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Choice of rational diameters of pipelines for hydraulic system of city quarter water

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Summary. The adequate mathematical model of hydraulic characteristics is made for system of water supply of city quarter. The method of integration of model, method of optimization of parameters of system is reasonable. It is shown that at the expense of a choice of rational parameters of system of water supply considerable economic effect can be gained.
Key words: mathematical model, hydraulic characteristics, water supply method of integration, economic effect

INTRODUCTION

The system of water supply is the whole complex of the constructions necessary for supply by water of user, demanded quality and in demanded quantity [8]. Therefore process of its development is not only technically difficult, but also responsible action to which it is necessary to approach with the maximum attentiveness and punctuality [21].

The analysis of methods of calculation of systems of water supply showed that existing methods not always meet the requirements of high efficiency and profitability of work of such schemes [9]. One of the perspective directions of improvement of design and modernization is use enough full mathematical models of calculation of their characteristics, both in a statics, and in dynamics [1].

OBJECTS AND PROBLEMS

Below possibility of modernization of existing system of water supply of a quarter of a city network with a choice of rational parameters of its elements [23] is shown [11]. The scheme of system is given in Fig. 1.

Source of system of water supply is the pump IE 50-160 NA [22] with a productivity of 60 m^3/hour, a pressure of 0.5 MPa on a nominal mode [2]. In system the pump works backwater 0.35 MPa discharge pressure 0.58 MPa.

Water supply in each house is defined, proceeding from number of inhabitants and norms of consumption [16].

Lengths of pipelines are determined by the area plan, and their diameters by the relevant standards [17]. Generally it is diameter there are 100 mm, only a site from pump station to the house No. 3 – 150 mm.

For a reasonable choice of the pump and diameters of pipelines the maximum water discharge in a network is defined [3]:

$$Q_{\max} = Q_0 K_{tp},$$

where: $Q_{\max}$, Q_0 is maximum and average discharge,

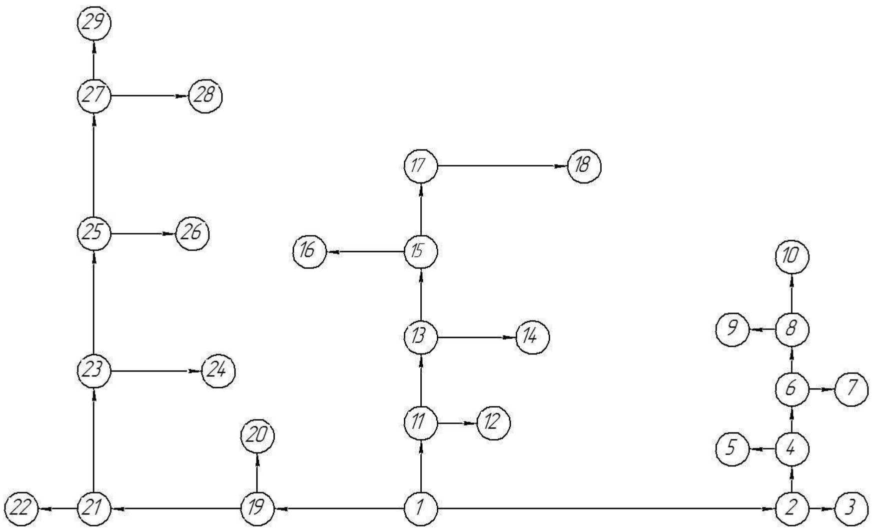

Fig. 1. Scheme of water supply system

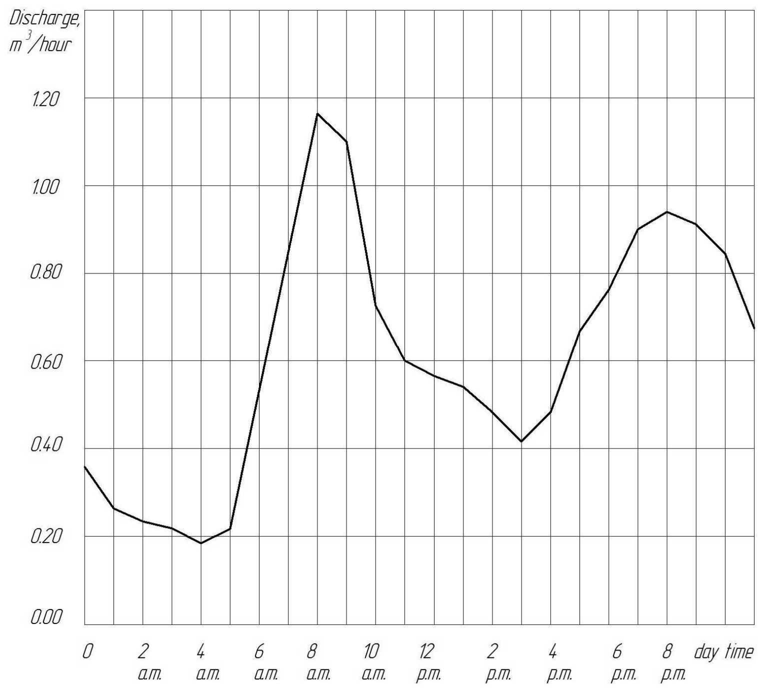

Fig. 2. Water consumption characteristic

K_{tp} is the correction coefficient considering unevenness of an expense in time.

For determination of coefficient a number of experiments were carried out [12]. On an entrance to houses water gauge (LLT-100 and LLT-150 depending on a consumption of water and diameters of pipelines) were established and measurements of water discharge within days on weekdays days, days off, and also a consumption of water on months were carried out [15]. Characteristic dependences are given in Fig. 2 [21].

The error of measurement of an expense didn't exceed 3% [10].

Statistical processing showed that the average discharge differs from maximum by =2.5 times [9]. Thus, for normal providing with water of inhabitants of the area it is necessary to increase an average discharge in time and in its size to choose the pump and diameters of pipelines [13].

Further the task is formulated thus: it is necessary to determine rational parameters of the considered hydraulic system which settlement scheme is given in fig. 1 [14]. Distances and sizes of selections in terminal points are set. Pressure in points of selection has to be not less than 0.425MPa. Parameters of optimization are diameters of pipes. Criterion function are the given expenses which consist of the cost of pipes and electric power cost for a year of operation of the pipeline [5].

The cost of pipes pays off as [20]:

$$\sum_{i,j} dist_{ij} \cdot pricetube(d_{ij}),$$

where: $dist_{i\,j}$ is site length between knots i and j,

$d_{i\,j}$ is diameter of a pipe on this site,

$pricetube\left(d_{i\,j}\right)$ is the cost of one meter of a pipe with a diameter $d_{i\,j}$.

Dependence of cost of pipes is given in Fig. 3 per one meter as function of their diameter [23].

Apparently, data are well described by linear function that allows finding the cost of pipes for any diameter.

The cost of the electric power paid off as [19]:

$$\frac{pressure \cdot qtot}{eff \cdot 1000} \cdot 365 \cdot 24 \cdot pelect,$$

where: $pressure$ is pressure created by the pump,

$qtot$ is full expense at the pump exit,

eff is pump efficiency (value undertook),

$pelect$ is the price of one kilowatt-hour of the electric.

Then the full given expenses $total$ can be calculated as the sum of these expenses [18]:

$$total = \sum_{i,j} dist_{ij} \cdot pricetube(d_{ij}) + \frac{pressure \cdot qtot}{eff \cdot 1000} \cdot 365 \cdot 24 \cdot pelect \cdot$$

The algorithm of optimization is constructed as follows.

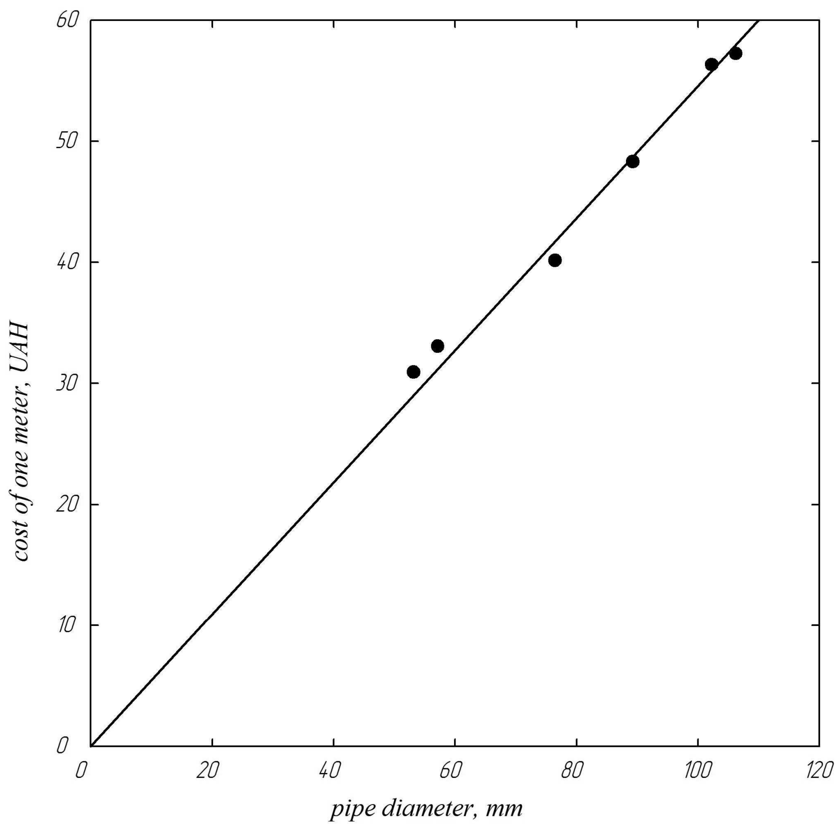

Fig. 3. Dependence of the price of pipes on diameter

Input of basic data. Drawing up list of unknown streams. The decision of system of the equations for expenses. Creation of criterion function. Creation of a matrix of coefficients. Drawing up the equations for pressure [3]. The received equations unite to the massif. Drawing up list of unknown pressure.

Pressure in all knots is considered as unknown. As the number of unknown is one more, than number of the equations, it is necessary to set pressure in one of knots. It is necessary equal to zero in a hub 10 (it is possible to take any other knot). The received system of the linear equations decides the Gauss method which main idea consists in a consecutive exception of unknown of this system.

Then the size of the given expenses which is output argument of criterion function is determined by the formula given above.

Minimization of criterion function was carried out by Hook and Jives which has been a little changed according to specifics of the solved task the method [5]. The method includes two main stages – studied search and search in a sample. Let's list the main stages of a method [6].

• Initial values of coordinates (entrance arguments of criterion function, in our case – diameters of pipes) are set.

• In a cyclic order each variable with increment addition changes.

• If after change value of criterion function decreased, old value of a variable is replaced with the new.

• If positive change wasn't successful, negative change is carried out on $-\Delta x_i$

• If after change value of criterion function decreased, old value of a variable is replaced with the new.

• If positive change wasn't successful, negative change is carried out on.

• If value of criterion function didn't decrease and in this case, the size of coordinate remains without changes.

• After carrying out such changes for all variables, the stage of studied search comes to an end.

• The changes of variables kept after studied search, show the direction of perspective minimization on all variables at once. It is the direction of search in a sample.

• In this direction the following, bigger step is taken.

• Procedure proceeds before achievement of a minimum of criterion function.

In our case we can't set randomly the step size as are limited to a discrete set of existing diameters of pipes [4]. Therefore the step for each variable, equal to distance between this value of diameter and next, turns out different. The size of a step turns out big that does impossible carrying out search in a sample. Therefore it is necessary to be limited to studied search.

Search began with values of diameters of the pipes which are really standing in system [7]. In Fig. 4 dependence of values of criterion function (the given expenses) on number of steps of iterative process is shown

As a result of minimization, value of criterion function decreased from 134284 to 110225, i.e. by 18%.

Optimum parameters of system turn out the following:

Pump's pressure - 0.455 MPa,
Pump's power -10.1 kWt ,
Cost of tubes – 35682 grn,
Reduced cost – 110225 grn.

Diameters of pipes, distances between knots and expenses between knots are specified below

The researches executed by authors showed that the offered technique of a choice of rational parameters of difficult hydraulic system allows reducing the given expenses considerably.

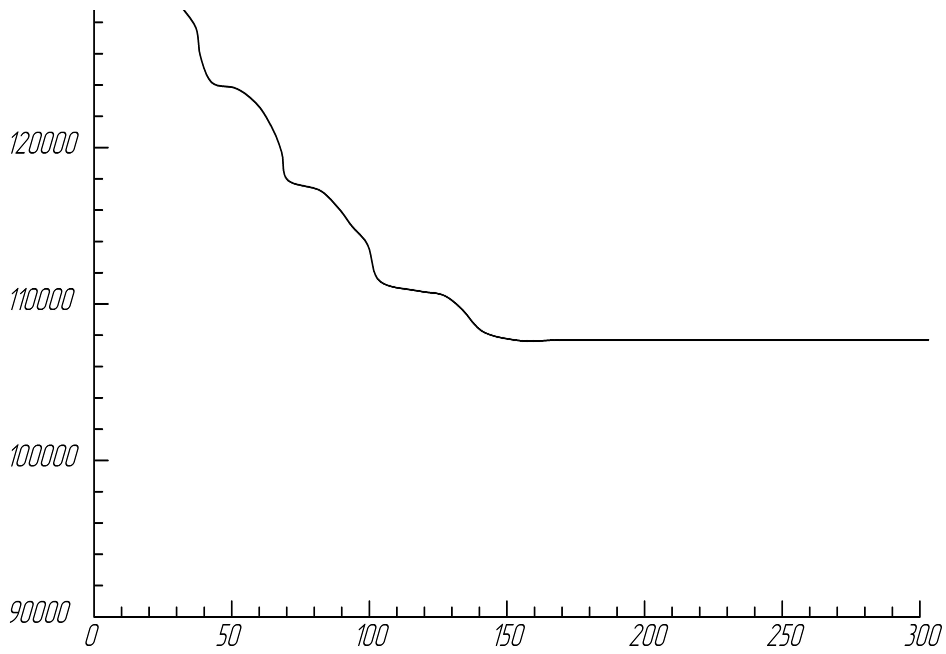

Fig. 4. Dependence of values of criterion function on number of iterations

CONCLUSIONS

1. The order of multiple parameter optimization of system of water supply of a site of the city area is developed, statistical researches on water consumption within year, month, week and days are executed.

2. It is shown that multiple parameter optimization allows to lower the given expenses only at the expense of a choice of diameters of the pipeline by 18%.

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ВЫБОР РАЦИОНАЛЬНЫХ ДИАМЕТРОВ ТРУБОПРОВОДОВ ГИДРАВЛИЧЕСКОЙ СИСТЕМЫ ВОДОСНАБЖЕНИЯ ГОРОДСКОГО КВАРТАЛА

Павел Акимов

Аннотация. Разработана адекватная математическая модель расчета характеристик системы водоснабжения городского квартала. Предложен и апробирован метод интегрирования математической модели. Показано, что за счет рационального выбора диаметров трубопровода системы водоснабжения может быть получен значительный экономический эффект.
Ключевые слова: математическая модель, гидравлические характеристики, водоснабжение, метод интегрирования, экономический эффект

Selective wear of cuttings elements of working organs of tillage machines with realization of self-sharpening effect

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S u m m a r y . The clause of strengthening of cuttings elements is conditioning and realization of such self-organization process as a self-sharpening. Sharpening of horizontal and vertical cuttings elements of working organs of tillage machines (CE WOTM) is considered in many works, but not found out the terms of realization and nature of these processes in a sufficient measure. The processes of sharpening and blunting of CE WOTM are related mainly to the processes of wear. The change of type of CE in the process of wear is conditioned mainly a size and character of tearing down each of its bevel and by volume of destruction of cutting edge in the process of exploitation in the medium of soil and depends on character of co-operation in tribosystem " WOTM -soil".

K e y w o r d s : self-organization, tribosystem, selective wear, cuttings elements, macro geometry, self-sharpening effect

INTRODUCTION

The results of researches and analysis of worn-out of WOTM shows that principal reason of refuses is a change of CE profile in the process of exploitation. In practice there are profiles of CE, resulted in Fig. 1

In most cases horizontal and CE is apeak placed sharp, their initial type is three-cornered (Fig. 1, a) and at the process of exploitation in soil it accepts other steady-state form (Fig. 1, b). Intensive wear is the results of its blunting of CE and increase of hauling resistance of WOTM. In such case there is a necessity to control the type of CE WOTM, strengthening of its working part and conditioning realization of sharpening effect. It is possible during the running-in and operating periods. Running-in is a process of change geometry of surface of friction and physical and mechanical properties of upper layers of material in an initial period of friction, showing up at permanent external terms in diminishing of friction force, temperature and intensity of wear. A concept "geometry of friction surface» is plugged in itself micro-roughness of surface and form (macro-geometry) of detail [8, 16]. Experimental confirmation of improvement of tribotechnical descriptions of friction surfaces at one of the running-in methods is presented in [29, 27]. The use of this high-efficiency method of forming of surfaces of details allows considerably increasing their resource [19, 28].

In this paper probed unsharp CE (Fig. 1, c), looking rotined after which, that their wears are less intensive than sharp (Fig. 1 a, b) unfortified CE. At certain operating time they had blunted (Fig. 1, d) and negative consequences are analogical.

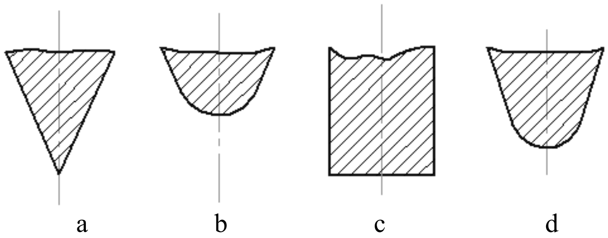

Fig. 1. Form of CE profiles: a – initial sharpen, c – initial blunten, b, d – after operating

OBJECTS AND PROBLEMS

Let’s will utilize model approach of research of dynamics of forming of CE WOTM in the considered cases. The initial and eventual types of considered CE WOTM are resulted on Fig. 2.

Let it is sharp and unsharp CE WOTM works in the same soil, notably ($\varphi_s = \varphi_{us} = \varphi$ – are identical corners of friction) and at the same mode.

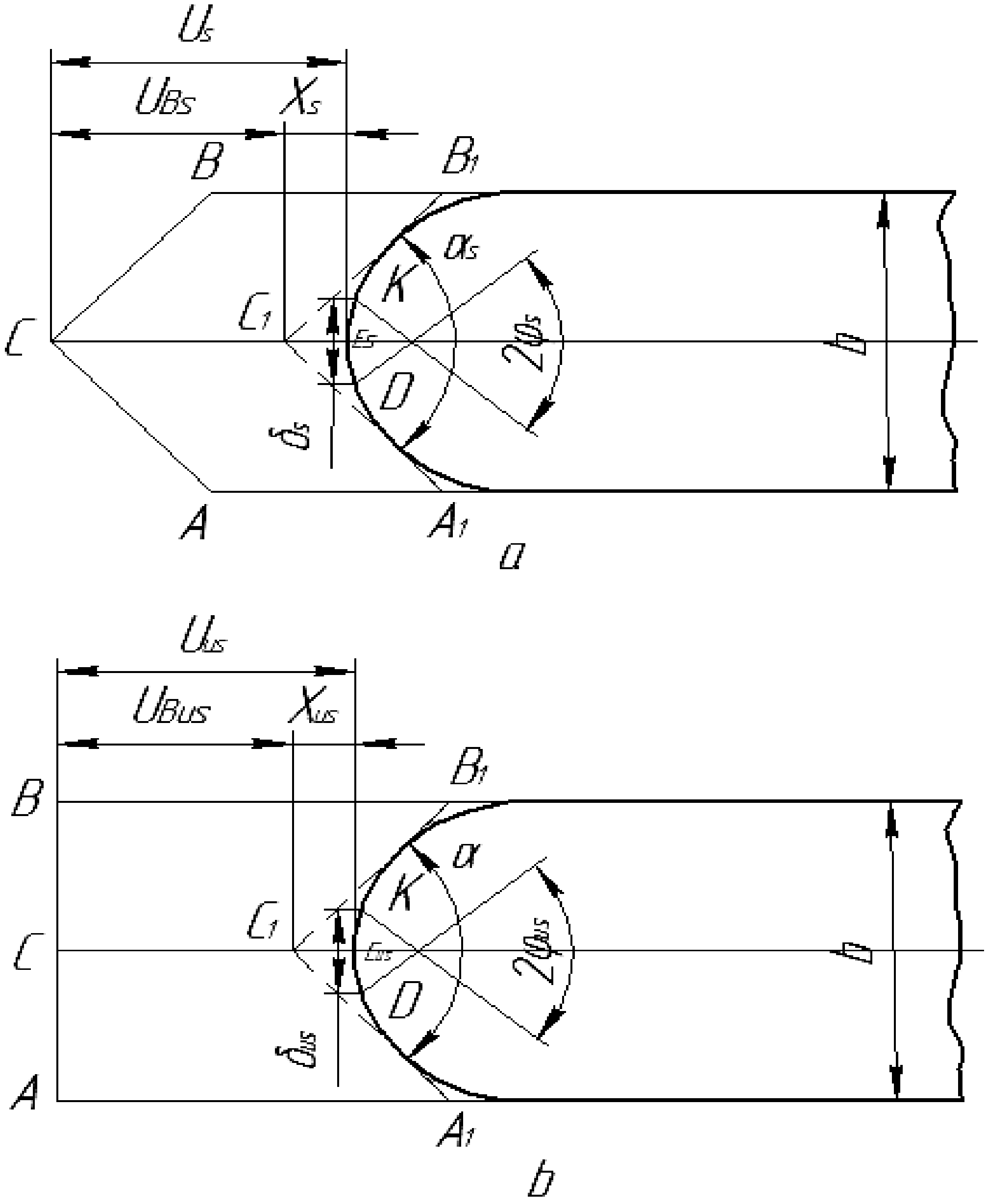

Fig. 2. Scheme of type′s change of unfortified sharp (a) and unsharp (b) CE WOTM

Will analyse character of wear of CE noted types to acquisition of identical corner of sharpening α ($\alpha_s = \alpha_{us}$). Thus will utilize length δ_s chords of edges arc of CE are with a central corner 2φ accepted in quality the criterion of sharpening of blade [17].

For considered CE, this criterion looks like:

$$\delta_s = 2x_s \frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}}, \quad \delta_{us} = 2x_{us} \frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}}. \quad (1)$$

For the moment of wear, when the type of CE is identical, will get:

$$\delta_s = \delta_{us}, \quad x_s = x_{us}.$$

Going out from the chart of change of types of CE and criteria of sharpening (2) quality, have:

$$u_s - u_{ds} = u_{us} - u_{dus}, \quad (2)$$

where: u_{ds}, u_{dus} - displacement of top sharp and unsharp CE, u_s, u_{us} - proper wear of these CE.

Experimental results testify that $u_s > u_{us}$, $u_{ds} > u_{dus}$, that at the wear of CE of displacement of top of unsharp CE carried out on a less size. Consequently from the results of researches distinctly, that CE is apeak placed it is possible not to sharpen, but expediently them to fix a working surface, to save the type of CE and create the terms of realization of sharpening.

Experimental researches after the changes of type of CE from a homogeneous metal in the process of exploitation shows that on the measure of wear are gradually stabilized and remain practically unchanging. The type of CE is formed does not depend on its initial type which was structurally given CE at making of WOTM from CE, from the thickness of CE (in possible limits) and from their material.

It is discovered that at the change of corners of setting of CE WOTM, physical-mechanical properties of soil, rate of movement of aggregate and at other terms the form of steady-state type can substantially change [23, 14].

Process of forming of types of CE at co-operating with the soil substantially depend on shock durability $\sigma_м$, material, sizes of wear and character of its distributing in edges points of CE, purchased in the process of exploitation (or preliminary formed) of sharpening corner α, thickness b, to pressure of soil p on CE, amounts of shots are on the plane of CE edge on unit of friction way L_{fr}, energies of blow of abrasive particles T, N·m, coefficient of proportion k, m^2/N:

$$\delta_s = 2(u_s - u_{ss}) \frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}} = 2L_{fr}\left(n_{1s}\frac{T}{\sigma_м} - \frac{k_{1us}pu_s}{b}\right)\frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}}, \quad (3)$$

$$\delta_{us} = 2(u_{us} - u_{sus}) \frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}} = 2L_{fr}\left(n_{1s}\frac{T}{\sigma_м} - \frac{k_{1us}pu_{us}}{b}\right)\frac{\sin\frac{\alpha}{2}\sin\varphi}{1-\sin\frac{\alpha}{2}}. \quad (4)$$

Thus, on character of forming of type of sharp and unsharp CE substantial influence has wearproofness of material which they are made from, shock durability, way of friction, size and character of distributing of pressure of soil on a working surface.

Creation of sharpened CE, as unique for the terms of work on the different types of soil is a thorny enough problem [12]. Foreign and domestic producers for providing of capacity of wearing CE utilize the row of structural and technological methods [6, 10].

Let’s will mark that making of detail from material of high wearproofness in general case is not a sufficient condition for achievement of the protracted term of maintenance of the given type of CE. At a correct choice constructions are utillized by the basic methods of increase of capacity of CE. For strengthening of workings surfaces which are most added wear, mainly composition materials are used.

The condition of strengthening of cuttings elements is conditioning and realization of such self-organization process as a self-sharpening. Sharpening of horizontal and vertical cuttings elements of working organs of tillage machine is considered in many works [2, 3, 4, 1, 7], but not found out the terms of realization and nature of these processes in a sufficient measure. The processes of sharpening and blunting of CE WOTM are related mainly to the processes of wear [9]. The change of type of CE in the process of wear is conditioned mainly a size and character of tearing down each of its bevel and by volume of destruction of cutting edge in the process of exploitation in the environment of soil and depends on character of co-operation in tribosystem " WOTM -soil".

Pressure of soil on CE WOTM is dynamic and it can be examined as a measure of intensity of continuous shots of abrasive particles on a working surface. A number and energy of their shots depend on a particle-size of soil.

In theory will ground the terms of realization of sharpening effect CE WOTM, in raising of flat task of change of form fixed CE at his wear in isotropic mass of abrasive averaging particles in size (Fig. 3).

Moving of fixed CE takes a place for axes OX. At the beginning of test an edge of CE is a rectilinear area ACB, and in the period of stabilizing of type of CE – by a curve $A_1C_1B_1$, with a top in a point C_1, farther with work of a withstand type A2C2B2, with a top C_2. After stabilizing of type CE wear of bevels takes a place congruent in accordance with the layers of CE. An edge of CE is in bevels A_1C_1 i C_1B_1 will has different speed of wear, as determines the first material bearing, and second – the fixed layer. In the process of realization of sharpening effect, the top of CE is displaced from the middle of thickness on a size Δ. As a wear on the width of CE much less than, than on length, accepted, that the general thickness of CE was saved: $b = const$.

For a constant process (Fig. 3), in obedience to work [5], it is possible to write down:

$$u_{uh}^{-1} \cdot b = 2u_h^{-1} \cdot k_{uh}\left(\frac{b}{2} + \Delta\right), \quad (5)$$

where: u_{uh}^{-1}, u_h^{-1} – wearproofness of unhardened and hardened layers, Δ – displacement of top of CE edge is in relation to the middle of its thickness in the case of causing of the hardened coverage, $k_{uh}=H_h/H_{uh}$ – ratio of hardness the of unhardened and hardened layers of CE.

General wearproofness of fixed CE, wearproofness of bearing and composition layers it is possible to define on formulas [1]:

$$u_{ha}^{-1} = \frac{k_1 p}{b^2}, \quad u_h^{-1} = \frac{k_1 p}{b^2}, \quad u_{uh}^{-1} = \frac{k_1 p}{b^2}, \quad (6)$$

where: k_1 – coefficient of proportion.

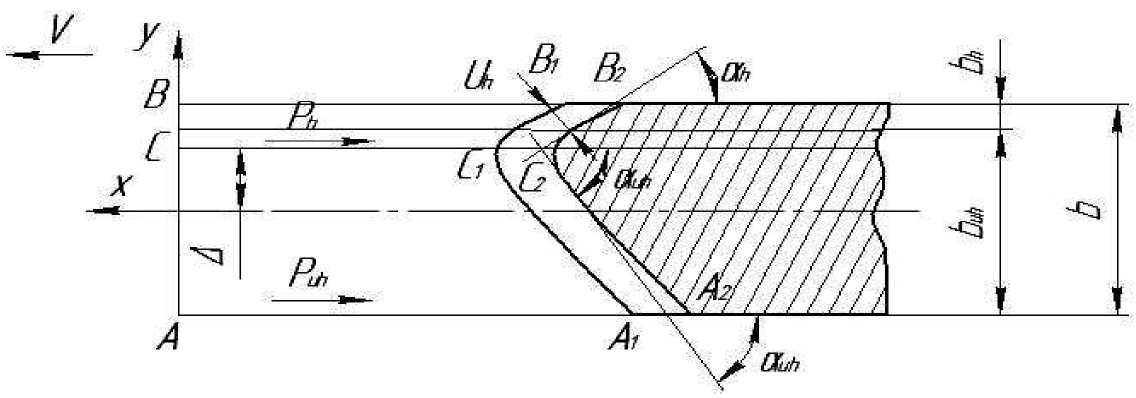

Fig. 3. Scheme of change of type of CE is with the inflicted composition layer of coverage in isotropic mass of soil

As a general loading on CE is evened:

$$P_{\Sigma}=P_h+P_{uh}, \quad (7)$$

where: P_h, P_{uh} – efforts which operate to unhardened and hardened layers.

From formulas (6) certain efforts are evened:

$$P_{\Sigma}=\frac{b^2u_{ha}^{-1}}{k_1},\ P_h=\frac{b^2u_h^{-1}}{k_1},\ P_{uh}=\frac{b^2u_{uh}^{-1}}{k_1}. \quad (8)$$

Will put (8) in (7) and will find the common size of wear of hardened CE:

$$u_{ha}=\frac{u_hu_{uh}b^2}{(u_{uh}b_h^2+u_hb_{uh}^2)}=\frac{v_{u\,h}\sigma_{u\,uh}b^2}{v_{u\,uh}b_h^2+v_{u\,h}b_{uh}^2}. \quad (9)$$

Will put expression (9) in equalization (5) and after some transformations obsessed:

$$b=2k_{uh}\frac{(v_{u\,uh}b_h^2+u_hb_{uh}^2)}{v_{u\,uh}b^2}\cdot\left(\frac{b}{2}+\Delta\right). \quad (10)$$

In a formula (10) take into account a coefficient $k_{vu}=\dfrac{v_h}{v_{uh}}$, what equals the relation of sizes of wears of composition and unhardened layers. After some transformations, have:

$$b=2k_{uh}\frac{(b_h^2+k_{vu}b_h^2)}{v_{u\,uh}b^2}\cdot\left(\frac{b}{2}+\Delta\right), \quad (11)$$

where: relocation of CE edge top of bias in relation to its middle is evened from:

$$\Delta=\frac{b^3}{2k_{uh}(b_h^2+k_{vu}b_{uh}^2)}-\frac{b}{2}. \quad (12)$$

Coming from the terms of realization of sharpening [18], it is possible to write down:

$$0\le\Delta\le b/2\ ,\quad \frac{b^3}{2k_{uh}(b_h^2+k_{vu}b_{uh}^2)}\ge\frac{b}{2}. \quad (13)$$

After some simplifications have a next condition:

$$\frac{b^2}{k_h(b_h^2+k_{vu}b_{uh}^2)}\ge 1. \quad (14)$$

As $b=b_h+b_{uh}=const$, taking into account the ratio of thickness of unhardened and hardened layers of CE, $k_b=b_h/b_{uh}$, will get:

$$\frac{k_b^2+2k_b+1}{k_{uh}(k_b^2+k_{vu})}\ge 1. \quad (15)$$

The last condition combines all of complex of requirements of realization of sharpening effect horizontally and apeak placed CE: relation of hardness $k_н$ of hardened and unhardened layers, speeds of their wear k_{vu} and thicknesses of these layers - k_b.

Setting the relation of the noted descriptions glowed fixed and bearing, not in contempt of condition (15), it is possible to project such construction of two layers CE WOTM, which in the process of exploitation enables to realize the process of its sharpening.

Complex of values of correlations $k_н$, k_{vu}, k_b influences on relocation bias Δ of CE edge: with an increase of k_{vm} and $k_н$ it is increased, and with an increase k_b - diminishes accordingly.

Making of CE WOTM from a laminate after different structural charts is perspective and not enough studied. A widespread chart in practice is a chart S_1-H-S_2, that with a hard layer in the middle and by soft external layers. Such construction of CE has a row of advantages as compared to material homogeneous or double-coated CE: CE is stronger, as a capacity of it is improved for a flowage, shock viscidity and construction durability rises [15, 13]. In addition, next to sharpening of CE, crumbing of hard and fragile cutting layer is shut out, as it is a pinch-off between two plastic external layers of material.

M.I. Voloshko [26] developed the basic requirements to multi-layered CE, which consist in the following: CE has to self-sharpening, to be strong, lasting, cutting edge of CE must not be pressed, wrapped up, a hard layer must not be crumbed.

The epure of normal forces which operate on workings surfaces RE settles accounts for the concrete terms of work taking into account physical-mechanical properties of materials [22, 24]. After the got epure set character of distributing of normal forces on cutting edge and edges of CE and they can be applied for multi-layered CE.

Thickness, geometry, wearproofness of material and number of external (unhardeneds) layers of multi-layered CE it is possible to define on the basis of analysis the distributions of normal forces taking into account wearproofness of material of hard layer. The general thickness of hard (fixed) layer is accepted even the optimum thickness of cutting edge. The wearproofness of material of hard layer must be such in relation to unhardeneds layers, that CE is self-sharpening in the process of exploitation, that terms were executed discovered previously.

Will consider three-layered CE, that is self-sharpening working in the environment of soil with the thickness of cutting edge h_p and with a sharpening corner $\alpha=\alpha_1+\alpha_2$. The distribution of normal forces on CE in this case is resulted in Fig. 4.

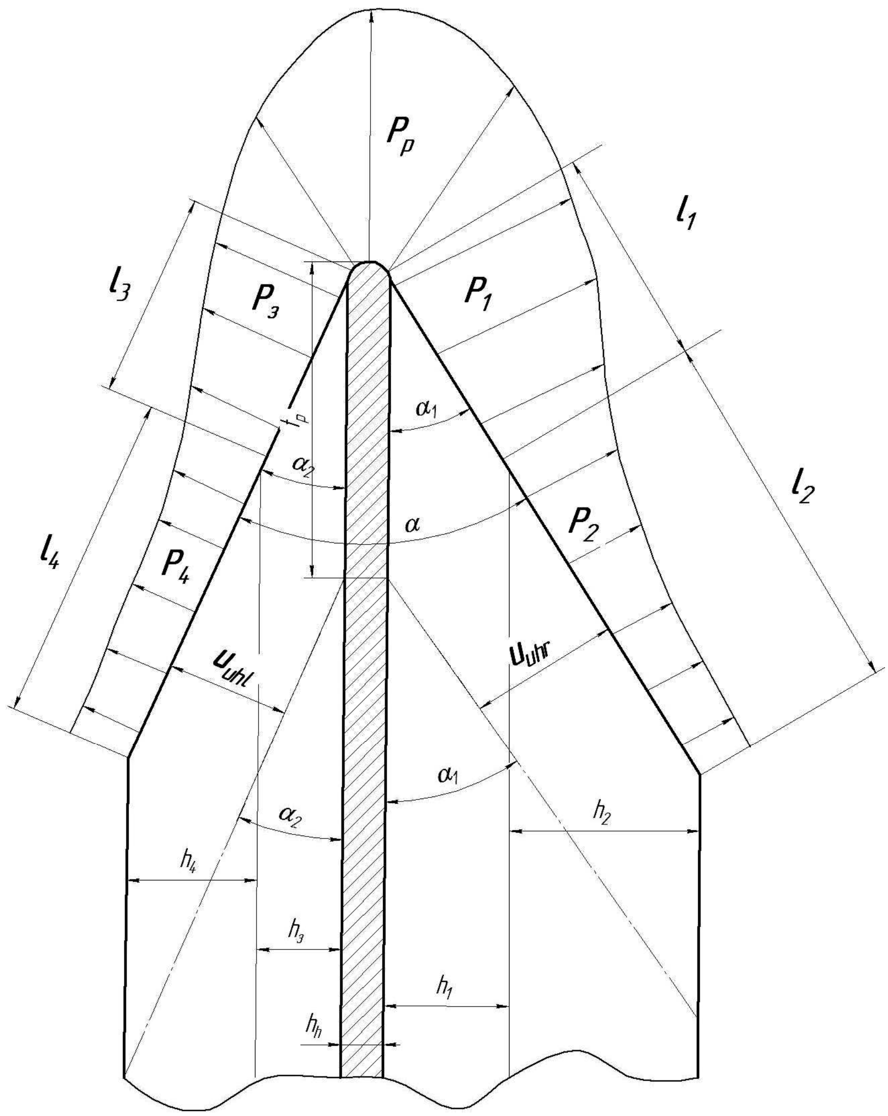

Fig.4. Scheme of multi-layered self-sharpening CE

The distribution of normal forces is divided into a few areas. A number of areas must be, on possibility, minimum, as after their amount the necessary amount of unhardeneds layers amount of which it must be such is determined, that as a result of wear there was not formation of appearances as a result of stepwise change of wearproofness of unhardeneds layers [25]. If CE is self-sharpening, as a result of wearing down there must be a parallel change of contour of it crosscut.

Will consider the linear wear of CE contour for normal to its surface. Thus the linear wear of surface of CE makes for a hard (cutting) layer $-U_h$, external unhardeneds layers from a right side – U_{uhr}, external unhardeneds layers from left U_{uhl}. Change a contour takes a place the cut of CE along the bisectricess of sharpening corner. For the maintainance of initial thickness of cutting edge and set corner of sharpening it must be the followings correlation are self-possessed linear wear of cutting (fixed) and unhardeneds layers:

$$\frac{u_{uhr}}{u_h} = \sin\alpha_1,$$

$$\frac{u_{uhl}}{u_h} = \sin\alpha_2,$$

$$\frac{\sin\alpha_1}{\sin\alpha_2} = \frac{u_{uhr}}{u_{uhl}}. \quad (16)$$

Linear wear of CE layers, determined from equalization of Khruschova-Babicheva for an abrasive wear [15]:

$$\frac{du}{dL_{fr}} = kp, \quad (17)$$

where: du — the linear wear for normal to the surface of friction, dL_{fr}– way of friction, p - contact pressure, k_a - coefficient of wear, which depends on composition and amount of abrasive, wearproofness of material and other factors. In the first approaching accept, that the wearproofness is straight proportional hardness of material, and that rate of movement of abrasive particles identical on all areas of CE. Thus basic conformity to the law of abrasive wear can be given:

$$u = \frac{k_a p L_{fr}}{w_{ha}}, \quad (18)$$

$$k = \frac{k_a}{w_{ha}},$$

$$L_{fr} = vt,$$

where: υ – rate of movement of particles of soil along the CE, k_a – coefficient of wear ability of soil, ω_{ha} – wear resistance of material, t – duration of test.

Using dependence (18), will define the linear wear of every layer of CE on the proper areas which the epure of normal forces is divided. The linear wear of hard (cutting) layer is evened:

$$u_h = \frac{k_a p_h L_{fr}}{w_h}. \quad (19)$$

The linear wear of unhardeneds layers, located on the right side of CE, makes:

$$u_{uh1} = \frac{k_a p_{uh1} L_{fr}}{w_{uh1}}, \; u_{uh2} = \frac{k_a p_{uh2} L_{fr}}{w_{uh2}}. \quad (20)$$

The proper linear wear of unhardeneds layers, located on left side of CE, is evened:

$$u_{uh3} = \frac{k_a p_{uh3} L_{fr}}{w_{uh3}},$$

$$u_{uh4} = \frac{k_a p_{uh4} L_{fr}}{w_{uh4}}. \quad (21)$$

As a corner of sharpening of self-sharpening CE remains unchanging in the process of wear and a change of contour takes a place along the bisectricess of corner α, have:

$$\sin\alpha_1 = \frac{u_{uh1}}{u_h} = \frac{u_{uh2}}{u_h}. \quad (22)$$

From other side:

$$\sin\alpha_1 = \frac{\overline{p}_{uh1} w_h}{\overline{p}_h w_{uh1}} = \frac{\overline{p}_{uh2} w_h}{\overline{p}_h w_{uh2}}. \qquad (23)$$

Like for $\sin\alpha_2$, get:

$$\sin\alpha_2 = \frac{u_{uh3}}{w_h} = \frac{u_{uh4}}{u_h}. \qquad (24)$$

$$\sin\alpha_2 = \frac{\overline{p}_{uh} w_h}{\overline{p}_h w_{uh}} = \frac{\overline{p}_{uh4} w_h}{\overline{p}_h w_{uh4}}. \qquad (25)$$

Value $\overline{p}_h$, $\overline{p}_{uh1}$, $\overline{p}_{uh2}$, $\overline{p}_{uh3}$, $\overline{p}_{uh4}$ is determined from the epure of the normal loading, as mean values of pressure on the selected areas.

As initial at designing of CE is wearproofness of hard (cutting) layer, from expressions (23), (24) it is possible to define necessary wearproofness of unhardeneds layers of CE:

$$\omega_{uh1} = \frac{A\overline{p}_{uh1}}{\sin\alpha_{uh1}},\ \omega_{uh2} = \frac{A\overline{p}_{uh2}}{\sin\alpha_{uh2}},$$

$$\omega_{uh3} = \frac{A\overline{p}_{uh3}}{\sin\alpha_{uh3}},\quad \omega_{uh4} = \frac{Ap_{uh4}}{\sin\alpha_{uh4}}, \qquad (26)$$

where: $A = \dfrac{w_h}{\overline{p}_h}$.

Coming from geometrical correlations, the thickness of unhardeneds layers is evened:

$$h_{uh1} = l_1 \sin\alpha_1,\ h_{uh2} = l_2 \sin\alpha_1,$$

$$h_{uh3} = l_3 \sin\alpha_3,\ h_{uh4} = l_4 \sin\alpha_4, \qquad (27)$$

where: l_1, l_2, l_3, l_4 – proper areas of loading of unhardeneds layers.

CONCLUSIONS

1. Self-organization in a due form takes a place proportionally to pressure and provides a self-sharpening effect.
2. The considered method exposes the generals of effect of sharpening of multi-layered CE, and enables to develop the algorithm of its optimum designing.

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ИЗБИРАТЕЛЬНЫЙ ИЗНОС РЕЖУЩИХ ЭЛЕМЕНТОВ РАБОЧИХ ОРГАНОВ ПОЧВООБРАБАТЫВАЮЩИХ МАШИН С РЕАЛИЗАЦИЕЙ ЭФФЕКТА САМОЗАТАЧИВАНИЯ

Виктор Аулин, Тарас Замота

Аннотация. Условием упрочнения режущих элементов является создание условий и реализация такого процесса самоорганизации как само затачивание. Самозатачивание горизонтальных и вертикальных режущих элементов рабочих органов почвообрабатывающих машин рассмотрены во многих работах, но условия реализации и природа этих процессов не обнаружены в достаточной мере. Процессы самого заострения и затупления РЭ РОПМ связанны в основном с процессами изнашивания. Изменение профиля РЭ в процессе изнашивания обусловлено в основном величиной и характером износа каждой из его фасок и объемом разрушения режущей кромки в процессе эксплуатации в среде почвы и зависит от характера взаимодействия в трибосистеме "РОПМ-почва".
Ключевые слова: самоорганизация, трибосистема, избирательный износ, режущие элементы, макрогеометрия, эффект самозатачивания

Parameter optimization of dosator for technique culturs on the quantity intervals, close by to calculation

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Summary: Results of multifactorial experiments by orthogonal planning for four factors: height and diameter of seed tube, rotary speed of seed disk and velocity of movement machine are presented. Experiment results were analyzed according to generally accepted methods and adequate model was received. Influence of each factor on the quantity intervals, close by to calculation, and optimal value of each factor were determined [19, 20].
Key words: the quantity intervals, close by to calculation, influence of factors, optimization.

INTRODUCTION

Sugar beet on Donbasse – one from leading technical culture: in the structure of seeding areas harcovchiny, for example, she occupy in 90-h years about 10% [7, 21, 22] and provide from above 25…30% of profit from plant-growing. By that only behind count accessory production (tops and other) from every hectare received about 35 centners feeding digit, that equivalently growing 35 c/h oats. But in period of transitional economy production of beet field sharply lower, and use hand labour by formed of density planting brought to unprofi tableness of production sugar beet in much economyes. In also time the row of agrarian undertaking of region, where don't to admitted of violations technolog, but hardly adhere to normative agrarian technical receptions of tilling sugar beet independently from weather conditions and economic crisis, annual receive high and constant harvests of sweet roots.

From aim of reliable securing of increasing need of region in sugar for the consumption and processing industry (136…137 thousand ton in year) foresee essential increasing of volume production of sugar row material no only behind count increasing of sowing areas, but and behind count introduction of high effective and energy savings technologs. Foresee distribution of sugar beet in rotation of crops of intense type, the growing of high productive sorts and hybrids. By that is necessary, to the density standing of the roots was on the level 103…105 thousand plants on hectare. In system of processing soil half fallow must be occupy about 75% of the areas. The introduction of integral system defence of plants from the pests, sicknesses and weeds, what includes the chemical processing and the preventive receptions, is appear most economic expediency and ecological safe means of increasing productive of the sugar beet, but the high quality processing of seeds defence stimulation composition must be obligatory. The of many yeans experience and data of the agronomical science is witness, that high harvests the root – crops it is possible in the all beet seeding economyes of the region, if every toiler is seize of the technolog growing and has be broadly inculcate the scientific working out and the experience of foremost people. In the zone of unstable molstening most high harvests receive after spring winter wheat at occupy fallow, the pea and of many years grasses. In east part of the forest – steppe of the Ukraina is mark positive role of the black fallow in the form of harvest sugar beet. On Ivanovskoy experiment station in the middle after 29 years on the lot with black fallow was received at 38,9 ton/hec root – crops, but at the lots with by vetch-oats mixture, maize on green fodder and the silo – less on 1,5…1,9 ton/hec, that is to say, in the zone of unstable molstening on the fertile chernozem soils better predecessor of sugar beet is appear spring winter wheat, which place after occupy fallow, but also after the pea on grain. In 10-field rotation of crops recommend the such alternation: 1 – the fallow occupied, fallow clean, 2 – spring winter wheat, 3 – sugar beet, 4 – summer grain with sowing of the grasses, 5 – of many years grasses of one year using, 6 – spring winter wheat, 7 – sugar beet, 8 – pea, 9 – spring winter wheat, 10 – maize, sunflower. In the zone of insufficient molstening most favourable water regime has be on the lot with black fallow, that stipulated more high productive of the sugar beet. So, in the middle after 1982…1995 years on Veselopodolskoy station the yield of the sugar beet after spring winter wheat on black fallow compose 41,6 ton/hec. That is say in the zone of insufficient molstening expediency to use such alternation: 1 – fallow black, 2 – spring winter wheat, 3 – sugar beet, 4 – annual cultures on the green fodder and silo, 5 – wheat and rye winter, 6 – maize, 7 – annuals with Sowing of the many years grasses, 8 – the grasses many – and annual, 9 – spring winter wheat, 10 – sugar beet, sunflower, maize on the grain. For farm economyes it is possible to recommend the rotation of crops with short rotation: 1 – black and occupied fallow, 2 – spring winter wheat, 3 – sugar beet, 4 – maize on the grain, 5 – barley with the sowing of many years grasses, grits cultures.

The processing of soil under sugar beet must provide:

– uniformite distribution in the arable layer near to the surface organic remainders of the predecessor (the straw, remainder of the intermediate culture and manure),

– removal of the harmful condensations in the arable and under arable layers, the destruction of the plough sole,

– provoke the shoots of the weeds and their destruction,

– the absorption and the delay of the water of autumnal and wintry sediments,

– sufficient even surface of the field for the sowing.

Distinguish three of the method of the processing of the soil: traditional, in the basis of which lie the plough processing, the soildefence (conserve) and straight the sowing without of the processing soil. The traditional and soildefence of the methods differ in fundamental of the application or of the no application plough, both method use the variants with before sowing or without her. By soildefence of the method distinguish the sowing to the layer from intermediate cultures or to the layer from the remainders of the predecessor. For deep of the loosen expediency use cultivators in aggregate with heavy teeth harrows, to the droughty weather – with the annulate-spur rinks by worker velocity from above 8 km/h. The fundamental processing of the soil is the major reception in the system of the autumn processing of the soil. Her make with the aim the deep of the loosen soil, careful doing up organic and mineral fertilizations, after harvesting remainders, but also the creation of the conditions for improvement of the water– air and nourishing of the regimes and qualitative constructions of the following field works. The early spring loosen of the soil (“closing of the moisture”) necessary make to the period her of the physical ripeness, by what the soil is loosen, but isn't stick on working organs of the soil processing instruments.

By that with an of importance no to admit losses of a moisture, make even a surface of a field and create of a conditions for before sowing of a processing soil, sowing and care of a sowing. A delay with closing of a moisture on one a day be able bring to productive of a losses in 60…120 t/h of a water and to lowering of an yield on 0,6…1,2 t/h. A thickness of the friable layer must be 2,5…3,0 sm and contain of a lump with a size 10…20 mm. A works expediency productive of a broad seizure aggregate on the draft of a caterpillar tractors.

In the dependence of a type soil and a density of an upper layer in first row of a coupling place heavy or middle a harrows БЗТС-1, БЗСС-1, in second – a sowing harrows ЗБП-0,6 or the paradise harrow ЗОР-0,7. With aim more careful of smoothing surface of a field applay aggregate from a train – harrow ШБ-2,5 in the first row and sowing harrow ЗБП-0,6 or ЗОР-0,7 – to second. In system of the technological operations of an intense technolog early spring loosen and a smoothing of a surface expediently unite in one pair complex operation, using aggregate АРВ-8,1-01,containing a mechanism for simultaneous of an entry of a herbicides. Before sowing processing of a soil make for the loosen of superficial layer to fine lump state on the give depth, creation of condense sowing a couch, destruction a shoots of the weeds. Before sowing processing of a soil appear of structure a part of common technological process – of a sowing sugar beet, its necessary realize without some break in time. For before sowing processing of a soil with middle density and insufficient moisture it is possible use a cultivator УСМК-5,4Б (В), equipped lancet claws, a rotors and passive trains. High productivity and a quality before sowing processing a soil reach by an utilization aggregate АРВ-8,1-02, what provide high a quality of the loosen of soil on give depth of the doing up of a seeds 3…4 cm without intermixing the layers.

The sowing appear one pair from major reception of the technolog growing. Careful implementation all norm demands of a technolog, but namely: sowing in optimum early and condensed of the date, guaranteeing of the uniformite a distribution of the seeds on a length of the row and a depth of doing up, distribution their on sufficiently condense couch and with give intervals appear condition of formed high productive sowings. With an of importance underline, what in good time a construction of sowing stipulated necessary for a received high of a harvest a duration of vegetal season – in the limits 150…160 days from the shoots to the cleaning. For dotted of the sowing after before sowing the processing of the soil broadly utilize mechanical or pneumatic the seeders, provide exact a sowing on one pair grain. Mechanical seeders provide exact a sowing of calibrate the seeds by work velocity 6 km/h. By that necessary provide right selection sowing of discs with the cells, appropriate to size of the seeds. Liqueur – bonbons seeds sowing of the seeder type ССТ by work velocity to 4 km/h. Pneumatic seeder provide more exact sowing by work velocity to 7…8 km/h.

The norma of the sowing seeds is regulate by the mounting appropriate discs, but also by the driving aim on the necessary asterisks of the box transmissions (Tab.1).

Table 1. Regime of the work a seeder ССТ-12В (one-row sowing disc)

Norma of the sowing, p/m of the row	Number of the tooth's on asterisks of the box transmission		Trans missive number on the sowing disc
	leading	driven	
8	12	19	0,158
10	19	26	0,183
11	12	15	0,2
12	21	23	0,218
15	21	19	0,276

The norma of the sowing necessary applay differentiately in the dependence from a germination of the seeds, a level of culture soil, a presence of the pests and further with a calculation on that, to on high level culture of a fields reseive 7…9 shoots, on middle level culture - 9…11 and on low level culture - 12…15 shoots on 1 m of the length row.

Deviation from calculation intervals at agrotechnical demands is admit no more

$\pm$10% [1-19], that is to say quantity intervals, close by to calculation, must be no less than 90% This exponent straightly influences on the harvestly and the expenses of hand labour on to send away “unnecessary” plants.

OBJECTS AND PROBLEMS

The quantity of an intervals, close by to calculation, was determinated by the formula:

$$Y = K_1 / K_2 , \quad (1)$$

where: K_1 – quantity of an intervals, close by to calculation, it was determinated by the formula: $0{,}9S_0 < K_1 < 1{,}1S_o$ (S_0 – calculation interval), K_2 – quantity of measuring intervals in the experiment.

In the capacity of apparatus with vertical disc the sowing of the seeder of CCT-type, which was installed on the special framework over a ribbon of the stand of a generally accepted construction was used. Four factors were varied: height $x_1(h)$ and diameter $x_2(D)$ of a seed tube, peripheral velocities $x_3(v_0)$ of the twirl of a seed disc and $x_4(v_Л)$ the ribbon of the stand.

Factors $x_1(h)$ and $x_2(D)$ were set by of round metal tubes, but factors $x_3(v_0)$ and $x_4(v_Л)$ – change of a reduction ratio of the mechanism the drive (replaceable starlets). The levels of the factors were varied according to the orthogonal planning of the second order for four factors, closen a condition of technological working ability of the dosator, they are presented in Tab.2.

The seeds of sugar beet of the sort “Verhngachsraya-038” of fraction “4,5…5,5” mm by the disc H 125.04.006 with diameter of the cell 6,0 mm and depth 3,3 mm were seeded. The disc with two row of cells the sectors were used, quantity of the measuring intervals – 200.

Experimental data were treated accordingly with the certain methods, recommended for orthogonal planning: Kohren criterion (characterizing homogeneous of variances), Student criterion (show the significance of regression coefficients) and Fisher criterion (pointing on the adequacy of mathematical model) were defined. The adequate regression model of the second order with variables in a code designation is the view:

$$y = b_0 + b_3x_3 + b_4x_4 , \quad (2)$$

where: $b_0 = 0{,}1295$; $b_3 = -0{,}0298$; $b_4 = -0{,}0136$.

The seeds of sugar beet of the sort “Verhngachsraya-038” of fraction “4,5…5,5” mm by the disc H 125.04.006 with diameter of the cell 6,0 mm and depth 3,3 mm were seeded. The disc with two row of cells the sectors were used, quantity of the measuring intervals – 200.

Table 2. The levels and intervals of a variation of the factors $x_1 - x_4$

Characteristics	Factors			
	$x_1(h)$, mm	$x_2(D)$, mm	$x_3(v_0)$, m/s	$x_4(v_Л)$,m/s
The basic level, $x_i = 0$	425,0	60,0	0,350	2,000
The interval of variation, I	265,0	28,3	0,177	0,708
The upper level, $x_i = 1$	690,0	88,3	0,527	2,708
The lower level, $x_i = -1$	160,0	31,7	0,173	1,292
The upper star point, $x_i = 1{,}4142$	800,0	100,0	0,600	3,000
The lower star point, $x_i = -1{,}4142$	50,0	20,0	0,100	1,000

Influence of each factor separately on the response function was defined at values of other factors, equal 0, ±1 and ±1,4142. The equation (2) takes a view:

when $x_4 = -1{,}4142$,
$$y_{3.1} = 0{,}1487 - 0{,}0298x_3,$$
when $x_4 = 0$,
$$y_{3.2} = 0{,}1295 - 0{,}0298x_3,$$

when $x_4 = 1{,}4142$,
$$y_{3.3} = 0{,}1103 - 0{,}0298x_3,$$

when $x_3 = -1{,}4142$,
$$y_{4.1} = 0{,}1716 - 0{,}0136x_4,$$
when $x_3 = 0$,
$$y_{4.2} = 0{,}1295 - 0.0136x_4,$$

when $x_3 = 1{,}4142$,
$$y_{4.3} = 0{,}0874 - 0{,}0136x_4. \qquad (3)$$

The importance of functions $y_{3.1} - y_{4.3}$ according (3) are computed on the points $x_i = 0$, ± 1, $\pm 1{,}4142$, calculation data are presented in Tab.3

According to the Tab.3 is built graphs, presented on the fig. From theirs is visible, that of the velocities $x_3(v_0)$, $x_4(v_A)$ function y was depended straightlinely, it being known that with increasing these of factors a response is diminishes (the lines $y_{3.1} - y_{3.3}$, $y_{4.1} - y_{4.3}$).

Table 3. The sequence of calculation functions $y_{3.1} - y_{4.3}$

x_i	0,0298 x_3	$y_{3.1}$=0,1487-(2)	$y_{3.2}$=0,1295-(2)	$y_{3.3}$=0,1103-(2)
1	2	3	4	5
-1,4142	-0,0421	0,1980	0,1716	0,1524
-1,0	-0,0298	0,1785	0,1593	0,1401
0	0	0.1487	0,1295	0,1103
1,0	0,0298	0,1189	0.0997	0,0805
1,4142	0,0421	0,1066	0.0874	0,0682
0,0136 x_4	$y_{4.1}$=0,1716-(6)	$y_{4.2}$=0,1295-(6)	$y_{4.3}$=0,0874-(6)	
6	7	8	9	
-0,0192	0,1908	0,1487	0,1066	
-0,0136	0,1852	0,1431	0,1010	
0	0,1716	0,1295	0,0874	
0,0136	0,1580	0,1159	0,0738	
0,0192	0,1524	0,1103	0,0682	

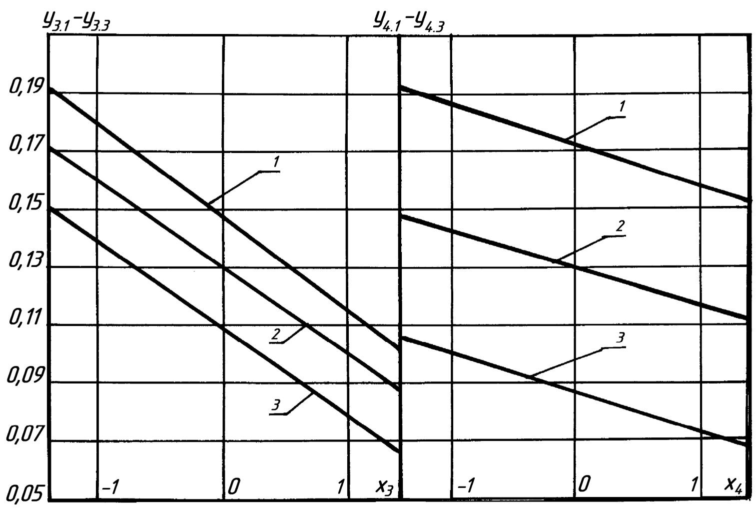

Fig. Graphs of functions $y_{3.1} - y_{4.3}$

PARAMETER OPTIMIZATION OF DOSATOR F0R TECHNIQUE CULTURS ON THE QUANTITY INTERVALS, CLOSE BY TO CALCULATION

The maximum importance function of response on the matrix planning is observed in the experiment № 11: ($y'_{max} = 0{,}212$, when $x_1 = x_2 = x_3 = -1$, $x_2 = 1$). We make the matrix for calculation of maximum importance of the function response Y by quantization of the independent variables [19, 20], Tab.4.

Table 4. The calculation of maximum importance function Y'_{max} of the response

№	b_0 = 0,1295	b_3 = -0,0295	b_4 = -0,0136	$\hat{y}$
1	2	3	4	5
1	1	-1	-1	y'_{max}=0,212
2	1	-1,4142	-1,4142	
3	$b_i x_i$ 0,1295	0,0421	0,0192	0,1908
4	1	-1	-1	
5	$b_i x_i$ 0,1295	0,0298	0,0136	0,1729

The Tab. 4 is constructed as follows: in left column independent arguments x_i and their productions on the regress coefficient b_i are located, in heading – coefficients of regress and their numerical importance. In the line 1 of experiment (that is to say importance of factors x_i) and maximum importance of function response Y from the matrix of planning are represented, further in even lines importance of arguments are represented, and in odd – their productions on corresponding coefficients of regress. In the right last column importance of function $\hat{Y}$, foretell by the equation of regress, are placed. From it is visible, that raise response impossible (the lines 3, 5). Therefore by the coordinates of a special point factorial space take conditions of line 1 Tab. 4 and matrix of planning:

$$Y'_S = 0{,}212;\ x_{1S} = x_{3S} = x_{4S} = -1;\ x_{2S} = 1. \quad (4)$$

So how in the function (2) members of second order is absent, that a surface of response is a plane, without the extreme.

CONCLUSIONS

1. The experimental data were treated with the methods for orthogonal planning second order: Kohren criterion G (characterizing reproduction of the experiments), Student criterion T (show the significance of coefficients regression) and Fisher criterion F (point on the adequacy of the mathematical model). The adequate regression model of the second order with variables in a code designation is in the view:

$$Y = b_0 + b_3 x_3 + b_4 x_4,$$

where: $b_0 = 0{,}1295$, $b_3 = -0{,}0298$, $b_4 = -0{,}0136$.

2. The influence of each factor on the quantity intervals, close by to calculation, was defined by levels other factor, equal ±1, ±1,4142 and 0. It is presented in equation (2), Tab. 3 and fig. From them it is visible, that of the velocities $x_3(v_0)$, $x_4(v_A)$ function Y was depended straightlinely, it being known that with increasing these of factors the response is diminishes (the lines $y_{3.1} - y_{3.3}$, $y_{4.1} - y_{4.3}$).

3. The maximum importance function of response on the matrix planning is observed in the experiment №11: ($Y'_{max} = 0{,}21$; when $x_1 = x_2 = x_3 = -1$, $x_2 = 1$). To raise of the response is impossible (the lines 3, 5 of Tab.4).

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ПАРАМЕТРИЧЕСКАЯ ОПТИМИЗАЦИЯ ДОЗАТОРА ДЛЯ ТЕХНИЧЕСКИХ КУЛЬТУР ПО КОЛИЧЕСТВУ ИНТЕРВАЛОВ, БЛИЗКИХ К РАСЧЕТНОМУ

Виктор Белодедов, Павел Носко, Григорий Бойко, Павел Филь, Марина Мазнева

Аннотация. Представлены результаты многофакторного эксперимента, поставленного по матрице ортогонального планирования для четырех факторов: высоты и диаметра семяпровода, а также скоростей вращения высевающего диска и движения посевного агрегата.

Результаты экспериментов обработаны в соответствии с методикой, характерной для ортогонального планирования, получена адекватная математическая модель процесса, по которой установлено влияние факторов и оптимальные условия высева.

Ключевые слова: количество интервалов, близких к расчетному, влияние факторов, оптимизация.

Mathematical modeling of magnetic stray fields defects ferromagnetic products

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S u m m a r y . Proposed a method of limiting the area occupied by a ferromagnetic material containing a defect such as "crack" in the calculation of the magnetic stray field defect method of integral equations. Two variants of restrictions are considered: in the numerical solution of the surface integral equation and the solution of the spatial integral equation.
K e y w o r d s : magnetic field, defect, computational domain.

INTRODUCTION

The simplest method of calculating the stray magnetic fields of the defects is a reference density of fictitious magnetic charges on the surface of their walls followed by calculation of the field on the analytical dependence [2, 13, 14, 15]. This method has several disadvantages. These include the following: density fictitious charges on the surface of defects is given a uniform and is calculated by semi-empirical formulas, leading to considerable error, moreover, in addition to fictitious surface magnetic charge in the vicinity of the defect volume include magnetic charges significant contribution to the magnetic field distribution in the defect. Therefore there is a need to find a method that provides a more accurate calculation of the magnetic stray field of the defect, which is important because by parameters of the magnetic field distribution the means are chosen, which measure the field and form the initial information about it.

MATERIALS AND METHODS

Promising in respect the calculation of the magnetic fields of defects is the method of integral equations [11, 17, 20, 23], which gives the opportunity to calculate the magnetization vector field in the local region containing the defect, and then determine the magnetic stray field defects such as discontinuities of metal. In a number of publications [10, 21, 22, 24] contains information about the used integral equations for calculating the defect fields.

A significant obstacle to the widespread use of the method of integral equations in the field of calculation of defect fields of ferromagnetic products is the uncertainty of the volume limits of the magnetized region, which is a defect. This uncertainty makes it necessary for the implementation of the method of calculation of the field defect of the numerical solution of the integral equation split into elementary volumes of the entire piece, while the defect takes insignificant of its volume. In some cases, the volume containing defect is cut out from the detail and placed in a uniform magnetic field and calculated the scattering field of the defect together with the field of the selected volume. The magnitude of the magnetizing strength of a uniform magnetic field is connected indirectly with the field strength of real magnetizing field source.

Therefore, for the effective application of the method of integral equations for the calculation of the magnetic stray field of the ferromagnetic part of the defect, we need a method that allows reasonably limit the ferromagnetic region of space in which there is a defect. It is dedicated to the real work.

Development of a method to limit the space of a ferromagnetic region in which the defect is located when calculating its magnetic leakage field by the numerical method of solution of the integral equation. Flaw detection of ferromagnetic production is performed in the applied and the residual magnetic fields. Is considered that if the article material has a coercive force of less than 1500 A/m [3, 5, 15] inspection of defects is advantageously carried out in an applied magnetic field, the magnetization and field measurement in the field of the defect with transmitter (ferroprobes, Hall sensor) to perform the same time. Inspection of defects in the residual field is made by the magnetization of part of the product or the entire product to a state close to saturation, then the source of the magnetic field is turned off, and the product is controlled by the residual magnetization.

The applied field does not lead to saturation of the material and for the calculation of the normal component of the magnetization vector on the surface of the product is used surface integral equation [19, 24]:

$$\sigma(Q)-\frac{1}{2\pi}\lambda\oint_S \sigma(P)\frac{\cos\left(\bar{r}_{QP},\bar{I}_{nQ}\right)}{r_{Qp}^2}dS_P = 2\mu_0\lambda H_{CTn}(Q), \quad (1)$$

wher: $\lambda=\frac{\mu-1}{\mu+1}$,

$$r_{QP}=\sqrt{\left(x_P-x_Q\right)^2+\left(y_P-y_Q\right)^2+\left(z_P-z_Q\right)^2},$$

$x_P, y_P, z_P, x_Q, y_Q, z_Q$ – coordinate points of P and Q,

H_{CTn} – normal component of the vector of the magnetizing (probing)field $H_{CTn}=\bar{I}_{nQ}H_{CT}$,

S – complete surface of the part and defect,

μ – relative magnetic permeability.

(Equation 1) for numerical solution has a bad convergence, because $\lambda\approx 1$, that's why while solving it different methods of regularization are used [6, 8, 18].

If you do not take into account the impact of the defect, then under the influence of the field of the magnetizing device fictitious magnetic charges appear on the surface of the product which equal to:

$$\sigma_\phi(Q)=2\mu_0\lambda H_{CTn}(Q), \quad (2)$$

as on an infinitely smooth flat part $\bar{R}_{QP}\perp\bar{I}_n$ and integral in equation (Eq. 1) equals zero.

The proposed method for isolating the defect is as follows. Around the defect rectangular area S_U is allocated, which has the density of charges $\sigma_\phi(Q)$, which creates a magnetic field directly on the surface of the defect equal:

$$\bar{H}_\phi=\frac{1}{4\pi}\int_{S_U}\frac{\sigma_\phi\cdot\bar{I}_{r\partial}}{\left|\bar{r}_u-\bar{r}_\partial\right|^2}dS, \quad (3)$$

where: $\bar{I}_{r\partial}$ – a unit vector directed from a point on the workpiece U, to the point on the surface of defect ∂,

$\bar{H}_\phi$ – the vector of the magnetic field created by surface fictitious magnetic charges.

For a geometric model shown in Fig. 1, equation (Eq. 1) can be rewritten as:

$$\sigma(Q)=\frac{1}{2\pi}\lambda\oint_{S_\partial}\sigma(P)\frac{\cos\left(\bar{r}_{QP},\bar{I}_{nQ}\right)}{r_{Qp}^2}dS_P + \frac{1}{2\pi}\lambda\oint_{U_\partial}\sigma_\Phi(P)\frac{\cos\left(\bar{r}_{UP},\bar{I}_{nQ}\right)}{r_{Up}^2}dS_U+2\mu_0\lambda H_{CTn}(Q), \quad (4)$$

where: S_∂ – surface of the defect.

The numerical solution of (Eq. 4) gives the density of the fictitious magnetic charges in the centers of the elementary areas. Then, according to the formula (Eq. 3) wherein σ_Φ is replaced by $\sigma(Q)$, magnetization vector of leakage field of the defect is calculated.

After calculation values of functon $\sigma(Q)$ space S_U receives an increment ΔS_U and again determined by the value of $\sigma(Q)$. The process of increasing the area S_U is as long as not fulfilled the condition:

$$\left|\sigma^{n+1}(Q)-\sigma^{n}(Q)\right|<\sigma^{n}\varepsilon, \tag{5}$$

wher: ε – given small number.

Condition (Eq. 5) means that the value S_U with a simple layer of fictitious magnetic charges located on it will cease to influence the distribution of the charge density on the surface of the defect.

Mathematical model of the magnetization vector field in a nonlinear medium. Calculation of the magnetic leakage field of the defect in the residual magnetization requires the calculation of the magnetization vector field in a nonlinear medium by numerical solution of the integral equation of the spatial.

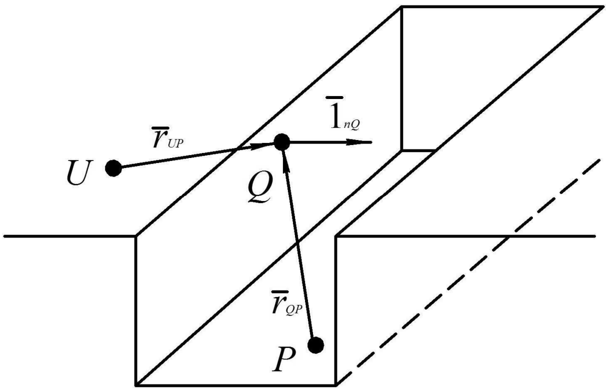

Fig. 1. The geometric model of the defect and the limited plane of the article

The numerical solution is carried out by dividing the area occupied by ferromagnetic materials for elementary volumes (EV). In this case, the spatial integral equation reduces to a system of algebraic equations [4, 12, 15]:

$$\overline{H}_i=-\frac{1}{4\pi}\sum_{j=1}^{N}\sum_{k=1}^{6}\left(\overline{M}_j\overline{1}_{nj}\right)\int_{S_{kj}}\frac{\overline{R}_{ij}}{\overline{R}_{ij}^{3}}dS_{kj}+\overline{H}_{CT.i}, \tag{6}$$

$$i=\overline{1,N_1},\ j=\overline{1,N},$$

where: i,j *– observation point and the source,*

$\left|\overline{R}_{ij}\right|=\left|\overline{R}_i-\overline{R}_j\right|=\sqrt{\left(x_i-x_j\right)^2+\left(y_i-y_j\right)^2+\left(z_i-z_j\right)^2}$,

$\overline{1}_{nj}$ – the unit vector normal to the surface j-th EV, $\overline{H}_{CT.i}$ – vector of the external magnetic field at the center *i*-th EV.

It's considered a variant of when the product is magnetized in a closed magnetic circuit (Fig. 2).

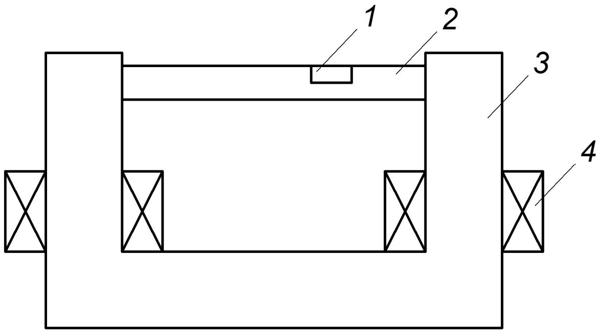

Fig. 2. Simplified design of the magnetizing device: 1 – the area of the defect, 2 – controlled part, 3 – magnetic, 4 – reel

When testing the items in a closed magnetic circuit magnetization of the product is equals the residual magnetization M_r. If the control part takes place outside of the magnetic circuit, the magnetic state of the circuit depends on the demagnetization factor modulated by volume. To determine the magnetization at the location of the defect it's necessary to calculate the demagnetization factor in volume adjacent to defect.

Demagnetization factor is calculated for each EV**.** It is assumed that the product is placed in a sided uniform magnetic field, and the direction of the magnetization vector coincides with the axis of the product**.** The magnetization of each EV is calculated by numerically solving the system of equations (Eq. 6). As a result of solution we find values M_{xi}, M_{yi}, M_{zx}, as well as the components of the tension field demagnetization H_{pxi}, H_{pyi}, H_{pzi} according to formula:

$$\overline{H}_{pi}=-\frac{1}{4\pi}\sum_{j=1}^{N}\sum_{k=1}^{6}\left(\overline{M}_j\overline{1}_{nj}\right)\int_{S_k}\frac{\overline{R}_{ij}}{\overline{R}_{ij}^{3}}dS_{kj}. \tag{7}$$

The known values of the components of the magnetization vectors and field intensity degaussing make it possible to calculate the demagnetization coefficients in each EV. Introduce the concept of vector demagnetization coefficient for each *i*-th EV, which is written in a rectangular coordinate system in such way:

$$\bar{N}_i = \bar{I}_{xi} N_{xi} + \bar{I}_{yi} N_{yi} + \bar{I}_{zi} N_{zi},$$
$$N_{xi} = \frac{H_{pxi}}{M_{xi}}, N_{yi} = \frac{H_{pyi}}{M_{yi}}, N_{zi} = \frac{H_{pzi}}{M_{zi}}. \quad (8)$$

The magnitude of vector $\bar{N}$ is determined by the external field strength, which provides the maximal value of the magnetic permeability of the ferromagnetic material.

The known values of demagnetization allow finding the magnetic field inside the product $\bar{H}$ with certain external field intensity $\bar{H}_{CT}$ according to the formulas:

$$N_x = \frac{\bar{H}_{CTx}}{1 + N_x \chi}, N_y = \frac{\bar{H}_{CTy}}{1 + N_y \chi}, N_z = \frac{\bar{H}_{CTz}}{1 + N_z \chi}, \quad (9)$$

where: χ – magnetic susceptibility of the material.

By solving the system of equations:

$$M = M(H), M = -(1/N)H, \quad (10)$$

the residual magnetization is found for each EV. Next is illustrated by the following example.

The hysteresis loop of the magnetic material in the second quadrant is approximated by a parabola of the form $M(H) = -aH^2 + b.$

Values a and b are found from condition: at $H = 0$, $M = M_{r}$, at $M = 0$, $H = H_c$, which implies:

$$M = \frac{M_r}{H_c^2} H^2 + M_r. \quad (11)$$

Dependence (Eq. 10) equates the linear function $M = -mH$, where m – permeability form, $m = 1/N,$ resulting in a quadratic equation:

$$\frac{M_r}{H_c^2} H^2 - mH - M_r = 0. \quad (12)$$

The solution (12) is analytical relations:

$$H_1 = \frac{m - \sqrt{m^2 + \frac{4M_r^2}{H_c^2}}}{2M_r / H_c^2}, M_1 = -m\frac{m - \sqrt{m^2 + \frac{4M_r^2}{H_c^2}}}{2M_r / H_c^2}. (13)$$

Equation of the form $H = -mf(H)$ is solved by iteration practically at any approximation curve of the hysteresis loop in the second quadrant.

With the known values of the coefficient of demagnetization $\bar{N}_i$ for each *i*-th EV according to known values $\bar{H}_{CT}$ it's possible to find the magnetization in each *N* of EV. For this it is necessary to solve the following three non-linear equations:

$$m_x(H_{CTx} - H_x) = M(H), m_y(H_{CTy} - H_y) = M(H),$$
$$m_z(H_{CTz} - H_z) = M(H).$$

Here *M(H)* is a function of magnetization.

Solving these equations gives the values of the constituent vectors $\bar{H}_i$ and $\bar{M}_i$ in ferromagnetic material at known value $\bar{H}_{CT}$ in each *i*-th EV.

When calculating the stray magnetic field in the closed magnet system the module of magnetization vector equals M_{r}, direction of magnetization vector coincides with the axle of a detail, the area around the defect as a parallelepiped, whose dimensions along the *x* axis by an order exceeds the size of the defect, and the axes *y*, *z* – 5 times (Fig. 3). The selected volume is divided into *N* EV.

At the ends of the selected volume placed EV whose length tends to infinity. Their quantity equals *T*. It's considered that magnetization in infinitely long EV equal M_r.

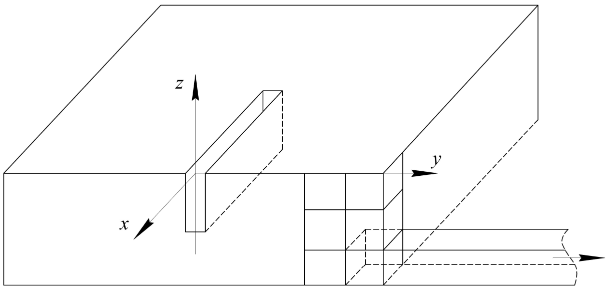

Fig. 3. Isolation of the subregion in the amount of controlled products

Simulating a closed magnetic circuit is performed by connecting to the subdomain EV of infinite length which contains defect**.** In the absence of a defect fictitious magnetic charges on the faces of the adjacent EO compensate each other, as a result the demagnetization field is missing and $H=H_{CT}$ (Fig**.** 4).

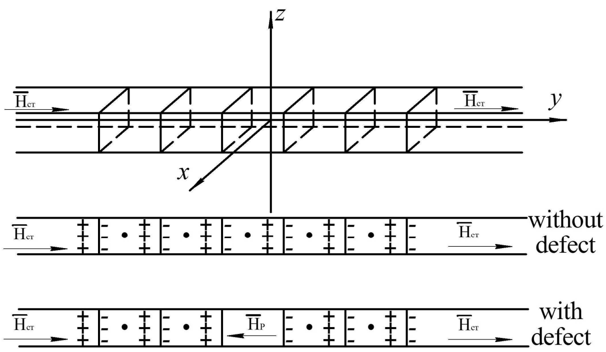

Fig. 4. Simulation of a closed magnetic system

If a defect arises degaussing field strength $\bar{H}_p$, which reduces the external magnetic field adjacent to the defect in the EV.

In the formula (Eq. 6) the integration is over the faces (planes) EV, so:

$$\left|\bar{r}_i-\bar{r}_j\right|= =\sqrt{\left(x_i-x_j\pm\Delta x_j\right)^2+\left(y_i-y_j\pm\Delta y_j\right)^2+\left(z_i-z_j\pm\Delta z_j\right)^2}. \quad (14)$$

In (Eq. 14) the sign in front Δx, Δy, Δz selected in accordance with the face on which the integration is performed. For EV infinite length $y_i\to\infty;\ \Delta y\to\infty$ (Fig. 5).

Therefore, the point t is transferred to the center of an infinitely long edge of EV which faces the selected volume with defect. Consequently, for the edges of EV of infinite length can be written:

$$\left|\bar{r}_i-\bar{r}_j\right|=\sqrt{\left(x_i-x_t\right)^2+\left(y_i-y_t\right)^2+\left(z_i-z_t\right)^2}.$$

For the calculation of the field in the selected volume in the mode of the external field $\left(\bar{H}_{CT}=0\right)$, (Eq. 6) is rewritten as:

$$2\pi\bar{H}_i=-\sum_{j=1}^{N}\sum_{k=1}^{6}\left(\bar{M}_j\bar{I}_n\right)\int_{S_k}\frac{\bar{I}_r}{\left|\bar{r}_j-\bar{r}_i\right|^2}dS_k+ +\sum_{t=1}^{T}\left(\bar{M}_{rt}\bar{I}_n\right)\int_{S_t}\frac{\bar{I}_r}{\left|\bar{r}_t-\bar{r}_i\right|^2}dS_t. \quad (15)$$

Thus, in (Eq. 15) the field source is magnetized volume of ferromagnetic material with the magnetization M_r. System of equations (Eq. 15) is solved iteratively. Start of iterations should be done with the value $M_1=M_r$.

After determination of M_1 values of M_1 are compared in EV, located at the border of the selected subdomain, which contains defect with the value M_r according to the formula: $M_1=M_r$.

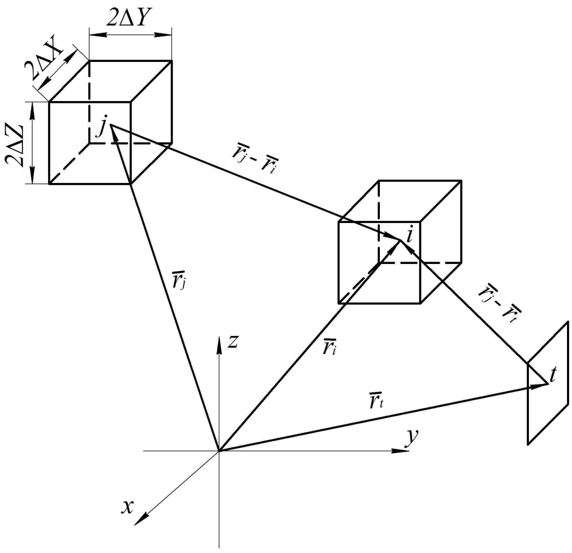

Fig. 5. To solving the system of equations (Eq. 15)

If this inequality is not satisfied, there is an expansion in subdomain containing the defect, by the amount $2\Delta x$, $2\Delta y$, $2\Delta z$ and calculation of magnetization is repeated.

When calculating the stray magnetic field defects in the product, which is out of the magnetizing device, it is also allocated the region in the vicinity of the defect. Outside this region, the magnetization is determined by solving the system of equations (Eq. 10) and the definition of the vector demagnetization factor for the EV. The equations are solved:

$$H_x = -N_x M(H), H_y = -N_y M(H), \\ H_z = -N_z M(H) \tag{16}$$

relatively to H_x, H_y, H_z values M_{1x}, M_{1y}, M_{1y} are determined. This value of the magnetization takes place in an infinitely long EV. The system of equations (Eq. 15), where M_{1t} is used instead of M_{rt} is solved. With these values of the magnetization begins an iterative process of solving a system of algebraic equations (Eq. 15). As a result of solutions are used vectors $\bar{M}$ in each EV of subdomain. After that the procedure of comparing the magnetization on the boundary of subdomain is held. If the inequality is satisfied for $|M_1 - M| \le M_1 \varepsilon$, where ε – given small number, then expansion of the defect at value $2\Delta x$, $2\Delta y$, $2\Delta z$ begins.

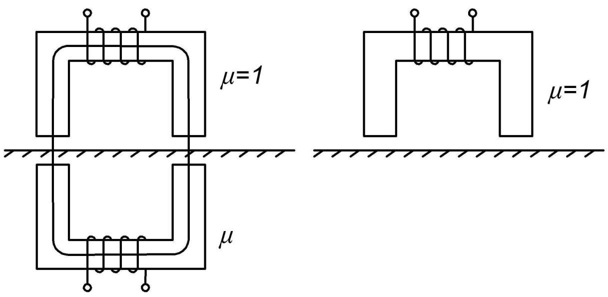

Fig. 6. Calculation of the field by mirror images (Searle basis): a – calculated magnetic scheme in air, b – the design scheme of the magnetic system in a ferromagnetic material

Mathematical model of the magnetization vector in locally magnetized region containing the defect. Calculation of the magnetic stray field of the defect is divided into two stages. On the first stage is a preliminary calculation of the field in a ferromagnetic material on the basis of Searle [1, 7, 9, 16]. As a result of the calculation performed in the first stage, pre-determined area in which the magnetization vector module exceeds a preset value M_c.

By the method of calculation of the magnetic circuit is calculated field strength in the air and magnetizable material Fig. 6. In the equivalent magnetic circuit:

$$Iw_3 = \frac{\mu - 1}{\mu + 1} Iw, \; R_C = R_{C3} = \frac{l_C}{\mu_0 \mu(H) S_C},$$

where: Iw – magnetizing force of the magnetic circuit,

R_C – the reluctance of the core.

The magnetic flux in the magnetic circuit is:

$$\Phi = \frac{Iw + Iw_3}{2R_C + R_B} = \frac{Iw + Iw_3}{\dfrac{2l_C}{\mu_0 \mu(H) S_C} + \dfrac{2l_B}{\mu_0 S_C}},$$

where: R_B – the reluctance of the air gap at twice the length $R_B = 2l_B / (\mu_0 S_C)$.

The flux is calculated using an iterative method depending *M(H)*. The calculated value of the magnetic flux allows finding induction and the magnetization of the core $B_C = B_B = \Phi / S_C$, $M = B_C / \mu_0 - H$.

In the second phase calculation of the field is held by the method of the numerical solution of the integral equation in the highlighted area in the first phase, which is divided into EV. The area is complemented with EV of infinite length (Fig. 7), which have a magnetization equals $\bar{M}_t = \chi \bar{H}_{CT}$, wher: χ – the average value of the magnetic susceptibility, $\bar{H}_{CT}$ – the vector of magnetic field strength of magnetizing device.

The system of algebraic equations corresponding to the integral equation takes the form:

$$H_i = -\frac{1}{4\pi} \sum_{j=1}^{N} \sum_{k=1}^{6} \left(\bar{M}_j \bar{I}_n \right) \int_{S_k} \frac{\bar{I}_r}{\left| \bar{r}_j - \bar{r}_i \right|^2} dS_k + \\ + \bar{H}_{CT} + \sum_{t=1}^{T} \left(\bar{M}_t \bar{I}_{nt} \right) \int_{S_t} \frac{\bar{I}_{ir}}{\left| \bar{r}_t - \bar{r}_i \right|^2} dS_t. \tag{17}$$

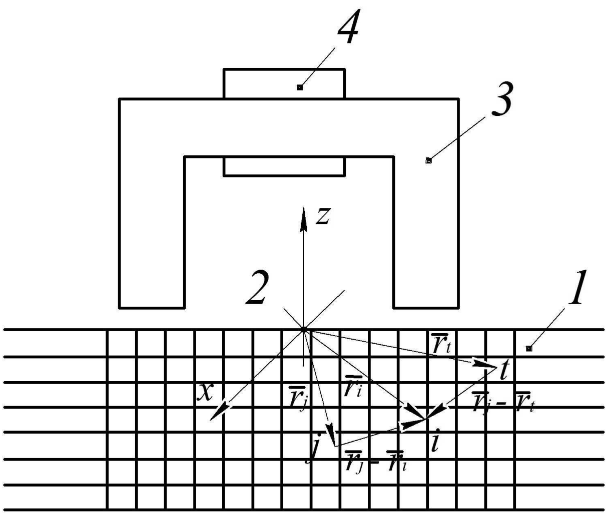

Fig. 7. The magnetizer of local type: 1 – controlled product, 2 – defect, 3 – magnetic circuit, 4 – inductor

The solution of the system (Eq. 17) is the value of the magnetization in each *i*-th EV. Equation (Eq. 17) is solved with the geometry of the defect, located in the subdomain.

After determining values $\bar{M}_i$ in EV, adjacent to the boundary of subdomain, there is a comparison $\bar{M}_i$ with the value $\bar{M}_t$ in accordance with the following relationship:

$$|M_t - M_i| \le M_t \varepsilon. \quad (18)$$

If the direction (Eq. 18) is not satisfied, expansion occurs in subdomain in the direction of vector $\bar{H}_{CT}$ for one linear dimension of EV and the whole calculation of the field vector $\bar{M}_i$ is repeated again.

Known values $\bar{M}_i$ and $\bar{M}_t$ allow the calculation of the magnetic field vector of the scattering defect according to formula (Eq. 16), in which $\bar{H}_{CT} = 0$.

Equal importance is normal component of the magnetization on the surface of the poles of the core of the magnetizing device facing the plane of the controlled product.

To calculate the field created by the poles in a ferromagnetic medium, it is necessary instead of M in the formula for the calculation of the field substitute $M' = M \cdot 2/(\mu + 1)$.

Calculated values $\bar{M}_i$ correspond to the applied magnetic field at the included current in the windings of the magnetizing device and allow you to find the magnetization vectors of the demagnetization factor for each EV according to formulas (Eq. 8).

Furthermore, by solving the nonlinear equations (Eq. 16) found the values of the vector $\bar{M}_i$ at the disconnected and remote field of verification of magnetizing device. The known values of the magnetization vector components make it possible to calculate the magnetic stray field of the defect.

CONCLUSIONS

1. Closed surface of the ferromagnetic part, on which the defect of "crack type" in the calculation of the magnetic field, its scattering the method of numerical solution of the integral equation can be restricted to the local rectangular platform with a simple layer of magnetic charges.

2. In the calculation of the field defect in nonlinear ferromagnetic medium proposed to localize the area surrounding the defect, by the introduction of infinitely long elementary volumes.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ МАГНИТНЫХ ПОЛЕЙ РАССЕЯНИЯ ДЕФЕКТОВ ФЕРРОМАГНИТНЫХ ИЗДЕЛИЙ

Владимир Безкоровайный, Павел Ивановский, Валерий Яковенко

Аннотация. Предложен метод ограничения области, занятой ферромагнитным материалом, содержащей дефект типа "трещина", при расчете магнитного поля рассеяния дефекта методом интегральных уравнений. Рассмотрены два варианта ограничения: при численном решении поверхностного интегрального уравнения и при решении пространственного интегрального уравнения. Ограничение области расчета производится путем использования элементов бесконечной длины, которыми охватывается область.

Ключевые слова. Магнитное поле, дефект, область расчета.

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Advanced methodology of assessment of technical state of overhead type cranes

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S u m m a r y . Methodology of assessment of technical state of metal structures as well as determination of the time of further safe operation of climbing cranes based on the use of generalized (complex) parameter which characterizes the technical state of metal structure of cranes has been considered in the article.

K e y w o r d s . Methodology, climbing crane, technical state, generalized parameter, desirability function.

INTRODUCTION

It is well known that the resource of climbing cranes is determined by the level of technical state (TS) of its metal structure. From a number of studies [12, 13, 18] it is known that TS of cranes metal structure is characterized by numerous parameters. There is large number of parameters which characterize TS of cranes. This makes it difficult to get a comprehensive assessment of TS of climbing cranes. It is possible to reduce the number of parameters (up to one) using the desirability function of Harrington [10] which allows to get one complex (generalized) parameters from some parameters. The concept of such approach and methodology of assessment of the TS of climbing cranes are given in studies [1, 2].

Approbation of the methodology of assessment of TS of metal structure of climbing cranes given in the scientific work [2] and analysis of recent publications on the subject of studies [5, 8, 20, 21] require modernization of the methodology offered before.

MATERIALS AND METHODS

In our opinion objective approaches of assessment of TS of metal structure of climbing cranes are concepts of methods described in the studies [13, 18]. According to the offered concept a criteria approach must be taken as the main approach while assessing TS of climbing cranes. In the course of this approach the quantitative assessment is determined by index or a group of indexes calculated or obtained from the measurements and compared with the admissible value.

The methods given in the studies [13, 18] deserve much attention. They include the fact that the author offers to use the multi-criteria approach to the assessment of the TS recommending compare current parameter values with its admissible values.

According to the information from the source [11] expert examination of climbing cranes is made abroad. But the task of expert surveys is formulated in a different way. A typical formulation of the task of expert survey is given in the introduction to the International Standard ISO 12482-1 [14]. It is noted that cranes cannot operate uncertain time. They must be operated within the limits specified by the manufacturer. The terms of expert examinations are specified by the manufacturer.

Recently the method of assessment of TS of metal structure and forecasting of residual resource of the crane on the basis of non-destructive check (coercive force, coefficient of variation of hardness, metal magnetic memory) has been widely spread [9, 19]. However, it has a number of significant shortcomings that limits possibility of their use to solve the set tasks, for example, while determining the damage of the unit of metal structure the tension value at which this unit was operated is not taken into consideration and there are no means that allow to use dependences obtained for laboratory samples to solve the tasks on assessment of residual life of metal structure of crane [8], difficulties of assessment of operational integrity of metal structure of cranes with different thicknesses of the elements [5] .

Thus, summing up the considered approaches of assessment of TS of cranes we can come to conclusion that there is not a single science-based method at present.

Assessment of TS of climbing cranes is held according to the normative document [17]. The scope of work includes even examination that has non-destructive check of metal structure of cranes. However, the values of parameters of TS of metal structure of cranes obtained on the indicated methodology remain discrete that does not provide a complete picture of TS and the risks of further operation of the crane.

RESULTS, DISCUSSION

To suggest a modernized methodology of assessment of TS of metal structure of climbing cranes on the example of the overhead type crane that is based on the use of generalized (complex) parameter subject to the latest trends in the field.

As an object of research the overhead type cranes have been chosen as the most common type of climbing cranes the number of which exceeds 50 % of the total number of cranes in Ukraine.

Considering that the number of parameters that characterize the TS of metal structures of overhead type cranes is large; in our opinion the main ones are:

- value of the normal stresses in the metal,
- value of the horizontal inertial load that makes influence on the metal structure of the crane,
- general and local residual deformation of the crane's metal structure,
- mechanical and corrosion damage of the metal structure's elements,
- mechanical properties and chemical composition of materials of the crane metal structure,
- the value of the elastic deflection of the main beams of the crane bridge under load , etc.

Knowing the current values of parameters of TS and the principles of their change, we can estimate the time of their marginal state.

When solving tasks with several variables (parameters) we offer to use a so-called desirability function as a versatility indicator [10].

The desirability d_i means one or another desirable parameter level. At a special scale (Fig.) the value d_i can vary from 0 to 1. The scale is as follows:

d = 1,00 - the maximum possible parameter value,

d = 1,00 - 0,80 - maximum and admissible parameter value,

d = 0,80 - 0,60 - admissible and good parameter value,

d = 0,60 - 0,37 – admissible and satisfactory parameter value

d = 0,37 - 0 – poor parameter value.

Values of d on the scale of desirability can be displaced up and down depending on specific situations.

The idea of using desirability function as a complex parameter of crane's TS is that the value of each parameter of TS (y_i), the number of which can be large, is converted into the appropriate particular desirability (d_i); thereafter the so-called generalized desirability function (D) forms that is a geometric mean of desirability of separate parameters of the TS :

$$D=\sqrt[g]{d_1 \cdot d_2 \dots \cdot d_g}, \qquad (1)$$

where: g is the number of selected technical parameters of technical state of the crane.

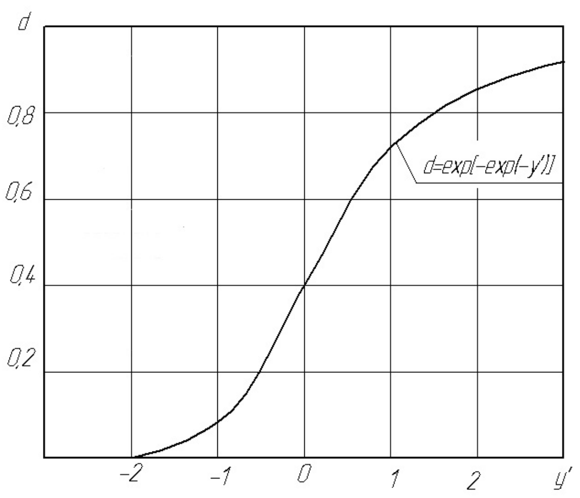

Fig. Chart of desirability function for one-sided constraint parameters

As a result the generalized desirability function turns to be the only parameter to assess the technical state instead of many ones.

The values of particular functions (parameters) of desirability d_1, d_2, d_3 are received by means of converting measured values of chosen parameters of the technical state into non-dimensional quantity on the formula (2):

$$d_i = e^{-(e^{-y_i'})}, \qquad (2)$$

where: y_i' is a certain non-dimensional quantity related (often linearly) with the response y_i,

$$y_i' = a_0^* + a_1^* y_i. \qquad (3)$$

The coefficients a_0^* and a_1^* are determined by setting the two values of the response function y_i corresponding to the basic (limiting) values of particular desirability function d_i.

Formula (2) can be applied when the parameter has got a one-sided constraint.

If these are two-sided constrains for parameter, notably, they are given as $y_{min} \le y \le y_{max}$ so then it is convenient to set the desirability function as follows:

$$d_i = e^{-\left(\left|y_i'\right|\right)^n}, \qquad (4)$$

where: n is a positive number,

$$y_i' = \frac{2y_i - (y_{max} + y_{min})}{y_{max} - y_{min}}. \qquad (5)$$

The exponent n can be calculated if to set the value d to the parameter y (preferably in the range 0,6 <d <0,9), calculate the counterpart $|y'|$ referring to (5) and thereafter use the formula:

$$n = \frac{\ln \ln \frac{1}{d}}{\ln\left|y'\right|}. \qquad (6)$$

Choosing different values n, it is possible to set different desirability curvature of a curve. This allows to take into account the particular importance of separate parameters of TS: for them n will be of greater importance and a small change of parameter near the limiting ranges will correspond to the rapid change of desirability.

