 1. The rotor is wound with aluminum alloy AK12M4 with an electrical resistivity of $\rho = 0.0952 \cdot 10^{-6}$ ohm·m at 115ºC. The cross section of the rotor slots to fill rod coil is shown in Fig. 6. The number of slots in the rotor – 56. Cross-section of a shorting ring coil is shown in Fig. 7.

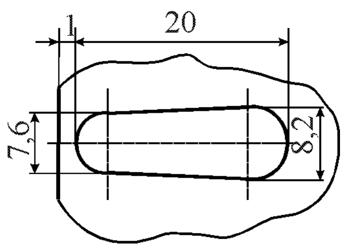

Fig. 6. AMF rotor slot

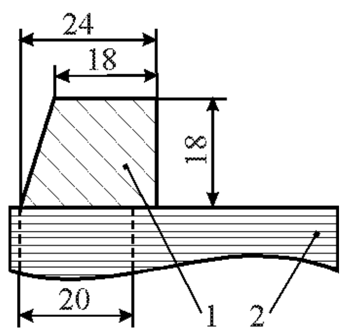

Fig. 7. Cross-section of a shorting ring rotor windings for series AMF: 1 – short-circuiting ring, 2 – package a laminated rotor

Variant 2. Rotor winding containing copper rods (copper M1 $\rho = 0.025 \cdot 10^{-6}$

Ohm·m at a temperature of 115ºC) and ferromagnetic short-circuiting ring of steel St. 3 ($\rho = 0.172 \cdot 10^{-6}$ Ohm·m at 115ºC). Scheme for construction of the rotor winding rods and ferromagnetic rings of steel shown in Fig. 8 (coil rolled on the plane).

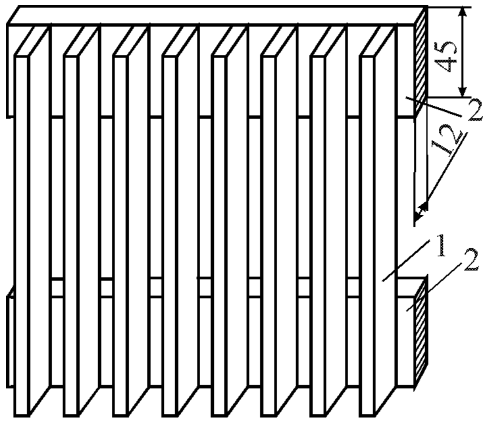

Fig. 8. Construction rotor winding deployed on plane 1 – copper rods 2 – short-circuiting ring of steel St. 3

Shape and dimensions of the rotor slot shown in Fig. 9. The package was made of the rotor pilot series of slots by melting the aluminum alloy in an electric furnace. Then slots serial AMF (Fig. 9) inserted rods 1 made of copper sheet mark M1, 4 mm thick (two in slot) to which are soldered brass ring of ferromagnetic steel St. 3 0.012×0.045 m section as the flux applied bit. In the manufacture of the rotor winding slots were involved in 28 (z_2 = 28) of the 56 series (through the slot rods were absent).

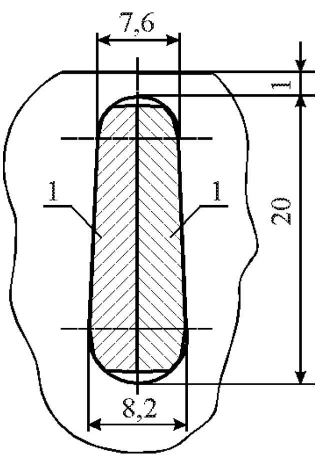

Fig. 9. The cross section slot of the rotor with copper rods: 1 – copper rods

Variant 3. Rotor winding containing brass rods (manganese brass L96 $\rho = 0.118 \cdot 10^{-6}$ Ohm·m at 115ºC, number of rods z_2=42) and ferromagnetic short-circuiting ring of steel St. 3.

Variant 4. The two-layer rotor (Fig. 10), which is a winding plug 1 of the special ferromagnetic alloy thickness b=10 mm, compacted in a laminated rotor 2 package of electrical steel 2411. Bush has one frontal outreach 3 length of 50 mm of the same alloy to reduce the equivalent resistance of the rotor winding. The alloy contains in % copper Cu – 18.7, carbon C – 0.06, manganese Mn – 0.91, silicon – 0.28, P – 0.054, sulfur S – 0.017, chromium Cr – 0.06, nickel Ni – 0.25, aluminum Al – 0.21, iron Fe – the rest [23].