The generalized parameter D of TS of cranes allows to take the examined crane to one or another group of its TS. The resulting value of the generalized parameter D of TS is to determine the safety factor K_s, which is rated by the formula:

$$K_s = \frac{1}{\kappa_a \cdot \kappa_c \cdot \kappa_m} \cdot D, \qquad (7)$$

where: κ_a – coefficient of crane's "age", κ_c – coefficient of the operating conditions, κ_m – coefficient of operating mode.

It should be noted that the number of coefficients can be increased according to the characteristics and special operating conditions as well as allocation of crane. Safety factor $K_б$ can be used to determine the time of further safe operation of crane which is determined on the formula according to [20]:

$$T = T_p \cdot K_s, \qquad (8)$$

where: T_p – the rated resource of the crane according to its operating mode and passport data, K_s – coefficient of the carne's safety.

On the basis of analysis of a priori information out of numerous parameters that characterize the TS of metal structures of overhead type crane we have adopted:

σ – normal stress in the main supporting girders of a crane, MPa,

HB – Brinell hardness of the metal from which metal structure of crane is made, MPa,

f – residual deflection of the middle part of the main beams of the crane bridge mm.

We take into consideration these parameters as they characterize the TS of the crane's metal structure in the best way. Let us examine their characteristics in details.

Normal stresses in metal.

Cranes that are in operation for a long time may decrease in size of the cross-section of bearing elements due to the impact of various environmental factors. Therefore, it is necessary to check the calculations on the strength and stiffness of metal structures subject to the actual thickness of the metal structures elements.

In the practice of crane building two methods of calculating metal structures are applied:

- calculation on the method of allowable stresses based on the coefficient of safety factor established by practice; in this case the calculation is made either at the equivalent and maximum loads or at the basic and additional loads,

- calculation according to the method of limiting states that is based on statistical study of the actual load of structures in the field.

When calculating crane bridges on the allowable tension on the basic and basic plus additional loads two kinds of loads are considered:

- main (vertical) loads subject to dynamic coefficients,

- basic loads subject to dynamic coefficients and additional (horizontal) loads which are calculated without dynamic coefficients.

The dynamic coefficient of influence of the main loads on the crane metal structure is taken by the generalized dynamic coefficients [3 , 4]. Two dynamic coefficients are given:

Ψg - dynamic coefficient for the weight of crane components taken depending on the speed of movement of the crane:

when: $V_к < 1$ m/s $\Psi_g = 1{,}0$, at $V_к = 1\text{-}2$ m/s $\Psi_g = 1{,}1$, at $V_к > 2$ m/s $\Psi_g = 1{,}2$,

Ψ_Q - dynamic coefficient for cargo taken depending on the mode of operation of the crane: $\Psi_Q = 1{,}1$, $\Psi_Q = 1{,}2$, $\Psi_Q = 1{,}3$, respectively for light, medium and heavy operating regime of cranes.

Allowable tensions when calculating crane metal structures on the basis of load are usually denoted as $[\sigma]_I$, and when calculating basic and additional loads they are denoted as $[\sigma]_{II}$. When defining $[\sigma]_I$ safety factors are in the range 1.5-1.7, and for $[\sigma]_{II}$ safety factors are 1,33-1,4.

Hardness of the metal HB from which metal structure of the crane is made. The quality of steel is one of the main factors that determine the duration of operation of metal structures of cranes. The quality of steel is characterized by index of mechanical properties of steel such as conventional yield strength $\sigma_{0,2}$, ultimate stress limit $\sigma_в$, percent elongation δ, narrowing ψ, and toughness KCV. In the process of long-term operation of cranes the values of mechanical properties of steel can change. They can be determined indirectly while testing the hardness of metal.

Ultimate stress limit $\sigma_в$ and hardness HB are related to each other:

$$\sigma_в = к \cdot HB \quad (9)$$

where: HB is measure of the Brinell hardness, k is the coefficient of the steel type (k = 0.33 - 0.36).

The table for re-calculation of HB and $\sigma_в$ is given in State Standard 227671-77 [6].

Conventional ultimate strength $\sigma_{0,2}$ on the HB values (for hardness HB ≥ 1500 MPa) can be determined from the formula:

$$\sigma_{0,2} = 0{,}367 \cdot HB - 240, \quad (10)$$

and for the hardness of HB <1500 MPa from the formula

$$\sigma_{0,2} = 0{,}2 \cdot HB\,. \quad (11)$$

It should also be noted that the hardness of metal and the coercive force have quite good correlation [8]. This allows to refuse to measure coercive force while assessing TS of cranes metal structure having given preference to measuring the hardness of HB as a less costly method.

The deflection f of the main beams of the crane’s bridge.

One of the main parameters that characterize the state of stress and operation life of the cranes is the deflection of the main beams of the bridges [7, 16]. At the time of cranes loading elastic vibrational deflections appear; they disappear after removal of the load and thereafter the beams come to their primary position. In the process of long-term operation of cranes residual deflection that exceeds the permissible norm appears in the bridge. It means that it is dangerous to use the crane at its nominal capacity.

Residual deflection can occur in welded and riveted (to a lesser extent) structures of beams after the first load. The second loading that does not exceed the level of the first one does not lead to the formation of residual deflection. As regards welded beams, residual deflection occurs from the beginning of load. Depending on the level of the stress state the residual deflection can be 1/1200 of the span (at a maximum stress 175 MPa). In this case the further work of the beam goes well.

Thus, the camber of longitudinal girders reduces significantly after the first load. With the further operation of the crane residual deflection will increase. Studies have shown that the crane can be operated without any restrictions if there is residual (negative) deflection f <0,0022 L (L - crane span). When deflections are 0,0022 L <f <0,0035 L there must be control over the development of residual deflection, namely, leveling at least once in four months. Residual deflection f=0,0035 L is the maximum, so that is why operation of the crane with such a residual deflection is not allowed.

The need to determine the residual deflection of the main beams is caused by the fact that during long-term operation of the overhead type cranes at recursive short-time mode the residual deflections of the main beams arise as a result of plastic deformations in the material of the structure. The maximum residual deflection of the main beams is regulated by the limiting state of metal structure of the crane and by the working joint welds on the basis of yield strength and safety factor of the structure material. If the tension in the welds exceeds the yield strength so then cracks can occur in the most loaded parts of the metal structure. Although the formation of cracks in the welds of local significance does not break the firmness of the whole structure, but they can be a focus of destruction so the work of the crane must be stopped until the strength of metal structure is restored [15].

The example of calculation of the generalized parameter D of TS for the bridge hook crane of general-purpose with the span L=18 m.

Creation of the desirability scale.

Conversion of the values of each of the above mentioned parameters into the corresponding desirability d_i is made by means of desirability scale the diagram of which is shown in Figure. To convert parameters of TS of crane the marks have been mapped on the scale of desirability for representative value of the parameters σ, HB, f. In this case, the following considerations have been taken. The lower bound "satisfactory" includes: for normal stresses σ - the maximum value [σ]≤160 MPa (for the steel grade St 3); for hardness of HB metal (steel CT3) - the maximum value of hardness [HB]≤1430 MPa, for the residual deflection of the main beams of the bridge f - the maximum value for the crane, for example, with a span L=18 m, equal to 1/700 L ≤ 26 mm.

The high bound "very good" includes:

for σ value is equal to triple reduction of stresses,

for HB value is equal to one of the possible values of hardness in the range of its variation,

for f value is equal approximately to triple decrease in deflection.

Having converted parameters into the particular desirability in accordance with formulas (2, 3) the following formulas have been received d1, d2, d3:

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot \sigma))], \quad (12)$$

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot \mathrm{HB}))], \quad (13)$$

$$d_1 = \exp[-\exp(-(4{,}3177 + (-0{,}0269)\cdot f))]. \quad (14)$$

Calculation of the generalized parameter of TS. After conversion of parameter values of TS into the corresponding desirabilities we unite them into a generalized desirability D, which is the geometric mean of particular desirabilities d1, d2, d3:

$$D = \sqrt[3]{d_1 \cdot d_2 \cdot d_3}\ . \quad (15)$$

The program has been developed in order to automate the calculation of the coefficients a_0 and a_1 as well as calculation of the particular desirability d1, d2, d3 and the generalized desirability D.

Analysis of the results of calculations for the particular case chosen by us shows that if the measured values of parameters of TS are equal:

- the stress in the metal structure is 160 MPa,

- the hardness of the bridge crane metal is 1200 MPa,

- the residual deflection of the main beam of the bridge crane is 20 mm,

so, their particular desirability functions d are respectively equal:

$d_1 = 0{,}3700$; $d_2 = 0{,}8158$; $d_3 = 0{,}6906$.

Generalized parameter of the technical state will be equal:

$$D = \sqrt[3]{d_1 \cdot d_2 \cdot d_3} = 0{,}5932,$$

that corresponds to a satisfactory evaluation of TS of metal structure of the crane on a scale of desirability.

CONCLUSIONS

Advanced methodology of assessment of TS of metal structures of climbing cranes allows to:

1. Get an objective assessment of the TS of metal structure of climbing cranes due to the generalized (complex) parameter,
2. Apply the generalized (complex) parameter of the TS of metal structures of cranes when calculating the safety factor,
3. Calculate the further safe operation life of the crane subject to the safety factor.

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МОДЕРНИЗИРОВАННАЯ МЕТОДИКА ОЦЕНКИ ТЕХНИЧЕСКОГО СОСТОЯНИЯ КРАНОВ МОСТОВОГО ТИПА

Григорий Бойко

Аннотация. В статье приведена методика оценки технического состояния металлоконструкций и определения сроков дальнейшей безопасной эксплуатации грузоподъёмных кранов, базирующаяся на применении обобщённого (комплексного) параметра, характеризующего техническое состояние металлоконструкций кранов.

Ключевые слова. Методика, грузоподъёмный кран, техническое состояние, обобщённый параметр, функция желательности.

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System-holistic modeling and evaluation of project-cluster management of regional educational space

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Summary. Based on models of economic tetrad and its improvements has been shown that within a regional education cluster development processes are implemented through projects. The system-holistic model of project-cluster management of regional educational space has been constructed. To form the projects portfolio of regional education cluster evaluation index system of the level of sustainable region development has been adapted, taking into account three metrics: development of cluster objects, connections between them and regional educational space as a whole.

Key words. Project, management, model, education, cluster, space, region, system, evaluation, index, development.

INTRODUCTION

Today at the state level in the national strategy of education development in Ukraine to the 2012-2021 years the need for modernization of the network of different types educational institutions, their reorganization and cooperation has been proclaimed in order to increase the efficiency of material and technical, human, financial and managerial resources for providing availability and quality of education [14]. Partially processes defined in the strategy have been already started through the forcible union of higher education institutions. However, force is not a rational way because of the loss of strong institutional memory of united educational institutions and opposition from the direct participants [15].

RESEARCH ANALYSIS

Taking into account the need of streamlining the existing network of high educational institutions in Ukraine management actions should be directed to creation of conditions for the adaptation and introduction of world model that provides mobility of student, teachers, resources and quality of educational service.

The basis of the modern perspective management models is strengthening the role of regions, new production systems based on network structures – innovation clusters [3].

Clusters have several advantages [23]:

- help fill the gap between business, researches and resources, thus faster giving knowledge to the market,
- provide intense competition simultaneously with cooperation,
- increase productivity, attract investments, stimulate researches and strengthen the industrial base.

One of the cluster disadvantages is the inability of obtaining quick results. International scientific researches of the clustering process have proved that cluster creating is a long and costly process. However, a cluster management model in any field of activity, including educational, is an effective tool for long-term development [4].

But development processes are advisable to carry through the projects implementing [20].

The combination of cluster and project management methodologies in the plane of the regional educational space development is one of the most promising models for solving problems of modernization of the educational system in way that does not include destruction, but directed on regional education development in polymeric space of its potential opportunities.

RESEARCH OBJECT

The development basis of the necessary models and methods of project-cluster management of regional educational space includes existing researches in certain directions, which have been received by the following scientists:

- in the direction of foundations of cluster management – R. Trion, P.V. Terent'ev, R. Luis, E. Fix, J. Hedges,
- in the direction of cluster management at the regional level – M. Porter, S.I. Sokolenko,
- in the direction of educational project management – Russian scientific school (D.A. Novikov, V.N. Burkov), Luhansk scientific school (V.A. Rach), Mykolaiv scientific school (K.V. Koshkin, V.S. Blintsov), Odessa scientific school (V.D. Gogunsky),
- in the direction of regional educational space management – A.A. Biloschytskiy, O.I. Sharov, K.M. Mikhailov.

System-holistic combination of these results will allow scientifically proving the methodological foundations of project-cluster management of regional educational space as integrity.

RESULTS OF RESEARCH

The study of systemic economic organization contains a definition of system in work [7] as the insular in space and relatively stable through time part of the environment, which is characterized by the properties of both: external wholeness and internal versatility. Kleiner G.B. (the author of the work outlined above) distinguishes four main types of systems: object, environment, process and project. Each of the selected systems is characterized by the limitations in spatial and temporal indicators.

Based on the model of economic tetrad entered by Kleiner G.B. in work [8] he has also proved that the cluster is a pronounced example of multifunctional and multidimensional economic system that has the properties of all four types of systems: object, environment, process and project (Fig. 1).

Projection of system-holistic organization model on the unfolded dual axis "space-time" executed in work [19] has allowed revealing the nature of the activity, development and existence processes (Fig. 2).

The possibility of development within project-cluster management of regional educational space will have been investigated in this research.

Suppose that there was a need in the performance of certain processes in the regional educational space. These processes can be implemented by several actors of cluster – such as organizations.

According to the model shown in Fig. 2, the functional connection between these elements is carried out due to the projects, which key feature is the innovative transformation.

If we consider the project as a collection of interconnected processes, for its implementation exist:

- a possibility of involving different actors for implementing different processes (activities),
- a possibility of choosing among cluster actors to perform the processes (activities) (Fig. 3).

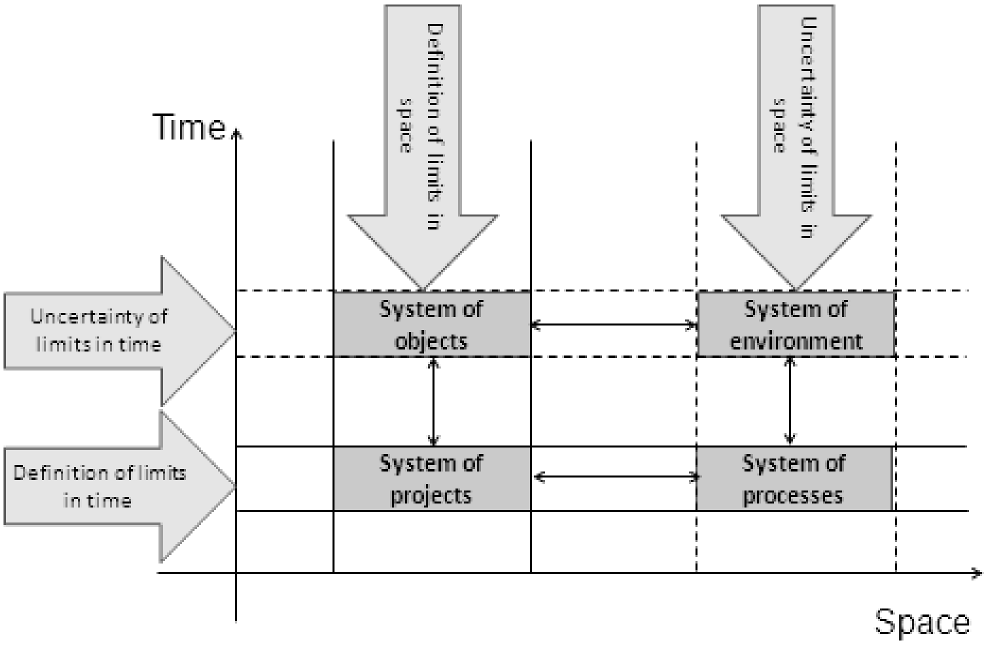

Fig. 1. Model of economic tetrad [8]

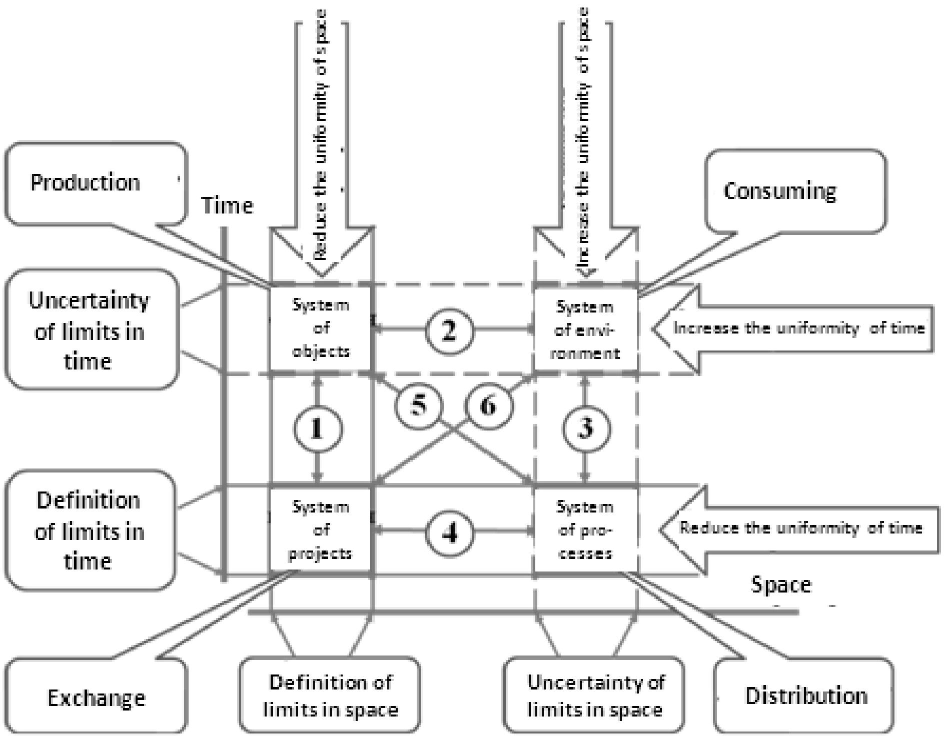

Fig. 2. The projection of the system-holistic organization model on the unfolded dual axis "Space-Time" [19]

Thus mutually sustainable relationship is implemented between project activities and educational space. It means that development is implementing (Fig. 4).

Thus, it is proved that within the regional educational space, in which the cluster has been created, the development processes are implementing through the projects.

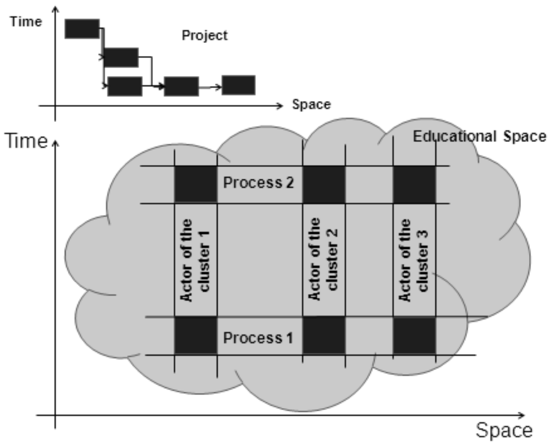

Fig. 3. Step 1 of constructing the system-holistic model of the project-cluster management of regional educational space

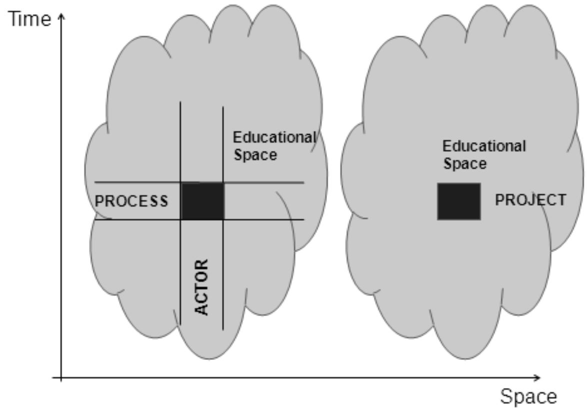

Fig. 4. Step 2 of constructing the system-holistic model of the project-cluster management of regional educational space

A set of activities components of educational institutions has been defined in work [9], which is limited by four main components: scientific, methodical, educational and business. This proves that, within the cluster activities of its actors aimed at implementing scientific, methodical, educational and business processes. These processes are realizing due to selected in work [2] types of educational projects: training, scientific, methodical, advanced training, material and technical, information, licensing, accreditation, etc.

Several projects can be simultaneously implemented to achieve the goals within the particular component of the regional educational cluster. Different actors of the cluster can be involved for the implementation of these projects. So, the set of projects is formed, which reflect all components of the activity that make the project portfolio of regional educational space. Fig. 5 shows the proposed system-holistic model of project-cluster management of regional educational space.

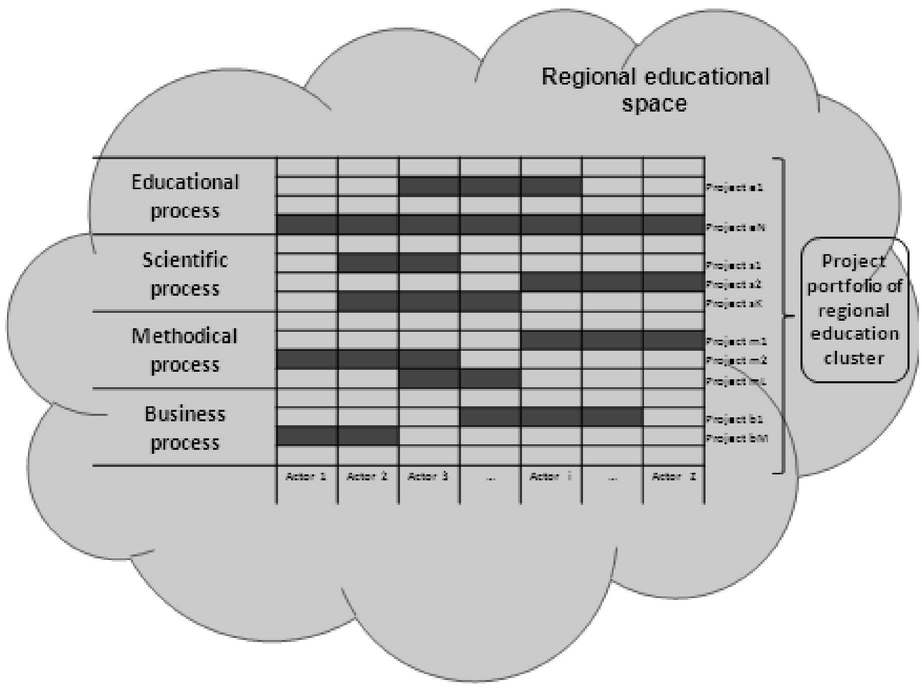

Fig. 5. The system-holistic model of the project-cluster management of regional educational space

According to the definition, given in work [5], essence of management function, as part of the six major activity functions, described in work [18]: management means the process of making decisions and implementation of coordinated actions that led the system to the desired state.

Desired state of educational cluster is an achieving of strategic development goals by its actors. Task of project-cluster management of regional educational space is to form a rational project portfolio of regional educational cluster to achieve the individual goals of its actors and the cluster as a whole. Forming of the project portfolio of regional educational cluster should be based on positions of identified and formalized strategic goals. Without this it is not possible to implement the function of the project-cluster management of regional educational space.

So, the next step of research is to develop a method of evaluating the development of regional educational cluster.

Regional educational space will be considered from the position set out in work [6].The educational space is understood as a set of objects between which the connections are established. Educational space is characterized by a dynamic unity of the actors and system of relations between them.

The global goal of regional educational space creation is the development of regional economy due to the formation of human capacity.

The importance of certain goal is confirmed by researches of several leading scholars, who claim that in the era of knowledge economy, regional development is not possible without creative, competent professionals [22].

Specific goal of cluster combination is the providing of competitiveness of regional education system through high quality of education service. The mentioned goals have been identified in the work [1].

Thus, three interacted elements of the regional educational space can be distinguished: high education institutions, enterprises and the labor market (Fig. 6).

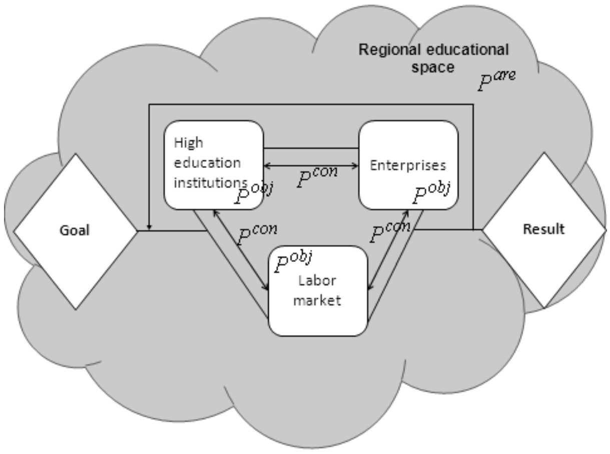

Fig. 6. System model of regional educational cluster

Project management of relationships between selected objects of cluster must ensure sustainable development of regional educational space.

Sustainability [10, 11, 12,21] is accepted to estimate by the six (or more) metrics: harmony of development, stability of development, balanced development, development equability, competitiveness of development, development security. Synthesis of defined metrics provides insight into the integrated assessment of sustainable development.

Methodic of evaluation the sustainable development level involves the following steps, pronounced in work [17]:

1) selection of the initial evaluation indicators,

2) normalization of the selected indicators,

3) analysis of the development level by field of activity,

4) analysis of sustainable development level for compliance with sustainability attributes,

5) integrated assessment of sustainable development level.

So the initial evaluation indicators should be provided at the first step for carrying out such assessment within a regional educational space. Their totality is determined by the regional educational space goals. Changing the values of the selected indicators depends on the projects implemented by the actors of regional educational cluster. In this case the totality of parameters ($P = \{p_1, p_2, ..., p_n\}$) should be divided into two groups:

- indicators of individual cluster object ($P^{obj} = \{p_1^{obj}, p_2^{obj}, ..., p_m^{obj}\}$),
- connection indicators between cluster objects ($P^{con} = \{p_1^{con}, p_2^{con}, ..., p_l^{con}\}$),
- education space indicators ($P^{are} = \{p_1^{are}, p_2^{are}, ..., p_k^{are}\}$).

The recommendations set out in the methodology of calculation of integrated regional economic development indices [13] are appropriate to apply for the indicators normalization. However, other methods that allow to transfer natural values of the initial indicators to the interval [0;1] can be used. So totality of normalized indicators is being got for:

- object ($NP^{obj} = \{np_1^{obj}, np_2^{obj}, ..., np_m^{obj}\}$),
- connection ($NP^{con} = \{np_1^{con}, np_2^{con}, ..., np_l^{con}\}$),
- space ($NP^{are} = \{np_1^{are}, np_2^{are}, ..., np_k^{are}\}$).

If we have values of normalized indicators we should proceed to assess the region development level by selected metrics: object, connection, space.

Indexes of the object (INP^{obj}), connections (INP^{con}) and space (INP^{are}) development will have been calculated, using the formula of arithmetic mean:

$$INP^{obj} = \frac{\sum_{i=1}^{m} NP_i^{obj}}{m}, \quad (1)$$

$$INP^{con} = \frac{\sum_{i=1}^{l} NP_i^{con}}{l}, \quad (2)$$

$$INP^{are} = \frac{\sum_{i=1}^{k} NP_i^{are}}{k}. \quad (3)$$

All of the indexes take values in the interval [0;1].

To perform the analysis of the regional development level of the educational space for compliance with sustainability attributes we shall use complex indexes: harmony, stability, balancing, equability, competitiveness, security of development.

Calculation of the harmony development index (I^g) is based on mathematical understanding of harmony. Harmony is a proportionality of part and the whole, merging the various components of an object into a single organic integrity [24]. The mathematical expression of harmony, which is called the "golden section", is used to calculate this indicator. It is calculated based on Fibonacci hyperbolic sinus. The formula for calculating is as follows:

$$I^g = \frac{\tau^{2(INP^{obj} \cdot INP^{con} \cdot INP^{are})} - \tau^{-2(INP^{obj} \cdot INP^{con} \cdot INP^{are})}}{\sqrt{5}}, \quad (4)$$

where: τ – the constant "golden section", which is equal to 1,618.

Stability of development is the characteristic of immutability of development character, its stability during studied period [16]. In other words, stability of development is a maintenance of positive parameters of the system as longer term as possible. This indicates that calculated index of stability must take into account the dynamics of processes.

To describe the stability of development it is advisable to use exponential-degree dependency [17].

Stability development index (I^s) of regional educational space is calculated as follows:

$$I^s = \left(\frac{INP^{obj} + INP^{con} + INP^{are}}{3} \right)^{1,471e}, \quad (5)$$

where: e – mathematical constant, which is equal to 2,718.

Balanced development allows estimating development processes by separate metrics as the integral space.

The basis of calculating the balanced development index (I^z) is the finding the medians of the triangle.

For regional educational space paired indices of sustainable development by separate metrics are calculated by the formulas:

$$I^{z}_{obj-con} = \sqrt{\left(INP^{are}\right)^2 + \frac{\left(INP^{obj}\right)^2}{2} + \frac{\left(INP^{con}\right)^2}{2}}, \quad (6)$$

$$I^{z}_{obj-are} = \sqrt{\left(INP^{con}\right)^2 + \frac{\left(INP^{obj}\right)^2}{2} + \frac{\left(INP^{are}\right)^2}{2}}, \quad (7)$$

$$I^{z}_{con-are} = \sqrt{\left(INP^{obj}\right)^2 + \frac{\left(INP^{con}\right)^2}{2} + \frac{\left(INP^{are}\right)^2}{2}}. \quad (8)$$

If the equality is executed:

$$\frac{2}{3} I^{z}_{obj-con} = \frac{2}{3} I^{z}_{obj-are} = \frac{2}{3} I^{z}_{con-are} = I^{z} = 1, \quad (9)$$

then the state of balanced development is reached in the region by separate metrics as parts of the whole.

So, the balanced development index is calculated by the formula:

$$I^{z} = \frac{\frac{2}{3}\left(I^{z}_{obj-con} + I^{z}_{obj-are} + I^{z}_{con-are}\right)}{3}. \quad (10)$$

Development equability is defined by Pareto as optimality. It means that increasing of the usefulness of one element does not reduce the usefulness of others [17].

In mathematical terms equability is estimated by the sum of corrected development indexes of objects, connections and space, that equal to one.

So, the equability development index (I^{r}) is calculated by the formula:

$$I^{r} = k_r INP^{obj} + k_r INP^{con} + k_r INP^{are}, \quad (11)$$

where: k_r – coefficient of equability, which is equal to 0,333.

The competitiveness development of the region is understood as the growth and effective using of competitive advantages over all metrics to ensure sustainable development [17].

Competitiveness development index (I^{k}) of regional educational space development is calculated as the geometric mean by the formula:

$$I^{k} = \sqrt[3]{INP^{obj} \cdot INP^{con} \cdot INP^{are}}. \quad (12)$$

Security of sustainable regional development involves the using of the region's potential, prevention of destabilizing factors acts [17].

Security development index (I^{b}) of the regional educational space is calculated by the formula:

$$I^{b} = \sqrt{\frac{\left(INP^{obj}\right)^2 + \left(INP^{con}\right)^2 + \left(INP^{are}\right)^2}{3}}. \quad (13)$$

The final step of evaluation is to calculate the integral indicator of sustainable development level.

Integral index (I) assuming equal importance of all metrics (objects, connections, space) of sustainable regional educational space development is calculated by the formula:

$$I = \frac{I^{g} + I^{s} + I^{z} + I^{r} + I^{k} + I^{b}}{p}, \quad (14)$$

where: p – total number of complex indexes.

To form conclusions about the implementation of management actions concerning expediency of inclusion separate projects into the portfolio of regional educational cluster should be used the data in Table 1. It contains the calculated limit values of evaluative indexes.

Table 1. The limiting values of evaluative indexes

Index	Value		
INP^{obj} INP^{con} INP^{are}	0,000	0,500	1,000
I^{g}	0,000	0,108	1,000
I^{s}	0,000	0,063	1,000
I^{z}	0,000	0,471	0,943
I^{r}	0,000	0,500	0,999
I^{k}	0,000	0,500	1,000
I^{b}	0,000	0,500	1,000
I	0,000	0,357	0,990

Graphically the limit values of evaluation indexes are shown on Fig. 7.

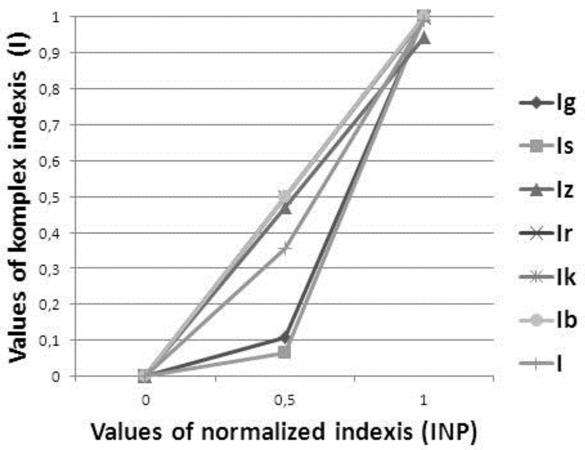

Fig. 7. Graphic of the limiting values of evaluative indexes

Shown character of changes is not the same. This determines the development peculiarities of management decisions concerning project portfolio of regional educational space. This is one of the directions for further research.

It should be noted that the chosen set of evaluation indicators is not exhaustive. Additionally, in theory and on practice, the following parameters are being used [16]:

- the scale of development,
- the speed of development,
- the density of development,
- the power of development,
- the effectiveness of development,
- the capacity development.

The calculation of these indicators also refers to destinations for further research.

Also, it is appropriate to develop evaluation tool for development of regional educational cluster by individual metrics: objects, connections, space.

To perform such evaluation it is necessary to identify specific indicators which have natural expression. The basis for formalizing set of indicators is totality of projects implemented in the regional educational space. Such research has already started by the author. Basic set of projects that may be included in the portfolio has been selected.

So, for example, traditionally high education institutions implement such projects:

- methodical,
- scientific,
- business,
- human resources,
- training ordered by enterprises,
- training ordered by the state,
- advanced training,
- licensing,
- accreditation,
- information,
- international, etc.

Classification of projects has been executed based on project product. Tables 2-3 include example of a set of projects, its products and initial quantitative indicators.

Among this list of projects can be distinguished the projects that lead to the development of high education institutions as members of the cluster. This set of projects includes: methodical, business and human resources projects.

The human resources projects are included in this group, because principles of manning labor resources require special attention to implement the project portfolio based on qualification, managerial and administrative capacities of all members of the cluster in the cluster organization conditions of regional educational space.

Table 2. Projects of regional educational cluster for actor

Object	Type of educational project	Product	Indicator
High education institutions	Metodical	Methodical support	Share of fully secured disciplines
	Business	Property and equipment, elements of infrastructure	cost
	Human resources	Teaching staff	The amount of human resources

Informatization projects can be considered as belonging to the business type. However, this point requires further formalization of the essence of such projects.

Table 3. Projects of regional educational cluster for connection between actors

Connection	Type of educational project	Product	Indicator
High education institutions - enterprise	Training on order	Specialist	The volume of orders
	Scientific	Innovative product	Quantity of scientific research on order
	Advanced training	Trained staff	The volume of the orders (number of trained staff or tuition costs)
High education institutions - the labor market	State Training	Specialist	The volume of orders
	Licensing	Speciality	The range of specialties
	Accreditation	Speciality	The range of specialties

The next group of projects reflects the connection between actors of regional educational space (Fig. 6). Thus, the connection between high education institutions and enterprises is being implemented through projects: training ordered by enterprises, scientific, advanced training. The connection between high education institutions and the labor market is defined by projects: training ordered by the state, licensing and accreditation.

The place of international education projects is not defined. The product of such projects is the competent foreign students [25]. But in most cases his training is ordered by the student or by the country in which he resides constantly. Therefore, typification of such projects requires refinement.

Also, there is no example of projects that are directly focused on development of regional educational space. This question is under investigation.

Listed characteristics and tasks determine the range of further researches.

CONCLUSIONS

Results of this investigation consist of the following:

1. The results of analysis of the tetrad economic model and its components allow proving that within a regional educational space, in which the cluster has been created, projects are the tool of development processes implementation.
2. System-holistic model of project-cluster management of regional educational space has been constructed.
3. Assumptions for modeling the rational project portfolio of regional education cluster have been formulated.
4. Evaluative indexes system of the level of sustainable region development is adapted to assess changes in level of regional education space development, depending on the set of potential projects of the regional education cluster portfolio.

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СИСТЕМНО-ЦЕЛОСТНОЕ МОДЕЛИРОВАНИЕ И ОЦЕНИВАНИЕ ПРОЕКТНО-КЛАСТЕРНОГО УПРАВЛЕНИЯ РЕГИОНАЛЬНЫМ ОБРАЗОВАТЕЛЬНЫМ ПРОСТРАНСТВОМ

Алина Борзенко-Мирошниченко

Аннотация. На основе модели экономической тетради и ее усовершенствований доказано, что в пределах регионального образовательного кластера процессы развития реализуются через проекты. Построена системно-целостная модель проектно-кластерного управления региональным образовательным пространством. Для формирования портфеля проектов регионального образовательного кластера адаптирована система оценочных индексов уровня устойчивого развития региона с учетом трех метрик: развития объектов кластера, связей между ними и регионального образовательного пространства в целом.
Ключевые слова: проект, управление, модель, образование, кластер, пространство, регион, система, оценивание, индекс, развитие.

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The model of decision-making about the implementation of technological innovation at the machine-building enterprise in the context of its economic security

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Summary. The model of decision-making about the implementation of innovation, focused on the economic security of the machine-building enterprise has been proposed in the article. A preliminary study and evaluation of the level of economic security of the specific innovative solution from the field of locomotive-building has been produced. The basic directions of the economic security of the innovation process have been described
Key words. Decision-making, machine-building, innovations, economic security.

INTRODUCTION

The process of innovation projects control is related to the high level of financial, time and labor costs. The main problem in the preparation of the innovative project is characterized by difficulties in determining the magnitude of the possible risks and deviations from the planned parameters.

That's why, to improve the efficiency of decision-making about the implementation of the innovative projects at the machine-building enterprise one need to have some specific tools to support the decision-making process, including the evaluation of the level of risks and economic security, carried out with the help of expertise and advanced computer technologies that can significantly improve the objectivity and reliability of the results obtained during the management decisions.

MATERIALS AND METHODS

This procedure of decision-making is focused on the implementation of the innovative solutions to ensure the economic security of the machine-building enterprise. For example, when having low energy efficiency of the output it is first of all necessary to develop and implement innovative solutions aimed at reducing energy consumption or to find cheaper alternative sources of energy etc.

A large proportion of the machine-building enterprises have developments, the implementation of which will enable them to compete effectively on the both domestic and global market, but it is difficult to realize it in the near future due to several reasons. The main problems of the innovative sphere development and implementation of the innovations at the machine-building enterprises are as follows [13, 31]:

1. The lack of investment or the critical level of investment in the innovations.

2. Inefficient use of available resources (difficulties in identifying effective and unprofitable production areas of the enterprise).

3. Old systems of accounting, control, planning, inefficient financial and innovation enterprise management, lack of methodological tools of evaluation and planning of the innovation and associated risks and threats.

4. The decrease of the intellectual capital of enterprises, as a result of the "brain drain" from the science sector, as well as the aging of the staff.

5. Low efficiency of the scientists' incentive.

6. Imperfect system of the search and selection of the innovation.

7. Short-term planning, lack of development strategy.

8. Ineffective communication between marketing and innovative business sector.

RESULTS

Nowadays, in the scientific literature the unified approach to the criteria for the selection and evaluation of innovative projects for a decision on its implementation had not yet developed. Typical decision-making algorithm, described in detail in [19, 29], includes:

- definition of the goals, objectives and criteria for decision-making,
- development of possible options,
- discussion and evaluation of possible options,
- select the optimal variant for the selected criteria,
- specification of the decisions creation of conditions for implementation of the project; - Testing of decisions,
- monitoring and analysis of the results of the decision, the possibility of its adjustment.

However, many authors are inclined to believe that the decision about the implementation of the innovative project should be based on an accurate analysis of individual criteria, especially with regard to possible risks that may arise during implementation of an innovative project [11, 30].

The innovative components plays a key role in the system of economic security of the enterprise, it includes a set of measures aimed at protecting innovation potential [17, 18].

The innovative potential of the company is the ability to achieve certain goals in the innovation sphere if they can be accomplished. To ensure the economic security of innovation one must regulate the level of innovative potential to support the innovative development of the enterprise and to reduce, neutralize endogenous and exogenous threats.

Most of the economic theories define innovation as a source of development which means that they must be actively and effectively used in the production and management, as well as the necessary conditions to implement the innovative potential must be created [25, 27].

World experience testifies to the fact that in terms of uncertainty and lack of development of market mechanisms in our country, the main directions of innovative development are first of all directed to minimize the costs when entering the new markets and, secondly, to reduce the risks of the innovative projects, including the development of models and methods for their evaluation [2].

When making any management decision about the implementation of the innovative project, one must take into account the evaluation and analysis of the specific information:

- the required bulk of resources to achieve concrete results in the innovative project,
- the stage of creation (the idea, research, implementation) of an innovative product or technology,
- the ratio of the effect of possible risks and the economic security after the introduction of the specific innovation project.

The author have developed a model of decision-making about the implementation of the innovative project at the machine-building enterprise, which is represented in Fig.1.

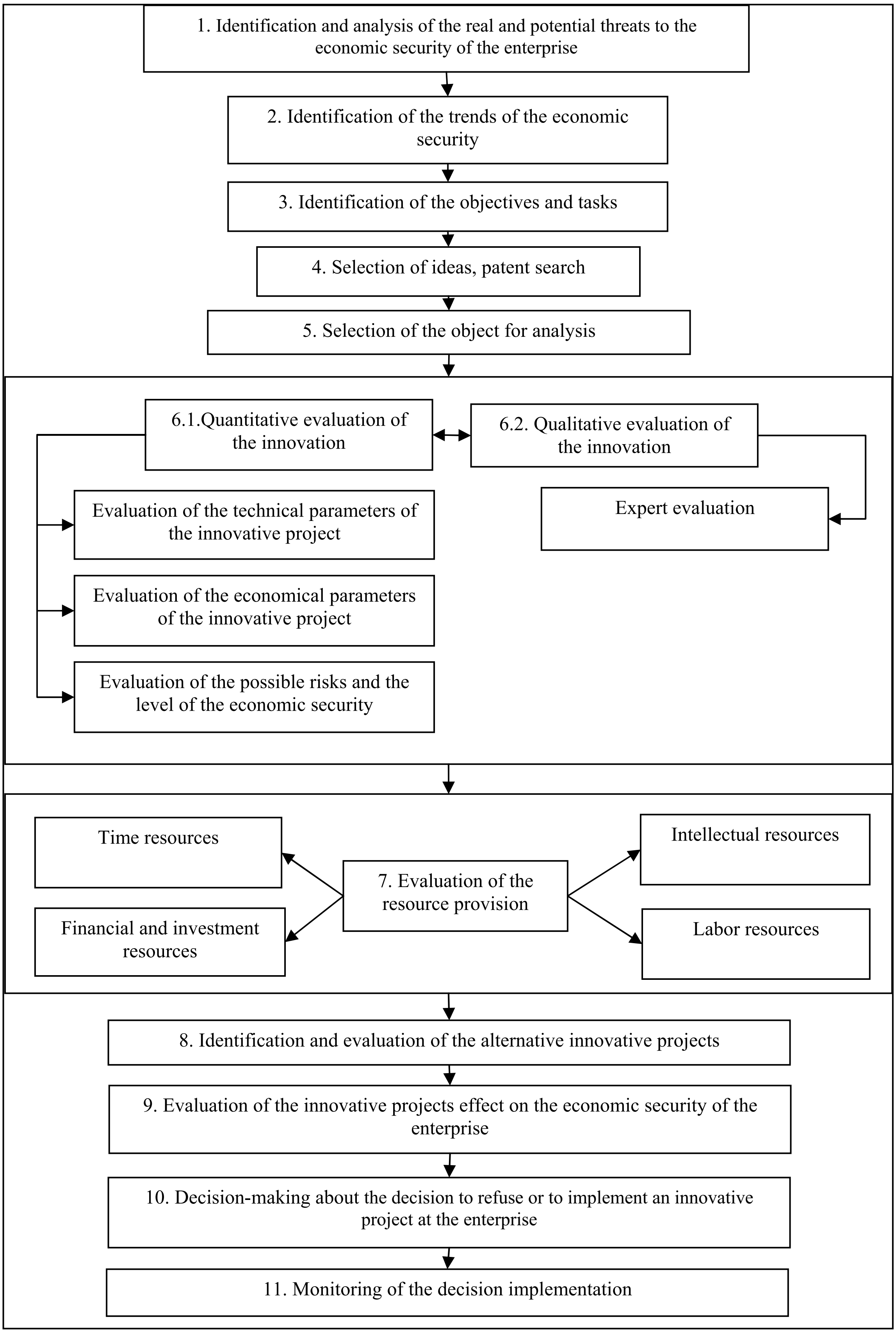

Fig. 1. Model of decision-making about the implementation of the innovative project at the machine-building enterprise

The proposed model of decision-making must contribute to the comprehensive system of innovation management, which will be closely linked with the system of economic security of the enterprise. The control and monitoring of the risks and threats to the innovation will ensure a sustainable development of the enterprise and increase its level of economic security.

One should also take into account that when introducing the innovative project, the factors which have a strong influence on the making management decision are the follows: the budget of the innovative project and financial resources of the enterprise as well as the risks of the acquisition additional external resources. To solve this issue one must have a precise expert evaluation of the innovative project, the procedure of which is described in [23, 24].

Let's consider the application of this algorithm for a specific innovation project in the field of transport engineering – «Device for lubricating of the wheel flange of the rail vehicle» [21, 22].

Innovative design belongs to the railway transport, in particular to devices for lubricating wheel flanges of the wheelset and may be used on the rolling stock.

According to the strategy of the railway transport development, the main directions of innovative development in technical and technological content of the railway transport have been given as follows [20]:

1. Innovations aimed to increase train speeds.

2. Increase in overhaul life of the rolling stock and the service life of the separate units.

3. Energy saving of traditional fuel resources and the use of alternative energy sources.

4. Improvement of the reliability of units and development of the rolling stock design.

5. Improvement of the interaction in the "wheel-rail" system etc.

To eliminate the technological gap in the national transport machine-building with the world level, it is necessary to conduct research and development studies on the following technologies:

a) technologies of high-speed movement:

- rolling stock production,
- rolling stock components production,
- the formation of the high-speed infrastructure subsystem (track, energy saving, management of the movement, and dispatching),

b) technologies of design and production of long aluminum profiles for rolling stock production and technologies of rolling stock design with the use of long aluminum profiles and composite materials,

c) technologies of design and production of double-decker passenger carriages.

The considered an innovative solution is an actual one for implementation since it refers to the three promising directions of the innovative development in railway machine-building, namely: the improvement of the "wheel-rail" interaction, energy saving of traditional resources, and increase in the service life of the rolling stock and its individual components.

A patent search and analysis of the literature showed that the for solid lubrication in the system "wheel flange - rail" are used method of ion-plasma spraying [16] and rotaprintny method [7], for liquid lubrication used method of irrigation free-fall stream [8], spray stream methods [9] and the filing of high-pressure stream of lubricant [10].

However, with increasing the role of resource and energy efficiency in a modern economy the use of different methods of lubricants activation in the " wheel flange - rail" gets a special urgency for railway transport. One of perspective directions is to use the ionized and ozonated air for improving the lubrication process.

Improving efficiency by using ionized and ozonated air as a lubricant in the "wheel flange - rail" may fluctuate in wide range of values from 20 to 300%

It was also found, that surface quality was improved by reducing the coefficient of friction, reducing surface roughness, residual stresses of the material reduction and increasing the durability of the processed surfaces, thereby increasing resource of wheels and rail [6,12,14,15]. Various aspects of the interaction of contacting surfaces under the influence of activated air is examined by many authors [1,3,4,15].

Technical nature and the function of the device is illustrated by a drawing, which shows a schematic diagram of the device for lubricating wheel flanges of a rail vehicle (Fig. 2).

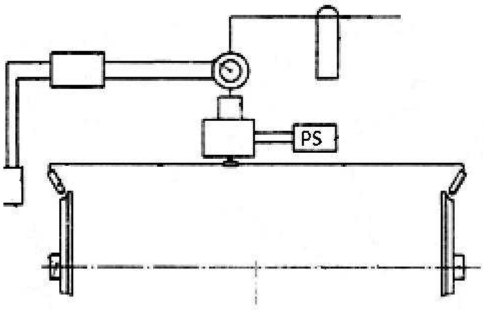

Fig. 2. Device for lubricating wheel flange of a rail vehicle with a mixture of ionized and ozonated air

The experts in the field of railway engineering and economics of transport have estimated the possible effect and cost of implementation of the proposed innovative solutions. The results of the expert evaluation are presented in Table 1 and Table 2.

Table 1. Evaluation of the factors of the innovative solution effect

	Factors of the effect	Min (UAH.)	Max (UAH.)
ES	Energy saving	600	1200
RS	Resource saving	4500	5800
LS	Labour saving	1800	3000
EC	Ecological conservation	1000	1800

Table 2. Evaluation of the factors of the innovative solution costs

	Factors of the costs	Min (UAH.)	Max (UAH.)
IC	Intelligent costs	2400	4800
MC	Material costs	3500	6000
LC	Labor costs	100	150
S	Services	30	60

The evaluation of the level of potential risks of the project has been carried out by means of the Monte Carlo method, which allows to determine the level of economic security when implementing certain innovative solutions in terms of the uncertainty and randomness of the selected factors of the effect and costs (Fig. 3) [26].

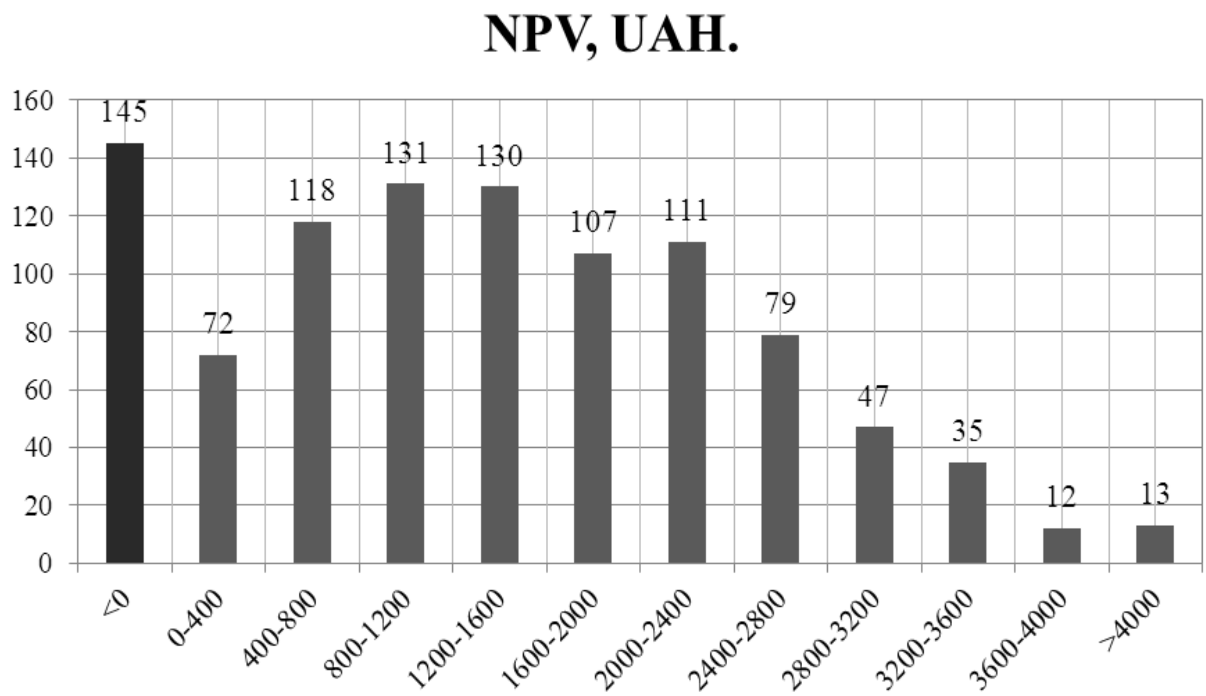

Fig. 3. The results of simulation of the level of risk and economic security Monte Carlo

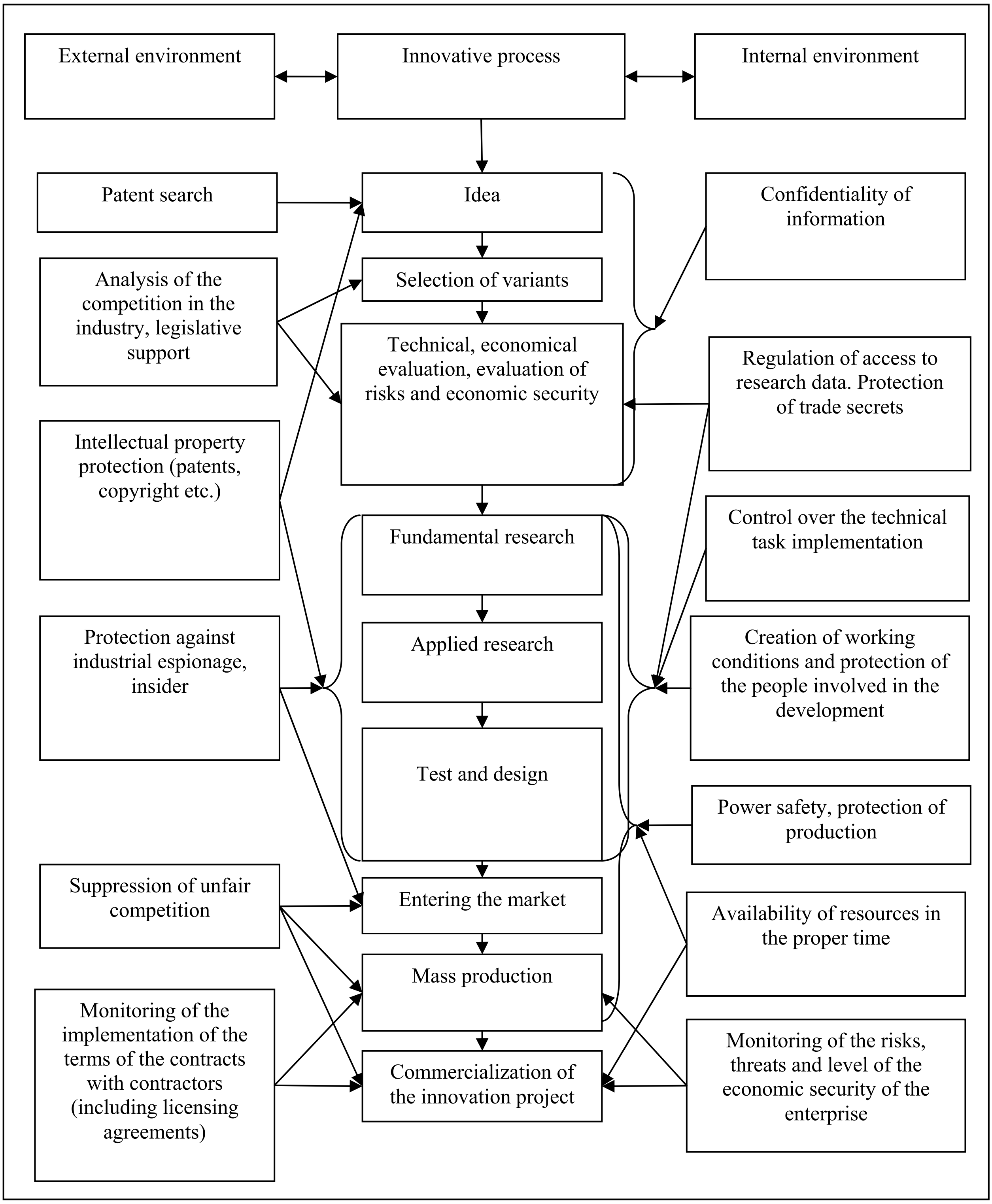

Fig. 4. The main directions of the economic security of the innovation process

The level of economic security of this innovative solution is 85.5% (855 of simulated scenarios from 1000), and the level of the risk of a negative result - 14.5% (145 scenarios from 1000), which indicates a high level of economic efficiency and innovation prospects.

The main advantages of the innovative project in comparison with the alternative developments are:

- increase in efficiency of the lubricating process by reducing the cost of lubricants and provision of the sufficient lubricant capacity,
- increase in traffic safety and reduction in operational risk by reducing pushes, fluctuations and vibration, by reducing slipping and skidding,
- a significant reduction in weight and dimensions of the device,
- a significant environmental effect on the environment as a result of not using traditional types of lubricant, which heavily pollute the roadbed,
- increase in the service life of the both wheels and rails,
- increase in the level of economic security of transport engineering enterprise due to the low cost of the project, its economic and environmental efficiency and protection of the intellectual property.

This innovative project is promising for the implementation, which was noted at the II International Youth Forum "Innovative projects for the development of the regions" (Luhansk), where the project was awarded the first prize [5].

However, besides support of decision-making and evaluation of the level of economic security of the innovative solution to ensure the economic security of the innovation activity of the machine-building enterprise one must determine the main directions of the economic security of the innovation process as a major component of the innovation activity of the enterprise.

Based on the results of [28], analysis of the features of innovation activity and economic security of the enterprise, a process model of economic security for certain stages of the innovation process, beginning from the idea to the commercialization of the innovation project demarcated by the medium of manifestation of internal and external has been presented (Fig. 4).

Economic security of the innovation process involves such components of economic security as power, intellectual, financial, personnel, legal, informational, and political-legal ones. All this points out a need for a systematic approach to ensure the economic security of the innovative activity of the machine-building enterprise.

CONCLUSIONS

1. Application of the proposed procedure of decision-making will improve the economic security of the machine-building enterprise through the implementation of innovative solutions aimed at reducing the real risks and threats to economic security of the enterprise, optimal allocation of resources for the innovation development of the machine-building production.
2. The innovative solution considered concerns several promising areas of innovation development of the railway engineering enterprise, has a high level of economic security and efficiency, which makes it actual to be implemented into production.
3. The implementation of this innovation will have a technical and economic effect, will reduce the consumption of energy resources and increase the service life of the unit, which will increase the competitiveness of its product and the level of economic security of the enterprise on the whole.

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МОДЕЛЬ ПРИНЯТИЯ РЕШЕНИЙ О ВНЕДРЕНИИ ТЕХНОЛОГИЧЕСКОЙ ИННОВАЦИИ НА ПРЕДПРИЯТИИ МАШИНОСТРОЕНИЯ В КОНТЕКСТЕ ЕГО ЭКОНОМИЧЕСКОЙ БЕЗОПАСНОСТИ

Чмелёв Вячеслав

Аннотация. В статье предложена модель принятия решения о внедрении инновации, ориентированная на обеспечение экономической безопасности предприятия машиностроения. Произведено предварительное обоснование и оценка уровня экономической безопасности конкретного инновационного решения из области локомотивостроения. Описаны основные направления обеспечения экономической безопасности инновационного процесса.

Ключевые слова. Принятие решений, машиностроение, инновации, экономическая безопасность.

Ratonal design modeling methods of complex surface workpiece creation

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S u m m a r y . The article describes a mathematical model for creating geometry of curved pieces on the basis of the minimum stress in the production of surfaces of complex shapes. The methods searching sweep of the workpiece, which can later be converted into a surface mechanically The approbation when compared with the models obtained as a result of visualization of objects in the modern 3D programs.
K e y w o r d s : curved workpiece, complex surface, 3D model, minimum stress.

INTRODUCTION

Modern production is characterized by an intense introduction of modern computer techniques that allows you to design modern processes in the manufacture of complex components to meet the requirements of natural goods saving. In case of complex parts manufacturing, especially when its surface is a complex curve, very important detail is to find a workpiece shape. Improving the accuracy of the curved shape blanks allow the most efficient use of materials, and also improves the efficiency of the process. The proposed method uses modern methods of 3D analysis in the computer environment, and also with the help of mathematical modeling.

MATERIALS AND METHODS

Three-dimensional surfaces from plane creation is a task that is relevant for many fields of industry. For example complicated surface [4] in the shoe industry is obtained by stretching the workpiece on the block. Similar processes occures in the furniture industry [20] and seewing industry [6]. Production of sheet products from flat blanks typical automotive [7] aviation [30] industry. The task of creating such products can be divided into a number of problems. Mathematical description of the surface part is described for example in [10]. Some methods for determining the geometry of the workpiece described [3]. Plane should be a sweep of the product [11, 16, 24]. Nowhere, however, are not given information about how to create a sweep if surface is not wrapable. To study such surfaces a number of methods of 3D modeling with using of computer technology was worked out. For example in generation algorithms were described. In surfaces, and solids 3d modeling were discribed.

For the manufacture and control of solid surfaces are widly used modern methods of 3D scanning [1, 2, 21] and rapid prototyping [9, 18]. Note that the theoretical issues covered 3D scanning is widely speared [14, 26].However, these methods have not yet received wide practical application.

Also have been developed a series of algorithms to build the virtual three-dimensional objects [17, 19, 29], but they do not take into account feedback in the control of real objects using rapid prototyping. It is advisable also to improve the methods of constructing such facilities [12, 15].

The aim of that work is to develop ways of curved pieces for three-dimensional surfaces creation by providing the best technological parameters basing on 3D modeling and 3D scanning methods.

To achieve this goal, we will need advanced technical software of 3d modeling 3d scanning and prototyping. To determine the surface it is necessary to apply mathematical techniques (such as differential and integral value [5, 8, 23]) or other [22, 25, 28]. To ensure minimal stress for creating surfaces and workpieces we will apply the methods of the theory of elasticity [13, 27].

RESULTS, DISCUSSION

Types of modeling used in practice of design engineering in the synthesis, are forming a certain principle to create shape of the object. An analysis of the simulation types applications are formulated and developed four principles simulation: traditional, inverted, generative and interactive.

The traditional principle involves four stages (Fig. 1) creative (Sketch modeling), or polygonal, modeling (Polygonal and mesh modeling)
---> surface modeling class «A» / «B» / «C» (Surface modeling)
---> solid modeling (Solid modeling)
---> prototyping (Prototyping).

Knowledge of this principle allows the designer to implement the concept of a computer in three dimensions, to study morphogenesis and just to print the object of rapid prototyping. This is a common way of allowing you to quickly create a variety of models forms of drawings, electronic and handmade sketches quickly. Well-suited for modeling concepts and the final forms of industrial products with a simple, intermediate, and advanced geometry shapes.

Step creative modeling (polygonal or hand-made) involves the creation of two-dimensional graphics information about the object (hand-made sketches, drawings, sections or sketches) or three-dimensional (e sketch polygon model).

The scheme shown in Figure 1 is simplified, it does not consider methods of obtain polygon nodes. Further technological problem is often hard to obtain the solid models and receive model shell surface. That occurs in actual processes when the bending the curved plane of the workpiece. Getting the geometry is the problem – that cannot be solved by the above methods.

The aim of that work is to develop ways of curved pieces for three-dimensional surfaces creation by providing the best technological parameters basing on 3D modeling and 3D scanning methods.

Graphic information is the basis for the subsequent of surface modeling. High-quality surface model provides a basis for further study of a solid model. Solid modeling is based on the resulting surface model: then thickness of the material is created, added to the design and technology elements. For calculation and CAM - CAE - systems can be used a solid, and a surface model, depending

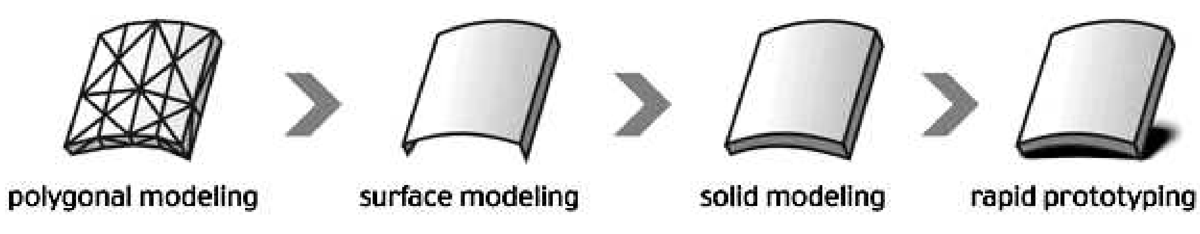

Fig. 1. Traditional principle algorithm

on the type of calculation and the requirements for the particular software. Resulting solid model can be sent to the press, such as 3D printers, CNC machines, etc. In the opposite sequence, but similar in type steps are the basis of the principle of inversion modeling.

The inversion principle of modeling on stages has similarities with the traditional. However, to create a surface model you have to use data obtained by human made 3d prototype or 3D scanner.

3D scanners are used extensively in various industries to produce accurate models of complex structure of objects. This method significantly reduces the time required to develop new products and launch into production. Besides 3D scanners are used for:

- accurate measurement of the geometric dimensions with automatic conversion of measured data in the digital form,
- Non-contact control of complex shape surface profile. In result user gets accurate digital information of the object scanned surface.

Basing on the data obtained as a result of scanning, it is possible to model the object shape as accurately as possible. Shaping is based on the results of the scan, so the input data is the field of points or polygon model. It's suitable for modeling the objects on the final stage of production, or for the restyling of the existing shape of object that is used to create objects with partially unified elements. This principle takes more time consuming the traditional, cause it's required layout creation or to have ready prototype, or to spend time scanning, but it's maximize the proximity of object parameters to the actual product or layout.

In principle, the inversion modeling is the most important phase of surface modeling.

In some cases (for example in the design of thin parts) we know only the shape of the product, but it is necessary to know the surface, or rather how it was received. In this case, the circuit shown in Fig. 1 does not work, cause it has a gap in the second paragraph. That's why we have to use other scheme shown on Fig. 2.

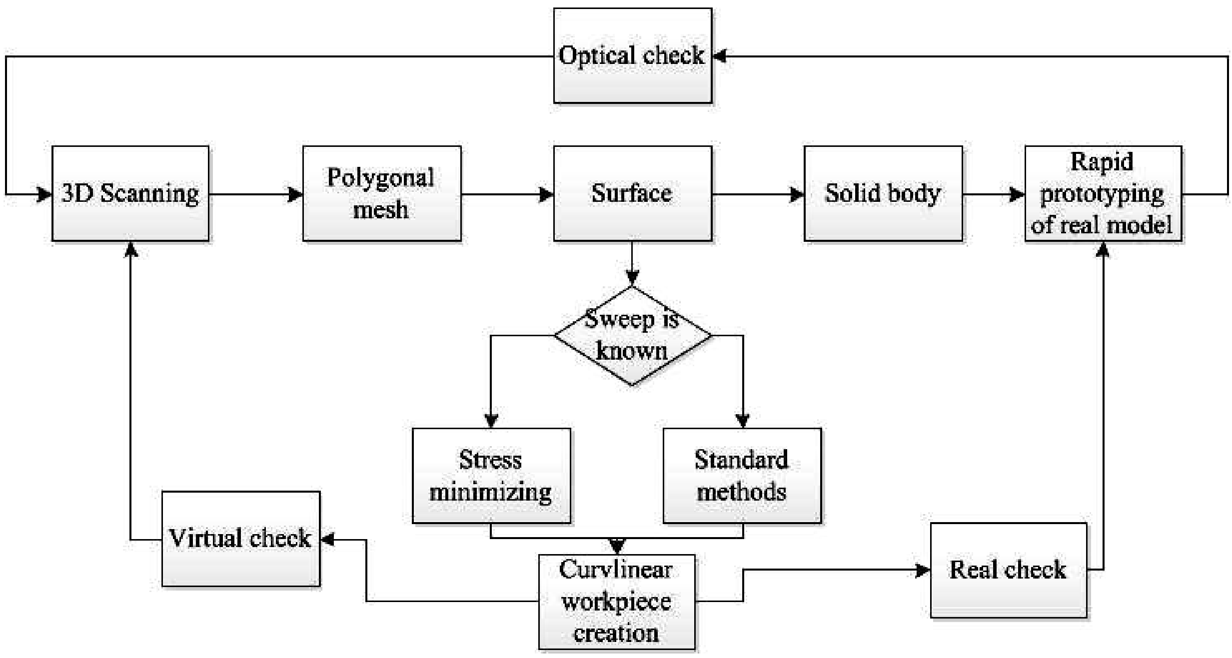

Fig 2. New scheme of production process

The surface is a set of consecutive positions of lines, moving in space. This line can be straight or curved surface. The curve can be constant or variable appearance. Moves forming the guides, which is a line in another direction than the forming one. Guide lines define the law of displacement the forming one. When moving the curve creates a frame for guiding the surface, which is a combination of several successive positions of forming lines and guides.

As a result of scanning object is implemented point-wise description of the surface. It provides a plurality of individual surface points that belong to this surface (Fig. 3).

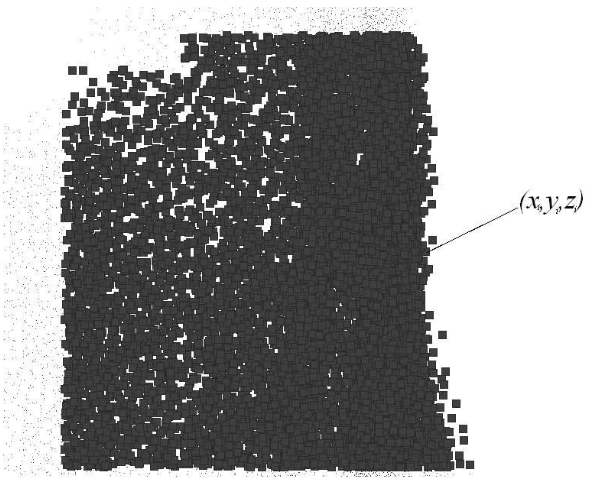

Fig. 3. Surface that is formed by point group

In theory, when a number of points increase to infinite, such model provides a continuous form of description. Points used for description have to be placed enough often to perceive the surface with no much losses and distortion of information. Such description has the lack of information on the surface between the points. For example, when setting the polygon surfaces of each planar polygon vertices, and therefore the entire model, the points have to be arranged with surfaces. Point-wise description of the surfaces used in cases where the surface is very complex, lacks smoothness, and a detailed understanding of many important geometric features.

The practical goal of such computer graphics surface creation method is usually in constructing images to form the best perception, including creating animated movies based on the synthesized image.

The best method to describe the surfaces, it's to describe it parametrically or explicitly written as a continuous function. In the case of point descriptions function surface can be obtained by multivariate regression.

The real detail surface that will be produced in the future can be designed using modern means of three-dimensional graphics, or using 3D scanning (Fig. 3).

Fig. 4. Object created by means of 3D scanning

Surface function can be analytically written as:

$$z = a_{00} + a_{10}x + a_{01}y + a_{11}xy + a_{20}x^2 + a_{02}y^2 + \ldots$$

or:

$$z = \sum_{k=0}^{m}\sum_{j=0}^{m} a_{kj} x^k y^m .$$

In the presence of n coordinate points obtained by 3D scanning we can write such table (Table 1) to provide the least squares method.

Table 1. Coefficients to provide least square method

i	x_i	y_i	z_i	$x_i y_i$	$y_i z_i$	x_i^2	y_i^2	$x_i^2 z_i$	$y_i^2 z_i$	$x_i^3 y_i$	$y_i^3 x_i$
1	x_2	y_1	z_1	$x_1 y_1$	$y_1 z_1$	x_1^2	y_1^2	$x_1^2 z_1$	$y_1^2 z_1$	$x_1^3 y_1$	$x_1^3 y_1$
2	x_1	y_2	z_2	$x_2 y_2$	$y_2 z_2$	x_2^2	y_2^2	$x_2^2 z_2$	$y_2^2 z_2$	$x_2^3 y_2$	$x_2^3 y_2$
...	...	...	...	...	...	...	...	...	...	...	...
i	x_i	y_i	z_i	$x_i y_i$	$y_i z_i$	x_i^2	y_i^2	$x_i^2 z_i$	$y_i^2 z_i$	$x_i^3 y_i$	$x_i^3 y_i$
...	...	...	...	...	...	...	...	...	...	...	...
n	x_n	y_n	z_n	$x_n y_n$	$y_n z_n$	x_n^2	y_n^2	$x_n^2 z_n$	$y_n^2 z_n$	$x_n^3 y_n$	$x_n^3 y_n$
n	$\sum x_i$	$\sum y_i$	$\sum z_i$		$\sum x_i$	$\sum x_i^2$	$\sum y_i^2$	$\sum x_i^2 z_i$	$\sum y_i^2 z_i$	$\sum x_i^3 y_i$	$\sum x_i^3 y_i$

Unknown regression coefficients in this case can be determined from the equation system. For example, for six coefficients:

$$\begin{cases} \sum z_i = a_{00} + a_{10}\sum x_i + a_{01}\sum y_i + a_{11}\sum x_i y_i + ... \\ \sum z_i x_i = a_{00}\sum x_i + a_{10}\sum x_i^2 + a_{01}\sum x_i y_i + a_{11}\sum x_i^2 y_i + ... \\ \sum z_i y_i = a_{00}\sum y_i + a_{01}\sum y_i^2 + a_{10}\sum x_i y_i + a_{11}\sum x_i y_i^2 + ... \\ \sum z_i x_i y_i = a_{00}\sum x_i y_i + a_{01}\sum x_i^2 y_i + a_{01}\sum x_i y_i^2 + a_{11}\sum x_i^2 y_i^2 + ... \\ \sum z_i x_i^2 y_i = a_{00}\sum x_i^2 y_i + a_{01}\sum x_i^3 y_i + a_{01}\sum x_i^2 y_i^2 + a_{11}\sum x_i^3 y_i^2 + ... \\ \sum z_i x_i y_i^2 = a_{00}\sum x_i y_i^2 + a_{01}\sum x_i^2 y_i^2 + a_{01}\sum x_i y_i^2 + a_{11}\sum x_i^3 y_i^2 + ... \end{cases}$$

or in matrix form.

Surface of future hollow items can be described by a function z=f (x, y). An example of such a surface is shown in Fig. 5. For the convenience of math solving the surface is have to be smooth, mathematically it can be represented as continuity and the ability to differentiate the in all points. In the cause when derivative breaks the most likely will be to design work piece with breaks.

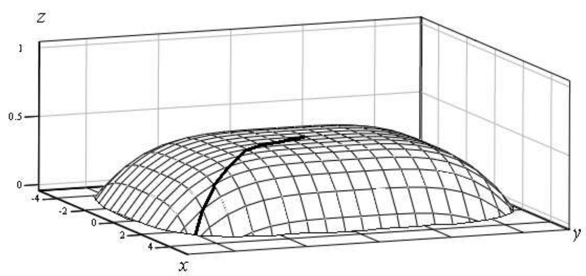

Fig. 5. Three dimensional model of detail surface

The lower limit of the details present in the form of a flat curve obtained from the intersection of the surface with plane *z=0*. Accordingly, this curve function is *f(x,y)=0*.

In technological problems there is the problem of providing a blank for the manufacture of the surface that is the best way to get a sweep

Let's consider a surface in the form of a thin, flexible but non-stretchable film. In this case, some surfaces can be combined with a gradual bending plane so that there is no any a gap or wrinkles. Surfaces with this property called wrap able, and the figure derived from the combination of the surface with the plane – sweep of the surface.

Construction of sweeps is an important technical task, which is widely used in a variety of industrial products, made from sheet material by bending. The surface is called wrap able if it bends without creasing and tearing can be aligned with the plane. At same time we can represent the surface of a flexible but inextensible and incompressible. Wrap able properties have polyhedral surfaces and curves, ruled surfaces with the edge of regression: torsos, conical and cylindrical. All non-ruled and ruled oblique surfaces are non wrap able. There are ways of construction their conditional sweeps using approximations.

Unfortunately, most surfaces are not wrapping able. Blanks for their manufacture are flat curved shapes. In the manufacture of the surface, they receive additional strain and stress (Fig 6).

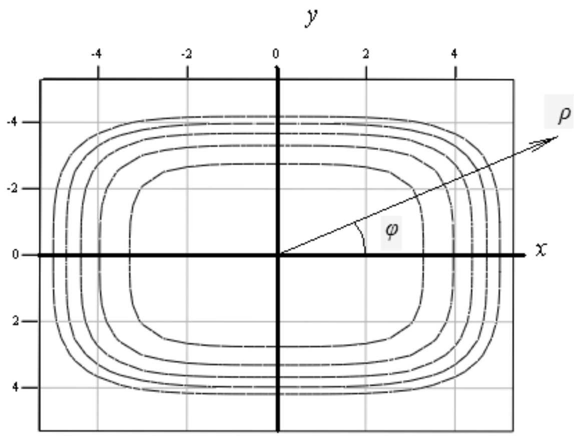

Fig. 6. Plane border of three dimensional detail

The border detail has closed form. The function of such a curve can be rewritten in polar coordinates, given that:

$$\begin{cases} x = \rho\cos\varphi, \\ y = \rho\sin\varphi. \end{cases}$$

Accordingly, the function of surface details can be rewritten as:

$$z = f(\rho\cos\varphi, \rho\sin\varphi) = f(\rho,\varphi).$$

The length of the envelope surface of an arbitrary value of the polar angle can be found as:

$$R(\varphi) = \int_{o}^{r(\varphi)} \sqrt{1+\left(\frac{\partial z}{\partial \rho}\right)^2}\, d\rho\,,$$

where: $\frac{\partial z}{\partial \rho}$ - partial derivative of the surface depends on the radius of the polar angle.

For example angle between 0 shown in Fig 7. Details of the boundary function in polar coordinates, an example of such boundary is shown in Fig. 8.

After the scanning surface integration sweep can be found, that also can be converted into surface mechanically.

Should be noted that using that technique with flat materials can bring unexpected stress caused by inseparability property of surfaces. In the circumferential direction of the workpiece strain can appear:

$$\varepsilon_\varphi = \frac{R(\varphi)}{r(\varphi)} - 1\,.$$

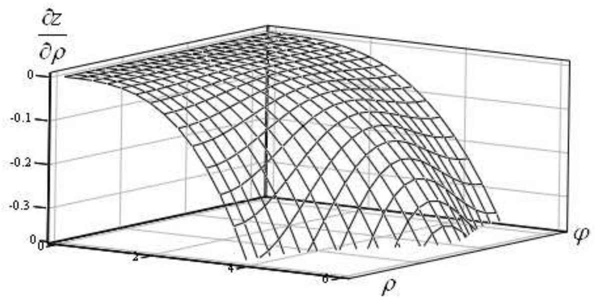

Fig. 7. Derivative of surface radius

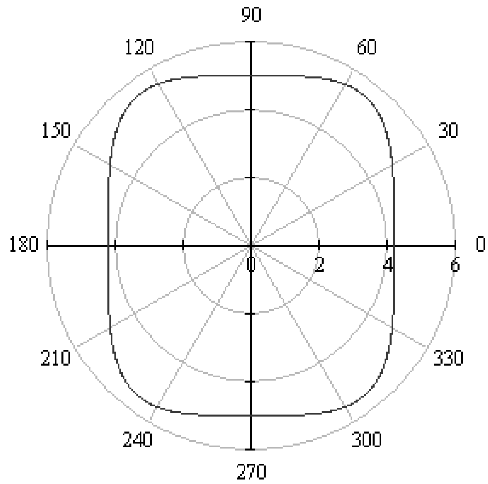

Fig. 8. The boundary in polar coordinates

The distribution function of the circumferential strain is shown in Fig. 9.

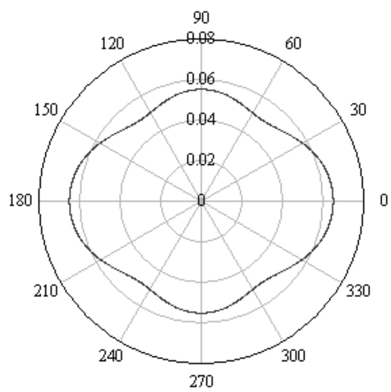

Fig. 9. Deformation of the material in the manufacture of complex surface

Even if the deformation in the radial direction $\varepsilon_r = 0$ is absent, stresses arise in the detail material, which could affect it badly.

In this case, the sweep plane stress state is realized, it is characterized by the absence of normal stresses at the sites that are parallel to one of the coordinate planes.

Such stress occurs in thin elements, when the load is applied only on the side surface of the forces parallel to the base and uniformly distributed over the thickness of the plane.

Since the base elements are free from the load, then on them $\sigma_z = 0$. Cause of the small thickness of the plane can be assumed that throughout its thickness.

From the generalized Hooke's law, follows that:

$$\varepsilon_z = -\frac{\mu}{E}\left(\sigma_r + \sigma_\varphi\right),$$

the base element will bend and take the shape of the surface.

$$\begin{cases} \sigma_r = \dfrac{E}{1-\mu^2}\left(\varepsilon_r + \mu \cdot \varepsilon_\varphi\right), \\ \sigma_\varphi = \dfrac{E}{1-\mu^2}\left(\varepsilon_\varphi + \mu \cdot \varepsilon_r\right). \end{cases}$$

Let's try to perform design of curve linear workpiece so that internal stresses in its surface during the manufacture of complex shape will be the lowest. Using the hypothesis of minimum energy formation, whereas the equivalent stress will be determined by the formula:

$$\sigma_e = \sqrt{\sigma_r^2 - \sigma_r\sigma_\varphi + \sigma_\varphi^2}.$$

We assume that the shape of the designed curved workpiece will be different from the calculated one. It's the shape define the function $R_m(\varphi)$.In this regard, any deformation in the radial and circumferential directions:

$$\varepsilon_m = \frac{R(\varphi)}{R_m(\varphi)} - 1, \ \varepsilon_\varphi = \frac{R_m(\varphi)}{r(\varphi)} - 1.$$

Taking into account that we calculated the boundary and the estimated function of workpiece, we will assume that these functions are known. So we introduce the notation:

$$\xi = \frac{R_m(\varphi)}{r(\varphi)}, \ \varsigma = \frac{R(\varphi)}{r(\varphi)}.$$

Then, stress we may describe in the form of:

$$\sigma_r = \frac{E}{1-\mu^2}\left(\frac{\varsigma}{\xi} + \mu \cdot \xi - (1+\mu)^2\right),$$

$$\sigma_\varphi = \frac{E}{1-\mu^2}\left(\mu\frac{\varsigma}{\xi} + \xi - (1+\mu)^2\right).$$

Given that we are looking for the minimum condition, we introduce a specific value:

$$s = \frac{\left(1-\mu^2\right)\sigma_e}{E}.$$

After completing the conversion, we get:

$$s = \sqrt{k_1\xi^2 - k_2\xi + k_3 - \frac{k_4}{\xi} + \frac{k_5}{\xi^2}},$$

Where: $k_1 = 1 - \mu + \mu^2$,

$$k_2 = 4(1+\mu) + (1+\mu)^2,$$

$$k_3 = (1+\mu)^2 + \varsigma\left(4\mu - \mu^2 - 1\right),$$

$$k_4 = \varsigma\left(4(1+\mu) - (1+\mu)^2\right),$$

$$k_5 = \varsigma^2\left(1 - \mu + \mu^2\right).$$

Noting that the unknown is a function ξ, other factors may be constant or depend on the geometry of the surface and its boundary.

The minimum stress we will try to determine by equating the derivative:

$$\frac{ds}{d\xi} = \frac{1}{2}\frac{2k_1\xi - k_2 + \dfrac{k_4}{\xi^2} - \dfrac{2k_5}{\xi^3}}{\sqrt{k_1\xi^2 - k_2\xi + k_3 - \dfrac{k_4}{\xi} + \dfrac{k_5}{\xi^2}}}.$$

Equality to zero expression determines the vanishing of the numerator. After adjustment to a common denominator and simplifying, we get:

$$\xi^4 - a_1\xi^3 + a_2\xi + a_3 = 0.$$

After solving this equation, we can find a function that characterizes the geometry of the curved workpiece that have the properties of minimal stress in the manufacture of its complex surface.

In the course of testing methods were compared with the three-dimensional visualization techniques. In this case, three-dimensional virtual model of the future is created in the computer environment, or by scanning a real 3D object.

Overlaying plastic structures on the surface of the layout is rendered using the rendering operation (Fig. 10).

Fig. 10. 3D visualization of deformation processes while creating a surface

Application of the methods of three-dimensional deployment, provides a geometric shape curved workpiece for a given surface (Fig. 11).

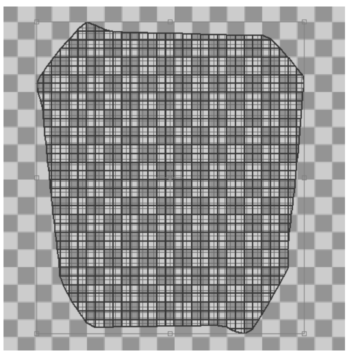

Fig. 11. Sweep of the surface as a result of 3D modeling

The proposed mathematical methods can greatly improve the existing three-dimensional methods in the most rational design of curved shape workpieces.

CONCLUSIONS

1. Thus mathematical modeling confirmed the possibility of designing curved workpieces for the manufacture of irregular surfaces on the basis of the minimum stress in the material.
2. The curved shape of the workpiece may also be obtained in the 3D simulation, the results of which must be refined by minimizing stresses.
3. The obtained results allow us to design the most accurate geometry of the workpiece for the manufacture of complex-shaped parts.

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МЕТОДЫ РАЦИОНАЛЬНОГО ПРОЕКТИРОВАНИЯ КРИВОЛИНЕЙНЫХ ЗАГОТОВОК ДЛЯ СОЗДАНИЯ ПОВЕРХНОСТЕЙ СЛОЖНЫХ ФОРМ

Инна Дейнека, Александр Рябчиков

Аннотация: Статья описывает математическую модель создания геометрии криволинейных заготовок исходя из минимума напряжений при изготовлении поверхностей сложных форм. Показаны методы поиска развертки поверхности, которую можно преобразовать механическим способом в поверхность Проведена апробация при сравнении с моделями, полученными в результате визуализации объектов в современных 3Dпрограммах.
Ключевые слова: криволинейная заготовка, сложная поверхность, 3D модель, минимальные напряжения**.**

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Wheel-rail conformal contact modeling

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Summary: Experimental tests have shown, that wheel – rail contact interaction modeling in a rail gauge corner zone with the use of halfspace - based theories can lead to a great inaccuracy in calculations. The most similar to experimental results one can obtain using FEM. However for certain reasons FEM contact solution can't be integrated directly to the railway vehicle dynamics simulation.
In the present paper the technique is developed for wheel – rail conformal contact modeling in a rail gauge corner. The difference in modeling results of presented technique from FEM results is approximately 5%. Thus the technique can be used for wheel – rail contact interaction modeling in a rail gauge corner zone during the railway vehicle dynamics simulation.
Key words: wheel, rail, conformal contact

INTRODUCTION

Numerical solutions based on Hertz theory [8,9,10,16] and Bussinesque – Cerutti solution [1,11,12,15,20] are often used when solving contact problems. The main limitations of these approaches is that characteristic geometrical sizes of contacting bodies are considerably greater then area of contact, and this allows to approximate the surfaces of bodies with half-spaces and separate the contact problem into two more simple problems - normal and tangential. This assumption is correct for the contact of new non - conformal profiles of wheel and rail in areas near the rail symmetry axis. However approximation with half-spaces surfaces of wheel and rail in the area of rail gauge corner is quite debatable, as the contact patch in this case is not settled in single plane and its sizes are near to characteristic sizes of contacting bodies. Moreover, a separation of contact problem into normal and tangential is improper due to the significant coupling of normal and tangential stresses , as will be shown further.

OBJECTS AND PROBLEMS

For a first time the weakness of Hertz theory when modeling conformal contact of two surfaces was theoretically grounded by Steuermann [18]. But his theory, as the Hertz one, is developed for half- spaces and the contact patch is assumed to be located in the single plane. That is not correct according to [6, 13, 17]. Also, the more sophisticated approaches must be used to define the initial separation between surfaces [7].

In paper [21] the methods of contact stresses investigation with the use of tensoresistors are presented. Taking these experiments as the basis, Yakovlev has shown, that when contact is moving to the rail gauge corner, where lateral curvature radius is 15 mm and is same order of magnitude with characteristic sizes of contact patch, the application of Hertz theory and half – space theory introduces a great inaccuracy in the calculation.

In our days the numerical methods for conformal contact modeling are seems to be the most attractive and precise. From the middle of 60 –s the finite elements methods (FEM) is often used when solving elastic problems. FEM modeling allows to obtain more realistic results, than from analytical solutions. The results of FEM modeling for different forms of conformal surfaces [2, 22] have shown, that contact stiffness, depending on the degree of surfaces' conformity and load applied, can be 50% greater than contact stiffness, predicted by Hertz theory.

Solving contact problem directly with FEM when modeling railway vehicle dynamics is very complicated and time-consuming. That's why in paper [19] was introduced the calculation of so – called "influence coefficients" with the use of FEM, as the alternative for the Bussinesque – Cerutti solution for conformal contact problems. A numerical modeling of real wheel and rail surfaces in rail gauge corner zone with curvature radiuses 10.5 and 15 mm have shown that the area of the patch decreases by 30–35%, and the maximum pressures increase correspondingly comparing to the Hertz theory. However with such approach for every wheel and rail profile combination it is necessary to calculate a great number of influence coefficients for every mesh node in advance. It seems to be more effective to use approach introduced in paper [17]. The idea of this approach is to get the most appropriate analytical influence functions by means of comparing them to FEM modeling results.

The aim of this paper is to present relatively robust and accurate technique for conformal contact, that can be painlessly integrated in railway vehicle dynamics simulation program.

When solving conformal contact problem with numerical methods, the following sub-problems have to be solved:

- definition of the spatial form of contact surface,
- definition of initial separation between contact surfaces,
- calculation of proper influence coefficient (functions).

The main difficulty for definition of spatial form of contact surface for conformal contact is that it not known in advance. So some hypnotizes are required to predict it's shape. In paper [13] it is suggested to use as contact surface the surface of one of the bodies in contact. It is motivated by the fact that conformal surfaces are very closed to each other in contact area. But this assuming the chosen body to be rigid and that can lead to some inaccuracies in calculations. So it seems to be more effective to define a contact surface as "intermediate" between surfaces of contacting bodies (see Fig. 1).

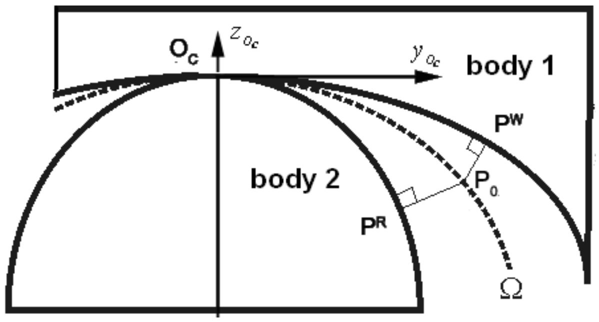


Fig. 1. Contact surface and initial separation calculation scheme

The expression for intermediate contact surface can be written in form:

$$z = f(x, y) = K \cdot f_1(x, y) + (1 - K) \cdot f_2(x, y), \quad (1)$$

where: $K = \dfrac{k_2}{k_1 + k_2}$, $k_i = \dfrac{1 - \nu_i^2}{\pi E_i}$, $i = 1,2$, $K \in [0,1]$, ν_1, ν_2, E_1, E_2 - Poisson coefficients and Young modulus of bodies, f_1 и f_2 - functions, that describes bodies surfaces.

In case when materials of bodies are the same, $K = 1/2$ and $f(x, y) = [f_1(x, y) + f_2(x, y)]/2$.

Next, for the numerical solution, the constructed surfaces can be meshed with grid with desired spacing in x and y directions. For every point P_0, which is grid cell center, its orthogonal projections P^W and P^R on the surfaces of contacting bodies are detected.

Uniqueness of the projections is insured by the regularity of the profile functions. Then the initial separation in point P_0 will be sum of distances from P_0 to points P^W and P^R:

$$d_R = \min(\rho(P_0, P^1)) + \min(\rho(P_0, P^2)), \quad (2)$$

where: $\rho(P_0, P^i)$ stays for the distance from point P_0 to arbitrary point of i –th body ($i = 1,2$). Thus, the problem reduces to finding the minimum of two – variables function, which can be solved with any suitable method of multidimensional optimization, for example with the gradient descent method.

It is common opinion, that friction has negligible influence on normal pressure distribution. The basic premise for that is the next expression for normal elastic displacements difference of contacting bodies' points:

$$w^+ - w^- = K \int_{A_C} \left(\frac{\cos\theta}{R} \tau_{x'z} + \frac{\sin\theta}{R} \tau_{y'z} \right) dx'dy' + \frac{1}{\pi E} \int_{A_C} \frac{1-\nu}{R} \sigma_{zz} dx'dy', \quad (3)$$

where: A_C - contact area,

$w^{\pm}$ - normal elastic displacements,

"+","–" - indexes of upper and lower bodies respectively,

$$K = \frac{1}{4\pi} \left(\frac{1-2\nu^+}{E^+} - \frac{1-2\nu^-}{E^-} \right).$$

If wheel and rail have identical properties, than $K = 0$ and tangential stresses have no any influence on normal pressures, and it is possible to divide contact problem on normal and tangential.

To check the correctness of contact problem division in conformal contact case we carried out the next numerical experiment. In ANSYS program environment parametric FEM models of cylinder with radius $R1$ and cylindrical cavity with radius $R2$ were developed (see Fig. 2). In the upper point of cylinder and lower point of cavity unit tangential loads were applied. The foundations of cylinder and cavity are supposed to be fixed and have corresponding boundary conditions applied.

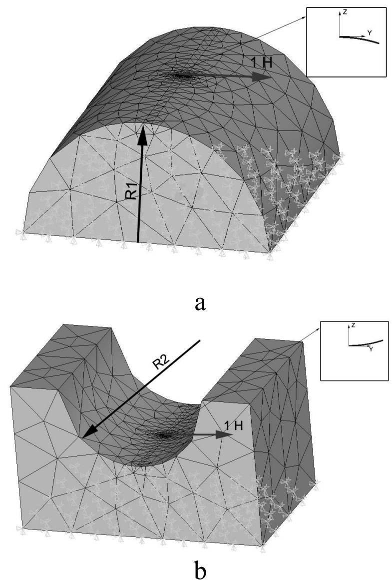
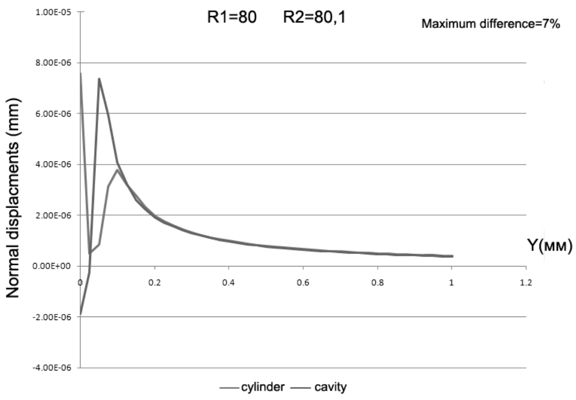


Fig. 2. FEM models of: a – cylinder, b – cavity

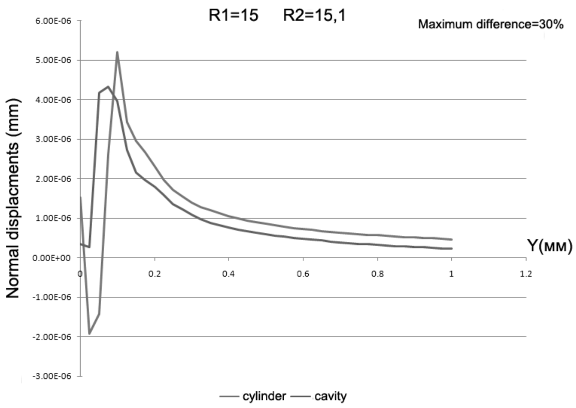
The experiment was carried out for two pairs of radiuses values: $R1 = 80$, $R2 = 80{,}1$ and $R1 = 15$, $R2 = 15{,}1$. After the solution converged, nodal displacements data was stored into structured file with a specially developed APDL macros . The file was further processed by Microsoft Excel, to calculate projections of displacement vector on surfaces normals (normal displacements). The difference of this projections for cylinder and cavity is shown on Fig. 3.

As it can be seen from Fig. 3, in the second case nodal normal displacement difference is significantly higher than in the first one. It is also can be seen that in the vicinity of load application point (< 0.1 mm) can be observed intermittent nodal displacements. That is common fact for FEM solutions. However when the distance from load application point increases the solution becomes more stable.

Thus for conformal contact problem solution in the rail gauge corner zone, where curvature radius is equal to 15 mm, it is necessary to use different from (3) expressions for normal elastic displacements.



a



b

Fig. 3. Normal nodal displacements for $R1 = 80$, $R2 = 80{,}1$ (a) and $R1 = 15$, $R2 = 15{,}1$ (b)

To obtain this expressions the numerical experiment described above was continued with different shapes of conformal surfaces. For a search of suitable semi - empirical function different modification of Kelvin fundamental solution were considered, similar to [17]. We derived a next expressions for normal elastic displacements of points on body surfaces, caused by unit load (the most correlated with FEM):

$$w_{ij}^{z} = \frac{1}{\rho_{ij}}\left[\frac{3k_f}{4} + \frac{k_d (z_i - z_j)^2}{\rho_{ij}^2}\right],$$

$$w_{ij}^{x} = k_d \frac{(1 + 0.25 sign(k))(x_i - x_j)}{\rho_{ij}^2}, \qquad (4)$$

$$w_{ij}^{y} = k_d \frac{(1 + 0.25 sign(k))(y_i - y_j)}{\rho_{ij}^2},$$

where: x, y, z – direction of load application, i – considered point index, j – load application point index, k – body index (1 – upper body (concave), -2 – lower body (convex)), ρ_{ij} – distance between points,

$$k_d = \frac{1}{8\pi(1-\nu)G}, \; k_f = (3 - 4\nu)k_d .$$

These expressions were used in specially developed program VDEUNU CONTACT (based on mathematical models [3, 4, 5]) for calculation of compliance matrix coefficients in conformal contacts.

RESULTS AND DISCUSSIONS

To check the correctness of the presented approach in VDEUNU CONTACT program and in the ANSYS environment was modeled a conformal contact of ДМеТИ wheel and worn P-65 rail (ГОСТ Р51685-2000) with 125kN vertical load. Two different approaches were implemented in VDEUNU CONTACT(see Fig. 4):

- contact patch is located in single plane, initial separation is calculated by normal to plane, Bussinesque – Cerutti influence coefficients are used (Model A),
- contact patch is located on surface (1), initial separation is calculated according to expression (4),.influence coefficients (4) are used (Model B).

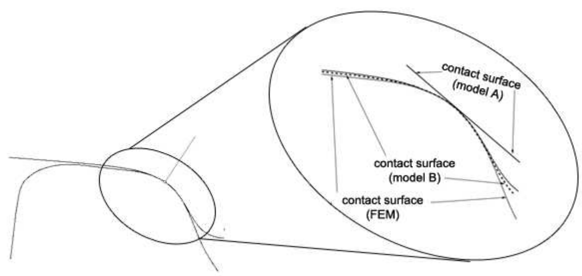
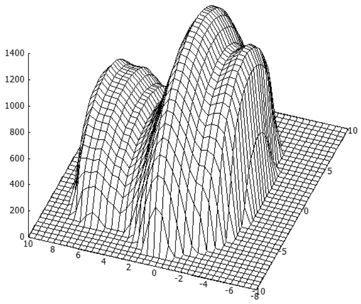


Fig. 4. Wheel – rail conformal contact with different model

Modeling results are shown on Fig. 5 and Table1. A significant difference can be seen in the modeling results between Model A and ANSYS (25% in contact area and 43% in maximal contact pressures). At the same time for Model B this difference is reduced to 5% approximately.



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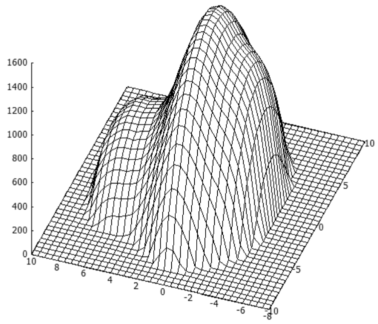

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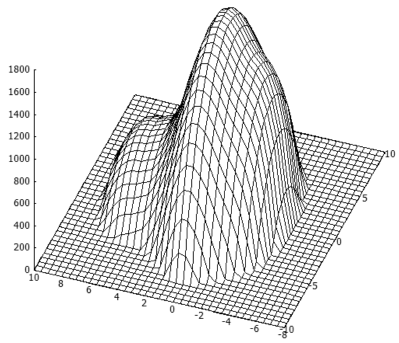

c

Fig. 5. Contact pressure distribution: a – VDEUNU CONTACT, Model A; b – VDEUNU CONTACT, Model B; c – ANSYS

Table1. Contact patch characteristics

Model	Contact area (mm^2)	Maximal contact pressure (MPa)
Model A	189	1244
Model B	160	1688
ANSYS	152	1787

CONCLUSIONS

1. The basics of numerical solutions of conformal contacts is presented.
2. It is shown, that conformal contact modeling results, based on half - space theory, can significantly differ from the FEM results.
3. The modeling results with the use of presented method differ from FEM results only by 5% approximately. Thus the technique can be used for wheel – rail contact interaction modeling in railway vehicle dynamics simulation.

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МОДЕЛИРОВАНИЕ КОНТАКТА СОГЛАСОВАННЫХ ПОВЕРХНОСТЕЙ КОЛЕСА И РЕЛЬСА

Александр Голубенко, Александр Костюкевич, Илья Цыгановский

Аннотация: Экспериментальная проверка показала, что моделирование контактного взаимодействия колеса и рельса в зоне выкружки рельса при помощи теории упругих полупространств может приводить к большим неточностям в вычислениях. В этом случае наиболее близкие к экспериментальным результаты можно получить при помощи МКЭ. Однако решение контактной задачи с помощью МКЭ по объективным причинам не может напрямую использоваться при моделировании динамики рельсовых экипажей.

В статье предложена методика моделирования контакта согласованных поверхностей колеса и рельса в зоне выкружки рельса. Полученная разница между результатами моделирования с помощью предложенной методики и результатами МКЭ составляет около 5%. Таким образом, данная методика может быть использоватна для решения контактной задачи в районе выкружки рельса при моделировании динамики рельсовых экипажей.

Ключевые слова: колесо, контакт, согласованные поверхности

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Flow in the main pipeline of the water-coal mixture

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S u m m a r y . Results of analytical research of water-coal mixture flow in the main pipeline are presented. It's received by the mathematical model solution of non-Newtonian liquid movement. The mathematical model considers effective viscosity, density and the module of elasticity of a mixture for pseudo-plastic reological model. Dependences of pressure and discharge change in various pipeline sections are received.
K e y w o r d s : unsteady flow, water-coal mixture, mathematical model, hydrodynamic processes, long pipeline.

INTRODUCTION

Mathematical model's adequacy of hydraulic transport of the water-coal fuel (WCF) [9] depends on completeness of the description of hydrodynamic processes [12] in each of these elements [15]. In presented paper the results of research of non-Newtonian liquid flow are given for the long pipeline (the long pipeline is the pipeline, length of which is much bigger than length of a pressure wave, caused by operation of the piston pump[16]. In presented model reological characteristics of transported liquid, its compressibility and some other parameters are considered, oppose to the previous researches [18].

The method of mathematical simulation is used as the main research instrument, considering complexity and laboriousness of carrying out physical experiment [13].

OBJECTS AND PROBLEMS

Water-coal fuel represents rather stable mixture of water with fine-grinded coal (class S particles=0,05-0,25 mm) [19], which flow is alike movement of homogeneous liquid [5] with the increased density [9].

To describe the unsteady WCF flow the one-dimensional mathematical model of movement [4] is accepted, as diameter of the pipeline is much less than its length [20]:

$$\rho_{см}\frac{\partial V}{\partial t}+\rho_{см}V\frac{\partial V}{\partial x}=-\frac{\partial p}{\partial x}-\frac{2\tau_{н}}{R}, \qquad (1)$$

and continuity of a flow [21]:

$$\frac{\partial p}{\partial t}+V\frac{\partial p}{\partial x}=-E_{см}\frac{\partial V}{\partial x}. \qquad (2)$$

In these expressions:

V and p are average by cross-section flow values of liquid speed and pressure,

ρ_{cm} and E_{cm} are density and the volume module of elasticity of water-coal fuel,

R is pipeline radius,

τ_N is tangential stress on a wall,

t, x are current coordinates of time and length of the pipeline.

Water-coal mixtures are described by various reological models depending on physical properties [3]. To choose concrete model you have to define experimentally dependences of tangential stresses τ from shear rate γ [8]. We accept pseudo-plastic reological model, as water-coal fuels are transported by coal pipes. It is described by the equation [9]:

$$\tau = k\dot{\gamma}^{n},$$

where: k and n are experimental factors of model.

The Reynolds's number [1] defines the mode of liquid flow and the value of hydraulic friction factor. For our flow model is defined by expression [2]:

$$\mathrm{Re} = \frac{8V^{2-n}\left(2R\right)^{n}\rho_{см}}{k\left(6+\frac{2}{n}\right)^{n}},$$

and effective (conditional) viscosity [3]:

$$\mu_{ef} = \frac{\left(2R\right)^{1-n} k\left(6+\frac{2}{n}\right)^{n}}{8V^{1-n}}. \qquad (3)$$

Unsteady flow of water-coal fuel with insignificant variations of speed around average value is characteristic at operation of the multicylinder pump on a network equipped with the pneumatichydraulic accumulator. In this case it is possible to accept size of effective viscosity constant and equal μ_{ef} = 0, 85 Pas [2] according to experimental data [10].

Quasistationary value [4] of tangential stress in a laminar stream of WCF is proportional to speed of mixture movement [5]:

$$\tau_{н}^{кв} = \frac{4\mu_{э}}{R}V.$$

The rheological properties of coal oil/coal water mixtures play a vital role in their storage, transportation, atomisation and combustion. Therefore it is important to establish a criteria tor controlling their rheological properties so as to obtain highly loaded mixtures with acceptable fluidity while maintaining sufficient stability against sedimentation of particles.

There is a voluminous literature available on rheology of coal oil mixtures but there is limited work done on the effect of coal particle size distribution on rheology of coal oil mixtures. However, a few references are available on the effect of coal particle size distribution on rheological properties of coal water mixtures. The viscosity of the slurry was found to be minimum when htrcent by weight of fines was 25-30% of the total weight. The decrease in viscosity was attributed to the lubricating effect of smaller particles in the gaps between the bigger particles. Three parameters signifying the effects of particle size distribution were used to predict the shear viscosity of suspensions.

Data on the effect of particle size distribution on viscosity of coal oil mixture is very limited. Therefore this study aims to understand how coal particle size distribution influences the viscosity of coal oil mixtures.

Eight coal samples of different composition have been selected for the present study. The proximate analysis and other relevant information is given in Table 1.

Table 1. Proximate Analysis and other Details of Coal Samples

№	Coal, gm/cc	Sample Density	Moisture, %	Ash, %	Volaile Matter	Fixed Carbon, %
I	5.0	8	31	56	2,00	1.32
II	5.5	10.0	31.5	53	1.80	1.35
III	5.62	11.40	32,00	50.98	1.77	1.36
IV	6.9	13.0	29,82	50.28	1.74	1.38
V	6. 72	14.5	31.0	47.78	1.63	1.3
VI	6.10	16.0	27.40	50.5	1.60	1.41
VII	5.80	24.5	29.20	40. 5	1 .50	1.49
VIII	5.4	20.0	30.0	44.6	-	1,42

Viscosity of oil at 35°C = 680 m Pa.s,
40°C = 450 m Pa.s,
45°C = 340 m Pa.s,
Specific Gravity = 0.98/

The first seven samples have been used to study how the composition affects its size distribution which in turn influences the viscosity of coal oil mixtures (COMsb The initial size of samples was 90% between 16 and 20 Taylor mesh and 100% less than H inch. Each of these samples has been ground in a ball mill for one hour and particle size distributions have been found out by using sieves and Warman Cyclosizer for sub-sieve particles. The top size of these samples varied between 211 and 85 microns. The data has been fitted into Rosin-Rammler equation to represent size distributions. The Rosin-Rammler equation is given below:

$$\frac{R}{100} = e^{-\left(\frac{\chi}{k}\right)^n},$$

where: R is cumulative weight % of coal retained on the screen,

χ is weighted mean diameter of particles retained on the screen,

n is distribution modulus,

k is size modulus.

The values of ‘n’ for the first seven samples have been given in Table-1

The VIHth Coal sample has been used to prepare two sets of samples. In the first set the parameter ‘κ’ in Rosin-Rammler equation maintained constant and 'n' is varied. In the second set vice-versa. This has been done to find out how individually 'n' and 'k' affect the viscosity of coal oil mixtures. Six more samples have been prepared using VIHth coal sample to find out how the fines and maximum packing fraction affect the viscosity of COMs.

The viscosity of COMs has been measured by using Brookfield synchro- lectric viscometer (Model RVT). For determination of viscosity the coal oil mixture has been taken in stainless steel jacketed vessel whose dimensions are: inner diameter = 110 mm: outer diameter = 120 mm, height = 150 mm. Thermostated water is circulated through the jacket to maintain required temperature of COM. All the viscosity measurements have been done at 10 rpm.

All the coal samples selected for the study as can be seen from Table-I, belong to sub-bituminous rank. The ash content of these coal samples varies between 8 and 24 percent. These coal samples have been selected in such a way that their daf volatile matter and fixed carbon, varied within narrow limits. This is done to minimize the effect of these components on grindability and size distribution of coal. Only the mineral matter content is expected to influence grindability thereby the particle size distributions of these samples. It can be seen from the Table-I that as the ash content of the coal increases the distribution modulus 'n1 decreases indicating wider size distribution of the coal sample. Though the size modulus of these samples varied but it did not show any definite trend with respect to ash content of the coal.

The viscosity of coal oil mixtures has been measured at five different coal volume fractions ranging from 25 to 45%. For clarity sake the results of only four coals are presented here. It was estimated that viscosity increases as coal volume fraction in COM increases, higher values of viscosities are observed at higher 'n' values. For the coals of the same rank, as the ash content increases the grindability decreases, therefore coals with higher mineral matter content when ground for same duration of time may give particles of broader size distribution. This is reflected in the smaller 'n' values for coals having high ash content indicating broader particle size distribution. A broader size distribution would normally lead to higher maximum packing fractions, which in turn results in higher relative mobility of coal particles in the coal oil mixture. Consequently COMs of broader coal particle size distributions will have lower viscosities. The reason for samples of broader particle size distributions giving rise to higher maximum packing fractions is that the smaller particles may enter the gaps between the bigger particles thereby apparently not occupying any space. The smaller particle entering the bigger particles may even act as lubricant resulting in lower values of slurry viscosity. Viscosity of coal oil mixture increases as coal concentration increases because of increased inter particle friction. Above 40% coal concentration the increase in viscosity is very steep.

In the second set of experiments coal oil mixtures have been prepared by using VIIlth coal sample. In the first group of experiments the 'n' in Rosin-Rammler equation varied between 1.2 and 2.0 at κ = 65 um. It was found that the viscosity of COM does not very much with 'n' if к is kept constant. Unlike the previous case where the top size of particles in samples varied, here the top size of particles in all samples remained constant. Only the distribution is varied. Apparently within the range of 'n' values studied there is not much variation in maximum packing fraction therefore there is no variation in the viscosity of COM. It was also shown viscosity values of COM at different 'k' values. The viscosity decreases as the 'k' value increases. The same trend has been observed at both 25 and 30% coal concentrations. As the 'k' value of the sample increases its coarseness increases therefore the specific surface area decreases resulting in lower values of viscosity of COM.

Finally six more samples have been prepared using the VHIth coal sample. The particle size distributions of these samples have been given in Fig.6. The average particle size of these samples varied bet-ween 127.5 and 18.5 microns. In this case it is not possible to represent the data by Rosin- Rammler equation. For the six samples the maximum packing fractions have been calculated using the formula given by Patton which is given below:

$$\left(\varphi_m\right)_i = \sum_{i=1}^{nf} \sum_{j=1}^{nf} \Phi_{ij}\varphi_j,$$

where: *nf* – is the number of size fractions φ_j refer to respective volume,

fractions $\Phi_{ii} = \Phi_{jj}$ =0.639 and Φ_{ij} represent coefficients to be used *ii ij,* in relating to larger particle group to a smaller and vice-versa. The value Φ_{ij} is given by:

$$\Phi_{ij} = 0.639 \pm \left(\frac{\varphi_{mo} - 0.639}{1.15 - 1.017\varphi_{mo}}\right),$$

where: φ is the maximum packing concentration for binary mixtures.

In the aSove equation positive sign applies when a coarse size fraction is blended with a finer size fraction and the negative sign applies otherwise.

The smallest of (Φ_{ij} ф). values is taken as maximum packing fraction for the sample. The necessary data is taken from reference [21]. Consequently the COM of sample I has less viscosity than COM of sample II. At all three concentrations studied it is observed the viscosity of COM is minimum when fines content is around 20-25%. The same trend has been observed at all the three concentrations studied. The reason for smaller values of viscosity when fines content is around 20-25% may be due to maximum packing fraction effect as well as lubricating effect of fines as mentioned earlier. But as the fines content in the sample increases the viscosity of COM increases because of increased specific surface area which results in higher inter particle friction leading to tighter viscosities.

The following conclusions can be drawn from the present study:

COM of broader coal particle size distributions have smaller values of viscosity. The composition of coal influences its particle size distribution.

Maximum packing fraction of coal sample influences the viscosity coal oil mixtures. Higher the maximum packing fraction of the coal sample smaller will be the viscosity of COM.

Density and volume module of elasticity of mixture [6]:

$$\rho_{cm} = \frac{\rho_m \rho_b}{\rho_m + k_m\left(\rho_b - \rho_m\right)}, \tag{4}$$

$$E_{cm} = \frac{E_b E_m\left[\rho_m + k_m\left(\rho_b - \rho_m\right)\right]}{\rho_m E_m + k_m\left(\rho_b E_b - \rho_m E_m\right)}, \tag{5}$$

where: E_b, E_m are volume modules of elasticity of water and of solid phase in a mixture [7],

ρ_{in}, ρ_m are densities of water and solid phase,

k_m is mass concentration of solid phase in mixture.

We receive system of the differential equations in total derivatives for each *i* point of a set *N* of splittings on length of the pipeline, replacing in the equations (1) and (2) partial derivatives on length of the pipeline with finite-difference analogs:

$$\left.\frac{dV}{dt}\right|_i = \frac{1}{\rho_{cm}}\left(\frac{8\mu_e}{R^2}V_i + \frac{p_i - p_{i-1}}{\Delta x}\right) - \frac{V_i^2 - V_{i-1}^2}{2\Delta x}, \quad (6)$$

$$\left.\frac{dp}{dt}\right|_{i-1} = -\frac{V_i + V_{i-1}}{2}\frac{p_i - p_{i-1}}{\Delta x} - E_{cm}\frac{V_i - V_{i-1}}{\Delta x}. \quad (7)$$

Flow speed at the beginning of the pipeline $V = V(0, t)$ is necessary boundary condition for mathematical model integration. It is defined by work of the pump and pressure at the end of the pipeline $p = p(l, t)$, where l is length of the pipeline.

The system of differential equations (6)...(7) and equations (4)...(5) was numerically integrated by Runge-Kutta's method with Merson's criterion. Adequacy of the accepted model and method of integration was estimated by comparison experimental data provided in literature with data received on model, modified for this case.

Installation consisted of pipeline diameter of 25,4 mm and length of 36 m. The line was joint to a tank in which constant pressure was maintained. Pressure sensors were installed on the pipeline, its transfered directly to the computer through analog-digital convertor (ADC).

ADC has analog inputs to connect the signals sources and digital outputs to transmit transformed data to the computer. The computer with special software manages ADC devices and accepts data for consequent processing and analysis.

The measuring system is constructed on the basis of the personal computer, it consists of three basic elements: signal sources, ADC system and software [11].

Unsteady pressure measurement was carried out by means of inductive sensors of the pressure signal of which was amplified and transformed by the amplifier. Thereby, pressure change was transformed to proportional signal in the form of tension of direct electric current which was signaled on ADC input.

There is large number of ADC varieties. However all ADC devices have common parameters, it allows creating universal system of data collection from analog-digital devices.

The software is very important in the course of registration and data collection as the software defines final quality and computer system efficiency. In experiments the adapted PowerGraph system, which allows connecting practically any analog-digital converters, was used. It gives advantages to software users: first of all, it is large choice of system hardware (from simple and cheap measuring devices to complex and expensive research installations), secondly, all this variety is uniform universal system.

Satisfacting speed coincidence of pressure waves distribution, frequency of own fluctuations and extent pressure waves attenuation is received.

Let's note that adequacy was defined by comparison of transients in system (reaction to abrupt liquid speed change). The gradient of speed and pressure in this case is much higher, than at liquid flow in main pipeline therefore the offered mathematical model of non-Newtonian liquid flow will describe obviously adequately hydrodynamic processes in the real pipeline [11].

The developed mathematical model of WCF flow in main coal pipeline was used for determination of regularities of water-coal mixture flow in the pipeline diameter of 0.5 m and length of 20 km at average speed of movement V_{cp} = 0.1-0.7 m/s that is characteristic for industrial coal pipelines.

Pulsing nature of speed change of water-coal mixture in inlet section (main pump outlet) and active loading in the form of throttle in outlet section (it is caused by system of latches on inlet in transitional pump station existence) are accepted as boundary conditions [17].

Diagrams of pressure change in various sections of the pipeline are shown on Fig. The oscillation amplitude of pressure in inlet section of the pipeline is defined by discharge pulsations on pump outlet. The amplitude is practically constant and is not influenced by reflected waves because of big extent of the main pipeline. The oscillation amplitude of pressure changes due to superposition of direct and reflected pressure waves reducting the length of pipeline to 2-3 km [14].

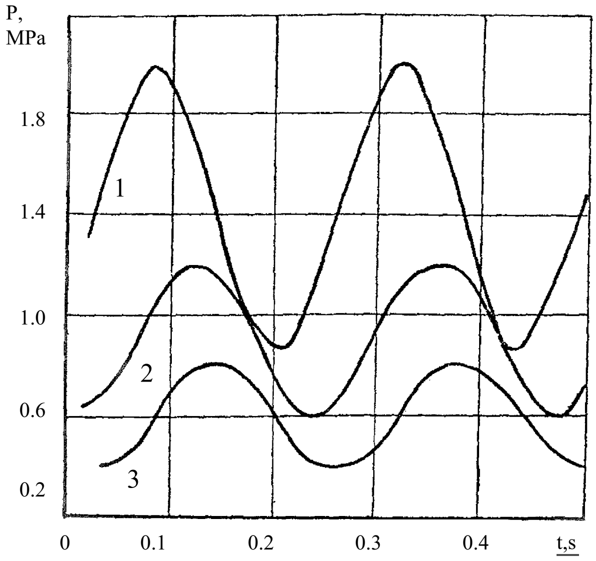

Fig. Pressure change in the main pipeline

Curve *2* and 3 (Fig.) show pressure change in pipeline sections at distance 6 and 9 km from initial pipeline section accordingly. Apparently, there is intensive damping, and practically, through 8-9 km of pressure pulsation wave processes completely decline.

The degree of pressure change damping of water-coal mixture depends on hydraulic friction factor and the WCF viscous properties. The frequency of pulsations is increasing and resistance factor is increasing as well, that leads to strengthening of damping degree.

CONCLUSIONS

1. We observe considerable divergences between data of physical and numerical experiment in a zone of the lowered pressure, when modeling the unstationary processes, which are accompanied with pressure decline below the atmospheric.

2. The possible reason of such a mismatch can be influence of undissolved air in working liquid, processes of allocation and dissolution of gas on value of elasticity volume module.

3. It is necessary to supplement the system of equations (4)...(7) with equations of gas diffusion from bubbles to liquid and equations of movement of walls of gas bubbles in that case.

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ТЕЧНИЕ ВОДОУГОЛЬНОЙ СМЕСИ В МАГИСТРАЛЬНОМ ТРУБОПРОВОДЕ

Яна Гусенцова

Аннотация. Приведены результаты аналитического исследования течения водоугольной смеси в магистральном трубопроводе, полученные с помощью решения математической модели движения неньютоновской жидкости. Математическая модель учитывает эффективную вязкость, плотность и модуль упругости смеси для псевдопластичной реологической модели. Получены зависимости изменения давления и расхода в различных сечения: трубопровода.

Ключевые слова: неустановившееся течение, водоугольная смесь, математическая модель, гидродинамические процессы, длинный трубопровод

Design concepts of gaseous detonation guns for thermal spraying

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S u m m a r y . Presented a structural analysis of gaseous detonation guns for spraying powder coatings and the possible variants of their operational cycle. The basic principles for the design of high detonation-gas plants for spraying powder coatings, including the concept of a valveless devices, are formulated.
K e y w o r d s . Gaseous detonation, coating deposition, operational cycle.

INTRODUCTION

In spite of competing processes (chemical vapor deposition (CVD), physical vapor deposition (PVD), etc.) and certain drawbacks, thermal spray process sales are increasing regularly (almost by 10% per year since 1990 [6]). The growth will probably continue, because spraying techniques are relatively harmless to the environment and the full potential of thermal spraying as an alternative to more conventional coating techniques (e.g., hard chromium) for processing "multimaterials" or for free forming and repairs is still undiscovered. However, this development could be enhanced with increased quality of coatings and process reliability. It demands improved process understanding and on-line control with a real time closed-loop control. Decades of research and development in thermal spray (TS) processes have exposed that higher performance and lifetime coatings can be produced if the feedstock particles are accelerated to a high velocity and heated prior to impact on the substrate to be coated [4, 13, 27].

Almost in parallel to plasma spraying, Union Carbide (now Praxair Surface Technologies, Inc., Indianapolis. IN) marketed the trademarked D-Gun producing premium coatings, especially metallic and cermet ones, which have long been the goal of all other coating processes, i.e., higher density, improved corrosion barrier, higher hardness, better wear resistance, higher bonding and cohesive strength, almost no oxidation, thicker coatings, and smoother as-sprayed surfaces. However, the detonation gun (D-Gun) process was available only as a service [12].

Historically, the two fundamental modes of combustion, namely flame and detonation, have found a wide variety of applications in human activities. It is a slow flame that has been extensively utilized in propulsion, power engineering, material science, and chemical technology, while detonations were used basically for military purposes. As the knowledge in detonation physics and chemistry is continuously advancing, one inevitably arrives at the time when this knowledge is to be used for constructive purposes as well to help humanity at large. Detonation is a very attractive phenomenon from the viewpoint of the thermodynamic efficiency of chemical energy conversion into thermal and kinetic energy. Once this advantage of detonation is capitalized properly, considerable benefits are expected to be achieved in terms of fuel consumption, manufacturing and operational costs, pollutant emissions, etc. [1, 3, 20].

For a long time, D-Gun technology has been the reference standard in producing metallic and cermet coatings. However, as it was available only as a service, no research work was published on the process. With the transformations that occurred in the former USSR, Russian equipment and literature on the subject became available in the mid 1990s [19].

Gas detonation can be used to generate thrust in engines, to induce force or destruction actions on objects located both inside and outside the device, to heat and accelerate condensed particles, to rapidly burn the fuel, etc. [19].

The development of detonation spraying is accompanied by broadening its industrial use [16]: deposition of coatings on aircraft engines and parts, jigs and fixtures [2], strengthening of cumulative punches [8, 9], improvement of wear resistance of work items re-adjustable dies [15], creation of a new metal-working tools [17], hardening of abrasive wheels, balancing of rotor systems [18], improvement of resistance to abrasion [21], etc.

There are many different D-Gun designs [14,23,24,28]. Unfortunately, the available literature contains no reliable data on the reliability of these devices and the comparative analysis of their structural characteristics.

Compared to HVOF or plasma spray processes, much work, some of which is in progress, is necessary to better understand the phenomena of the D-gun process [10, 11].

The aim of this work is to develop the basic principles of structural analysis and synthesis of structures of high efficiency detonation-gas plants for spraying of powder coatings.

BASIC PRINCIPLES OF GASEOUS DETONATION GUNS

The detonation-spraying technique is cyclic. In a D-Gun, detonation is initiated in a tube that serves as the combustor. The detonation wave rapidly traverses the chamber resulting in a nearly constant-volume heat addition process that produces a high pressure in the combustor and provides the formation of high velocity impulse flow, which used for powder heating and acceleration. A typical duty cycle of detonation-gas spraying of coatings and its main parameters are shown in Fig. 1.

To facilitate the description and analysis of basic physicochemical phenomena involved in the working cycle, nine principal steps will be considered: (1) filling the detonation gun barrel with a fresh charge of combustible gas mixture (GF), (2) powder doze feeding into DC (barrel) (PF), (3) creation of “phlegmatizing gas plug” between ignition point and gas mixer (GP), (4) ignition of gas mixture (Ig), (5) DC purging of residual gases (Pr), (6) deflagration to detonation transition (DDT), (7) impulse burn-out of the fresh charge (B), (8) interaction of the powder particles with an impulse flow of combustion products and two phase outflow from barrel (AP), (9) interaction of the gas-powder stream with the substrate and single layer coating formation (CF).

In the most general case the gaseous detonation gun (GDG), as an auto-oscillatory system, has a block diagram shown in Fig.1. The oscillatory system can also be represented as a sequence of systems of the GDG itself and of the environment receiving the powder being processed (the product being coated, cooling chamber, etc.). The behavior (state) of the environment may affect parameters of the working cycle because of the effect of feedbacks on the controllers and actuators. Growing pressure to improve the performance of D-Guns, as of IC engines, has resulted in development of improved control systems [5].

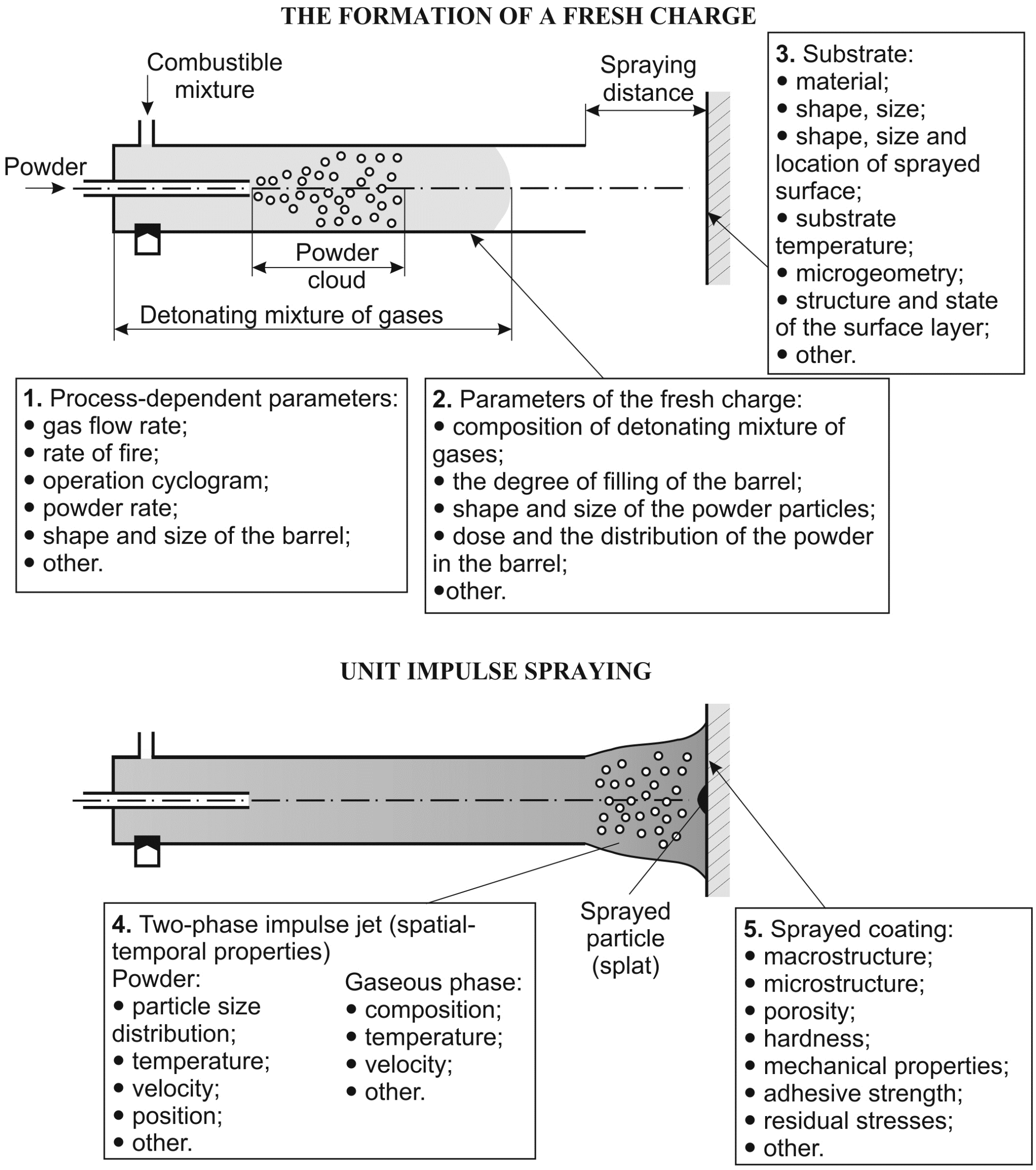

Fig. 1. A typical duty cycle of detonation-gas spraying and its main parameters

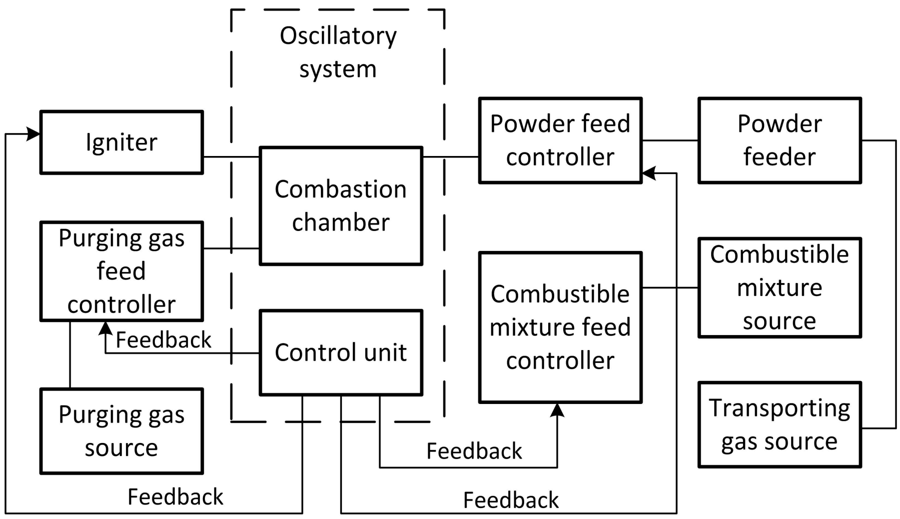

Fig. 2. Block diagram of gaseous detonation gun for thermal spraying

The steps of an impulse burn-out of the combustible mixture and formation of an impulse heterogeneous stream are governing steps and depend greatly on the quality of barrel filling. Repetition of cycles causes the fresh charge to contain a certain amount of combustion products and powder from the preceding spraying cycle. The gases and powder, on the one hand, reduce the mass of a fresh charge and, on the other hand, adversely affect the processes of burn-out and formation of an impulse heterogeneous stream themselves. It is therefore natural to attempt to reduce the fraction of residual gases and powder in a fresh charge. Also the flow of a working medium (purging gas, fresh combustible mixture or gas suspension of the initial powder) has a limited time to overcome the resistance of inlet paths, to contact heated surfaces etc. All this changes the density of the working medium and hence also the mass of charge capable of filling a barrel of predetermined dimensions, the degree of barrel filling, the spatial distribution of fresh charge components in the barrel. The barrel-filling processes have been poorly studied.

After the barrel has been filled, an ignition source operates, installed in the combustion chamber, or in an ignition chamber or in the combustible mixture feed piping. The mixture ignites, a flame front emerges, and burn-out of the combustible mixture occurs accompanied by progressive acceleration of the flame until a stationary detonation mode arises. The flow field around spark plug impacts the spark discharge in spark ignited D-Guns. Ignition resulting from spark discharge between spark plug electrodes is a crucial factor which strongly influences the combustion process [22]. As a consequence the flow field around the spark plug significantly affects D-Gun work repeatability and toxic components concentration in exhaust gases.

The pressure in the barrel during combustion rises and burn-out and is accompanied by ejection of incandescent combustion products jointly with suspended powder particles through the open end of the barrel [25]. After the discharge, the pressure in the barrel first drops below atmospheric pressure (because of the inertia of the flow) and then equalizes. The combustion chamber is again filled with a fresh charge, and the process is repeated. Thus, vibration burning with discontinuous oscillations (relaxation or non-resonance burning) occurs in the barrel.

The regularities in the burn-out of the combustible mixture and in the outflow of combustion products from the barrel are the scientific fundamentals to be considered in an efficient development of spray-coating production processes [26]. However, this step of the working cycle has not yet been studied sufficiently. The most urgent issues for further investigations should include the following: the effect of design characteristics and the geometric configuration of the barrel, ignition chamber and other pre-barrel spaces on the development and conditions of the combustible mixture burn-out, outflow of detonation products and heat exchange with the barrel walls, the composition and properties of combustion products and their change during mixture burn-out and gas outflow from the barrel, the optimization of the design characteristics of detonation-spraying plants to provide the most efficient conditions of combustible mixture burn-out and subsequent interaction of combustion products with the powder.

OPERATIONAL CYCLE OF GASEOUS DETONATION GUNS

A specific feature of operation of gaseous detonation gun (GDG) consists in periodical sustained oscillations of the pressure, velocity, temperature, and acceleration, which arise inside the barrel and other structural elements of the GDG. The oscillations are not caused by external periodical effects and therefore belong to auto-oscillations. Like any auto-oscillatory system, the GDG consists of the following main elements: energy source (a container or line with a gaseous or liquid energy carrier and oxidant), oscillatory system of a varying complexity (including the combustion chamber and control unit) with a definite dynamic characteristic, device controlling the energy input from the source into the oscillatory system in both the amount and the rate (the metered amount of energy defines the work accomplished by the GDG per a working cycle, while the rate, along with other system parameters, defines the frequency or cyclicity of GDG operation, the cycle energy and the GDG operation frequency will define its power). A feedback providing the control of the energy input (amount and rate) from the source into the oscillatory-system exists between this system and the control device [7]. Because of a specific nature of the production processes accomplished, the GDG are also fitted with a source of the powder material processed (powder feeder), a device controlling the powder feed into the combustion chamber in the amount, rate, and time (the metered amount of powder will define the output and the useful work performed by the GDG per a working cycle, the feed rate and time interval, the spatial arrangement of powder in a fresh charge and the nature of its interaction with combustion products), a combustible mixture igniter, compressed gas sources for the powder feed and combustion chamber purging (cleaning), a feedback exists between the oscillatory system and the powder feed controller, the igniter (it provides for controlling the time between the combustion chamber filling and the combustible mixture ignition) and the purging gas controller, (provides for the control of the amount and rate of purging gas feed into the combustion chamber).

The conditions of processing powder materials are governed by the thermal, velocity, and chemical relaxation of particles in a high-temperature two-phase pulsed stream generated at every working cycle of the GDG. The relaxation of particles is conditioned by the parameters of the entire system under consideration and depends not only on the energy of a single pulse and the parameters of the high-temperature gaseous medium, but also on the spatial arrangement of a fresh gas charge and a single dose (metered amount) of powder.

The traditional structure of the operating cycle of the GDG (version 1) can be represented as a sequential method of performing its individual steps:

$$\begin{aligned}&\boxed{GF}\to\boxed{PF}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\\&\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF}\end{aligned}. \qquad (1)$$

Elements *GF, PF, GP, Ig* and *Pr* belong to the so-called preparatory ones, and elements *DDT, B, AP,* and *CF* to independent ones which do not depend on the GDG control system. Functions of elements *GF, PF*, and *Ig* are clear from the essence of the DCP as an auto-oscillatory system, while element *GP* is aimed at providing a localization of the burn-out of combustible mixture in the combustion chamber and preventing flashbacks into the GDG actuators and energy source. Independent elements *DDT, B, AP,* and *CF* of the working cycle are separated for convenience of the analysis and organization of the control of processes proceeding at a pulsed burn-out of the combustible mixture.

Varying the parameters of the preparatory elements of the working cycle and the design features of the GDG, predominantly of the combustion chamber, provides a means for controlling the independent (self-proceeding) elements of the working cycle and thereby, e.g., the coating formation processes.

The operating frequency of a given GDG is $f = 1/t_c$, where t_c – operation cycle duration, $t_{c1} = \sum_{i=1}^{i=k} t_i$, is composed of characteristic time intervals of steps of operation cycle. For this case i = 9. The gas and powder filling and exhaust/purging processes tend to be the longest duration.

A *version* 2 represents a common combination in time of the processes of filling the combustion chamber with a fresh mixture and feeding the powder:

$$\begin{aligned}&\frac{\boxed{GF}}{\boxed{PF}}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\\&\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF}\end{aligned}. \qquad (2)$$

In this case operation cycle duration will be $t_{c2} = t_1 + t_3 + t_4 + ... + t_9$, that is will be shorter as a result of combining of gas and powder filling.

We will now consider the specific features of other versions of the GDG working cycle structure.

Version 3. When powder feed actuators are present, a command from the control system arrives after the delivery (or even execution) of the command for initiating the combustion:

$$\begin{array}{l} \boxed{GF}\to\boxed{GP}\to\boxed{Ig}\to\ \boxed{PF} \\ \qquad\qquad\qquad\ \downarrow \\ \qquad\qquad\qquad\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \end{array}. \quad (3)$$

In this case for given GDG operation cycle duration $t_{c2} = t_{c3}$. However, the time of operation of the pulse feeder of powder should be matched with the flame propagation time and with the period of its pre-detonation acceleration. In view of a considerable lag of powder feed devices, ignition and combustion chambers should be connected by passages providing for a delay of combustible mixture ignition in the barrel, sufficient for introducing the powder. Another way consists in using a direct combustion process for the powder feed.

Version 4. The powder feed is effected by the gaseous mixture combustion products in the detonation mode:

$$\begin{array}{l} \boxed{GF}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \\ \qquad\qquad\qquad\qquad\qquad\quad\downarrow \\ \qquad\qquad\qquad\qquad\qquad\ \boxed{PF} \end{array}. \quad (4)$$

Version 5. Differs from the preceding one by the use of burnout products in the pre-detonation mode:

$$\begin{array}{l} \boxed{GF}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \\ \qquad\qquad\qquad\qquad\ \ \downarrow \\ \qquad\qquad\qquad\qquad\ \boxed{PF} \end{array}. \quad (5)$$

Version 6. Elimination of the combustion chamber "locking" is attained by means of special design features of the GDG, with the aid of hard-to-ignite combustible gases and at a relatively low frequency of GDG operation, which ensures cooling of the combustion products before filling of the combustion chamber:

$$\frac{\boxed{GF}}{\boxed{PF}}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF}. \quad (6)$$

Version 7. Differs from the preceding one in that the powder feed is carried out similarly to version 3:

$$\begin{array}{l} \boxed{GF}\to\boxed{Ig}\to\ \boxed{PF} \\ \qquad\quad\ \downarrow \\ \qquad\quad\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to CF \end{array}. \quad (7)$$

Version 8. Differs from version 6 by a sequential filling of the combustion chamber with a fresh mixture and in the powder feed method:

$$\begin{array}{l} \boxed{GF}\to\boxed{PF}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to \\ \to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \end{array}. \quad (8)$$

Versions 9 and 10 are combinations of the specific features of structure 4 and 6, 5 and 6 respectively:

$$\begin{array}{l} \boxed{GF}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \\ \qquad\qquad\qquad\qquad\downarrow \\ \qquad\qquad\qquad\quad\ \boxed{PF} \end{array}. \quad (9)$$

$$\begin{array}{l} \boxed{GF}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{DDT}\to\boxed{B}\to\boxed{AP}\to\boxed{CF} \\ \qquad\qquad\quad\ \downarrow \\ \qquad\qquad\quad\boxed{PF} \end{array}. \quad (10)$$

Subsequent versions are derivatives from preceding ones and differ by a restriction of the combustible mixture burn-out by the pre-detonation mode: 11 corresponds to 1, 12, to 2, 13, to 3, 14, to 5, 15, to 6, 16, to 7, 17, to 8:

$$\begin{array}{l} \boxed{GF}\to\boxed{PF}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to \\ \to\boxed{B}\to\boxed{AP}\to\boxed{CF} \end{array}. \quad (11)$$

$$\frac{\boxed{GF}}{\boxed{PF}}\to\boxed{GP}\to\boxed{Ig}\to\boxed{\mathrm{Pr}}\to\boxed{B}\to\boxed{AP}\to\boxed{CF}. \quad (12)$$

$$\begin{array}{l} \boxed{GF}\to\boxed{GP}\to\boxed{Ig}\to\boxed{PF} \\ \qquad\qquad\qquad\ \downarrow \\ \qquad\qquad\qquad\boxed{\mathrm{Pr}}\to\boxed{B}\to\boxed{AP}\to CF \end{array}. \quad (13)$$

$$\boxed{GF} \rightarrow \boxed{GP} \rightarrow \boxed{Ig} \rightarrow \boxed{\mathrm{Pr}} \rightarrow \boxed{B} \rightarrow \boxed{AP} \rightarrow \boxed{CF} \quad \begin{array}{c}\downarrow \\ \boxed{PF}\end{array} . \quad (14)$$

$$\frac{\boxed{GF}}{\boxed{PF}} \rightarrow \boxed{Ig} \rightarrow \boxed{\mathrm{Pr}} \rightarrow \boxed{B} \rightarrow \boxed{AP} \rightarrow \boxed{CF} . \quad (15)$$

$$\boxed{GF} \rightarrow \boxed{Ig} \rightarrow \boxed{\mathrm{Pr}} \rightarrow \boxed{B} \rightarrow \boxed{AP} \rightarrow \boxed{CF} \quad \begin{array}{c}\downarrow \\ \boxed{PF}\end{array} . \quad (16)$$

$$\boxed{GF} \rightarrow \boxed{PF} \rightarrow \boxed{Ig} \rightarrow \boxed{\mathrm{Pr}} \rightarrow \boxed{B} \rightarrow \boxed{AP} \rightarrow \boxed{CF} . \quad (17)$$

Purging for removing residual gases is not considered since it is in fact combined with filling the combustion chamber with the combustible mixture.

The above-described features of the working cycle can be implemented in more numerous design versions of the GDG, but the working cycle of any of them consists of the above-considered elements. Their analysis will make it possible to create a scientific basis for calculating and designing the processes proceeding in the GDG. Comparing and evaluating different versions of the working cycle structure are possible only at a joint analysis of their design features and physical principles of GDG operation.

The sequence of accomplishing individual elements of the working cycle is given by the GDG operation cyclogram. The plants are of two types: with an adjustable (changes can be made, when required, in the cycle duration and operation of its individual elements as well as in the time intervals between them) and non-adjustable (rigid) cyclogram of the working cycle. The former type of cyclograms is typical for general-purpose GDG intended for depositing coatings of various types and on various products (having different service functions, shapes, sizes, arrangement of surfaces being coated). The latter type of cyclograms, which makes possible the use of simpler and more reliable control systems, is more preferable for special and specialized GDG.

The regularities of implementing the independent elements of the working cycle are primarily determined by the design features of ignition and combustion chambers, properties of the combustible mixture, and parameters of filling with a fresh combustible mixture and powder. Only a partial automation of the GDG control, associated with the execution of the working cycle, has been attained at present. The operator, however, has to interfere all the time with the GDG operation control at its starting (sequential feed of individual working gases and powder, switching-on of the ignition and actuation of protective devices to protect the surface to be sprayed until the plant reaches the working conditions, gaining of the working conditions by the plant, feed of the part being coated, monitoring the spraying process on instruments and visually) as well as with the spraying process when intolerable deviations from the parameters occur. The production process quality therefore depends to a great extent on the operator's skill.

D-GUN DESIGN CONCEPTS

The permanent efforts are directed to the achievement of the highest quality of coatings and productivity of GDS at lowest possible cost. This may be achieved:

Firstly: by better understanding of patterns of relationship of DGS operation cycle, by better understanding of gaseous detonation products interaction with processed powder, by search of methods for powder particles behavior control at impulse jet, by better understanding of impulse jet-substrate and particle-substrate interaction,

Secondly: by continuous improvement of process technology of DGS on basis of system approach and better understanding of materials interaction in process of coating formation, by full control of all parameters involved in the GDS, by adequate GDS process simulation and optimization of all working conditions,

Thirdly: by development of the fully adaptive systems for GDS and the process monitoring devices.

In order to use propagating detonations for processing of powder materials and realize the D-guns advantages, a number of challenging fundamental and engineering problems has yet to be solved. These problems deal basically with low cost achievement and control of successive detonations in a gaseous detonation device. To ensure rapid development of a detonation wave within a short cycle time, one needs to apply (1) efficient fuel injection and oxidizer supply systems to provide fast and nearly homogeneous mixing of the components in the detonation chamber (DC), (2) efficient powder injection and supply systems to provide mixing of powder with gas mixture and controllable location into DC, (3) low energy source for detonation initiation to provide fast and reliable detonation onset [20], (4) cooling technique for rapid, preferably recuperative, heat removal from the walls of detonation chamber (DC) to ensure stable operation and avoid premature ignition of gaseous mixture leading to detonation failure, (5) geometry of the combustion chamber to promote detonation initiation and propagation at lowest possible pressure loss and to ensure high operation frequency and control of powder heating and acceleration, and (6) control methodology that allows for adaptive, active control of the operation process to ensure optimal performance at variable processing conditions, while maintaining margin of stability of repetitive two phase impulse jets. In addition to the fundamental issues dealing with the processes in the DC, there are other issues such as (7) efficient integration of DC with inlets and nozzles to provide high performance. The other problem is noise. Therefore, the equipment for detonation-gas spraying should be placed in soundproof booths. It is promising additional reduction of noise by suppressing the noise themselves detonation-gas guns, including the use of devices for active noise reduction.

To date it are created manifold gaseous detonation guns (DG) which differ by mode of functioning (principle of operation) and embodiment. Therefore it is urgent question of estimation of technological capabilities, as advantages and shortages of different variants of DG and development of justified recommendations for their industrial application. For DG classification the next attributes are used: 1. types of fuel and oxidant, 2. typical mode of gas mixture burning, 3. type and design philosophy of barrel (configurations of transverse and longitudinal sections, microgeometry of barrel surface, type of cooling, attitude position), 4. type, location and operation mode of ignition generator, 5. technique of predetonation distance control, 6. peculiarities of gaseous exchange at barrel, 7. technique for gas mixture preparation and flow rate control, 8. initial gas mixture pressure at barrel, 9. technique for localization of gas mixture burning at barrel, 10. technique and point of powder injection into barrel, 11. ambient medium of spraying, and others.

Valved D-Gun concept implies the use of mechanical or electromagnetic valves to ensure a controlled (periodic) inward flow rate of fuel-oxidizer mixture into the DC, to prevent detonations or shocks from moving outwards from the DC through the inlet, and to provide a sufficient time for mixing of fuel with air. Several designs with mechanical or electromagnetic valves are available in literature. These types of D-Guns are in industrial use.

Valveles D-Guns concepts imply continuous or intermittent supply of propellants (fuel and oxidizer) to the DC without using mechanical valves.

Predetonator concept implies the use of a two-step detonation initiation process in the DC, namely, the use of an additional, highly sensitive reactive mixture contained in a tube of small diameter and readily detonated by a source of low energy, and transmitting the obtained detonation wave into the larger-diameter DC containing considerably less sensitive reactive mixture. The small-diameter tube is referred to as predetonator.

Enchanced deflagration to detonation transition (DDT) concept implies the use of various passive means to promote DDT and obtain a detonation wave in the main DC with the working mixture ignited by a low-energy source.

Stratified-charge concept implies controlled injection of propellants into the D-Gun DC aimed at formation of the explosive charge with variable spatial sensitivity to detonation. Stratified explosive charge can be obtained by proper timing of fuel and/or oxidizer valves, by controlled distributed injection of fuel and/or oxidizer along the DC, or by various geometrical means creating a proper vertical structures in the barrel, or use of multipoint gas injection systems.

Multibarrel schemes allow one to control the relative time of detonation products outflow, operation frequency, and productivity of gaseous detonation spraying. Most of the D-Guns schemes can be readily extended to multibarrel configurations. In addition to the study of single-barrel D-Gun system performance, much effort was made to investigate the intricate combustion and gasdynamic processes in multibarrel pulse detonation combustors.

CONCLUSIONS

1. Enhancement of operational efficiency of detonation-gas spraying technology can achieved only through the establishment of applicable reliable equipment.

2. The permanent efforts are directed to the achievement of the highest quality of coatings and productivity of gaseous detonation spraying at lowest possible cost. First of all, this may be achieved by better understanding of patterns of relationship of DGS operation cycle, by better understanding of gaseous detonation products interaction with processed powder, by search of methods for powder particles behavior control at impulse jet, and by better understanding of impulse jet-substrate and particle-substrate interaction.

3. Continuous improvement of process technology of D-Gun spraying could be done using system approach and better understanding of materials interaction in process of coating formation, by full control of all parameters involved in the GDS, by adequate GDS process simulation and optimization of all working conditions, and by development of the fully adaptive systems for GDS and the process monitoring devices.

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ПРИНЦИПЫ КОНСТРУИРОВАНИЯ ДЕТОНАЦИОННО-ГАЗОВЫХ УСТАНОВОК ДЛЯ НАПЫЛЕНИЯ ПОКРЫТИЙ

Юрий Харламов, Максим Харламов

Аннотация. Представлен структурный анализ детонационно-газовых установок для напыления порошковых покрытий и проанализированы возможные варианты их рабочего цикла. Сформулированы основные принципы конструирования высокоэффективных детонационно-газовых установок для напыления порошковых покрытий, в том числе концепции создания бесклапанных устройств.

Ключевые слова. Газовая детонация, осаждение покрытий, рабочий цикл.

Ultrasonic testing of discontinuties of metal of gear blanks of rolling stock

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S u m m a r y . Was made an analysis of the location of metal's discontinuities of gear wheels blanks of locomotive of rolling stock. There is shown that gear wheels blanks of rolling stock might have unacceptable internal discontinuities of metal of flat shape, and planes of these flat discontinuities might be situated in both the radial and axial directions of the blank. The necessity of conducting of ultrasonic control of gear wheels in radial and axial directions is substantiated. Was proved that conducting of ultrasonic control leads to prevention of getting into exploitation of gear wheels with unacceptable discontinuities and also excludes technological operations on defective blanks, and as a result saves money.
K e y w o r d s : gear blank, discontinuities of metal, magnetic particle method, ultrasonic control in radial and axial directions.

INTRODUCTION

In the transport system of Ukraine railway transport has the leading role [1]. Globalization of economics leads to the development of international partnership and as a result to increasing flow people and goods [2].

Strengthening of interconnections of national economics needs high quality of transport provision. The global transport system consists of integrated national transportation systems, which ensure the implementation of both internal and international transportation [3].

The transition of Ukrainian economy to a market economy in and its integration into the global economy contribute to the expansion of economic relations of enterprises in Ukraine with foreign enterprises [4]. In the Transport Strategy of Ukraine till 2020 (the Decree of the Cabinet of Ministers of Ukraine dated 20.10.2010, the, № 2174) noted that transport is one of the basic branches of the national economy. The realization of this strategy aimed at ensuring the effective functioning of the transport system, will accelerate the pace of integration of the national transport system in the European and global transport system [5].

The integration of the transport system of Ukraine into European and world system requires compliance with international norms and standards in various fields, including technical one. Competition in the global transport market requires high technical and technological level, of transportation safety [6, 7].

Because of the wear and tear of railway rolling stock, which is one of the main part of the production assets of the railway, about 80%, is needed to upgrade railway rolling stock of Ukraine [8, 9].

Condition of railway rolling stock and its low technological level does not respond to modern requirements of the railway transport.

The economic efficiency of railway transport is largely dependent on operability of rolling stock.

Modern trends of development of railway transport of Ukraine are inseparably linked with the growth of the significance of the results of non-destructive control for improving the quality of parts and units of rolling stock. Questions of quality control in the manufacture of modern rolling stock become especially important in provision the security exploitation of rolling stock. Timely detection of defects in the production of metal allows both reduce the cost of technical operations in case of a defect in the blank and prevent getting into exploitation of parts and components with unacceptable defects of metal, which are the effective measures of preventing accidents.

The increase in traffic density and speed of rail is accompanied by increasing cyclic, temperature and stress impacts on parts and components of the rolling stock [10].

Discontinuities of the metal are stress concentrators and operation may be the first step to a premature fatigue failure of parts and components of the rolling stock [11].

To avoid getting into exploitation of important parts with unacceptable discontinuities of metal is needed non-destructive control of important components of railway transport, as in the manufacturing process as well as in the current repair. That is why, works related to the analysis of metal discontinuities of critical components and their identification by nondestructive methods are relevant.

In works [12, 13] was analyzed the location of discontinuities of metal bandages of wheel pairs, which occur during the manufacture of this bandages. Given the characteristics of the location of discontinuities of metal near the landing surface in the bandage [14] is presented an improved definition of ultrasonic control. In work [15] are given the results of the analysis of detected surface defects of metal of wheel pairs. The necessity of further improving the visual control is proven. In work [16] is given the analysis of the location of discontinuities of metal of casting bogie frames that occur during the manufacture of castings and features that make it necessary to define additional developments of identifying such discontinuities under ultrasonic control. Questions of improvement of the reliability of the results of ultrasonic control of locomotive rolled wheel centers during the manufacturing process are considered in work [17].

In work [18] the question of the appearance of fatigue cracks on the rail-axes. Was proved the necessity of improvement of ultrasonic control for the diagnosis of axes. In work [19] observed decrease in the spectrum frequency of the reflected echo signals from the bottom surface under the discontinuities with an increase in the size of the lack.

Destruction of elements of gears of the rolling stock in exploitation is considered in works [20-25].

The identification of the location of metal discontinuities that occur during the manufacture of gear wheels gear traction locomotives is poorly investigated.

The aim of this work is to determine the location of the discontinuities of metal of gears of locomotive`s traction transmission.

MATERIALS AND METHODS

The objects of investigations were gears made of steel 20C2N4MA and gears made of steel 45CN. Gears made of steel 20C2N4MA were hardening with the help of chemical heat treatment of the surface (cementation). Gear wheels made of steel were hardening by high frequency currents. Table 1 shows the comparative analysis of the chemical composition of the investigated steels [26].

Table 1. Chemical composition of steels for the manufacture of gears

Steel	C	Mn	Cr	Ni	Mo	S	Si	P
20C2N4MA	0,16-0,22	0,30-0,60	1,25-1,65	3,25-3,65	0,2	0,035	0,17-0,37	0,035
45CN	0,41-0,49	0,50-0,80	0,45-0,75	1,00-1,40	0,30	0,05	0,17-0,37	0,04

According to [27], gear blanks and gear wheels are made by forging, hot punching, rolling with forging or hot punching with rolling. Technical conditions set the normative requirements to unacceptable discontinuities of metal on the working surfaces of the wheels and gears.

The visible surface defects were detected visually. Cracks were detected by magnetic particle technique in accordance with State Standart 21105 [17]. For exploration of discontinuities in the metal of gears and cogwheels was used magnetic particle method of control that allows to reveal cracks with opening from 0,002 mm. The type and method of magnetization was chosen depending on the nature and orientation of the defects to be detected. The best condition for the detection of defects - the perpendicular direction of the magnetizing field to the plane of the alleged defects. If required the detection of defects of different orientation magnetization was used in two or three mutually perpendicular directions.

Additional researches of discontinuities were made by ultrasonic echo impulse method of control with the help of flaw detector UD2-70 at the frequency of 2.5 MHz with a maximum sensitivity of 7.1 mm^2.

To set up sensitivity appropriate to apply the artificial defect type of flat-bottomed hole, which satisfactorily simulates flat discontinuities identified in gears.

From steel round bars were manufactured samples of cylindrical shape with a diameter of 60 mm and a height of 60 mm (Fig. 1, b). In one flat surface at the center are performed holes with a flat bottom made by drilling, diameter of holes is 3 mm and they are located at the minimum, average and maximum depth. After applying a contact liquid (industrial oil) the ultrasonic transducer was placed on a flat surface of the sample, opposite to the plane with drilling (Figure 1). Before testing the investigated sample surface was grind to R_a = 6,3 micrometers.

Fig. 1. The steel sample with an artificial reflector - drilling with a flat bottom: a - general view of the sample, b - a flat surface scanning with an ultrasound transducer, c - the flat surface of the sample with a flat bottom made by the drilling

RESULTS AND DISCUSSION

The analysis of the defects that were identified during the production of locomotive gears revealed both surface and internal discontinuities in metal. Was found that internal discontinuities in metal occur during the manufacturing process. It was also found that certain discontinuities located on the inner surface. Fig. 2 shows a crack occurs during the process of hardening and grinding rims.

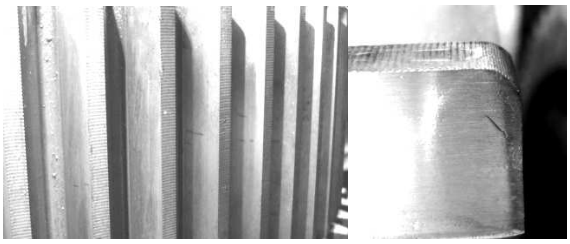
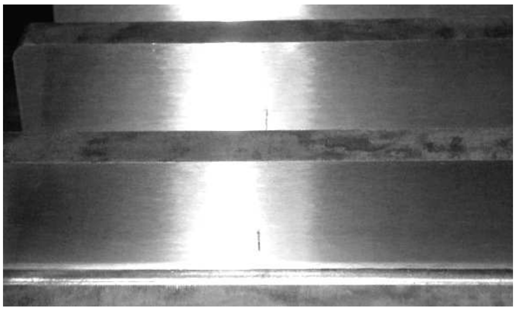
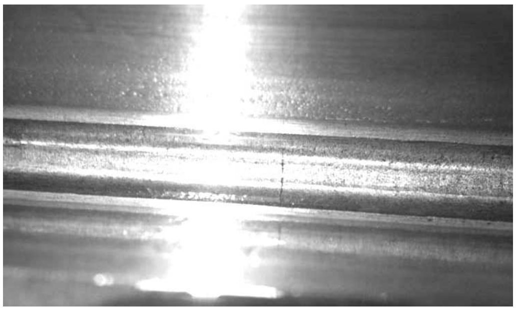


Fig. 2. Cracks on the working surface of the cog occurs during manufacturing gear

On Fig. 3 shown a side surface of the locomotive gear with an internal defect that goes to the working surfaces of the adjoining cogs (Fig. 3a) and in the tooth space between the cogs (Fig. 3b).



a



b

Fig. 3. Discontinuities in a metal blanks: a – on the working surface of the cog, b – in the tooth space between the cogs

Experimental verification has shown internal lack of adhesion, revealed with ultrasonic impulse echo technique in the axial direction. That gear (Fig. 3a, b) does not meet the requirements of GOST 30803, so not admitted in the operation as non-responsive product. A second example of unacceptable defect of metal on the working surface of gear's cog, which also was not admitted in the operation is shown in Fig. 4.

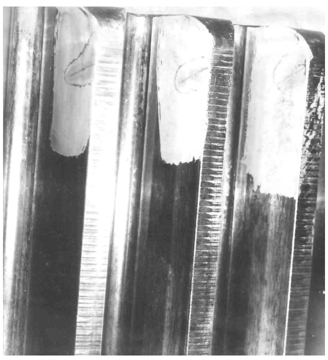


Fig. 4. Unacceptable defects on the working surfaces of the adjoining cogs

Was found that discontinuities in the metal blank manufacturing tooth crown can be observed from the end face of the teeth (Fig. 5).

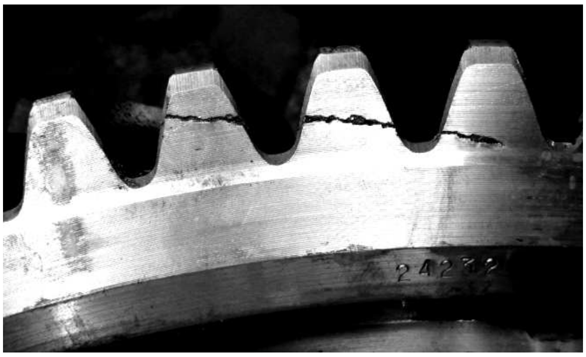


Fig. 5. Face plane of the locomotive gear with a visible defects

However, internal discontinuities in metal can't be connected to the surface and will not be detected visually. It is known that discontinuities are the stress concentrators and may cause a destruction of the locomotive gear in operation.

To avoid getting the final processing steps and into operation gears with unacceptable defects the metal blanks must be checked by non-destructive testing methods. On railway transport is widely used ultrasonic testing. The effectiveness of ultrasonic testing is largely dependent on the correct choice of the method of testing. So, the most common method of ultrasonic testing - ultrasonic impulse echo method requires to know the location of the expected discontinuity of the metal.

The ultrasonic impulse echo method is based on the registration of echo signals from the discontinuities of the metal and their analysis. Arrival time of the impulses from the discontinuities to the ultrasonic transducer depends on the depth of its occurrence. The geometric shape of the surface of the ultrasonic transducer must be simple and allows moving the transducer while testing process. The analysis of internal discontinuities of metal of locomotive gears showed that they are planar. The optimal condition for receiving ultrasonic echo signal by the ultrasonic transducer is the case where the acoustic axis is incident on the reflecting surface discontinuity at a right angle. It was noted earlier that the discontinuities of metal blanks of locomotive gears are planar. The amplitude of the echo signal depends on the size of the reflecting surface of the discontinuity and its incidence to the acoustic axis of the transducer.

Let's consider the amplitude of reflection in view of the positional relationship between the ultrasonic transducer and reflector that inclined towards the axis of the transducer at an angle φ (Fig. 6).

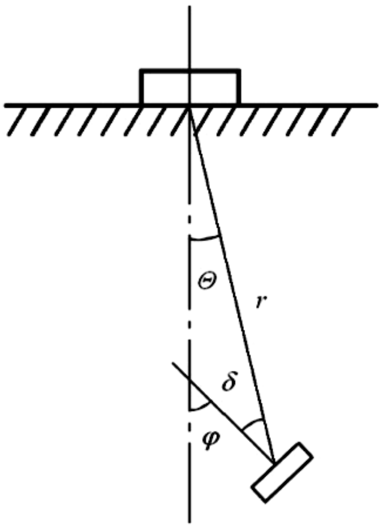


Fig. 6. Calculation scheme of reflection from the inclined defect which is located on the axis of the transducer

For planar reflectors the amplitude of the echo signal depends on the area and the slope of the plane of reflector to the axis of the transducer [28]. The formula for the calculation of the echo signal for the reflector which is located in the far field of the combined transducer with square S_a and size $L_{\hat{a}} = 2\hat{a}$ and inclined to the axis of the transducer at an angle φ to the Kirchhoff approximation (fig. 6) has the following form:

$$\frac{P'}{P_0} = \frac{S_a \cdot S_b \cdot e^{-2\Delta r}}{\lambda^2 \cdot r^2} \cdot \cos\delta \left|R(\delta)\right| \Phi^2(a\kappa \sin\theta)\Phi'(\kappa b \sin\delta),$$

here: S_b – the square of the reflector,

S_a – the square of the transducer,

$\delta = \varphi - \theta$ – the angle of incidence of ultrasonic beam on defect,

P_0 – the amplitude of the signal that emitted by ultrasonic transducer,

P' – the amplitude of received signal,

Φ – diagram of directedness of the transducer,

θ – the axis between the direction of echo signal and its projection on the axis of the cylinder,

$r = h/\cos\theta$ – the distance from the surface to the cylindrical reflector,

λ – ultrasonic wave length,

Δ – coefficient of attenuation of ultrasonic wave.

It is known that the surface quality of the ultrasonic input surface should provide its maximum flow in the controlled metal. The increase in the roughness of the surface leads to a decrease in the amplitude of the echo signal and reduces the possibility of detection the lacks of adhesion. Therefore, before the ultrasonic testing is performed the special surface preparation of the forgings, stampings and castings [29] for the purpose of improving the quality of ultrasonic testing. It is recommended to conduct the ultrasonic testing on gear blanks after its mechanical pretreatment to obtain the proper surface quality. Given the fact that a discontinuity of metal of gear blanks have a flat shape and their plane is located in both radial and axial directions, the ultrasonic testing must be performed in the axial and radial directions.

CONCLUSIONS

1. It is shown that the metal surface of the locomotive gears in the manufacturing process can have cracks, which can be detected using the visual inspection methods and magnetic particle method.

2. In locomotive gear blanks may be present unacceptable flat shaped internal discontinuities of the metal which may be both radial and axial directions of the blank.

3. Was grounded the necessity of ultrasonic testing of gears in two directions: axial and radial. To ensure the required

acoustic contact while ultrasonic testing it is necessary to perform the special surface preparation.

4. Ultrasonic testing will prevent getting into the operation gears with unacceptable defects and exclude inputs for further processing steps of defective blanks.

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УЛЬТРАЗВУКОВОЙ КОНТРОЛЬ НЕСПЛОШНОСТЕЙ МЕТАЛЛА ЗАГОТОВОК ЗУБЧАТЫХ КОЛЕС ПОДВИЖНОГО СОСТАВА

Павел Колодяжный

Аннотация. Проведен анализ расположения несплошностей металла в заготовках ответственных узлов подвижного состава. Показано, что в заготовках зубчатых колес подвижного состава могут быть недопустимые внутренние несплошности металла, которые имеют плоскую форму, а их плоскости могут находиться как в радиальном, так и осевом направлениях заготовки. Обоснована необходимость ультразвукового контроля зубчатых колес в двух направлениях: осевом и радиальном. Доказано, что проведение ультразвукового контроля позволит исключить попадание в эксплуатацию зубчатых колес с недопустимыми несплошностями, а также исключить затраты на дальнейшие технологические операции бракованных заготовок.

Ключевые слова: заготовки зубчатых колес, несплошности заготовок, ультразвуковой контроль в осевом и радиальном направлении несплошностей плоской формы.

Development of structure and the concept of functioning the modernized logistic system of service industrial enterprise by railway

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Summary. The article is about the mechanism of regulation of unevenness arriving wagons on the industrial enterprise. Creation of information system, which consists of various program modules, is offered. Instrument of modeling is the program AnyLogic.

Keywords. Logistic system, traffic volume, imitating model.

INTRODUCTION

Now before logistic service of production companies there is a complex challenge on co-ordinated подвозу traffic volumes on the enterprise. This problem existed and earlier, however, new tools of its decision now start to appear. It is possible to carry railway-shipping companies, management-information systems to such elements etc. It should be noted that at normally co-ordinated work between logistic service and shipping company, the last can influence delivery periods of cargoes and wagons. In case of need, wagons can be late on the way. This option can use, if the critical overload of transport system of industrial transport in concrete days is predicted.

However even existence of such tool does not exclude need for logistic service of high-quality planning of the schedule and parties of traffic volumes at the initial stage. That is the problem of a message work is put so that on the enterprise arrived in due time raw materials. Thus at an assessment of purchase of party of raw materials, the discount for wholesale (at the expense of increase in the order) could be compared to additional costs. The enterprise cannot incur these costs in connection with irregularity of receipt of wagons. Thus before the conclusion of the contract it would be desirable to simulate the schedule of shipment and the size of parties of sending [23].

MATERIALS AND METHODS

Similar procedure is necessary at the organization of sale and export of finished goods. As at this procedure the priority is given to timely shipment and sending of wagons from the enterprise. It is caused by that buyers, as a rule, receive production on an advance payment and the subsequent failure of terms of sending not in the best way influences mutually beneficial cooperation [23,9].

Therefore, the sales department can make out the order and receive payment if with big degree it will be confident in timely execution. Thus it is necessary to consider also and expenses suffered by transport system. [29]

In general this problem is not new and to a science. In it for many years were engaged many scientists, such as Zaverkin A.V., Pitelguzov N. A., Levyte B. M, Kozlov P.A. etc. [2,23,15,14,16]. But, by virtue of complication of task, until now it fully is not decided.

Therefore improvement of structure of planning of a logistic subsystem on formation of orders and planning and management of traffic volumes will be the purpose of this scientific work. I.e. to offer methods of solutions of certain transport and warehouse tasks and to specify their place and functions in the general system.

RESULTS, DISCUSSION

The modern logistic service should work in close interaction with department of supply and enterprise sale. Thus all orders for raw materials (traffic volumes) and empties for finished goods should work according to the following scheme. [23].

In Fig. 1 the following system of designations is accepted: $I_{(a\text{-}b)}$ – information, $Z_{(a\text{-}b)}$ – the order for formation of traffic volumes, $R_{(a\text{-}b)}$ – results of calculations of system of modelling and forecasting for the order (a-b), $P_{(a\text{-}b)}$ – parameters of the approved plan, $S_{(a\text{-}b)}$ – coordination between departments.

Indexes indicate a place of origin of information, the order, etc. and as they are addressed to what block.

System essence in the following: the purchasing department, on the basis of a forecast of model of warehouse orders of $I_{1\text{-}2}$ and negotiating with suppliers forms the demand plan for shipment at the sender of a consignment ($Z_{2\text{-}3}$). This information is loaded ($I_{2\text{-}3}$) into computer system where time of receipt of party for the enterprise ($R_{2\text{-}3}$) is predicted. Check is made, whether this sending overloads transport system and whether it influences ensuring implementation of more priority demand.

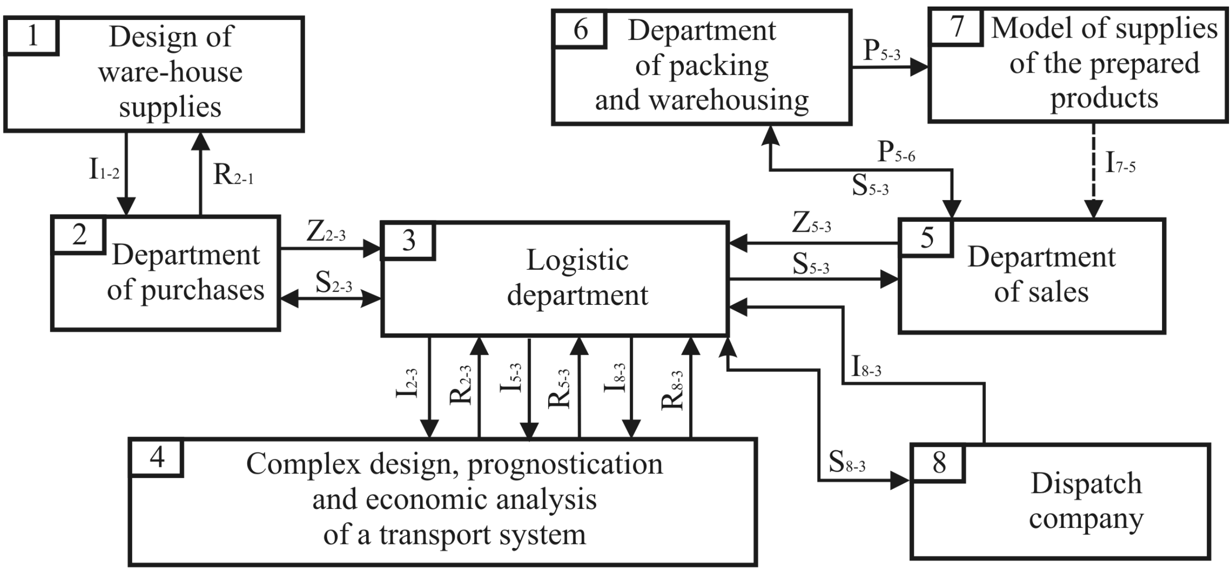

Fig. 1. Scheme of functioning of a subsystem of formation of traffic volumes.

In case of any slips, terms of sending of raw materials can be co-ordinated ($S_{2\text{-}3}$).

Similar procedure passes and when planning shipment of finished goods. The sales department, on the basis of data on the actual and future existence of stocks in enterprise warehouses, makes the order ($Z_{5\text{-}3}$) for empties giving, and after check of $I_{5\text{-}3}$ and calculations of $R_{5\text{-}3}$ there is a coordination of $S_{5\text{-}3}$ and the approval of the plan of $P_{5\text{-}6}$. The department of logistics traces the actual location of wagons of I_{8-3} and predicts time of their arrival of R_{7-3} in case of need S_{8-3} terms are co-ordinated.

Realization of the offered procedure is possible performed by the automated subsystem of planning (Fig. 2).

The essence of system will be in the following: the kernel of system should consist of well debugged imitating model. Such model really to receive in the environment of AnyLogic. As basic data for this system the real traffic volume, its look and structure serves.

The imitating model can have modular structure, is based by a principle of system of mass service, but with the determined standard time of operations. [18, 31, 21, 19, 15]. The discipline of turns can be under construction by FIFO principle – «the first came – the first left». However, in system of turn's possibility of a problem of priorities separate to groups of wagons and types of cargoes should be entered [13, 11].

Further the system models time of a turnover of the enterprise of each batch of wagons with a conclusion of indicators:

$$I_{31} = \begin{Bmatrix} t_{lok_i}, E_{lok_i}, t_{vag.h.з}, \mathring{A}_{vag.h.з}, \mathring{A}_{RGP_i}, \mathring{A}_{RGF}, \\ Ks_i, Nts_i, N_{lok_i}, Mi, K_{dvag_i}, K_{GRi}, M_{kdvagi} \end{Bmatrix},$$

where: t_{lok_i}, E_{lok_i} - time and working costs and idle time of locomotives, $t_{vag.h.з}, \mathring{A}_{vag.h.з}$ - time and cost of payment of car-hours, $\mathring{A}_{RGP_i}, \mathring{A}_{RGF}$ - working costs and GF idle time, Ks_i - criterion of initial information, Nts_i - the current quantity of wagons in system, N_{lok} - number of working locomotives, Mi - the size and a code of arriving types such as wagons, K_{dvag_i} - a code of arriving cargo, M_{kdvagi} - quantity of wagons in system with a similar code such as wagons and cargo type. $Mi, K_{dvagi}, K_{GRi}, M_{kdvagi}$ it is necessary to fix in a database for further training of a neuronal.

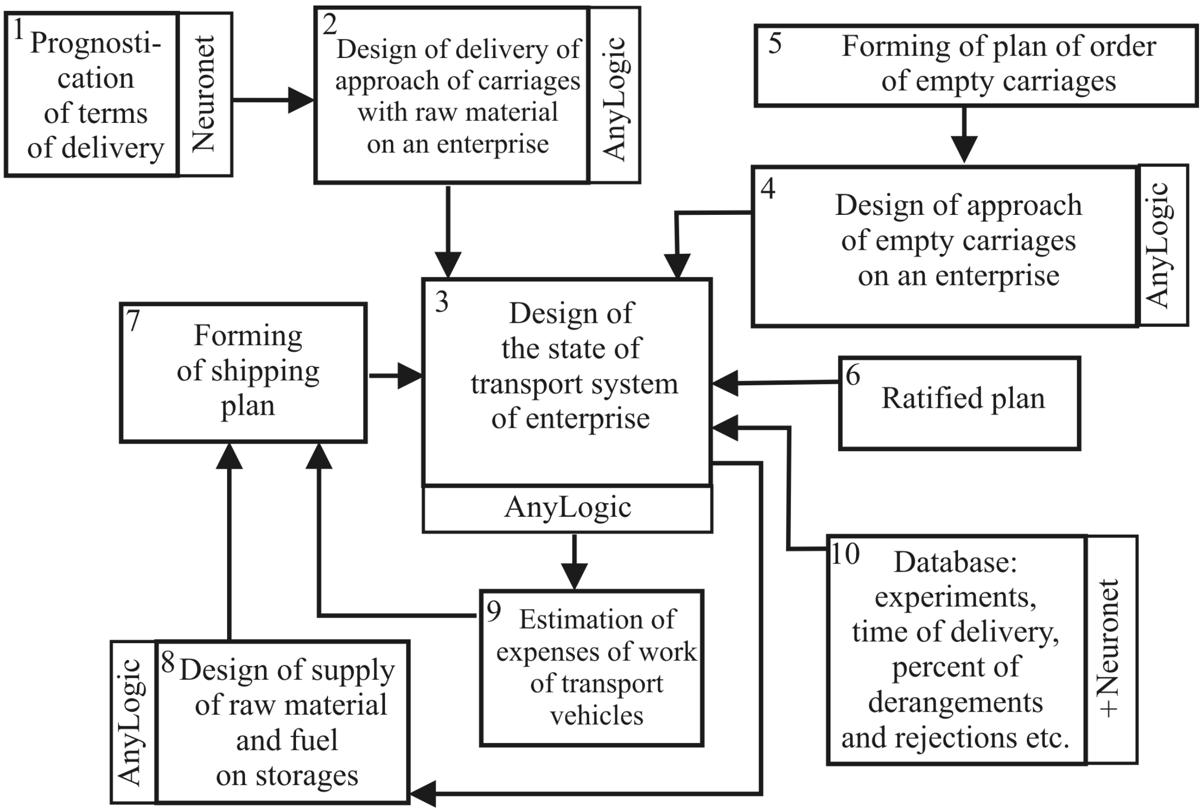

Fig. 2. Scheme of functioning of system of modelling of receipt and processing of traffic volumes

Cost of processing of the last giving will be defined as follows:

$$E\ serve = Et.S_{.II} - Et.S_{.I}\ ,$$

where: $Et.S_{.II}$ – cost of expenses of transport system taking into account processing of the last giving, $Em.c_{.I}$ - cost of expenses of transport system without processing of the last giving

However real process strongly differs from "ideal" models that considerably reduces and narrows their use in the real world. To increase stability of such model it is possible at the expense of the automated training with the minimum attraction of human resources.

At present the most powerful device capable самообучаться and to generalize received information neuronets are. Participation of the person in this process is necessary at the initial stage.

To be trained a neuronet should on the basis of the actual experience.

As result from a neuronet it is possible to wait for the following conclusion:

- percent (probability of a deviation from the plan),

- correction factor which will allow to modify target indicators of the imitating AnyLogic model.

Actual data on the basis of which the neuronet will study, can be imported on the basis of reporting data or from a database of the pooperatsionny accounting of wagons, and the actual loading of the locomotive from the analyzer of moving's received on the basis of GPS of monitoring of location of the locomotive.

The working costs of transport system are offered to be estimated on a formula [15, 17, 22]:

$$\text{Å}_{\text{ÒÑ}} = \sum_{³=1}^{Ð} \text{Å}_{vag.h.³} + \sum_{j=1}^{ò} \text{Å}_{lok.h.j} + \sum_{³=1}^{n} \text{Å}_{FF.k}\ ,$$

where: $\text{Å}_{vag.h.³}$ - cost of payment of car-hours i of car, $\text{Å}_{lok.h.j}$ - cost of payment of work of j of the locomotive, $\text{Å}_{FF.k}$ - cost of payment of work of k of the cargo front.

The assessment should be made by the day.

The block of modelling of an approach of empty wagons and raw materials should be the following block of system. Similar complex modelling should show the moment of a condensation of arriving traffic volumes in separate days and hours, and further modelling in imitating system will allow to show processing visually.

The modelling block of «external traffic volumes» and their advance on a network of roads of the country can be realized too in the environment of AnyLogic [3, 4]. As basic elements (units) there should be switchyards, and time of delivery of cargo and advance on separate sites to decide on the help of a neuronet. Basic data for imitating system will be:

$$I_{11} = \{Dto_i, St_i, Sst_i\},$$

where: Dto_i - date of sending of wagons on the enterprise, St_i - sending station, Sst_i - the coded parameters of group of wagons.

At the initial stage modelling should be conducted on the basis of standards on daily advance of wagons, and in the future, in process of neuronet training on the basis of its results [7, 29].

Basic data for a neuronet should be:

$$I_{12} = \{St_i, N_i\},$$

where: St_i - sending station, N_i - quantity of wagons.

Days off:

$$I_{13} = \{t_{(ds)_i}, v_{ds\,i}, gv_i, gn_i\},$$

where: $t_{(ds)_i}$ - delivery period, $v_{ds\,i}$ - percent of a deviation of term, gv_i - probable top border of a deviation, gn_i - probable bottom border of a deviation.

Further the obtained data on a probable approach of wagons are added to earlier planned traffic volumes and the behavior of system and its check on lack of congestion, and in case of the approval of the plan is analyzed, information on arriving raw materials can be transferred in the block of modelling of stocks in enterprise warehouses [13].

Use of this system on modelling and forecasting of terms of an approach of wagons, time of a turn them on the enterprise will allow to reduce costs of processing of wagons. The result will be received for the account of planning of more flexible hours traffic volumes.

Let's describe process of functioning of imitating system «Access road of the cement enterprise» which is presented on Fig. 3.

Primary element of model is process or a stream. In system arrive, are processed and leave its loaded and empty wagons. The secondary element is "entrance" that represents the stream demanding processing.

The third element – "Exit", i.e. a stream is processed.

The industrial station has 4 entrance and an exit.

With adjunction station, on an entrance 1 (α_1) the loaded traffic volume arrives $\tilde{O}_1$, and on an entrance 2 (α_2) empty traffic volume $\tilde{O}_2$.

On an entrance 3 (α_3) the loaded traffic volume arrives $\tilde{O}_3$ from loading cargo fronts. Thus $x_3 = y_{12} + y_{13}$. In accordance with the circumstances (congestion of industrial station) or technological need, this freight traffic can be processed previously after cargo fronts on points: exhibition ways and scales.

On an entrance 4 (α_4) empty fright traffic from vygruzochny fronts arrives $x_4 = y_{10} + y_{11}$. This traffic volume as in case of congestion of station or in the course of accumulation can remain on exhibition ways or enterprise deadlocks.

In a podsistemny element deadlocks and exhibition ways we will allocate 2 elements of an entrance. First entrance β_1 it is intended for processing of a loaded traffic volume $\tilde{O}_5$, and the second β_2 for the empty $\tilde{O}_6$.

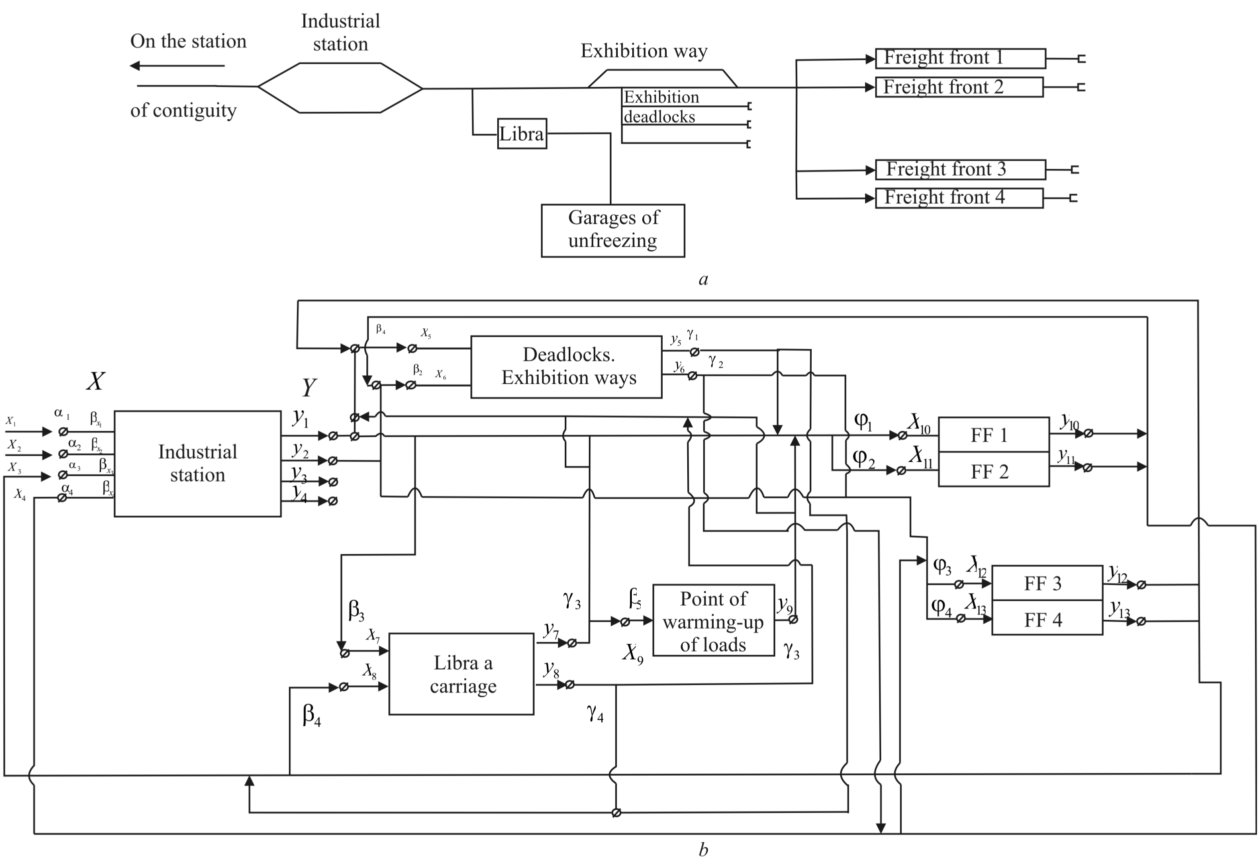

Fig. 3. Models of transport system: a - structure of road development, b - cybernetic model

Loaded stream $\tilde{O}_5$ there can be a target traffic volume from industrial station y_1 or the wagons which have passed перевеску (y_7) or expecting giving on FF1 and FF2. To $\tilde{O}_5$ it is possible to carry the shipped traffic volume also $y_{11} + y_{13}$, passing a stage of accumulation or documentation registration.

To the empty X_6 to traffic volume the target traffic volume belongs y_2 the industrial station, intended for loading on FF3 and FF4.

On a subsystem element scales only the loaded traffic volume arrives, but thus it divide into 2 look: arrival freight traffic (Ψ_1) and departure fright traffic $(y_{11} + y_{13})$. Thereof 2 entrances are allocated β_3 and β_4.

The element «defrosting garages» has one entrance β_5 and on it freight traffic can arrive only y_1.

On entrances of elements of a subsystem «The cargo front of unloading» (FF1 and FF2) points Ψ_1 and Ψ_2 traffic volumes arrive loaded $\tilde{O}_{10}$ and $\tilde{O}_{11}$, which have characteristics, excellent from $\tilde{O}_1$.

Entering traffic volume $\tilde{O}_{12}$ and $\tilde{O}_{13}$ loading fronts of FF3 and FF4 can be as a target traffic volume of station y_2 and target traffic volume of FF1 and FF2 y_{10} and y_{11}. Thus wagons can get not directly on FF3 and FF4, and to pass expectation and accumulation process on exhibition ways.

The fourth element are direct and return communications. If communication carries out transfer of initial influence of one element on an entrance of any following element of the same system, it has the name of direct link. If transfer of influence occurs between an exit of any element and an entrance of the previous element to it in the same system, such communication carries the name of return. Restrictions which for the considered system cannot be presented graphically belong to the fifth element, but always exist (the spaciousness of ways processing ability of cargo fronts etc.).

CONCLUSIONS

1. The offered system was partially realized in the environment of AnyLogic and at the initial stage showed quite good results.
2. Research about training of a neuronet was in parallel carried out to predict time of delivery of cargoes and wagons.
3. It allows to assume about possibility further creations of the above described logistic computer program with high degree of adequacy and flexibility.

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РАЗРАБОТКА СТРУКТУРЫ И КОНЦЕПЦИИ ФУНКЦИОНИРОВАНИЯ МОДЕРНИЗИРОВАННОЙ ЛОГИСТИЧЕСКОЙ СИСТЕМЫ ОБСЛУЖИВАНИЯ ПРОМЫШЛЕННОГО ПРЕДПРИЯТИЯ ЖЕЛЕЗНОДОРОЖНЫМ ТРАНСПОРТОМ

Геннадий Короп

Аннотация. В статье рассматривается механизм регулирования неравномерности поступающих вагонов на промышленное предприятие. Предлагается создание информационной системы, которая состоит из различных программных модулей. Моделирование выполняется в программной среде Any Logic.

Ключевые слова. Логистическая система, вагонопоток, имитационная модель.

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Substantiation of parameters and calculation of vibration isolators

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Summary. The method of determining the parameters of vibration isolation of conic crushers with rubber-metal elements is described. The resolving equations for determining the parameters of vibration isolators are built. To describe the behavior of elastomeric elements are used in the calculation of Volterra integral relations.
Keywords: vibration isolator, elastomer, viscoelasticity.

INTRODUCTION

The problem of protecting operators, machinery, instruments, equipment, buildings and structures from the effects of vibration and sound pressure is still relevant.

It is especially important for complex technical system such as enterprise mining industry, in which heavy equipment is installed in a specific sequence according to the technological requirements, and this quite often machines are installed in three-dimensional space, for example, taps can be placed on the ceilings at around 18 m etc. [5].

In this vibration loading mining equipment is quite significant, and the frequency spectrum includes the entire range from low to high. Vibrations are often random white noise and to a first approximation can be considered as quasi-harmonic. Higher frequencies are usually suppressed by damping strips the higher the vibration frequency, the easier it is suppressed. To suppress the low frequencies requires the use of special vibration isolation systems.

Usually for this the vibration isolators, dampers, and the dynamic dampers, etc., which are arranged between the machine and the frame (foundation supporting structure) are used. The long experience of operating machines shows that the most effective vibration isolation systems are those that use the rubber isolators.

The long experience of operating various machines developed a trend for vibration of heavy machinery in the mining and construction industries rubber elements are preferred over steel springs and other types of vibration isolators. Rubber due to its high absorption capacity, durability, reliability (rubber elements have a lack of random failure) has almost no equal among other materials (metal, wood, plastic, etc.) [18-21].

In connection with the need for vibration isolation with long life and high reliability, there is a problem of accounting changes in the physics-mechanical properties of the material over time [11, 13, 14]. Temporary rubber mechanical properties (shear modulus and damping coefficient) may be obtained either during prolonged experimental studies or by thermal aging. The resulting function $G(t)$ and $\psi(t)$ can be entered directly into the equation.

Experience in operating mills with rubber and rubber-metal vibration isolators showed their high efficiency and performance. However, the service life of rubber vibration isolators greatly depends on the quality of their production.

Vibration isolation of machines is part of the theory of vibrations of elastic systems. On this issue there is an extensive literature [1, 3, 8, 13, 22].

RESEARCH OBJECT

For the design of rubber-metal mounts is very important to configure their work. You also need to take into account the structural features of the machine and determine the number of anti-vibration mounts. Rubber elements exhibit nonlinear viscoelastic properties, as well as the weak compressibility.

RESULTS OF RESEARCH

It is known [1, 5, 8] at least three types of tasks, in which the power dissipation has a significant influence: the problem of the natural vibrations of elastic systems, the power dissipation contributes to their rapid decay, the problem of forced resonant oscillations with amplitude due to energy dissipation reaches the final value, the problem of the effect of short pulses or shocks, the dissipation of energy helps reduce stress in such systems.

For rubber, as viscoelastic material with heredity, the most suitable are the following theory: the theory of viscous friction of the Kelvin-Voigt and Maxwell-Boltzmann theory of heredity of Volterra. The first two use the hypothesis of proportionality of the internal friction of the loading rate and lead to known equations of oscillatory systems.

In engineering practice, the study of the dynamics of stationary production machines of the above complexities of trying to avoid using certain assumptions: random fluctuations believe quasi-harmonic, elastic system is performed in such a way that the working of the amplitudes and frequencies of its elastic response was almost linear and angular variations as small that they can be ignored .

In this case, the vibration isolation system is considered as a system with one degree of freedom, and the equation of oscillations recorded in the known form:

$$\ddot{x} + 2n\dot{x} + \omega_0^2 x = P \sin \omega t \,. \tag{1}$$

The solution of this equation is described in detail in the literature [1,7,9].

If it is necessary to consider the nonlinear stochastic process oscillations, then the right side of the disturbing force f (t) are as broadband stationary random process and input actions are recorded either in the form of correlation functions, either in the form of the spectral power:

$$\ddot{x} + 2n\dot{x} + \omega_0^2 x = f(t)\,, \tag{2}$$

where: *f(t)* – a function of random input influence on the oscillating system.

Typically, as elements of the elastic suspension the specially designed rubber parts is used. Today for the vibration protection of heavy mineral processing machinery tires can’t be replaced by any of the existing materials. It has the ability to large reversible deformations is having a high elastic and dissipative properties, has no random failure and its fatigue characteristics exceeds all existing structural materials.

The disadvantages include the dependence of the viscoelastic properties of the mode of loading, aggressive environment and time of operation. In addition, rubber is not subject to simplified models of the Kelvin-Voigt, and its dissipative properties are not directly proportional to the rate of deformation. However, Thanks to well-developed mathematical apparatus of the theory of oscillations use these equations. Recently, there are other approaches to this issue.

We consider two methods for calculation of linear vibrating systems with one degree of freedom.

The first method requires that the mechanical response of the elastic suspension is described by the Kelvin-Voigt and stress obeys:

$$\sigma = E\varepsilon + \mu E\dot{\varepsilon}\,, \qquad (3)$$

where: E – modulus of elasticity, ε – relative strain isolator, μ – the coefficient of internal resistance of rubber, which is proportional to the strain rate for medium-filled rubber $\mu = 2\cdot10^{-3}$ s [12]

In this case, the equation of motion can be written as:

$$\ddot{x} + \mu\omega_0^2\dot{x} + \omega_0^2 x = q\sin\omega t\,. \qquad (4)$$

For the amplitude of steady-state forced oscillations of the relation:

$$A = \frac{q}{\sqrt{\left(\omega_0^2 - \omega^2\right)^2 + \mu^2\omega^2\omega_0^2}}\,, \qquad (5)$$

where: ω - frequency of forced oscillations of the system, ω_0 - natural frequency of the system, q - inertial force per unit mass of the vibrating.

The second method requires that a mechanical reaction condition described by the integral ratio of the Boltzmann - Volterra type with kernels of relaxation and aftereffect. In this case, equation (4) in the operator form can be rewritten as:

$$\ddot{x} + C(t, \varepsilon, T)x = q\sin\omega t\,, \qquad (6)$$

where: C is the operator of the elastic stiffness of the suspension.