Variant 5. The two-layer rotor [14, 12] (Fig. 10) with the sleeve 1 steel St. 3. Thickness 3 mm, b = 8. Sleeve has one frontal outreach 3 length of 50 mm.

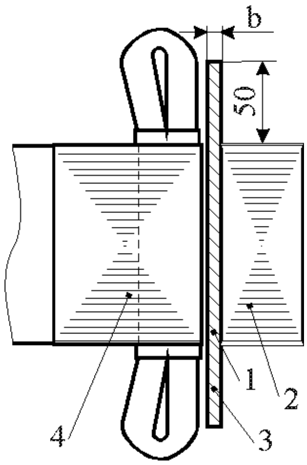

Fig. 10. Scheme for construction of a two-layer rotor AMF: 1 – ferromagnetic sleeve, 2 – package a laminated rotor, 3 – frontal outreach of sleeve material, 4 – stator

Variant 6. The two-layer rotor (Fig. 11), the coil which is one of the ferromagnetic sleeve steel St. 3, 8 mm thick, pressed in a laminated rotor package 2 of electrical steel in 2411. By the sleeve 1 soldered copper brass ring 3 to reduce the resistance of the rotor winding.

At the beginning of the test net power induction motor in the motor-fan determined to "squirrel cage" (winding rotor 9, Fig. 5) aluminum alloy AK12M4 with an electrical resistivity $\rho = 0.0952 \cdot 10^{-6}$ Ohm·m at a temperature of 115ºC. Fulfilling experience idling (no blades 7). We determined the stator iron losses and mechanical losses for rated power mode with frequency 100 Hz, and a phase voltage 230 V. Experiments were also conducted at idle power for other frequencies below 100 Hz.

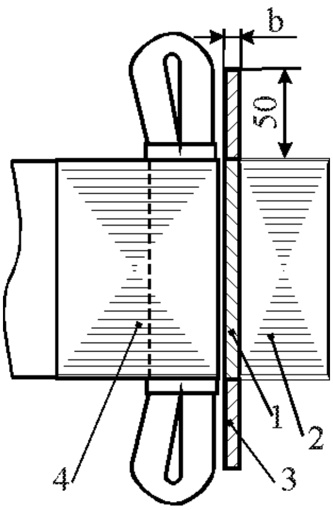

Fig. 11. Scheme for construction of a two-layer AMF rotor and copper frontal outreaches: 1 – ferromagnetic sleeve of steel St. 3, 2 – a laminated rotor package, 3 – ring of copper M1 (frontal outreach), 4 – stator

The shape of the voltage – sinusoidal. The maximum voltage for these experiments was set proportional to the square of the frequency of the current. Next to the fan wheel 6 (Fig. 5) were welded blades 7 at an angle of 18 degrees, and the stand was carried out under a load of experience at the same frequencies and the current values of the maximum stress that the experiments and idling. The method of separation of losses to determine the relation of the net power of the fan wheel speed.

Measuring instruments used in class 0.5. The maximum error in the determination of net power does not exceed 0.5% of the active power supplied to AMF, as additional losses in the AMF to be equal to 0.5% of the input power to the AMF according to GOST 183-74 "Rotating electrical machinery. General specifications" (experimentally determine them was not possible). Thus the experimental characteristics (efficiency, cosφ) motor fan with a different rotor design were determined using the same net power AMF depending on the speed.

Table shows the results of experimental studies of AMF in the nominal mode. Fig. 12 shows the results of experimental investigations of options rotors number 1 – № 3 in the regulation of sinusoidal voltage, from which it follows: AMF with squirrel-cage rotor alloy AK12M4 not controlled by varying the voltage on the stator winding (at U <100 V – "tipped") with AMF copper rods (z_2 = 28) and the steel ring is not good enough in regulating energy characteristics (maximum current value I_{max} in regulating a half times the nominal value I_n) with AMF rotor winding of a brass rod (z_2 = 42) and rings of steel St. 3 has a good leveling properties ($I_{max} = 1.25 I_{max}$).