In the simplest case this operator is have form:

$$C = C_0\left(1 - \chi E_\alpha^*(-\beta)\right), \qquad (7)$$

$$E_\alpha^*(-\beta)\varepsilon(t) = \int_0^t E_\alpha(-\beta t - \tau)\varepsilon(\tau)d\tau\,, \qquad (8)$$

$$E_\alpha(-\beta t - \tau) = (t-\tau)^\alpha \sum_{n=0}^{\infty} \frac{(-\beta)^n (t-\tau)^{n(1+\alpha)}}{\Gamma\left[(n+1)(1+\alpha)\right]}\,, \qquad (9)$$

where: C_0 – the instantaneous value of the elastic stiffness of the suspension, $E_\alpha(-\beta, t-\tau)$ – exponential function of fractional order of Rabotnov, α, β, λ – rheological properties of rubber, Γ - gamma function..

In [13], the following basic relations for determining the rheological properties of rubber:

$$\psi = 2\pi B\,,$$
$$\frac{G}{G_0} = 1 - A\,,$$
$$A = \frac{\chi\left(\omega^{1+\alpha}\cos\delta + \beta\right)}{\omega^{2(1+\alpha)} + 2\omega^{1+\alpha}\beta\cos\delta + \beta^2}\,,$$
$$B = \frac{\chi\omega^{1+\alpha}\sin\delta}{\omega^{2(1+\alpha)} + 2\omega^{1+\alpha}\beta\cos\delta + \beta^2}\,,$$
$$\lambda = \frac{G_0 - G_\infty}{G_0}\,,\quad \alpha = 1 - \frac{4}{\pi}arctg\frac{\psi_{\max}}{\pi\lambda}\,,$$
$$t_0 = \frac{1}{\omega(\psi_{\max})}\,,\ \beta = \frac{1}{t_0^{1+\alpha}}\,,\ \chi = \frac{\lambda}{t_0^{1+\alpha}}\,, \qquad (10)$$

where: A and B – the rheological characteristics of rubber (sine and cosine Fourier transform function), ψ – rate of energy dissipation, $G(\omega)$ – the current value of the shear modulus, G_0 – the instantaneous value of the shear modulus, t_0 – a generalized relaxation time.

To use less than the average filled rubber type 2959 (or its analog 6620) rheological parameters have the following values: $\alpha = -0{,}6$, $\beta = 1{,}1$, $\lambda = 0{,}58$.

In view of the expression ratios of the amplitude of oscillation will be of the form:

$$A = \frac{q}{\sqrt{\left(\omega_0^2(1-A) - \omega^2\right)^2 + B^2\omega_0^2}}\,, \qquad (11)$$

where: ω_0 is natural frequency of the system is perfectly elastic.

Expression (Eq. 11) can more accurately determine the amplitude and phase characteristics of the transient regimes, for example in the region of resonance in which the expression (Eq. 5) and (Eq. 11) give similar results.

As can be seen, the mathematical model using the Volterra integral relations based on more stringent assumptions and more accurately take into account the viscoelastic properties of rubber than the Kelvin-Voigt model. It is most effective in the study of nonlinear systems, transient oscillatory systems, as well as in the study of systems, rheological characteristics are significantly dependent on the time of loading mode or slowly varying temperature (external or self-heating of the dissipative)..

Consider the problem of inertial vibration isolation cone crushers. The input data for the calculation of the stiffness characteristics of vibration isolation systems crushers are their structural characteristics: J - moment of inertia about the axis OX crusher, a - radius of the circle on which the centers of anti-vibration mounts, b - distance from the center of the spherical bearing cone to the fixing of vibration isolators, Z_c - distance from the center of gravity of the crusher to the center of the spherical bearing cones, M - mass of the moving parts of the crusher, ω - frequency forced oscillation crusher (crushing cone rotation frequency). These data crushers CSC1500 and CSC1750 are shown in Table.

Table. Specifications of crushers

Characteristic	CSC-1500	CSC-1750
M, kg	38100	65000
ω, s^{-1}	52	47
J, kg·m^2	58530	220000
a, m	1.3	1.9
b, m	2.25	2.57
Z_c, м	0,89	1,62

To achieve a sustainable mode of vibration isolators system must ensure the machine in above the resonance mode with the value of the detuning $q = \omega/\lambda_{i\max} \geq 3$, where $\lambda_{i\max}$ - maximum of the natural frequencies λ_i - machines with vibration isolation system. This will also satisfied the requirements for stability in transient conditions and provided with a sufficient degree of vibration crusher housing from the base.

For crushers type CSC values of natural frequencies λ_i, $i = \{1, 2, 3\}$ are defined by the following expressions:

$$\lambda_1 = \sqrt{\frac{C_v}{M}},$$

$$\lambda_{\substack{2\\3}} = \sqrt{\frac{C_h}{2M}\left(1 + N \mp K\right)},$$

$$N = \frac{\frac{1}{2}\mu a^2 + (b - Z_c)^2}{J/M - Z_c^2}, \tag{12}$$

$$K = \sqrt{(1+N)^2 - \frac{2\mu a^2}{J/M - Z_c^2}},$$

$$\mu = \frac{C_v}{C_h},$$

where: λ_1 – the natural frequency of the vertical oscillations, λ_2 and λ_3 – the natural frequencies associated rotary and horizontal vibrations, C_v and C_h – vertical and horizontal stiffness vibration isolation system, respectively.

To find the maximum natural frequency of the need to compare the frequencies λ_1 and λ_3 at the value μ, which corresponds to the characteristics of vibration isolators (frequency λ_3 more λ_2 for all μ). Transform (Eq. 1) to the form [5]:

$$\lambda_i = \lambda_1 \Lambda_i, \quad i = \{1, 2, 3\}$$

$$\Lambda_1 \equiv 1$$

$$\Lambda_{2,3} = \sqrt{\frac{1 + N \mp K}{2\mu}}. \tag{13}$$

The coefficient Λ_3 defines the desired frequency ratio:

$$\Lambda_3 = \lambda_3 / \lambda_1.$$

Thus, the condition for determining the maximum stiffness vibration isolation system $C_{v\max}$ crushers CSC1500 and CSC1750 is:

$$C_{v\max} = \frac{\omega^2 M}{9\Lambda_i^2}, \quad i = \{1, 3\}. \tag{14}$$

Find the value of Λ_3. Of the estimated shapes of vibration isolators - diameter approximately equal to three or four heights - you can determine the approximate value of μ. For such isolators $\mu \approx 6$.

From (Eq. 2) we find for the CSC1500: $N = 9.3$, $K = 8.01$, $\Lambda_3=1.24$, $C_{vmax} = 9.6$ MN/m

For CSC1750: $N = 15.32$, $K = 14{,}47$, $\Lambda_3= 1{,}6$, $C_{vmax} = 13.45$ MN/m

Largest $C_{v\max}$ can find the minimum required static draft $\Delta_{\min}$ crusher housing on vibration isolators:

$$\Delta_{\min} = \frac{Mg}{C_{v\max}}. \tag{15}$$

Values $\Delta_{\min}$ are 39.6 mm for CSC1500 and 48 mm for CSC1750. The relative compressive strain isolator is:

$$\varepsilon = \frac{\Delta}{H}, \tag{16}$$

where: Δ – displacement of isolator surface, H – height of the rubber of the array.

If we choose $N = 350$mm, based on the design requirements, the minimum will be equal to the relative strain $\varepsilon_{\min}$ = 11% for CSC1500 and $\varepsilon_{\min}$ = 13,8% for CSC1750. These values are acceptable for reliable long-term operation of vibration isolators (it being understood that the dynamic deformation does not exceed 3%, and a significant impact on the stress-strain state of the isolator does not have).

We now pose the problem of finding isolators with characteristics on the basis of which could be picking them in the required quantities to construct a vibration isolation system for crushers CSC1500 and for the CSC1750. We find that for a maximum stiffness for the isolator Svmax1 both grinders, from the fact that each grinder must be four legs, and each leg can be positioned 3-4 isolator (Fig 1).

Stiffness of each support for CSC1500 - 2.4 MN/m, for 1750 - 3.36 MN/m

For construction purposes accept stack height equal to its diameter shock absorbers and equal ≈ 350 mm.

Determine the number of elements in a stack and the height of each element, respectively.

We use the formula:

$$C_{v1} = \frac{E\pi\left(D^2 - d^2\right)\beta}{4H},$$

or

$$H = \frac{E\pi\left(D^2 - d^2\right)\beta}{4C_v}, \tag{17}$$

where: E – modulus of elasticity of rubber, D – outer diameter solid rubber, d – diameter of the inner hole, H – height of the rubber of the array, β – rate tightening, rubber for 2959 $E = 4$ MPa.

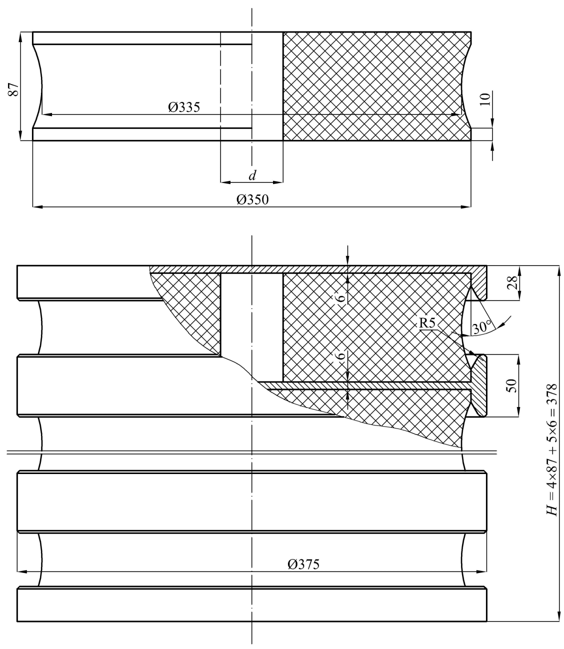

Fig 1. Vibration isolator support

Stiffness of vibration isolator support obtained based finite element method with the help of complex "MIRELA+" [9,12].

For description of nonlinear conduct of elastomeric element of vibroisolator taking into account weak compressibility a Peng-Landel law is used:

$$W = \frac{\mu j_1}{\sqrt[3]{I_3}} + \frac{1}{2} B\left(\sqrt{I_3} - 1\right)^2 . \tag{18}$$

In a component form the law of Penga-Landela looks like:

$$\sigma^{ij} = \sqrt{I_3}\left[\mu I_3^{-\frac{4}{3}} g^{ij} + \frac{B}{2}(I_3 - 1)G^{ij} + \right.$$
$$\left. \cdot + \mu\left(-I_3^{-\frac{1}{3}} + \frac{4}{9}(I_3 - 1)(I_1 - 2) + \frac{2}{9}(I_3 - 1)\right) G^{ij} \right]. \tag{19}$$

In the high-elasticity state the viscoelastic conduct of elastomer shows up carries the cleanly expressed relaxation character. Large viscidity, expressed relaxation character of tensions, geometrical and physical non-linearity of deformation requires bringing in of mathematical vehicle of nonlinear three-dimensional theory of viscoelasticity.

Using principle of Volterra [10] connection between components of tensions and deformations for nonlinear viscoelastic weakly compressible material it is possible to accept as a law of Hooke, Peng-Landel or Lindli, replacing resilient constants the integral operators of Volterra.

Then for viscoelastic material have:

$$\sigma^{ij} = \sqrt{I_3}\left[\mu\left(I_3^{-\frac{4}{3}} g^{ij} + \left(-I_3^{-\frac{1}{3}} + \frac{4}{9}(I_3 - 1)(I_1 - 2) + \frac{2}{9}(I_3 - 1)\right) G^{ij} - \right.\right.$$
$$\left. - \int_{-\infty}^{t} R_\mu(t-\tau)\left(I_3^{-\frac{4}{3}} g^{ij} + \left(-I_3^{-\frac{1}{3}} + \frac{4}{9}(I_3 - 1)(I_1 - 2) + \frac{2}{9}(I_3 - 1)\right) G^{ij}\right) d\tau \right) +$$
$$\left. + \frac{B}{2}\left((I_3 - 1)G^{ij} - \int_{-\infty}^{t} R_b(t-\tau)(I_3 - 1)G^{ij} d\tau \right)\right]. \tag{20}$$

The most complete description of the real process of deformation of elastomeric element of construction can be obtained using the kernels of Rabotnov and Rzhanicyn [9].

As laws of Peng-Landel and Lindli in maximum case have the appearance of law of Hooke, nonlinear equalizations can linearized for the case of weak compressibility of material.

Covariant components of tensor of eventual deformations look like:

$$\varepsilon_{ij} = \frac{1}{2}\left(C_j^m \nabla_i u_m + C_i^m \nabla_j u_m + \nabla_i u_m \nabla_j u_n g^{mn} \right), \tag{21}$$

where: $\nabla_i u_m = u_{m,i} C_i^k \Gamma_{mk}^l u_l$, $C_i^n = \frac{\partial z^n}{\partial x^i}$, z^n – coordinate system coordinates of the baseт, x^i – the local coordinate system.

The tensor of deformation can be represented as the sum of the linear and nonlinear components:

$$\varepsilon_{ij} = \varepsilon_{ij}{}^L + \varepsilon_{ij}{}^N . \tag{22}$$

The first invariant of the Cauchy-Green tensor of deformation can also be expressed as the sum of the linear and nonlinear components:

$$j_1 = j_1{}^L + j_1{}^N . \tag{23}$$

After substituting relations for weakly Peng-Landel's material can be linearized relationship:

$$\tilde{\sigma}^{ij} = \tilde{\mu}\left(g^{ij} - G^{ij}\right) + \tilde{B} j_1^L G^{ij} - \frac{1}{3}\tilde{\mu}\left(H_1 g^{ij} - H_2 G^{ij}\right) + \tilde{B}\theta^n G^{ij},$$

or

$$\tilde{\sigma}^{ij} = 2\tilde{\mu}\varepsilon_{ij}^L + \tilde{B} j_1^L G^{ij} - \frac{\tilde{\mu}}{3}\left(H_1 g^{ij} - H_2 G^{ij}\right) + \tilde{B}\theta^L G^{ij}, \tag{24}$$

where: H_1, H_2, θ^N – ratio due to non-linear components of invariants.

Furthermore, in expression (24) can be isolated viscous and elastic stress tensor components:

$$\tilde{\sigma}^{ij} = 2\mu\varepsilon_{ij}{}^L + B j_1^L G^{ij} - \frac{1}{3}\mu\left(H_1 g^{ij} - H_2 G^{ij}\right) + B\theta^N G^{ij} -$$
$$- 2\mu \int_{-\infty}^{t} R_\mu(t-\tau)\varepsilon_{ij}^{L\ddot{e}}(\tau) d\tau - B\int_{-\infty}^{t} R_b(t-\tau) j_1^L(\tau) G^{ij} d\tau -$$
$$- \frac{1}{3}\mu \int_{-\infty}^{t} R_\mu(t-\tau)\left(H_1 g^{ij} - H_2 G^{ij}\right) d\tau -$$
$$- B\int_{-\infty}^{t} R_b(t-\tau)\theta^N G^{ij} d\tau . \tag{25}$$

To solve the problem of deformation of structural elements from a weakly elastomers the moment scheme of finite element, which uses a triple approximation of displacements, strains and function of volume change, are used. Construction stiffness matrix is based on the use of the principle of virtual movements.

Simulation of viscoelastic deformation of the elastomer is based on the use of space-time finite element with independent approximation of displacements in scope and in time [10]. The solution of the nonlinear deformation produced by the modified of Newton-Kantorovich method [9].

On Fig. 2-5 the rezults of the solving of nonlinear deformation of elastomer elements are presented.

The solution of the problem of deformation of the package elastomeric isolators with the weakly nonlinear deformation of the viscoelastic material allows us to estimate the stiffness of construction [15-17]. To support shown in Fig. 1 static draft displacement not exceed 53.6 mm for the crusher CSC1750. Stiffness support member in this case is 3.26 MN/m.

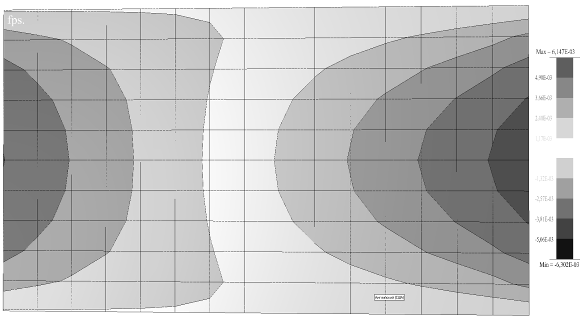

Fig 2. Radial displacements of rubber element

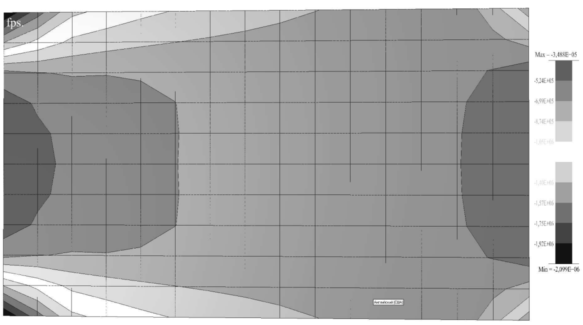

Fig 3. Distribution of axial stresses σ_z

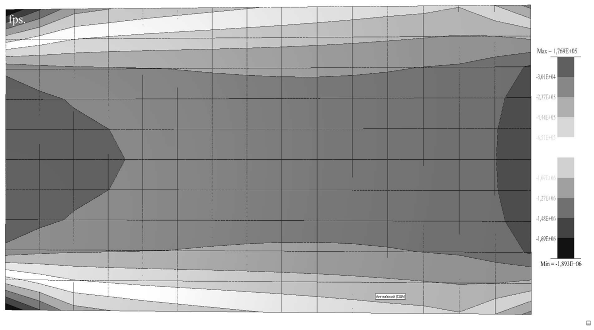

Fig 4. Distribution of radial stresses σ_r

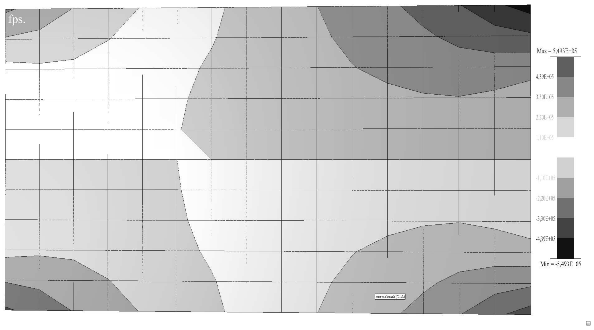

Fig 5. Distribution of tangential stresses σ_{rz}

To ensure the necessary rigidity of the stack for CSC1500 of 2.4 MN/m according to (Eq. 17) accepts for crusher CSC1500 – the number of elements in the stack – three 116 mm in height, the rigidity of one element – 7.2 MN/m (d = 50 mm, β = 2,2).

Based on the finite element solutions to obtain such support sludge 37.2 mm, the stiffness of 2.32 MN/m.

CONCLUSIONS

1. On the basis of governing equations for the viscoelastic material weakly constructed a method of solving the problem of non-linear deformation of the elastomeric structural elements.

2. The use of solutions of nonlinear deformation of weakly compression elastomeric elements can more accurately assess the properties of the isolators. Construction of vibration isolator, produce the stacks of different heights, which can be used for vibration isolation of machines for various technological purposes.

3. The parameters of the design and developed shock absorbers and anti-vibration supports for crushers CSC1500 and CSC1750.

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ОБОСНОВАНИЕ ПАРАМЕТРОВ И РАЧСЕТ ВИБРОИЗОЛЯТОРОВ

Юрий Козуб, Виталий Дырда, Николай Лисица

А н н о т а ц и я . Рассмотрен метод определения параметров виброизоляции конических инерционных дробилок с помощью резино-металлических элементов. Построены разрешающие уравнения для определения параметров виброизоляторов. Для описания поведения эластомерных элементов при расчете используются интегральные соотношения Вольтерра.

К л ю ч е в ы е   с л о в а : виброизолятор, эластомер, вязкоупругость.

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Diagnostics of the regional transport and logistic system's functioning (in the case of Luhansk region)

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Summary. The results of the diagnostics of the regional transport and logistics system's (RTLS) functioning are presented, the comprehensive evaluation of its functioning is calculated. Algorithm for Luhansk RTLS functioning estimation technique is developed on the basis of the normative system of diagnostics indicators.

Key words. Transport system, diagnostics, indicators, technique, algorithm.

INTRODUCTION

Transport diagnosis is at the beginning of its formation, it represents branch of science that studies the status of the objects of diagnostics on transport, develops methods and tools for detecting defects of transport systems and their causes and systems of diagnostics using the methods and means of Cybernetics [6, 8, 12].

French scientist B. Colas [3] believes that, that making the diagnosis means to consider in dynamics phenomena symptoms, which may delay the achievement of the set goals and problem solving, endanger the planned activity. This involves developing adjustment solutions or viewing the goals and forecasts. Knowing the signs (symptoms) allows quickly and accurately to detect the nature of disorders, without making direct measurements, that is without actions that require extra time and money.

The existing framework for the diagnosis on transport one can consider to be approaches related to the evaluation and analysis of the functioning of transport and systems, in which it participates. Examples may include works [5, 14].

In the frame of transport diagnostics the following research areas can be distinguished: diagnosis in terms of energy and resource conservation, diagnosis on indicators of security and risk, diagnosis on indicators of capacity and diagnostics on territorial indicators [11].

The direction of research in the works [2, 4] is carried out on indicators of potential. This is due to the extensive use of category of potential in economics and its distribution into the transport sector. In turn, in [1, 16] attention is paid to the territorial indicators. It is caused by the natural essence of transport systems: to implement the delivery in space, as well as the dispersal and diversity of participants in the transport process and transport infrastructure.

Diagnostic approach as one of a number of scientific approaches (along with systemic, process, etc.) is used in two aspects: general - as a realization of the concept of diagnostics in relation to the selected application object (object of investigation) and private – as implementation of methodological tools for diagnostics united by any sign, in relation to the selected application object (object of investigation) [13].

Thus, as diagnosis objects on transport we may identify: technological maintenance (transport infrastructure facilities, rolling stock, etc.), items of manufacture (goods, people), executors (drivers, dispatchers, etc.) [9].

The work [10] distinguishes the following diagnostic tools: informational – that is diagnostic information obtaining, its storage, systematization, software should be included here, technical and technological – that are various devices for receiving and processing information (devices, sensors, computer facilities, etc.), mathematical – that are diagnostic models, algorithms, of diagnosing.

Diagnostics of transport systems is a new research direction of the regional transport and logistics system (RTLS) functioning in the modern world.

According to the work [18] RTLS means a series of transportation logistics subjects, combined into logistics chains and channels and interconnected in a single process of material, informational, financial, service and other flows management, created or moved in the territory of the region for optimal and rational organization of their movement in the transport sector with minimal logistics costs and maximum useful effect for all participants in the system while respecting the necessary level of service.

In the work [23] transport system is considered as an element of a higher level – transport and logistics system, consisting, respectively, of transport and logistics systems. The authors consider interaction of these systems is an extremely complex process main purpose of which is to organize an efficient and uninterrupted movement of goods within a particular country (region).

Recent elaborations mainstream development and perfection of transport service in manufacturing sphere, distribution and production consumption abroad is logistics. 25-30% of a total national product of leading foreign countries are connected with logistical systems, such, as the USA, Japan, the Great Britain, France, Germany [20].

Luhansk region – is the transit gate of Eastern Ukraine and Luhansk, as a regional center and the city, located less than 45 km from the Russian Federation border, almost at the crossroads of the main railway and highways, in fact is the key, the use of which has been providing a positive trade balance volume between the neighboring regions. For example, in the first quarter of 2010 Rostov region's foreign trade turnover with Ukraine had increased by 55% and had reached almost $ 400 million. Due to close interaction of border areas, the share of Ukraine in foreign trade turnover of the Southern Federal District of Russia has been growing steadily and now comprises almost 30% [19, 21].

The positivity of formation and functioning of the Euroregion "Donbass" (further "Euroregion", depends a lot on condition of transformational logistic system of the incoming definite border territories – Luhansk region, Donetsk region (Ukraine) and Rostov region (the Russian Federation)) [22, 24].

Creation of a transport-logistics system in Luhansk region will ensure the effective establishment of a transport corridors network, causing the most complete use of the economic potential of the region. In addition, it can provide the opportunity to achieve increase in traffic volume and improve the competitiveness of domestic carriers, increase their share in the global market of transport services, transport potential of Luhansk region using international transport corridors [15].

Diagnostics of RTLS functioning in Luhansk region will allow: to provide reliable estimation of its current development, to lay the groundwork for hypothesizing about patterns and possible unstable state of the system, to identify the causal relationships in dysfunctions in system management, to build an explanatory and predictive model of its operation and development, emphasizing the relevance of research.

OBJECTS AND PROBLEMS

The object of the work is diagnostics of the RTLS functioning in Luhansk region using techniques based on the creation of regulatory indicators that will allow to calculate the comprehensive evaluation of the effectiveness of its functioning in retrospect and current development, to develop an algorithm of the method based on the transport diagnostics facilities.

RESULTS OF RESEARCH

To conduct a reliable diagnosis of the overall level of RTLS efficiency it is suggested to use the regulatory system of indicators, each of which is expressed by ratio (index) of results, costs, and resources of the transport system.

A set of indicators by which standards are set, we will call the recommended regulatory indicators system (RRIS) (Fig. 1).

They are divided into primary and secondary ones. The initial parameters mean such that resulted from the direct functioning accounting of RTLS (such as turnover tkm, public highways length km, etc.). Secondary indicators – are those that are calculated (e.g. self-cost of 100 tkm, CU). RRIS is mobile for each individual case, i.e. can be added, specifically for the given region.

Structural and logical model of RTLS functioning diagnostics according to RRIS is reduced to four basic provisions (Fig. 2):

– forming a set of initial indicators that fully characterize RTLS functioning,

– calculation of the growth rates that express the most efficient mode of RTLS functioning and its ranging,

– comparison of practically ordered growth rate with the regulatory one,

– determination of integral evaluation of RTLS functioning efficiency.

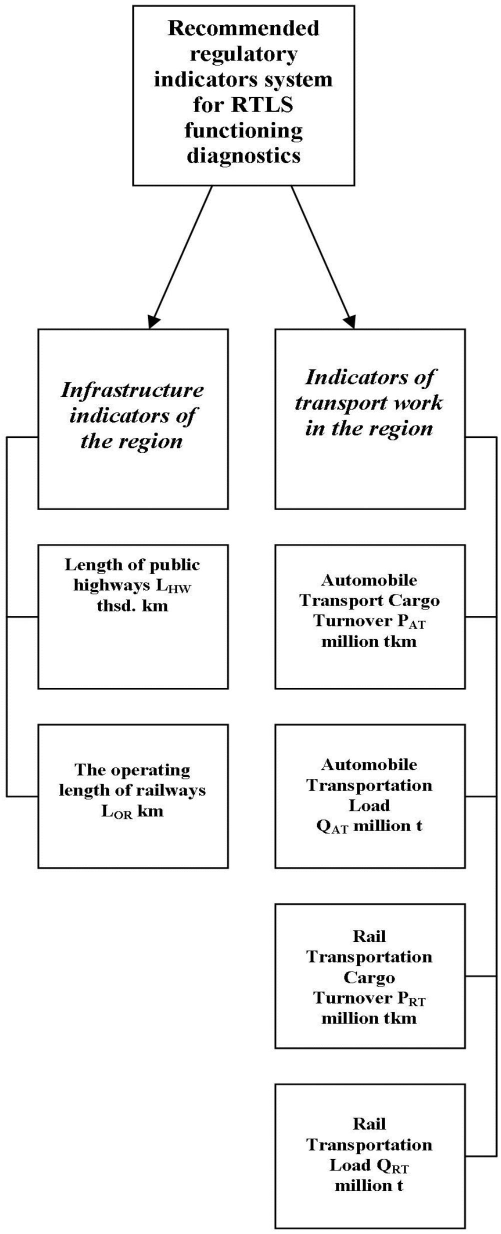


Fig. 1. The recommended regulatory diagnostics indicators system of RTLS functioning in Luhansk region

Using the method of ranking we assign the rank (priority) for each of the indicators in RRIS. The first rank (priority) is assigned to the index with the largest growth rate, the second – to the growth rate index lower, than the first index, but higher than in all the rest. When the growth rate indexes are the same, the one that is top-priority for the effective functioning of the RTLS in the region is preferred.

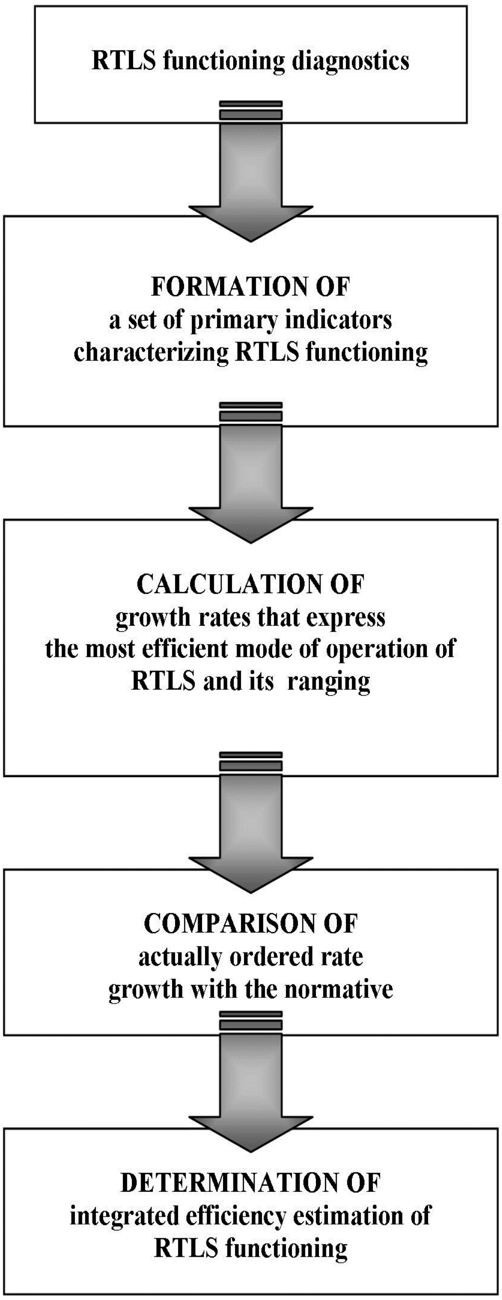


Fig. 2. The structural and logical diagnostics model of RTLS functioning in Luhansk region by the RRIS

Regulatory ranks (priorities) of the growth rates of the RTLS in Luhansk region, that are listed in Table 1, were determined on the basis of the following reasons.

Automobile transport has a list of significant advantages (has a high level of mobility and the possibility of "door to door" delivery, has a very short delivery time, regular frequency of departures, traffic time reliability), has a sectoral and regional character (is used mainly for transport destination of 200 km).

The automobile transport cargo turnover, P_{AT}, million t, determines the volume of transport work for cargo transportation, measured in tariff tkm, and is an important indicator that characterizes the RTLS functioning.

The automobile transportation load Q_{AT} million t, is the sum of the sent and received cargoes from other enterprises (units) for further transportation.

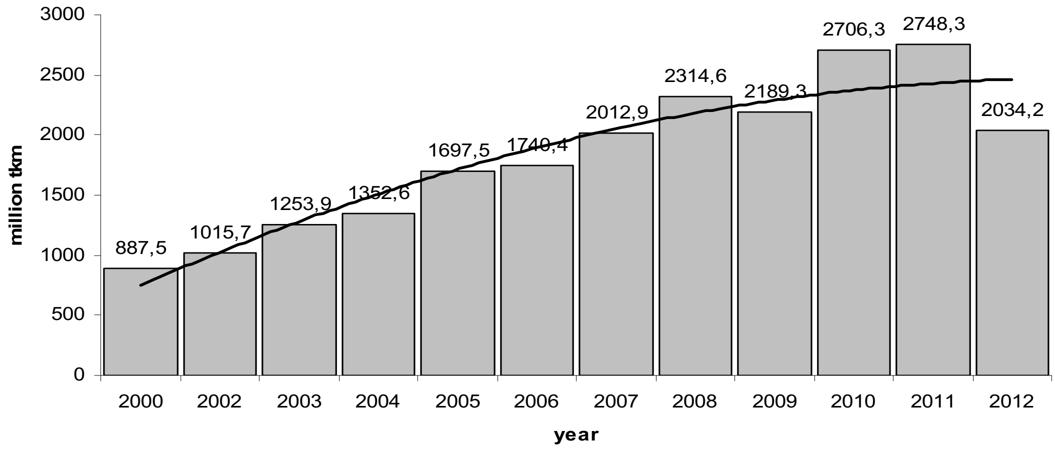
Table 1. Regulatory ranks (priorities) of Luhansk region growth rates

#	Diagnostics Indicators of THE RTLS Functioning	Regulatory ranks (priorities) of the growth rates
1	Automobile Transport Cargo Turnover P_{AT} million tkm	1
2	Automobile Transportation Load Q_{AT} million t	2
3	Length of public highways L_{HW} total thsd. km	3
4	Rail Transportation Cargo Turnover P_{RT} million tkm	4
5	Cargo transported by rail transport Q_{RT} million t	5
6	The operating length of railways L_{OR} km	6

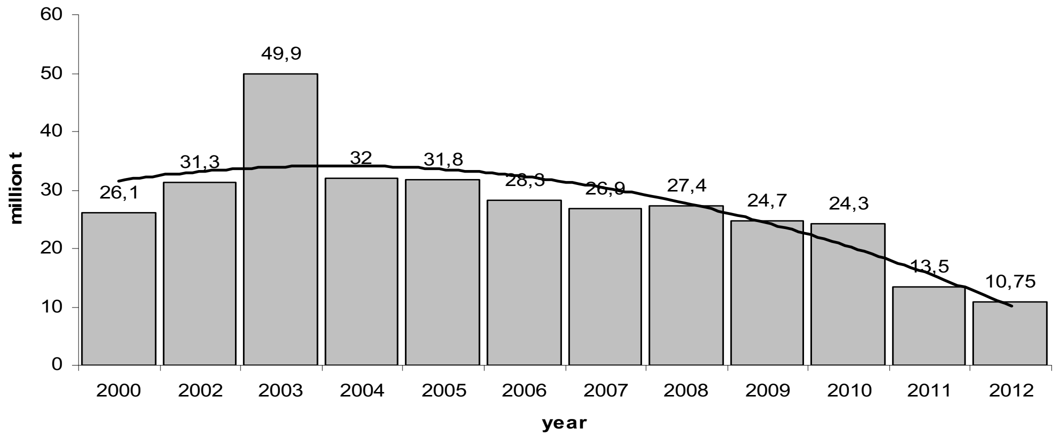
The previous two indicators are not possible to obtain in the absence of an extensive network of routes (the length of public highways in Luhansk region is 5.9 thsd km, the density of highways in Luhansk region is 209.7 km per 1000 km^2 (in Ukraine 269 km per 1000 km^2)).

Rail transport is used mainly for transportation on big enough distance, has the property of mass transportation and relatively low cost of transportation. The operating length of railways in Luhansk region is 1092.4 km (the sixth place in Ukraine), extensive length of routes is 2,380 km.

Let us consider the dynamics of development of each of the indicators of the recommended regulatory system (Fig. 3 for automobile transport, Fig. 4 for rail transport) according to [25, 26].



a



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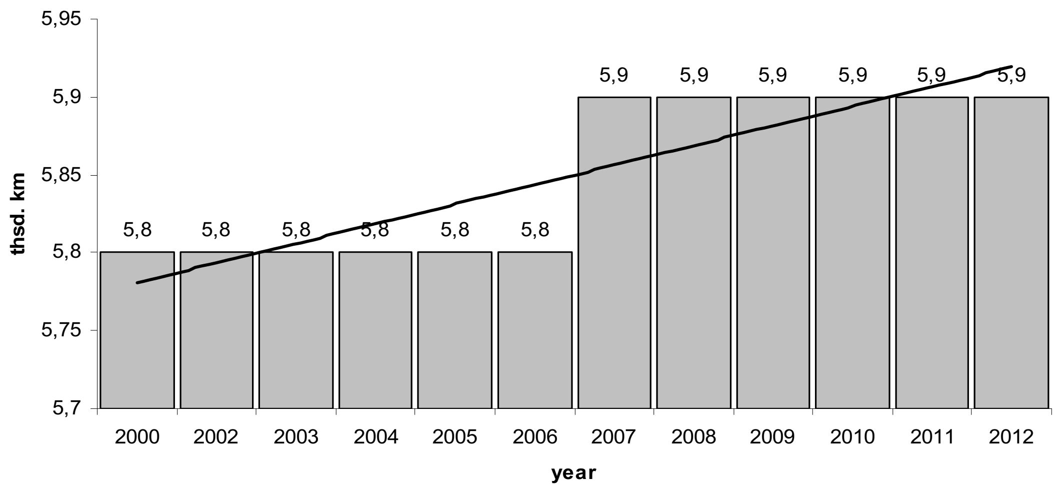

c

Fig. 3. Dynamics of automobile transport indicators development in Luhansk region: a – by cargo turnover million tkm, b – by transportation of cargoes million t, c – by the length of public highways thsd km

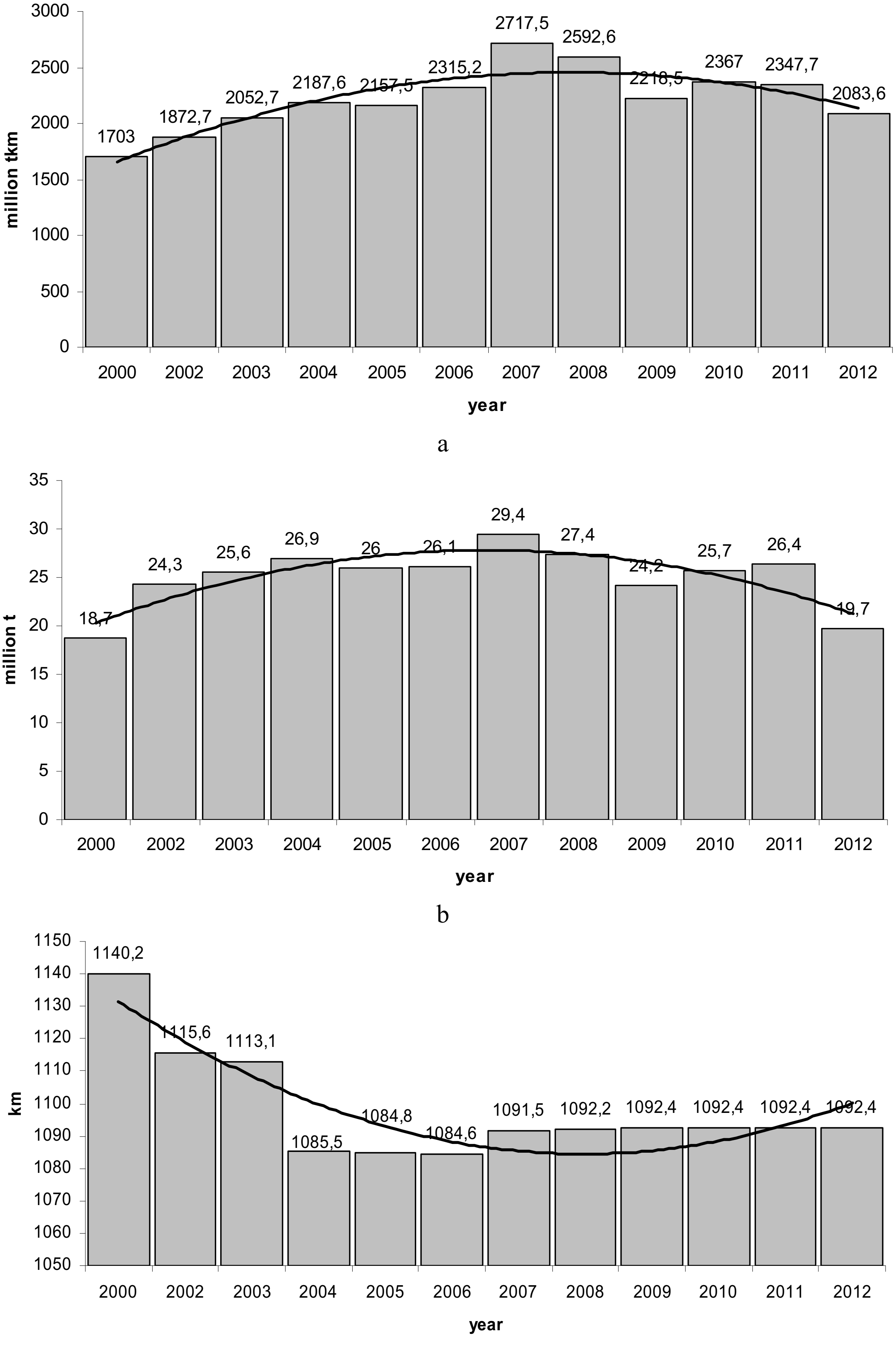

Fig. 4. Dynamics of rail transport indicators development in Lugansk region: a – by cargo turnover million tkm, b – by transportation of cargoes million t, c – by the length of railways operating length km

The level of efficiency of RTLS should be determined on the basis of two coefficients: Kendall coefficient K_K and Spearman coefficient K_S. Complex (resulting) estimation of the RTLS functioning efficiency will be calculated by the following formula:

$$K_R = \frac{(1+K_K)+(1+K_S)}{4}. \quad (1)$$

The RTLS functioning efficiency assessment is calculated using the formula of the Kendall Rank Correlation Coefficient [7, 17, 27]:

$$K_K = 1 - \frac{4\sum_{i=1}^{n} m_i}{n(n-1)}, \quad (2)$$

where: $\sum_{i=1}^{n} m_i$ – is a number of violated regulatory ratios of *i* indicators growth rates,

n – is a number of indicators in the regulatory system.

By the results of calculations of Kendall coefficient using the formula (2) we obtain the following dynamics (Fig. 5).

The value of the numerator and denominator of the calculation formula are directly proportional to the number of violations of the requirements and therefore their total number. Value of the coefficient that is calculated changes from -1 to +1. The value of the rate +1 corresponds to RTLS functioning with the highest efficiency. If the rate is -1, there is deterioration in absolutely all efficiency indicators. Zero-rating of RTLS functioning efficiency proves that in the estimated period it has not changed compared to the previous.

To improve the accuracy of evaluation of RTLS functioning efficiency the Spearman's rank correlation coefficient is used [7, 17, 28], which is calculated by the following formula:

$$K_S = 1 - \frac{6\sum_{i=1}^{n} y_i^2}{n(n^2-1)}, \quad (3)$$

where: y_i – is the difference of *i* indicator ranks in the actual and normative ordering of the growth rate.

Spearman's rank correlation coefficient K_S shows that the integral evaluation is given not only to the number of violated regulatory ratios, but also quality content and significance of these violations are taken into account. K_S allows to reveal a more efficient regime of RTLS functioning among those that have the same value assessment K_K.

By results of calculations of Spearman's coefficient using formula (3) we obtain its following dynamics (Fig. 6).

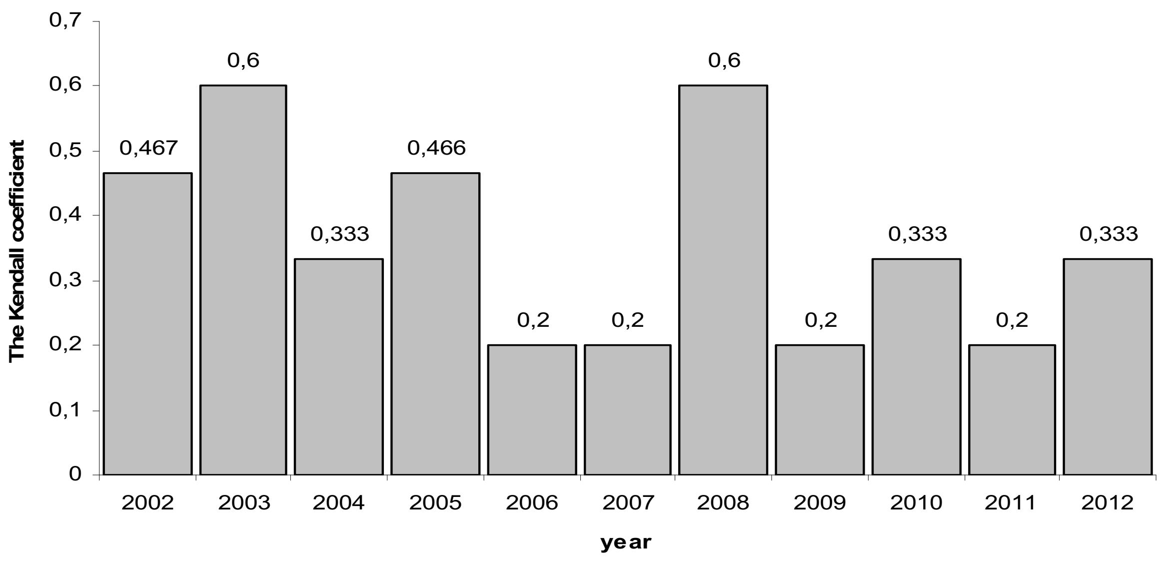

Fig. 5. Dynamics of Kendall coefficient for Luhansk region

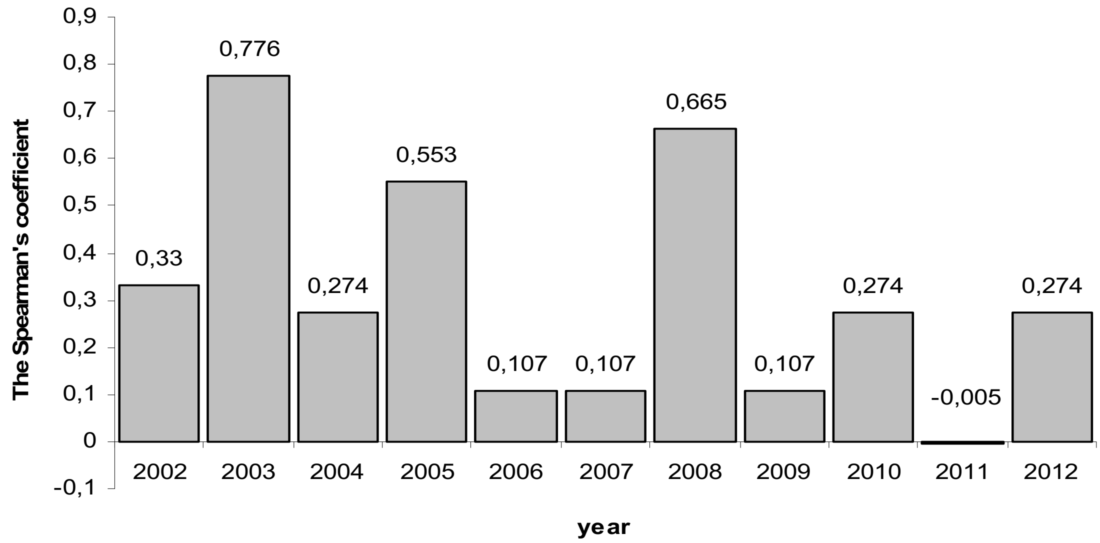

Fig. 6. Spearman's coefficient dynamics for Luhansk region

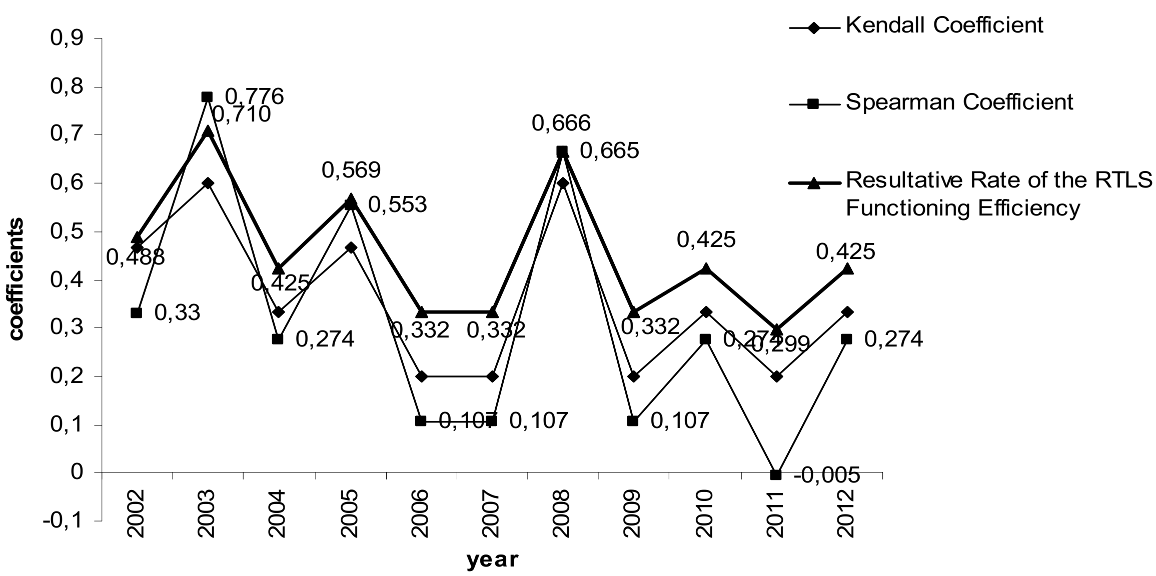

Fig. 7. Dynamics of the comprehensive assessment of RTLS functioning efficiency in Luhansk region

Comprehensive assessment of RTLS functioning efficiency calculated by formula (1) has the following dynamics (Fig. 7):

Aggregation of K_K and K_S by formula (1) changes the scale of assessments of RTLS functioning efficiency: if K_K and K_S change their values from -1 to +1, then range of values K_R is from 0 to 1. Herewith the value of $K_R = 0.5$ corresponds to the middle of the scale of assessments K_K i K_S.

Comprehensive assessment is characterized by quantitative criteria of levels of RTLS functioning efficiency (Table 2).

Table 2. Quantitative criteria of the level of RTLS functioning efficiency

Quantitative criteria	Level of RTLS functioning efficiency
up to 0.3	practically doesn't function
0.3-0.5	lightly functioning
0.5-0.7	moderately functioning
0.7-1.0	operate with the highest efficiency

The algorithm for methodology of assessing the RTLS functioning in Luhansk region is shown in Fig. 8.

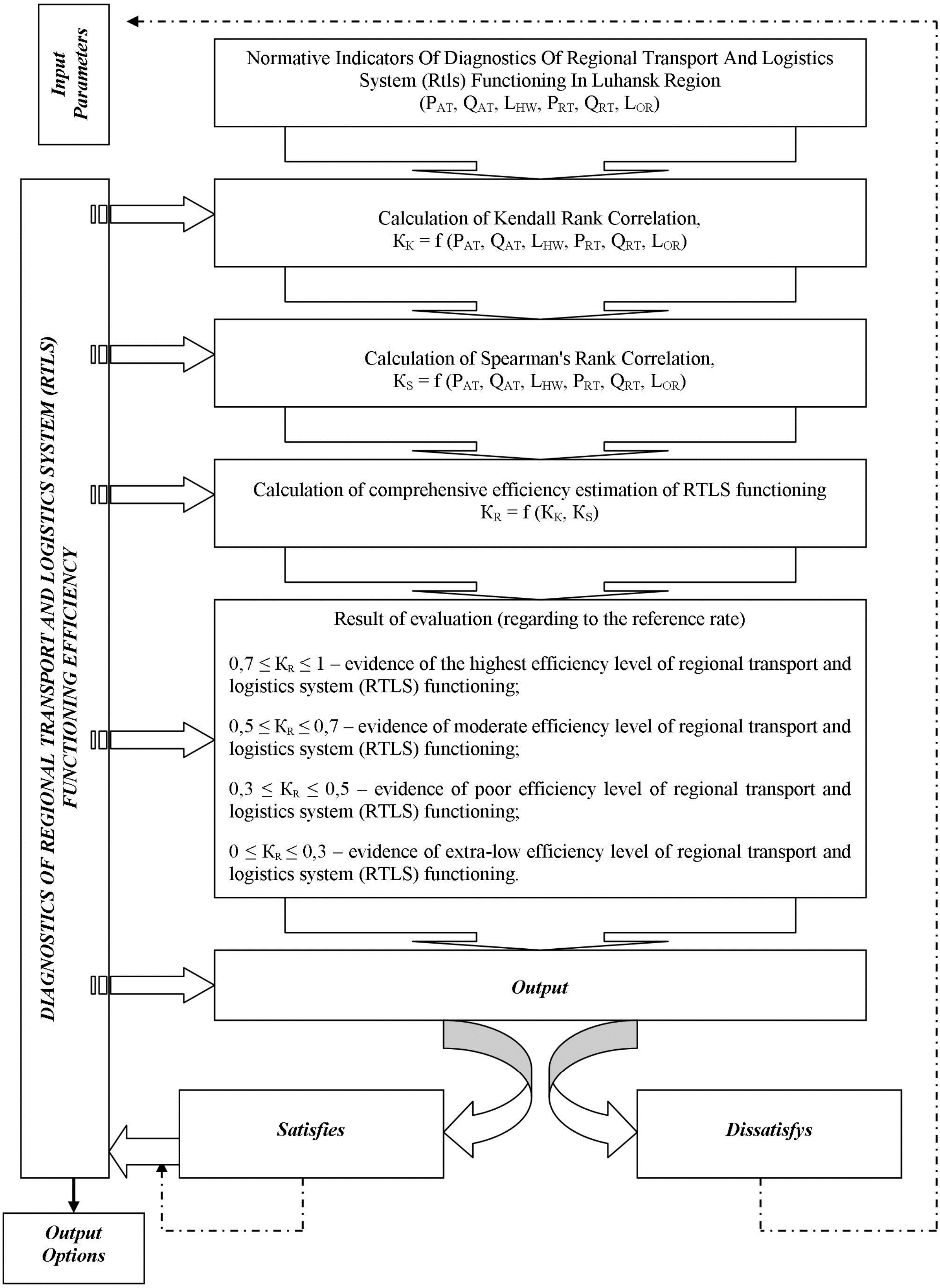

Fig. 8. Algorithm for methodology of assessing RTLS functioning in Luhansk region

CONCLUSIONS

1. Stable RTLS functioning is provided through the implementation of advanced transport diagnostic methods.
2. Diagnostics of the RTLS in Luhansk region is conducted on the bases of methodology that is based on RRIS creation, allows calculating a comprehensive assessment of the effectiveness of the system and determining its level. The calculation results revealed the following: in 2003 the RTLS in Luhansk region functioned with the highest efficiency, moderate functioning of the system was achieved in 2005, 2008, in 2002, 2004, 2006, 2007, 2009, 2010, 2011, 2012 a comprehensive assessment index indicates poor functioning of the system.
3. The sequence of actions that lead to the solution the given task is confirmed by the development of algorithm for methodology to assess the functioning of the RTLS in Luhansk region on the basis of transport diagnostics.
4. Qualitative diagnosis of RTLS functioning will allow achieving the transportations volume growth and increasing the competitiveness of domestic carriers, increasing their share in the global transport market, implementation of transport potential in Luhansk region.
5. Further research on this issue should be conducted in developing predictive model of the RTLS, which will characterize the state of technical and technological development of the region and improvement of transport diagnosis methods.

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ДИАГНОСТИКА ФУНКЦИОНИРОВАНИЯ РЕГИОНАЛЬНОЙ ТРАНСПОРТНО-ЛОГИСТИЧЕСКОЙ СИСТЕМЫ
(на примере Луганского региона)

Александр Кравченко, Евгений Медведев

Аннотация. Представлены результаты диагностики функционирования региональной транспортно-логистической системы, рассчитана комплексная оценка ее функционирования. Разработан алгоритм методики оценки функционирования РТЛС Луганского региона на основе нормативной системы показателей диагностики.
Ключевые слова. Транспортная система, диагностика, показатели, методика, алгоритм.

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Force structure impact on the wheel module stability and oscillation process

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S u m m a r y . The stability and shimmies of the front non-steerable pillar free to turn on two channels – the yaw and roll relative to the longitudinal axis of the body is analyzed. Offered approach close analysis of self-oscillation in the nonlinear raising, that enables to estimate stability in «large». The analysis of the typical system parameters impact on the unstable oscillatory region and oscillation amplitude is carried out. The approximation percent influence of the slip force and heel moment on the oscillation character is considered (analytical expression, relating amplitude of vibrations with the parameters of model, is got: by the moment of inertia of wheel in relation to the ax of turn, turning inflexibility of steering management, coefficient of relaxation, size of bearing-out and angle of slope proof).
K e y w o r d s : wheel module, wobbling, force structure, oscillation amplitude.

INTRODUCTION

Self-oscillation guided wheels of car (wobbling) were first considered in-process Brul'e in 1925. In future this question was the article of research of many authors, as representatives of theoretical direction M.V. Keldysh [11], G.V. Aronovich [2], N.A. Fufaev [21], V.F. Zhuravlev, D.M. Klimov [33, 34], L.G. Lobas [14], N.P. Plakhtienko [23], H. Paceyka [22], G. Somesky [28], Yi. Mi-Seon [20], so engineers-researchers of aviation and motor-car transport B. fon Schlippe, R. Dietrich [26], I. Besselink [4], V.S. Gozdek [9], V.I. Goncharenko [7, 8], K.S. Kolesnikov [12], N.P. Plakhtienko, B.M. Shifrin, F. Smiley et al [13, 23, 25, 29].

From point of modern analysis of question, wobbling is the intensive самовозбуждающиеся vibrations of rolling wheels, showing up as turning motions of wheels in a horizontal plane (their rotations), which are accompanied other motions in a longitudinal vertical plane. First of all the wobblings of the chassis elements are connected with the elastic pneumatics availability. Under certain conditions it transforms some power entering the vehicle into the power of wheel torsional oscillations.

There is a great number of variants of description of model of co-operation of balloon wheel with an absolutely even and ideally rough horizontal plane, however necessary it is to take into account that they not all allow to take into account some characteristic features of nonlinear dependences of lateral withdrawal, including descriptions of rigid heterogeneity (conical and angular).

In the tasks of dynamics of the wheeled transport vehicles most distribution was got by two approaches at determination of co-operation of wheel with an underlayment. There are two raising at determination of descriptions of lateral reaction of resilient wheel: model (theory of M.V. Keldysh [11]) and phenomenological one (axioms of I. Rokar [24]). In this work the Rocar model is used – slip force and aligning torque are considered to be well-known nonlinear relations (slip angle functions), obtained empirically.

In the work [15] the analysis of the force structure impact on the unperturbed linear motion stability of the hitch model with two degrees of freedom (values of typical design parameters corresponding to different on mathematical classification force groups have been varied).

One of the first results in this direction there were theorems of Tomsona-Teta-Chetaeva [6] about influence of dissipative and gyroscopic forces on stability of the linear conservative system and results of I.I. Metelicyna [19] for the case of the unconservative systems. Presently receptions are successfully used constructing of quadratic functions of Lyapunova [17], taking into account the mathematical structure of breaking up of forces of the initial system [1, 7, 10, 32]. In spite of absence of general algorithm of construction of functions of Lyapunova, he got wide distribution. The attractiveness of method of functions of Lyapunova is conditioned his high-quality character, allowing to unseal physical essence in a task, and also possibility of receipt of estimations of areas of attraction of unperturbative motion (research of stability is «in large») [5, 16, 29].

In the work [30] on the basis of the suggested approximate approach [31] the nonlinear analysis of the pattern shimming of the wheel module with one degree of freedom is carried out for various approximations of slip forces (monotonic and with flowing section). The results of the analytic treatment are confirmed by a number of phase portraits obtained in the result of numerical integration. In the work corresponding estimates are carried out for a more complete model [14, 16], taking into account aligning torque. The impact of the design parameters and approximation percent of the slip force nonlinear relation on characteristics of system oscillations is considered.

PROBLEM STATEMENT

Let θ and ψ – rotation angles of the chassis setting around front axle and roll axle respectively, then schematically A-pillar of a vehicle is given at Fig. 1.

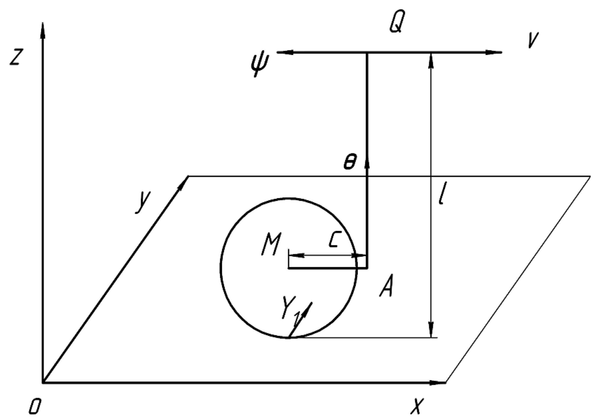

Fig. 1. Wheeled Module

Equations of the chassis leg motion in the linear motion environment at zero removal ($c = 0$) have the form [16] (to complete the setting the aligning torque $M(\alpha)$ is added, occurring in the wheel contact with bearing surface at rolling with slipping):

$$\begin{aligned} &B \cdot \ddot{\theta} + \chi_1 \cdot \theta + h \cdot \dot{\theta} - \frac{I \cdot v}{r}\dot{\psi} + M(\alpha) = 0, \\ &C \cdot \ddot{\psi} + \chi \cdot \psi + h_1 \cdot \dot{\psi} + \frac{I \cdot v}{r}\dot{\theta} + l \cdot Y(\alpha) = 0, \\ &\alpha = \theta + \frac{\dot{\psi} \cdot l}{v}, \end{aligned} \tag{1}$$

where: *B, C* – axial moments of the pillar inertia relative to the rotation axis and rolling axis respectively,

I – central axial moment of the wheel inertia relative to own rotation axis,

r – wheel radius,

v – unperturbed motion velocity,

χ, χ_1 – coefficients of the wheel module torsional stiffness,

h, h_1 – parameters, determining oscillation damping,

l – distance from road surface up to rolling axis.

Slip forces and heel moment are considered in the form of nonlinear relations of the slip angle α :

$$Y(\alpha) = k\alpha / \sqrt{1 + (k\alpha/\varphi N)^2} \ ,$$

where: k – resistance coefficient to the slip,

N – vertical bearing reaction,

φ – traction coefficient in the transverse direction,

$$M(\alpha) = \mu\alpha / (\mu_4 \alpha^4 + \mu_2 \alpha^2 + 1) .$$

Linearized equations of the wheel module perturbed motion have a wide range of forces according to the conventional mathematical classification – inertial, dissipative, gyroscopic, potential, and non-conservative positional ones:

$$A\ddot{x} + (D + vG)\dot{x} + (K + lP)x = 0,$$

where:

$$A = \begin{pmatrix} C & 0 \\ 0 & B \end{pmatrix}, \ D = \begin{pmatrix} h_1 + \dfrac{k \cdot l^2}{v} & \dfrac{\mu \cdot l}{2v} \\ \dfrac{\mu \cdot l}{2v} & h \end{pmatrix},$$

$$G = \begin{pmatrix} 0 & \dfrac{I}{r} - \dfrac{\mu \cdot l}{2v^2} \\ -\left(\dfrac{I}{r} - \dfrac{\mu \cdot l}{2v^2}\right) & 0 \end{pmatrix},$$

$$K = \begin{pmatrix} \chi & \dfrac{k \cdot l}{2} \\ \dfrac{k \cdot l}{2} & \chi_1 + \mu \end{pmatrix}, \ P = \begin{pmatrix} 0 & \dfrac{k}{2} \\ -\dfrac{k}{2} & 0 \end{pmatrix},$$

where: A, D, K – symmetrical matrixes of the inertial, dissipative and potential forces coefficients,

G, P – alternate matrixes of the gyroscopic, non-conservative positional forces coefficients.

The availability of two typical parameters, determining values of gyroscopic terms (according to the traverse speed) and non-conservative positional terms (according to the pillar height), enable to apply general theorems of the force structure impact on the unperturbed motion stability using linear analysis.

Known results [8, 10, 19, 27, 32] of stabilization conditions of linear mechanical systems, under the impact of arbitrary mathematical structure forces, ensure stability at sufficiently great complete dissipation and positive definiteness of the conservative forces matrix or sufficiently great potential forces and positive definiteness of the dissipative forces matrix which is imposed certain additional condition [31]. And availability of sufficient great positional non-conservative forces as a rule leads to the stability loss of the general linear system. However, in case of finite forces, mechanisms of the stabilization and stability loss are possible. They result in an ambiguous treatment of the force structure impact on the stability of linear system.

In the regions of the flutter instability stationary monofrequent oscillations can occur (one of mechanisms of their occurrence – the Andronov – Hopf bifurcation [18]). The problem of the stability loss character (unsafe-safe according to N.N. Bautin [3]) can be solved on the basis of the amplitude curve analysis and characteristics of the linearized model stability. Then the approximate approach how to get an amplitude curve as an implicit function of system parameters is given. It is related, in turn, to the solvability condition of a certain auxiliary system of non-linear finite equations.

EVALUATION OF THE OSCILLATION AMPLITUDES IN THE NEIGHBORHOOD OF LINEAR MOTION CONDITION

To carry out the approximate method of the self-oscillating system amplitude evaluation let's introduce an auxiliary differential equation, corresponding to the unsteady slip theory:

$$\sigma \cdot \dot{\alpha} + \mathrm{v} \cdot \alpha - \mathrm{v} \cdot \theta - l \cdot \dot{\psi} = 0 .$$

Then the system (1) is:

$$\sigma \cdot \dot{\alpha} + \mathrm{v} \cdot \alpha - \mathrm{v} \cdot \theta - l \cdot \dot{\psi} = 0,$$
$$\mathrm{B} \cdot \ddot{\theta} + \chi_1 \cdot \theta + h \cdot \dot{\theta} - \frac{I_1 \cdot v}{r} \dot{\psi} + M(\alpha) = 0, \quad (2)$$
$$C \cdot \ddot{\psi} + \chi \cdot \psi + h_1 \cdot \dot{\psi} + \frac{I_1 \cdot v}{r} \dot{\theta} + l \cdot Y(\alpha) = 0.$$

It is supposed that the system periodic solution (2) in the neighborhood of the largest deflection moment from the equilibrium position and in the moment neighborhood when deflections amount zero varies according to the harmonic law having some phase delay:

$$\alpha = a \sin \omega t,\ \psi = p_0 \sin(\omega t + \varphi_\psi),$$
$$\theta = q_0 \sin(\omega t + \varphi_\theta),$$

where: a, p_0, q_0 – amplitude, ω – angular frequency of oscillations, $\varphi_\psi, \varphi_\theta$ – phase delay.

In typical instants of time phase variables and their generated variables possess the value:

$$\theta = q_0 \cos \varphi_\theta,$$
$$\dot{\theta} = -q_0 \omega \sin \varphi_\theta,$$
$$\ddot{\theta} = -q_0 \omega^2 \cos \varphi_\theta,$$
$$\omega t = \pi/2: \qquad \alpha = a,\ \dot{\alpha} = 0,\ \ddot{\alpha} = -a\omega^2,$$
$$\psi = p_0 \cos \varphi_\psi,$$
$$\dot{\psi} = -p_0 \omega \sin \varphi_\psi,$$
$$\ddot{\psi} = -p_0 \omega^2 \cos \varphi_\psi,$$
$$\omega t = 0: \qquad \alpha = 0,\ \dot{\alpha} = a\omega,\ \ddot{\alpha} = 0,$$
$$\psi = p_0 \sin \varphi_\psi,\ \dot{\psi} = p_0 \omega \cos \varphi_\psi,\ \ddot{\psi} = -p_0 \omega^2 \sin \varphi_\psi,$$
$$\theta = t_0 \sin \varphi_\theta,$$
$$\dot{\theta} = t_0 \omega \cos \varphi_\theta,$$
$$\ddot{\theta} = -t_0 \omega^2 \sin \varphi_\theta$$

substituting these correlations in the system (2), we'll get the system of six finite equations relative to the required parameters of oscillations (a, p_0, q_0, ω, φ_ψ, φ_θ).

After the elimination of unknowns $p_0, q_0, \varphi_\psi, \varphi_\theta$ from the first four equations of the system, two remaining equations are polynomials relative to the amplitude a and angular frequency ω. Composing their resultant (unknown angular frequency is eliminated ω), we'll get the implicit function determining the amplitude of oscillations according to design parameters of the system and traverse speed v.

Amplitude curves are given on the Fig. 2: a – slip force is approximated by the linear and cubic terms $Y(\alpha) = k\alpha - \frac{k^3\alpha^3}{2N^2\varphi^2}$, curve 1 takes into account aligning torque, curve 2 – its absence, b – slip force presents fractionally irrational dependence $Y(\alpha) = k\alpha(1 + k^2\alpha^2 / N^2\varphi^2)^{-1/2}$, curve 1 takes into account aligning torque, curve 2 – its absence.

Obtained at following numerical values of parameters: N=5000 H, k=42700 H, B=9,81 kg·m^2, h=37,3 H·m·s, h_1=981 H·m·s, χ=421100 H·m, χ_1=12160 H·m, C=165 kg·m^2, I_1=11,8 kg·m^2, r=0,4 m, l=0,85 m, ϕ=0,7, μ=0,3742771659, μ_2=71,4533726, μ_4=39122,6523.

Thereby, approximate approach of the slip force leads to the branch of unstable oscillations (Fig. 2, a), in case of slip force assignment in the form of fractionally irrational dependence the branch of unstable oscillations is absent (Fig. 2, b). Aligning torque impact causes either insignificant expansion of the unstable region (Fig. 2), or significant qualitative changes of the oscillation region according to the damping characteristics (Fig. 3).

Note. In general at the implementation of the oscillation analysis method (1), the introduction of an auxiliary differential equation (describing unstable wheel slip) can be avoided. The third system equation (1) enables to introduce formally redundant variable α, and two auxiliary finite equations occurring in this case $v \cdot q_{0S} + l \cdot q_{0C} \cdot \omega = 0$ and

$$v \cdot q_{0C} - l \cdot p_{0S} \cdot \omega = a \cdot v,$$

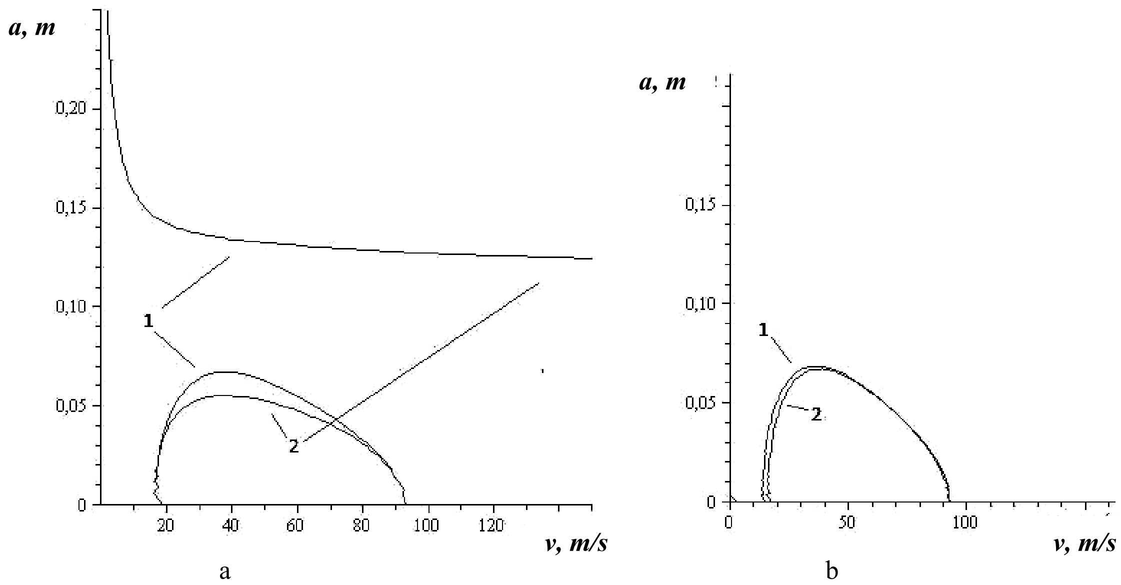

Fig. 2. Amplitude Curves

where:

$$q_{0S} = q_0 \sin(\varphi_\theta), p_{0C} = p_0 \cos(\varphi_\psi),$$
$$q_{0C} = q_0 \cos(\varphi_\theta), p_{0S} = p_0 \sin(\varphi_\psi),$$

ensure implementation of the following correlation for linear combination of two harmonics with similar frequencies (quad erat for this method implementation):

$$a \sin \omega t = q_0 \sin(\omega t + \varphi_\theta) + \frac{l}{v}\omega \cdot p_0 \cos(\omega t + \varphi_\psi),$$

as:

$$\mathrm{v} \cdot q_0 \sin(\omega t + \varphi_\theta) + l \cdot \omega \cdot p_0 \cos(\omega t + \varphi_\psi) = $$
$$= (v \cdot q_{0S} + l \cdot p_{0C} \cdot \omega) \cos(\omega t) +$$
$$+(v \cdot q_{0C} - l \cdot p_{0S} \cdot \omega) \sin(\omega t).$$

Suggested approach makes possible to determine onset regions of stable and unstable oscillations – a curve abutting upon the abscissa axis meets to stable oscillations but an interval cut by it on the axis of the longitudinal velocity meets to the region of oscillatory instability. It enables to analyze parallel the force system impact on the stability of linear system.

The consistency of obtained results has been confirmed on the basis of the Routh-Hurwitz criterion.

THE IMPACT OF THE FORCE STRUCTURE ON THE OSCILLATION AMPLITUDE (CASE WITH AN INCOMPLETE DISSIPATION)

Using the method examined above the following results have been obtained:
if $h_1=0$, then:

1. A damping increase on the rotational angle relative to the vertical leads to the decrease of the unstable region and oscillation intensity. The first part of deductions is coordinated with general theorems of the force structure impact. Thus the impact of the aligning torque reveals insignificantly.

2. An increase of the non-conservative positional forces parameter l (pillar height) leads to the increase of the unstable region according to the velocity and growth of the oscillation intensity (Fig.3, a: curve1 corresponds to l=0,85 m., curve 2 – l=1,1 m., curve 3 – l=0,6 m). It corresponds to deductions from general theorems of the force structure impact.

3. An increase of the wheel inertia moment leads to the decrease of the unstable region and oscillation amplitude.

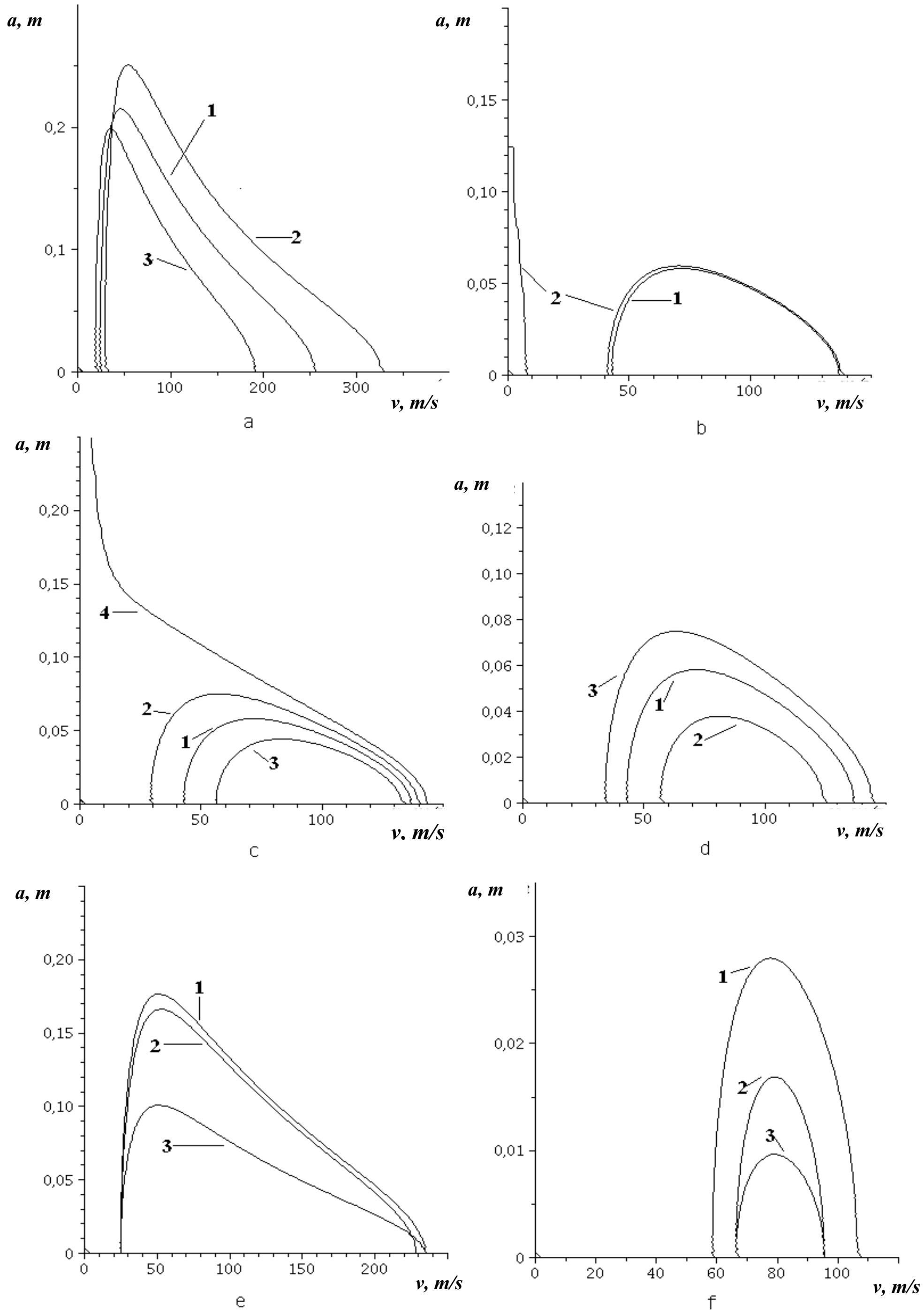

Fig. 3. Amplitude Curves

4. An impact of the relaxation parameter ($\sigma \neq 0$) – an increase σ leads to the decrease of the unstable region and oscillation amplitude (Fig. 3, d: curve 1 corresponds to σ=0,45, curve 2 – σ=0,5), a decrease of the traction coefficient leads also to the decrease of oscillation amplitude (Fig. 3, d: curve 1 corresponds to φ=0,7, curve 3 –φ=0,4).

If h=0, then:

1. An aligning torque impact is characterized in this case by an auxiliary oscillation region occurrence at slow speeds (up to 7,3 m/s), "main" oscillation region

(existed in the range of 42,7 m/s<v<136,7 m/s) doesn’t change here (Fig.3, b: a curve 1 corresponds to the absence of the aligning torque, a curve 2 – its availability).

2. An increase of the torsional stiffness (relative to the vertical axis) leads to the increase of the oscillatory instability region and oscillation amplitude. In general it doesn’t conflict with theorem points about force structure impact as in this case complete dissipation is absent. Oscillation region connected with the aligning torque availability doesn’t change practically but at sufficiently great values of the torsional stiffness it "is absorbed" by the oscillation region, determined by single side force (Fig. 3, в: curve 1 corresponds to χ_1=12160 H·m, curve 2 - χ_1=20160 H·m, curve 3 - χ_1=4160 H·m, curve 4 - χ_1=32160 H·m).

3. An increase of the torsional stiffness (relative to the longitudinal axis) leads to the decrease of the oscillation region and intensity. Oscillation region connected with the aligning torque availability doesn’t change practically. (Fig. 3, г: curve 1 corresponds to χ=421100 H·m, curve 2 - χ_1 =501100 H·m, curve 3 - χ =361100 H·m,).

4. A relaxation parameter change ($\sigma \neq 0$) leads to same results as in the point 4 (Fig. 3, f: curve 1 corresponds to σ=0,45, curve 2 – σ=0,5), the same impact as in the point 4 (Fig. 3, f: curve 1 corresponds to φ =0,7, curve 3 – φ =0,4) remains at variations of the traction coefficient.

CONCLUSIONS

1. In the work the method of approximate construction of amplitude curves in the task of the wobbling of the front non-steerable chassis pillar is developed – possibility of the redundant variable introduction for the method implementation is examined.

2. Force structure impact on the oscillatory instability region and oscillation characteristics is analyzed.

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ВЛИЯНИЕ СТРУКТУРЫ СИЛ НА УСТОЙЧИВОСТЬ КОЛЕСНОГО МОДУЛЯ И ПРОЦЕСС АВТОКОЛЕБАНИЙ

Александр Кравченко, Владимир Вербицкий, Валерий Хребет, Наталия Вельмагина

Аннотация. Анализируется устойчивость и автоколебания передней «неуправляемой» стойки, имеющей свободу поворота по двум каналам – рысканья и крена относительно продольной оси корпуса. Предложен подход приближенного анализа автоколебаний в нелинейной постановке, что дает возможность оценить устойчивость в «большом». Проведен анализ влияния характерных параметров системы на область колебательной неустойчивости и амплитуды автоколебаний (получено аналитическое выражение, связывающее амплитуду колебаний с параметрами модели: моментом инерции колеса относительно оси поворота, крутильной жесткостью рулевого управления, коэффициентом релаксации, величиной выноса и углом наклона стойки).

Ключевые слова: колесный модуль, шимми, структура сил, амплитуды автоколебаний.

Modeling of spindle for turret of the specialized tool type SF16MF3

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Summary. The considered procedure of the making the models spindle's nodes in CAD KOMPAS and complex study tense-deformed conditions of the tools product in module APM FEM.
Keywords: the spindle, 3D-model, equivalent stress, moving the section.

INTRODUCTION

The variety of the problems, solved under design modern metal cutting tools, use the different mathematical methods and toolboxes solid and parametric modeling does the necessary choice of the efficient systems computer aided design and algorithm of searching for of the optimum decisions in problem of the designing formative spindle's nodes of tools.

PUBLICATION AND METHOD ANALYSIS

The solving standard of rating to capacity to work and efficiency created designs of the spindle is stiffness. The study to stiffness spindle's nodes with use the methods solid modeling is dedicated to work [9,14,16,17]. The hollow sliding spindle multi-objective tool is considered on the base of the models IS1250, produced Ivanov plant heavy tool building. For this spindle characteristic of reduction to stiffness of the springy system tool, which typical of technological operation boring hole by sliding spindle. The reduction to stiffness causes and reduction to accuracy, which, possible partly compensate the account to systematic inaccuracy numeric program management facility. The Authors of the work [14] consider the problem of the qualification to regularities of the change to stiffness sliding two support spindles depending on lengths of the flight, which is a base to further numeric correction to velocities moving of feed presenting formative node. As base software programs are used package solid modeling Solid Works and integrated system of the analysis and calculation of the physical processes Cosmos Works. As full supports spindle's nodes were used radial and thrust bearings V7036E. T,P4S.DUL (180×280×46) of the company FAG. As a result of study's authors [14] have got the mathematical description to dependencies to stiffnessspindle's node tool IS1250 from position spindle of boring and have developed the algorithms to correcting the value of the presenting, which provide increasing to accuracy bored hole numeric program management facility.

Together with that on stiffness spindle's node, but, consequently, and on accuracy of the processing significant influence render the features a bearing in support, which are not presented in work [14]. So in mathematical model of stiffness and accuracy are used factors, reflecting type and design supports (including way of the creation preloading, its value and particularities of the mounting duplex support).

Alongside with criterion of stiffness in speediest spindle's head solving is a criterion vibration resistance and phenomena of the loss to stability. Such sort problem for rotating shaft, sending turning moment, is considered in work [1]. The Author values the moment of the loss to stability deformed and rotating shaft depending on axial power and turning moment. Using CAD SolidWorks Simulation [1-3, 22]. has allowed to get value of the critical load, give the estimation of conditional time, in which occurs sharp increase a moving the sections of the shaft and fix the respective interval of the angular velocities. Together with that influence of the features supports of shaft on behavior of the under investigation design in process loading is not considered. Scientist MGTU "STANKIN" and firm "ENIMS" is designed program complex SpinDyna (the version 2.3) [9], allowing modeling the designs an spindle's nodes on springy supports. In composition of the complex enter set of the modules: shaping to geometric model, tasks parameter of support and others modern interface is used in program in the manner of panels of the forms, at, the model of spindle's node includes the elements: span, joint, support and others. So element "Support" is intended for modeling bearing or their combination, but geometric sizes bearing and their stiffness are assigned manually or are chosen from database. Method initial parameter is used at building of the models dynamic of spindle in matrix production [17], founded on shaping the pass on matrixes separate area between initial and final elements. The particularity of this author's product is an account mechanism damping spindle in its support and joints with use stickiness and springy model on base of the analysis of the imaginary part to dynamic stiffness under investigation spindle's node. Together with that absence of the facilities solid modeling and toolbox of the method final element limits [13,15,24,25]. the area of the conducted studies. Appear and problems of the following join with the known integrated CAD in the course of decisions of the tasks design and technological preparation production.

OBJECTS AND PROBLEMS

The purpose given work is improvement process of modeling spindle's nodes metal cutting tool to account of the choice integrated toolbox CAD KOMPAS and APM WinMachine.

THE MAIN SECTION

As object of the designing is considered spindle's element for turret (revolver head) of specialized vertical milling-drill tool second standardsize models SF16MF3. The givenned tool is used in condition small series and production in batch series and is intended for multioperation processing product complex steel profile, cast iron, light and non-ferrous metals. On tool can be executed processing vertical, horizontal and inclined planes, shaped surfaces, hole, slot by different technological methods: milling, drilling, core-drilling and reaming [11]. The tool is the instrument equipped by device of the automatic change, which is realized by turn six-spindle revolver head (turret) in necessary position on program. Six-spindle revolver head presents itself cast-iron body, in radial bore which is fixing six-spindle of the elements. The choice of the instrument is realized by means of special cam, but rotate of the head is realized by means of rack gearing with use hydraulic motor [20, 21]. When working tool, moving part of revolver head is fixed by set of Belleville springs with constant effort 20580 N. For analysis of capacity to work design and choice optimum alternative design by author is created by 3D-model six-spindle revolver head (Fig.1) in CAD KOMPAS-3D [6-8, 12].

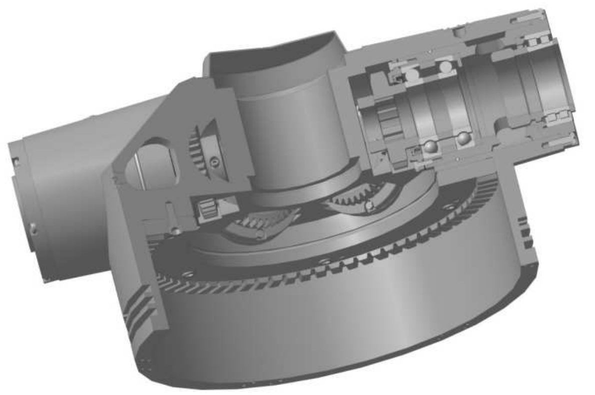


Fig. 1. 3D-model six-spindle revolver head

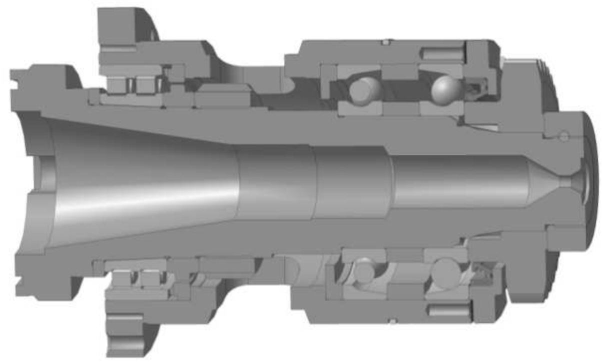


Fig. 2. 3D - model spindle's node tool SF16MF3

This system computer aided design, created by group of the companies ASKON, allows realizing technology collective end-to-end 3D-designing product different purpose. Whole spectrum of the necessary work can conduct with its help constructor from initial three-dimensional preparation of its ideas and detailed modeling of the final product before automatic creation of documentation and drawings. As from versions KOMPAS-3D V13 and above appears the possibility of the study stress-deformed conditions by means of integrated module APM FEM [18,19,23], as well as realize technological preparation production and preparation controlling programs for tool with NC.

The main formative spindle's element presents two-support design. In process of the study is built solid model spindle's element of the revolver head (Fig.2). In front support of the spindle is installed high accuracy radial and thrust double - rowroller bearing, which perceives radial and two-way axial loads and is characterized by possible radial load in 1,7 times above, than beside corresponding to single-in-line bearing [4, 5]. Except this, the support provides raised stiffness of design head. In back support are installed two-set radial and thrust bearing ball bearings, which perceive radial multifunction and double-sided axial loads that in turn allows to use them in moving support without fixing externally rings in axial direction. So their effectively use in elements with greater axial effort under for high frequency of the rotation.

At montage back support is chose X-arrange join radial-thrust ballbearing ("face" sides) with use preloading in the manner of distance sleeve to width miscellaneous. The regulation distance sleeve allows to reduce the surplus heating a support. Herewith follows to enlarge the width a distance sleeve between internal race of the bearing (change its) or reduce on value depth of grinding for width sleeve between externally race of bearing. In practice of tool building value depth of grinding depends on diameter hole of bearing. For internal diameter within the range of from 70 before 100 mm - a value depth of grindingis order 6 μm.

For building of design documentation spindle's node effectively to use the KOMPAS-Graphic - an universal system, which automatically generates the associative types of the three-dimensional models, which are associated with 3D - model spindle's node. At changes to models brings about change the graphic representation. The new possibilities are opened and for building of the constructive schemes spindle's nodes (Fig. 3), where spindle together with support create system a "spindle–supports". On base of the constructive schemes is formed several conclusion important with standpoint of the decision of the problems to stiffness and vibration two-support spindle's nodes on rolling bearing.

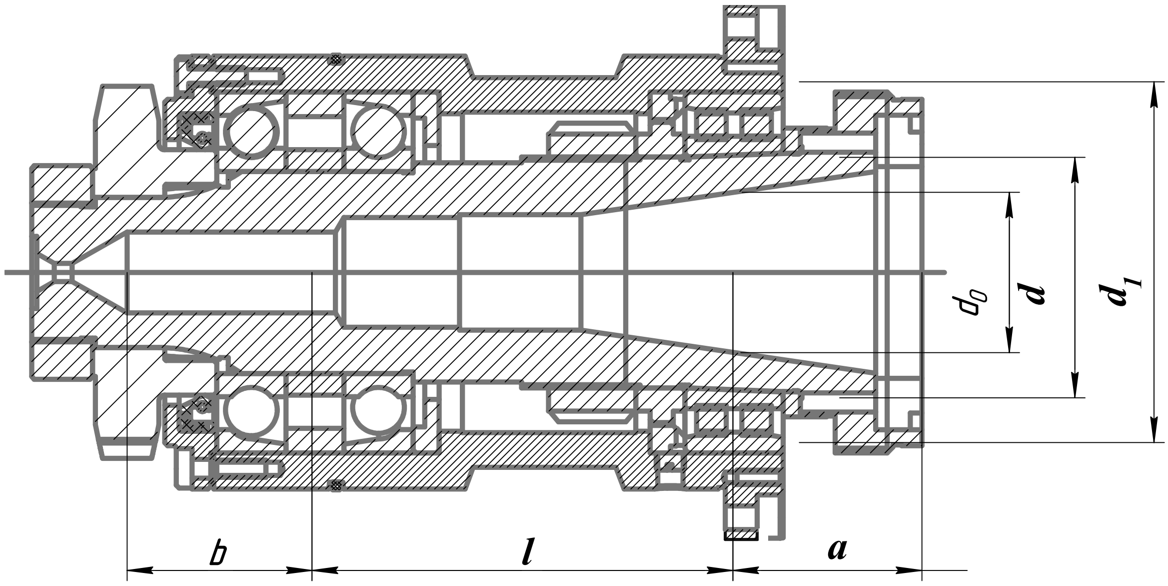


Fig. 3. Constructive scheme spindle's node

On the base constructive scheme (fig.3) is designed accounting scheme of the spindle as statically indeterminable beam, which is assembled on three supports (each bearing - a support), which possess linear and angular softness. The known more simple accounting scheme [2], in which two-set bearings on back support are changed by one support, and scheme becomes the two-support. Herewith ball bearings are considered as hinge springy support, factor to softness which is defined by amount contact deformation ball and race.

For calculation and designing the spindle of the free form under free nature loading and supporting is intended specialized module APM Shaft [23]. Specialized graphic facilities allow executing the procedure of preparing the initial data.

The module APM Shaft has specialized graphic editor for task of the geometries shaft and axles. The editor gives at the disposal of the user for facilities, providing:

- a task to designs of the shaft,
- an entering the loads, acting on shaft,
- a placement support, on which is mounted shaft.

When designing the shaft reasonable to use the main difference of the graphic editor APM Shaft from similar editor of the other systems, which consists in special set primitive, with which it handles. The Primitives APM Shaft - a main elements to designs of the shaft (cylindrical and cone-shaped area, chamfers, fillets, grooves, holes, area with thread, keys, spline), as well as loads, which can act on spindle.

Drawing the shaft included:

1. Draw cylindrical and cone-shaped area of the shaft.
2. Set the transition elements (chamfers, fillets, grooves).
3. Set the holes, area with thread, keys, spline of the join.
4. Enter attached to shaft of the load and place supports.

By means of editor APM Shaft possible to assign radial and axial concentrated power, distribution power, as well as moments of bending and torsions.

With use the toolbox of the module APM Shaft shall realize designing the spindle of the box of the velocities milling-drill-bore tool to models SF16MF3. The results of the calculation of the spindle in module APM Shaft systems "APM WinMachine" are submitted for Fig.4.

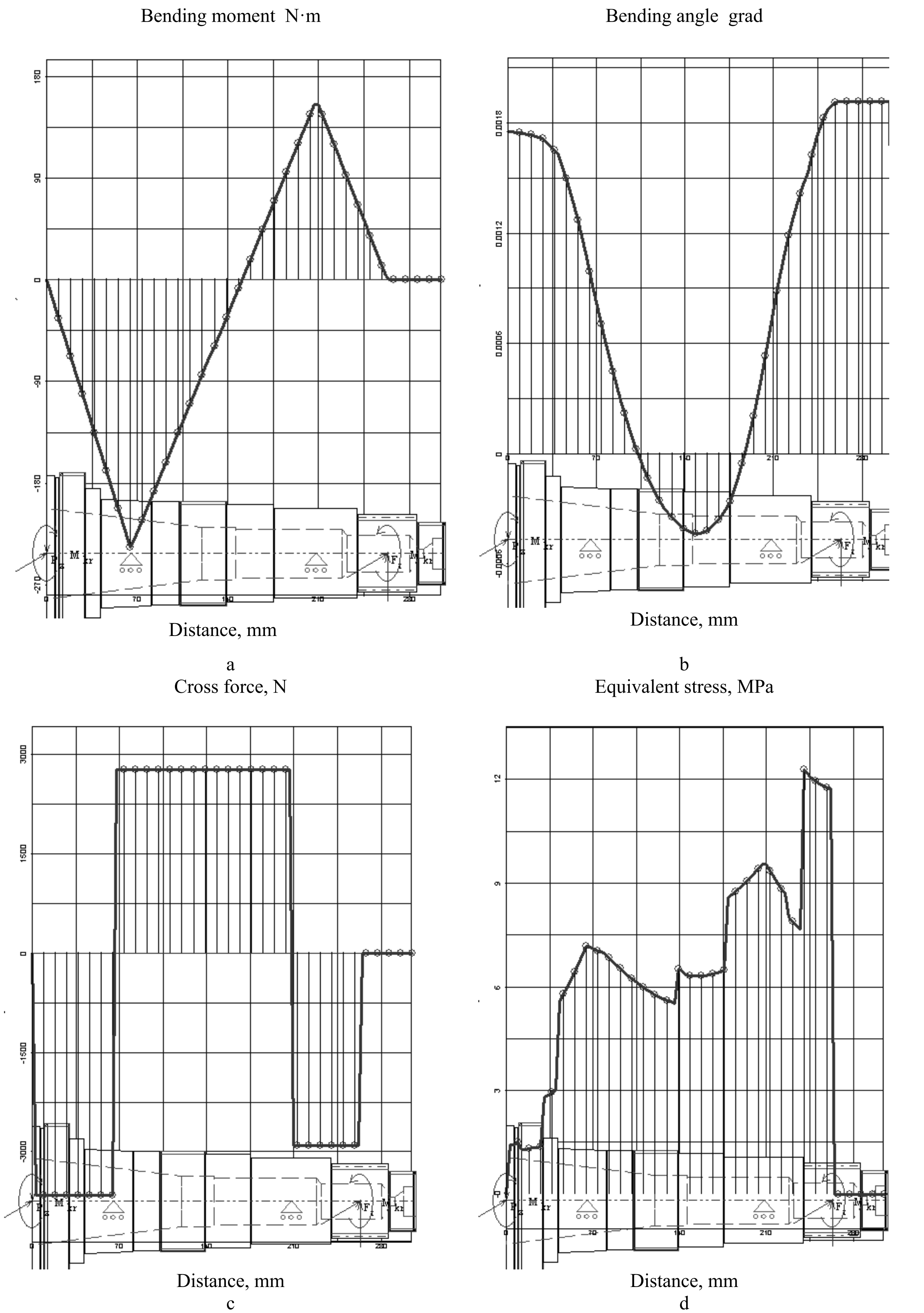


Fig. 4. Result of calculation for spindle in module APM Shaft: a – bending moment, b – bending angle, c – cross force, d –equivalent stress

When designing supports metal cutting tool on criteria of longevity is realized choice bearing from collection standard on dynamic load rating *C*. Specifics of the calculation bearing shaft and spindles tool consists in account of the additional load on bearing from preloading bearing and from functioning the node on raised frequency of the rotation. For majority bearing tool typical following conditions work: on spindle are found group driven gear and instrumental block. In current whole lifetime bearing of the spindle tool works under different velocity. Under each velocities of the spindle works one of the driven gear. Thereby, each of bearing of the spindle on different time lag work is found under the action of loads to variable value. The account variable mode is defined by value of the equivalent load under the most disadvantage from one of the driven gear and corresponding to condition of the cutting.

For two-set radial-stubborn bearing, installed on back support of the spindle of the revolver head in calculation is taken into account base static load rating C_0 equal duplicated value of static load rating of one bearing. In turn dynamic load rating C_r complete two-set (specially selected at the factory) radial-stubborn bearing on scheme X ("face-to-face arrangement") is taken as for one double-row bearing. Total dynamic load rating C_Σ the complete from two ball bearings take equal $1{,}62 \cdot C_r$.

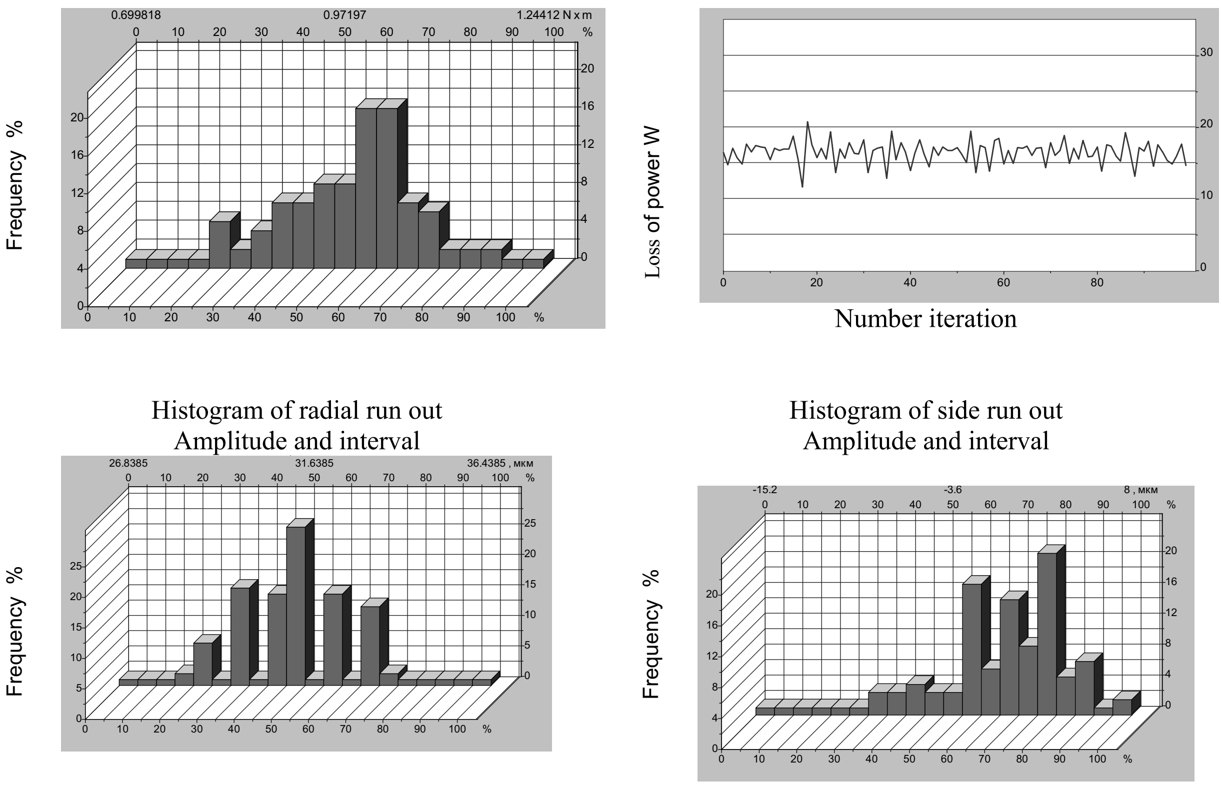
The bearings assembled on face-to-face arrangement, can have different preloading, as well as variable angular contact. In change from back-to-back arrangement this scheme is characterized by limited possibility to sustain the overturning moments. Hereupon limited support surface shortens the stiffness of the system and possible breach alignment.

For estimation of serviceability spindle's supports we use the module APM Bear, which executes the complex analysis of rolling bearing, executing calculation of the main features supports and provides the choice to optimum design bearing nodes. The particularity of this module is a presentation of the bearing in nonideal variant with provision for inaccuracy of the machining roller and raceway of the bearing. Exactly such consideration for many tasks of contact stiffness and contact stress characteristic. In APM Bear is executed whole complex of the checking calculations, when its output features estimate on the known geometry of the bearing. Are they herewith used original analytical and the numerical approaches, as well as methods of mathematical modeling that enables to present the results of the calculation these parameter and values their statistical diffusing in suitable for user type - a tables, graph, histograms.

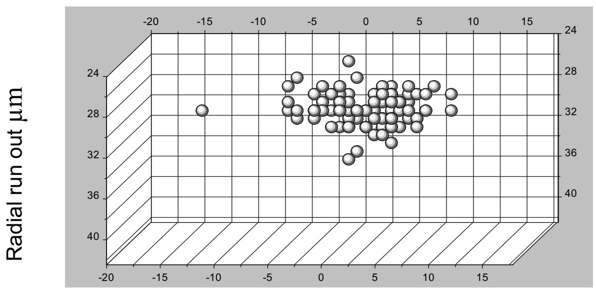
Complex calculation double-row roller bearing radial type 4 - 3182116 G0ST 7634-75, installed in front support of spindle is presented on fig.5.

For issue competitive tool it is not enough be limited by geometric modeling. Necessary undertaking the all-round engineering analysis of the designed object with use instrument CAE-analysis. To such toolbox appertain finite-element analysis APM FEM integrated with system of three-dimensional modeling KOMPAS-3D. APM FEM are a component part of united ambience of the designing and analysis with use the associative geometric model, united library material and the general with KOMPAS-3D interface To advantage of the module APM FEM pertains:

- an united interface, both for geometric, and for accounting model, which provides the simplicity and lightness of the work with library. All actions on creation 3D-models, preparation it to calculation and viewing result are realized in united window,
- a system FE-analysis works straight with geometric model (the kernel) KOMPAS-3D, and there is no need to in transmission of the files through outside formats that reduces probability an error,
- an acceptable price: APM FEM - an simple and inexpensive decision, which allows without acquisition "heavy" full functional CAE-systems to value strength an element to designs.



Field of run out
Side run out µm



Resume

Mean longevity	**2511**	**hour**
Contact stress max	**1285**	**MPa**
Heat release	**59628**	**J/h**
Dynamic load rating	**127831**	**N**
Radial run out	**31.478**	**µm**
Side run out	**0.216**	**µm**
Moment of friction	**0.989**	**N × m**
Loss of power	**16.564**	**W**

Fig. 5. Result of calculation for support in module APM Bear

The procedures of the calculation in module APM FEM are built on the basis of the method final element so in accounting model can be taken into account practically all particularities design and conditions to their usages.

The conditions of the operation to designs are realized by means of different types of the loads and fastening: uniformly distribution pressure to surface of the three-dimensional model, uniformly distribution power on face or rib, given in projection X, Y, Z global coordinate system, the loads, acting on the whole design as a whole - linear and angular speedup, the loads in the manner of uniformly distribution temperature to rib, surfaces and element.

The generation FE-nets is realized in automatic mode with using such parameter, as maximum length sides element, maximum factor of the thickening on surfaces and factor rarefaction in volume (Fig. 6) At choice of the size tetrahedron follows to use the recommendation: maximum length sides element must be approximately in 2…4 times thicknesses of the most thin detail less in assembly.

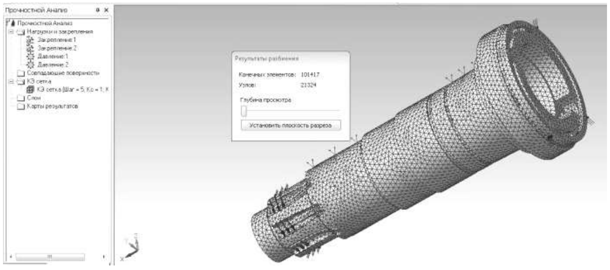


Fig. 6. Finite-element net in module APM FEM

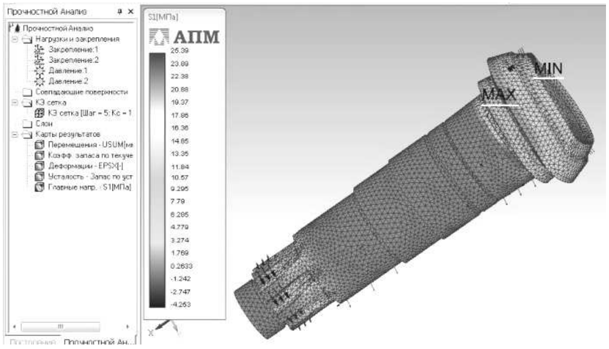
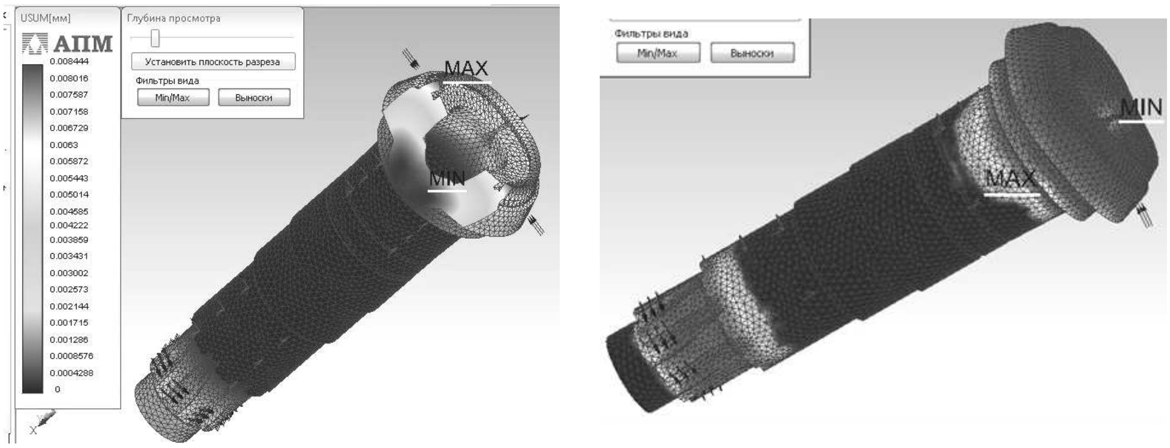


Fig. 7. Cards equivalent stresses



a b

Fig. 8. Result finite-element account: a – card of displacement, b – card of deformation

As result of the calculation available cards stress (Fig.7), displacement (Fig.8), safety factor on different criteria of strength, the temperature, own frequencies and the forms of the fluctuations. The cards of the stresses allow most exactly analyzing functioning the node under the action of loads, revealing the concentrators of the stress, value stiffness to designs.

The associative relationship is provided between geometric and accounting model. When contributing the changes to geometric model, the editing the fastening or loads it is enough whole only execute reconstructing the net and repeat the calculation. More possibilities opened parametric modeling work peace and nodes of tool [10]

CONCLUSIONS

1. Complex research to designs spindle's node specialized vertical milling-drill tool second standardsize models SF16MF3 with0020use geometric modeling CAD KOMPAS and engineering analysis of the designed object with use instrument CAE-analysis are realize.

2. 3D-model of the spindle's node in system KOMPAS-3D, giving real belief about designs this main formative node of tool is built.

3. All-round analysis tense-deformed conditions of the spindle's tool in module APM FEM method final element is executed. The fields of the equivalent stress and displacement in different sections of the designed object is built.

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МОДЕЛИРОВАНИЕ ШПИНДЕЛЯ РЕВОЛЬВЕРНОЙ ГОЛОВКИ СПЕЦИАЛИЗИРОВАННОГО СТАНКА МОДЕЛИ СФ16МФ3

Олег Кроль, Виталий Журавлев

Аннотация. Рассмотрена процедура создания модели шпиндельного узла в САПР КОМПАС и процедура проведения комплексного исследования напряженно-деформированного состояния проектируемого изделия в модуле APM FEM.

Ключевые слова: шпиндель, 3D-модель, эквивалентные напряжения, перемещение сечений

Stress-strain analysis of metal butt connection with composite propeller blade

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Summary. Modeling of stress-strain state of metal butt connection with cylinder composite propeller part has been considered based on Composite PrepPost module of ANSYS software. Relations between stress of composite connection and mounting arrangement of tenons butt have been obtained. Application of computer systems allows optimize construction choice has been shown.
Key words: propeller blade, physical-mechanical properties, polymer composite materials, finite element analysis.

INTRODUCTION

Progress aerospace technology over the past 10 ... 15 years led to a significant improvement in the most important parameter of aircraft - weight reduction while maintaining the strength and reliability. A significant role in these achievements is the creation of a fundamentally new structural materials - fiber composite materials that have such a high level of physical and mechanical properties that are virtually unattainable in conventional metal alloys and plastics, as well as the emergence of a number of computational *software* tools that allow for a design stage get all the design parameters of the future material. One such modern computational systems is a well-known software ANSYS. The use of this tandem has made it possible to create structures with desired properties that best suits the nature and working conditions [3-5, 7, 8].

OBJECTS AND PROBLEMS

Fiberglass blade is the main part which laid from fiber glass and connected with her butt made from metal. Preferred are permanent joints (welded, glued, etc.). They have a much smaller than the plug-in connectors, mass construction, less expensive, less time-consuming and have a shorter duration of production cycles. Therefore, the establishment of rational structures of compounds for various types of loading is the actual problem.

The aim is to develop a rational connection the metal butt with composite cylindrical portion of the blade on the basis of analyzing the characteristics of the local mode of deformation using ANSYS [11-14].

Fig. 1 shows the blade of the propeller plane of light aircraft.

To achieve this goal it is necessary to solve the following problems:

- creating a model compound in a medium ANSYS,

- definition of the rational design of compounds of metallic and composite butt (offset and the location of tenons).

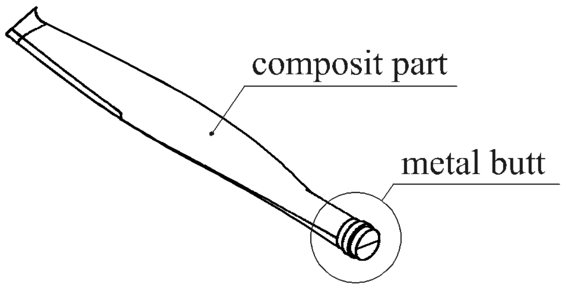

Fig. 1. The composite blade with a metal butt

For a simplified calculation of the strength of the connection is taken into account only the influence of the centrifugal force generated by the work of propeller. Is not taken into account bending and twisting the blade around its own axis of air flow. Centrifugal force is calculated based on the parameters and the operation of the blade shown in Table 1.

Table 1. The parameters of the blade

Parameter	Symbol	Value
Weight of composite blade, kg	m	1
Rotation diameter, m	D	1,8
The maximum allowable propeller revolutions, rpm	ω	3000

Find the centrifugal force acting on the operation of the compound:

$$F_c = m \cdot \omega^2 \cdot R_{cg} . \quad (1)$$

The radius of the center gravity of the blade is taken approximately 1/3 of the radius rotation of the blade:

$$R_{cg} = \frac{1}{3} \cdot \frac{D}{2} . \quad (2)$$

Taking into account the higher resulted parameters centrifugal force is numeral equal F_c = 750 N.

Butt is a tube which executed from duralumin. On one side of the butt machined protrusion for fixing it to the hub, on the other hand machined tenons for fastening the composite part of the blade. Butt scheme shown in Fig. 2.

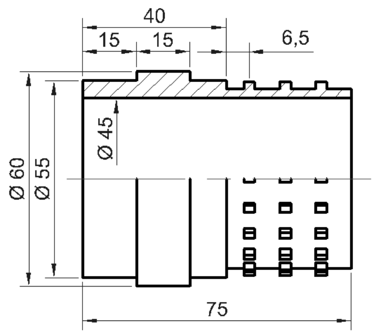

Fig. 2. Scheme butt

In the software package ANSYS produced static loading of the connection, which will allow to estimate the distribution of stresses in the joint. For this was created the model of butt (Fig. 3) and model compounds (Fig. 4) [9, 10].

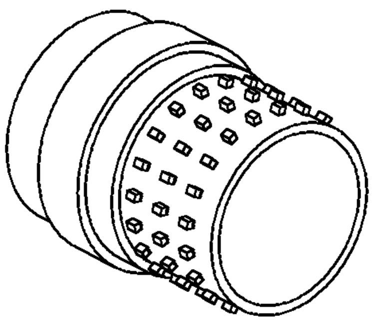

Fig. 3. Model butt

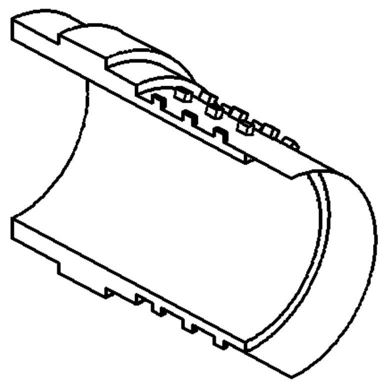

Fig. 4. Model compounds sectional

The composite of the blade in place with butt fixing is a composite package comprising a 4 woven layer impregnated with epoxy resin. All 4 layers are laid along the axis of the blade.

Details of the materials used in the calculation of the loaded state shown in Table 2 [1, 2, 6].

Table 2. Materials parameters

Element (material)	Modulus of elasticity, MPa	Poisson ratio
Butt (duralumin)	71000	0,33
Fiberglass blade (glass fiber fabrics)	45000	0,3

In order to test a compound finger-butt contact between the blade and the composite part is received with a friction coefficient of 0,3. The elements of this model are calculated on the tensile force generated by the rotating screw.

To determine the sound of spikes selected two varying parameter:

- the number of rows of tenons along the radius,
- the number zones of tenons.

Fig. 5 shows the arrangement of studs at the junction of the metal and composite.

The blade is fixed to the hub. For this purpose the projection butt prevent longitudinal and lateral movement of the blade. The scheme of loading and securing the connection is shown in Fig. 6 [15-17, 20].

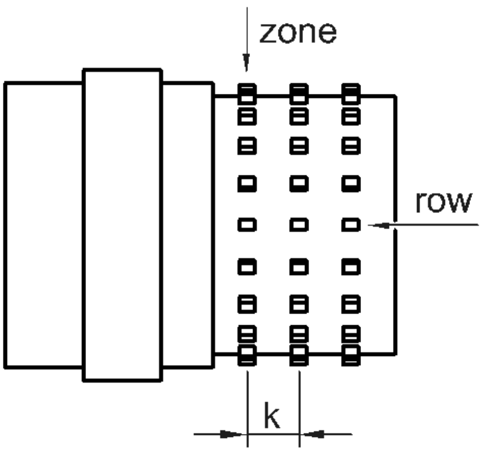

Fig. 5. Arrangement of tenons

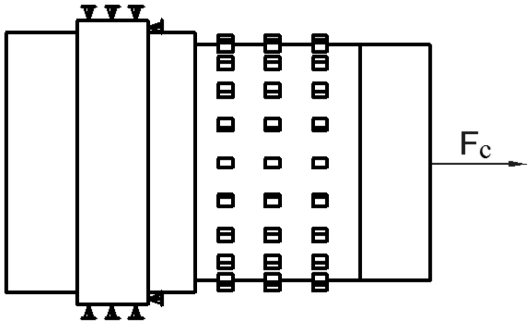

Fig. 6. Scheme of loading

Depending on the number of zones, changing the distance between zones shown in Table 3.

Table 3. Distance between zones

Number of zones	2	3	4
k, mm	15	10	8

To calculate the strength of the connections on the finite element method is used for this program was built automatically finite-element mesh shown in Fig. 7 [18, 19, 21, 22].

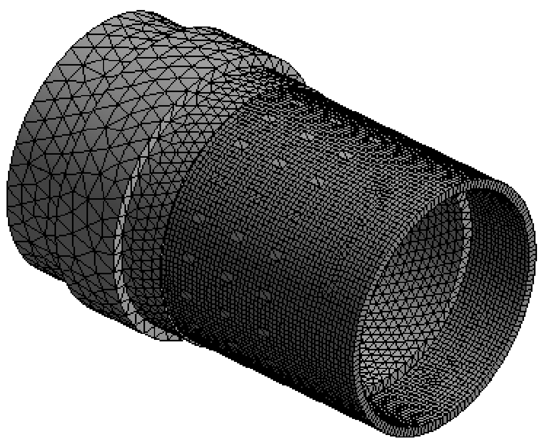

Fig. 7. Finite-element mesh connections

For clarity, depending on the nature distribution of equivalent stresses of the layout tenons, in Fig. 8 and 9 show the extremes of the layout tenons.

Table 4 displays the stresses arising under various schemes of tenons arrangement. Unit of measure stress – MPa.

Tabular data plotted in Fig. 10.

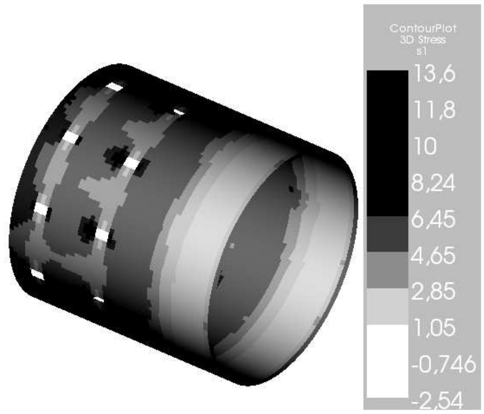

Fig. 8. Scheme: 2 zones, 10 rows

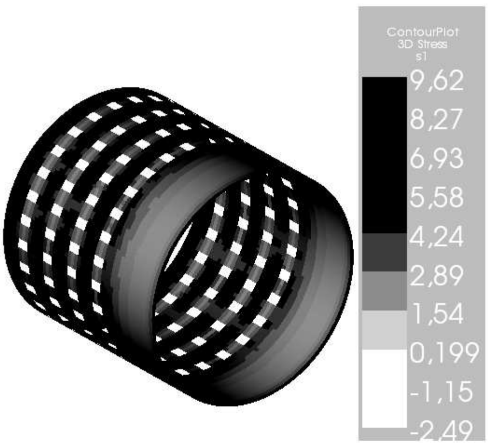

Fig. 9. Scheme: 4 zones, 30 rows

Table 4. The stresses arising under various schemes

Number of zones	Number of rows		
	10	20	30
2	13,6	9,3	9,2
3	12,2	9	9,3
4	11,2	8,9	9,6

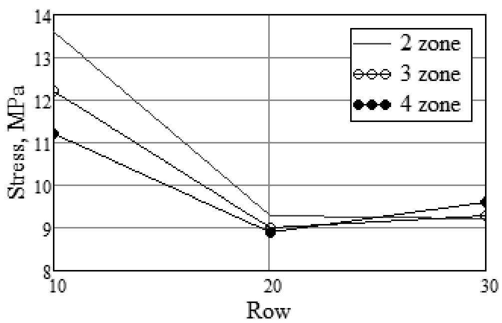

Fig. 10. Graph of the distribution stress, depending on the layout of thorns

The optimal mounting arrangement of tenons butt is an arrangement of 4 belts and 20 rows based on received results. However discrepancy between close result of 3 belts and 20 rows is up to 1.1% (mash error) but the first option of 4 belts and 20 rows is more expensive.

Hence, optimal mounting arrangement of tenons is arrangement of 3 belts and 20 rows. It may be inferred that a few mount of tenons doesn't secure uniform load distribution (Fig. 8) and vice versa a lot of tenons of first row restrict load transmission to other belts that are shown in figure 9.

There is divergence of results of numerical experiment and full-scale experiment due to difficult non-linear physics characteristics of materials.

CONCLUSIONS

1. The optimal mounting arrangement of tenons butt of 4 belts and 20 rows has been determined based on finite element analysis using ANSYS.

2. Engineering time has been reduced and consequently consumptions of constructions design have been decreased according to required strength characteristics.

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АНАЛИЗ ХАРАКТЕРИСТИК ЛОКАЛЬНОГО НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ СОЕДИНЕНИЯ МЕТАЛЛИЧЕСКОГО КОМЛЯ С КОМПОЗИТНОЙ ЛОПАСТЬЮ ВОЗДУШНОГО ВИНТА

Игорь Малков, Геннадий Сыровой, Игорь Непран

Аннотация. В статье рассмотрено моделирование напряженно деформированного состояния соединения металлического комля с композитной цилиндрической комлевой частью лопасти с применением специализированного программного приложения ANSYS и его модуля Composite PrepPost. Получены зависимости напряжения в композитной части соединения от схемы расположения шипов комля. Показано, применение современных вычислительных комплексов, позволяет оптимизировать выбор варианта конструкции.

Ключевые слова. лопасть воздушного винта, физико-механические свойства, полимерные композиционные материалы, метод конечных элементов.

Introformation model of the project evaluation

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Summary: A research aim consists in development and research of introformation model of evaluation, that is based on understanding of expert's (or expert system) work as a display of his attitude to a project, that is fixed as an integral entire mark. For this purpose interpretation of introformation model of expert's display for the task of the project evaluation is executed, theoretical analysis of introformation model of the project evaluation and a computer experiment are implemented. Methodological basis are methods of graphic and mathematical simulating, base points of evaluation theory, non-force interaction theory in fuzzy raising. It is shown that in introformation interpretation an integral entire mark of the project is the reflection of expert's attitude to the project as "motion" in direction "yes" or "no". Introformation evaluation indicators are: integral entire marks of the project - base absolute, conditional, final, definiteness and informness of expert, increase of definiteness and informness, calculated definiteness and informness. In proposed introformation model of the project evaluation there are entrance indicators: base absolute entire mark of the project and conditional entire marks of the project for all indexes on all criteria. It is educed that the change of values of conditional marks between themselves does not change a final mark. The change of absolute mark, on the contrary, substantially influences the change of the project final mark. Rational amount of indicators needed to be taken into account during the project evaluation should be not less than 5-6. As a base absolute entire mark of the project it is recommended to use a volume 0,5.

Key words: project, integral evaluation, expert, introformation indicators.

INTRODUCTION

In the practical activity related to the project/program/portfolio management a task of the project evaluation is very actual [20, 22, 32, 34]. It is confirmed by the following. In project management methodology there is an approach according to which management activity is making decisions activity [18, 25]. And every managerial decision, made during the project/program/portfolio life cycle, requires to applicate procedure of alternatives evaluation regardless of aim, scope and other context terms of decision-making. Exactly these terms determine the various types of managerial decisions on different classification signs [11, 18]. Thus constantly within the strategic managerial activity there is a necessity to evaluate the project on the whole or project as a portfolio or a program component [1, 6, 35].

Being the complex multidimensional phenomenon [9, 18], a project is a complex multidimensional integral object of evaluation. It is represented by heterogeneous components, including, components of intangible nature, between which there are nonlinear dependences. Such objects of evaluation are traditionally considered as formalized badly [2]. On this account it's common to apply expert methods and/or expert systems for the project evaluation. They are based on the different approaches to creation of decisions generating method, to organizing work of experts, to processing of expert evaluation results. Therefore the result of their application is characterized by the different degree of preciseness and reliability. Thus the always actual is point of cost of the decision got after their help that straight depends on algorithms' complication. And complication straight depends on that, as far as such algorithms are "distant" from natural mechanisms of personality thinking. Therefore a task to find the most rational approaches to the project evaluation, regardless way of their implementation in expert methods or expert systems, is still actual today. In addition, it's necessary also to take into account the level of development of information technologies that are used for evaluation [23].

BACKGROUND

At conceptual level an evaluation task is taken to the receipt of certain integral mark that integrally characterizes the degree of the project accordance to the set requirements [7, 14]. When evaluating great number of projects it gives an opportunity to get homogeneous marks, and on that ground to compare projects considering context of particular managerial decision that should be made.

Traditionally the approach to aggregate separate marks of many project components in an integral final mark is used for this purpose. The most widespread "branches" of such approach are statistical methods of generalization of marks (on the basis of calculation average or dispersion) [8, 24] and aggregating methods within the structural system analysis which use relative weight coefficients [19, 33]. The first approach provides that marks of separate project components are homogeneous and not necessarily form the one system, that categorically does not answer nature of the project as an integral complex object of evaluation. The second approach, being nonlinear, allows to take into account a sinergistical effect from the marks interaction, but as a certain hierarchy of elements of the system. But this conflicts with consideration of the project as a complex multidimensional integral object of evaluation. According to the conclusions of work [17], consideration of project as an integral object of evaluation provides, that marks of its separate components are organized in a hieratical network [16], but not hierarchy. Taking this into account, both approaches are is not acceptable enough to the project evaluation. However, exactly they are implemented as basis of many known expert methods and expert systems of evaluation that are used in managerial activity of different spheres.

There is an alternative to calculate the integral project mark on the basis of aggregating marks of of separate components. It is a theory of non-force interaction [27, 28]. Main points of this theory are based on supposition, that "in real nature there are only non-force interactions conditioned by informative reasons, and their laws are common to all matter organization levels (therefore can be used for social interaction in the project activity). Thus motion (display, activity) of any material formations is formed by their internal organization (by essence, content) - their introformation" [31]. Being based on "consideration laws of motion as informative processor of Nature", the theory author worked out system of models and methods of introformation change of for the natural and artificial intellectual systems in the processes of non-force interaction. The mathematical system of theory, presented in the probability raising, gives an opportunity integrally to take into account the cross-influence of heterogeneous factors with nonlinear intercommunications without aggregating them in an integral indicator.

From position of base categories and positions of this theory, the project evaluation is expedient to consider as a display of the expert's attitude to the project formed on the basis of perception information about different components of project, each of that it is possible to evaluate separately. It confirms possibility and expediency to applicate mathematical system of the non-force interaction theory for a task of the project evaluation.

However the task of evaluation the project components of intangible nature predetermines a necessity to use the system of fuzzy sets theory for this purpose. Besides a project itself is a unique phenomenon, that eliminates possibility of application for its evaluation the system of the non-force interaction theory in the probability raising. The same conclusions were got in work [10] during application of non-force interaction theory for the tasks of the valued-oriented management of the project stakeholders' interaction. Therefore by an author of [10] the introformation model in fuzzy raising was offered to reflect display of the project stakeholders' attitude to information percepted in processes of interaction. In paper [4] this model was applied to evaluate projects by the criterion of accordance to directions supported (financed) by an organization-donor. However for practical activity of the project/program/portfolio management the most actual task today is to develop a model of the project evaluation, which is universal and invariant to different criteria and indicators (as approach of [15]).

THE GOAL AND TASKS

Research aim is to work out and investigate an evaluation model, that is based on understanding of expert's (or expert system's) work as a display of his attitude to a project, that is fixed as an integral mark. As a source of forming such attitude is expert's introformation, that's why a model is expedient to name "introformation". Such integral entire mark should be formed on the basis of evaluation of compatible cross-influence of the project separate components marks, and here to be universal and invariant to the different criteria and indicators for different projects.

Coming from it, basic tasks of research are following:

1) interpretation of introformation model of the expert's display for the task of the project evaluation,

2) theoretical analysis of introformation model of the project evaluation.

METHODS

Theoretical basis of work is presented by base positions of evaluation theory, theory of non-force interaction in fuzzy raising, scientific researches in branches of evaluation, project/program/portfolio management. Methods of theoretical research - analysis and synthesis, simulating, including, graphic, mathematical, are applied for the first task. Computer experiment is conducted for the second task.

FINDINGS AND THEIR ANALYSIS

The mathematical system of the non-force interaction theory is based on probably behavior of the introformation system S that with probability p_0 realizes an action D_0 in ordinary (standard) for the system situation. Also probabilities p_i are known, with that the system realizes actions D_i at the change of terms $b_j \in B,\ j=\overline{1,n}$ [28]. By essence p_0 is absolute (without any condition) probability of action D_0, and p_i is conditional probability of action D_i at display of condition b_j. The display of introformation content of the system S is its "motion" in direction "yes" or "no" [28]. Therefore all conclusions of the theory are based on *Vip*-interpretation of this motion (where i is information, p is probability, V is speed) [31].

For the situation of the project evaluation the introformation system S is represented by an expert (or expert system), and his display ("motion" in direction "yes" or "no") is represented by an increase/reduction of integral entire mark of the project. Let's consider this situation more precisely.

Let an expert evaluates each project m from the set of projects M as integral universum, phenomenon of entire without the account of particular characteristics that describe this phenomenon in more details.

Such mark will name "base (absolute) entire mark of the project" and will present it as:

$$E_B^m = E(P_B)\,. \qquad (1)$$

Due to the further taking into account of the project particular characteristics a base entire mark is specified finally. Such mark will define as a "final entire mark of the project".

Let the project's particular characteristics be presented by the set of criteria L. Each criterion l from the set L can be characterized by different amount of indicators J_l. And determining the amount and range of such criteria and indicators is a separate task that is not examined in this research. But their amount and range always should be necessary and sufficient to present essence and the project evaluation as integrity.

Let's designate the project indicators as ${}_j^lP, j = 1, J_l, l = 1, L$. Then entire mark of the project as universum taking into account only this indicator will designate as:

$${}_j^lE^m = E(P_B / {}_j^lP)\,. \qquad (2)$$

Such mark will define as "conditional entire mark of the project". The amount of conditional entire marks of the project n is equal to amount of indicators that represent all criteria from the set L:

$$n = \sum_{l=1}^{L}\sum_{j=1}^{J_l} j_l\,. \qquad (3)$$

To determine the final entire mark of the project ${}^lE^m$ will use introformation models that are described in paper [4], but using denotations introduced above. Basing on general requirements to the project evaluation systems that are driven to work [5] will realize following calculation steps.

First step: calculation of definiteness ${}_j^ld^m$ according to a formula:

$${}_j^ld^m = \operatorname{sgn}\left({}_j^lE^m - \frac{1}{2}\right)\cdot\sqrt{\frac{\tilde{F} - {}_j^lE^m\left(1 - {}_j^lE^m\right)}{{}_j^lE^m\left(1 - {}_j^lE^m\right)}},$$

$$j = 1, J_l, l = 1, L, \qquad (4)$$

where: $\tilde{F}$ is a fuzzy number 0,25.

The indicator of definiteness ${}_j^ld^m$ in our task can be interpreted as an expert's confidence in relation to "force of motion" of a base entire mark of m-th project in direction of increase/reduction of this mark due to taking into account of j-th indicator of l-th criterion.

Second step: calculation of informness ${}_j^li^m$ according to a formula:

$${}_j^li^m = \sqrt{\left({}_j^ld^m\right)^2 + 4\tilde{F}}\,. \qquad (5)$$

Informness can be interpreted as an idea about the expert's confidence in relation to "motion" of base entire mark of m-th project in direction of increase/reduction by its value due to taking into account the information about j-th indicator.

On next two steps will calculate additional indicators - compatible increase of definiteness and increase of informness. By essence they reflect the phenomenon of "re-calculating" by an expert of his judgement about basic entire mark on the basis of information, that he got during independent step by step determination of conditional entire marks of the project from each separate indicator ${}_j^lE^m$. The phenomenon of "re-calculating" is a introformation component of mechanism of changing the activity by informed element (in our case – by expert) after perception of new information about the evaluation object (in our case – about the project).

The third step: calculation of compatible increase of definiteness ${}^l\Delta d^m$ according to a formula:

$${}^l\Delta d^m = i_B^m \sum_{j=1}^{J_l} {}_j^ld^m - d_B^m \sum_{j=1}^{J_l} {}_j^li^m\,. \qquad (6)$$

The indicator of compatible increase of definiteness is interpreted as integral confidence of expert about change of "force of motion" of base entire mark of the project in direction of its increase/reduction as a result of taking into account of all conditional entire marks ${}^{l}_{j}E^{m}$ on J_l indicators of l-th criterion.

The forth step: calculation of increase of informness ${}^{l}\Delta i^{m}$ as:

$$ {}^{l}\Delta i^{m} = \sqrt{({}^{l}\Delta d^{m})^{2} + 4\widetilde{F}} \,. \qquad (7)$$

Richly in content indicator of informness increase gives an idea about the size of change of expert's confidence about how base entire mark of the project "motions" in direction of increase/reduction of its value as a result of taking into account of all J_l indicators of l-th criterion.

The fifth step: calculation of recalculated definiteness ${}^{l}d^{m}$ according to a formula:

$$ {}^{l}d^{m} = {}^{l}\Delta d^{m} \cdot i_{B}^{m} + d_{B}^{m} \cdot {}^{l}\Delta i^{m} \,. \qquad (8)$$

By analogy with ${}^{l}_{j}d^{m}$, this indicator characterizes "re-calculated" confidence of expert about "force of motion" of the base entire mark of the m-th project in direction of its increase/reduction taking into account all conditional entire marks of the project ${}^{l}_{j}E^{m}$ on all indicators of l-th criterion.

The sixth step: calculation of the re-calculated informness ${}^{l}i^{m}$ as:

$$ {}^{l}i^{m} = \sqrt{({}^{l}d^{m})^{2} + 4\widetilde{F}} \,. \qquad (9)$$

The value of this indicator gives an idea about the "re-calculated" confidence of expert about "motion" of base entire mark of the project in direction of increase/reduction taking into account all conditional entire marks of the project ${}^{l}_{j}E^{m}$ on all indictors of l-th criterion.

The seventh step: calculation of final entire mark of the project taking into account all conditional entire marks of the project of l-th criterion according to a formula:

$$ {}^{l}E^{m} = 0{,}5 + \frac{{}^{l}d^{m}}{2 \cdot {}^{l}i^{m}} \,. \qquad (10)$$

As one can see, in proposed introformation model of the project evaluation there are entrance indicators - the base absolute entire mark of the project and conditional entire marks of the project for all n indexes from the set of L criteria. In the non-force interaction theory in fuzzy raising these marks are fuzzy numbers in a range 0 - 1. That's why, coming from essence of introformation model, it is necessary to determine the rational range of base absolute entire mark and conditional entire marks, and also rational amount of the project indicators, that should be taken into account during evaluation.

For today within the non-force interaction theory there are no researches related to the exposure laws of changing the introformation indicators, and also related to influence of different amount of conditions on the change of display of the system S in a possible range 0-1 [3, 13, 26, 29, 30]. It stipulated the necessity to realize computer experiment.

A variant was examined in an experiment, when the base entire mark of the project and two conditional marks are known. A choice exactly of three components is predefined by possibility to present the results of experiment graphically enough evidently. Each of components in experiment was examined on five levels. In terms of theory of experiment [12] changes took on rationed values -2,-1,0,+1,+2. That is why 125 calculations were done for all possible combinations of three marks (5^3).

These components were examined as fuzzy triangle numbers ${}_{i}\widetilde{p} = \{\mu_p(x)/x\}$, for which the core was $core({}_{i}\widetilde{p}) = {}_{i}x$, ${}_{i}x = \{0{,}1; 0{,}3; 0{,}5; 0{,}7; 0{,}9\}$, and infinite was calculated as: $\inf({}_{i}\widetilde{p}) = {}_{i}x - 0{,}05$; $\sup({}_{i}\widetilde{p}) + 0{,}05$.

The absolute entire mark of the project in experiment was designated as x_1, and conditional marks - as x_2 and x_3. Fuzzy number $\widetilde{F}$ was also set by fuzzy triangle number as: $core(\widetilde{F}) = 0{,}25$, $inf(\widetilde{F}) = 0{,}245$, $sup(\widetilde{F}) = 0{,}255$.

For making calculations the computer program which implements introphisical methods of non-force interaction theory [27, 28] in probability and fuzzy raising is worked out. The program is written with the object-oriented Java language. For fuzzy calculations alpha-level principle of membership functions generalization of fuzzy number was used as totality of clear numbers set of alpha-levels for the select finite set of values of membership - alpha. In experiment three levels were selected: 0, 0,5, 1. The program envisages translation of calculations in the environment of Excel. It gives opportunity to conduct additional calculations, build necessary graphic, diagrams if necessary.

Testing of the program was conducted on examples that is driven in [28]. Before to begin experiment a few variants were calculated for different values of absolute and conditional marks of the project (Table 1).

Table 1. Results of test experiment

№	X_1	X_2	X_3	Re-calculated definiteness	Re-calculated informness	Final mark
1	0,3	0,5	0,7	0,769	1,262	0,805
2	0,3	0,7	0,5	0,769	1,262	0,805
3	0,5	0,3	0,7	-0,001	1	0,500
4	0,5	0,7	0,3	-0,001	1	0,500
5	0,5	0,2	0,7	-0,31	1,047	0,353
6	0,5	0,2	0,8	0,008	1,001	0,504
7	0,5	0,3	0,8	0,318	1,05	0,652
8	0,7	0,3	0,5	-0,769	1,262	0,196
9	0,7	0,5	0,3	-0,769	1,262	0,196
10	0,5	0,1	0,9	0,019	1,001	0,51

As evidently from the table 1, the change of values of conditional marks between themselves does not change a final mark, recalculated definiteness and informness (lines 1-6). And the change of base absolute mark substantially influences a final mark. It is confirmed by symmetry of introformation indicators' values in relation to a diagonal plane that passes through a vertical axis and diagonal 0 - 1 of horizontal plane x_2-x_3 (Fig. 1).

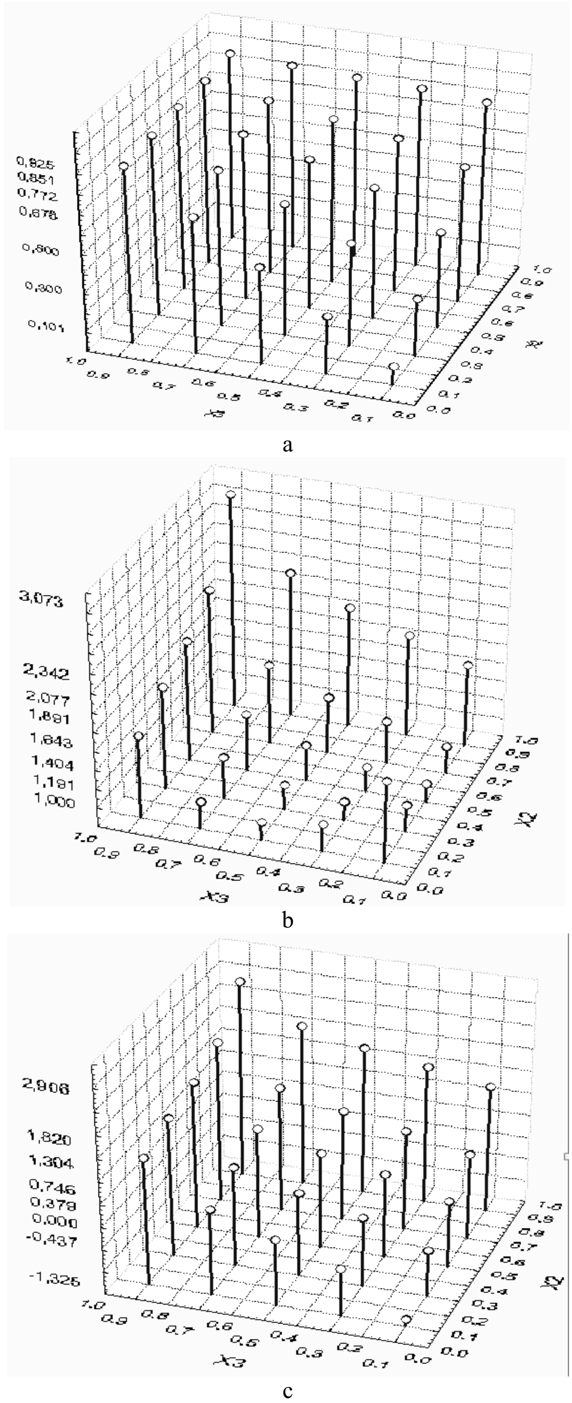


Fig. 1. Graphic presentation of test experiment results a final mark, b recalculated informness, c recalculated definiteness

Therefore in further results of calculations were presented as charts on a plane. It gives an opportunity evidently to see laws of changes between indicators. Thus it will be enough to consider one variant of fixing of conditional mark, for example x_2 at the change of conditional mark x_3.

Results of test experiment allow to pass to more detailed research of task to determine the rational amount of indicators of the project, that should be taken into account during evaluation. For this purpose by means of the program will conduct the calculation of change of final entire mark of the project depending on amount and values of conditional entire marks of the project.

For the absolute entire mark of the project will take value $E_B = 0{,}7$. Thus will examine variants, when conditional marks have an identical value, and their amount changes only. On Fig. 2 we brought results of such calculations.

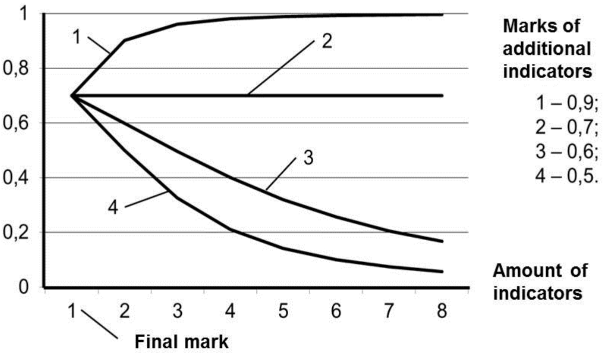


Fig. 2. A chart of change of the project final mark depending on amount and values of conditional marks

As one can see, at the change of conditional marks of the project from 0,5 to 0,9 range a final entire mark is situated in that intensively broadens at the amount of indicators of the project from 1 to 4. It is confirmed by the calculation of increase of change distance (Table 2). Introduction of additional 5th index extends a change distance on 5,2%, and 6th and 7th - on 3% and 2% accordingly. At reduction of low bound of conditional marks from 0,5 to 0,1 5%-th increase of distance expansion comes already at the amount of indicators - 3.

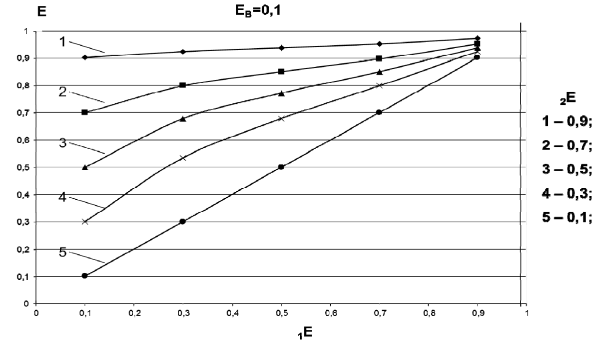
Table 2. Increase of change distance of the project final mark

$E_B = 0{,}7$	Amount of the project indicators						
$E_j^i = 0{,}5 - 0{,}9$	1	2	3	4	5	6	7
Increase of change distance, %	100	36,9	17,5	9,1	5,2	3,0	2,0

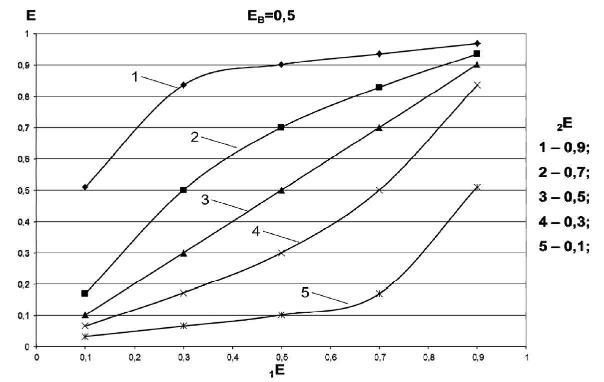
Calculations showed that change of basic absolute mark of the project value to 0,5 does not influence the character of expansion of the final mark location zone. It grounds to assert that a rational amount of indicators, needed to be taken into account during the project evaluation, should be not less than 5-6. Reduction of this amount will result in reduction of range, where values of final mark of the project will be situated. And this in turn will lead to reduction of difference between project marks that only complicates their comparison during further selection (for example, to the project portfolio).

For finding the rational value of range of absolute mark of the project will calculate change of final entire mark of the project depending on values of base entire mark and conditional entire marks of the project. For comfort of graphic presentation of calculation results let execute it for two indicators of the project. Thus will consider a range of change both base and conditional marks of the project from 0,1 to 0,9. On Fig. 3 results of such calculations are presented.

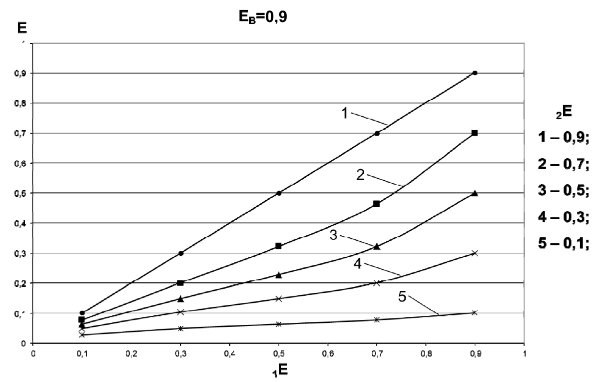
As one can see, at the maximum values of base absolute entire marks of the project $E_B = 0{,}1$ and $E_B = 0{,}9$ all values of final entire mark are located or higher ($E_B = 0{,}9$, Fig. 3a), or below ($E_B = 0{,}1$, Fig. 3c) to the diagonal that passes through points 0,1;0,1 and 0,9;0,9. Such character of dependence change on absolute values of conditional entire marks of the project does not allow on all range of their change to get the identical sensitiveness of calculation of final entire mark. Dependence changes of final entire mark of the project respond to such request, if the value of base absolute entire mark equals 0,5 (Fig. 3b). Exactly this is a base to recommend as a base absolute entire mark of the project to use a value $E_B = 0{,}5$.



a



b



c

Fig. 3. Chart of change of the project final mark depending on value of absolute and conditional marks a for base mark 0,1, b for base mark 0,5, c for base mark 0,9

CONCLUSIONS

1. Introformation interpretation of evaluation allows to consider it as a display of the expert's attitude to a project. This display is fixed as increase/reduction of integral entire mark of the project ("motion" in direction "yes" or "no").

2. Introformation evaluation indicators are: base absolute entire mark of the project E_B^m, conditional entire marks of the project ${}_j^l E^m$, final entire mark of the project ${}^l E^m$, definiteness of expert ${}_j^l d^m$, informness of expert ${}_j^l i^m$, compatible increase of definiteness ${}^l\Delta d^m$, increase of informness ${}^l\Delta i^m$, re-calculated definiteness ${}^l d^m$, re-calculated informness ${}^l i^m$. In generated introformation model of the project evaluation entrance indicators are the base absolute entire mark and conditional entire marks of project for all *n* indexes from the set *L* of criteria.

3. The change of conditional marks values between themselves does not change a final mark, recalculated definiteness and informness. And the change of base absolute mark substantially influences the change of final mark of project.

4. Rational amount of indicators needed to be taken into account during the project evaluation should be not less than 5-6.

5. As a base absolute entire mark of the project it is recommended to use a volume $E_B = 0{,}5$.

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ИНТРОФОРМАЦИОННАЯ МОДЕЛЬ ОЦЕНИВАНИЯ ПРОЕКТОВ

Елена Медведева, Алена Евдокимова

Аннотация. В статье разработана и исследована модель оценивания проектов, которая базируется на базовых категориях и положениях теории несилового взаимодействия в нечеткой постановке. Работа эксперта интерпретируется как интроформационное проявление его отношения к проекту как к целостному явлению. Интегральная целостная оценка проекта формируется на основании определения взаимного влияния оценок отдельных компонентов проекта, является универсальной и инвариантной к разным критериям и показателям разных проектов.

Ключевые слова: проект, целостное оценивание, эксперт, интроформационные показатели.

Research of friction indices influence on the freight car dynamics

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S u m m a r y . The work is devoted to study of friction indices influence in the "body – bogie" system in freight cars (the change of the friction coefficient in the side bearers during operation) on their basic indices – the coefficients of the horizontal and vertical dynamics, vehicle body acceleration, frame strength, and derailment stability coefficient. The study was conducted by mathematical modeling of the freight car dynamic loading using the software package «DYNRAIL». The focus was mainly concentrated on the influence of the friction force change between the body and bogies. Theoretical studies of dynamic loading of the freight open cars were conducted in both the empty and loaded conditions with the bogies model 18–100 during motion in the tangent and curved railway sections with different radii and the established motion speeds. In this case, the basic dynamic parameters of the freight car were calculated. The theoretical research results in determination of freight car dynamic indices taking into consideration the friction coefficients in the system "body – bogie" allow for an adequate assessment of the friction coefficient between the freight car bearers parameters, on the railway traffic safety factors (coefficients of dynamics, vehicle body acceleration, frame strength and derailment stability coefficient).

K e y w o r d s . Freight cars, bearers, dynamic parameters.

INTRODUCTION

The railway transport in developed countries plays an important role in social and economic life of the country and carries out the large containment of transportation activities [3, 4, 7].

This motivates the transport industry to move towards innovation changes and increase its significance as an important transit subsystem on the way of renovation of both the infrastructure and the strategy of all transportation process components including the interaction with other transport modes [15, 18].

First of all the basic areas of the railway industry activity are the following:

– development of the high-speed train traffic,

– improvement of the road safety,

– development of new rolling stock and modernization of the existing fleet.

PROBLEM DEFINITION

According to the previous publications [6, 11], the researches of freight car dynamics is a complex theoretical problem. Its purpose is the definition of permissible and safe speeds in terms of interaction between wheels and rails.

Due to the urgency of this subject one should cope with the task to study the effects of various factors and characteristics of technical conditions of the freight cars running gears (which are unavoidable to arise during operation) on their basic dynamic indices. Among these factors the system "body – bogie" plays an important role. This paper focuses on the impact of the friction force changes between the body and bogies [24, 25].

Theoretical studies were conducted by the mathematical modeling of dynamic loading of the open car in both the empty and loaded conditions with the bogies TsNII-Kh3 (model 18 – 100) during motion in the tangent and curved railway sections with different radii and the established motion speeds. In this case, the basic dynamic parameters of the freight car were calculated [2, 9].

Mathematical modeling of the freight car dynamic loading was carried out using the software package «Dynamics of Rail Vehicles» («DYNRAIL») [15, 16, 17] developed in Dniepropetrovsk National University of Railway Transport named after Academician V. Lazaryan.

THEORETICAL BACKGROUND

The first studies on sliding friction were conducted by Kulon and were repeated by Moren [1, 26]. The founder of the theory of friction with lubrication is a scientist M. Petrov. Further the theory was developed in the writings of M. Zhukovsky and other researchers.

As we know, there are two cases of sliding friction:

1) friction at rest and, in particular, the friction at the start of motion,

2) friction in motion.

When the system is in equilibrium state, the pressure of horizontal surface on the element has a resultant *N*, normal to the surface, which is equal and opposite to the weight P of the body with the weight (Fig. 1, a).

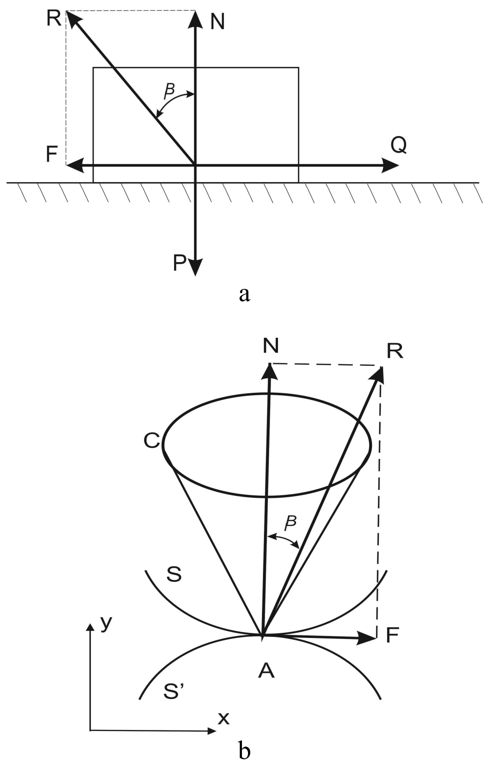


Fig. 1. Schematic illustration of the forces between bodies including friction: a – at rest, b – with one contact point – friction cone

The reaction of surface *R* on the body is equal and opposite to the resultant of weight *P* and the applied horizontal force *Q*. This reaction is decomposed into two parts: the normal *N*, equal and directly opposite to the force *P* and the tangential *F*, which is equal and opposite to the force *Q*. Tangential component is the force of friction. For the angle *β* between the reaction *R* and the normal *N* we have:

$$tg\beta = \frac{F}{N} = \frac{Q}{P}. \qquad (1)$$

If one gradually increases the *Q*, then there is a moment when the force reaches the value F_p, at which body is put into motion. The corresponding numerical value F_p of the force *F* is called the friction at the start of motion. The corresponding value φ of the angle β for which:

$$tg\varphi = \frac{F_p}{P}, \qquad (2)$$

is the angle of friction.

Sliding starts from the moment when the resultant of forces *P* and *Q*, applied to the body, makes an angle with normal that exceeds φ.

Kulon measured the values F_p and φ during the experiment, on the results of which he deduced three laws [1, 26]:

1. Friction at the start of motion does not depend on the area of surfaces that are in contact.
2. It depends on the nature of these surfaces.
3. It is proportional to the normal component of the reaction, or the normal component of the pressure.

Constant correlation of the friction force F_p at the start of the motion to the normal reaction *N*, or to the normal pressure *P*, is the friction coefficient *f*:

$$f = \frac{F_p}{N} = \frac{F_p}{P}. \qquad (3)$$

The angle of friction φ is determined by the formula:

$$tg\varphi = f. \qquad (4)$$

In practice, equilibrium of bodies with friction at one contact point is the prevalent case. In this case it is considered the body *S* (Fig. 1, b) laid on another body *S′* with which it has a contact on the very small part of the surface [1, 26]. It is assumed that the latter reduced to one point A. The reaction *R* of the body *S′* on the body *S* is the normal reaction *N* and the tangent reaction *F*, the direction of which is unknown and the maximum is equal to $f \cdot N$. The angle β between *R* and *N* will be less than the friction angle φ. In order to bring the body *S* to equilibrium, a balance between the forces applied directly to the body *S* and the reaction *R* is necessary, or the forces applied to the body should have a resultant equal and directly opposite to the force *R*, that is:

a) passing through the point *A*,

b) directed in the way to press the body *S* to the body *S′*,

c) making an angle with the normal *AN*, which is less than the angle of friction.

These necessary demands are sufficient and if they are met, it is possible to assume that the resultant of the applied forces is moved directly to the point *A* and is decomposed into two forces: the normal force *P* and the tangent force *Q*. Under the influence of these forces the sliding is absent, as the angle of the resultant with the normal is less than φ, therefore (Fig. 2, b):

$$\frac{Q}{P} < f, \;\; Q < f \cdot P, \qquad (5)$$

and the tangential component is less than the friction at the start of the motion. If the cone of revolution with the axis *AN*, which makes an angle φ with *AN* is considered, then to put it to equilibrium it is necessary and sufficient the forces had the resultant, the direction of which passes through the points *A* and *C*, lying in the middle of the cone.

From the previous considerations one can conclude that any applied to the body force, which passes through the point *A* and makes an angle with the normal, less than φ, i.e. the force lying in the middle of the cone *C* is balanced by the reaction of the body, since this force can be decomposed as we described above.

To calculate the angle of friction let us set up a static equations, from which we obtained:

$$R_1 = R \cdot \cos\beta = N, \qquad (6)$$

$$R_2 = R \cdot \sin\beta = F_{sr} \le F_{sr}^{\lim} \le N \cdot f = \cos\beta, \qquad (7)$$

where: R_1, R_2 are the components R.

After performing the arithmetic operations we can see that:

$$R \cdot \sin\beta \le R \cdot f \cdot \cos\beta , \quad (8)$$

$$tg\beta \le \beta . \quad (9)$$

Friction angle – is the force angle with *N*, the tangent of which is equal to the coefficient of friction:

$$tg\phi_{sr} = f ,\ \beta \le \phi_{sr} . \quad (10)$$

Coefficient of friction *f* – is a dimensionless quantity, it is determined empirically and depends on the material of the contacting bodies and surfaces (character of treatment, temperature, humidity, etc.).

The coefficient of friction f_0 for some materials:

– wood friction 0,4 – 0,7,

– metal friction 0,15 – 0,25,

– steel on ice friction – 0,027.

In the case of motion, it is assumed that it is moving the solid body, limited by some surface and contacting with another body in the point. If there is a friction, the reaction of one body on the second is decomposed into two forces: the normal *N*, which is called a normal reaction, and tangent *F*, which is the force of friction and is subject to the following three laws:

1. The friction force is directed to the side opposite to the relative velocity of the material pointing relation to the body surface.
2. It does not depend on the velocity magnitude.
3. It is proportional to the normal reaction: $F = f \cdot N$, coefficient f is the friction coefficient at the start of the motion.

According to Hertz's experiments, these laws can be applied mainly in the case of direct friction (i.e., when the friction surfaces are dry). They should be changed if the surfaces have lubricants. In this case the ratio F/N depends on the speed and the force N [26]. During engineering calculations one usually comes from the number of empirically established laws that with the sufficient accuracy reflect the basic features of the friction phenomenon.

Dynamic coefficient of the sliding friction f is also the dimensionless quantity and is determined empirically. The coefficient value depends not only on the material and condition of the surfaces, but also, to some extent, on the speed of moving bodies. In most cases, when the velocity increases, the coefficient f initially decreases and then keeps almost a constant value [19].

MAIN PART

Establishment of admissible car speeds in tangent and curved track sections is a challenging engineering task that requires a differentiated approach and takes into account the technical condition of the track superstructure (TS) and the running gears of the rolling stock [8, 12]. Permissible speeds were determined at the results of comparison of the obtained dynamic parameters with the permissible values according to the "Standards" [10].

Among all the friction pairs in determining the dynamic loading of the freight cars the friction in the system "body – bogie" is one of the dominants. It is the study of the system in connection with the technical condition of the freight cars running gears and determination of their basic dynamic parameters this research is dedicated to [20, 21, 22, 23].

The bearing connection of the body and bogies is the most important subsystem of the freight car. Dynamic and other technical and economic characteristics of the car depend on the correct choice of structural schemes and parameters of this subsystem. The car body oscillates during the motion and makes angular rotations relative to the vertical, longitudinal and transverse axes. The main bearing connection of the body and bogie is center plate – center bowl, in which is realized the friction torque, preventing rotation of the bogie around the vertical axis, as well as frictional forces, preventing movement along the longitudinal axis of the body and along the transverse axis [13].

The main functional purpose of the body bearers and the bolster is to prevent excessive swaging of the body center bowl of the bogie and to reduce the wabbling. In this moment the friction in the bearing connection center plate – center bowl – bearers should not exceed certain values in order to avoid the excessive impact on the track, wheel sets and axle box truck [27, 28].

RESULTS OF RESEARCHES

In the study of the friction influence on the dynamic loading of the car several consitions considered:

– the normal condition, at which the damping factor is taken as 1,

– the condition of the low friction, which arises in the bogie construction when the gib is higher as compared to the normal condition, in that case the coefficient φ is taken as 0,2 or 0,5,

– overdamped condition of the system, at which the coefficient φ is taken as 1,5,

– full absence of the friction in the system, at which the coefficient φ is taken as 0.

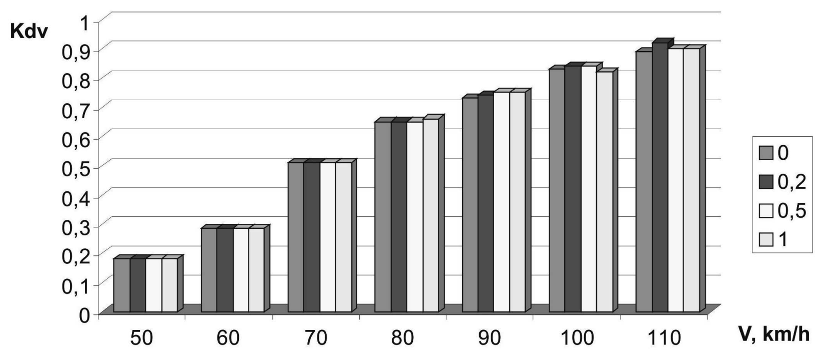
As a result of the calculations the dependency diagrams of the basic dynamic parameters were constructed (Fig. 2):

– coefficients of the vertical and horizontal dynamics,

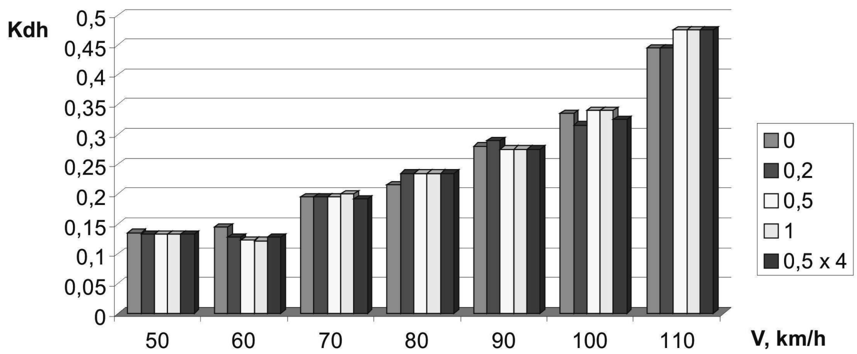
– frame strength,

– coefficient of resistance,

– horizontal and vertical acceleration of the four–axle freight open car body, taking into account the speed of motion from the friction coefficient of in the system "body – bogie".



a



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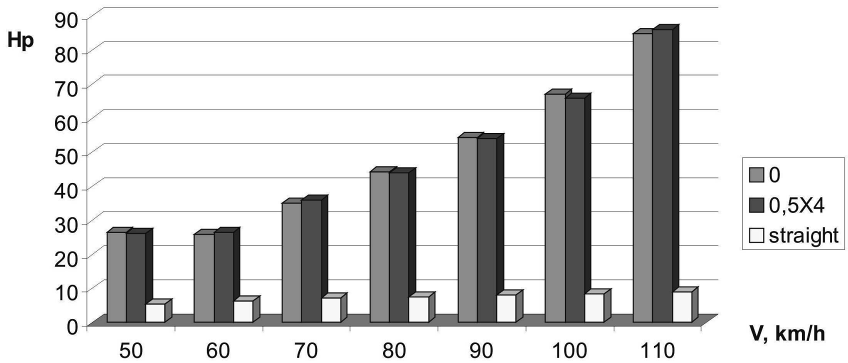

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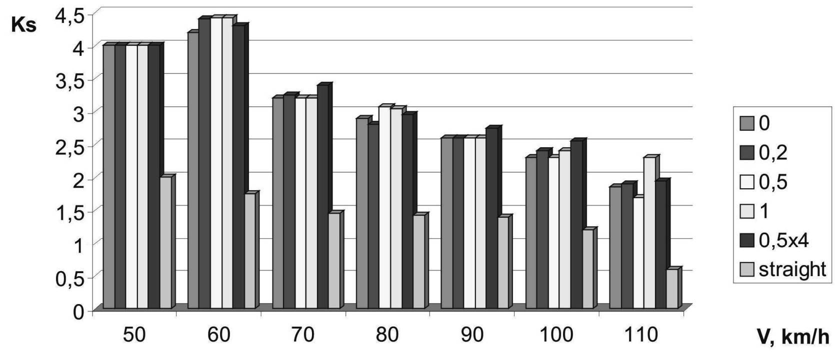

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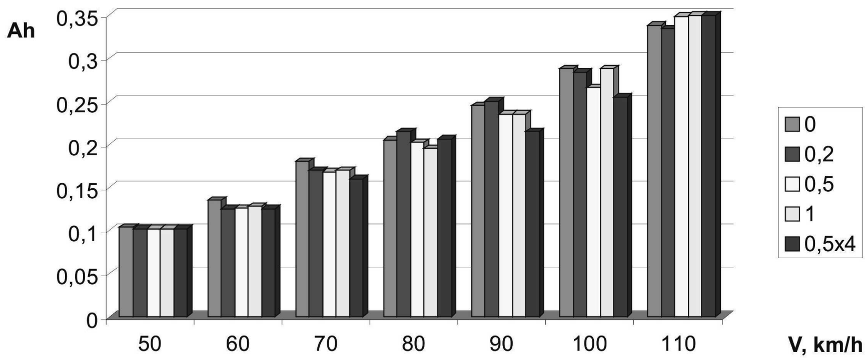
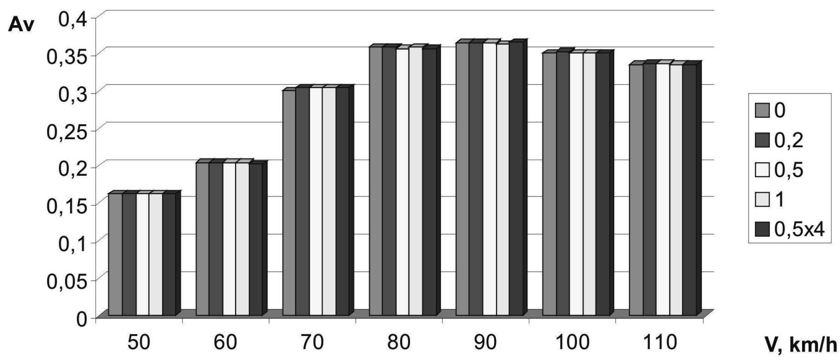


e



f

Fig. 2. Change diagram of dynamic performance from the motion speed:

a – the coefficient of vertical dynamics, b – the coefficient of horizontal dynamics, c – frame strength, d – stability coefficient, e – horizontal acceleration of the body, f – vertical acceleration of the body

From the resulted diagrams one can see that the basic dynamic performance of the four–axle freight open car is not significantly depends on the friction coefficient and at the motion speed up to 100 km/h within the allowable values, corresponding to the "Standards" [10].

The theoretical calculations allow concluding that the friction in the bearing connection center plate–center bowl–bearer of the freight open car in empty and loaded conditions with the bogies TsNII–Kh3 (model 18 – 100) doesn't have a significant impact on the road safety performance. It is the radii of the curved track sections and the outer rails height, etc influence the road safety performance.

CONCLUSIONS

1. As a result of researches the dependencies of the basic dynamic coefficients of the four–axle open car from the friction coefficient in the system "body – bogie", taking into account the motion speed were obtained.

2. Thus, the obtained results of calculations allow evaluating the impact of the technical condition of the car running gears on the road safety performance.

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ПОКАЗАТЕЛЕЙ ТРЕНИЯ НА ДИНАМИКУ ГРУЗОВОГО ВАГОНА

Сергей Мямлин, Лариса Недужая,
Александр Тен, Анжела Швец

Аннотация. Работа посвящена исследованию влияния показателей трения в системе «кузов – тележка» грузовых вагонов (изменение значения коэффициента трения в скользунах во время эксплуатации) на их основные показатели – коэффициенты горизонтальной и вертикальной динамики, вертикальные и горизонтальные ускорения кузова, рамную силу, коэффициент устойчивости от схода с рельсов. Исследование проводилось методом математического моделирования динамической нагруженности грузового вагона с использованием программного комплекса «DYNRAIL». Основное внимание уделялось в основном влиянию изменения силы трения между кузовом и тележками. Теоретические исследования динамической нагруженности грузового полувагона проводились в порожнем и груженном состоянии с тележками ЦНИИ-Х3 (модель 18–100) при движении в прямых и кривых участках железной дороги различных радиусов с установленными скоростями движения. В результате исследований, с целью определения динамических показателей грузовых вагонов с учетом влияния показателей трения, получены зависимости основных динамических показателей от изменения значения коэффициента трения в скользунах с учетом скорости движения на прямых и кривых малого и среднего радиуса участках железной дороги. Результаты теоретических исследований определения динамических показателей грузовых вагонов с учетом показателей трения в системе «кузов – тележка» позволяют объективно оценить влияние коэффициента трения между скользунами грузовых вагонов на показатели безопасности движения по железной дороге (коэффициенты горизонтальной и вертикальной динамики, вертикальные и горизонтальные ускорения кузова, рамную силу, коэффициент устойчивости от схода с рельсов).
Ключевые слова: грузовые вагоны, скользуны, динамические показатели.

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Searching of the ways of definition of the rational configuration of divisions of the car-repair facilities on the basis of the flexible stream on the design stage

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S u m m a r y . The technique, allowing to carry out rational configuration of various divisions of the car-repair enterprise at a stage of its design is presented. The grafo-matrix principle considering interdependence between divisions is put in a basis of a technique. The authors chose the volumes of cargoes moved between divisions as the main criterion defining the value of communication level. On the basis of this technique it's offered the configuration mode of units of the main production builging for the car-repair enterprise for gondola cars repairing on the basis of a flexible stream.
K e y w o r d s . repair of cars, flexible stream, design of the car-repair enterprises, configuration of

INTRODUCTION

At a design stage of the modern car-repair enterprises applying a flexible stream for cars repairing there is a need of using the original layout decisions which could allow to realise all advantages of this repairing method. Considering the fact that repairing of cars involve a number of various specialised technological sites and units with continuous movement of labour objects, in the form of cars, their separate parties, various details and materials, there is a need for rational coordination of these units among themselves for minimising the ways of the internal goods turnover. Reduction of ways of cargoes moving promotes decreasing the intra production losses that affect a production cost. Therefore, rational configuration of production divisions is one of the important conditions of increasing the efficiency of car-repair production. The general questions of car-repairing facilities design of are considered in works [20, 22, 23, 25, 29]. As a rule, the existing car-repair enterprises using a stationary car repairing method or a traditional "rigid" stream, represent a rectangular building of a car building site with two or three cross-cutting tracks. The workshops are attached to both sides these tracks on all length [1, 2, 3, 4, 28]. And though the traditional car-repair enterprises have rather simple and convenient configuration of production rooms, there is absolutely other problem – the "rigid" structure of the most car assembly sites does not correspond to the requirements of the probabilistic nature of car-repair production and needs more difficult structure ensuring the flexibility. Thus, the flexible car-repair streams have more difficult configuration and, in this regard, the general configuration of production sites for them demands a special approach.

Purpose of this article consists of the development of the methods allowing to carry out rational configuration of divisions of the perspective car-repair enterprises using flexible car repairing streams. It’s made an attempt to develop the concrete effective mechanisms for practical tasks.

MAIN MATERIAL

On a production stage various divisions of the car-repair enterprise co-operate among themselves. There are different types of interrelations between separate divisions of the enterprise: administrative, technological, supplying, informational. In the point of view of operational expenses these communications have various specific weight. There are communications expenses that don’t depend of the range of divisions arrangement, and there the ones that depend. The most powerful are the material interrelations concerning movings of various cargoes. But also there are different interrelations. There are the cases associated with moving of the big weighed objects between units, and there is another situation when it’s necessary to move, for example, the electric motor and to deliver it to the workshop, and after repair - to return the motor back. The most powerful are those connections that provide perfoming of technological process: continuous moving of cars, bogies, wheel pairs, and also other units, details and materials. Therefore, during arranging the rooms it’s necessary ensuring the smallest value of the goods turnover between them (measured in tonne-kilometres). Considering the fact that we can’t influence to the weight of moved products, there is only one variant – to reduce whenever it is possible the distances between adjacent technological divisions. In other words, rooms with biggest freight traffics, need to be located as closely as possible to each other in order to reduce the operational moving process expenses.

The works [9, 12, 13, 15, 17] describe theoretical development of flexible streams for cars repairing. The works [10, 11, 16, 19] discuss the modeling modeling methods and calculations of the main indicators of flexible car-repair streams. The articles [8, 14, 18, 24] presents the various configurations of car-repair sites and possible configurations of other production divisions. All divisions, in one way or another, participate in technological process of cars repairing. There is a constant process of moving various units, details, materials or even cars between them by means of floor transport or cargo transporters. As it’s known any intershop moving demands certain operational expenses. The longer the distance of cargo moving is, the greater the expenses are. In order to minimize the transportation costs the divisions should be placed in the optimum manner. In this case it is more important to us to place the technologically related divisions more closely to each other as possible as we can, it allows to reduce the distances of intershop cargoes movings. It is naturally that the area of separate divisions depends of the enterprise capacity as well as the total area of all enterprise. This can affect the layout of the rooms in the particular enterprise.

Let's try to develop a rational configuration of enterprise divisions enterprise on a basis of example of depot for repairing gondola cars. For this purpose we’d better to use the theory of graphs [21, 30]. The graph is the abstract mathematical tool for solving many practical problems [6, 7]. Visually the graph represents the geometrical figure consisting of points (tops), connected among themselves with lines (edges) in a certain order. Therefore, the graph can be defined by a set of tops $v_1, v_2, ..., v_n$, denoted like V, and set of edges $r_1, r_2, ..., r_m$, connecting among themselves the tops denoted like R. In the analytical form the graph can be written down as follows: $G = (V, R)$, where V – set of tops, $v \in V$, R – set of edges, $r \in R$. Each edge is a combination two tops. If v_i and v_j are the end tops of an edge $r_к$, the tops v_i and v_j are incidental to an edge $r_к$ (or edge $r_к$ is incidental to the tops v_i and v_j).

There is also another approach. If two sets V_1 and V_2 are known, it’s possible to form a set of all pairs (v_1, v_2), $v_1 \in V_1$, $v_2 \in V_2$. Each edge of the graph G represents a separate element in multiplication of sets $V \times V$. It's very convenient to present results of this multiplication in a form of cages of a square matrix M with quantity of elements of a set V as co-ordinates on both axes. The matrix of interactions or contiguity belongs to the most useful designing tools created as a results of searching the optimum design method [5]. The matrix of interactions between car-repair divisions of the enterprise is presented in tab. 1. In this table a "top" can be interpreted as technological division, and the "edge" – as process of moving of cargoes from one technological division to another.

In a section with coordinates (v_i, v_j) we will write down the figures from 2 to 0 depending of value of interaction between these tops. It means that existence of interrelations was estimated on a three-point scale: 2-interrelation considerable, 1-interrelation insignificant, 0-interrelation insignificant or there is no interrelation. In order to avoide the overloading of a matrix, let's fill only those sections of the table that are to the right of a diagonal. The assignment of some interrelations between divisions is conditional and depends of the subjective qualities of the specific designer. Hence, it's desirable to involve more accurate specialists ensuring the best accuracy of work. The more divisions are, the more difficult is to estimate interaction level between them. The value of cargoes moved between divisions can be very important, as we've already noted.

It is necessary to draw the preliminary graph on the following stage after drawing up of a matrix of elements interactions. As we already noted, it represents a configuration consisting of tops, connected among themselves with links (edges). Tops of graph we represent as circles, and edges – as lines. The form and lenght of lines isn't important. The fact of connecting two tops is an only important fact. The circle form for graph is the most convenient one, i.e. tops of graph can be arranged on perimetre of an imagined circle. The considerables interrelations (2) between tops can be represented as fat lines, and insignificant interrelations (1) – thin lines. The figures in circles correspond to numbers of the divisions presented in Tab. 1. The general view of the preliminary graph is shown on Fig. 1.

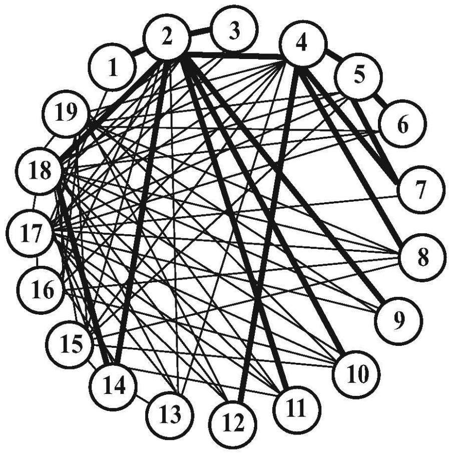

Fig. 1. A general view of the preliminary graph constructed on the basis of a interactions matrix

Tab. 2 presents the calculations of mass value of separate units of the gondola cars moved between divisions, and also the norms of material expenses for repairing purposes per one car. Expenses of materials on depot cars repairing can be found in [27].

As a matter of fact the graph shown on fig. 1, contains the same information as in an interaction matrix, but this information has a more acceptable for further actions form. Nevertheless, this graph represents still quite difficult interlacing of edges and doesn't allow accurately present a configuration of premises of the designed enterprise. Therefore, the following stage includes transformation of this graph to the more convinient one. For this purpose it is necessary to develop a topological structure of a network and to arrange the graph tops so that to avoid crossings of the most significant edges, or, at least, to minimise them. This procedure isn't absolutely simple also can take certain time. First of all it's necessary to construct the base structure of the graph consisting of tops with considerable interrelations. On tab. 1, and on fig. 1 it is visible that the main car-repaire site (2) has all considerable interrelations.

Table 1. The matrix of divisions interactions of the car-repair enterprise among themselves

№	Division name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Site of preparation of cars to repairing		2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2	Main car-repair site	-		2	2	0	0	0	0	2	2	2	0	1	2	0	1	1	2	1
3	Painting site	-	-		0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
4	Bogies site	-	-	-		2	0	2	2	0	0	0	2	1	0	1	1	1	1	1
5	Wheel site	-	-	-	-		2	2	0	0	0	0	0	0	0	1	0	1	1	1
6	Department of roller bearings repairing	-	-	-	-	-		0	0	0	0	0	0	0	0	0	0	1	1	1
7	Yard of bogies and wheel pairs	-	-	-	-	-	-		0	0	0	0	0	0	0	0	0	1	0	0
8	Site of triangely repairing	-	-	-	-	-	-	-		0	0	0	0	0	0	1	1	1	1	1
9	Site of the brake equipment repairing	-	-	-	-	-	-	-	-		0	0	0	0	0	0	0	1	1	1
10	Site of the autochain equipment	-	-	-	-	-	-	-	-	-		0	0	0	0	1	1	1	1	1
11	Site of the hatches and doors covers repairing	-	-	-	-	-	-	-	-	-	-		0	0	1	0	0	1	1	1
12	Yard of the springs repairing	-	-	-	-	-	-	-	-	-	-	-		0	0	0	0	1	1	1
13	Forge yard	-	-	-	-	-	-	-	-	-	-	-	-		1	0	0	1	1	0
14	Metal store yard	-	-	-	-	-	-	-	-	-	-	-	-	-		1	1	0	2	0
15	Electro-gas welding office	-	-	-	-	-	-	-	-	-	-	-	-	-	-		0	1	1	1
16	Mechanical yard	-	-	-	-	-	-	-	-	-	-	-	-	-	-			1	1	1
17	Yard of the depot equipment repairing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1	1
18	Material warehouse	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-		1
19	Tool and distributing storeroom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table 2. The value of mass of separate units of the gondola cars moved between divisions, and norm of the material expenses per one car repairing

№	Cargo name	Mass of unit, kg	Quantity per car	Total, kg	Share in car weight, %
1	Gondola car (assembled)	24 000	1	24000	100,00
2	Bogie 18-100 (assembled)	4745	2	9490	39,542
3	Wheel pair RU1Sh-950-A (with axle-boxes)	1390	4	5560	23,167
4	Axle box case	45	8	360	1,500
5	Axle box bearing	17,5	16	280	1,167
6	Triangel	76	4	304	1,267
7	External spring	15	28	420	2,567
8	Internal spring	7	28	196	
9	Hatch cover	186	14	2604	10,850
10	Doors	515	2	1030	4,292
11	Automatic coupling (assembled)	206	2	412	1,717
12	Absorbing device Sh-2B-90	132,6	2	265,2	1,105
13	Brake equipment (set), including: Air distributor 483 Brake cylinder Reserve tank Automatic regulator Automode Main part Draughts Sleeve brake End crane	288 84 110 26 30 19 6 3 3,5	1 1 1 1 1 1 1 2 2	288 84 110 26 30 19 6 6 7	1,200
14	Metall rolling			696,0	2,900
15	Electrodes			20,0	0,083
16	Wire welding			22,9	0,095
17	Flux welding			20,0	0,083
18	Paint materials			10,21	0,043
19	Lubricants			20,0	0,083
20	Advis			17,0	0,071
21	Pipes and fitting			1,5	0,006

Bogie site (4) follows after the main car-repaire site. Therefore, on the transformed graph the corresponding tops should be in the centre of the graph, the other tops should be around them. Besides, it is desirable at this stage to form the graph as a future building of depot. During realisation of this stage it is desirable firstly to develop some alternative variants of the base graph structure, and then to choose the most preferable one among them. One of the possible variant of such transformed graph is shown on Fig. 2.

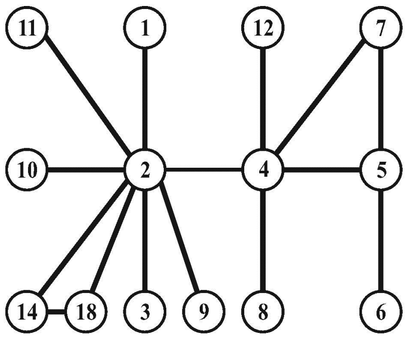

Fig. 2. The variant of base structure of the transformed graph

On the basis of the transformed graph structure presented on Fig. 2, let's make the updated graph. For this purpose we add the tops having insignificant interrelations. Let's try to arrange them so that they were closer to adjacent tops as possible as we can and to shape a configuration of future building. The updated variant of the graph is presented on Fig. 3.

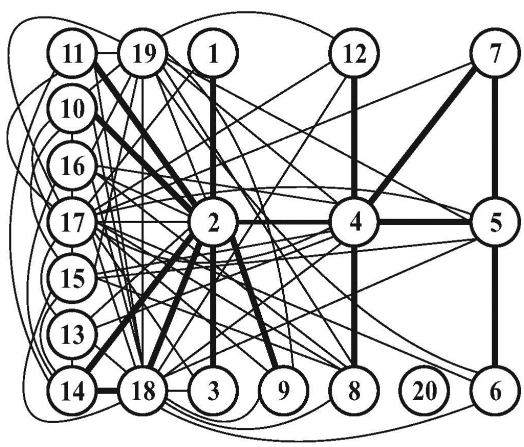

Fig. 3. The updated variant of the graph

On the basis of the graph presented on Fig. 3, we can to develop a configuration of divisions of the car-repair enterprise. Sometimes it's very difficult to consider the areas of separate rooms and a configuration of all building with correct form. In this article we aren't going to consider in detail a configuration of each separate division. Usually the rooms have a rectangular shape, and their area corresponds to technological design norms [26].

The final variant of divisions configuration of the car-repair enterprise is shown on Fig. 4.

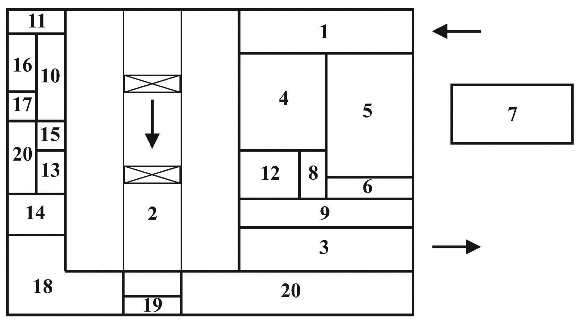

Fig. 4. The variant of divisions configuration of the car-repair enterprise (the arrows shows the direction of the general car-repair stream)

The top of the graph with number 20 represents the auxiliary rooms which directly aren't involved to the technological process, but accompany it and occupy a certain areas which should be considered in configuration of the main production building (knots of input-output of communications, ventilating chambers, transformer substations, lavatories, etc.).

It should be noted that it isn't possible to completely consider the all requirements. But it is possible to neglect the insignificant interrelations.

CONCLUSIONS

1. Reduction of operational expenses is an important indicator of the increase of production efficiency. The considerable part of these expenses is directly connected to the

continuous movings of various cargoes between technological divisions of the enterprise.

2. These expenses can be reduced at a design stage by means of rational configuration of the enterprise divisions.

3. This article discusses an example of the tools allowing at a design stage to arrange the perspective car-repair enterprises, using a flexible car-repair stream, to develop a rational configuration of divisions of the enterprise, to reduce the excess movements of inter-depot cargoes.

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ПОИСК ПУТЕЙ ОПРЕДЕЛЕНИЯ РАЦИОНАЛЬНОЙ КОМПОНОВКИ ПОДРАЗДЕЛЕНИЙ ВАГОНОРЕМОНТНОГО ПРЕДПРИЯТИЯ, ИСПОЛЬЗУЮЩЕГО ГИБКИЙ ПОТОК, НА СТАДИИ ЕГО ПРОЕКТИРОВАНИЯ

Владислав Мямлин

Аннотация. Представлена методика, позволяющая осуществлять рациональную компоновку различных подразделений вагоноремонтного предприятия на стадии его проектирования. В основу методики положен графо-матричный принцип, учитывающий взаимозависимости между подразделениями. В качестве главного критерия, определяющего величину уровня связи между подразделениями, выбраны объёмы, перемещаемых между ними грузов. На базе этой методики предложен вариант компоновки подразделений главного производственного корпуса вагоноремонтного предприятия для ремонта полувагонов, использующего гибкий поток.

Ключевые слова: ремонт вагонов, гибкий поток, проектирование вагоноремонтных предприятий, компоновка помещений

Model of the relationship of residual magnetization and the elastic stress of ship's hulls during cargo and ballast operations

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Summary. The mathematical model of the relationship of residual magnetization and the acting elastic stresses of ship's hulls during cargo and ballast operations is determined. The validation of adequacy of the approximating model by Fisher criterion and the experimental check of adequacy approximating model are carried out.

Key words. The mathematical model, the residual magnetization, the elastic stresses, ship's hull.

INTRODUCTION

Cargo and ballast operations on the dry cargo ship has always belonged to the category of the most demanding. Typically, a long-term effect of constantly changing the mechanical elastic stresses accompany to the maintenance of the ship's hull. The nature and values of this stresses vary and depend on sailing conditions, correct loading and unloading, ballasting and deballasting of ship and other factors [20]. In some negative cases, individual components of the ship's hull are overloaded. Because of this, there are risks of occurrence of excessive permanent deformation and local destruction, which in turn can lead to an accident – disruption or loss of the general hull strength. Therefore, today the control of the ship's hulls during cargo and ballast operations in conditions of uncertainty as to the actual (instantaneous) state of the ship's hull remains topical, which would apply principally new methods of control, taking into account all the features of operation of bulk carriers.

ANALYSIS OF PUBLICATIONS

The research in [1, 3, 8, 9, 17] show that to estimate the elastic stresses are widely used magnetic methods of non-destructive testing (NDT), which are based on the relationship of the magnetic and mechanical properties of ferromagnetic materials. Among these magnetic values are: initial χ_a and reversible χ_r magnetic susceptibility, coercive force H_c, magneto-elastic increase of magnetization $\Delta M_\sigma(H_i, \sigma_0)$ (H_i – the internal magnetic field), residual magnetization M_r.

Made analysis of literary sources allows to state that most of the control methods of elastic stresses are special occasions (the construction made of a particular grade of steel with specific structural and magnetic state). At the same time, applying the mentioned methods, it is difficult to determine the sign of acting elastic stresses in ferromagnetic structures, so they could not get wide distribution in practice.

However, an exception is the ability to estimate the elastic stresses on the value of residual magnetization, that is connected with a very large range of changes M_r during the transition from tension to compression [3].

THE PURPOSE OF ARTICLE

Get the adequate mathematical model of the relationship of residual magnetization and the acting elastic stresses in the ship's hulls during cargo and ballast operations.

MATERIALS AND RESEARCH RESULTS

A special interest is the determination of the relationship residual magnetization and the mechanical stresses in structural steels, which including used for the manufacture of ship's hulls. The relatively low carbon content not exceeding usually 0.3-0.4% and a low content of alloying elements is characteristic for this type of steel (St3S, 09G2S, 10ChsND etc).

1. Approximation of the dependence of the residual magnetization of mechanical stresses in ferromagnetic steel constructions. During the carried out analysis of magnetic characteristics shown that in magnetic method of NDT magnetic parameter such as residual magnetization essentially depends on the elastic compression and tensile stresses. The experimental results of measurements of the values of plastic deformations ε and true stresses $\sigma_{true} = F/S$ (where F − the load, S − cross-sectional area of the sample at a given value ε) during modes «slow» and «fast» loading on samples of steel St3S are obtained in research work [10]. The value M_r is measured by the ballistic method, while the residual magnetization measurement error was 3%. On the Fig. 1 it is shows the experimentally the obtained dependence [10] the residual magnetization M_r of the tensile and compressive stresses in the elastic diapason: $-\sigma_T \le \sigma \le \sigma_T$.

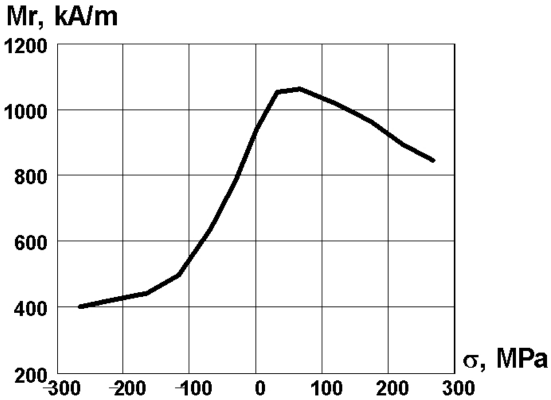
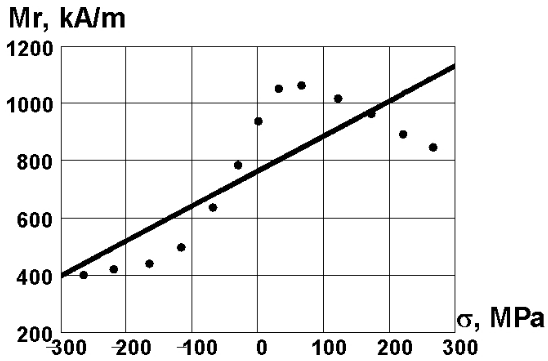


Fig. 1. The residual magnetization – tensile and compressive stresses relation in the elastic diapason: $-\sigma_T \le \sigma \le \sigma_T$ for steel St3S

The experiment was carried out on samples of steel St3S after annealing at 650 ºC for 2 hours duration (cooling oven) in order to eliminate differences in the initial crystallographic and magnetic structures. By its nature, the shown relations (Fig. 1) is exactly the same as the dependencies for a large number of ferromagnetic steel (40H, 30HGSA etc.) in other research work [8-10]. The difference from each other is only in the numerical data.

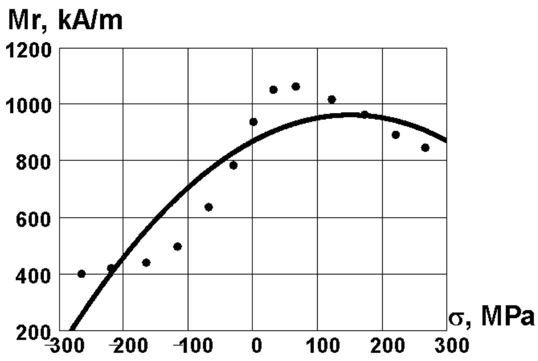
At the same time dependence shows an extremely large diapason of changes M_r during the transition from tension to compression: $M_r(+\sigma) - M_r(-\sigma) \approx 450\ kA/m$, that once again confirms the effectiveness of application of function $M_r(\sigma)$ to the NDT stresses in ferromagnetic steel structures.

The experimentally obtained the residual magnetization M_r - tensile and compressive stresses relation for steel St3S [10] is approximated by a linear dependence, as well as polynomials of the second, third, fourth and fifth degree. One of the most effective way of approximating the specified models is the application of the program Mathcad 11 with using polynomial regression function: *«regress»*. The obtained graphics and the corresponding regression equation of mentioned approximating models are shown in Fig. 2.