Table. The results of experimental studies of AMF in nominal mode (supply frequency – 100 Hz, phase voltage – 230 V)

The embodiment of the rotor	Active power consumption, kW	The power factor, cosφ	Efficiency, %	Slip of the motor, %	Useful power, kW
№1	27.0	0.74	90.0	1.44	24.4
№2	26.4	0.65	88.0	3.1	23.4
№3	27.0	0.64	86.0	5.0	23.2
№4	26.6	0.73	87.6	4.6	23.3
№5	26.1	0.67	85.0	6.7	22.2
№6	26.1	0.73	88.5	3.5	23.1

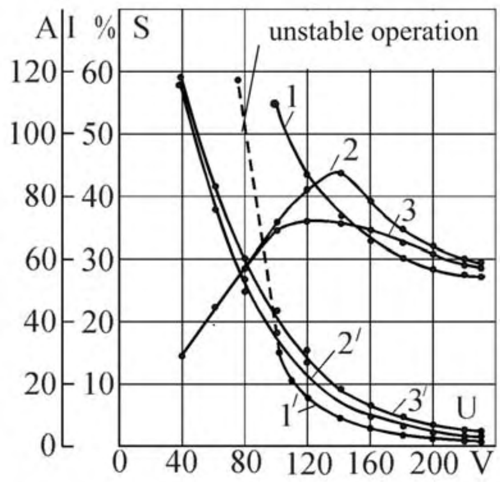

Fig. 12. Dependence consumed current I (1-3) of rotor and slip s (1'-3') AMF supply voltage at various squirrel cage construction: 1 – rotor embodiment 1, 2 – № 2, 3 – № 3

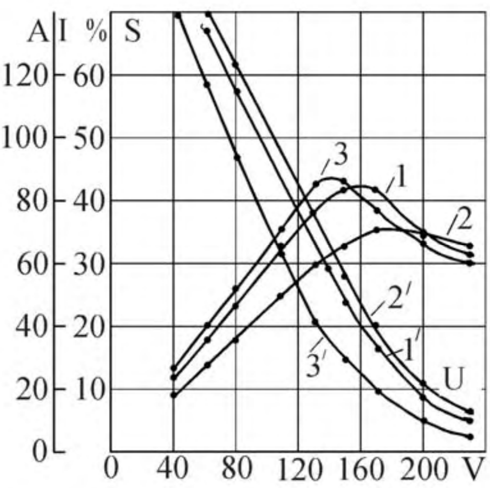

Fig. 13. Dependence consumed current I (1-3) of rotor and slip s (1'-3') AMF supply voltage for different rotor-layer ferromagnetic sleeves 1 – embodiment number of the rotor 4, 2 – № 5, 3 – № 6

CONCLUSIONS

1. From the design of the rotor compared (Table, Fig. 12-13) that the most rational choices are: squirrel cage rotor with brass rods and ferromagnetic short-circuiting rings of steel St. 3 (variant 3) and double-layer rotor-magnetic alloy (variant 4). At acceptable nominal characteristics (efficiency 86.0-87.6%, cosφ 0.64-0.73) motor fans have good regulation properties, with a maximum current of the stator in the regulation of 1.25-1.3 of the rated value.

2. However, variants number 3 and number 4 are significant shortcomings in series production. Variant number 3 requires a manual and labor-intensive technology soldered brass rods to steel rings – for AMV 24 kW with the number of poles $2p=6$, the number of solder joints is $2z_2=84$ for AMF power of 65-75 kW with the number of poles $2p=8-10$ number of solder joints is $2z_2=168-216$. For option number 4 to cast a special low-magnetic alloy. In fact - it is a solid solution [19].

3. For the manufacturing application to the series locomotives are also needed additional vibration testing of solder joints and low-magnetic alloy in order to determine the mechanical characteristics of the winding under severe operating conditions, AMF operation - by vibrations during rotation of the rotor windings in single-bearing rotor blades (see Fig. 5), which summed up with the vibration of the body of the locomotive diesel engine is running, and dynamic accelerations during the motion of the locomotive.

REFERENCES

1. **Bulgakov A., 1966.:** Frequency controlled induction motors. Moscow, Energiya, 462. (in Russian).
2. **Dzetcina O., Fedorchenko V., 2011.:** On the issue of energy efficiency of industrial locomotives. TEKA Commission of Motorization and Power Industry in Agriculture, Vol. XI A, 69-77.
3. **Filonov S., Gibalov A., Bykovskii V., 1985.:** Diesel locomotive 2TE116. Moscow, Transport, 328. (in Russian).
4. **General Motors., 1988.:** Locomotive SD60. Service manual 121S885, 248.
5. **Gerich S., 1991.:** Combined thermal control system of locomotive diesel engine with phase control motor-fan: diss. ... Candidate Techn. Science. Lugansk, 246. (in Russian).
6. **Gervais G., 1984.:** Industrial testing of electrical machines. Moscow, Energiya, 346. (in Russian).
7. **Khramenkov S., Heifetz L., 1971.:** Investigation of the system electric fans for locomotive TE109. Trudy VNITI. Kolomna, Vup. 35, 72-81. (in Russian).
8. **Kolesnychenko S., 2000.:** Improving the efficiency improvement of electro-diesel