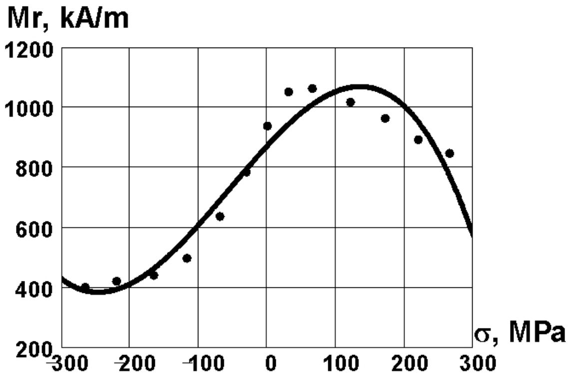
$$y(x) = 764.637 + 1.221x$$

a



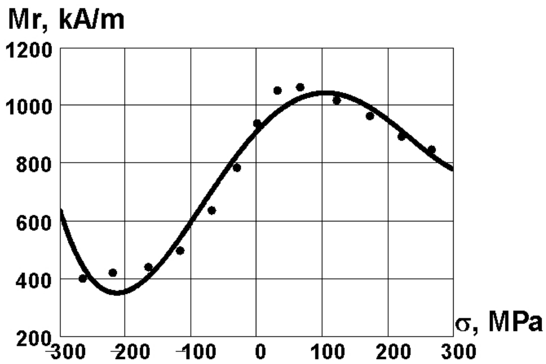
$$y1(x) = 870.154 + 1.227x - 4.097 \times 10^{-3} x^2$$

b



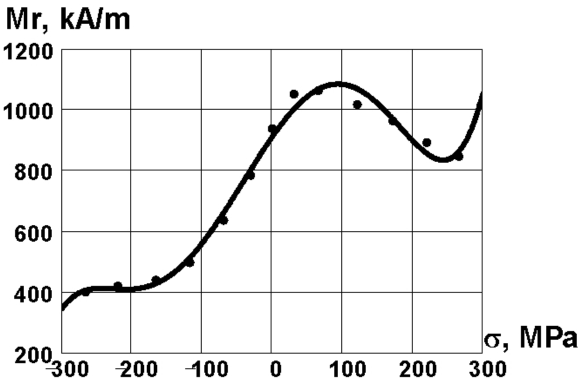
$$y2(x) = 871.768 + 2.466x - 4.134 \times 10^{-3} x^2 - 2.475 \times 10^{-5} x^3$$

c



$$y3(x) = 910.381 + 2.47x - 9.837 \times 10^{-3} x^2 - 2.476 \times 10^{-5} x^3 + 8.396 \times 10^{-8} x^4$$

d



$$y4(x) = 910.117 + 3.308x - 9.68 \times 10^{-3} x^2 - 7.506 \times 10^{-5} x^3 + 8.17 \times 10^{-8} x^4 + 5.714 \times 10^{-10} x^5$$

e

Fig. 2. Graphics of approximation of the dependence of residual magnetization M_r of the tensile and compressive stresses in the elastic diapason: $-\sigma_T \le \sigma \le \sigma_T$ for steel St3S: a – a linear relationship, b – the second degree polynomial, c – the third-degree polynomial, d – the fourth degree polynomial, e – the fifth degree polynomial

Relying on the results of the foregoing analysis of residual magnetization - tensile and compressive stresses relation is justified to take that as a kind of mathematical model for approximating function is the most appropriate model of a third-order polynomial.

2. Construction of a mathematical model of the relationship of residual magnetization and elastic stresses in ferromagnetic steel *construction.* The obtained above approximating dependence $f = M_r(\sigma)$ makes sense in case of change only of acting in the ferromagnetic structure (ship's hull) elastic stresses. In reality, the situation is somewhat different. The experimental measurements were carried out on the researched vessel at various points on the surface of the horizontal plate of hatch coaming as the upper plane of equivalent girder [12]. Here solid coaming of cargo holds (Fig. 3) is one of the most important carrying longitudinal connections and is therefore used as a control object of elastic stresses in the ship's hull during cargo and ballast operations.

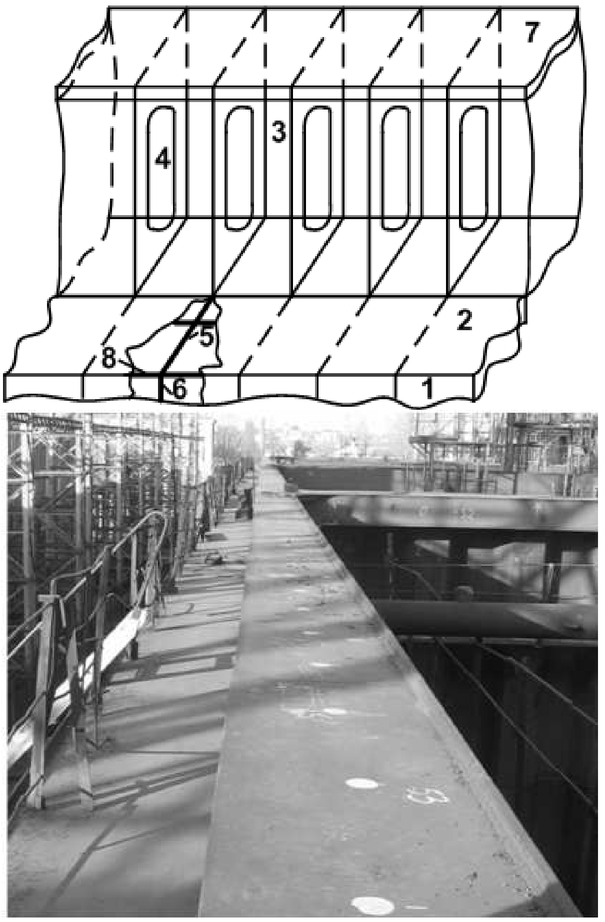


Fig. 3. Hatch coaming: 1 – ship's side (sheer-strake), 2 – deck plate, 3 – hatch coaming, 4 – coaming stay, 5 – beam, 6 – frame, 7 – coaming's horizontal plate, 8 – deck stringer

Therefore, in practice, in the course of the measurements, it was found that the obtained values of the residual magnetization depend on many different factors: the elastic stresses in ferromagnetic steel construction (ship's hull) during its operation (σ), size of the gap between the controlled surface of the coaming and transmitter (δ), the coercive force of material of coaming (H_c), which in the course of the experiment was measured previously by coercimeter, the normal and tangential vector component of the magnetic field strength of Earth, depending on the spatial orientation of the ship's hull (H_r, H_x), the geometric dimensions of the field of control in view of the edge effect (a, b, c) (Fig. 4).

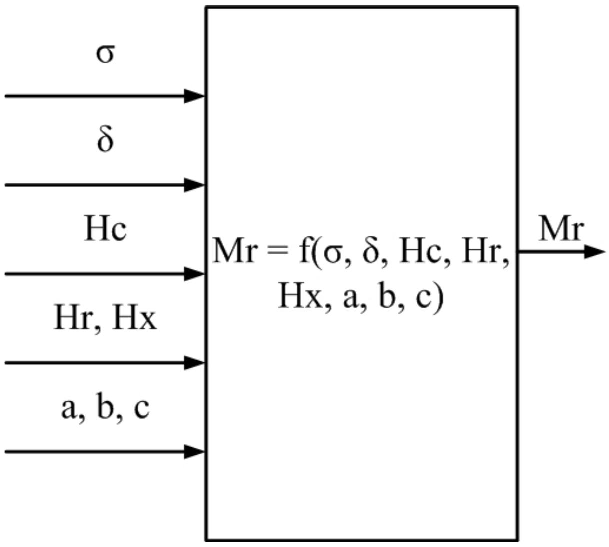


Fig. 4. The structure of the system of mathematical model of residual magnetization relation M_r

The approximating model of the relationship of the residual magnetization and the considered above parameters was obtained by the mathematical theory of experimental design [2, 4, 6]. The effectiveness of the method experimental design is that it allows to build a approximating model of a certain value in the form of a polynomial of n-th order depending on a number of arguments – the factors on the basis of data obtained by carrying out experiments in a given set of points. Furthermore, based on the obtained by the method experimental design function, it is possible to evaluate the effect of each factor on the test parameter value, in this case – the residual magnetization.

All set basic requirements, according to the method of experimental design for the response function (M_r) and the factors discussed above are satisfied in full. That is, the create of a mathematical model approximating dependence of residual magnetization of the influencing factors in the form of a second order polynomial based on the theory experimental design is hypothetically possible.

In such a way, it is required to establish the relationship of residual magnetization and the three selected on the basis of a priori information the most important factors: the elastic stresses in the structure σ, the coercive force of the material of the coaming H_c and the gap size between the coaming and transmitter δ.

Relationship $M_r(\sigma, H_c, \delta)$ can be approximated by a polynomial of the second degree. The experiment was carried out on the program planning of the central composite rotatable the second order [4, 6]. Planning is called a rotatable [2], if it is invariant to rotation of the coordinate system. It means that the information contained in the regression equation to be equally distributed over the hypersphere. When planning is rotatable the predicted values of optimization parameter have a minimum dispersion in a different points of the factor space, that is determined with minimal errors in all directions at the same distance from the center plane.

The main advantage of rotatable plan is to ensure the same accuracy of predicted value in all directions at the same distance from the center of the plan.

The intervals variation and natural levels of: the elastic stresses σ and the coercive force H_c are taken in accordance with relevant mechanical and magnetic characteristics of the material coaming ship's hull [15], as well as on the basis of experimental data [10]. But varying intervals and natural levels of the gap size between the coaming and transmitter have been determined taking into account the coaming surface unevenness (roughness, rust, etc.).

Selected in the research the levels and intervals varying factors are listed in a Table 1, in which the following notation: 0 – ground level, 1 – upper level, -1 – lower level, 1.682 – maximum value, -1.682 – the minimum value of the independent variable.

Table 1. Calculated planning matrix

Factors	Code designation	The varying intervals	Natural levels of factors corresponding to coded factors				
			+1.682	+1	0	-1	-1.682
σ, MPa	x_1	210	265	210	0	-210	-265
H_c, kA/m	x_2	0.15	0.68	0.6	0.45	0.3	0.29
δ, m	x_3	0.75× ×10^-3	3.5× ×10^-3	3× ×10^3	2.25 ×10^-3	1.5× ×10^-3	1× ×10^-3

Compiled the central composite rotatable the second order plan for the three factors consists of the full factorial experiment plan of type 2^3, the six experiments in the «star points» and the six experiments in the center of the plan.

Based on the results of experiments carried out in accordance with the plan of the experiment it can be estimated the coefficients of the regression equation of the form:

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + \\ + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2. \quad (1)$$

Using the formulas [2, 4, 6], coefficients of the regression equation were determined: $b_0 = 772{,}37$, $b_1 = 99{,}82$, $b_2 = -101{,}1$, $b_3 = 43{,}02$, $b_{12} = 17{,}16$, $b_{13} = 0{,}48$, $b_{23} = -45{,}07$, $b_{11} = -69{,}88$, $b_{22} = 9{,}59$, $b_{33} = -18{,}1$.

The obtained regression equation is of the form:

$$y = 772{,}37 + 99{,}82 x_1 - 101{,}1 x_2 + 43{,}02 x_3 + \\ + 17{,}16 x_1 x_2 + 0{,}48 x_1 x_3 - 45{,}07 x_2 x_3 - \\ - 69{,}88 x_1^2 + 9{,}59 x_2^2 - 18{,}1 x_3^2. \quad (2)$$

Passing from a coded value of factors (x_1, x_2, x_3) to natural factors (σ, H_c, δ), and after the necessary transformations, the dependence $M_r(\sigma, H_c, \delta)$ was obtained:

$$M_r(\sigma, H_c, \delta) = 464 + 0{,}22\sigma - 156H_c + \\ + 3{,}82 \cdot 10^5 \delta + 0{,}55\sigma H_c + 3{,}05\sigma\delta - 4{,}01 \cdot 10^5 H_c\delta - \\ - 1{,}58 \cdot 10^{-3}\sigma^2 + 426H_c^2 - 3{,}22 \cdot 10^7 \delta^2. \quad (3)$$

3. *Verification of the accuracy and adequacy of the obtained approximating model* of *the relationship of residual magnetization and the influencing factors.* Response function approximated by a polynomial could not correspond to (to be inadequate) the observed values of magnitude y. So, before you use the obtained mathematical model to validate its adequacy to the experimental data. According to [2] for a rotatable plans, the validation of adequacy of the mathematical model is carried out in several stages.

Stage 1. The dispersion of reproducibility S_r^2 is calculated, which is defined in this case by the results of experiments in the center of the design according to the expression:

$$S_r^2 = \frac{\sum_{U=1}^{n_0} (y_U - \bar{y})^2}{n_0 - 1}, \quad (4)$$

where: n_0 − number of experiments in the center of the plan, $\bar{y}$ − the average value of the parameter y_U from n_0 measurements at the center of the plan, then $S_r^2 = 1369\ kA/m$.

Stage 2. The dispersion characterizing errors in the determination of the coefficients of the regression equation is calculated according to the formulas [2]:

$$S_{b0}^2 = \frac{2A\lambda^2(k+2)}{N} S_r^2, \quad (5)$$

$$S_{bi}^2 = \frac{c}{N} S_r^2, \quad (6)$$

$$S_{bil}^2 = \frac{c^2}{N\lambda} S_r^2, \quad (7)$$

$$S_{bii}^2 = \frac{Ac^2[(k+1)\lambda + (k-1)]}{N} S_r^2, \quad (8)$$

where: $A = \frac{1}{2\lambda[(k+2)\lambda - k]}$, $c = \frac{N}{\sum_{j=1}^{N} x_{ij}^2}$, $\lambda = \frac{k(n_0 + n_\Pi)}{(k+2)n_\Pi}$, N − number of experiments in the matrix, k − number of factors, y_j − the value of the response function in the *j-th* experiment, x_{ij}, x_{lj} − the coded values of *i-th* and *l-th* factor in the *j-th* experiment, $n_\Pi = N - n_0$.

Then the dispersions of coefficients of the obtained regression equation will be: $S_{b0}^2 = 228{,}09$, $S_{bi}^2 = 100{,}2$, $S_{bil}^2 = 171{,}2$, $S_{bii}^2 = 95{,}11$.

Stage 3. The confidence intervals are calculated for the coefficients of the regression equation:

$$\Delta b_0 = \pm t S_{b0}^2 = \pm 38{,}81, \\ \Delta b_i = \pm t S_{bi}^2 = \pm 25{,}73, \\ \Delta b_{il} = \pm t S_{bil}^2 = \pm 33{,}63, \\ \Delta b_{ii} = \pm t S_{bii}^2 = 25{,}06, \quad (9)$$

where: $t = 2.57$ − a table value of Student criterion at the 5% significance level and degrees of freedom $f = 5$.

Stage 4. Dispersion of adequacy S_{ad}^2 is determined by the formula:

$$S_{ad}^2 = \frac{S_R - S_E}{f}, \quad (10)$$

where: S_R − the sum of squared deviations of the empirical values y_j of the response function from its values $\hat{y}_j$, calculated by the model at all points of the plan, $S_E = \sum_{U=1}^{n_0} (y_U - \bar{y})^2$, f − number of degrees of freedom, $f = N - k' - (n_0 - 1)$, k' − the number of coefficients of the approximating polynomial, then $S_{ad}^2 = 6550\ kA/m$.

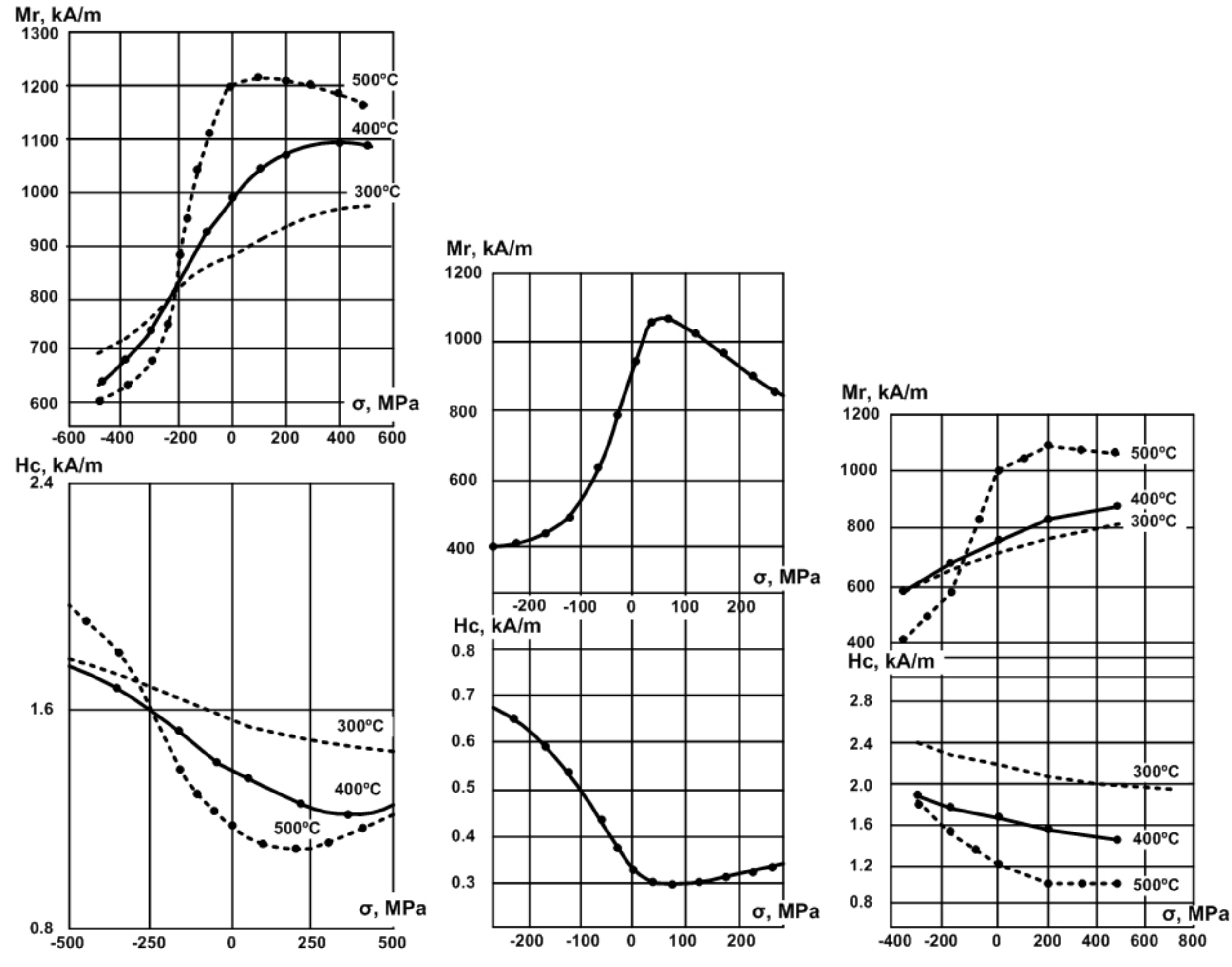
Stage 5. The adequacy of the regression equation is tested by the Fisher criterion:

$$F_{\exp} = \frac{S_{ad}^2}{S_r^2}, \ F_{\exp} = 4{,}78. \quad (11)$$

The founded value of adequacy is less than the table value [2] ($F = 5{,}1$) when adopted 5% significance level and the corresponding number of degrees of freedom ($f = 5$), so the hypothesis of adequacy of the calculated model is adopted.

Defined by means of experiment and from equation (2) the values of the residual magnetization M_r are of the same character as the values obtained M_r for a large number of ferromagnetic steel (40H, St3S, 30HGSA) in other investigations [5, 7, 8, 10]. The difference from each other is only in the numerical data that proves the curves shown in Fig. 5. Here, the families of curves are for different temperatures are tempering.

4. The experimental check of adequacy the obtained approximating model of the relationship of residual magnetization and the acting elastic stresses. To test adequacy the obtained model was also carried out an experiment on a sample of steel St3S with size: 240 mm x 69 mm x 10.25 mm (Fig. 6).



Steel grade: 40H ($H_c = 0{,}95$ kA/m)
a

Steel grade: St3S ($H_c = 0{,}3$ kA/m)
b

Steel grade: 30HGSA ($H_c = 1{,}0$ kA/m)
c

Fig. 5. The experimental dependences of the residual magnetization and coercive force of elastic stresses for different steel grades

Fig. 6. Experimental samples of steel St3S

The sample was deformed by stretching at the tensile machine ZIM GMS-100A (Fig. 7). The coercive force was determined under load using structurescope – coercimeter CRM-C-K2M.

Fig. 7. The tensile machine ZIM GMS-100A

By the magnetization curve for St3S [16], the values of magnetic induction B, corresponding to the measured values of the coercive force, were determined. Assuming that the test sample is a directly (rod) core with a rectangular cross section, the value of the magnetic permeability μ [18] was determined by the formula:

$$\mu = \frac{\pi l^2}{4S\left(\ln \frac{kl}{a+b} - 1\right)}, \tag{12}$$

where: l − sample length, S − cross-sectional area of the sample, a, b − transverse dimensions of the sample, k − coefficient, depending on the shape of the sample [18].

Further from the well-known expression for the magnetic permeability according to [18], the values of the magnetic field strength H were founded:

$$H = \frac{B}{\mu\mu_0}, \tag{13}$$

where: $\mu_0 = 4\pi \times 10^{-7}$ − the magnetic permeability of vacuum.

According to expression:

$$M_r = \chi H, \tag{14}$$

where: χ − the magnetic susceptibility, the values of the residual magnetization M_r were founded.

In the Table 2 values of the residual magnetization, calculated from the above the obtained approximating model $M_r(\sigma, H_c, \delta)$ (Eq. 3), and the values M_r, obtained from the tests of the sample St3S, are presented. Error of calculation totaled 10-12%.

Table 2. The comparative table of experimental verification of the adequacy of the obtained mathematical model and by Fisher criterion

Experiment №	σ, MPa	Hc, kA/m	B, Tesla	H, kA/m	Mr, kA/m	Mr*, kA/m
1.	0	0.277	0.346	5.985	269.5	708.29
2.	141.4	0.27	0.338	5.847	263.3	711.43
3.	212.1	0.27	0.338	5.847	263.3	966.31
4.	282.8	0.31	0.388	6.711	302.2	789.17
5.	339.5	0.35	0.438	7.642	341.1	473.37
6.	386.8	0.36	0.45	7.424	350.9	478.43
7.	407.4	0.38	0.475	7.871	370.3	800.03
8.	451.9	0.40	0.5	7.837	390.3	624.81
9.	496.2	0.43	0.534	7.933	417.2	742.57
10.	782.8	0.785	0.889	7.918	699.9	406.77
11.	–	–	–	–	–	629.45
12.	–	–	–	–	–	969.55
13.	–	–	–	–	–	793.52
14.	–	–	–	–	–	648.80
15.	–	–	–	–	–	772.37
16.	–	–	–	–	–	772.37
17.	–	–	–	–	–	772.37
18.	–	–	–	–	–	772.37
19.	–	–	–	–	–	772.37
20.	–	–	–	–	–	772.37

Mr* – a values of the response function $M_r(\sigma, H_c, \delta)$ at the points of factorial design

CONCLUSIONS

1. As a result of carried out analysis of the magnetic characteristics of the ferromagnetic steels changing under the influence of elastic stresses, it was found that the change of residual magnetization M_r of the mechanical stresses occurs in a sufficiently large range during the transition from compression to tension, therefore estimate the acting elastic stresses in the ferromagnetic structures can be made in magnitude of residual magnetization.
2. The mathematical model of the relationship of residual magnetization and the acting elastic stresses of ship's hulls during cargo and ballast operations was defined by the mathematical theory experimental design.
3. The dependence $M_r(\sigma, H_c, \delta)$ is approximated by a polynomial of the second degree. The obtained mathematical model is adequate to the experimental data that proves check of adequacy regression equation by the Fisher criterion.
4. The experimental check of adequacy approximating model of the relationship of residual magnetization and the acting elastic stresses was carried out.
5. The error of calculations of the acting mechanical stresses by the obtained mathematical model does not exceed 10-12%.
6. In such a way, it can pass to residual magnetization [13, 14] by measuring the magnetic field strength on the surface of the control object – hatch coaming (eg, fluxgate magnetometer), and from it by a numerical method using the resulting model it can determine the value of the acting mechanical stresses in the ship's ferromagnetic constructions.

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МОДЕЛЬ ВЗАИМОСВЯЗИ ОСТАТОЧНОЙ НАМАГНИЧЕННОСТИ И УПРУГИХ НАПРЯЖЕНИЙ КОРПУСОВ МОРСКИХ СУДОВ В ПРОЦЕССЕ ГРУЗОВЫХ И БАЛЛАСТНЫХ ОПЕРАЦИЙ

Вадим Мирошников, Ольга Завальнюк,
Владимир Нестеренко

Аннотация. Определена математическая модель взаимосвязи остаточной намагниченности и действующих упругих напряжений в корпусах морских судов в процессе грузовых и балластных операций. Выполнена проверка адекватности аппроксимирующей модели по критерию Фишера, а также экспериментальная проверка.

Ключевые слова: математическая модель, остаточная намагниченность, упругие напряжения, корпус судна.

The basic principles in development of the program module for calculating time of movement of enterprise's rolling stock

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Summary. The basic principles are presented in this article for development of the program module for calculating of adequate time of enterprise's rolling stock movement. As an alternative tool to traction calculations, a neural network is offered to be used.

Keywords. Shunting work, trip, traction calculations, neuronet.

INTRODUCTION

One of the characteristics for the large and medium-sized industrial enterprises is absence of accurate daily plan of conducting, cargo and shunting works. It is caused by that many processes are subordinated to stochastic probabilistic character and are not reliable subject to forecasting process. With development of computer and management information systems more attention began to be paid to this problem. In this regard there was a question raised on adequacy of planning and rationing of shunting work.

The purpose of this work is allocation of the main aspects for calculating of time of shunting work, and also development of a program module for calculating of the time of movement of enterprise's rolling stock.

To find adequate time of shunting work, it is necessary to know specific conditions of its performance, such as data on enterprise infrastructure, cross-sections of ways, quantity of locomotives, cars, loading/unloading areas and so forth. Besides that, reaching this objective is not possible without initial dividing of this process into the "pure" time of movement that consists of trips, and additional operations.

MATERIALS AND METHODS

The most justified method of realization of calculating of time of movement is modeling of this process [15, 16, 25, 26, 29]. Many scientists dealt with this problem, but it still remains unsolved as it was generally mend for train work only. Conditions of shunting work significantly differ from the train work: while maneuvering accelerating and slowing down is the main repeating elements, shunting locomotives diesel engines do not operate at a normal state, and mainly in the conditions of repeated mode transitions, braking is carried out by a direct-action of locomotive's wheel brakes, braking and change of positions of the hand lever of the brakes crane operated by the driver happens more often, the condition and cross-section of railways at the industrial enterprises considerably differ from the railways on which the organized trains operate [1, 2, 9, 11, 12]. Taking into account the specified factors for receiving results of calculations with demanded degree of accuracy, the only applicable calculations would be the automated traction calculations adapted for shunting work.

Nowadays traction calculations are carried out mainly by computers according to available software. DIIT crew is engaged in software implementation (for example, the MoveRW program), DVGUPS crew (the SPARK program, ERA), etc. Each of the listed programs carries out separate tasks, but none of them is capable to completely cover requirements and conditions of industrial railway transport.

By means of traction calculations under the set conditions, it is possible to calculate the time of performance of the trips, its maximum speed, fuel consumption and other parameters [33]. It is more difficult to find these parameters in the presence of restrictions on length of a way, speed, time and fuel. In Klyuyev's article [15, 18] there is developed program complex described, which allows to find values of these parameters upon transition from one system state to another during each of the steps. Each step includes time interval equal to three seconds as a minimal interval given for transition by the driver from one working state of the controller to another.

Advantage of such program complex can become its downside if to try to introduce it at the large enterprise. All initial parameters are very detailed, giving the exact time of movement, but calculation takes a lot of time if to consider complexity of an enterprise scales. The device of the same accuracy, which would spend less system resources is required.

Given the knowlage on modern scientific researches in the field of information systems and technologies [8], the following is offered: to use neuronets as the device which would predict the time of a trip, trained on data received from the automated system of traction calculations at the concrete enterprise [6, 17, 20].

RESULTS, DISCUSSION

This background for this idea serves such property as uniformity and the limitation of shunting work caused by its binding to a track diagram of the enterprise.

During the analysis based on possible options, such as a linear neural network, radial basic function and multilayered perceptron, the last was chosen, as the most corresponding to such type of tasks. The artificial neural network is described as follows:

$$MP \quad 7:7-2-1:1.$$

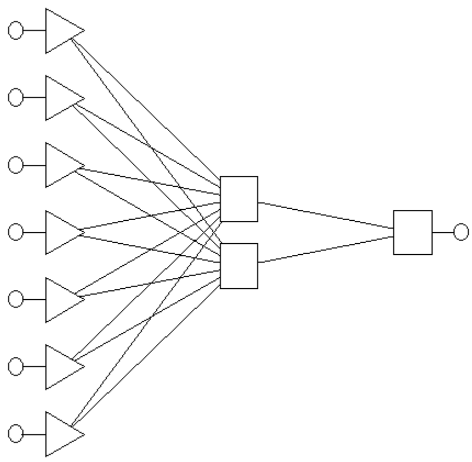

Fig. 1. Multilayered perceptron

"MP" means "Multilayered perceptron ", number to the first colon – quantity of the variables given on an entrance, after – quantity of entrance neurons, the following number – quantity of neurons in an intermediate layer, number standing before the second colon – quantity of output neurons, and the last number – quantity of the variables containing the solution of a neural network, in our case – time. The vector of input parameters has the following appearance:

$$t=\{\ Li;Mi;Ni;Ki;Pi;Ri;Ii\ \},$$

where: *Li* – way length, *Mi* – locomotive capacity, *Ni* – number of cars, *Ki* – a limit position of the controler, Pi – the mass of structure, *Ri* – radius, *Ii* – the given bias of a way.

Each of these parameters is significant for a neural network and the task set for it, thus such quantity of variables doesn't influence speed of a neural network.

During this work 200 examples was picked up and analysed, consisting of seven (among the above presented) input parameters, and also the only initial parameter – time which is accepted as a standard when training a neural network. Such format is an optimal one for training of a neural network. Sufficient quantity of needed parameters would allow a neural network to become multiple-purpose and applied both at a given enterprise, and on a great number of others, without considerable deterioration of accuracy, otherwise caused by different features of an enterprise. Thus, the neural network favorably differs from other methods of operational planning when the calculation of features of the enterprise requires a lot of time and resources causing operational planning to be carried out only partially.

Further it is necessary to conduct research which would show adequacy of a model. By comparison of timing results between traction calculations and neuronet calculation, the following results were received.

Figure 2 shows comparison of calculations for two systems: neural network and traction calculations for 46 experiments sorted by increase. On abscissa axis numbers of experiments are designated, on ordinate axis - time movement in seconds. Rather exact predicting of result by a neural network is provided because of giving the right architecture as well as the amount of educational selection. If one of the needed elements would appear absent, the result of these examples would not be a success.

But to judge the accuracy of work of a neuronet according to the schedule insufficiently, it is necessary to check adequacy of the presented artificial neural network, in comparison with the decision the provided method of traction calculations. It is possible to solve this problem by means of Fischer's criterion:

$$F_{p.} = \frac{D_{\grave{A}}}{D_E},$$

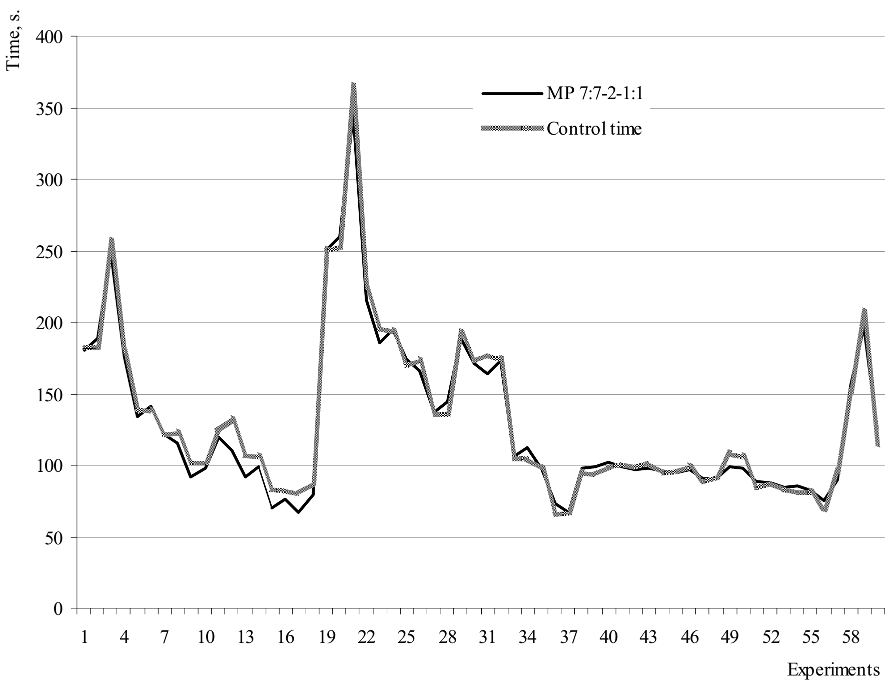

Fig. 2. Example of work of a neural network

where: D_A – adequacy dispersion:

$$D_A = \frac{\sum(\mathrm{y}_{\mathrm{im}} - \bar{\mathrm{y}}_{\mathrm{ie}})}{\mathrm{n - d}},$$

where: y_{im} -value of function calculated with the equation of regression for factors of *i* experiment, $\bar{y}_{ie}$ - average experimental value of the constructed model in *i* experience, *n* – number of measurements in one series of experiences, *d* – number of coefficients of the equation of theoretical regression, D_E - average dispersion of experiment:

$$D_E = \frac{\sum_1^m \sum_1^n (\bar{\mathrm{y}}_{\mathrm{ie}} - \acute{o}_{\mathrm{ie}})^2}{\mathrm{m \cdot n}},$$

where: y_{ie}- the current experimental value of function in *i* experiment, *m* – number of series of experiments.

Therefore, if in these formulas to substitute parameters which answer the data obtained by means of a neural network, Fischer's criterion will be equal 0,033, therefore the received mathematical model of a neural network significant, answers an objective and is adequate. Thus, the task is set above, solved.

Let's consider now realization of mathematical model which was presented above for the solution of a problem of calculating time of movement of rolling stock on industrial railway transport.

The program which realizes mathematical model, is the independent module which can be used in other software products. Let's consider program structure as a whole, and also each of its parts separately.

As shown in Figure 3, the program comprises two classes: class of the most neural network and shell class. The class of a neural network comprises all necessary parameters for work of a neural network, and also the only method starting its work then the result of calculations is given. It allows using this class not only in this program, but also and in others, while applying it practically without adaptation.

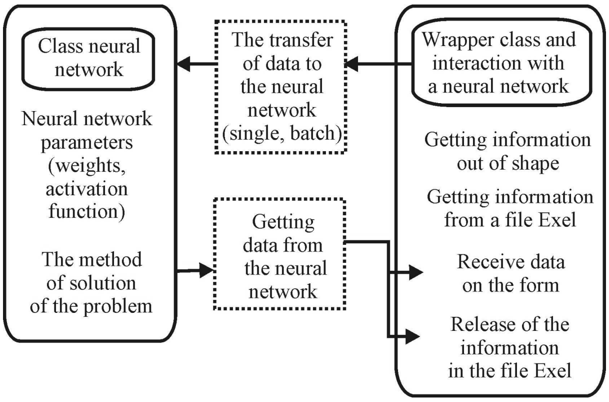

Fig. 3. Program structure

Other class allows using a neural network for examples which were presented earlier. Except the interface, this class also allows to carry out communication with the Excel files. Thus, the user has an opportunity to receive result not only "here and at the moment", directly in a program window, but also to store the received answer for the subsequent use including in other programs.

Let's refer now to the program interface, we will consider its features (Fig. 4).

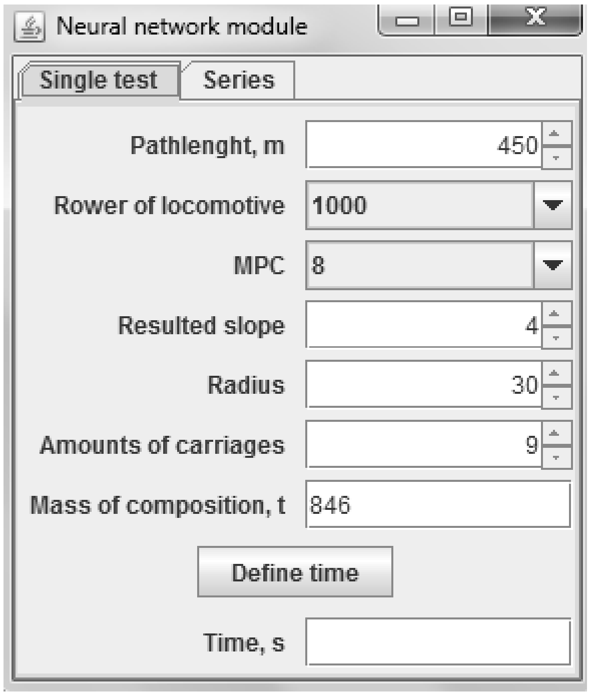

Fig. 4. Appearance of the program (single experiment)

The Single Test tab serves in order that the user could conduct the program's experiment, without using additional data sources. The Series tab is intended for performance of a series of experiments which can be found within the Excel format file. After that the result is registered in the conclusion file. Windows "Way Length", "Locomotive Capacity", "LPC" (Limit position of the controler), "The given bias", "Radius", "Quantity of cars", "Mass of structure" serve for input of initial information. By pressing Define Time button in the Time window the result in seconds is displayed.

The interface of the Series tab appears as follows (Fig. 5).

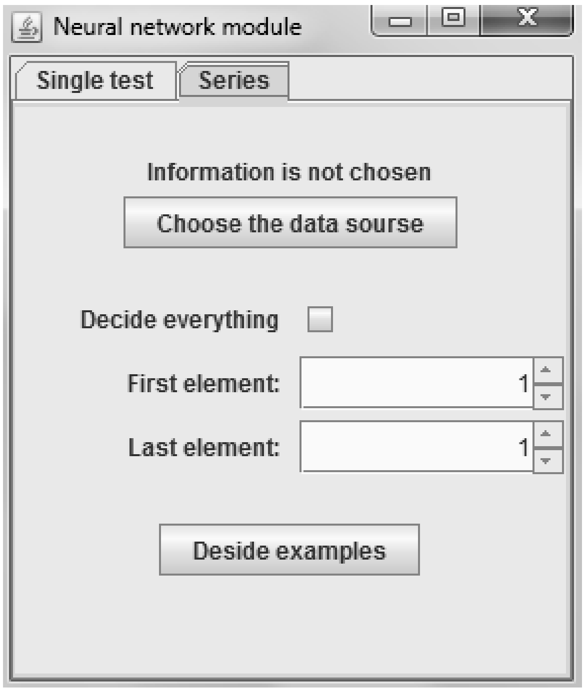

Fig. 5. Appearance of the program (serial experiment)

The file - data source (the Excel format file) allows to select the Choose Data Source item by means of a dialog box. After a file choice its name will be displayed in an inscription over this button. Tag "Solve everything" allows solving all experiments within the chosen file automatically. The window areas "First Element" and "Last Element" allow choosing the first and last experiments which will be solved at start of a neural network if there is no need to solve each example separately. Solve Examples button starts resolving process conducted by a neural network of experiments. After completion of process the program generates new Excel-file (or replaces already existing), which contains answers to the provided tasks.

Thus, the program has the simple, intuitively clear interface. The top part of program's window has two tabs, which are responsible for different types of interaction of neural network with the program and the user. In the "single test" tab allows user to solve different examples, entering their parameters manually (or taken from offered options) into the signed fields, receiving result in corresponding fields.

The 'Series tab', represents different approach. This tab allows user to choose the file from which information would come (the file should have the same or compatible to Excel's format which would correspond to the above-stated table of educational data). After a choice, user can also specify the range of examples which they intend to solve or tick "Solve Everything" trigger. After solving given examples, answers will be put in the output.xls file, from where they can be used further. It should be noted that after each new task the contents of the output.xls file is deleted and updated to more recent one.

The program is based Java, and therefore is cross-platform and can be used in aggregate with other software within different operating systems.

The solution of this task by means of a neuronet, serves as one more step to more global task – calculating of time of shunting work which consists of time of movement of the train (time of trips) and additional operations.

CONCLUSIONS

1.This work consists of the main aspects for the solution of a problem of calculating shunting work time which would allow to put planning and rationing processes to a higher level.

2. Such tasks, as receiving adequate time of the trips based on traction calculations are solved with the ability to take less calculation resources via application of neuronets.

3. Creation of the automated system considering additional operations during the

shunting work is planned as the following stage in this work. The basis of the checklist will be applied that would allow revealing weak spots in shunting work and gradually coming to the era of information systems for planning and rationing.

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ОСНОВНЫЕ ПРИНЦИПЫ В РАЗРАБОТКЕ ПРОГРАММНОГО МОДУЛЯ ДЛЯ НАХОЖДЕНИЯ ВРЕМЕНИ ДВИЖЕНИЯ МАНЕВРОВОГО СОСТАВА НА ПРЕДПРИЯТИИ

Татьяна Нечай, Юрий Шкандыбин, Александр Клюев, Татьяна Балицкая, Никита Соснов

А н н о т а ц и я. В статье представлены основные принципы для разработки программного модуля для нахождения адекватного времени движения маневрового состава на предприятии. В качестве инструмента, альтернативного тяговым расчетам, предлагается использование нейронной сети.

К л ю ч е в ы е с л о в а. Маневровая работа, полурейс, тяговые расчеты, нейросеть.

Measuring device moisture content of transformer oil

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Summary. This paper deals by determination of moisture content of transformer-oil (TO). A method for rapid determination of moisture content of the TO is proposed. Developed by measuring circuit with flow measuring transducer for determining the quality factor of TO. Analytical dependences of capacitance and resistance measuring transducer with TO from the integral of the charge and discharge voltage are obtained.

Keywords. Transformer oil, moisture content, schema of substitution, function of Lambert, measuring transducer, quality factor

INTRODUCTION

Now a lot emphasis is paid to improving the reliability of electrical installations as well as energy saving and improve the technical and economic indicators [12, 13, 16, 26, 27].

The influence of moisture on the degradation electrical insulation properties of transformer oil and the transformer insulating materials studied and characterized quite fully [3, 11, 22].

OBJECTS AND PROBLEMS

Known methods of moisture testing TO have several of shortcomings and for the most part require of laboratory testing [8, 11]. Precision testing of moisture content in transformer oil is not high enough, some of the methods can not be attributed to the non-destructive testing, for example, chemical methods [5, 10, 22]. Up to now many scientists investigated the processes occurring at the testing of the moisture content in various solid and granular environments. The insufficiently studied is the non-destructive testing moisture content in liquids [5, 11, 23].

For operational testing of the moisture content TO, device is offered on principle of the high quality factor measurement of oil. The main element of the device is a sensor – measuring transducer of flowing type mounted on the transformer [9, 14, 15].

RESULTS, DISCUSSION

Functional diagram of device and measuring process of quality factor. Measuring of quality factor TO, located in the converter executed by way determination of charge, amassed by a converter with TO, as shown on a Fig. 1.

Principle of action of this circuit consists of the following. The generator of *G1* generates rectangular impulses with frequency of *f1*, which supplied to on measuring transducer (MT) through high-precision resistance *R1*. The device of voltage registration (DVR) performs the cyclic measuring of voltage on MT from the moment of supply of the first impulse on MT. The charging process lasts to appearance of negative wavefront, after which a pause is formed and there is the parallel connecting of high-precision resistor *R2* by the switch *S*. Thus the process of discharge MT begins through *R2*, for which the cyclic measuring of voltage is also conducted on MT. This process lasts to appearance of positive wavefront of the pulse generator. Then all repeats in the loop.

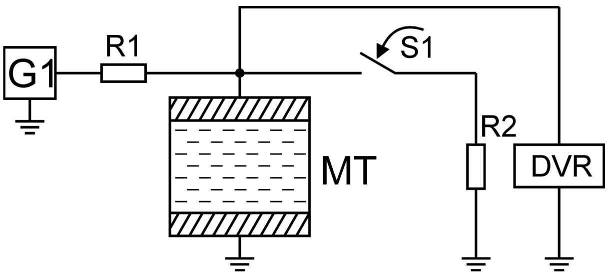

Fig. 1. Scheme of measurement quality factor

Since the structure measuring transducer is designed as a coaxial flowing condenser (Fig. 2.), the voltage on the MT, which is filled TO, will change along the curve 1 as shown in Fig. 3.

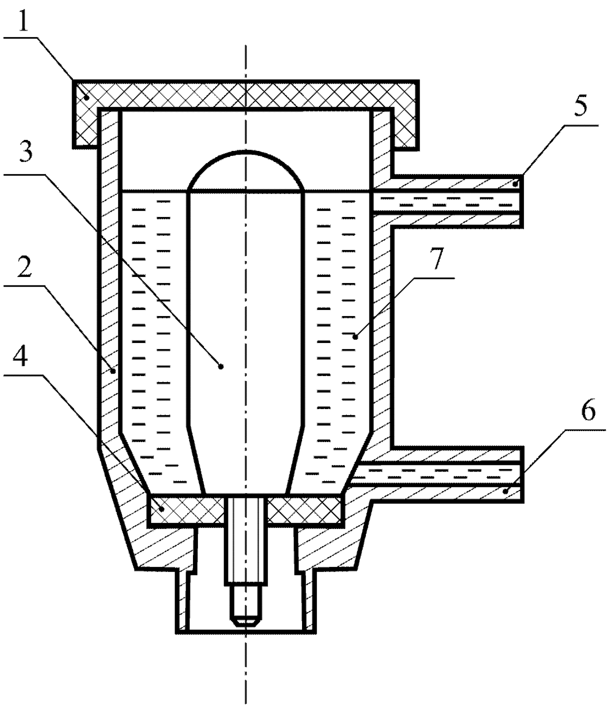

Fig. 2. Measuring flowing coaxial converter

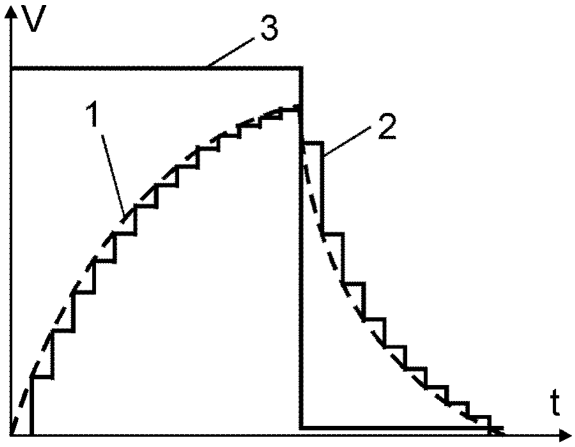

Fig. 3. Oscillograms of charge and discharge of capacity MT: 1 – voltage on MT, 2 – voltage, measured DVR, 3 – voltage from the return of generator of G1

Measuring flowing coaxial converter is a component design. Cover lid 1 made of plexiglass is screwed along the thread of corps 2 which is made of bronze. Inside the case 2 is installed insulating washer 4, wherein the central electrode 3 is fixed. Through the channel inlet tube 5, TO 7 is supplied in MT, and through the channel outlet tube 6 it are outputted from the MT. An influencing signal (voltage) is given on a central electrode 3 and corps 2.

Thus the device of DVR, which measuring voltage on MT must measure the instantaneous voltage with frequency far higher than frequency of generator $G1$, to get a stepped curve 2, which maximally is repeated as close to the curve 1.

The resistor R1 should be selected so that the maximum value of the curve charge was 90-95% of the output voltage of the generator $G1$. Resistor R2 must be selected so that the minimum value on the discharge curve was 5-10% of the generator output voltage $G1$. This is necessary because if the specified voltage will deviate from these limits, then with the same frequency f1, the testing accuracy decreases.

Schema of substitution of the process of charge and process of discharge. Quality factor of measuring transducer with TO depend of correlation from active conductivity to reactive conductivity. Thus, for determination of quality factor should be measure capacity and active constituting of conductivities of MT with TO. For this purpose in beginning necessary to get dependence of voltage of charge and voltage of discharge on time ($U_{ch} = f(t)$ and $U_{dis} = f(t)$).

Measuring of dependences of voltage of charge and voltage of discharge from time is made in accordance with a schema, shown on a Fig. 1.

The got results will directly correlate with a capacity and active conductivity of TM with transformer oil. However it is necessary obtain reverse dependencies capacity and active resistance TM integral voltage charge and discharge voltage $C_I = f(U_{ch}, U_{dis})$ and $R_I = f(U_{ch}, U_{dis})$.

Therefore were composed of the equivalent schemas of substitution for the charging and discharge process [17].

When during a 0.5 sec. there is a charge of capacity MT with transformer oil, then a circuit of discharge is disconnect, and transitional resistance of the switch *S1* and internal resistance of generator *G1* it is possible to ignore [25]. To accept, that in the process of charge of MT a generator will be the DC voltage source, because the charging process on duration is equal to time of impulse of generator *G1* and equal 0,5 sec. Under the above assumptions was obtained the schema of substituting for the process of charge MT with transformer oil, shown in Fig. 4 [24].

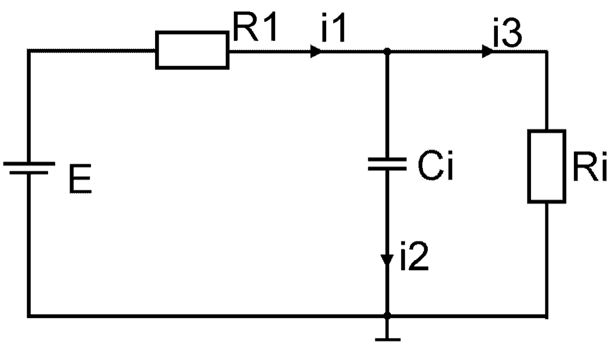

Fig. 4. Schema of substituting for the process of charge MT with transformer oil

When during a 0,5 sec. there is a discharge of capacity MT with transformer oil, then a circuit of charge is a disconnect, and transitional resistance of the switch *S1* it is possible to ignore and consider that a condenser is charged to the maximal value of voltage [25]. Under the above assumptions was obtained the schema of substituting for the process of discharge MT with transformer oil, shown on a Fig. 5 [24].

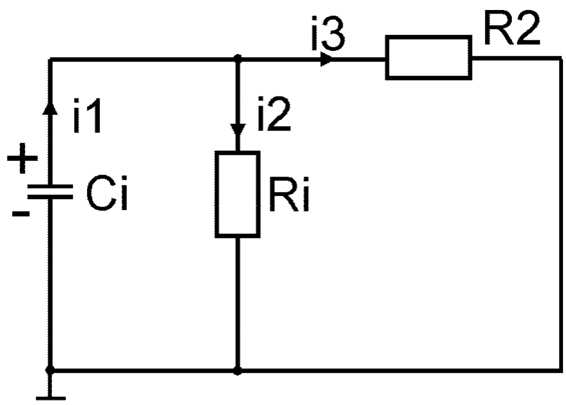

Fig. 5. Schema of substituting for the process of discharge MT with transformer oil

Calculation of analytical dependences for the process of charge. For determination of dependence of voltage of charge on MT U_{ch} from a capacity C_I and active resistance R_I in the schema of substitution, shown on a Fig. 4, the system of equations was made by the system of equations on I and II Kirchhoff laws [2, 18] at zero initial conditions [6, 7]:

$$\begin{cases} i_1 - i_2 - i_3 = 0, \\ i_1 R_1 + \dfrac{1}{C_I} \int i_2 dt = E, \\ i_1 R_1 + i_I R_I = E. \end{cases} \quad (1)$$

For free currents the system of equations will look like the following:

$$\begin{cases} i_1 - i_2 - i_3 = 0, \\ i_1 R_1 + \dfrac{1}{C_I} \int i_2 dt = 0, \\ i_1 R_1 + i_I R_I = 0. \end{cases} \quad (2)$$

Passing to operator form, obtain [2, 18]:

$$\begin{cases} i_1 - i_2 - i_3 = 0, \\ i_1 R_1 + \dfrac{i_2}{C_1 p} = 0, \\ i_1 R_1 + i_1 R_1 = 0. \end{cases} \quad (3)$$

Completely decide the all system does not necessarily, because there is not necessary to obtain current values circuit, but it is necessary to define dependence voltage of charge on the parameters MT with transformer oil, therefore make up a matrix for the determinant of the system:

$$\begin{vmatrix} 1 & -1 & -1 \\ R_1 & \dfrac{1}{C_1 p} & 0 \\ R_1 & 0 & R_1 \end{vmatrix}. \quad (4)$$

From the obtained matrix define characteristic equation [2, 18]:

$$\frac{r1 + ri + C_1 \cdot p \cdot r1 \cdot ri}{C_1 p} = 0. \quad (5)$$

This equation has only one root of the equation is not equal to 0:

$$p = \frac{-R_1 - R_1}{R_1 \cdot R_1 \cdot C_1}. \quad (6)$$

For a root, not having imaginary part, it is possible to consider a process, which is described by equation for the current charge of condenser:

$$i_c = A_{ch} \cdot e^{pt}. \quad (7)$$

For a root, not having imaginary part, it is similarly possible to consider the process of charge of condenser, which is described by equation for voltage on a condenser [6, 7]:

$$U_c = A \cdot (1 - e^{pt}). \quad (8)$$

Solving the equation (Eq. 6) with the following parameters MT: $R_1 = 100000\,Ohm$, $C_1 = 10^{-6}\ F$, $R_1 = 1000000\ Ohm$, obtain:

$$p = \frac{-R_1 - R_1}{R1 \cdot RI \cdot CI} = \frac{10^5 - 10^6}{10^5 \cdot 10^6 \cdot 10^{-6}} = -11. \quad (9)$$

When: $p = -11$ obtain the following dependence of the current through the capacitor during the its charge:

$$i_c = A_{ch} \cdot e^{-11 \cdot t}. \quad (10)$$

Parameter A_{ch} is the maximum current at the moment when a the voltage pulse edge supplied from the generator $G1$, and this current is defined:

$$A_{ch} = i_{max} = \frac{U_{out}}{R_1} = \frac{5}{100000} = 5 \cdot 10^{-5}\ A, \quad (11)$$

where: $U_{out} = 5V$ – a voltage output from the generator $G1$.

A result obtain graph of depending of the capacitor charge current from the time, which is represented in Fig. 6.

For the root, which has no imaginary part as it is possible to consider the charging of the capacitor, which is described by the equation for the voltage on the capacitor [6, 7]:

$$U_c = A \cdot (1 - e^{pt}). \quad (12)$$

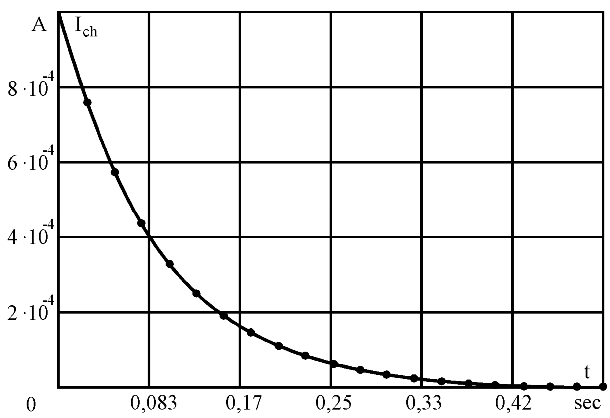

Fig. 6. Oscillograms of the capacitor charging current

As a result, obtain the following dependence of the voltage on the capacitor during the charge:

$$U_c = A_{ch}\cdot(1-e^{-11t}). \tag{13}$$

The parameter A is the maximum voltage supplied from the generator $G1$, which is defined:

$$A_{ch} = U_{max} = 5V. \tag{14}$$

A result obtain graph of depending of the capacitor charge voltage from the time, which is represented in Fig. 7.

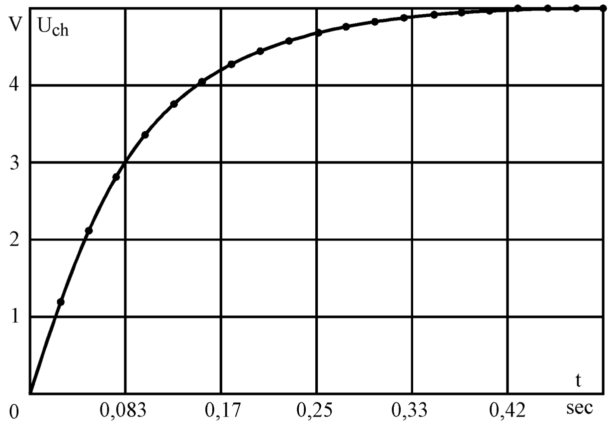

Fig. 7. Oscillograms of the capacitor charging voltage

An area under the curve charge of measuring transducer is determined for voltage:

$$S = A_{ch}\int(1-\cdot e^{p\cdot t})dt = A_{ch}\cdot\left(t-\frac{1}{p}\cdot e^{pt}\right). \tag{15}$$

The size of this area can be got by adding up of voltages in times of a 0.5 s., while there is a discharge, and multiply this sum on the size of interval between measuring dt:

$$A_{ch}\cdot\left(t-\frac{1}{p}\cdot e^{pt}\right) = dt\sum_{n=1}^{m}U_n. \tag{16}$$

Hence obtain the value of *p*, using the Lambert *W* [4]:

$$p = -\frac{1}{t}\cdot W\left(-A_{ch}\frac{t}{A_{ch}\cdot t - dt\cdot\sum_{n=1}^{m}U_n}\right). \tag{17}$$

Since the root of the characteristic equation is $p=\frac{-R_1-R_1}{R_1\cdot R_1\cdot C_1}$, then putting (Eq. 6) in (Eq. 17) get next equality:

$$\frac{-R_1-R_1}{R_1\cdot R_1\cdot C_1} = -\frac{1}{t}\cdot W\left(-A_{ch}\frac{t}{A_{ch}\cdot t - dt\cdot\sum_{n=1}^{m}U_n}\right). \tag{18}$$

Hence find the value C_1 and R_1

$$C_1 = \frac{(R_1+R_1)\cdot t}{W\left(-A_{ch}\cdot\frac{t}{A_{ch}\cdot t - dt\cdot\sum_{n=1}^{m}U_n}\right)\cdot R_1\cdot R_1}. \tag{19}$$

$$R_1 = \frac{t\cdot R_1}{W\left(-A_{ch}\cdot\frac{t}{A_{ch}\cdot t - dt\cdot\sum_{n=1}^{m}U_n}\right)\cdot R_1\cdot C_1 - t}. \tag{20}$$

Calculation of direct and reverse analytical dependences for the process of discharge. For determination of dependence voltage of charge on MT U_{dis} from a capacity C_1 and active resistance R_1 in the schema of substitution, shown on a Fig. 5, the system of equations was made by the system of equations on I and II Kirchhoff laws [2, 18] at zero initial conditions[6, 7]:

$$\begin{cases} i_1 - i_2 - i_3 = 0, \\ \frac{1}{C_1}\int i_1 dt + i_2 R_1 = 0, \\ \frac{1}{C_1}\int i_1 dt + i_3 R_2 = 0. \end{cases} \tag{21}$$

Passing to operator form, obtain [2, 18]:

$$\begin{cases} i_1 - i_2 - i_3 = 0, \\ \dfrac{i_1}{C_1 p} + i_2 R_1 = 0, \\ \dfrac{i_1}{C_1 p} + i_3 R_2 = 0. \end{cases} \quad (22)$$

Completely decide the all system does not necessarily, because there is not necessary to obtain current values circuit, but it is necessary to define dependence voltage of charge on the parameters MT with transformer oil, therefore make up a matrix for the determinant of the system:

$$\begin{vmatrix} 1 & -1 & -1 \\ \dfrac{1}{C_1 p} & R_1 & 0 \\ \dfrac{1}{C_1 p} & 0 & R_2 \end{vmatrix}. \quad (23)$$

From the obtained matrix define characteristic equation [2, 18]:

$$\frac{r2 + ri + Ci \cdot p \cdot r2 \cdot ri}{Ci \cdot p} = 0. \quad (24)$$

This equation has only one root of the equation is not equal to 0:

$$p = \frac{-R_2 - R_1}{R_2 \cdot R_1 \cdot C_1}. \quad (25)$$

For a root, not having imaginary part, it is possible to consider a process, which is described by equation for the current charge of condenser:

$$i_c = A_{dis} \cdot e^{pt}. \quad (26)$$

For a root, not having imaginary part, it is similarly possible to consider the process of charge of condenser, which is described by equation for voltage on a condenser [6, 7]:

$$U_c = A_{dis} \cdot e^{pt}. \quad (27)$$

An area under the curve charge of measuring transducer is determined for voltage:

$$S = A_{dis} \int e^{p \cdot t} dt = \frac{A_{dis}}{p} \cdot e^{pt}. \quad (28)$$

The size of this area can be got by adding up of voltages in times of a 0.5 s., while there is a discharge, and multiply this sum on the size of interval between measuring dt:

$$\frac{A_{dis}}{p} \cdot e^{pt} = dt \sum_{n=1}^{m} U_n. \quad (29)$$

Hence obtain the value of p, using the Lambert W [4]:

$$p = -\frac{1}{t} \cdot W\left(-A_{dis} \frac{t}{dt \sum_{n=1}^{m} U_n} \right). \quad (30)$$

Since the root of the characteristic equation is $p = \frac{-R_2 - R_1}{R_2 \cdot R_1 \cdot C_1}$, then putting (Eq. 25) in (Eq. 30) get next equality:

$$\frac{-R_2 - R_1}{R_2 \cdot R_1 \cdot C_1} = -\frac{1}{t} \cdot W\left(-A_{dis} \cdot \frac{t}{dt \sum_{n=1}^{m} U_n} \right). \quad (31)$$

Hence find the value C_1 and R_1

$$C_1 = (R_2 + R_1) \cdot \frac{t}{W\left(-A_{dis} \cdot \frac{t}{dt \sum_{n=1}^{m} U_n} \right) \cdot R_2 \cdot R_1}, \quad (32)$$

$$R_1 = t \cdot \frac{R_2}{W\left(-A_{dis} \cdot \frac{t}{dt \cdot \sum_{n=1}^{m} U_n} \right) \cdot R_2 \cdot C_1 - t}. \quad (33)$$

Supposing that C_1 unchanging and for the process of charge and for the process of discharge will equate (Eq. 19) and (Eq. 32)

$$\frac{(R_1+R_I)\cdot t}{W\left(-A_{ch}\cdot\frac{t}{A_{ch}\cdot t-dt\cdot\sum_{n=1}^{m}U_n}\right)\cdot R_1\cdot R_I}=\frac{(R_2+R_I)\cdot t}{W\left(-A_{dis}\cdot\frac{t}{dt\sum_{n=1}^{m}U_n}\right)\cdot R_2\cdot R_I}. \quad (34)$$

Since the maximum charging voltage equals the maximum voltage of the discharge, i.e. $A_{ch}=A_{dis}$, from (Eq. 34) determine the active resistance of MT:

$$R_I=\frac{R_1R_2\left(W\left(\frac{-A\cdot t}{A\cdot t+dt\sum_{n=1}^{m}U_{n\,ch}}\right)-W\left(\frac{-A\cdot t}{dt\sum_{n=1}^{m}U_{n\,dis}}\right)\right)}{-W\left(\frac{-A\cdot t}{A\cdot t-dt\sum_{n=1}^{m}U_{n\,ch}}\right)R_1+W\left(\frac{-A\cdot t}{dt\sum_{n=1}^{m}U_{n\,dis}}\right)R_2}. \quad (35)$$

Supposing that R_I unchanging for the process of charge and for the process of discharge will equate (Eq. 20) and (Eq. 33)

$$\frac{R_1\cdot t}{W\left(-A_{ch}\cdot\frac{t}{A_{ch}\cdot t-dt\cdot\sum_{n=1}^{m}U_{n\,ch}}\right)\cdot R_1\cdot C_I-t}=\frac{R_2\cdot t}{W\left(-A_{dis}\cdot\frac{t}{dt\sum_{n=1}^{m}U_{n\,dis}}\right)\cdot R_2\cdot C_I-t}. \quad (36)$$

Since maximal voltage of charge is equal to maximal voltage of discharge, i.e. $A_{ch}=A_{dis}$, then from (Eq. 36) determine the capacity of MT:

$$C_I=\frac{-t\cdot(R_1-R_2)/R_1\cdot R_2}{\left(W\left(\frac{-A\cdot t}{A\cdot t-dt\cdot\sum_{n=1}^{m}U_{n\,ch}}\right)-W\left(\frac{-A\cdot t}{dt\sum_{n=1}^{m}U_{n\,dis}}\right)\right)}. \quad (37)$$

Thus, first measured the voltage of the charge $U_{n\,ch}$ and discharge $U_{n\,dis}$ after a fixed period of time dt (equal to the time single conversion of ADC [20]) during the charge equal to the time of discharge, i.e. 0.5 sec.

Then, knowing R_1 and R_2, with the use of function of Lambert calculated R_I on (Eq. 35) and C_I on (Eq. 37). On these parameters of measuring transducer the quality factor is calculated on the known formula:

$$Q=\omega R_IC_I. \quad (38)$$

where: ω – frequency of generator G_1, equal 1 Hertz.

Should be noted that the function Lambert is calculated by recursion formula:

$$W_{j+1}=W_j-\frac{W_je^{W_j}-x}{e^{W_j}(W_j+1)-\frac{(W_j+2)(W_je^{W_j}+x)}{2\cdot W_j+2}}. \quad (39)$$

where: x – argument of function of Lambert [4], W_j – the value calculated of the function of Lambert on a previous iteration, W_{j+1} – the value calculated for the current iteration of the Lambert function.

At first set by the arbitrary value of function of Lambert [4], for example $W_j=0$, calculated x on a formula:

$$x=W_je^{W_j}. \quad (40)$$

Then on (Eq. 39) is calculated the following approximation for the function Lambert W_{j+1} and are checked: if $\Delta<W_{j+1}-W_j$, then $W_j=W_{j+1}$ and the calculation function is repeated.

In view of the foregoing, has been developed a block-scheme of the device transformer oil moisture testing with microprocessor system (Fig. 8).

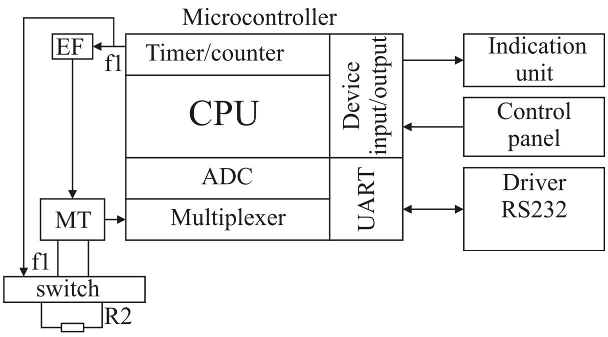

Fig. 8. Block-scheme of the device moisture content testing transformer oil

The timer-counter, which is part of the microcontroller is configured to operate as a generator of issuing rectangular pulses with a frequency f1 = 0.5 Hz.

These rectangular pulses at a frequency f1 coming to an emitter follower EF and to the controllable inputs of switch.

EF performs amplification function signal input of timer-counter for current, which allows to significantly increase the loading ability of the generating device.

Thus, the timer-counter, which is part of the microcontroller and EF perform the function generator G1 (Fig. 8) [1, 19].

With the emitter follower signal of amplification current is applied to measuring transducer MT, where there are processes of charge and discharge capacity of MT.

When the negative edge of the input signal comes to the MT, then at the same time the switch connects the resistance R2 for the discharge capacity of MT.

Voltage of MT through a programmable-controlled multiplexer is supplied to analog-to digital converter (ADC), which, as well as a multiplexer, is part of microcontroller [21].

ADC digitizes the input voltage and supplies a result the central processing unit (CPU) for further processing.

The CPU calculates quality factor from the obtained data and transformer oil moisture content, correspondingly, and saves the results in RAM or in non-volatile memory data.

Through built-in interface UART microcontroller connected to a PC through the driver RS232 with the PC, which evens of logic levels [1].

Using the interface connection allows you to transfer measurement results to a PC for further processing.

After computing the result of moisture content periodically displayed on the indicating unit, which is an alpha-numeric liquid crystal display (LCD).

Control of device the measuring of moisture content of TM implemented by the keys on the control panel, which is a matrix keyboard.

Using the keypad, the operator controls the operation of the device may specify the type of the investigated TO transmit testing results to a PC, perform testing for faults, save, and view the results of testing.

CONCLUSIONS

1. The proposed method of determination of quality factor of MT on the integral value of the measured voltage of charge allows directly through calibration characteristics relate the value of quality factor Q with a moisture content of transformer oil.

2. Use of the function of Lambert in analytical dependences $C_I = f(U_{ch}, U_{dis})$ and $R_I = f(U_{ch}, U_{dis})$, for a moisture testing device of transformer oil necessitates the use microprocessor, able to realize the algorithm of decision these recurrent formulas.

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ИЗМЕРИТЕЛЬНОЕ УСТРОЙСТВО ВЛАГОСОДЕРЖАНИЯ ТРАНСФОРМАТОРНОГО МАСЛА

Дмитрий Половинка, Борис Невзлин, Анатолий Сырцов

А н н о т а ц и я . В работе рассматриваются вопросы определения влагосодержания трансформаторного масла (ТМ). Предложен метод оперативного определения влагосодержания ТМ. Разработана измерительная схема с проточным измерительным преобразователем для определения добротности ТМ. Получены аналитические зависимости емкости и активного сопротивления измерительного преобразователя с ТМ от интегрального напряжения заряда и разряда.
К л ю ч е в ы е с л о в а : трансформаторное масло, влажность, схема замещения, функция Ламберта, измерительный преобразователь, добротность.

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Study of structural stresses in the monolithic concrete of natural hardening

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Summary: This article presents the results of the study of structural stresses in the monolithic modified concrete when it is saturated with a certain amount of coarse aggregate, as well as the impact of structural stresses on concrete properties. This will solve a number of technological problems in the construction of high-rise buildings in summer temperatures.
Key words: modified concrete, structural stresses, strains.

INTRODUCTION

In the natural conditions of summer period occurs temperature-humidity gradient as a result of uneven heating (cooling) or drying (moistening) on the concrete construction section and, consequently, inherent stresses balanced in the whole construction occur.

Qualitatively other inherent stresses, structural stresses, are caused by temperature-humidity strains in anisotropic structure of concrete. Analysis of concrete structural stresses showed that their intensity is high and it often exceeds the ultimate strength of the material. Structural stresses are balanced in aggregate grains area [1, 14, 16, 18].

ANALYSIS OF PUBLICATIONS, MATERIALS, METHODS

Submicrostructural stresses in the cement matrix of concrete occur due to the development of new crystalline hydrate formations. The study of these stresses present considerable difficulties, as they are balanced in microscopic volumes of the cement matrix of concrete. Development of crystallization micro-cracks in the concrete was not observed. This can probably be explained by capillary-porous structure of the cement matrix. Moreover, there is an assertion [2-5, 27] about crystallization stresses usefulness, as they improve the cohesion of spontaneously growing formations. Sharp differences of the stress state of the hardening gel in various conditions are not to be expected because of the possibility of stress relaxation during the deformation of the pores of the material [6, 18].

In 1936 F. Thomas made a review of the works on crack formation of concrete, he found that the first cracks in the concrete become apparent in the age of a few days, while the theoretical period of crack forming was supposed to be 5 weeks. In this same survey it was established that crack formation depends both on the amount of shrinkage and physical-mechanical properties of concrete. To a greater extent crack resistance was determined by the nature of the aggregate. Aggregates of high elasticity contributed to the development of crack formation [7, 9-11]. According to this data tensile stresses in the concrete due to the cement shrinkage make 4,0…5,0 MPa. The intensity of these stresses, calculated by R. Lermit and B. Hank [8], makes 12…16 MPa, i.e. it exceed tensile strength of the material. A.V. Byelov, also considering shrinkage stresses, has established that shrinkage identical to the cooling of the concrete up to 70°C, causes stresses close to the specified [13].

Two types of inherent stress play an important role in natural conditions:

a) stresses of the first type caused by gradients of the temperature-humidity strains on the section of the elements have a certain orientation depending on the geometry of the construction. Stresses of the first type are often called mechanical, because they are determined by the methods of the elasticity theory,

b) structural stresses of the second type caused by the temperature-humidity strains in anisotropic structure of concrete. Stresses of the second type are in a certain way oriented in regard to the surface of the aggregate particles. The analysis of the material structure, apart from the theory of elasticity and plasticity, is necessary to determine them.

It is obvious, that the fields of these stresses are quite different, but their mutual overlapping and joint impact on the continuity of the constructions and relaxation of stresses in time are doubtless. Strength and deformability of concrete depend mostly on the stresses of the first and second type, therefore, the criterion of the concrete crack formation must be determined from their joint action with regard to the age of the material and construction zone [19-23]. Moreover, when studying the elasticity problem of the development of crack formation in concrete elements, the additivity of the stresses of the first and second type is considered to be fair.

As is well known, concrete is an elastoplastic material and this precondition is only partially true [28]. Anyway, plastic properties of concrete play a great role in crack formation [25, 26, 29, 30]. Due to the gradual change in time humidity strains develop droningly. Due to their continuous development, the stresses caused by them significantly relax in time [12, 13, 15, 17, 24]. Thus, the demonstration of plastic properties of concrete is the most complete here.

PURPOSE AND STATEMENT OF A PROBLEM

The purpose of the work is to study the stress state of the high-rise buildings monolithic concrete which hardens in natural conditions in summer period. The task of the research is to prevent the occurrence of technological cracks caused by temperature-shrinkage strains of concrete during its hardening.

THE MAIN SECTION

The development of inherent stresses has different influence on concrete properties. When temperature-shrinkage strains increase in time and, consequently, when structural stresses in the material of the cement sheath around the aggregate increase, there may develop two contrary processes: the area of plastic flows or the area of cracks. The possibility of any process depends on strength and elastic properties of the material. Using the strength theory [14], the condition of the formation of a plastic zone around the grain will be written as follows:

$$\tau_{max} = \frac{V \cdot \Delta E(t)}{\dfrac{1+V}{K_1} + \dfrac{1-V}{K_2}} \leq \frac{k_{nn} R_t}{2}. \qquad (1)$$

The condition of the beginning of crack formation will be expressed using Fere formula for the concrete tensile strength:

$$\sigma_T^{max} = \frac{(1+2V)\cdot 0{,}5\cdot \Delta E(t)}{\frac{1+V}{K_1}+\frac{1-V}{K_2}} = \frac{1}{2}\sqrt[3]{R_t^2}. \quad (2)$$

Hence, we shall express the quantity of ΔE

a) from the condition of the plastic zone formation:

$$\Delta E_{пл} = \frac{k_{пп}\cdot R_t}{2V}\cdot\left(\frac{1+V}{K_1}+\frac{1-V}{K_2}\right), \quad (3)$$

b) from the condition of the crack zone formation:

$$\Delta E_{тр} = \sqrt[3]{R_t^2}\left(\frac{\varphi}{K_1}+\frac{\xi}{K_2}\right). \quad (4)$$

Apparently, for the summer temperatures the limiting crack formation strains are always far less than plastic flow strains. There is a possibility of plastic flow at low values of R/K in unreal concrete compositions, when V>0,8, therefore, only the condition of crack formation as a sequent of a bulk concrete strain is to be considered hereinafter.

Equation of equilibrium for a spherical element separated from the shell around the aggregate looks like [16]:

$$2\cdot(\sigma_p - \sigma_T) + r\frac{d\sigma_p}{dr} = 0. \quad (5)$$

For the crack zone at $\sigma_T = 0$ after the separation of variables it will become:

$$\frac{d\sigma_p}{\sigma_p} = -2\frac{dr}{r}. \quad (6)$$

Integrating the equation between the limits $a \le r \le r_T$, where r_T is the radius of the crack zone, we shall find $\ln\sigma_p = -2\ln r + \ln H$. Therefore, $\sigma_p = \frac{H}{r^2}$. Using the boundary conditions we shall define the arbitrary constant of integration at $r = a, \quad \sigma_p = \sigma_{pa}$. Therefore, considering $a = \frac{d}{2}$; $H = \frac{\sigma_{pa}\cdot d^2}{4}$, definitely $\sigma_r = \sigma_{pa}\frac{d^2}{4r^2}$. The equation is true only within the zone of cracks.

Radial stresses on the boundary of the elastic zone and the crack zone are equal, and unit stresses at $r = r_T$ in the limit equal the tensile strength of material at a time $t : \sigma_T(t) = R_p(t)$. From this condition the radius of the crack zone can be defined:

$$\sigma_t(\tau) = \frac{V\cdot\left(1+2\frac{r_T^3}{\eta^3 d^3}\right)\Delta E(t)}{2\frac{r_T^3}{\eta^3 d^3}\left(\frac{1+V}{K_1}+\frac{1-V}{K_2}\right)\cdot(1+0{,}5\varphi_t)} = \quad (7)$$
$$= R_p.$$

Here we adopt the convention that $b = \eta\cdot d$. In addition coefficient η can be defined by the value with regard to the content of aggregate in a unit of the concrete volume V : $\eta = \frac{1}{2\cdot\sqrt[3]{V}}$.

The crack zone radius around the aggregate equals to:

$$r_T = \frac{d}{2}\sqrt{\frac{\Delta E_t}{2\left\{\left[\frac{R_p}{K_1}\cdot(1+V)+\frac{R_p}{K_2}\cdot(1-V)\right]-\Delta E_t\cdot V\right\}}}. \quad \text{(8a)}$$

It is obvious from the obtained formula that the size of the crack formation zone increases with the extension of the size of aggregate particles (d) and strains $\Delta E(t)$. The formula (8a) can be simplified by adopting, for example K_1=K and $\frac{R_p}{K} = E_R$:

$$r_T = \frac{d}{2}\sqrt{\frac{\Delta E(t)}{4E_R(1+0{,}5\varphi_t) - 2\Delta E(t)\cdot V}}. \quad \text{(8b)}$$

Let's analyze radial and unit stresses in an elastic zone of the aggregate shell.

The elasticity theory considers the problem of the stresses state in axially symmetrical bodies which states that:

$$\mathrm{E}_p = \frac{dU}{dr} = -\frac{2A}{r^3} + B, \tag{9a}$$

$$\mathrm{E}_p = \frac{U}{r} = \frac{A}{r^3} + B, \tag{9b}$$

where: U is a radial displacement of the given point of the element.

Using the generalized Hook's law, the stresses in the mortar shell equal to:

$$\sigma_p = \frac{\mathrm{E}_1}{1-\mu_1-2\mu_1^2}\left[2\mu_1 \mathrm{E}_T + (1-\mu_1)\mathrm{E}_{p1}\right], \tag{10a}$$

$$\sigma_T = \frac{\mathrm{E}_1}{1-\mu_1-2\mu_1^2}\left[\mathrm{E}_T + \mu_1 \mathrm{E}_p\right]. \tag{10b}$$

Substituting into equation (10) the values of the relative strains from the (9), we obtain:

$$\sigma_p = \frac{\mathrm{E}_1}{1-\mu_1-2\mu_1^2}\left[-\frac{2A}{r^3}\cdot(1-2\mu_1)+B(1+\mu_1)\right], \tag{11a}$$

$$\sigma_T = \frac{\mathrm{E}_1}{1-\mu_1-2\mu_1^2}\left[\frac{A}{r^3}\cdot(1-2\mu_1)+B(1+\mu_1)\right]. \tag{11b}$$

It is necessary to obtain the constants of integration real for every layer (A, B, A_1: B_1, A_2, B_2, A_3) to describe the properties of the material equivalent to the adopted structural model. For this purpose, the conditions of equality of radial displacements (9b) and stresses (11a) at the junction of each layer of the element are used like:

$$U = Ar + Br^{-2},\ \sigma_p = 3KA - 6\lambda \cdot K \cdot Br^{-3}, \tag{12}$$

where: K is a modulus of volume elasticity of the material of a given layer, λ is a transverse elasticity parameter.

The reduced equations are true only in the free of cracks layers of the element. For the crack zone, where the convention $\sigma_T = 0$ is made, we shall formulate new integrated forms of equations (12) out of the following conditions.

If $\sigma_T = 0$, it follows from the general Hook's law that:

$$\mathrm{E}_p = \frac{\sigma_p}{\mathrm{E}} \quad \text{or} \quad \mathrm{E}_T = -\mu\frac{\sigma_p}{\mathrm{E}}. \tag{13}$$

Expressing radial strain through the interchange $\mathrm{E}_r = \frac{dU}{dr}$, we find:

$$\sigma_p = \frac{dU}{dr}\cdot \mathrm{E}. \tag{14}$$

The obtained dependence of σ_p on U, as well as the equation of equilibrium (5), allow to write down the equation of strain compatibility on the area between the cracks:

$$\frac{d^2U}{dr^2} + \frac{2}{r}\cdot\frac{dU}{dr} = 0. \tag{15}$$

The integration of the obtained differential equation of second order results in the dependence:

$$U = A + B\,r^{-1}. \tag{16}$$

For the searching of A and B it is necessary to substitute relatively the first and the second columns in this determinant by the right side of the equations.

$K_{\max}$ is defined by formula obtained from the condition that $r_T = a$:

$$K_{\max} = \frac{K_1 K_2}{K_2 - (K_1 - K_2)\cdot V}. \tag{17}$$

At $V = 0;\ K_{max} = K_1$, and at $V = 1{,}0;\ \ K_{max} = K_2$.

The constants of integration of *A* and *B* allow solving a number of tasks. Expressions to determine constants when $r_T = 0$, after elementary simplifications look like:

$$\left.\begin{aligned} A &= \frac{4}{3}\sigma_y \cdot 3b^3 - (1-V)/K_1 - V/\cdot K_2 \\ B &= -3\sigma_y b^3 \cdot \frac{K}{K_1} \end{aligned}\right\}. \tag{18}$$

Using these values in the equation (12) together with the criterion of crack resistance $\sigma_T \le R_p$, as well as the dependence (18), it is possible to calculate the condition of the material continuity conservation, which depends on the shrinkage strain limits of concrete.

Let us write the unit stresses equation for the case of the full development of the crack in the mortar shell $r_T = b$, and ΔE_y we shall express through the ultimate shrinkage of the mortar and coarse aggregate saturation of concrete. Then the real unit stresses, considering their relaxation equal to:

$$\sigma_T = \frac{3V[\Delta E]}{2\left(\frac{1+V}{K_1} + \frac{1-V}{K_2}\right)S} = R_p, \tag{19}$$

where: S is a function of the inherent stresses relaxation which equals one month period of hardening:

$$S = 1 + 0{,}5\,\varphi_t. \tag{20}$$

Here φ_t is a creep characteristic, it is accepted for one month period of concrete hardening, $\varphi = 2{,}0$.

Let's define the intensity of unit stresses as a function of coarse aggregate saturation of concrete, expressing ΔE from the dependence (4):

$$\sigma_T = \frac{3 \cdot E_p \cdot K \cdot V \cdot (1-V)}{2 \cdot S \cdot [(1-V)+nV] \cdot [(1+V)\cdot n + (1-V)]}, \tag{21}$$

where: E_p is a shrinkage strain of the mortar shell of concrete,

n is a ratio of moduluses of volume elasticity of aggregate and mortar $\left(n = \frac{K_2}{K_1}\right)$.

For this purpose we should define the derivative $d\sigma / dV$ and equate it to zero. However, as in general form the equation is rather lengthy, this difficulty can be overcome, giving the amounts of ***n*** certain values and differentiating specific equation at a given value ***n***. For example, if *n=1* than unit stresses equal to $\sigma_T = \frac{3 \cdot E_p \cdot K_2}{4 \cdot S} \cdot V \cdot (1-V)$.

Consequently, $\frac{d\sigma}{dV} = \frac{3 \cdot E_p \cdot K_2}{4S} \cdot (1-2V) = 0$,

whence at $n = 1; V_{onm} = 0{,}50$, analogously $n = 2; V_{onm} = 0{,}38$.

CONCLUSIONS

1. When temperature-shrinkage strains increase in time and, consequently, when structural stresses in the material of the cement sheath around the aggregate increase, there may develop two contrary processes: the area of plastic flows or the area of cracks. The possibility of any process depends on strength and elastic properties of the material.

2. Using values in the equation (12) together with the criterion of crack resistance $\sigma_T \le R_p$, as well as the dependence (18), it is possible to calculate the condition of the material continuity conservation, which depends on the shrinkage strain limits of concrete.

3. The obtained equations allow solving the problem of low level of structural stresses in monolithic concrete when saturating it with a certain amount of coarse aggregate, and also to evaluate the impact of structural stresses on concrete properties.

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ИССЛЕДОВАНИЕ СТРУКТУРНЫХ НАПРЯЖЕНИЙ В МОНОЛИТНОМ БЕТОНЕ ЕСТЕСТВЕННОГО ТВЕРДЕНИЯ

Владимир Пунагин

Аннотация. В статье представлены результаты исследований структурных напряжений в монолитном модифицированном бетоне при определенном насыщении его крупным заполнителем, а также влияния структурных напряжений на свойства бетона. Это позволит решить ряд технологических задач при возведении высотных зданий в условиях летних температур.

Ключевые слова: модифицированный бетон, структурные напряжения, деформации.

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Thermomechanical polymer material molding techniques

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Summary. The possibility of creating a predetermined surface of the polymeric material by heating with stretching proved. The results of thermo-mechanical tests for linear and two-dimensional deformation are given. The methods of approximation of thermomechanical curves are given. The methods of determining the temperature field and stress for getting a given form are given.
Key words: thermomechanical characterization, plane strain deformation, three-dimensional surface, the polymeric material.

INTRODUCTION

The molding of polymeric materials base on their properties change from resilient to elastic and viscous state. These transitions can provide permanent deformation, that can be used for changing the shape of the polymer product.

In practice, these characteristics are obtained, based on the thermo-mechanical diagrams (Fig. 1).

Constructing diagram can identify portions of the resilient (I), elastic (II) and viscous-flow (III) state. Although a number of sources and the need to keep these factors, there are only a few actual recommendations. Given that the process of complex shape polymeric materials is at least two-dimensional distribution, it is desirable to obtain characteristics under plane stress state, that is still not done.

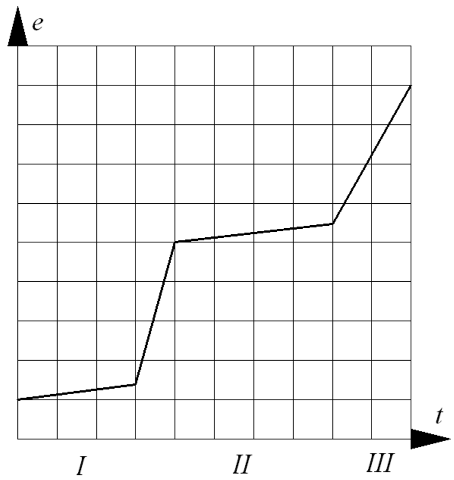

Fig. 1. Typical thermomechanical chart polymeric material

MATERIALS AND METHODS

Creating a three-dimensional shape from sheet polymeric materials is an important task of modern technology. Such materials may include polymeric films or artificial skin [16, 18], textile materials [6, 12] and other polymeric materials [19, 23]. Methods for creating space forms are described in several publications [3 ,7, 22]. Thus in some cases, one can use different properties of polymeric materials such as kinetic [4, 15], plastic [5, 14, 28] and other mechanical properties [1, 21]. A number of publications give the attempts to describe deformation processes from the standpoint of chemical processes [2, 13] or the thermodynamic transformations [9, 29, 30]. A number of experimental data [11, 20] unfortunately does not end with the mathematical modeling and the available approximation [17] have not yet received the practical implementation of the design of process parameters.

Purpose of this article - to develop the approximation model and to determine process parameters for the manufacture of complex parts on the basis of an analysis of various forms of polymeric deformation of the sheet metal and textiles.

The results can be obtained using methods of physics and chemistry of the polymers [13, 24], thermomechanical methods of materials test [8, 26] of the methods of textile materials [3, 25], methods of elasticity and plasticity [10, 27], mathematical methods of approximating and regression [15, 17].

OBJECTS AND PROBLEMS

To construct the thermomechanical characteristics of textile materials it is necessary to maid an experiment where the material is simultaneously subjected of heat and deformation. In such unit (Fig 2) the load, temperature and elongation is fixed at the same time.

Experiment process consists of a heating together with load. The heating temperature of the material is fixed by laser pyrometer, deformation - using a strain gauge. Pyrometer measurement methods in that case are convenient in that case due to the following factors: temperature measurement is made directly on heated body and not the air, infrared measurement technology provides easy check temperature during fast and dynamic processes, lack of feedback the impact on the measurement object by which measurements, measurements can be made on sensitive surfaces and sterile products, in hazardous or inaccessible areas obtained for technical place. Results of the experiment on cotton fabric can be plotted as scatter plots (Fig. 3).

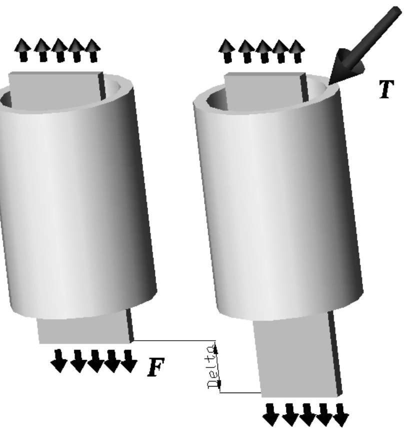

Fig 2. Thermomechanical curves construction principle

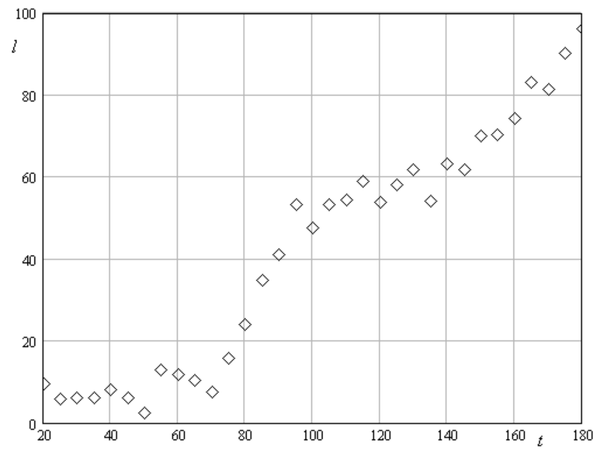

Fig. 3. Textile material thermomechanical curve

It is inconvenient to work with chart in that form, although quite clearly distinguished resilient, flexible and viscous-flow states. Conventionally, each of them can be considered a straight line. These sites can be used for the correlation and regression techniques analyze and result of the temperature dependence of the deformation may be obtained as it is shown:

$$\Delta l = \frac{F}{b}\begin{cases} a_1 + b_1 \cdot t, t < t_1, \\ a_2 + b_2 \cdot t, t_1 < t < t_2, \\ a_3 + b_3 \cdot t, t_2 < t < t_3, \\ a_4 + b_4 \cdot t, t > t_3, \end{cases}$$

where: F - external force, Δl - the width of the sample, ai, bi-linear regression coefficients, t1 - the temperature began to move in an elastic state, t2-temperature end of the transition in the elastic state, t3 - temperature transition in a viscous-flow state.

After the force has changed the family of thermomechanical characteristics can be construct. Piecewise linear function is inconvenient in the case of solving the inverse problem of determining the temperature dependence cause of the deformation necessary to determine several parameters. To construct a continuous function, we can use the methods of the power regression in which the coefficients of the powers determined by method of least squares.

During building dependencies for different values of strength, we can obtain a family of specifications.

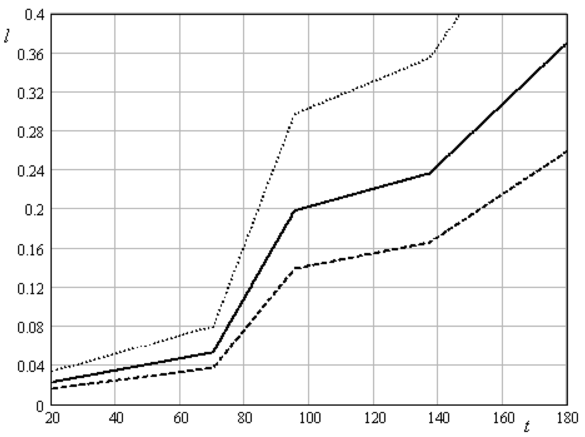

Fig. 4. Family of thermo mechanical characteristics

These dependencies characterize the behavior of textile materials under load during heating. Using them, we can determine the extension that material would be receive under load power and heated to a certain temperature.

For technological purposes during determining the parameters of humid heat treatment we are interested in the reverse goal - we need to define the desired temperature and the power to enforce the wet process - heat treatment, which most often determines the deformation of material.

Given this goal, the original diagram must be rebuild in other coordinates, i.e. dependence temperature from elongation.

In this case, the total temperature dependence of the elongation of the specimen can be written as:

$$t = \begin{cases} \alpha_1 + \beta_1 \cdot \Delta l, \Delta l < \delta_1, \\ \alpha_2 + \beta_2 \cdot \Delta l, \delta_1 < \Delta l < \delta_2, \\ \alpha_3 + \beta_3 \cdot \Delta l, \delta_2 < \Delta l < \delta_3, \\ \alpha_4 + \beta_4 \cdot \Delta l, \Delta l > \delta_3. \end{cases}$$

Family of graphics that characterize this dependence is shown on Fig.5.

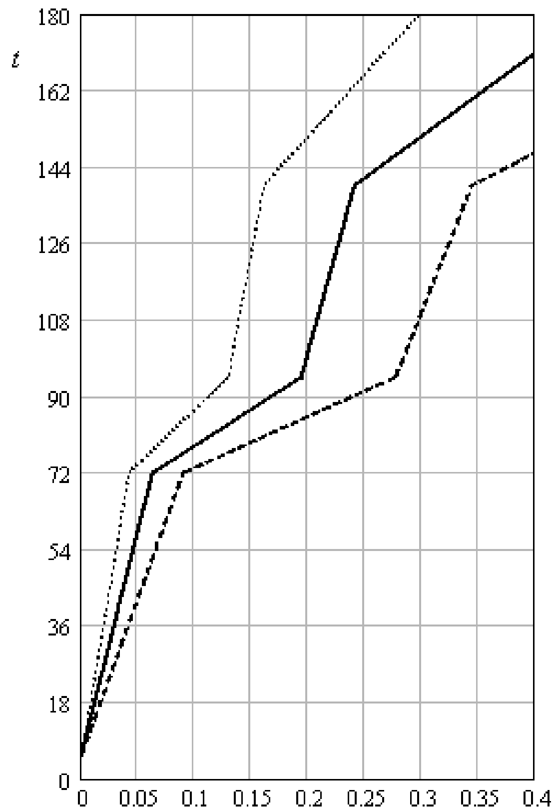

Fig. 5. Family of dependence between temperatures and deformation

Using these dependencies the desired temperature can be fined for a given level of strain.

Meanwhile, it should be noted that the obtained dependences are rather complex structure that does not fully meet the requirements of the process.

In general, the experimental points don't lie on a straight line. In the case of quadratic regression this relationship can be played using a square parabola whose equation has the form:

$$y = a + b \cdot x + c \cdot x^2.$$

For complex relationships can be proposed multistage regression type:

$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + ... + a_m \cdot x^m.$$

Let's analyze the relationship as two branches of cubic parabolas.

From these dependencies we can make two conclusions. The first - a cubic regression line quite well with the behavior of the material in the first two areas. The second - a cubic regression coefficients dimensional and inconvenient to use. To improve this situation we introduce the dimensionless coordinates:

$$\tau = \frac{t}{t_{\max}}, \; e = \frac{\Delta l}{l_0}.$$

Under these conditions, thermomechanical curve is described by the equation:

$$e = \begin{cases} k_{01} + k_{11} \cdot \tau - k_{21} \cdot \tau^2 + k_{31} \cdot \tau^3, \tau < \tau_1, \\ k_{02} - k_{12} \cdot \tau + k_{22} \cdot \tau^2, \tau > \tau_1. \end{cases}$$

Using this equation we have graphic functions

The experimental and regression curve, rebuilt in the specified coordinates will look like Fig.6.

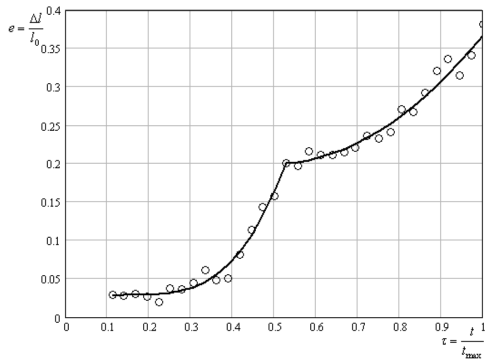

Fig. 6. Comparison of experimental data with polynomial regression

Obviously, the recording function is less cumbersome and involves fewer conditions than four plots with linear regression, in addition, the diagram obtained closer to the experimental points.

Let us try to solve the inverse problem of thermomechanics by defining the temperature dependence of the strain, which is very important for the purpose of technological regimes moist heat treatment.

First reconstruct the experimental dependence in the coordinates where the argument is the relative deformation and function - temperature. Mathematical methods can find points of intersection, then the temperature dependence of the deformation can be represented as:

$$\tau = \begin{cases} \lambda_{01} + \lambda_{11} \cdot e - \lambda_{21} \cdot e^2 + \lambda_{31} \cdot e^3, e < e_1, \\ \lambda_{02} + \lambda_{12} \cdot e - \lambda_{22} \cdot e^2 + \lambda_{32} \cdot e^3, e > e_1. \end{cases}$$

Comparison of regression based on the experimental data shown in Fig.7.

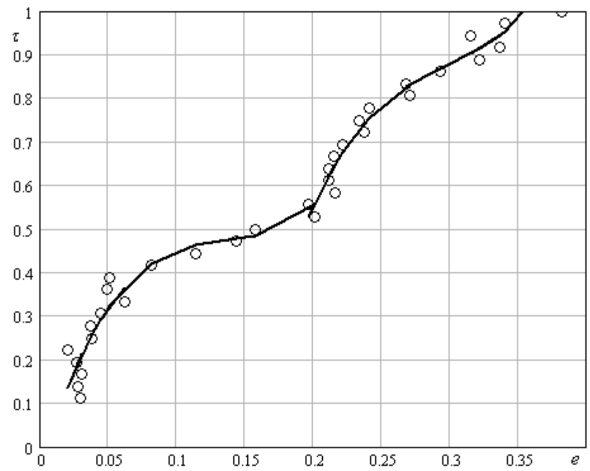

Fig. 7. Polynomial temperature dependence of the strain

Let's go on a logical approach by approximating function to experiment together with the reduction of the number of sites. We make a patch that try to approximate a stepwise function.

The desired function can be made by as

$$e = -0{,}329 + 7{,}3 \cdot \tau - 55{,}077 \cdot \tau^2 + 197{,}937 \cdot \tau^3 - 368{,}124 \cdot \tau^4 + 368{,}326 \cdot \tau^5 - 188{,}231 \cdot \tau^6 + 38{,}58 \cdot \tau^7.$$

Graph which already well reflects the process presents on Fig.8.

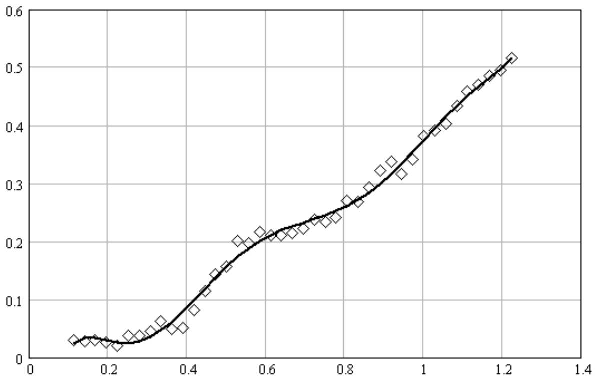

Fig. 8. Approximation of the seventh order

Subsequent analysis shows that the functions of higher order does not give a significant increase in accuracy. Fig. 9 shows a family of thermomechanical curves described regression polynomials for different forces.

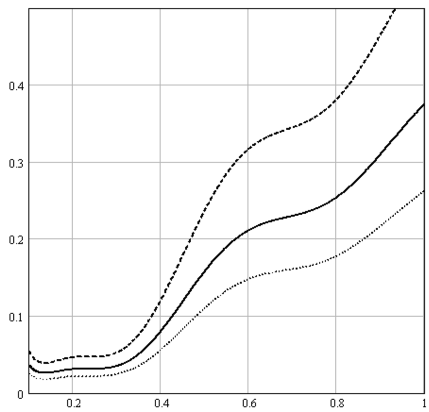

Fig. 9. Different thermo-mechanical forces regression curves

As already mentioned, the real modes of materials deformation are at least two-dimensional. We must also take into account the real properties of the polymers, which also include technical fabrics. The most characteristic feature is the anisotropy - different material properties in different directions. These properties always must be read in the design process changes shape.

Unfortunately, data on the two-dimensional deformation of materials are virtually absent. We have developed an installation, perfected technique and the results obtained by the two-dimensional testing of polymeric materials (Fig.10). In the construction of this experiment the sample is loaded in two perpendicular directions. At the same time it was heated. Resize fixed in two directions.

The family dependence of the material longitudinal and transverse deformation with the ratio of the longitudinal and transverse forces was built.

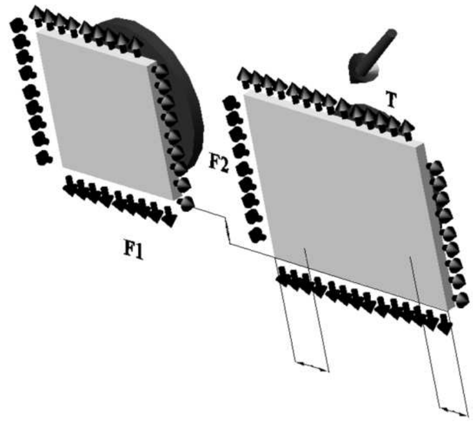

Fig. 10. Definition of two-dimensional thermo-mechanical characteristics

As a research result the complex of relationships, using it a particular material can be written as a system, was obtained.

$$\begin{cases} \varepsilon_1 = f_{11}(t)\cdot\sigma_1 - f_{12}(t)\cdot\sigma_2, \\ \varepsilon_2 = -f_{21}(t)\cdot\sigma_1 + f_{22}(t)\cdot\sigma_2, \end{cases}$$

where: ε_1, ε_2 -relative deformation in two directions, σ_1, σ_2 - stresses in these directions, f_{ij}-thermo-mechanical stiffness characteristics that were found from experiments.

We express the stress through deformation. The result is:

$$\begin{cases} \sigma_2\left(f_{22} - \dfrac{f_{12}\cdot f_{21}}{f_{11}}\right) = \varepsilon_2 + \dfrac{f_{21}}{f_{11}}\cdot\varepsilon_{1,} \\ \sigma_1\left(f_{11} - \dfrac{f_{12}\cdot f_{21}}{f_{22}}\right) = \varepsilon_1 + \dfrac{f_{12}}{f_{22}}\cdot\varepsilon_{2.} \end{cases}$$

In the case of known values of stress strain, results that define the external load on the material and the required temperature distribution on the surface of the material to provide a given deformation can be obtained.

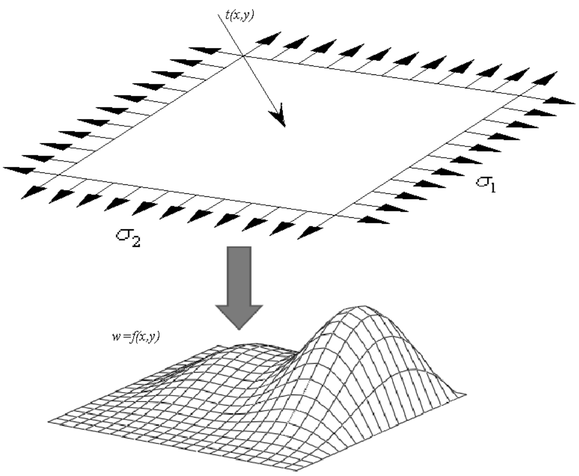

Fig. 11. Thermomechanical deformation of the polymer material

Lets solve the problem of creating a convex surface shape of the polymeric sheet material by stretching it while heating.

We give the material deformation in two mutually perpendicular directions, which we fix like rigid boundaries. We denote this strain ε_0.

Note the following. Real technological processing of polymeric materials should be in the interval t_e- t_p. Temperature, smaller than these values determine the elastic deformation characteristic of the products of these materials. Temperatures above the specified interval defined viscous-flow deformation, characterized by changes in the structure of the polymer material, to achieve these temperatures is unacceptable.

Whereas we are interested only one period of dependence, which is based on appearance, stepwise function can be written. For convenience, lets translate the origin to the start point of elastic deformation and introduce the dimensionless coordinate:

$$\tau = \frac{t - t_e}{t_p - t_e}, \ \bar{\varepsilon} = \varepsilon - \varepsilon_e.$$

The relationship between deformation and temperature will be sought in the form:

$$\varepsilon = \varepsilon_e - p\left(\frac{t - t_e}{t_p - t_e}\right)^k.$$

To find the unknown coefficients using the method of least squares.

Found by the method of least squares coefficients (in this case p = 0,21, k = 0,33) give approximation function, which for experimental comparisons provided in Fig. 12.

The proposed relationship is very convenient. We can use it as a direct deal with the problem of finding a given deformation temperature and the inverse problem of finding the temperature, as this provides the deformation.

Elastic deformation, which preceded the highly elastic traditionally, considered proportional stress acting in the material. We assume that the highly elastic deformation and stress dependence

$$\varepsilon = \frac{\sigma \cdot p}{E}\tau^k,$$

where: E - modulus of elasticity of the material.

Lets solve the problem of creating convex surface of the polymer sheet material by stretching it while heating (Fig. 12).

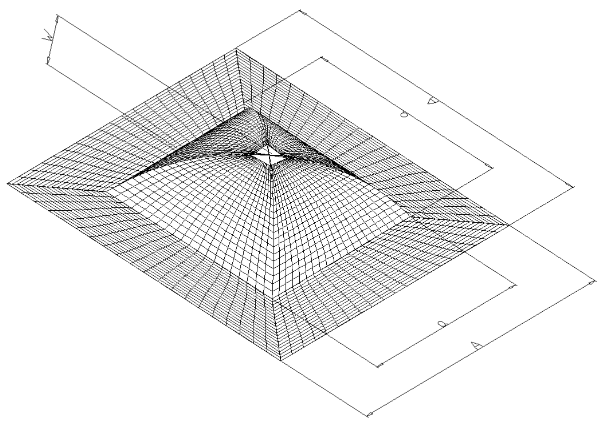

Fig. 12. The form of the material after deformation

The median area of the material with the size of a × a we heat with the temperature t. Then the stress in the cold material is determined by Hooke's law σ = Eε. The tension in the heated material is determined by the law of the state of elastic deformation:

$$\sigma_t = \frac{E_{s_0}}{p\tau^k}.$$

After removing the cooling load in the preheating zone strain is:

$$\varepsilon_x = \varepsilon_0 - \frac{\sigma_t}{E} = \varepsilon_0 (1 - \frac{1}{p\tau^k}).$$

The final deformations cause deflections, that form material surface. Deformation associated with the movement of the terms of the deformation compatibility:

$$\begin{cases} \varepsilon_x = \dfrac{\partial u}{\partial x} + \dfrac{1}{2}(\dfrac{\partial w}{\partial x})^2, \\ \varepsilon_y = \dfrac{\partial v}{\partial y} + \dfrac{1}{2}(\dfrac{\partial w}{\partial y})^2, \end{cases}$$

where: u - longitudinal displacement, v - transverse displacement, w-vertical displacement (deflection). The coordinate system is further associate with the center of symmetry of the sample material.

Compatibility equation in the form of Saint-Venant in the absence of distortions of the material is written in the form:

$$\frac{\partial^2 \varepsilon_x}{\partial y^2} + \frac{\partial^2 S_y}{\partial x^2} = \frac{\partial^2 w}{\partial x^2}\frac{\partial^2 w}{\partial y^2}.$$

This equation, as well as the conditions of equality of zero deflection on the boundary corresponds to the function:

$$w = C\cos\frac{\pi x}{2a}\cos\frac{\pi y}{2a}.$$

Boundary conditions in the longitudinal direction of the movement meets function:

$$u = B\sin\frac{\pi x}{a} f(y).$$

Substituting in the first equation of strain compatibility, we get:

$$\frac{\partial u}{\partial x} = B\frac{\pi}{a}(1 - 2\sin^2\frac{\pi x}{2a}) f(y).$$

Having taken $f(y) = \cos^2\frac{\pi y}{2a}$, we obtain the condition:

$$C^2 = \frac{16a}{\pi}B, \varepsilon_x - B\frac{\pi}{a}\cos^2\frac{\pi y}{2a} = 0.$$

In order to satisfy the second condition, consider the average value of the area integral:

$$\bar{f} = \int_{-a}^{a}\cos^2\frac{\pi y}{2a}dy = \frac{1}{4}.$$

So $B = \dfrac{4a\varepsilon_x}{\pi}, C = \dfrac{8a}{\pi}\sqrt{\varepsilon_x}.$

Given the expression for the residual strain, we can find the maximum deflection:

$$W = \frac{8a}{\pi}\sqrt{\varepsilon_0 (1 - \frac{1}{p\tau^k})}.$$

If we solve the technological problem, we usually specified form of the surface, or at least the maximum convexity to be provided. From this, we can find the necessary technological deformation or desired temperature. Given that the deformation process is limited in terms of the elastic base material, we will determine the appropriate temperature for the deformation process:

$$t = t_e + (t_p - t_e)\left[\frac{64a^2(\varepsilon_0 - \varepsilon_e) - \pi^2 W^2}{p(64a^2\varepsilon_0 - \pi^2 W^2)}\right]^k.$$

This dependence will determine reasonable temperature heat treatment of polymeric materials under deformation, will reduce excessive energy costs when assigning surplus temperature regimes, as it happens now.

An experiment with three-dimensional deformation was also constructed (Fig.13).

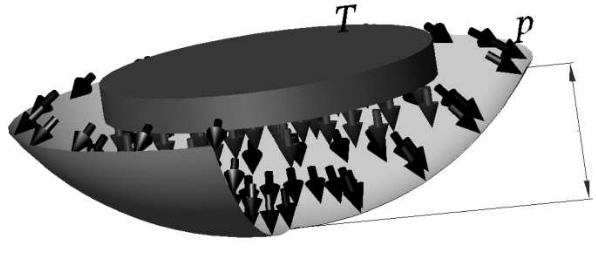

Fig. 13. The complex deformation of the material

The real technological task of forming the surface of the textile product by means of heat treatment is solved.

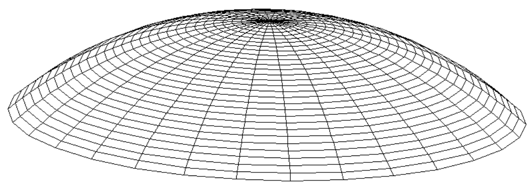

Fig. 14. The surface of the material to be forming

Define the function of surface curvature, and the extension. For this we consider a separate section of the surface that is required for processing. Let's represent it in the Cartesian coordinate system. Isolate in the surface a small element with size *dx*, it corresponds to a change ordinates section *dy*. Element of length *dx* changed its length to $dl=\sqrt{dx^2+dy^2}$. Thus, this element became elongation:

$$e=\frac{dl-dx}{dx}=\frac{dl}{dx}-1=\sqrt{1+\left(\frac{dy}{dx}\right)^2}-1.$$

Whereas not too much curvature obtained surfaces are:

$$e=\sqrt{1+\left(\frac{dy}{dx}\right)^2}-1\approx\frac{1}{2}\left(\frac{dy}{dx}\right)^2.$$

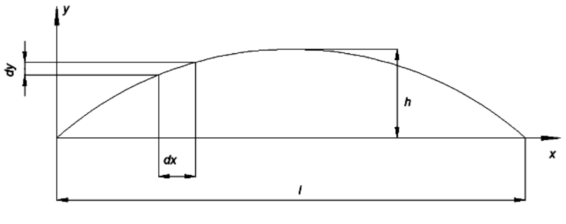

Fig. 15. Curvatures of the surface material

Given that we have a function of temperature, which is recorded depending on the extension, we can find the required temperature settings. It should be noted here that the function is written as a system of two expressions not very convenient to use because it requires binding of the deformation and comparing it with the parameter. Easier would be to use the tool, which would strain expressed clearly, without additional conditions. Try to approximate the function as a power curve.

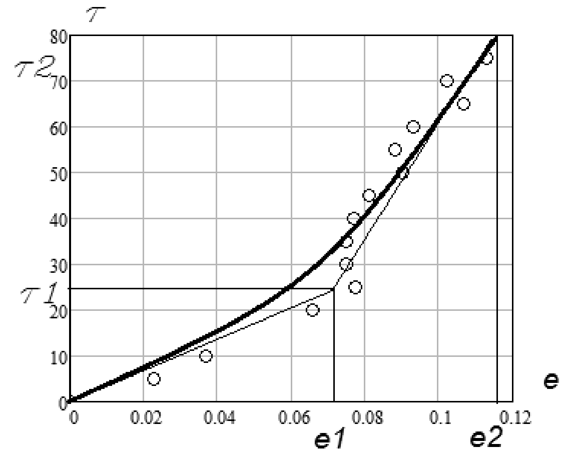

Fig. 16. Curve of thermomechanical changes

If this function is written in the form *t = f (e)*, we can determine the conditions:

When *e*=0, *t*=0, when *e=e2, t=t2,* when *e*=0, $\frac{d\tau}{de}=\frac{\tau 1}{e1}$, when *e=e2,* $\frac{d\tau}{de}=\frac{\tau 2-\tau 1}{e2-e1}$.

Thus, we have four conditions that are sufficient to create a polynomial of the third degree. Considering first zero condition, write it in the form of:

$$\tau=k1\cdot e+k2\cdot e^2+k3\cdot e^3.$$

The derivative of this expression can be written as:

$$\frac{d\tau}{de}=k1+2\cdot k2\cdot e+3\cdot k3\cdot e^2.$$

The third condition gives $k1=\frac{\tau 1}{e1}$.

After consideration of the first and third terms of two unknown coefficients found by solving the system of equations, written for the second and fourth terms:

$$\begin{cases}\tau 1\dfrac{e2}{e1}+k2\cdot e2^2+k3\cdot e2^3=\tau 2,\\ \dfrac{e2}{e1}+2\cdot k2\cdot e2+3\cdot k3\cdot e2=\dfrac{\tau 2-\tau 1}{e2-e1}.\end{cases}$$

Solving the system gives:

$$k2 = \frac{(\tau 2 \cdot e1 - \tau 1 \cdot e2)(2 \cdot e2 - e1)}{e1 \cdot e2^2 \cdot (e2 - e1)},$$

$$k3 = \frac{(\tau 2 \cdot e1 - \tau 1 \cdot e2)(2 \cdot e1 - e2)}{e1 \cdot e2^2 \cdot (e2 - e1)}.$$

Then the general expression for a function of temperature:

$$\tau = \frac{\tau 1}{e1} e + \frac{(\tau 2 \cdot e1 - \tau 1 \cdot e2)}{e1 \cdot e2^2 \cdot (e2 + e1)} e^2 \times$$
$$\times \left[2 \cdot e2 - e1 + (2 \cdot e1 - e2) \frac{e}{e2} \right].$$

Comparison of the obtained functions with discontinuous linear as shown in Fig. 16.

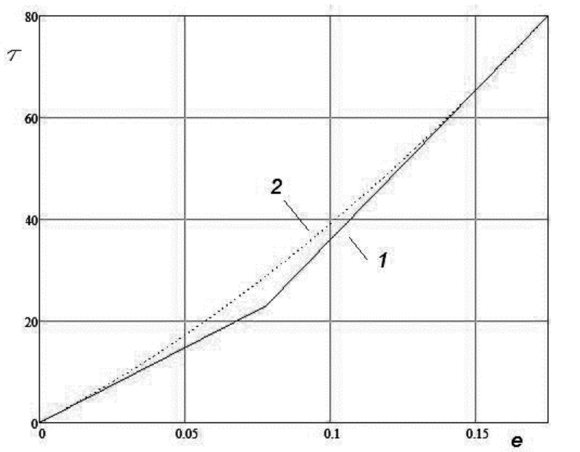

Fig. 17. Comparison of step functions with discontinuous linear

If the specified surface is set up by means of heat treatment, the temperature distribution, which provides a surface can be written as:

$$\tau = \frac{\tau 1}{e1} \frac{1}{2} \left(\frac{dy}{dx} \right)^2 + \frac{(\tau 2 \cdot e1 - \tau 1 \cdot e2)}{e1 \cdot e2^2 \cdot (e2 + e1)} \frac{1}{4} \left(\frac{dy}{dx} \right)^4 \times$$
$$\times \left[2 \cdot e2 - e1 + (2 \cdot e1 - e2) \frac{e}{2 \cdot e2} \left(\frac{dy}{dx} \right)^2 \right].$$

CONCLUSIONS

1. The opportunity of creating the product surface with longitudinal deformation of the material while heating has been proved.

2. On the basis of the solution of the differential equation of strains compatibility the parameters of deformation and heating to ensure the formation of a given surface are determined.

3. The required temperature for the process of deformation is defined as an explicit function of the surface shape.

4. Getting evidence-based temperature creates the prerequisites for energy savings in the enterprise.

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ТЕРМОМЕХАНИЧЕСКИЕ МЕТОДЫ ФОРМОВАНИЯ ПОЛИМЕРНЫХ МАТЕРИАЛОВ

Рябчиков Николай, Челышева Светлана, Волошина Ольга, Мокшина Ольга

Аннотация. Доказана возможность создания заданной поверхности полимерного материала при нагреве с растяжением. Приведены результаты термомеханических испытаний при линейном и двумерном деформировании. Показаны методы аппроксимации термомеханических кривых. Приведена методика определения поля температур и нагрузок для получения заданной формы.

Ключевые слова: термомеханическая характеристика, плоская деформация, деформирование, трехмерная поверхность, полимерный материал.

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Properties of the phase components of the modified cement system

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Summary: The article presents the results of the study of the influence of modification on the clinker mono minerals structure formation. A research of synthesized and modified mineral systems resistance to the weathering (carbonation, varying conditions), as well as to the aggressive solutions exposure was conducted.
Key words: cement system, modification, mono minerals, resistance.

INTRODUCTION

There are many ways of purposeful control of structure formation of the concrete mixtures' cement systems at different stages of hardening [1, 3, 6]. The most rational way is a structure adjustment through the introduction of modifiers. Modification of cement systems by various chemically-active components intentionally changes hardening and structure formation processes, provides the improvement of the technological properties of the material [2, 4, 7-9]. However, modification has an ambiguous impact on the properties of mono minerals of the cement system [12, 13, 21, 22, 26].

Modification means creation of favorable conditions for the clinker minerals chemical interaction and further formation of the concrete cement matrix with specified properties. The simplest way of intensification of hydration process and optimization of cement systems structure formation is a usage of polyfunctional admixtures [5, 11, 16, 19, 23]. Such additives, intensifying hydration process, having an effect on the hydration products morphology and their structure formation process, can't be composed of one component [15, 27, 28, 30]. Obviously, such additives must form a complex with polyfunctional properties. At the same time, organic plasticizers, widely used at building industry enterprises, require an addition with special mineral components, chemically interacting with clinker minerals. Thus, it's necessary to choose a complex composition modifier with polyfunctional effect on the structuring cement system. An optimizing effect of the complex modifier becomes apparent on the crystallochemical level of structure formation. Consequently, crystallochemical optimization of the cement systems structure formation may be performed by a special complex, based on modern non-deficit and effective components [10, 17, 18].

Nowadays there are many ways of modification of binding systems, most of them based on the turbulent mixing of components. At the turbulent motion material particles move randomly both in the direction of current and transversely to it. The particles interpenetrate from one layer to another, the number of their encounters increase [14, 19, 20, 24].

Usually abroad turbulent mixing is used for the preparation of injection compositions, as they help to raise the stability of concrete mixtures.

In the authors' opinion, turbulent mixing leads to the deflocculation of a cement-water suspension, as a result saturation of suspension with colloid particles increase, the paste becomes more stable, bleeding reduces. As a result of turbulent mixing, cement paste viscosity decreases to a certain point in time, when the mixture temperature rise due to the exothermal reaction of clinker minerals hydration starts acting back and the mixture thickens. The optimal duration of mixing, when paste viscosity decreases with the simultaneous reduce of bleeding, is in a certain relationship to a water-cement ratio [10, 17, 18, 25].

The authors [18, 23] are of opinion that turbulent treatment leads to an increase of the cement specific surface area due to the grinding of fine fraction. However, the results of the research conducted by authors [10, 29, 30] showed that specific surface area remains unchanged. Hence, contradictoriness of opinions is indicative of insufficient knowledge of binding systems modification. An ambiguous impact of different modifiers on clinker mono minerals should also be taken into account, as in bulk this may have a negative impact on the processes of structure formation of the concrete cement matrix.

PURPOSE

The purpose of the work is a research of synthesized and modified mineral systems resistance to the weathering (carbonation, varying conditions), as well as to the aggressive solutions exposure.

RESEARCH DATA

Study of the property change of the phase components of the modified cement system during six months carbonation shows that the bending strength of both, hydrated calcium silicate (tobermorite group) and xonotlite, diminishes, whereas on the contrary the strength of the highly basic hydrated calcium silicate significantly increases (Table 1). In this conditions low-basic hydrosilicates, especially tobermorite group, despite their higher density, carbonate much faster and change more intensively in comparison with the less dense highly basic hydrated calcium silicate.

Table 1. Operating abilities of modified monomineral systems

Phase components	Bending resistance, MPa		
	after synthesis	after carbonation	after alternate wetting and drying
C–S–H(I)	8,0	9,3	8,6
Xonotlite	14,3	11,6	10,2
$C_2SH(A)$	4,5	5,9	6,6
$C_2SH(C)$	2,8	4,8	5,4
C_3AH_6	4,4	6,2	5,6
C_3ASH_4	3,9	5,7	6,3

Bending resistance, MPa		Freeze-thaw resistance, cycles	Degree of shrinkage after carbonation, %
in 5% solution of Na_2SO_4	in 2,5% solution of $MgSO_4$		
7,6	6,7	54	2,4
12,9	9,6	47	0,93
4,4	2,5	275	0,52
3,6	2,7	154	0,34
Fractures in 17 days	Fractures in 26 days	-	0,21
Fractures in 46 days	Fractures in 57 days	-	0,12

The reason of it is a big specific surface area of C–S–H(I), which accelerates its interaction with carbonic acid gas and leads to a fast oversaturation and occurrence of a big number of nuclei. A lot of small defective crystals emerge as a result. Besides, the significant carbonation speed of low-basic hydrated calcium silicate (tobermorite group) can be explained by its layer structure.

Access of moisture-dissolved carbon acid gas inside the hydrated calcium silicate takes place together with hygroscopic water when a water molecule penetrates along the layered crystal cleavage surface. The carbonation speed of hydrated calcium silicate to a great extent depends on the humidity of environment. At the same time, ions of Ca^{2+} in hydrosilicate, being a center of water molecule persorption according to the two types of a bond (silicon-oxygen radicals and OH^- ions) in a crystal cell, take carbon acid gas much easier. If CO_2 is replaced according to OH^- bonds, then $CaCO_3$ forms instead of hydrosilicate, and if the replacement takes place according to the silicon-oxygen radicals bond, then scawtite forms. It should be mentioned that in the usual terms replacement of CO_2 takes place according to the ionic bond OH^-.

It is established that modified concrete strength and deformability change differently depending on the concentration of carbon dioxide in the atmosphere. In the first case, when the concentration of CO_2 is weak, i.e. the oversaturation of the solution is not too big, calcite crystallizes calmly and its crystals are larger. Calcite crystals grow due to the joining of atoms near the active centers, calcite has better structural properties (less defect and dislocation cluster).

In the second case, when the CO_2 concentration is strong and the oversaturation is significant and even exceeds a critical value, calcite crystallization takes place in a spontaneous formation of nuclei, small crystals of the same size form for a certain period of time. Therefore, to improve the structure and properties of the crystals of calcite, which is one of the products of hydrated calcium silicate carbonation, it's necessary to reduce oversaturation, i.e. to reduce the concentration of the carbonized environment.

The strength of the carbonated calcium hydrosilicate is determined by the degree of crystallization and the size of crystals. In the process of carbonation of a less crystallized C–S–H(I) a large amount of loose calcium carbonate is formed.

A physical phenomenon, accompanied by bulking of a solid phase, and bringing forth the inherent stresses in concrete can be observed in the process of carbonation of calcium hydrosilicate, besides the chemical processes listed above. The intensity of stress and its tension seem to raise with the increase of carbonation speed.

Study of changes of the hydrated calcium aluminate and calcium hydrogarnet properties showed that when artificially carbonated the hydrated calcium aluminate strength increases in a greater degree than calcium hydrogarnet strength. Judging by the amount of the combined CO_2 this corresponds to a significant degree of carbonation of hydrated calcium aluminate in comparison with calcium hydrogarnet. In the conditions of alternate wetting and drying during 50 cycles the strength of tobermorite group and xonotlite decreases and the strength of $C_2SH(A)$ and $C_2SH(C)$ increases, but in a lesser degree than at carbonation (Table 1). In these conditions the strength of hydrated calcium aluminate almost doesn't change and the strength of calcium hydrogarnet increases slightly. Along with this an imperceptible shrinkage is observed.

The layered structure and water contained in the structure of hydrated calcium silicate (tobermorite group) are able to change depending on the effect of environment. If we consider a layered crystal of tobermorite as compiled packages connected along the basal planes of the elementary crystallites than abrupt change of desorption curves is due to exudation of hygroscopic water from the interplanar spacing. At the same time a unit cell *c* parameter changes from 27 to $24{,}6 \cdot 10^{-10}$ m [5, 12, 15].

Properties of hygroscopic water in hydrated calcium silicate with layered structure depend on H_2O/SiO_2 ratio. When the ratio value is less than one then molecules of hygroscopic water are not included in the structure of the crystal lattice and have a mobility of liquid water and so the water is inconstant due to the environment factors variations [6, 22].

It is established that when silica-containing component is introducted in the amount more than 20% of cement weight then new phases form, and if the amount is less the

20% then there is a replacement of ions in the crystal lattice of the cement phase components. The ability of the cement phase components to replace isomorphously the ions of other elements in their lattices varies according to the type of a mineral modifier, the similarity of its physical and chemical characteristics and atomic size with the cement phase components. We have studied the processes of substitution of ions of Na^{+}, Al^{3+}, Fe^{3+}, $SO^{4-}{}_2$ and $CO_{3-}{}^{2-}$ by the hydrated calcium silicate and the change of the properties of the latter during carbonation. It is established that the optimal amount of mineral modifier, by the degree of substitution and its positive influence on the properties of hydrated calcium silicate, varies depending on the ratio CaO/SiO_2 in the mixture and intensity of modification.

The positive effect of substitution of these ions on the properties of the cement phase components can be estimated to a large extent by the degree of shrinkage behavior after carbonation of the hydrated calcium silicate. It is established that that the major part of the shrinkage of C–S–H(I) takes place on the first 5…10 days, shrinkage of the tobermorite on the 20…25 days, xonotlite and $C_2SH(C)$ on the 10…20days. Depending on the type of modifier shrinkage processes of the hydrated calcium silicate proceed in varying degrees. So, for example, replacement of Na^{+} reduces shrinkage of C–S–H(I) up to 4 times, tobermorite and $C_2SH(C)$ almost up to 1,5 times. In these conditions replacement of ions of Al^{3+} reduces the shrinkage of C–S–H(I) and tobermorite up by 10…20%, xonotlite up to 1,5 times, $C_2SH(C)$ up to more than 2,5 times. Replacement of CO_3^{2-} and SO_4^{2-} is conductive to the significant reduction of shrinkage, especially in tobermorite and xonotlite – up to 2 times, in $C_2SH(C)$ almost up to 1,5 times.

Analysis of the data shows that selection of the type and the degree of substitution of ions allows reducing the shrinkage of hydrated calcium silicate extensively. Especially it refers to hydrated calcium silicate C–S–H(I) and tobermorite, which have a significant shrinkage, their shrinkage can be brought to the level of low-shrinkage type of hydrated calcium silicate, such as xonotlite and $C_2SH(C)$. Although the shrinkage of the latter is high, however it can be minimized by substituting ions of Al^{3+}, Fe^{3+} and SO_4^{2-} in their lattice. Beneficial effects are caused by the fact that ions of Al^{3+}, Fe^{3+}, SO_4^{2-} are in the structure of hydrated calcium silicate, substituting Si^{4+}, and Fe^{3+} hardly gets in the crystal structure due to the large ionic radius in comparison with Si^{4+} [27]. The replacement of Fe^{3+} has a more beneficial effect on the shrinkage of xonotlite and $C_2SH(C)$ which are synthesized at higher ratio of CaO/SiO_2, than C–S–H(I).

The study of the corrosion stability of the phase components of the modified cement system in sulphate solutions within 12 months showed that the most intensive fracture of hydrated calcium silicate can be observed ian $MgSO_4$ solutions. In this solution in the initial period of storage (up to 3 months) the strength of the samples increases, in the sequel it reduces. The strength in Na_2SO_4 solution starts reducing from the initial period of storage. Low-basic hydrated calcium silicate (tobermorite group and xonotlite) corrode more in the sulphate of magnesia solutions, than highly basic hydrated calcium silicate [$C_2SH(A)$ и $C_2SH(C)$]. After one year storage in a 2,5% solution of $MgSO_4$ their resistance coefficient decreases to 0,76…0,68.

The increased corrosive action of $MgSO_4$ solutions on hydrated calcium silicate in comparison with Na_2SO_4 solutions is due to the fact that ions of the latter because of the heterovalent substitution by the scheme $2NA^{+}\leftrightarrow Ca^{2+}$, as well as the difference in their ionic radii complicate their interaction, while the substitution $Mg^{2+}\leftrightarrow Ca^{2+}$ between cations Mg^{2+} and Ca^{2+}, which have closer ionic radii, goes on faster. Reactive capacity of the specified solutions with hydrated calcium silicate is also determined by the adsorption capacity of their ions. So, polyvalent cations of Mg^{2+} are better adsorbed in hydrated calcium silicate than monovalent cations of Na^{+}. This can be explained by Pyeskov-Fajans rule: when hydrated calcium silicate interreacts with $MgSO_4$ solution, all the occurring products ($MgSO_4$ and gypsum) are hardly soluble, whereas with Na_2SO_4 solution only gypsum is hardly soluble and the second type of the reaction product NaOH is in the liquid phase. Furthermore, in these conditions adsorbability of the cations of Mg^{2+}, which form with OH^- ions less soluble $Mg(OH)_2$ (water solubility at $20^{\circ}C$ makes 0,9 mg/l), is more than adsorbability of SO_4^{2-} ions, which form gypsum with cations of Ca^{2+} (its water solubility makes 2,41 mg/l).

From this it follows that a double electric layer is formed on the border of hydrated calcium silicate and the specified solutions, and in $MgSO_4$ solution a double electric layer on the surface of hydrated calcium silicate is formed from the ions of Mg^{2+} and OH^-, and in Na_2SO_4 solution from the ions of Ca^{2+} and SO_4^{2-}. The speed of the electric double layer formation depends on the adsorption capacity of the ions of solutions, and this determines the intensity of the corrosive processes.

Considering the kinetics of cement phase components interaction with aggressive solutions it may be said that chemical heterogeneous reaction rate is determined by the interacting particles diffusion rate. As a result of interaction of the hydrated components of cement with the corrosive environment an interfacial film occurs, it has different density depending on the ratio of a volume of reaction products and reacting substances. This film, consisting of a mixture of $CaSO_4 \cdot 2H_2O$, $Mg(OH)_2$ and gel SiO_2, inhibits or in some cases neutralizes the rate of heterogeneous reaction between the binding material and liquid corrosive environments if the condition of continuity according to the rule of Pming and Betwarts is satisfied [10]. According to this rule the molecular volume of the mixture of $CaSO_4 \cdot 2H_2O$, $Mg(OH)_2$ and gel SiO_2 must be more than the volume of binding materials spent on the formation of the molecules of these compounds. Otherwise, the film created by the molecules of these corrosion products is not enough to cover with the solid layer the entire surface of binding materials, as a result it is loose and porous. Consequently, protective properties of the film depend on its quality (density and continuity), i.e. on the diffusion coefficient of the particles interacting through the film.

The analysis showed that interfacial films formed at the interaction of $C_2SH(A)$ and $C_2SH(C)$ with sulphate solutions (Na_2SO_4 and $MgSO_4$) have a dense structure and when tobermorite group and xonotlite interact with the specified solutions they , on the contrary, have a porous structure. It means that ions of xonotlite, tobermorite, C–S–H (I) and interacting solutions can freely diffuse through them.

Thus, the formation of a porous film in the 2,5% solution of $MgSO_4$ is one of the reason of such a fast fracture of low-basic hydrated calcium silicate. But, despite this they fracture more slowly in a 5% solution of Na_2SO_4 that is the consequence of the less reacting capacity of the ions of Na^+, than of Mg^{2+}.

CONCLUSIONS

1. Based on the above we can conclude that highly basic hydrated calcium silicate in solutions of $MgSO_4$ and Na_2SO_4 must fracture slower or slightly lose its original strength due to the protective film. In fact, in $MgSO_4$ solution that's the way it is and in Na_2SO_4 solution, on the contrary, highly basic hydrated calcium silicate fractures intensively.

2. Such inconsistency of the mechanism of Na_2SO_4 solution on the highly basic hydrated calcium silicate is due to the fact that the resulting corrosion products are reactive to each other.

3. So, the presence of NaOH in the liquid medium complicates the formation of gypsum crystals and their intergrowth with each other and dissolving in it, they form porous, available for ionic diffusion interacting particles. Besides, sodium hydroxide partially transfers SiO_2 gel into soluble sodium silicate. This allows generating a protective film whose volume is larger than the raw

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СВОЙСТВА ФАЗОВЫХ СОСТАВЛЯЮЩИХ МОДИФИЦИРОВАННОЙ ЦЕМЕНТНОЙ СИСТЕМЫ

Дмитрий Руденко

Аннотация. В статье представлены результаты исследований влияния модифицирования на структурообразование мономинералов клинкера. Исследована стойкость синтезированных и модифицированных мономинеральных систем к воздействию атмосферных факторов (карбонизации, переменных условий), а также агрессивных растворов.

Ключевые слова: цементная система, модифицирование, мономинералы, стойкость.

The influence of direct extrusion parameters of porous powder billets on the quality of products

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Summary. The mathematical model of stress-strain state has been developed for solving the problem of direct extrusion of hollow porous powder billets by finite element method. The dependences of backpressure on the ratio of dimensions, depth and wall thickness of the cavity parts have established. Distributions of the intensity of stress and intensity of deformation at optimal value of backpressure have obtained. Distributions of relative density, hardness and appearance of defects at direct extrusion of powder billets with backpressure and without it have been investigated experimentally. The production technology for hollow powder parts from porous powder billets by direct extrusion has been developed.
Key words: powder billet, direct extrusion, backpressure, defect.

INTRODUCTION

Extrusion of details from porous powder billets allows production of complex-shaped parts with internal cavities and substantial differences of sections [9, 10, 23]. The main forming condition of porous billet is the uniform compression scheme that ensures plasticity of hard phase. Powder billets with the relative density 0.85 and more are used for extrusion of details [5, 6, 29].

One of the factors ensuring a high quality of powder products is the backpressure that impacts a stress-strain state and, consequently, shaping and appearing of shape defects during extrusion of compact materials [11, 25, 27]. The influence of backpressure at deformation of porous powder billets promotes to reach the required density of products and eliminates density variation [9, 16].

According to the literature [7], it is recommended to take the backpressure for extrusion of compact materials equal to yield stress. At the same time, significant values of accumulated deformation of hard phase at extrusion of porous billets are leading to considerable deformation hardening and, consequently, growing of yield stress that increases a hydrostatic pressure on the matrix and punches. The intensity of stress into the die tool may reach conditional yield stress of tool steel and even exceed it, while increasing of the backpressure, resulting in destruction of die. The conditions mentioned above are limiting the applicability of such recommendations [7].

It is necessary to refer that two simultaneous processes are taking place at extrusion of porous powder billets – densification of the compacting material and deformation with flowing into hollows of the die impression [29]. The higher density of billets was achieved at the densification stage and the later forming stage started, the greater density and lower inhomogenuity of its distribution obtained [22].

Friction forces of billet along matrix walls during densification stage are preventing flowing of material into the wall of product and the beginning of the second deformation stage at direct extrusion of parts such as 'cartridge' [3] resulting in high density of products. Metal flow to the wall at the reverse extrusion of such parts starts without densification and the final density of the products is lower [12].

This work aims on development the mathematical model of stress-strain state at direct extrusion of hollow porous powder billet, as well as experimental investigation of the influence of backpressure on the density, hardness, pressure variation and quality of products.

MATERIALS AND METHODS

Mathematical modelling of direct extrusion has been provided on the basis of laws of the plasticity theory of porous bodies. Plastic potential is considered as a function of the stress tensor components and presented in the following form [1, 2, 13, 21, 27]:

$$F=\frac{\tau^2}{\varphi}+(1+m)^2\frac{\left(p+\frac{m}{m+1}\bar{\rho}\sigma_s\sqrt{\psi}\right)^2}{\psi}-\bar{\rho}\sigma_s, \quad (1)$$

where: $p=\frac{1}{3}\sigma_{ij}\delta_{ij}$ – is the medium pressure,

$\tau=\sqrt{\left(\sigma_{ij}-p\delta_{ij}\right)\left(\sigma_{ij}-p\delta_{ij}\right)}$ – is the intensity of shear stress,

$\varphi=(1-\theta)^2$, $\psi=\frac{2}{3}\frac{(1-\theta)^2}{\theta}$ – are functions of porosity θ,

$\bar{\rho}=1-\theta$ – is the relative density,

m – is the parameter characterizing the degree of imperfection of the contacts in the powder billet and defining different resistance of a porous body during its testing in tension and compression.

The rate of volume change resulting from the plastic deformation is presented by the expression [28]:

$$e\sim\frac{2(1+m)^2}{\psi}p+\frac{2m(1+m)\sigma_0}{\sqrt{\psi}}, \quad (2)$$

where: σ_0 – is the flow stress of hard phase, may be presented by the following dependence [30]:

$$\sigma=\sigma_0+K\omega^{0.5}, \quad (3)$$

where: K – is the hardening coefficient.

The rate of accumulating deformation in hard phase of porous body has determined on the basis of postulate of uniqueness of the dissipation function formulated by Skorokhod V.V. [26]:

$$\omega=\sqrt{1-\theta}\left(\frac{m}{1+m}\sqrt{\psi}e+\frac{\sqrt{(1+m)^2\gamma^2+e^2\psi}}{1+m}\right), \quad (4)$$

where: γ – is the shape changing rate.

The value of accumulated deformation ω is renewed by solving of differential equation [15]:

$$\frac{d\omega}{dt}=W, \quad (5)$$

where: W – is the equivalent strain rate:

$$W=\frac{1}{\sqrt{1-\Theta}}\sqrt{\psi e^2+\varphi\gamma^2}. \quad (6)$$

The extremal requirement for the functional was implemented for calculating distributions of intensity of stress, intensity of deformation and relative density [2, 15]:

$$J(v_i(x))=\int_{\Omega}D(e_{ij}(V_i))d\Omega+\int_{\partial\Omega_p}p_iv_id(\partial\Omega), \quad (7)$$

where: $D(e_{ij}(V_i))$ – is the dissipative function,

p_i – is the stress vector on the surface of investigated billet,

v_i – is the velocity vector on the surface of investigated billet.

The first integral in the expression (Eq. 7) is the total energy dissipation rate and the second integral − is the power of the external stresses.

The dissipation function $D(e_{ij}(V_i))$ for a porous billet that deforms plastically is presented by the following expression [6, 14]:

$$D\left(e_{ij}\left(V_i\right)\right)=\frac{\sqrt{\gamma^2\varphi+e^2\psi}}{\sqrt{1-\theta}}\tau_s+\frac{p_0 e}{\sqrt{1-\theta}}, \quad (8)$$

where: $V_i=v(x)$,

$e_{ij}=\frac{1}{2}\left(\frac{\partial v_i}{\partial x_j}+\frac{\partial v_j}{\partial x_i}\right)$, $p_0=-\sqrt{\frac{2}{3}}\tau_s\sqrt{\psi}\frac{m}{1+m}$,

τ_s – is the shear yield stress.

On the basis of experimental data in the first approximation the dependences of backpressure p_{bp} on compacting pressure p and the dimensions ratio of the part h/b may be described by exponential functions [20]:

$$p_{bp}(p)=A\,exp(K_1 p),$$
$$p_{bp}\left(\frac{h}{b}\right)=A\,exp\left(K_2\frac{h}{b}\right). \quad (9)$$

where: $K_1=(0{,}01-0{,}1)\eta$ – is the stiffness coefficient of stress state,

$\eta=\frac{\sqrt[3]{\sigma_1\sigma_2\sigma_3}}{\sigma_i}$ – is the stiffness exponent of stress state,

$K_2=\frac{\varepsilon_i^{max}}{\varepsilon_i^{min}}$ – is the coefficient of non-uniformity of deformation,

h – is the depth of cartridge hollow,

b – is the thickness of cartridge wall.

At the initial time $h=0$, $K_1=0$ and $K_2=0$, the backpressure p_{bp}, according to [4], assuming equal to initial yield stress σ_{s0}. Equating functions (Eq. 9) leads to the following expression:

$$p_{bp}(p)=p_{bp}\left(\frac{h}{b}\right)=A=\sigma_{s0}. \quad (10)$$

Substitution of A in functions (Eq. 9) with accounting (Eq. 10) leads to the expressions for backpressure:

$$p_{bp}\left(\frac{h}{b}\right)=\sigma_{s0}\,exp\left(K_2\frac{h}{b}\right), \quad (11)$$

$$p_{bp}(p)=\sigma_{s0}\,exp(K_1 p). \quad (12)$$

The proposed mathematical model is used for stress-strain state analysis of hollow powder parts such as ‘cartridge’. Copper billets of 20% porosity were used as the initial billets with dimensions: diameter D = 28 mm, height H = 26 mm, cavity diameter d = 14 mm, height of the cavity h = 14.8 mm, wall thickness of the ‘cartridge’ b = 7 mm, friction coefficient μ = 0.25.

The problem has been solved by finite element method. A stress-strain state has been analyzed in the axial section of the bottom part (A-A), angular section (B-B), and by the width of the wall (C-C) (Fig. 1).

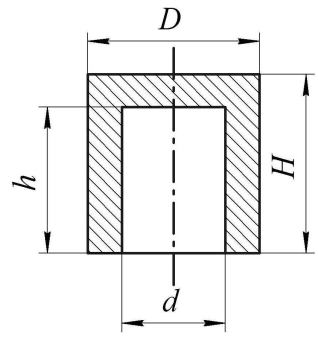


Fig. 1. The sample for investigation

Finite element model of the "billet-die" system constructed using eight-node fully integrated prismatic elements is presented in Fig. 2.

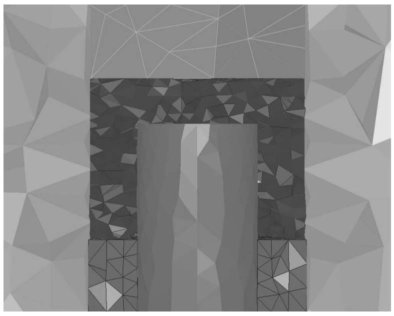


Fig. 2. The calculation scheme of extrusion

The results of mathematical modelling have been verified experimentally. Billets were made of copper powder M1 obtained from wastes of current conductors [17, 19]. Copper scrap with copper wires has been extracted from various electrical devices that are reached the end of their service life. Wastes are in form of twisted strands, shapeless pieces of current conductors of various length and diameter.

The technology for production of copper powder from such wastes consists of the following steps: oxidative annealing, hydrogenazing annealing, fragmentation into small fractions, removing combustion products by air separation, grinding of crushed scrap into powder, recovery annealing, grinding of porous sponge to the powder of given granulometric composition [18]. The chemical composition of the copper powder obtained by proposed technology is presented in Table 1 and granulometric composition – in Table 2.

Table 1. Chemical composition of copper powder

Powder	Mass fraction, %				Calcined residue, no more than
	Cu, not less	Fe	O	Si	
		No more than			
Copper powder from wastes	99.7	0.18	0.10	0.10	0.05

Table 2. Granulometric composition of copper powder

Powder	Content of particles, %, size, mm			
	<0.160	<0.100	<0.063	<0.045
Copper powder from wastes	28	27	17	25

Billets of 20% porosity have been produced on the hydraulic press model PD-476, force 1600 kN, by uniaxial compression. Sintering has been performed into a laboratory shaft furnace in the synthesis gas medium (the gas composition is 72.0% H_2, 21.0% CO, 5.5% CO_2, 1.5% H_2O) by stepwise mode with final delay for one hour at the temperature of 950 – 920 °C [24]. The diameter of billets after sintering was 28.5 mm, the height – 26.3 mm, the relative density – 0.89 – 0.91. The hollow samples for experimental study (Fig. 1) obtained from sintered pressings at the same press by direct extrusion without backpressure and at backpressure of 120 MPa [20]. A molybdenum disulfide used as the lubricant.

The influence of depth of the cavity on a quality of extruded products has been investigated during experiments. The depth of the cavity has changed by adjusting the extrusion pressure. Extrusion without backpressure included the following steps: the pressing 3 was installed into the matrix 1 on the limit stop 4 (Fig. 3a) and upset by the upper punch 2 (Fig. 3b), then limit stop 4 was removed, the lower punch 6 was inserted and the sample 5 extruded (Fig. 3c). The dimensions of samples after extrusion were $D = 32.0$ mm, $H = 20.1$ mm, $d = 18$ mm, $h = 2.6, 7.8, 13.7, 14.8$ mm.

Extrusion with backpressure has been performed without preliminary upsetting of pressings (Fig. 4). The pressing 3 was placed in the matrix 1 on the movable punch 5 with backpressure created by moving stop 6. The sample 5 was extruded by the upper punch 2. The diameter of matrix – 32.0 mm, the lower punch diameter for extrusion of cavity – 18.0 mm. The cavity depth was taken the same as in the first experiment.

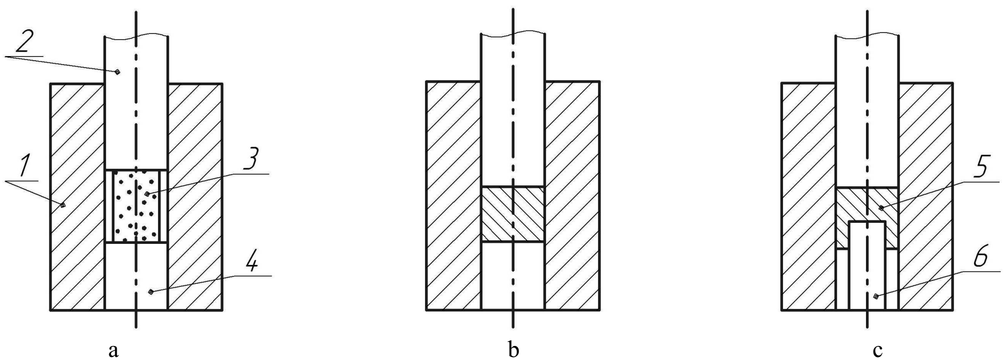


Fig. 3. The extrusion scheme without backpressure: loading of the billet (a), upsetting on the limit stop (b), extrusion (c)

The density after extrusion was determined by hydrostatic weighing. The hardness has been measured on Rockwell hardness meter using ball indentor of 1.587 mm at the load of 1000 N by scale HRB (GOST 9013–59).

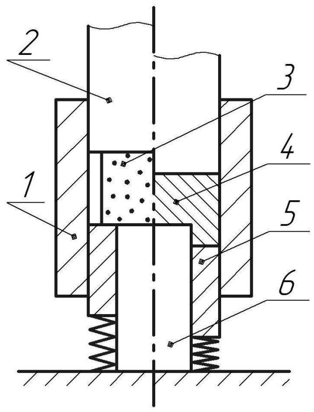


Fig. 4. The extrusion scheme with backpressure

RESULTS OF RESEARCH

Calculation of the dependence of backpressure on the ratio of depth of the cavity and wall thickness using (Eq. 10) and the backpressure depending on extrusion pressure of porous billet by expression (Eq. 11) are presented in Fig. 5.

The backpressure is growing while increasing of ratio h/b and extrusion pressure. The data in Fig. 5 may be used for selection of backpressure depending on the dimensions ratio and the pressure of direct extrusion.

Simulation of the stress-strain state at direct extrusion of "cartridge" detail with the wall thickness of 7 mm has been conducted at the backpressure 120 MPa (Fig. 6). The highest intensities of stress and deformation has observed under the punch in section A-A.

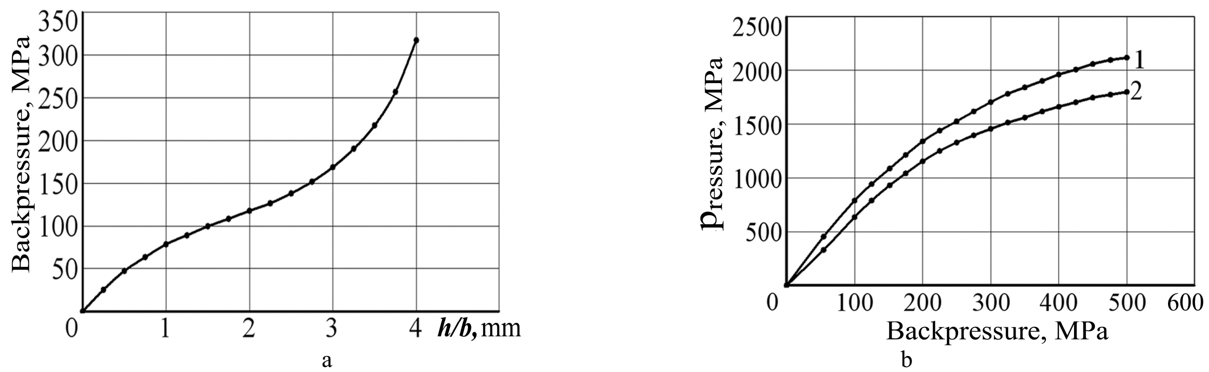


Fig. **5**. The dependence of backpressure on relative depth of the cavity (a) and extrusion pressure (b): 1 – is the theoretical dependence, 2 – is the experimental dependence

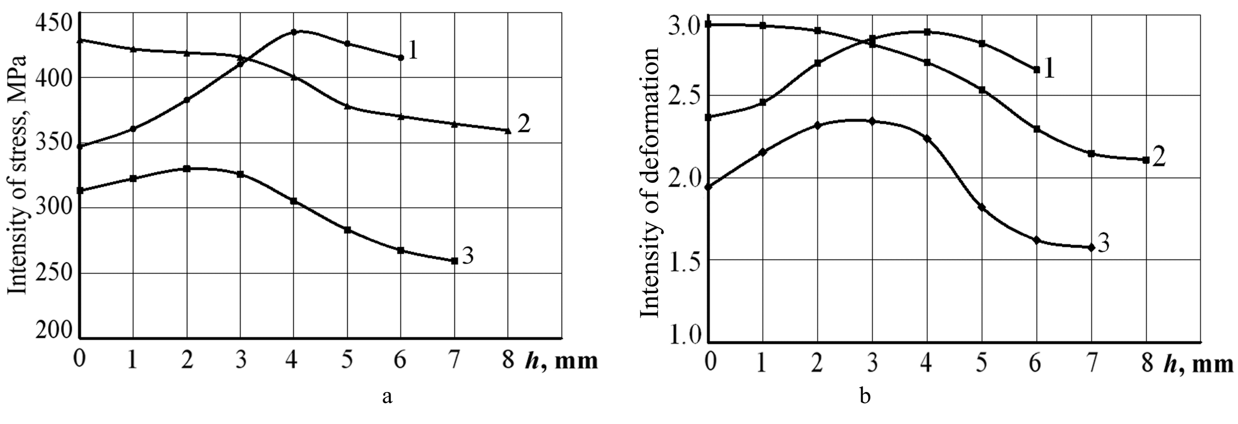


Fig. 6. Distribution of the intensity of stress (a) and intensity of deformations (b) in different sections of the sample: 1 – is the bottom section, 2 – is the corner section, 3 – is the ring section

The experimental results of determination of relative density by height of the sample are presented in Fig. 7. The relative density of samples increased from initial value 0.94 to 0.97 and then decreases with increasing depth of the cavity to 13.7 mm at extrusion without backpressure. In this case, it varies non-homogeneously by the volume of sample. The relative density of the bottom part has grown to almost nonporous state, dramatically increasing at the depth of the cavity 14.8 mm. The relative density of the ring part increases up to a certain limit for the depth of the cavity 13.7 mm, and then decreases as a result of tensile stresses in the butt end of ring part, which is the reason of decreasing the whole density of the sample.

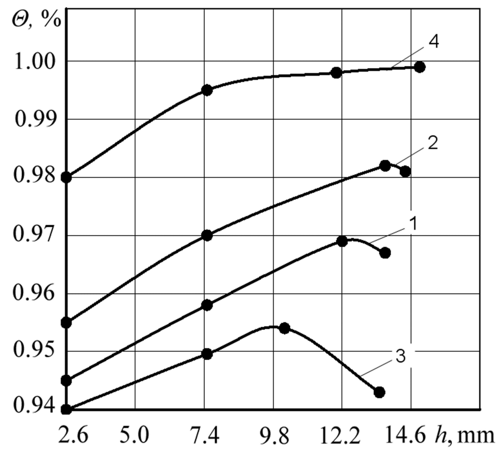


Fig. 7. The influence of the depth of extruded cavity on relative density: 1 – is the density of sample extruded without backpressure, 2 – is the density of bottom part of the sample extruded without backpressure, 3 – is the density of ring part of the sample extruded without backpressure, 4 – is the density of sample extruded without backpressure

The hardness is distributed non-uniformly by the volume of sample. The average hardness on the bottom surface adjacent to a moulding punch was 56.4 HRB, on the inner side – 67.8 HRB, on the wall adjacent to the bottom part – 64.5 HRB, on the free butt end – 37.3 HRB, at the depth of the extruded cavity 13.7 mm. The hardness of the bottom part increases and on the butt end of the wall decreases while increasing the depth of the cavity.

The results of extrusion of sintered billets with backpressure 120 MPa are different. At the first stage, upsetting of billet, transversal flow of the metal and filling of the matrix are taking place. The relative density increases rapidly and the process of extrusion cavity is beginning (Fig. 7). The relative density was 0.98 at the cavity depth equal to 2.6 mm with further increase till achieving a pore-free state while growing the depth of the extruded cavity.

Variations in the relative density and hardness by the volume of extruded samples were not observed. The average hardness was 68.3 HRB at cavity depth of 15.6 mm. Samples with depth of the cavity 18.2 mm were of regular shape and shape defects were not found during visual inspection.

Analysis of forming of the sample during extrusion without backpressure allowed mark out three zones (Fig. 8): 1 – is the ring part, where tension in axial direction has observed and leads to increase in porosity and decrease in hardness, 2 – is the transition from the ring part to the bottom part, where compression occurs due to dam by the metal of bottom and ring parts, wherewith the high density and hardness reached, 3 – is the bottom part, where the compression and radial tension are taking place, which leads to formation of flow-through flaw on the front surface and decrease of hardness. The deformation of metal layers adjoining to the wall of die tool impeded by friction resulting in formation of pit on the butt end surface of the ring part (Fig. 6).

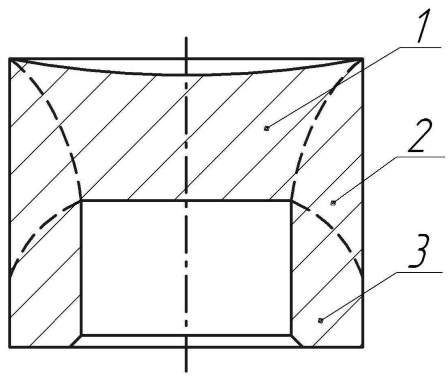
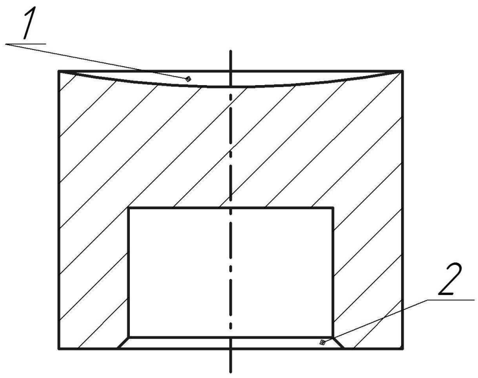


Fig. 8. Distribution of deformation zones by the section of detail: 1 – is the axial tension zone, 2 – is the compression zone, 3 – are compression and radial tension zone

Defects were not found upon visual inspection of samples with the depth of extruded cavity 2.6 mm and 7.8 mm. Cracks and other surface defects were not observed at the cavity depth of 13.7 mm, but the defects of shape: pit on the outer surface of the bottom of 0.05-0.15 mm and flow-through flaw of 0.1-0.3 mm height on the butt end of the wall (Fig. 9). The cracks on the butt end surface of tubular part appeared after increasing the depth of the cavity to 14.8 mm.



a

b

Fig. 9. Shape defects: the sketch (a): 1 – is the tip, 2 – is the flow-through flaw, photo (b)

Implementation the backpressure of 120 MPa leads to increase of extrusion pressure [24]. The pressure was 560 MPa during extrusion of cavity 13.7 mm in depth without backpressure and with backpressure the cavity of 15.6 mm depth was obtained at pressure of 682 MPa. It happens due to growing of stresses and deformations in each part of the extruded sample and may be observed clearly through changes of the coordinate grid in the sample (Fig. 10).

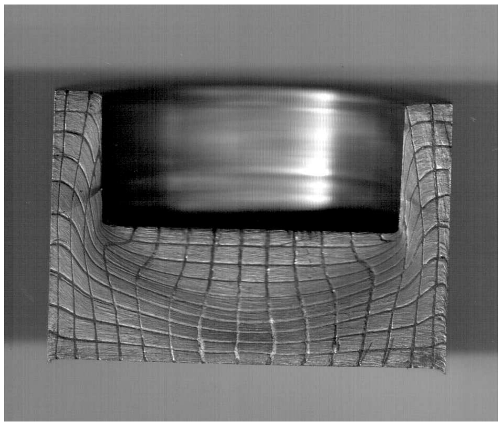


Fig. 10. The coordinate grid on the sample after direct extrusion

The "cartridge" details produced from copper powder billet of 15% initial porosity at back pressure 120 MPa are shown in Fig. 11: with wall thickness 7 mm (Fig. 11, a) and with wall thickness 2 mm (Fig. 11, b) [22]. The density of details is 8.92 g/cm^3.

a

b

Fig. 11. The "cartridge" details produced from porous copper powder billet by direct extrusion with backpressure 120 MPa: the wall thickness 7 mm (a) and the wall thickness 2 mm (b)

CONCLUSIONS

1. The mathematical model of the stress-strain state used for solving the problem of direct extrusion of hollow porous powder billet by finite element method has been developed on the basis of plasticity theory of porous bodies.
2. The dependences of backpressure on the ratio of cavity depth and wall thickness of the detail have obtained on a basis of developed mathematical model and may be used for selecting the value of backpressure at direct extrusion.
3. The distributions of the intensity of stress and deformation into the porous powder billet at the optimal value of backpressure have obtained. The highest values of stresses and deformations appeared under the punch and in the corner section of the billet.
4. The distributions of the relative density, hardness and presence of defects at direct extrusion of porous powder billet with backpressure and without it have been investigated experimentally.
5. The production technology for hollow powder details from porous powder billets by direct extrusion with backpressure proposed.

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ВЛИЯНИЕ ПАРАМЕТРОВ ПРЯМОГО ВЫДАВЛИВАНИЯ ПОРИСТЫХ ПОРОШКОВЫХ ЗАГОТОВОК НА КАЧЕСТВО ИЗДЕЛИЙ

Людмила Рябичева, Николай Белошицкий,
Дмитрий Усатюк, Юрий Негрей

Аннотация. Предложена математическая модель напряженно-деформированного состояния, которая использована для решения задачи прямого выдавливания полой порошковой пористой заготовки методом конечных элементов. Определены зависимости противодавления от соотношения размеров глубины полости и толщины стенки детали. Получено распределение интенсивности напряжений и деформаций при оптимальной величине противодавления. Экспериментально исследовано распределение относительной плотности, твердости, наличие дефектов при прямом выдавливании заготовки с противодавлением и без него. Предложена технология изготовления полых порошковых деталей из пористой заготовки прямым выдавливанием.

Ключевые слова: порошковая заготовка, прямое выдавливание, противодавление, дефект.

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Justification of Permissible wear parameters of Lokomotives crest wheel

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Summary. The article is devoted to justifying the choice of admissible tread wheels profile parameters and control technology improvement of locomotive wheels flange wear parameters. The authors conclude that the rational choice of admissible wear parameters depend strongly on the technical and economic performance of the rolling stock, namely mileage wheelset turning between bands, the total number of tires turning life cycle, overall tires life.

Key words: Railway locomotive wheel sets, tires, wheel profiles, wear parameters, ridge thickness parameter.

INTRODUCTION

The most common problems that arise in the operation of the "wheel-rail" in different periods of the development of the railway in the whole world is the problem of high rate of wheels and rails wear and the problem of rolling off the rails [1]. The main objective of almost all known studies of wheel wear was to reduce the rate of ridges wear [2-6]. The authors of this study strongly support any steps to help reduce the rate of wear in contact with the rail wheel flange and consider them not only useful but also necessary for the solution of life extension bandages [7-11]. At the same time, the authors believe that the primary task, aimed at increasing the life cycle of locomotive wheelsets, is the justification admissible parameters evaluation and wheel flange wear control.

PURPOSE AND THE PROBLEM OF RESEARCH

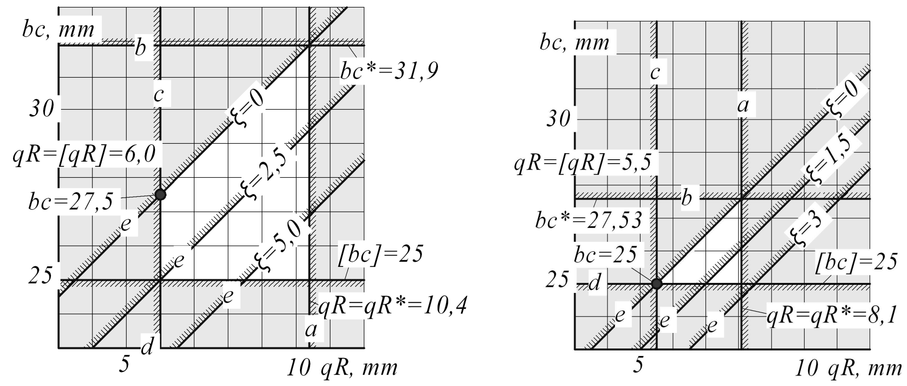
The aim is to justify the choice of admissible values of the basic profile parameters: a minimally admissible parameter of ridge steepness and minimally admissible thickness of the ridge.

RESEARCH RESULTS

To solve the research problem it was proposed by the authors to analyze the dynamics of ridges bandages profile parameters change using block-contours by analogy with contours that are used in the design of gears. Block-contours of possible values of the ridge thickness b_c and ridge steepness parameter qR of profiles GOST 11018:2005 and "MIHETEK" are shown in Fig. 1. The boundary of block-contours are marked by lines "*a*", "*b*", "*c*", "*d*", "*e*".

Line "*a*" – the line limiting the contour by the nominal ridge steepness parameter value:

$$qR = qR^* . \quad (1)$$



a b

Fig. 1. Block-contours of bandage profile parameters possible values in coordinates $b_c - qR$
a – profiles GOST 11018:2005, b – profile "MIHETEK"

Line "*b*" – nominal ridge thickness line defined by the function:

$$b_c(qR) = b_c^* . \qquad (2)$$

Line "*c*" – the line, limiting the contour by the minimally-admissible ridge steepness parameter:

$$qR = [qR]. \qquad (3)$$

Line "*d*" – the line, limiting the contour by the minimally-admissible ridge thickness parameter:

$$b_c(qR) = [b_c]. \qquad (4)$$

Lines "*e*" limit the contour by the ridge form and relate to the function:

$$b_c(qR) = [qR] - qR^* + b_c^* - \xi , \qquad (5)$$

Numerous statistical performance data about the ridges undercut indicate that the wear ξ at point B of the ridge occurs very rarely and only after achieving a significant undercut ridge at point A. Based on these observations, based on the analysis of blocking contours in Fig. 1 with a high degree of probability, we can conclude that in operation at reaching by its crest steepness parameter qR its minimally admissible value $[qR]$, ridge thickness will have stock on 30-40% undercut.

Thus, the existing standard for admissible value for the ridge steepness for GOST 11018:2005 profile $[qR] = 6{,}0$ creates prerequisites for premature bands turning and as a result, ineffective use.

Given that bandages resource is determined not by indicators of wear, but by minimal bandage thickness allowed by the "Instruction" [12], we can say that the operational wear has only a secondary influence on the tires operational life cycle. To a greater extent lifetime tires depends on the thickness reduction brace during turning, the process of wear. Therefore, research to improve the life of the tires should be carried out in two ways: first, the development of methods to reduce the intensity of wear in the trainset operation, secondly, to develop proposals to reduce the wear process.

As to the first direction, a large number of studies are aimed at reducing the bands wear, including undercut ridges. Concerning the second direction, it should be noted that there are not so many works concerning technology wear reduction, improving turning processes, rational profiles search, determination of optimal values of admissible profiles parameter and increasing tires usage coefficient [13-17].

Determination of the optimal value of minimally admissible ridge steepness parameter $[qR]$. Two important characteristics of wheels and rails interaction depend on ridge steepness parameters: the angle of the ridge and "dangerous form" of the ridge [18-20]. The angle of the ridge at the point of contact determines the wheelset stability during rolling on the rail, and dangerous form of the ridge may lead to the derailed wheelset when hit by turnout studs at wrong way movement.

Determination of the of minimally admissible optimal value of ridge steepness parameters $[qR]$ was carried out jointly by two criteria: minimum intensity of ridges wear and safety of wrong way movement at turnouts.

Based on the analysis of experimental data obtained by the authors, there were determined the intensity and average intensity of ridges wear on the current steepness value qR and minimally admissible parameter of the ridge steepness $[qR]$, respectively $I(qR)$ and $Icp([qR])$ (Fig. 2).

Analysis of dependence in Fig. 2 allowed finding out the following:

- at values $qR < 7{,}0$ intensity of ridges wear stabilizes, and with further reduction remains practically constant,

- medium intensity, which determines locomotive overhaul mileage, decreases with decreasing of the fixed threshold steepness parameter - $[qR]$.

In Fig. 3 in the system of coordinates $\sigma - h$ there is shown the area of admissible and non-admissible values of clearance between the point rail and the frame rack σ and vertical deformation of the point rail *h* and the curve of safety *qR*.

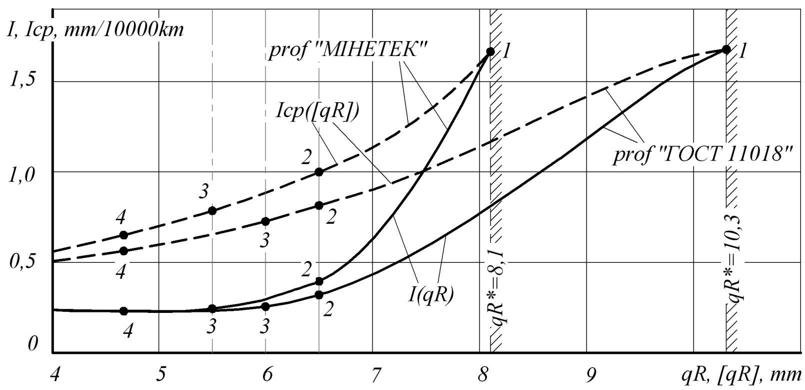


Fig.2. Experimental dependence of wear intensity *I* and medium intensity of ridges wear *Icp* on the current value of ridge steepness qR and minimally admissible ridge steepness parameter $[qR]$ for profiles GOST 11018:2005 and "MIHETEK"

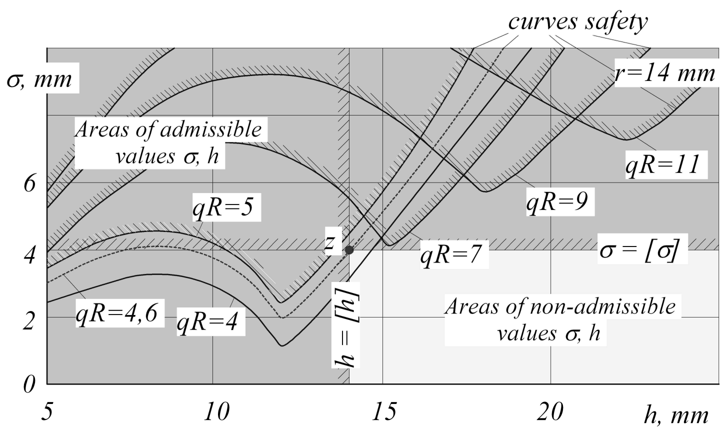


Fig. 3. Areas of admissible and non-admissible values of clearance between the point rail and frame rack σ and vertical deformation of the point rail *h* and curves of safety qR, at which safety is fulfilled: $\gamma_3 = [\gamma_3] = 60^o$

Curves of safety are the locus of points which are a combination of critical values σ, h, qR, at which there is fulfilled the condition of secure wrong way movement at turnouts, namely:

$$\gamma_3 = [\gamma_3], \tag{9}$$

where: γ_3 – ridge angle profile at the point of contact with the edge of the studs turnout - angle of contact, $[\gamma_3] = 60^o$ - minimally admissible value of contact angle at which there is no danger of inrolling of the wheel at turnouts. Safety isoline $qR = 4{,}6$ mm in Fig. 3, which passes through the critical point z, under current rules on the rejection of turnout parameters ($[h] = 14$ mm, $[\sigma] = 4$ mm) defines minimally admissible value of ridge steepness $[qR] = 4{,}6$ mm.

Determination of minimum permissible ridge thickness $[b_c]$**.** It is known that the minimum permissible ridge thickness is defined by "Technical operation rules of railways in Ukraine" (PTE). According to p.10.3 PTE "it is forbidden to operate and let the movement on main tracks with a maximum rolling stock with speed of 120-140 km/h when the thickness of the ridge is less than 28 mm, and for the movement with a maximum speed of up to 120 km/h - less than 25 mm. "Measuring the thickness of the ridgeby ridge-measurer GU-1 is based, unlike PTE, not on top of the ridge (point G in Fig. 4), but on the rolling circle (point D).

In Fig. 4 there are shown the profile options without rolling and with rolling. In fig. 4 it is shown that the measurement of the ridge thickness for PTE does not depend on steel, and the measurement of GU-1 - does. Thus, when $\delta = 0$ $b^*_{cPTE} > b^*_{cGU1}$, and for worn-out profile $b_{cPTE} < b_{cGU1}$.

Calculated relationship between the results of the ridge thickness measurement by different methods – according to PTE and ridge-measurer GU-1 - is shown in Fig. 5.

In particular, Fig. 5 shows that when the ridge thickness is measured according to the requirements of PTE equals the minimally admissible value, namely $b_c = [b_c]$, the ridge thickness, measured by ridge-measurer GU-1, depending on the rolling, varies from 22.9 mm (for $\delta = 0$) to 26 , 6 mm (for $\delta = 7$ mm). During rolling, approximately 3 mm measurement results of the two methods are the same.

Thus, during rolling less than 3 mm, in determining of the ridge thickness by the ridge-measurer, there is a systematic measurement error with the sign "minus", i.e., the measurement results are lower than the actual thickness of the ridge. In the absence of rolling, the error reaches minus 2 mm. Negative measurement error is a metrological prerequisite for unreasonably early turning bands and as a result, reduce the term of their service through inefficient use.

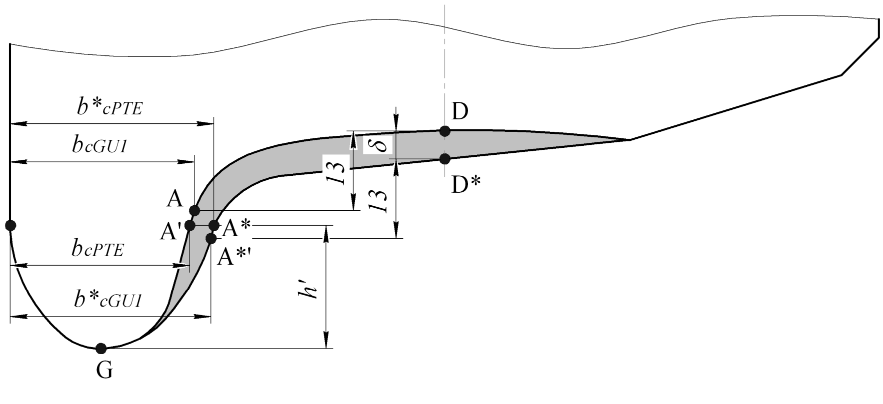


Fig. 4. Scheme for measuring the ridge thickness according to PTE and "Regulation":
b^*_{cPTE}, b_{cPTE} – thickness of the ridge, measured by PTE under new and worn profiles,
b^*_{cGU1}, b_{cGU1} – ridge thickness measured by GU-1 under the new and worn profiles

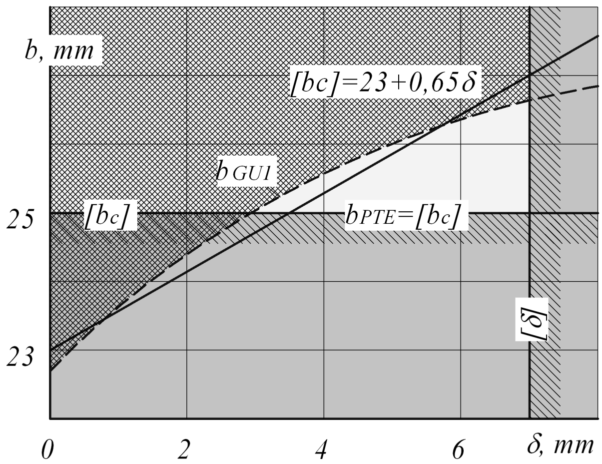


Fig. 5. Relationship between the results of the ridge thickness measurement according to PTE and ridge-measurer GU-1

In contrast, at rolling greater than 3 mm there is a measurement error with the sign "plus" in consequence of which the measurement is greater than the actual thickness of the ridge. The maximum error is plus 1.6 mm at maximum rolling of 7 mm. Positive measurement error is a metrological precondition for violation of PTE regulation as for minimum thickness of the ridge.

The authors see two possible ways of maintaining PTE demands and methods of measuring the ridge thickness by a ridge-measurer GU-1.

The first is that the minimum permissible thickness of the ridge is defined as a variable, i.e. $[b_c] \neq const$, that depends on the rolling. In this case, each measurement parameters of wear surface rolling wheels minimum permissible ridge thickness should be determined as a function of the actually measured rolling δ by the approximate formula:

$$[b_c] = 23 + 0{,}65 \cdot \delta \,. \quad (10)$$

The second is to change items of PTE and introduce as a rule, determination of ridge thickness at its intersection at a distance of 13 mm from the wheel bearings, i.e. from point D in Fig. 4.

CONCLUSIONS

1. The authors conclude that the rational choice of admissible parameters of ridges wear depend strongly on the technical and economic performance of locomotives.

2. There was suggested the method of optimal values determination of the minimum-admissible ridge steepness parameter and minimally admissible thickness of the wheel flange.

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ОБОСНОВАНИЕ ПРЕДЕЛЬНО-ДОПУСТИМЫХ ПАРАМЕТРОВ ИЗНОСА ГРЕБНЕЙ КОЛЕС ЛОКОМОТИВОВ

Светлана Сапронова, Виктор Ткаченко

Аннотация. Статья посвящена обоснованию выбора допусковых параметров профилей поверхностей катания колес и усовершенствованию технологии контроля параметров износа гребней колес локомотивов. Авторы делают вывод, что от рационального выбора допусковых параметров износа существенно зависят технико-экономические показатели работы подвижного состава, а именно: пробег колесных пар между обточки бандажей, суммарное количество обточек бандажей за жизненный цикл, общий срок службы бандажей.

Ключевые слова: колесная пара локомотива, бандажи, профиль колеса, параметры износа, толщина гребня, параметр наклона гребня.

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Feature comparison regeneration particulate filter with the catalytic coating and the use of oxidation catalyst

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Summary. The paper presents the results of computational and theoretical research of passive regeneration particle filter diesel engine. According to the results of the analysis are reasonable prospects of application of the direct and indirect path burnout soot into the layer filter element under passive regeneration of the diesel particle filter.

Key words: diesel particle filter, regeneration, soot.

INTRODUCTION

The important objective at the currently is to reduce the amount of harmful emissions with exhaust gases vehicles. Exhaust gases contain a lot of harmful substances, the most significant of which are nitrogen oxides, particulate matter (PM), carbon monoxide, hydrocarbons, sulfur compounds. Particulate matter is one of the main components of the diesel vehicles emissions. Analysis of the composition of exhaust gases is made by the method of determining the reduced mass of the harmful release, showed that the fraction of PM is more than 40 % of the total exhaust emissions of diesel vehicles operating in Ukraine [28]. Particulate matters have the broad range of negative impacts on the environment and human, including contribute to the emergence of cancerous diseases [26]. Implementation of the existing and promising standards for emissions of PM diesel vehicles only by the impact on the operating process engine is almost impossible. For this to need the trapping PM with diesel particulate filters (DPF) that are installed into the engine exhaust system. The most simple, effective and reliable are mechanical DPF's, where the trapping of PM is the porous layer of the filtering material. However, under the exploitation of DPF there is the problem with filling the filter material of the PM, which precipitously reduces the operating time of filter and impairs the effective performance of the diesel engine [5, 9]. Therefore, ensuring the regeneration of particulate filters is the actual problem, the solution to which will enable their widespread introduction in exploitation.

MATERIALS AND METHODS

There are different ways of regeneration DPF [20], among which the most simple and reliable seems thermal regeneration. Its essence lies in the fact that, under the temperature exhaust gases above 550 °C with PM begin to burnout at the expense of residual oxygen, always contained into exhaust gases diesel engines. However, under operation diesel vehicle such temperature exhaust gases not achieved or reached not long, that does not provide self-regeneration DPF. Therefore, to implement the regeneration DPF using different ways of the exhaust gases heating to the required temperature or ways of lowering the temperature of the beginning burnout soot.

Thermal or catalytic burnout soot under regeneration DPF is possible direct ($C + O_2$) or indirect ($C + NO_2$) paths. It is believed that the regeneration of the DPF for both paths are based on assumptions of the kinetic behavior of the process of burnout soot into the layer filter element according to the law of the Arrhenius [1, 10, 16]. The kinetic equation is the basis of the material balance of the flow of reactants. Depending on the availability of experimental and calculated data kinetic parameters are presented in the form of modified the temperature dependence of the soot burning rate:

$$k(T) = k_0 T^b e^{-E_a/(RT)}, \qquad (1)$$

where: $k(T)$ – reaction rate constant, m/s (1/s for gas-phase reactions), $k_{0,th}$ – pre-exponential factor Arrhenius, m/(s·K^b) (1/(s·K^b) for gas-phase reactions), T – thermodynamic temperature, K, b – exponent at T, usually is accepted 0,5 or minus 0,5, E_a – activation energy, J/mol, R – universal gas constant, J/(mol·K).

The factor k_0T^b depends on the temperature is much weaker exponent, therefore it is taken as constant, and equation (1) are as follows:

$$k(T) = k_0 e^{-E_a/(RT)}, \qquad (2)$$

where: k_0 has a rank of $k(T)$.

Recently, a lot of research is devoted to the regeneration of the DPF, which under the organization of the process burnout soot into the layer filter element occurs on indirect ($C + NO_2$) path with the use of diesel oxidative converter (DOC) [2, 7, 14, 15, 24]. In international publications occurs mainly experimental material obtained in the laboratory or move trials, which confirms the applicability of this method for neutralization exhaust gases diesel engines.

In this paper was performed computational and theoretical research of regeneration DPF for two cases: direct burnout diesel soot – catalytic oxidation of soot at the expense of residual oxygen exhaust gases and indirect – oxidation soot with nitrogen dioxide obtained by the oxidation of nitrogen oxide in DOC. It is obvious that on the process of regeneration DPF affects the mode of the operation diesel engine and kinetic constants soot burning rate.

The purpose of this research was to compare the specific soot burning rates for direct and indirect paths at the temperature exhaust gases typical for catalytic oxidation of soot, as well as to assess the possibility of the regeneration DPF for direct path burnout soot under operation of the diesel engine.

RESULTS, DISCUSSION

These types of burnout soot filter element DPF need to be assessed the position of the possibility of their application in real conditions regeneration. To do this made the comparative analysis of the above regeneration paths.

Quantitative characteristics of diesel engines equipped DPF with continuous regeneration (CRT), which applies indirect path burnout soot. Consider the example of the running tests of the bus in the Central part of the city (Fig. 1). Use fuel with ultra-low sulfur (27 ppm) significantly improves the operation of DOC for CH and CO in comparison with fuel with low sulfur content (247 ppm), and the reduction of emissions of PM happens by reducing the fraction of sulfates in their composition.

The use of CRT improves DOC and reduces emissions of PM, which is determined by the efficiency of the operation DPF and the quantity of the burnt soot. The use of CRT impairs the efficiency of the diesel engine, increases the emissions of CO_2 and NO_x which is a disadvantage.

On the soot oxidation of NO_2 affects the amount of soot into exhaust gases and filter element, concentration of NO_2 and temperature of exhaust gases and the filter element. The concentration of NO_2 into the exhaust gases of the diesel engine KAMAZ-740M is 2300-240 ppm, that with under significant filling DPF not enough for regeneration through the low soot oxidation rate and low concentration of NO_2. At the temperature above 250 °C is possible soot oxidation at stoichiometric ratio NO_2/C or excess NO_2. For DPF of a volume of 12,5 l with the total amount soot of 0,05 kg under gas flow of 920-206 kg/h formed the mass ratio NO_2/C from 0,00035 to 0,000064. Stoichiometric mass ratio NO_2/C is 3,83. At low concentrations of the NO_2 into DPF and taking into account the developed surface of the soot to wait for high oxidation rate of the accumulated soot is not possible.

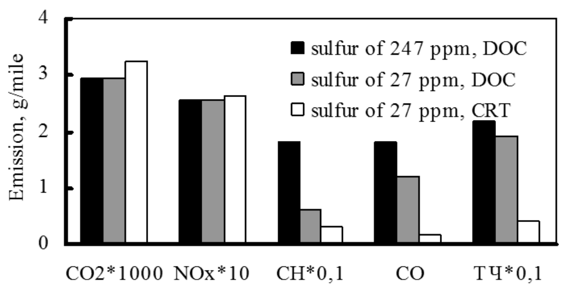

Fig. 1. Emission of pollutants according to the results of the test bus in the city centre, equipped with a diesel engine 1999 DDC Series 50 volume of 8,5 l and power of 275 hp [14]

Into the exhaust gases of the diesel engine KAMAZ-740M ratio NO_2/C is from 18 to 93 that exceeds the stoichiometric and with the growth of load and engine speed this ratio decreases. This means that local burnout soot into the volume of exhaust gases and accumulated soot layer possible due to the appearance of the area depletion (with $NO_2/C \geq 3{,}83$), where at a certain temperature oxidation occurs soot.

Stoichiometric mass ratio O_2/C under the burnout soot for the oxygen mechanism is 2,67. In operation conditions of CRT concentration of the O_2 varies in the range 6-18 % by volume. The ratio O_2/C for residence time of exhaust gases into the filter up to the moment of the beginning regeneration is 0,03-0,01.

The application of the scheme C + NO_2 for the regeneration of DPF in some cases not justified for a number of reasons. According to the data of the running tests (see Fig. 1) the total emission of nitrogen oxides is not reduced, and even slightly increase. It is adversely affects the total exhaust gases emissions of diesel engine because oxides of nitrogen have the greatest contribution in total toxicity of exhaust gases.

The Johnson Matthey Company suggested the path burnout soot particulate filter in two stages (Fig. 2). In front of the diesel particulate filter to the exhaust gases flow is set oxidation catalyst, whose main function is the oxidation of NO, which is contained in the exhaust gases, to the formation of NO_2. The short distance from DOC is installed DPF with filter element of the cellular structure, in which the soot trapping and its oxidation of NO_2 according to the thermal mechanism.

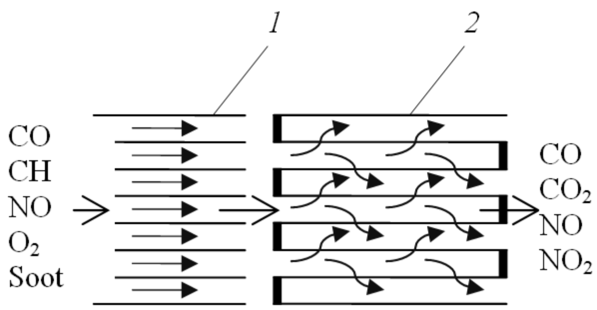

Fig. 2. The scheme of the CRT: 1 – diesel oxidation catalyst, 2 – diesel particulate filter

According to the data of the Johnson Matthey company requirements to the operation of this system CRT there is:

1. Proportion (over 50 %) of engine modes that provide heat of exhaust gases more than 250 °C,

2. The ratio of NO_x/PM in the diesel exhaust gases should be 20:1 and higher,

3. The maximum sulfur content in the diesel fuel pets at the level of 50 ppm (by mass).

Such strong requirements for the application of DPF in the operation conditions of the diesel engine can be the disadvantage. In addition, this design of DPF needs about two times more space than a conventional of DPF, and possible oxidation reaction of NO to NO_2 with the high sulfur content in diesel fuel that limited the scope of the method.

The mechanism of the soot indirect oxidation in the system CRT is divided into two stages [3, 8, 22, 23, 27]. The first stages in DOC (Fig. 2) are oxidized CO, CH and NO according to the following reactions:

$$2CO + O_2 \xrightarrow{Pt} 2CO_2, \quad (3)$$

$$C_nH_m + \left(n + \frac{m}{4}\right)O_2 \xrightarrow{Pt} nCO_2 + \frac{m}{2}H_2O, \quad (4)$$

$$2NO + O_2 \overset{Pt}{\rightleftarrows} 2NO_2. \quad (5)$$

In the second stage of the soot oxidation by restoring NO_2 to NO:

$$C + 2NO_2 \rightarrow CO_2 + 2NO, \quad (6)$$

$$C + NO_2 \rightarrow CO + NO, \quad (7)$$

$$NO_2 + NO_2 \xrightarrow{t>500\,^{\circ}C} O_2 + NO + NO. \quad (8)$$

Decrease in particle diameter according to the summary mechanism (Eq. 6) and (Eq. 7) in [22] is empirically described using a modified form of Arrhenius expression to account for variable NO_2 concentrations given as:

$$\dot{D}_p = -A_{soot} T^{1/2} e^{-47100/(RT)} [NO_2]^n, \quad (9)$$

where: $\dot{D}_p$ – rate of decrease of particle diameter with time, nm/s, A_{soot} – frequency factor, A_{soot}=2,4×10^{-14} nm·cm^3/ ($K^{0,5}$·s·molecule), [NO_2] – concentration of NO_2, molecules/cm^3, $n = 1$ – order of reaction in [22] was not determined.

Scheme burnout diesel soot in DPF with the catalytic coating on the basis of copper is shown in Fig. 3.

Copper is the transitional metal and has two main valence states. The literary sources it is known that when heated in air copper oxidizes to CuO and Cu_2O oxides [4]. In the temperatures of 200-375 °C the copper to air oxidized to black copper oxide (II) CuO (decomposition temperature of 1026 °C to Cu_2O [13]). At high temperatures occurs two-layer oxide. The surface layer consists of black copper oxide (II) CuO, and the inside is made of red copper oxide (I) Cu_2O (melting point of 1235 °C [13]). At high temperature oxidation (1000 °C or more) of copper metal, when values of the oxygen partial pressure about 13,3 kPa or less oxide CuO is not formed, and the only product of the reaction is the oxide of Cu_2O [6]. The existence region of CuO in the air lies in the temperature of 250-1000 °C, and with decreasing the partial pressure of the O_2 this interval is decreases. When the partial pressure of O_2 less of 0,133 Pa and temperature less than 700 °C with the total oxidation rate of copper is very low. Also in the [6, 12] notes that the oxide CuO is formed at the further oxidation of Cu_2O. There is a certain critical thickness of the layer Cu_2O on the metal surface above which formation oxide of CuO possible.

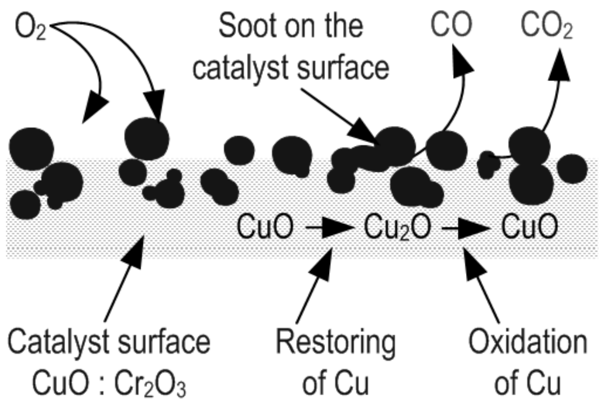

Fig. 3. Scheme burnout soot on the surface of catalytic coating, which includes oxide CuO

Oxidation of copper nanopowders when heated in air investigated in [11]. At the linear heat in the air of copper nanopowders samples with a large fraction of the small fraction oxidized with the clearly the staging of Cu→Cu_2O→CuO. On the first stage rate proportional to the fraction of small fraction particles. For the second stage of the clearly dependence rate on dispersion is not detected. With the growing proportion of particles big fraction in the sample of staging process oxidation becomes less expressive as well as for roughly dispersed copper powder (average size is 40 μm) staging is also not expressed.

According to [4] oxide CuO detects oxidizing properties. The copper oxide (II) oxidizes carbon to CO_2 and hydrogen to H_2O when heated with various organic substances as well as copper oxide (II) restored to copper metal. The author of this paper provides the mechanism of catalytic burnout in the following form:
stage recovery:

$$2CuO + C \rightleftarrows 2Cu + CO_2, \quad (10)$$

$$CuO + C \rightleftarrows Cu + CO, \quad (11)$$

$$CuO + CO \rightleftarrows Cu + CO_2, \quad (12)$$

$$2Cu_2O + C \rightleftarrows 4Cu + CO_2, \quad (13)$$

$$Cu_2O + C \rightleftarrows 2Cu + CO, \quad (14)$$

$$Cu_2O + CO \rightleftarrows 2Cu + CO_2, \quad (15)$$

stage oxidation:

$$4Cu + O_2 \rightleftarrows 2Cu_2O, \quad (16)$$

$$2Cu + O_2 \rightleftarrows 2CuO, \quad (17)$$

$$2Cu_2O + O_2 \rightleftarrows 4CuO, \quad (18)$$

decomposition stage at the temperature over 800 °C:

$$4CuO \rightleftarrows 2Cu_2O + O_2. \quad (19)$$

Chromium oxide Cr_2O_3 is refractory substance green, manifests amphoteric properties, insoluble in water and many solvents, slightly soluble in all acid and alkali, persistent in the air [4, 13]. Oxide Cr_2O_3 contributes to the development of the inner surface of the active component and the increase of the catalyst thermal stability [25], also not restored to the metal Cr when interacting with reducing agents: C, CO, H_2.

For soot burning rate according to the summary mechanism C + O_2 for catalyst with CuO in [19] applied the Arrhenius equation:

$$k_{cat}(T) = 80{,}4\, e^{-82308/(RT)}. \quad (20)$$

The diffusion process can influence the burnout soot in DPF. Soot burning rate of the kinetic equation Arrhenius decreases faster at decrease of temperature than the diffusion rate. It is therefore possible to assume that at temperatures 300-1000 °C and small sizes of soot particles the burning process occurs in the kinetic region. This assumption requires an assessment depending on the conditions and features of the filter element. Mechanisms of catalytic burnout soot differ because of the diversity catalytic systems used for DPF. For example, platinum promotes the oxidation of soot at the temperature about 450-500 °C and the mechanism its oxidation consists in the adsorption of oxygen molecules on the catalyst surface, dissociation and interaction with carbon on the periphery soot particles.

Usually for path C + O_2 assumes kinetic regime burnout soot on the Arrhenius law. Kinetic equations are the basis of the material balance of the reactants flow. Their views are in classical (Eq. 2) or modified (Eq. 1) form depending on the availability of data kinetic parameters. The estimates or experimental investigation of the kinetic regime burnout soot in filter is absent.

The influence of the gas-phase reaction:

$$2CO + O_2 \rightarrow 2CO_2, \quad (21)$$

on the chemism burnout soot were checked using the criterion Semenov (Se). It is defined as the ratio of the oxygen flow into the reaction of burnout CO, to its diffusion flow [18]:

$$Se = \frac{\sqrt{kD}}{\alpha_{dif}}, \quad (22)$$

where: k – constant velocity of gas-phase reaction burnout of CO, 1/s, D – diffusion coefficient, m^2/s, α_{dif} – coefficient of diffusion mass transfer, m/s.

For soot particles, which are in the free volume of the granular filter element, the criterion of Se in the range of temperatures and velocities of the flow exhaust gases significantly less than the limit Se = 0,4 (Fig. 4). In this case burnout CO near the particles considers not need. In the layer of granular filter element at the temperature of 960 °C and more to show excess limit of Se for speeds of exhaust gases 0,1 m/s or less. For the conditions of catalytic thermal regeneration of the filter element, the affect of gas-phase reaction on the material flows the surface of the soot particles and grains not be considered and assume that this reaction is observed only on the surface of oxidative catalyst or in the volume of the exhaust gases.

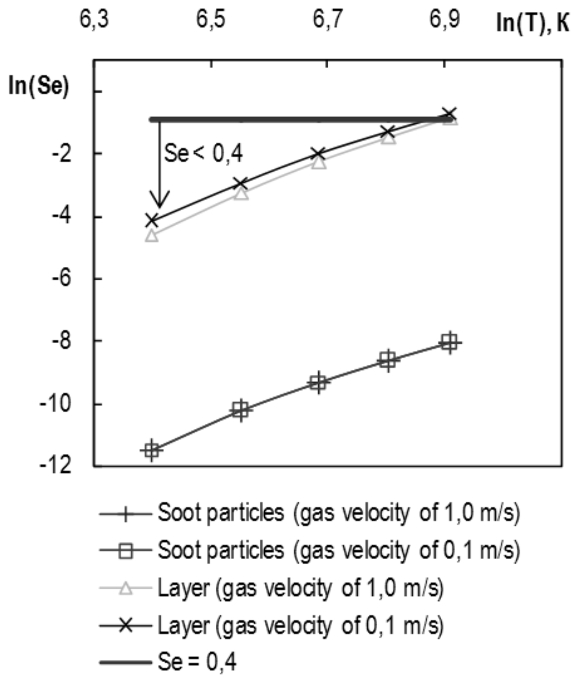

Fig. 4. Temperature dependence of the criterion Se for the layer of granular filter material and soot particles (for the average temperature of 600-1000 K)

Role of surface reactions burnout soot:

$$C + CO_2 \rightarrow 2CO, \quad (23)$$

$$C + H_2O \rightarrow CO + H_2, \quad (24)$$

significantly manifested under diffusion combustion, where the integral rate of carbon oxidation according to the reactions has approximately the first order as well as for the reactions:

$$C + O_2 \rightarrow CO_2, \quad (25)$$

$$2C + O_2 \rightarrow 2CO. \quad (26)$$

But the interaction of soot with CO_2 and H_2O can be not taken into account when the kinetic mode burnout carbon. This is determined by diffuse-chemical criterion of similarity [18]:

$$Nu_{ch} = \frac{k_1 + k_2}{\alpha_{dif}}, \quad (27)$$

where: k_1, k_2 – rate constants reactions of (Eq. 25) and (Eq. 26). Kinetic burning mode is determined by the value criterion of 0,1 or less.