locomotives smooth combined cooling heat transfer related powerplant: diss. ... Candidate Techn. Science. Lugansk, 203. (in Russian).
9. **Konyaev A., 1972.:** The research traction properties and high efficiency diesel sectional capacity to improve them: diss. ... Doct. Techn. Science. Moscow, 542. (in Russian).
10. **Kulikov Yu., 1977.:** Complex research and selection of cooling devices of large sectional power locomotives: diss. ... Doct. Techn. Science. Moscow, 495. (in Russian).
11. **Kulikov Yu., 1988.:** Cooling systems of power units of locomotives. Moscow, Mashinostroenie, 280. (in Russian).
12. **Kutsevalov V.M., 1979.:** Asynchronous and synchronous machines with massive rotors. Moscow, Energiya, 212.
13. **Kuzmich V., 1978.:** Improving the cooling systems of traction electric machines for locomotives: diss. ... Doct. Techn. Science. Moscow, 540. (in Russian).
14. **Lischenko A., Lesnik V., 1984.:** Asynchronous machine with a massive ferromagnetic rotor. Kyiv. Naukova dumka, 168. (in Russian).
15. **Lukov N., 1978.:** Theoretical foundations and development systems for controlling the temperature of heat transfer power units of locomotives: diss. ... Doct. Techn. Science. Moscow, 520. (in Russian).
16. **Lukov N., 1995.:** Automatic temperature control of motors. Moscow, Mashinostroenie, 271. (in Russian).
17. **Lukov N., Khutoryansky N., Gursky N., 1976.:** Determination amount of energy to the drive fan refrigerator in discrete and continuous regulation of its productivity. Trudy MIIT. Moscow, Transport, Vup. 83, 31-44. (in Russian).
18. **Mohyla V., Sklifus Y., 2010.:** The prospects of increasing the effectiveness of the cooling device of a diesel locomotive. TEKA Commission of Motorization and Power Industry in Agriculture, Vol. X C, 198-203.
19. **Nesterov E., 1987.:** News of foreign locomotive building. Overview. Moscow, CNII TEITYAZHMASH, 120. (in Russian).
20. **Novikov V., 1987.:** Increased efficiency regulated electric fan for cooling unit of diesel locomotive: diss. ... Candidate Techn. Science. Lugansk, 311. (in Russian).
21. **Pasunok L., Torba S., Kolesnychenko S., 1985.:** Unified voltage converter to power auxiliary loads locomotives. Theses of reports All-Union Scientific-Technical Conference "Creation and maintenance of high-power locomotives", Vorochilovgrad, 146. (in Russian).
22. **Remen V., Osenin Yu., 2000.:** Pneumatic control device of temperature heat transfer in cooling systems of diesel locomotives. Lugansk, Bulletin of the East-Ukrainian National University named after Volodymyr Dahl. № 5(27). 156-161. (in Russian).
23. **Strel'nikov A., Mikhailidi V., 1967.:** Cast iron-based alloy. A.s. № 240262 SSSR. Zayavl. 23.11.67. Bull. № 12. (in Russian).
24. **Torba S., 1982.:** Application of the phase method of speed control of induction motor fan for cooling devices of electric locomotive. Construction and production of transport vehicles. Vup. 14. Kharkov. Vusha shkola, 48-50. (in Russian).
25. **Torba S., 1986.:** Determination of load capacity of asynchronous motors of fans at the phase regulation. Regulated AC Motors. Kyiv, 70-74. (in Russian).
26. **Volodin A., Fofanov G., 1979.:** Fuel efficiency of power units of locomotives. Moscow, Transport, 126. (in Russian).

РАЦИОНАЛЬНАЯ КОНСТРУКЦИЯ РОТОРА АСИНХРОННОГО РЕГУЛИРУЕМОГО МОТОР-ВЕНТИЛЯТОРА ДЛЯ ОХЛАЖДАЮЩИХ УСТРОЙСТВ ТЕПЛОВОЗОВ

Игорь Захарчук, Александр Захарчук,
Игорь Бухтияров

Аннотация. Приведен сравнительный анализ конструкций и характеристик асинхронных мотор-вентиляторов (АМВ) по результатам экспериментальных исследований натурных образцов на стенде. Определен рациональный вариант АМВ, частота вращения которого регулируется изменением напряжения на обмотке статора, для новых тепловозов. Определены достоинства и недостатки рационального варианта.
Ключевые слова: асинхронный мотор-вентилятор, скольжение, конструкция ротора, регулирование частоты вращения.

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