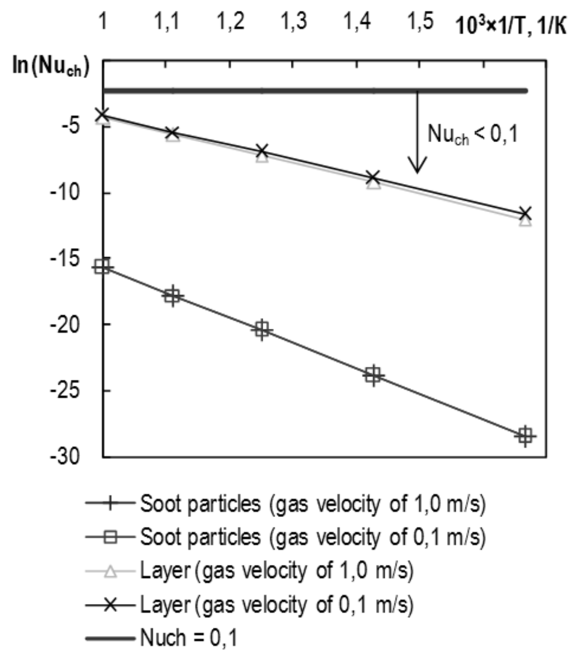

Fig. 5. Temperature dependence of the criterion Nu_{ch} for the layer of granular filter material and soot particles (for the average temperature of 600-1000 K)

Burnout soot in the free volume of the filter element and on the surface of grains runs in the kinetic region in the whole range of temperatures and velocities of exhaust gases (Fig. 5). Excess can be considered insignificant, because if the value of Nu_{ch} of more than 100 do not take into account kinetic burning. In this case, burnout proceeds in the diffusion region.

Soot burning rate depends on the operation mode of the diesel engine, which is characterized by the engine speed and its power. These indicators determine the temperature exhaust gases and also the concentration of nitrogen oxides and residual oxygen in them. To account for the operation modes and operation conditions of the diesel engine were used the data of the 13-mode diesel engine test of KAMAZ-740M (Table 1).

Table 1. The data of the 13-mode diesel engine test of KAMAZ-740M

Mode	Engine speed, min^{-1}	Load, %	Engine power, kW	Fuel flow, kg/h	Air flow, kg/h	Concentration	
						NO_x, ppm	PM, g/m^3
1	600	0	0	1,3	205	240	5,2
2	1400	10	9,1	4,7	492	340	5,2
3	1400	25	23,1	6,9	487	300	5,2
4	1400	50	46,8	10,9	483	1350	8,9
5	1400	75	71,4	15,4	478	2200	27
6	1400	100	94,4	20	471	2300	94
7	600	0	0	1,3	207	250	5,2
8	2600	100	157,5	36,4	890	700	200
9	2600	75	118,2	28,6	892	1300	145
10	2600	50	79,2	21,1	892	900	32
11	2600	25	40,3	14,3	891	520	17
12	2600	10	15,6	10,7	886	370	13
13	600	0	0	1,3	205	270	5,2

For the analysis of the soot burning rate resulted equation (Eq. 20) in the form equation (Eq. 9). After transformations for soot particles with a density of 2000 kg/m^3 were the following equation:

$$\dot{D}_{p,cat} = 4{,}02 \cdot 10^7 \, e^{-82308/(RT)} [O_2], \qquad (28)$$

where: $\dot{D}_{p,cat}$ – rate of decrease of particle diameter with time, nm/s, $[O_2]$ – concentration residual of O_2, kg/m^3.

The concentration residual of O_2 is determined by the equation:

$$[O_2] = \frac{\mu_{O_2} r_{O_2} P}{RT}, \qquad (29)$$

where: μ_{O_2} – molar mass of O_2, kg/mol, r_{O_2} – volume fraction residual of O_2 in the exhaust gases, m^3/m^3, P – absolute pressure, Pa.

Volume fraction residual of O_2 in the exhaust gases is determined with fuel factor Bunte by the equation

$$r_{O_2} = \frac{0{,}21(\alpha - 1)(0{,}79 + \beta)}{\alpha(0{,}79 + \beta) - 0{,}21\beta}, \qquad (30)$$

where: α – excess air ratio, β – fuel factor Bunte.

Excess air ratio is calculated by the equation:

$$\alpha = \frac{G_{air}}{14{,}33 G_{fuel}}, \qquad (31)$$

where: G_{air} – air flow, kg/h, G_{fuel} – fuel flow, kg/h.

Fuel factor Bunte is calculated by the equation [18]:

$$\beta = \frac{2{,}37(\mathrm{H} - 0{,}125\mathrm{O})}{\mathrm{C}}, \qquad (32)$$

where: H, O, C – mass fraction of hydrogen, oxygen and carbon in the fuel, accordingly, accept for diesel fuel: H = 0,126, O = 0,004, C = 0,87.

The concentration of NO_2 for (Eq. 9) is calculated by the equation:

$$[NO_2] = \frac{r_{NO_2} P}{kT}, \qquad (33)$$

where: r_{NO_2} – volume fraction residual of NO_2 in the exhaust gases, ppm, P – absolute pressure, Pa, $k = 1{,}38 \cdot 10^{-23}$ J/K – Boltzmann constant.

For the test conditions of diesel engine according to (Eq. 9), (Eq. 28)-(Eq. 33) calculated rate of burning soot particles (Table 2). Is assumed that the concentration of NO_2 is 50 % of the total concentration of NO_x in the exhaust gases at the temperature of 300-350 °C [22].

Due to low the exhaust gas temperature (less than 250 °C) on modes 1-3, 7 and 11-13 burnout soot does not occur to both paths

(Table 2). Modes of the diesel engine operation of 4-6 and 8-10 are favorable for burnout soot by temperature (Fig. 6). At modes of 4-6 of soot burning rate by the direct path less of 1,3-3,5 in times than the indirect path, conversely, at the modes of 8-10 – more in 1,3-5,6 in times.

Table 2. The rate of direct (Eq. 28) and indirect (Eq. 9) burning of soot particles for the test conditions diesel engine of KAMAZ-740M

Mode	Ex. gases T, °C	Excess air ratio	[O_2], kg/m^3	[NO_2], 1/cm^3	$\dot{D}_p$, nm/s	$\dot{D}_{p,cat}$, nm/s
1	120	11,00	0,191	2,24E+15	0,00059	0,00009
2	170	7,31	0,160	2,82E+15	0,00398	0,00126
3	217	4,93	0,133	2,25E+15	0,01137	0,00900
4	260	3,09	0,104	9,30E+15	0,12473	0,03585
5	320	2,17	0,074	1,36E+16	0,56486	0,16792
6	470	1,64	0,043	1,14E+16	3,62988	2,83530
7	120	11,11	0,190	2,34E+15	0,00061	0,00009
8	590	1,71	0,039	2,98E+15	2,95934	16,45833
9	420	2,18	0,064	6,89E+15	1,22552	1,60485
10	330	2,95	0,090	5,48E+15	0,26849	0,26745
11	230	4,35	0,125	3,80E+15	0,02624	0,01428
12	187	5,78	0,147	2,95E+15	0,00681	0,00266
13	120	11,00	0,189	2,52E+15	0,00066	0,00009

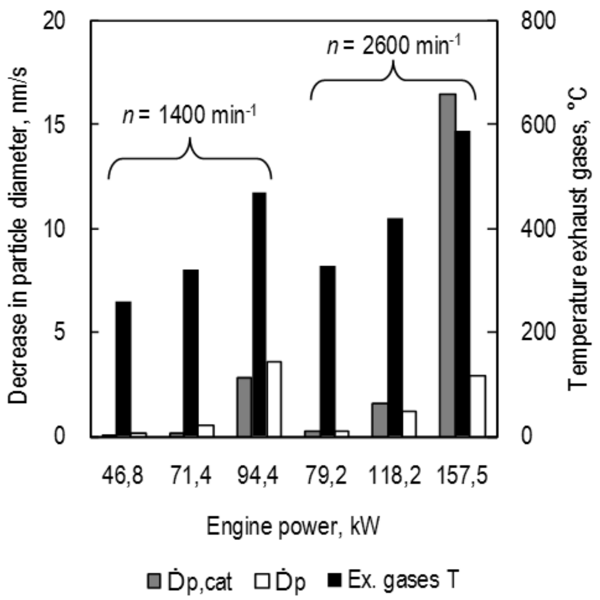

Fig. 6. Soot burning rate on the operation modes of 4-6, 8-10 (Table 2) of diesel engine

For the temperature of exhaust gases close to 250-300 °C are expected high degree regeneration of DPF with the catalytic coating according to the scheme C + O_2 in comparison with the system of CRT. Despite the high soot oxidation rate of NO_2 on modes of partial loads, the degree regeneration is higher for soot oxidation with oxygen. For example, in mode n = 1400 min^{-1} NO_2 weight is 0,15 g/s, PM – 0,94 g/s and the O_2 – 21,6 g/s. Soot oxidation rate on the oxygen path is less than 3,5 times, but the amount of oxygen is sufficient to oxidize the soot stream and in the filter element. This evaluation shows that the system CRT cannot ensure the operation of DPF when it is completely filled. In such case, the necessary force regeneration [21], which contradicts the idea of self-regeneration. The advantage of catalytic oxidation of soot on the scheme C + O_2 is the possibility of using the oxide catalysts, which are cheaper catalysts on the base of noble metals (Pt, Pd, Au), and organize a comprehensive neutralization of toxic components of exhaust gases diesel engines. In addition, a decrease in emission standards of nitrogen oxides to the level Euro 5 entails a decrease in the soot burning rate. The system CRT is intended for to operate in conditions of ultra low content of sulfur in the diesel fuel (50 ppm by mass) due to the use of DOC with the catalytic coating containing Pt. The quality of diesel fuel for the system CRT must comply with standards Euro 4 or Euro 5 that narrows the application of this system in Ukraine.

CONCLUSIONS

1. Assessment of diffuse-chemical criterion by (Eq. 27) showed the practical possibility of use of the kinetic dependences for the description of the regeneration process material balance into granular filter element excluding oxygen diffusion near the reaction surface of soot.

2. For satisfactory operation of system CRT are desired high content of nitrogen oxides into the exhaust gases. It is the downside.

3. Regeneration for the path C + NO_2 depends not only on the diesel operation mode, but also the operation DOC. The DOC failure will lead to excessive filling of DPF and the inability to vehicle operation without forced

regeneration. It is contradicts the concept of system CRT.

4. Requiring ultra low content of sulfur in diesel fuel limits the application of system CRT in Ukraine, on the contrary regeneration for the path C + O_2 less demanding to the quality of diesel fuel.

5. In the temperature range of 250-350 °C soot burning rate profitable direct path than indirect and conditions for the self-regeneration of DPF is favorable.

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СРАВНЕНИЕ ВОЗМОЖНОСТЕЙ РЕГЕНЕРАЦИЯ САЖЕВОГО ФИЛЬТРА С КАТАЛИТИЧЕСКИМ ПОКРЫТИЕМ И ПРИМЕНЕНИЕМ ОКИСЛИТЕЛЬНОГО НЕЙТРАЛИЗАТОРА

Юрий Шеховцов, Леонид Заиграев

Аннотация. В статье представлены результаты расчетно-теоретических исследований пассивной регенерация дизельного сажевого фильтра. На основе анализа рассмотрены перспективы применения прямого и непрямого типа выгорания сажи в слое фильтрующего элемента при пассивной регенерации сажевого фильтра.

Ключевые слова: дизельный сажевый фильтр, регенерация, сажа.

Structural analysis of an interregional transport network and assessment of capability for its multi-level optimization

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S u m m a r y. We have presented the results of the structural analysis of a interregional multi-level transport system. We have proved that generally speaking, a transport network can consist of three levels, including separate clusters at the local level, groups of interconnected clusters at the regional level and clusters tied together in transit corridors at the interregional level. We have generated the criteria and the method to determine the number of levels in the transport system, which is necessary for subsequent multi-parameter performance optimization of the entire system.

K e y w o r d s. Transport, systems, optimization, structural level, cluster, transit hub, corridor.

INTRODUCTION

In terms of economic activity, individual territories and regions are interconnected through transport networks ensuring the satisfaction of emerging transportation needs [1, 2, 8, 21, 24].

This is the transport network that connects individual economic agents, and the possibility of their interaction while implementing production processes creates the necessary prerequisites for the comprehensive development of territories and economic regions.

The task of forming the rational structure of the transport network at the regional and interregional levels in these circumstances is important and urgent [5, 7, 12, 15, 16].

This is due primarily to the fact that the construction of transport communications, infrastructure facilities, their repair and maintenance, are quite expensive, and the poor quality of roads leads to increase in terms of delivery of goods, increased wear of vehicles, increased fuel consumption, environmental degradation in regions, etc. [3, 9, 13, 14, 22].

OBJECT OF RESEARCH

This paper's object of research is interregional transport systems with complex network structures. A structural analysis of such systems is carried out based on the assumption that the investigated objects are multi-leveled and characterized by the following sequence of features.

1. Economic activities of local businesses lead to the localization of production transport flows mainly at the local level within individual clusters, and the amount of transport work carried out within the boundaries of individual clusters is at least two-thirds of the total volume of the work performed by local businesses.

2. Cargo transit transportation is carried out mainly through transit corridors performing a connecting role in the interregional transport system. In this case, the transport flows, which pass through interregional transport hubs (Fig. 1), are the transit ones, and their share in the total volume of traffic between such hubs is at least two-thirds.

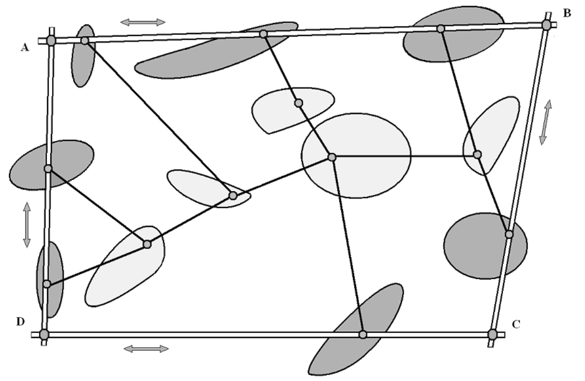

Fig. 1. Fragment of the interregional transport network bounded by hubs A, B, C, D and four transit corridors: A, B, C, D – transit transport hubs, AB, BC, CD, AD – transit corridors

If the above conditions are met, the network structure in question can be considered as multi-leveled, and the performance optimization of such transport system shall be carried out sequentially at each structural level established.

The presence of the above features of multi-level systems allows to decompose network structures and optimize the performance of systems at local, regional and interregional levels, while implementing their structural analysis [4, 6, 10].

In this case, there is a need for a consistent solution of problems related to the definition of:

- boundaries and structural components of individual clusters, within which the basic transport operation shall be carried out at the local level,

- procedure for the connection of transport hubs of individual clusters located far from transit corridors and the formation of relevant groups of clusters at the regional level,

- routes of vehicles while managing the operation of transit corridors,

- possibility of forming a unified transport network with an efficient mechanism for resolving transport issues at each system structural level established.

This approach allows to carry out multi-parameter optimization of structurally complex transport systems, thus ensuring their effective operation [17, 19, 23].

RESEARCH RESULTS

To assess the properties of the interregional transport network in accordance with the scheme proposed, we shall consider its fragment bounded by four transit corridors containing four transit transport hubs and presented in Fig. 1.

Distinctive features of the analyzed fragment are as follows:

- the presence of four transit corridors, for which transport flows passing through transit hubs are determinative, and the transit share in the total volume of traffic along the corridors is at least two-thirds,

- clusters, included in the interregional network, are located along transit corridors, and their territory is used while managing the movement of transit flows,

- located away from transit corridors, a group of clusters is characterized by the fact that the basic scope of transportation work (at least two-thirds of the total scope) at the local level is carried out within them, and the transit component is negligible and can be ignored while carrying out further analysis.

The cargo flow shall hereinafter mean the amount of cargo (in tons) carried in a given direction for a given period of time (e.g., one year) [11, 18, 20].

The cargo flow within the individual cluster, directed from the point i to the point j, is characterized by the value $q^A_{i,j}$. The cargo flow between the centers of clusters i and j is indicated by $l^B_{i,j}$. Accordingly, the flow between points i and j of the transit corridor is indicated by $q^C_{i,j}$.

In case the issue of forming the fragment in question is resolved correctly, the coordinate system q0l (Fig. 2) can be divided into three areas A*, B* and C* as a cluster of groups of points characterizing the presence of three structural levels.

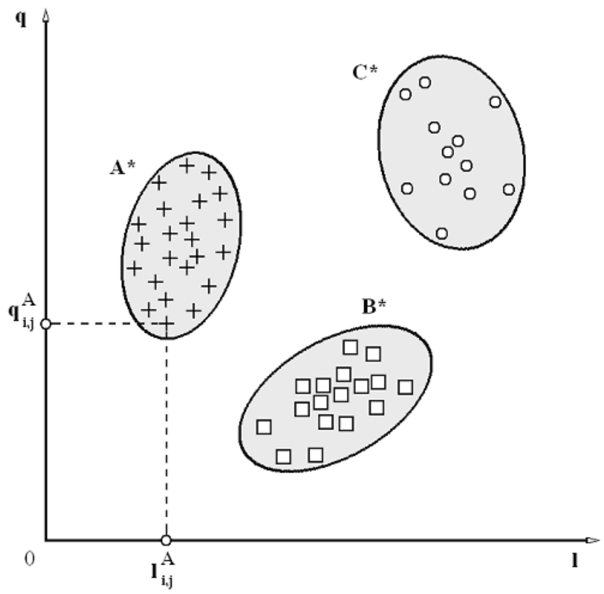

Fig. 2. Relative positions of the areas A*, B* and C*, characterizing the cluster of points in the coordinate system q0l

The group of points belonging to a particular set shall hereinafter mean a cluster of a finite number of homogeneous elements with common characteristics.

With regard to the issue in question, the points belonging to the area A* form a set characterizing transport routes, relatively short in length $l^A_{i,j}$, within individual clusters, where local transportation, characterized by cargo flows $q^A_{i,j}$, is carried out.

Area B* comprises a group of points characterizing transport routes of a greater length between the individual clusters $l^B_{i,j}$, with less regional traffic volumes, compared to the previous case, and cargo flows $q^B_{i,j}$ relevant to them.

Area C* comprises a group of points characterizing cargo flows $q^C_{i,j}$ along existing transit corridors with the appropriate length $l^C_{i,j}$.

In case of separate location of areas A*, B* and C* on the plane q0l, we shall assume that the predefined principles of forming a multi-level transport network are implemented in practical work, and the capability to ensure the optimal functioning of the entire system should be seen as achievable.

If the decisions made in connection with the definition of the boundaries of clusters and further formation of the transport network are unsuccessful or faulty, then the areas A*, B* and C* will be partially or completely overlapped in the coordinate system q0l (Fig. 3).

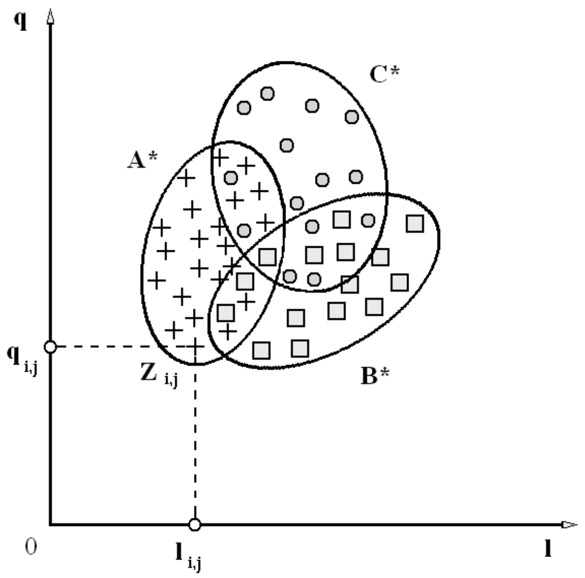

Fig. 3. Relative positions of overlapping areas A*, B* and C* in case of synthesis of the transport network with unsatisfactory properties

This means that the decisions made in connection with the formation of clusters, location selection of transport hubs and their gathering, construction of transport corridors, should be clarified or corrected.

Thus, in accordance with the proposed approach, the appropriateness of certain decisions related to the formation of the interregional transport network at different structural levels can be assessed using the appropriate graphical representations in the coordinate system q0l.

And the appearance of the areas covering certain sets gives an idea of the structure of the analyzed transport network.

However, a disadvantage of the proposed approach is that all the graphical representations are made using the dimensional quantities q and l. To increase the obviousness of the results and to create conditions for the development an appropriate computer program, one shall first convert the raw data. For example, sets within the boundaries of the areas A*, B* and C* (Fig. 2) formed with the use of quantities q [tpd] and l [km] with the specified dimension, shall be converted into dimensionless characteristics through the use of new variables.

These conversions for the elements of the set A* are performed using connections (1) and (2):

$$x_i^A = \frac{l_i^{A^*} - l_{\min}}{l_{\max} - l_{\min}}, \qquad (1)$$

$$y_i^A = \frac{q_i^{A^*} - q_{\min}}{q_{\max} - q_{\min}}, \qquad (2)$$

where: $l_{\max}$ – the maximum length of the transport route among all the elements belonging to the sets A*, B* and C*,

$l_{\min}$ – the respective minimum value,

l_i^A – the length of the transport route for the element i of the set A*,

$q_{\max}$ – the maximum value of cargo flow among all the elements belonging to the analyzed sets,

$q_{\min}$ – the respective minimum value,

q_i^A – the value of cargo flow for the element i of the set A*.

Using similar connections, a transition to dimensionless coordinates is carried out for all the elements of the sets B* and C*.

The procedure for change of variables, generally considered by us, leads to the fact that all the elements of the new sets A, B and C are located within a square with a side equal to one (Fig. 4).

In this case, the initial divided sets A*, B* and C* will be matched by the divided sets A, B, C, in the new coordinate system Y0X.

In Fig. 4, the approximate boundaries of these sets are represented by solid lines.

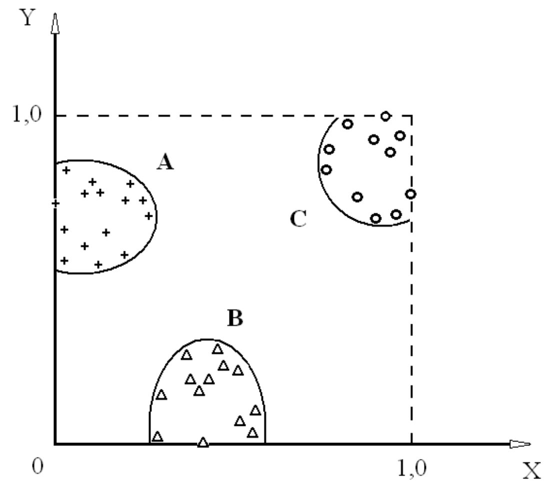

Fig. 4. Relative positions of sets of elements belonging to the divided areas A, B and C

In case the initial sets A*, B* and C* are overlapped, the corresponding elements shall be arranged in the new coordinate system Y0X as shown in Fig. 5, and it shall not be possible to visually divide them into separate sets A, B, and C with their boundaries.

Thus, the further analysis is connected with the assessment of the relative positions of the sets A, B, C, and determining the nature of their partial or complete overlap in the coordinate system Y0X.

If there is no overlap of the three areas, then the system is three-leveled, and its performance optimization shall be done for each of these levels separately.

If two of the three areas overlap, such system is two-leveled, and its performance optimization shall be carried out at the levels established.

In case where there is an overlap of the three areas, as shown in Fig. 5, the system is single-leveled, and its performance optimization shall be carried out accordingly.

Thereby, the evaluation for mutual proximity of sets, characterizing the structure of transport system, is important for analysis, the results of which determine the nature of future actions, related with optimization of system functionality.

In accordance with existing ideas, the measure of proximity for each of the elements of the set is the distance between them, which can be determined differently according to the nature of task at hand.

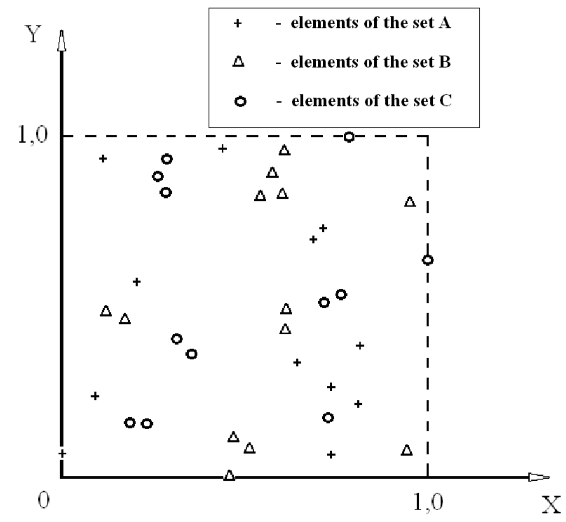

Fig. 5. Relative positions of sets of elements belonging to overlapping areas A, B and C

The choice of metric or measure, that allows evaluating the proximity of elements, which belong to one set, is very important for conducting future analysis. In common case, the measure of proximity for elements is the distance, which can be determined differently. For example, it can be Hamming distance, "balanced" Euclidean distance, distance, which is determined with the help of potential functions and so on.

Further on the proximity for elements $A_i(x_i, y_i)$ and $A_j(x_j, y_j)$ will be evaluated with the help of Euclidean distance d, which is determined on the plane Y0X this way:

$$d^{(E)}(A_i,A_j)=d\left[A_i(x_i,y_i),A_j(x_j,y_j)\right]=d_{i,j}^A=\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}\,.$$

In this case the concept of proximity for each element of the set matches with their geometrical proximity on the plane Y0X, and characteristic as a set of N_A elements, depending on the nature of task at hand, can be the diameter of the set D_A, determined, as the biggest distance between elements or average distance between all the elements of the set:

$$D_A=\frac{\sum_{i=1}^{N_A}\sum_{j=1}^{N_A} d_{i,j}^A}{N_A(N_A-1)}\,.$$

If for determining of diameter for the set, we are using formula (3), we can say that value of D_A, which is the characteristic for whole set, is in the range of $dmin \le D_A \le dmax$,

where: dmin – is minimal Euclidean distance between elements of the set,

dmax – respectively, maximal Euclidean distance between elements of the set.

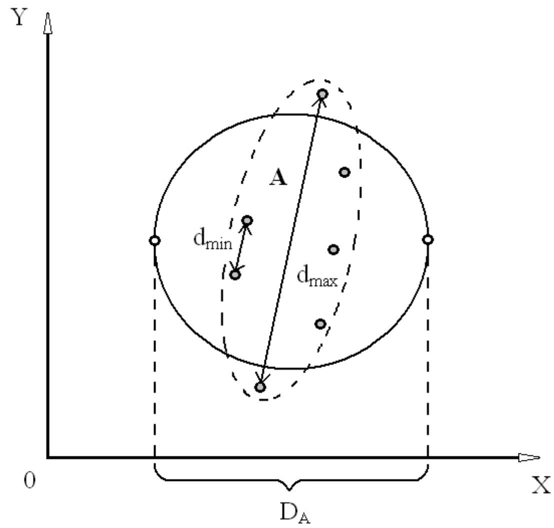

Fig. 6. Set of seven elements and graphical representation of determined characteristics dmin, dmax and D_A

It is easy to show, that if you will place a circle with the diameter of D_A in the "center" of the set A on the plane Y0X, this circle wouldn't be able to "cover" all the elements of the set, and outside of it boundaries will be at least one element (Fig. 7).

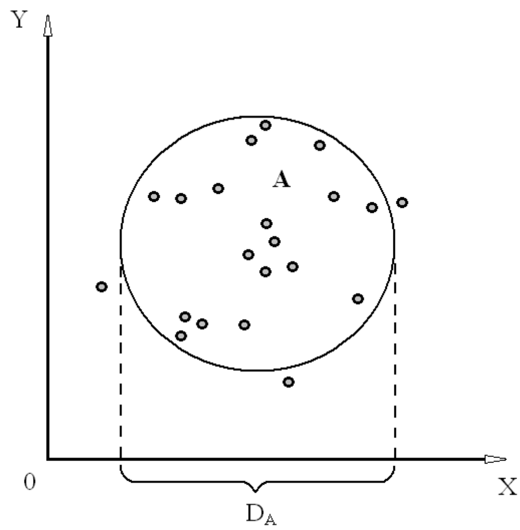

Fig. 7. Position of elements of the set A and the circle with the diameter D_A

This includes the possibility of situation, when circle with diameter D_A, which is situated in the "center" of set A does not contain any element (Fig. 8).

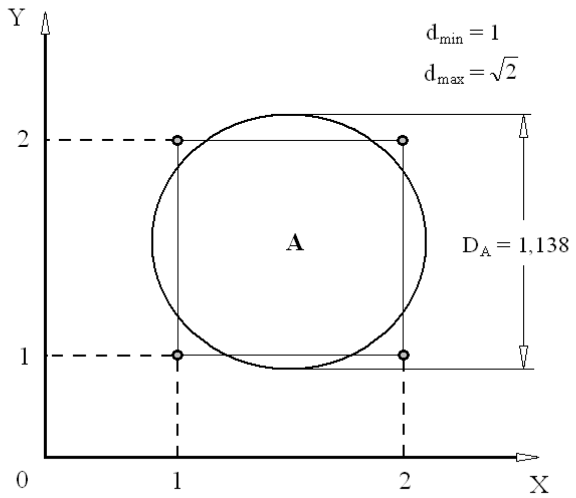

Fig. 8. Position of the four elements of the set A, which are situated outside the circle with diameter D_A.

Thus we can conclude that, regardless of the method for determining the diameter of the set, the value of D_A must be seen, as characteristic for the size of round area, in boundaries, or in close proximity of which are situated the elements of this set.

The concept of distance between groups of similar objects, usually used in development of procedure for their classification, and is related to evaluation for relative position of sets with different natures. Thus the measure of proximity for different sets can be a distance, determined using "close neighbor" rule, between "the centers of gravity", using potential function and so on.

Generalized (according to Kolmogorov) distance between sets A and B is calculated using next relation:

$$D_\tau^{(K)}(A,B) = \left\{ \frac{1}{N_A \cdot N_B} \sum_{i=1}^{N_A} \sum_{j=1}^{N_B} \left[d^{(E)}(A_i, B_j) \right]^\tau \right\}^{\frac{1}{\tau}},$$

where: N_A and N_B – quantity of elements, which analyzed sets A and B contain,

τ – some numerical parameter, chosen depending on the nature of task at hand.

In the process of future analysis we take $\tau = 2$, and distance between sets A and B can be determined using "average connection" rule, i.e. as average distance between sets, in term of arithmetic mean for all possible pair wise distances between elements of sets under consideration. Then distance D_{AB} between analyzed sets is:

$$D_{AB} = D_{\tau=2}^{(K)}(A,B) = \frac{\sum_{i=1}^{N_A} \sum_{j=1}^{N_B} d_{i,j}^{A,B}}{N_A \cdot N_B},$$

where: $d_{i,j}^{A,B}$ - Euclidean distance between elements A_i and B_j of sets A and B respectively.

For elements of sets A and B, situated on the plane Y0X, distance is determined this way (Fig. 9):

$$d_{i,j}^{A,B} = d(A_i, B_i) = \sqrt{(x_i^A - x_j^B)^2 + (y_i^A - y_j^B)^2}\ .$$

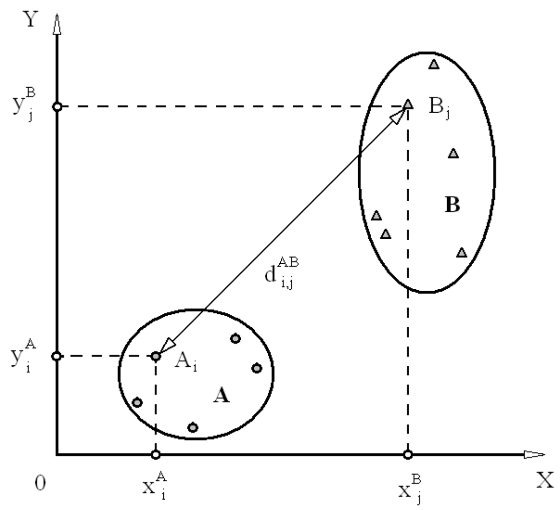

Fig. 9. Determining distance between individual elements of sets A and B

Obtained dependencies for determining D_{AB}, D_{AC}, D_{BC} can be used for determining the relative position of individual sets and structural properties for multi-level transport systems (Fig. 10).

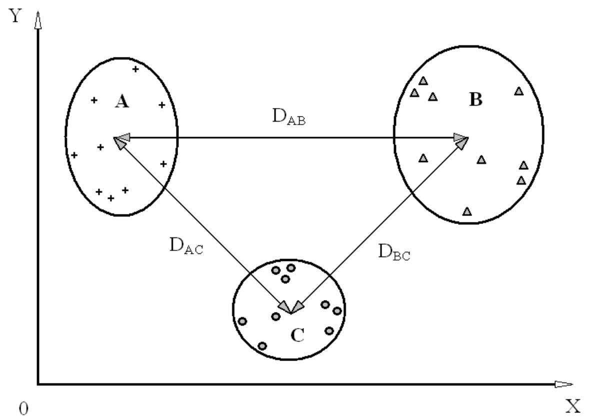

Fig. 10. Relative position of sets A, B and C on the plane Y0X

It should be noted, that from practical point of view the most interesting is situation, when analyzed system has three structural levels (local, regional and interregional), and sets of respective elements on the plane Y0X is not mixed. In this case the use of criteria D_A, D_B, D_C, D_{AB}, D_{AC}, D_{BC} allows us to determine the number of levels for interregional transport system and justify on this basis, used methods for optimization of their functionality.

CONCLUSIONS

1. We have developed a method for the structural analysis of interregional transport systems, based on the determination of their individual levels for the subsequent multi-parameter performance optimization.

2. We have proposed to present the analysis results in graph form, and thus evaluate the properties of the interregional transport systems analyzed and the capability to optimize their performance.

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СТРУКТУРНЫЙ АНАЛИЗ МЕЖРЕГИОНАЛЬНОЙ ТРАНСПОРТНОЙ СЕТИ И ОЦЕНКА ВОЗМОЖНОСТИ ЕЁ МНОГОУРОВНЕВОЙ ОПТИМИЗАЦИИ

Максим Слободянюк, Игорь Тарарычкин, Григорий Нечаев

Аннотация. Представлены результаты структурного анализа межрегиональной многоуровневой транспортной системы. Показано, что в общем случае транспортная сеть может быть трехуровневой, включая отдельные кластеры на местном уровне, группы взаимосвязанных кластеров на региональном уровне и кластеры, связанные в транзитные коридоры на межрегиональном уровне. Сформулированы критерии и метод, позволяющий определять число уровней в транспортной системе, что необходимо для выполнения последующей многопараметрической оптимизации функционирования всей системы.

Ключевые слова. Транспорт, системы, оптимизация, структурный уровень, кластер, транзитный узел, коридор.

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Installation criteria of the braking device in a bulk hydraulic drive

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Summary. The criterion set braking actuator in bulk hydraulic drive with an inertial load is proposed. Estimate of the error of its positioning on the internal rigid supports is give, which caused by the presence of film resistance between the working fluid and the working body.
Results obtained for the bulk hydraulic drive, which was considered in this work, controlled two-position reverse distributor. But they can easily be extended to other schemes of the drive.
Key words: hydraulic, braking power, positioning error.

INTRODUCTION

Effective use of special technological equipment for advanced manufacturing technologies and materials processing in engineering raises a number of challenges to improve the functional and performance capability of automatic machinery with volume hydraulic actuators, increasing their speed and accuracy [10, 13, 20]. The solution of these problems involves reasonable choice of ways to control the speed of the actuators, their braking and positioning [17, 18].

In most cases, the engines of machinery with hydraulic actuators use simple hydraulic reciprocating engines or reciprocating rotary movement, the management of which the steps are carried out by way of a relay hydraulic valves. In this case, the executive mechanism in the process usually has only two fixed positions, i.e. double-positional [3, 4, 11, 15, 21]. If you want to select the control method in the literature, there are recommendations based on the efficiency and reliability of the drive [6, 19, 14, 16]. But the necessity to install a braking device is usually solved intuitively, based on the subjective experience of designing such kind of drives [2, 5, 9, 22].

The aim of this work is to develop a test installation of a brake actuator unit volume hydraulic drive with inertial load and the definition of positioning error caused by the presence of the film fluid between the stop and the working body.

OBJECTS AND PROBLEMS

Consider a typical volume hydraulic actuator (Fig. 1), on-off control reversing valve [5].

Positioning of the actuator is a hard stop that is the internal surface of the cylinder end caps. The results can be easily extended to other driving circuits [2, 8].

The brake is applied by displacement of fluid from the end clearance between the piston and the side surfaces of the lid. Design scheme of the fluid in the gap is shown in Figure 2.

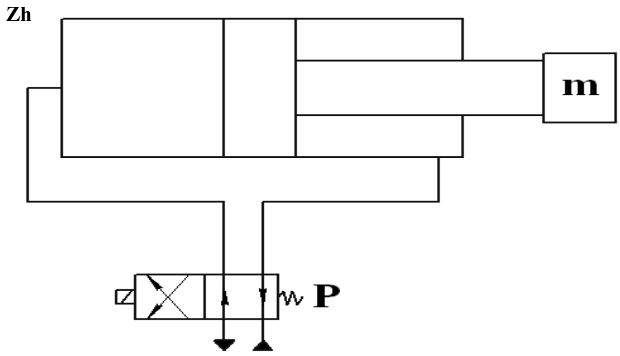

Fig. 1. Scheme of typical volumetric hydraulic actuator

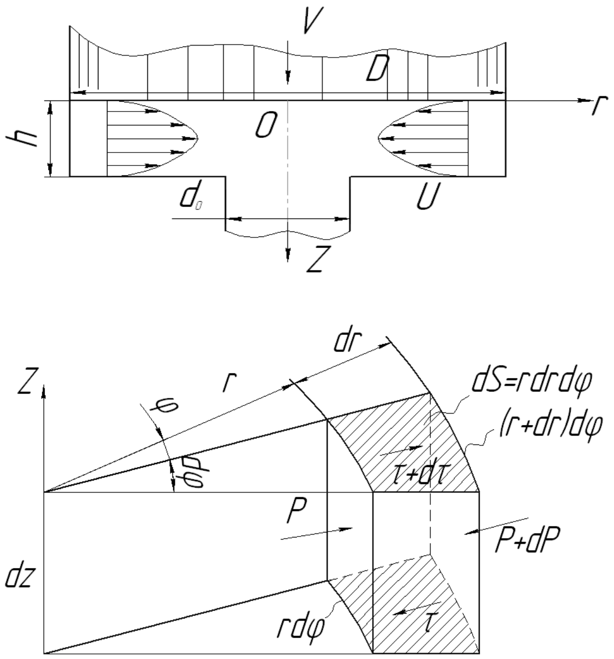

Fig. 2. Design scheme

Due to the axial symmetry of the flow in the gap using the cylindrical coordinate system by positioning the Z axis along the axis of the piston. We make the basic assumption - the flow is radial , i.e. velocity components uφ and uz are zero, and ur = u is a function of the coordinates z and r. Also neglect the inertia of the flow, compressibility of the fluid , the mass forces and consider for laminar.

By virtue of the assumptions made for the elementary volume of the liquid (see Fig. 2) is valid differential equation of uniform motion:

$$(\tau + d\tau\tau)d - \tau ds = (P + dP)(r + dr)d\varphi d - \Pr d\varphi dz, \quad (1)$$

where : $ds = rd\varphi d\gamma$ – the elementary area, which operates the shear stress, P – hydrostatic pressure, τ – shear stress, $dP, d\tau, dz, dr, d\varphi$ – the increment of variables and coordinates.

Neglecting terms of higher order of smallness, simplify the expression (1):

$$rd\tau d\tau d\varphi = Pdzdrd\varphi + rdPdzd\varphi,$$

and obtain the following differential equation:

$$\frac{d\tau}{dz} = \frac{P}{r} + \frac{dP}{dr}. \quad (2)$$

Integrating (2) in Z ranges from zero to the size of the gap h, given that $dP / dz = 0$, we have:

$$\frac{\tau_{|z-h} - \tau_{|z=0}}{h} = \frac{P}{r} + \frac{dP}{dr} \cdot \quad (3)$$

To calculate the shear stress on the piston and the lid, the velocity distribution requires adjustment of the gap. For this we use the expression (2), substituting in it the law of the Newton fluid friction:

$$\tau = \rho\nu\frac{du}{dz}, \quad (4)$$

where : ρ, ν – the density and kinematic viscosity of the fluid.

Then:

$$\rho\nu\frac{d^2u}{dz^2} = \left(\frac{P}{r} + \frac{dP}{dr}\right). \quad (5)$$

Since $dP/dz = 0$, we have:

$$\frac{d^2u}{dz^2} = A, \quad (6)$$

where: A – the parameter that does not depend on the coordinate z.

Consequently, the velocity profile is a parabola whose equation can be written in the form of a:

$$u = -6u_{av}\left(1-\frac{z}{h}\right)\frac{z}{h}. \qquad (7)$$

Here: u_{av} – the average height clearance rate, and the sign "-" indicates the direction of the velocity to the coordinate axes.

Liquid flow without compressibility through the annular gap area $2\pi rh$ equal to that of, displaces the piston in the square $\pi\left(D^2/4 - r^2\right)$ [13], so:

$$u_{cp} = \frac{V\pi\left(D^2/4 - r^2\right)}{2\pi rh} = \frac{V}{2h}\left(\frac{D^2}{4r} - r\right), \qquad (8)$$

where: V, D – the speed and the diameter of the piston.

Then:

$$u = -\frac{3V}{h}\left(\frac{D^2}{4r} - r\right)\left(1-\frac{z}{n}\right)\frac{z}{n}. \qquad (9)$$

According to (3), we determine:

$$\tau_{|z=0} = pv\frac{du}{dz}\Big|_{z=0} = -\frac{3Vpv}{h^2}\left(\frac{D^2}{4r} - r\right), \qquad (10)$$

$$\tau_{|z=h} = pv\frac{du}{dz}\Big|_{z=h} = \frac{3Vpv}{h^2}\left(\frac{D^2}{4r} - r\right). \qquad (11)$$

Substituting (10) and (11) into (2), we have the first order differential equation:

$$\frac{dP}{dr} = \frac{6Vpv}{h^2}\left(\frac{D^2}{4r} - r\right) - \frac{P}{r}, \qquad (12)$$

is integrated over the initial condition: p_0 with $r=d_0/2$ where d_0 – diameter fluid discharge from the cylinder discharge.

We have:

$$p = \frac{6Vpv}{h^2}\left[\frac{D^2}{4}\left(1-\frac{d_0}{2r}\right) - \frac{r^2}{3}\left(1-\frac{d_0^3}{8r^3}\right)\right]. \qquad (13)$$

Knowing the pressure distribution, we find the drag force:

$$F_m = \int_0^{2\pi} d\varphi \int_{d_0/2}^{D/2} \Pr dr. \qquad (14)$$

Integrating (14), we obtain:

$$F_m = K_D\frac{pvVD^4}{h^3}, \qquad (15)$$

where: K_D – dimensionless coefficient that depends on the diameter ratio d_0/D :

$$K_D = \frac{3\pi}{4}\left\{\frac{1}{2}\left(1-\frac{d_0}{D}\right)^2 - \frac{1}{3}\left[\frac{1}{4}\left(1-\frac{d_0^4}{D^4}\right) - \frac{d_0^3}{D^3}\left(1-\frac{d_0}{D}\right)\right]\right\}. \qquad (16)$$

Now consider the braking piston, moving with an initial velocity V_o, taking into account only the drag force due to stamping fluid from the end clearance. This approach is approximate, since the uniform motion of the pressure force is balanced not only the load on the rod, but the resistance of the system, depending on the speed of movement.

However, this analysis allows us to estimate the influence of the inertia of the moving mass by an amount of braking force.

Based on the above, we write the equation of motion of the piston:

$$m\frac{dv}{dt} = -F_m, \qquad (17)$$

where: t – time, m – reduced to the stem mass of moving parts.

Considering the linear motion along the X coordinates are (see Figure 3) for $X<0$, and taking into account (15), we obtain:

$$m\frac{dv}{dt} = K_D pvD^4\frac{V}{x^3}. \qquad (18)$$

Given that:

$$\frac{dv}{dt} = \frac{dv}{dx}\frac{dx}{dt} = V\frac{dv}{dx}, \qquad (19)$$

reduce (18) to the differential equation:

$$dv = \frac{K_D pvD^4}{m}\frac{dx}{x^3}. \qquad (20)$$

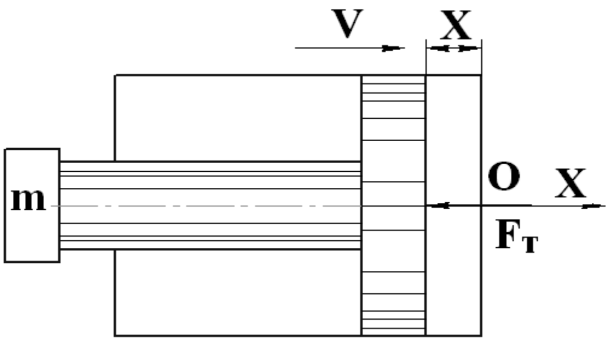

Fig. 3. Design scheme

For the initial conditions $V = V_0$ at $X = -\infty$, we have :

$$V = V_0\left(1 - \frac{K_D pvD^4}{2mV_D}\frac{1}{x^2}\right). \quad (21)$$

Using (18) we find the acceleration:

$$\alpha = \frac{dv}{dt} = \frac{K_D pvD^4}{m}\frac{V_0}{x^2}\left(1 - \frac{K_D pvD^4}{2mV_D}\frac{1}{x^2}\right). \quad (22)$$

According to (22), the maximum absolute value of acceleration is achieved at:

$$x^* = -D^2\sqrt{\frac{5pvK_D}{6mV_0}} \quad (23)$$

and is:

$$|a|_{\max} = 0{,}526\frac{V_0^{5/2}\sqrt{m}}{D^2\sqrt{K_D pv}}. \quad (24)$$

The maximum braking force:

$$F_{m\max} = m|a|_{\max} = 0{,}526\frac{m^{3/2}V_0^{5/2}}{D^2\sqrt{K_D pv}}. \quad (25)$$

Precision pre-hydraulic calculation drive performed in order to choose the pump, actuators, distribution, control and safety equipment and pipe small. This is because the friction in the seals and pumps actuators can vary within wide limits depending on the operating conditions, the timing of exploitation vary as hydraulic volume and mechanical efficiency of pump performance and hydraulic engine. Even the refined calculation of hydraulic taking into account the hydraulic characteristics of the pump set-up and the system generates an error due to determining the speed of the actuator and pressure ~ *10-15%* with the same factors. For this reason, the safety factor is usually the choice of pumps and drive motors of the values *1,2-1,5.*

All of the above gives reason to believe that if the maximum braking force, 50% of the force–calculated using the formula (25) will be 20 developed by a hydraulic cylinder, it will not lead to a breach of the drive, since all its members are chosen by an adequate margin (cylinder strength of the component is calculated with the factor 2-3 [7, 12]).

Thus, we can formulate the necessary condition for the installation of a brake device actuator drive-off: in the absence of specific requirements of the braking device must be installed if the maximum power of the hydraulic motor at a stop on a hard palm exceed 0,2-0,5 ultimate static force on the piston hydraulic cylinder :

$$F_{m\max} > 0{,}2...0{,}5 p_{ном}\pi D^2/4, \quad (26)$$

or if the condition:

$$K_C = \frac{0{,}67m^{3/2}V_0^{5/2}}{D^4 p_{nom}\sqrt{K_D \rho v}} > 0{,}2...0{,}5. \quad (27)$$

In this expression, p_{nom} – nominal pressure in the drive system.

Fig. 4 shows the nomogram for determining the parameter K_c, calculated for typical parameters of the two-position actuators, manipulators and machinery equipment.

Use the nomogram is recommended as follows.

For reasons of strength or requirements to the process equipment are given the value of K_c range 0,2-0,5. Next, find a point with ordinate $K_C m/1000$ and abscissa mV_0. If the point is below the curve corresponding to the diameter of the piston, then you must install the braking system.

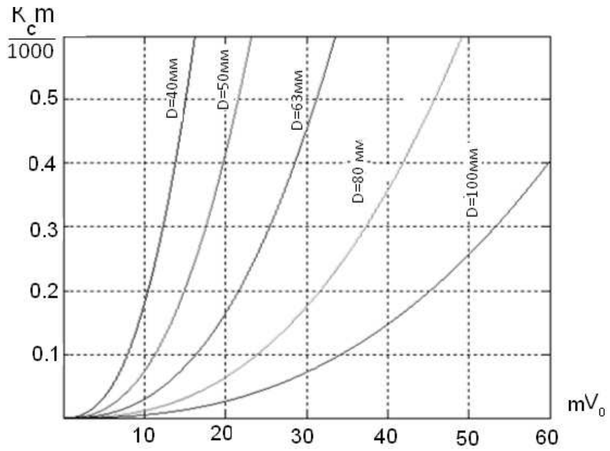

Fig. 4. Nomogram for determining the parameter K_c

Of particular interest are the results of the assessment for the positioning error on the hard stop when the piston moves by inertia at V_0. In this case, putting in (21) $V=0$, we have the amount of error positioning to equal the thickness of the oil film between the piston and the cover:

$$X_{ct} = D^2 \sqrt{\frac{K_D \rho \nu}{2mV_0}} \cdot \tag{28}$$

Figure 5 shows the nomogram error detection X_{ct}, calculated for the same characteristic examples.

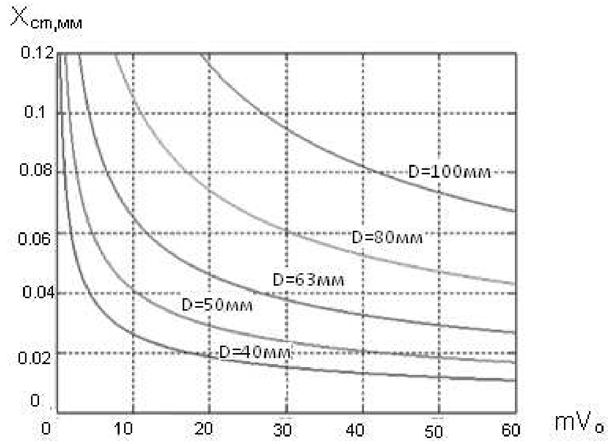

Fig. 5. Nomogram determine the position error

Condition (27) and the nomogram (Fig. 4) to set the braking devices are still not sufficiently comfortable in practical use. In this context , is correct to introduce the more simple and objective criterion . If we analyze the range of fluid density ρ, the typical values of the K_D, then by (27) we can offer the following test installation of the brake actuator unit volume hydraulic drive with inertial load:

$$C_{YS} = \frac{mV_0^2}{p_{nom} D^4} \sqrt{\frac{mV_0}{\nu}} > 10 \cdot \tag{29}$$

CONCLUSIONS

1. Thus, the objective criteria to set braking actuator of the volume hydraulic drive with inertial load is proposed and the evaluation of the error of its positioning on the internal hard legs is given.
2. Results obtained for the bulk hydraulic drive, which was considered in this work, controlled two-position reverse distributor. But they can easily be extended to other schemes of the drive.
3. Results can be used to solve a number of problems to improve the functional and operational capability of automatic machines with volume hydraulic drives. And also to improve their speed and accuracy.

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КРИТЕРИЙ УСТАНОВКИ ТОРМОЗНОГО УСТРОЙСТВА В ОБЪЕМНОМ ГИДРАВЛИЧЕСКОМ ПРИВОДЕ

Яна Соколова

Аннотация. Предложен критерий установки тормозного устройства исполнительного механизма в объемном гидравлическом приводе с инерционной нагрузкой и дана оценка погрешности его позиционирования на внутренних жестких упорах.
Ключевые слова: гидропривод, сила торможения, ошибка позиционирования.

The use of an air cushion for the movement of goods in the shelving storage

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Summary. This article describes a possible scheme of the transport system shelving store for storage unit loads on pallets using an air cushion, the results of investigation of the influence constructive factors on the major acceleration of the pallet with cargo in the cell and the time of issuing it on the transport conveyor. Determine the flow rate of air to move the scum with a cargo rack in the cell, and his extradition to the transport conveyor. The dependence of the flow rate of the main factors.

Key words: shelving storage, conveyor, air cushion, pallet.

INTRODUCTION

The storage area of goods - this is one of the most important technological areas warehouse, the creation of which spent most of the funds in the construction of the warehouse. Storage and movement of goods in the warehouse to ensure their qualitative and quantitative safety, rational distribution of goods at the storage site, the maximum use of space and volume of storage space, the best performance of mechanization, safety performance, the ability to automate all kinds of works. When storing the unit loads, these requirements are met the most complete in the shelving storage [10, 11].

RESEARCH ANALYSIS

The existing shelving storages are serviced by either forklift trucks, which is typical of a large weight of the goods, or stacker cranes [1, 17]. The use of such mechanical means requires the creation of large transportation passes, which entails in a reduction of usable space in the storage area of goods, large capital investments, a significant consumption of energy [1, 8]. The use of stacker cranes allows fully automate the process of moving goods, but the scheme of automation are quite complex and involve a large number of different sensors that not only complicates the work, but also entails a reduction in the reliability of the whole system [1, 12].

RESEARCH OBJECTS

Recently, drive and non-driven conveyors with an air bag for transporting general cargo with flat supporting surface or placed on a flat pallet receive their own development [4, 7, 9]. In the non-driven conveyors cargo movement (pallet) is due to the reaction force which is inclined to the support surface of air jets emanating from the inclined feed channels [2, 3]. The use of such conveyors in shelving storages will significantly increase the utilization of useful storage space in the storage area by reducing traffic passes, reduce the capital costs of construction and energy consumption during use, to simplify and improve the reliability of the automation system management of transportation process. [4, 5]. Furthermore, in this transport and storage system is possible work on load and delivery of loads simultaneousty in several cells of shelves, which considerably increases its productivity [15,16]. The possible scheme of the shelving storage is shown in Fig.1. The pallet with cargo transport conveyor 1 is applied to hoist elevator type 2, rises to the desired stage is sent to a distribution conveyor with inclined feeding channel 3, which moves it to the destination cell and placed in a cell. Delivery of cargo from storage cell is carried out in reverse order with the help of the distribution conveyor 3, 5 lifts and transport conveyor 6. All movements of pallet are carried out slanted jets of air, which in the base plate of transport conveyors and cells feed channels are tilted in different directions. With the help of the control plate, moved to a position in which only open the necessary channels, creates the desired direction of movement of pallets.

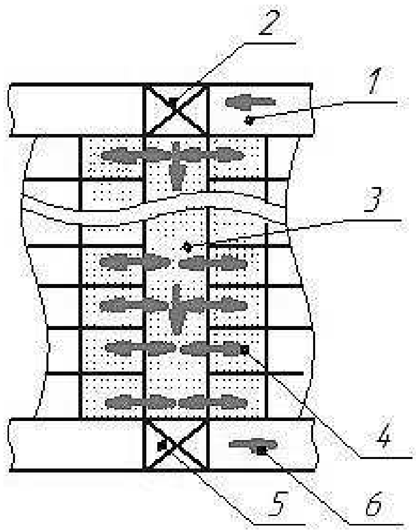


Fig. 1.The possible scheme of the shelving storage

RESULTS OF RESEARCH

To move the pallet with cargo non-drive conveyor with an air cushion, which has a sloping supply channels, the condition must be met:

$$F_x \geq W_0 + W_u = W_0 + G\frac{a}{g}, \qquad (1)$$

where: F_x – traction force, which creates a slant by the air stream,

W_0 – resistance to the movement of the pallet with a load,

W_u – the force of inertia during acceleration cargo up to the necessary speed,

G – weight of the pallet with the cargo,

a – acceleration of the pallet with the cargo, which necessary to achieve the required speed,

g – the acceleration of free fall.

Analysis of the proposed scheme of mechanization shelving storage showed that in the most severe conditions pipes work in racking the pallet boxes in the issuance of the cells on the transport pipeline, as pan starts to move from a state of rest, and in a short time has to travel a distance equal to the length of the pallet, which determines the performance of the system. Also, typically, the center of gravity of the pallet with cargo offset from the geometric center of the pallet, whereby height of the air cushion at different points of the supporting surface varies. This causes a torque about the vertical axis and the occurrence of additional resistance to movement of the pallet by friction on the guide ledges [5].

Time of issue the pallet with the cargo from the cell length l can be defined as:

$$t = \sqrt{\frac{2l}{a}}. \qquad (2)$$

The acceleration of the pallet with the main operating factors can be determined by a formula obtained as a result of the research:

$$a = \frac{l \cdot g}{l + 2 f_2 \Delta b} * \left\{ \begin{array}{l} \frac{C_{x1} + C_{x2}}{2C_{y0}} - f_1 \cdot \exp^{-\frac{6}{\Delta}\cdot\sqrt{h_1 \cdot h_2}} - 0{,}0008 - \\ -2 f_2 \cdot \frac{b}{l} \cdot \left[\begin{array}{l} \frac{C_{x2} - C_{x1}}{2C_{y0}} + \\ + \left(\begin{array}{l} f_1 \cdot \exp^{-\frac{6}{\Delta}\cdot\sqrt{h_1 \cdot h_2}} + \\ + 0{,}0008 \end{array} \right) \cdot \\ \cdot \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) \end{array} \right] \end{array} \right\} . \quad (3)$$

where: f_1, f_2 is coefficients of friction pallet on the bearing surface of the pipeline and the directing side,

Δb – the magnitude of the center of gravity of the pallet with cargo relative to the geometric center of the pallet,

b – the width of the supporting surface of the pallet,

l – the length of the supporting surface of the pallet,

Δ – the height of roughness of bearing surface of the conveyor,

C_{x1}, C_{x2} – the values of the coefficients of the traction force at the extremes pallet [5, 19].

$$C_{x1} = (16 \cdot \left(\frac{H + h_1}{d}\right)^2 \cdot \left[\begin{array}{l} 1 - 2 \cdot \frac{H + h_1}{d} \cdot \\ \cdot \left(1 - \exp^{-0{,}5 \cdot \frac{d}{H + h_1}} \right) \end{array} \right]^2 * \quad (4)$$

$$* \frac{\overline{\Pi^2}}{\overline{S_1}} \cdot h_1^2 \cdot Sin\varphi) \div \left(1 + \frac{\overline{\Pi^2}}{2\overline{S_1^2}} \cdot h_1^2 \right),$$

$$C_{x1} = (16 \cdot \left(\frac{H + h_1}{d}\right)^2 \cdot \left[\begin{array}{l} 1 - 2 \cdot \frac{H + h_1}{d} \cdot \\ \cdot \left(1 - \exp^{-0{,}5 \cdot \frac{d}{H + h_1}} \right) \end{array} \right]^2 * \quad (5)$$

$$* \frac{\overline{\Pi^2}}{\overline{S_1}} \cdot h_1^2 \cdot Sin\varphi) \div \left(1 + \frac{\overline{\Pi^2}}{2\overline{S_1^2}} \cdot h_1^2 \right),$$

h_1, h_2 – the height of the air cushion in the extreme points of the reference surface of the pallet.

$$h_1 = \frac{\overline{S_1} \cdot b \cdot l}{b + l} \cdot \sqrt{\frac{1}{2} \cdot \left(\frac{b}{C_{y0} \cdot (b + 2 \cdot \Delta b)} - 1 \right)}, \quad (6)$$

$$h_2 = \frac{\overline{S_1} \cdot b \cdot l}{b + l} \cdot \sqrt{\frac{1}{2} \cdot \left(\frac{b}{C_{y0} \cdot (b - 2 \cdot \Delta b)} - 1 \right)}, \quad (7)$$

H – chamber depth in supporting surface of the pallet,

d – the diameter of the supply channel,

$\overline{\Pi} = \frac{2 \cdot (b + l)}{b \cdot l}$ – the ratio of the perimeter to the area of the supporting surface,

$\overline{S} = \frac{n \cdot \pi d^2}{4 \cdot b \cdot l}$ – the relative area of the supply channels,

n – the number of the supply channels under the base area of the pallet,

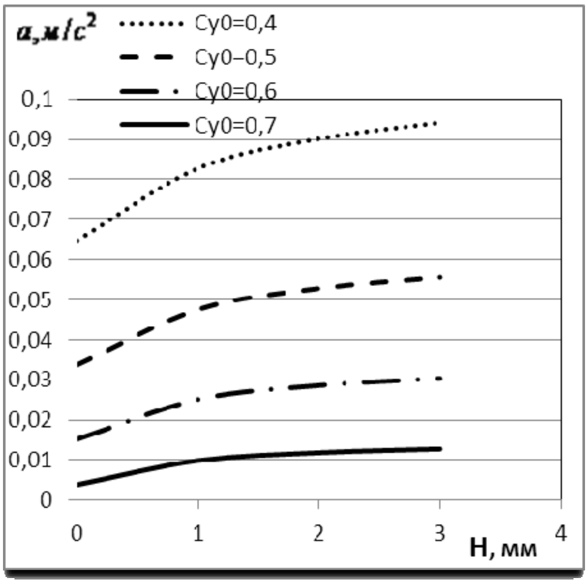
φ – the deflection angle of the axis of the supply channel from the vertical,

$C_{y0} = \frac{G}{P \cdot S} = \frac{G}{P \cdot b \cdot l}$ – the averaged coefficient of lifting force,

P – the air pressure in the receiver conveyor.

As you can see, the acceleration of the motion of the pallet with the cargo depends on many factors. However, factors such as the size of the pallet the supporting surface and the magnitude of the offset center of gravity regulated characteristic of the transported cargo, coefficients of friction and the height of the surface asperities depend on the materials from which the conveyor is made, the optimal values of diameter and angle of supply channels defined earlier [6], the acceleration can be achieved by variation $H, \overline{S_1} u P$. The graphics of dependence of acceleration from these factors are shown on Fig. 2 [6, 13].

The conducted theoretical and experimental investigations of the process of displacing the pan with the load in the cell made it possible to determine the influence of basic design and technological factors (the conducted theoretical and experimental investigations of the process of displacing the pan with the load of vugla of the inclined of the axis of the feeding channel, cross-sectional area of channels, depth of camera in the bottom of pan, air pressure in the receiver, the center-of-gravity disturbance of load, relative to the center of the pan) on the pulling power, the air flow rate and the time of one operation on the delivery of load of the cell, and to also develop the procedure of the determination of the optimum value of the design parameters of installation[14, 18].



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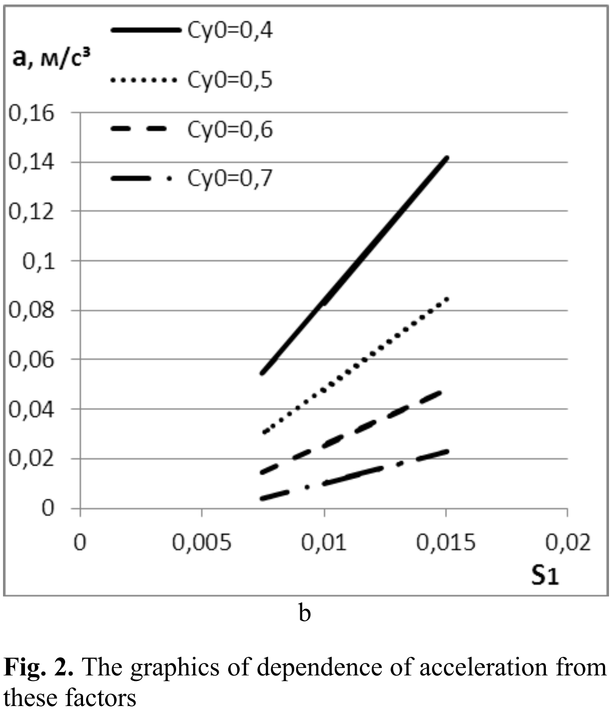

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Fig. 2. The graphics of dependence of acceleration from these factors

Rashod air moving pallet rack with load cell and surrender it to the transport pipeline consists of flow directly under the pallet and flow through the open supply channels out of the Pan in a cell or at the receiving station transport pipeline (Fig. 3):

$$Q = Q_n + Q_k \,. \qquad (8)$$

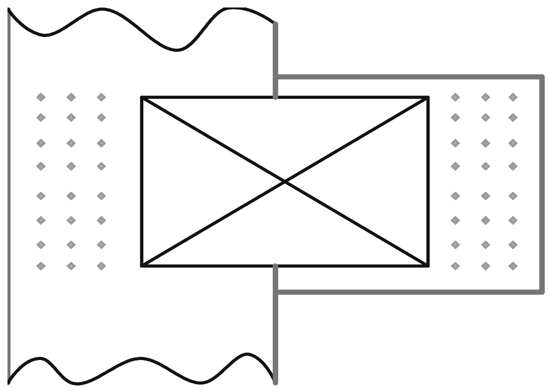


Fig. 3. The receiving station transport pipeline

Air consumption. the pallet can be determined by the formula [9]:

$$Q_n = \alpha * \overline{S_1} * b * l * \sqrt{\frac{2p}{\rho}} \,, \qquad (9)$$

where: α - is the air flow rate

$$\alpha = \frac{4\sqrt{2*\frac{H+h_{cp}}{d}} * \left[1-2*\frac{H+h_{cp}}{d}\left(1-e^{-0.5*\frac{d}{H+h_{cp}}}\right)\right] * \frac{b+l}{\overline{S_1}*bl} h_{cp}}{\sqrt{1+2*\frac{(b+l)^2}{S_1^2*b^2*l^2}*h_{cp}^2}} \,, \qquad (10)$$

h_{cp} – the average height of the air bag,

$$h_{cp} = \frac{h_1 + h_2}{2} ,\ldots \qquad (11)$$

P – is the pressure of air in the Chamber resivernoj

ρ – the density of air at atmospheric pressure

The area of open supply channels, is approximately equal to the square of the supporting surface of the pallet. Therefore, the air flow of the Piazza:

$$Q_k = \overline{S_1} * b * l * V_k = \overline{S_1} * b * l * \sqrt{\frac{2P}{\rho}} \,, \qquad (12)$$

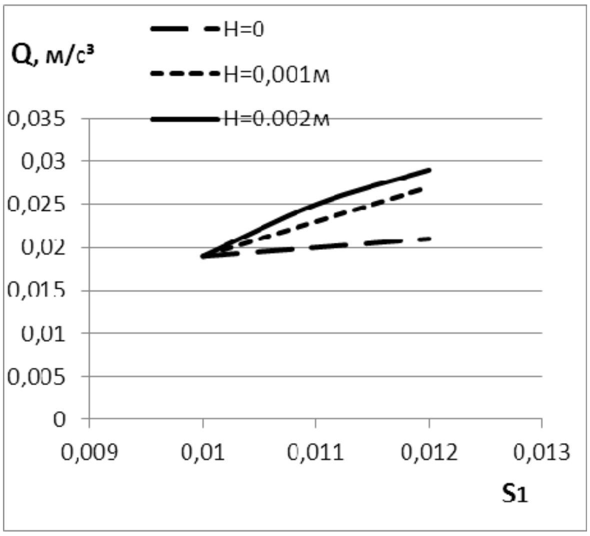
where: V_k – is the velocity of movement of the air in pitaûčih channels [20].

Total air consumption in cell Office rack:

$$Q = Q_n + Q_k = \overline{S}_1 * b * l * \sqrt{\frac{2P}{\rho}} (\alpha + 1) = \overline{S}_1 * b * l * \sqrt{\frac{2P}{\rho}} * \tag{13}$$

$$* \left(\frac{5.6 * \frac{H + h_{cp}}{d} * \left[1 - 2 * \frac{H + h_{cp}}{d} * \left(1 - e^{-0.5 * \frac{d}{H + h_{cp}}} \right) \right] * \frac{b + l}{\overline{S_1 * b * l}} * h_{cp}}{\sqrt{1 + 2 * \frac{(b + l)^2}{\overline{S_1^2 * b^2 * l^2}} * h_{cp}^2}} . + 1 \right).$$

The dependence of the air flow from the main factors shown in Fig.4.



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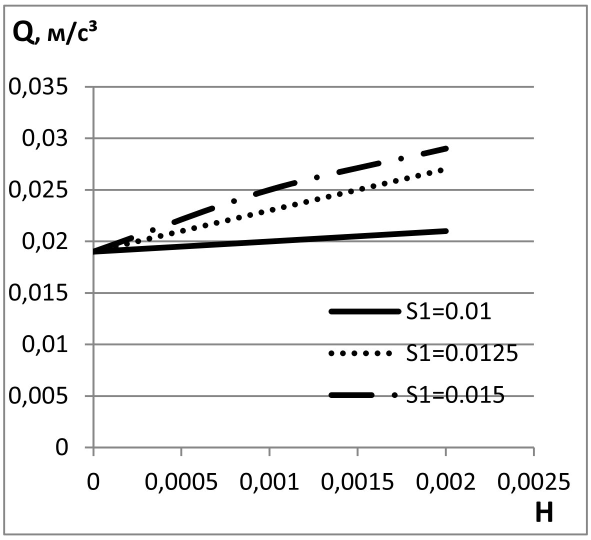

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Fig. 4. The dependence of the air flow from the main factors

CONCLUSIONS

1. The results of these researches showed that the creation of the chamber at the reference surface of the pallet can significantly increase the acceleration of the motion of the pallet in storage cell, however, the increase in its more than two-mm does not give significantly effect.

2. The increase of relative area of supply channels (increased supply channels) leads to a significant increase of acceleration, but thus air consumption significantly increases, which leads to an increase in energy consumption for the formation of an air cushion.

3. Increasing the pressure in the receiver also leads to increasing of acceleration, but causes an increase in energy consumption. Furthermove, the area of the feeding channels deperds on their quantity on the carrying plate and diameter and is the efficiency factor, realized, in the process of design and manufacture of conveyor.

4. A change in this factor with a change in the nomenclature of load, its weight and amount of the center-of-gravity disturbance entails the replacement of the carrying plates, which is very difficult, and in a number of cases it is practically impossible.

5. Therefore reaching the necessary acceleration, and, therefore, also the productivity of entire transport and storage system, possibly by changing the air pressure in the receiver of the conveying appliance of the cell of storage.

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ИСПОЛЬЗОВАНИЕ ВОЗДУШНОЙ ПОДУШКИ ДЛЯ ПЕРЕМЕЩЕНИЯ ГРУЗОВ В СТЕЛЛАЖНЫХ СКЛАДАХ

Наталия Турушина, Григорий Нечаев, Владимир Турушин

Аннотация. В статье описана возможная схема транспортной системы стеллажного склада для хранения штучных грузов на поддонах с использованием воздушной подушки, приведены результаты исследования влияния основных конструктивных факторов на ускорение движения поддона с грузом в ячейке и время выдачи его на транспортный конвейер. Определен расход воздуха для перемещения поддона с грузом в стеллажной ячейке и выдаче его на транспортный конвейер. Определена зависимость рас хода воздуха от основних факторов.

Ключевые слова: стеллажный склад, конвейер, воздушная подушка, поддон.

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Management conception designer preproduction of electronic vehicles

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Summary. As a result of undertaken studies new conception of management is worked out by designer preproduction of electronic vehicles, leaning against single informative space of arrangement of electronic vehicle, operative management designer preproduction and control system by the resources of enterprise, allowing to promote management efficiency designer preproduction of electronic vehicles.

Key words: designer preproduction, electronic vehicle, management conception, informative space, arrangement of electronic vehicle, operative management, resources of enterprise, system of support of making decision.

INTRODUCTION

The offered conception of management embraces the next stages of creation of electronic vehicle designer preproduction of electronic vehicles : arrangement, constructing, preproduction, test and directly production of preproduction model of good [1, 3-5].

The feature of the offered conception of management of designer preproduction of electronic vehicles is that, leaning against single informative space of arrangement of electronic vehicle, operative management designer preproduction and control system by the resources of enterprise, a cost and prime price of preproduction model of electronic vehicle cutout is arrived at, reduction of terms of producing of new electronic vehicles, the competitiveness of enterprise rises at upgrading of electronic vehicles, reliability, oscillation and resonant stability [2, 6, 14].

An achievement such of results is maybe by means of application of the developed system of support of making decision, realizing a management the systems of arrangement and designer preproduction and their cooperation in single informative space, that changes maintenance of designer preproduction in a root, orients a management arrangement of electronic vehicle on the resources of enterprise, providing management efficiency designer preproduction on the whole [5, 8, 16].

OBJECTS AND PROBLEMS

For realization of management conception it is necessary designer preproduction of electronic vehicles without the changes of technical equipped of production on the whole to modernize control system only. It is necessary to work out the system of support of making decision, providing with a managing personnel facilities, methods and instruments, providing possibility to realize the offered conception of management [7 – 11, 15].

For an enterprise - producer of electronic vehicles there is providing of management efficiency, including minimization of material production inputs new good or good with the parameters of quality and reliability, excelling analogues, reduction of duration of process of production etc., maybe by the decision of management task exactly designer preproduction by means of choice of arrangement, parameters and properties of producible block of electronic vehicle(exactly as the completed structurally executed good).

The conceptual model of the automated management of designer preproduction of electronic vehicles looks like, brought around to a Fig. 1. The designer preproduction implies producing of pre-production model of good with the parameters of quality, excelling analogues on condition of cost and unit cost cut out and reduction of terms of producing of good [16 - 19].

By analogy with existent classification of CASS of planning, making, tests of and other, the functions of components of the developed system of support of making decision of designer preproduction of electronic vehicles are analogical to the functions of ERP -, MES -, PDM - systems, applied on the enterprises of instrument-making industry [12, 20]. Application of the functions realized in the developed system of support of making decision analogical to the functions executable PDM - by the system, provides integration of data about arrangement of electronic vehicle, got as a result of planning and design. The constituent of the developed system of support of making decision of designer preproduction, realizing the functions of PDM, are the systems, executes a management data

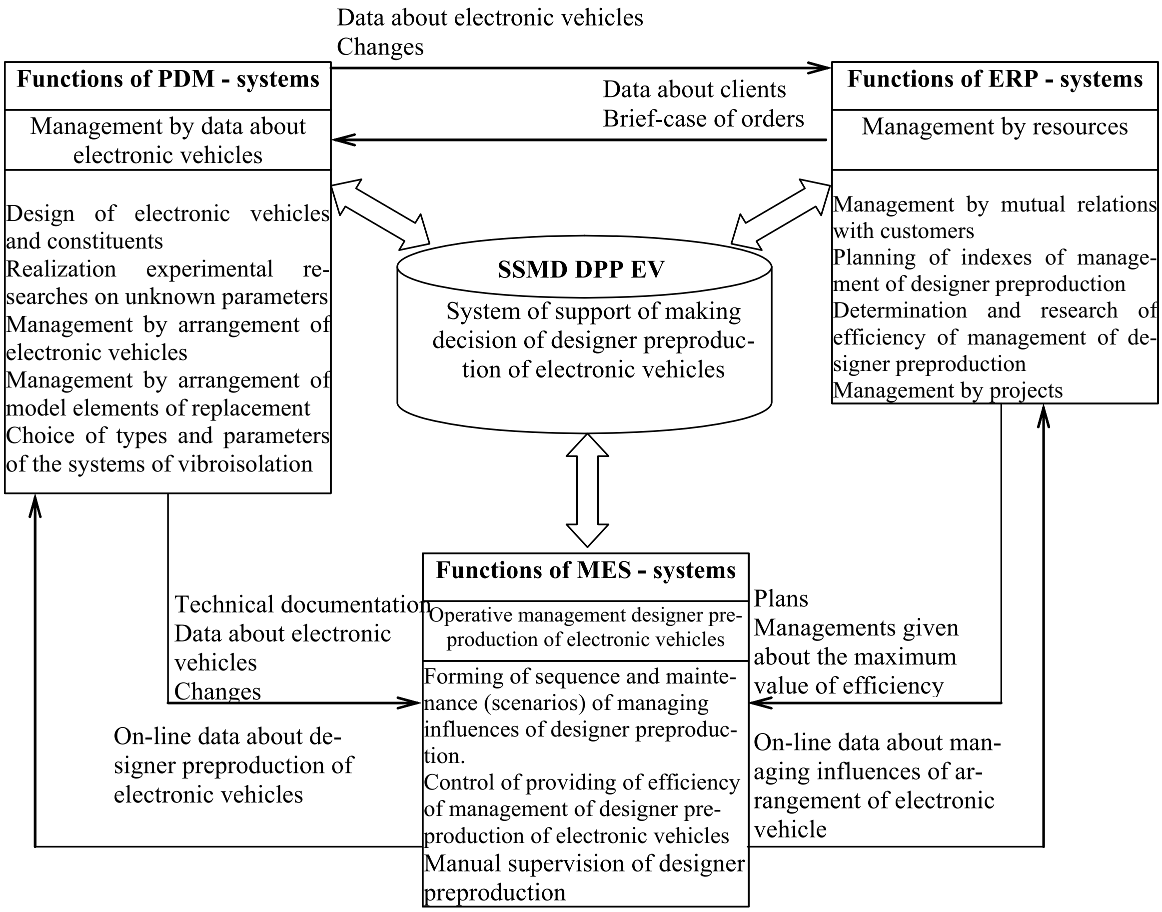

Fig. 1. Conceptual model of the automated management of designer preproduction of electronic vehicles

about electronic vehicles, including the design of electronic vehicle as an object of designer preproduction and management by arrangement of electronic vehicle [13 - 15].

Functions of MES - the systems in the developed system of support of making decision of designer preproduction of electronic vehicles suppose implementation of operative management designer preproduction of electronic vehicles on the basis of generated by the system of support of making decision of management scenarios realizing optimal maintenance and sequences of operations of arrangement on condition of observance of condition of management efficiency designer preproduction on the whole [14].

The constituent of the developed system of support of making decision of designer preproduction, realizing the functions of ERP, are the systems, organizes interrelation with the customer of company-producer of electronic vehicles, management by the developed projects and determines the possible size of management efficiency designer preproduction of electronic vehicles, that will allow to the company to produce competitive good, save the markets of sale and get a profit at minimum material production inputs preproduction model of good.

The developed system of support of making decision of designer preproduction of electronic vehicles supposes an association and active cooperation of functions of the examined systems with the purpose of achievement of the required properties, quality, reliability, to resonant and oscillation stability of electronic vehicles on condition of minimization materially - technical production inputs, achievement of cost expended on retraining and in-plant training of personnel effectiveness, expenses on consultative services of experts etc.

The system of support of making decision designer preproduction of electronic vehicles supposes implementation of functions of design of electronic vehicle taking into account setting and supposed external environments with the purpose of receipt of great number of effective decisions on a management by arrangement of electronic vehicle for the achievement of the required parameters of quality, reliability, oscillation and resonant stability of electronic vehicles. Realization of similar arrangement is possible by the managing affecting of designer preproduction, providing the achievement of financial viability of production of pre-production model of good, exception of tests, returns, revision of good, reduction of time, material production inputs and formalizations of knowledge and experience of experts.

In the conceptual model of the automated management the designer preproduction of electronic vehicles is distinguish next basic essence: management efficiency designer preproduction, electronic vehicle, model element of replacement. Every type of essence at the construction of conceptual model appears as a separate rectangle with the name inwardly, thus the dependent types of essences are represented in a double scope.

The attributes of essence appear as ellipses with the name of the attributes connected by a continuous line with corresponding essence (or by a relation). Every type of relation is shown as a rhombus with the name of relation inwardly. Thus a rhombus is surrounded by a double line, if a relation is set between a dependent type to essence, from existence of that it is in dependence. The separate elements of diagram unite continuous lines (determined raising of management task designer preproduction of electronic vehicles) or dotted lines (stochastic raising of management task). Because connections(relations) of corresponding types of essence are not binary, therefore they are connected by no directional ribs.

It should be noted that for a management the designer preproduction of electronic vehicle is examine the technical and economic indexes of management(management efficiency) and stochastically up-diffused selections of managing influences, divided by teaching and verification for formalization of management process.

The conceptual model of management efficiency is brought designer preproduction of electronic vehicle around to a Fig. 2. On a Fig. 2 the attributes of essence are not shown,

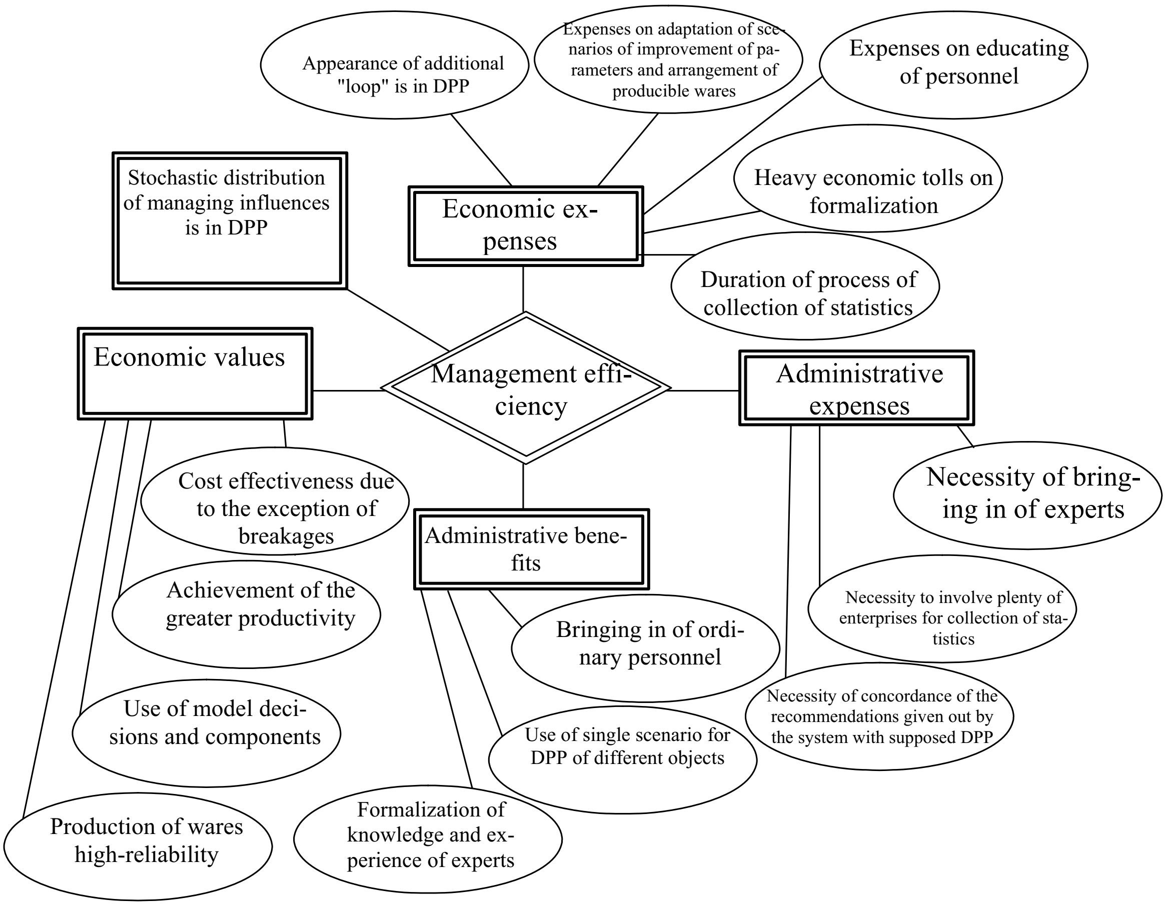

Fig. 2. Conceptual model of management efficiency designer preproduction of electronic vehicle

because we deal with a management designer preproduction of electronic vehicle a few levels of organization are distinguished in that, each of that includes elements from different levels, therefore in detail relations are explained in description to the conceptual model of the system of support of making decision.

Here it should be noted that for a management the designer preproduction of electronic vehicle is examine the technical and economic indexes of management (management efficiency) and stochastically up-diffused selections of managing influences, divided by teaching and verification for formalization of management process.

Management process implementation of certain sequence and maintenance of the managing influences sent both to arrangement of electronic vehicle implies designer preproduction of electronic vehicles and operative management by a personnel and resources of enterprise.

Thus, both for modern firms - producers of domestic electronic technique and for scientific and production enterprises airplane and rocket productions, a management process has identical procedure leaning against subjective presentations and skills of personnel in this area designer preproduction of pre-production model of good.

The unstructured and semistructured multicriterion tasks decide by means of the developed system of support of making decision of designer preproduction of electronic vehicles. The decision of the examined multicriterion tasks will allow not only to improve quality, reliability, resonant and oscillation stability of electronic vehicles, but also to provide financial viability of production of pre-production model of good, eliminate tests, returns on the revision of good, to shorten time, material production inputs and formalized knowledge and experience of experts [15].

In the examined automated management [16] subsystems are distinguished: creations of preliminary character of good, implementation of design of object of designer preproduction, realizations of experimental researches on authentication and research of failing parameters, estimation of quality, reliability, oscillation and resonant stability of electronic vehicle, estimations of management efficiency designer preproduction of electronic vehicles, system of support of making decision, including the subsystems of receipt and treatment of knowledge.

It should be noted that each of them is fully independent and universal for the different sort of tasks, and also each of subsystems is characterized the high degree of noninteraction, that allows to realize the different variants of the parallel including of components of the system and organize an interface for a few users with the simultaneous processing of data.

Examining the computer integrated production of electronic vehicles, characterized by the high degree of automation and application of computer-aided designs, it should be noted that, the object of designer preproduction is characterized repetition, concurrent execution of operations of arrangement and constructing, difficult internal organization.

On an electronic vehicle as an object of designer preproduction is laid on row of requirements on the parameters of quality, reliability, oscillation and resonant stability, it is here necessary to execute the requirements of financial viability and management efficiency designer preproduction, characteristic for the electronic vehicles of the different setting and external environments. All requirements, touching both arrangement and properties of electronic vehicle and management efficiency designer preproduction of electronic vehicle, must be realized in developed system of support of making decision [15].

It should be noted presence and variants of differentiation of the developed system of support of making decision and degree of her use for different on purpose and to composition of objects of designer preproduction.

In the process of functioning the system of support of making decision carries out:

- Ground of necessity of initializing of management process,
- Task of type of object,
- Choice of setting of object,
- Analysis of external environments,
- Prognostication of the possible states of object by means of probabilistic criterion leaning against the base of knowledge and rule of support of making decision,
- Maps the state of object to his components and vice versa,
- Offers methodologies of upgrading, reliability, resonant and oscillation stability of electronic vehicle by means of the offered criteria of arrangement of block of electronic vehicle and constituents,
- Provides the selection of instruments of mathematical design,
- Contains explanations about that, how to work with the instruments of mathematical design,
- Identifies the unknown parameters of mathematical models by realization of experimental researches on a corresponding chart, methodology of the programmatic and technical providing of experiments,
- By means of the worked out criterion of management quality the designer preproduction of electronic vehicles (management efficiency) is watch rationality made alteration in a management designer preproduction of electronic vehicle and their influence is determined on the technical and economic indexes of management on the whole,
- Provides subsequent treatment of control program for a technological equipment, tuned to the same not only under a corresponding technological equipment but also under quality parameters, reliability, oscillation and resonant stability of electronic vehicle.

On the other hand this single cycle of management is mapped to some association of making electronic vehicles, subject to strict hierarchicalness, being with each other in different conceptual relations. It does not allow to talk about possibility of successive implementation of each of operations above some certain object, and supposes the presence of possibility of application of separate operation on the package(great number) of objects or great number of operations on one object, not except possibility of the simultaneous processing of great number of objects.

In the offered conception of management it is assumed designer preproduction, that the type of object for that make an electronic vehicle determines not only external environments but also possibility of bringing of modifications in a management his designer preproduction(management effect), assuming variations of technical and economic indexes and some variations on speed implementations of designer preproduction. The base of knowledge and mechanism of receipt of decision are related to setting of object and object of exploitation, determined by the probabilistic criterion of management efficiency, that systematizes knowledge of experts and experience of specialists engaging in the problem of upgrading and reliability of electronic vehicles.

The variants of terms are possible exploitations that is taken into account in the mathematical model of object, that gives universality in-process designer preproduction the offered management. There is transformation of indexes of quality, reliability, to oscillation and resonant stability of electronic vehicle depending on the results of design on the basis of criteria of arrangement of object of designer preproduction. At changing of mathematical model of electronic vehicle management methodology is applicable designer preproduction either for other external environments or for other objects.

The hierarchy of the prospected objects of designer preproduction is characterized encapsulation, when the elements of subsequent levels consist of great number of elements of previous levels. Such the organization is possible for different objects, what universality of the offered algorithm allows to mark and to reflect his principles on a management by other systems.

Requirements to instrumental part are conditioned by realization of mathematical model as a complex of programmatic and technical facilities, supporting a receipt and transformation of informative character of electronic vehicle in accordance with the criteria of his arrangement. Also the distinguishing feature of instrumental part is methodology plugging in the arsenal of tools of the experimental setting equipped by rigging for authentication of failing parameters of object of designer preproduction.

A return to the management is needed designer preproduction, because virtual building on in form system of support of making decision, including designing complexes, brings in some changes in a structure and parameters of electronic vehicle, that must be passed on a management by designer preproduction and to watch rationality made alteration on the criterion of management quality designer preproduction of electronic vehicles (management effect).

A single algorithm taking into account all these facts differs in large universality and flexibility, because allows to reform on control system designer preproduction of any electronic vehicles without depending on their informative filling.

In respect of task of type of object, then it the simplified enough classification and scientific and practical interest here present not classification, and standing after it components of probabilistic criterion of management efficiency. The values of components of probabilistic criterion are identified in the process of educating of the system of support of making decision determine, take into account and visualize the base of knowledge of probabilistic descriptions of frequencies of refuses, reasons of refuses, influencing active factors and correlation of technical and economic parameters for a management designer preproduction for the certain type of electronic vehicle and external environments.

The automated management designer preproduction of electronic vehicles is based mainly on dialogue instructions acting on behalf of accepting decision. In order that realization of such possibility took place, it is necessary to supply a person, a decision-making, by instruments, allowing to get, process and analyze information, and mechanism, for preparation of decision-making. To that end it is necessary to build the row of informative, programmatic, technical and intellectual subsystems of the developed system of support of making decision of designer preproduction of electronic vehicles.

Management process implementation of certain sequence and maintenance of the managing influences sent both to arrangement of electronic vehicle implies designer preproduction of electronic vehicles and operative management by a personnel and resources of enterprise. Thus, both for the modern firms of producers of domestic electronic technique and for scientific and productive enterprises airplane and rocket productions, a management process has identical procedure leaning against subjective presentations and skills of personnel in this area designer preproduction of pre-production model of good [16, 19, 20].

The unstructured and semi structured multicriterion tasks decide by means of the developed system of support of making decision of designer preproduction of electronic vehicles. The decision of the examined multicriterion tasks will allow not only to improve quality, reliability, resonant and oscillation stability of electronic vehicles, but also to provide financial viability of production of pre-production model of good, eliminate tests, returns on the revision of good, to shorten time, material production inputs and to build an algorithm knowledge and experience of experts.

Integration of the developed system of support of making decision is arrived at by implementation of row of functions of the systems of production of electronic vehicles, presenting the results of modulating, arrangement and management designer preproduction as data, mechanisms of processing of data and receipt of knowledge making the base of knowledge of the system of support of making decision.

The managing affecting process of designer preproduction acts from outside, in particular on behalf of decision making, in order to ratify the offered scenarios of managing influences of arrangement of electronic vehicle, corresponding to the condition of management efficiency designer preproduction. In a fundamental chart the variant of the use of the developed system of support of making decision is envisaged also for the design of electronic vehicles of the different setting and external environments with the use of the experimental setting for research of failing parameters or additional research of electronic vehicle and constituents.

The offered fundamental chart of the system of support of making decision of designer preproduction of electronic vehicles will realize the mechanism of educating of the system of support of making decision, sent to adaptation of scenarios of achievement of necessary parameters, properties and arrangement of electronic vehicle under the existent terms of financial viability of production and corresponding technical and economic indexes of making of pre-production model of electronic vehicle.

Facial, decision making as the making developed system of support of making decision, it is necessary to distinguish the row of functions:

- preparation of information,
- input of information,
- implementation of design,
- preparation and input of information in the system of support of decision-making,
- analysis of the results got from the system of support of making decision,
- implementation of directive management directly designer preproduction of electronic vehicle, including of necessity executions of the given out recommendations.

For the decision of existent productive situations it is necessary formally to describe the actions of face of decision making, consisting in that his activity is presented by the task of great numbers of requests for implementation: designs, arrangements, operative management designer preproduction, research of management efficiency [14, 17 - 20].

Query on behalf of decision making can touch implementation of design, task of preliminary variant of arrangement, research of resources of enterprise on making of pre-production model of good and their variation.

Person an accepting decision, leaning against subjective knowledge and experience, can obtain the certain indexes of efficiency for some period of time and amount of heuristic iterations, however the developed system of support of making decision, leaning against the mechanisms of educating and multicriterion optimization, allows to bring down expenses and prime price of pre-production model of electronic vehicle, to reduce the terms of producing of new electronic vehicles, to promote the competitiveness of enterprise at upgrading of electronic vehicles, reliability, oscillation and resonant stability, to economize the facilities expended on retraining and in-plant training of personnel, expenses on consultative services of experts etc.

On results a design the system of support of making decision forms the components of criteria of arrangement of electronic vehicles, on results processing of statistical data are criteria of arrangement, on the basis of questioning of experts, from literary sources and statistics are management scenarios designer preproduction, coming from the analysis of technical and economic, skilled and other of indexes of production of electronic vehicles is management efficiency. Synthesizes all these indexes, the system of support of making decision prospects and processes, preparing information facial decision making [14 - 16].

Except the functions of search of optimal scenarios of achievement of the required parameters of quality, reliability, to oscillation and resonant stability of electronic vehicle in the process of designer preproduction the offered system of support of making decision, both produces variants and adapts existing before methodologies oscillation, shock and other variants of defense of electronic vehicles from external influences to the existent economic terms and market mechanisms of development of production of electronic vehicles.

Similar family systematization is possible by means of statistical treatment of results of the expert questioning, formalization of procedure of management and forming of case frames for the certain types of electronic vehicles. Introduction of the offered innovations in the existent chart of management of designer preproduction of electronic vehicles will give an opportunity to tune the prospected management under the certain setting of the produced good and condition of exploitation, to attain optimal combinations of economic and administrative parameters of management designer preproduction of electronic vehicles.

For the achievement of the put aim it is necessary to organize questioning of experts concerning the estimations of priorities of results of application of the offered methodology of management of designer preproduction for different objects with subsequent statistical treatment of results of questioning. It is also necessary to estimate adequacy of the got experimental data, define priorities of parameters and their functional intercommunications and on them to produce the analysis of the got results with organization of feed-back for the estimation of efficiency of management of designer preproduction of electronic vehicles. As a method of decision of this task the method of analysis of hierarchies is applied.

Integration of the developed system of support of making decision is arrived at by implementation of row of functions of the systems of production of electronic vehicles, presenting the results of modulating, arrangement and management designer preproduction as data, mechanisms of processing of data and receipt of knowledge making the base of knowledge of the system of support of making decision [14 - 16].

The managing affecting process of designer preproduction acts from outside, in particular on behalf of decision making, in order to ratify the offered scenarios of managing influences of arrangement of electronic vehicle, corresponding to the condition of management efficiency designer preproduction. In a fundamental chart the variant of the use of the developed system of support of making decision is envisaged also for the design of electronic vehicles of the different setting and external environments with the use of the experimental setting for research of failing parameters or additional research of electronic vehicle and constituents.

The offered fundamental chart of the system of support of making decision of designer preproduction of electronic vehicles will realize the mechanism of educating of the system of support of making decision, sent to adaptation of scenarios of achievement of necessary parameters, properties and arrangement of electronic vehicle under the existent terms of financial viability of production and corresponding technical and economic indexes of making of pre-production model of electronic vehicle.

CONCLUSIONS

1. New conception of management is worked out by designer preproduction of electronic vehicles, leaning against single informative space of arrangement of electronic vehicle, operative management designer preproduction and control system by the resources of enterprise, allowing to promote management efficiency designer preproduction of electronic vehicles.

2. First it offers to examine designer preproduction of electronic vehicles as system determined and stochastic constituents, allowing depending on setting of object of designer preproduction to determine management scenarios for the achievement of the required parameters and arrangement of electronic vehicles.

3. Decision of stochastic task of management the receipt of functional dependences supposes designer preproduction for research of management efficiency including quality and amount of management cycles, allows to optimize the technical and economic and administrative indexes of management, that it is necessary to realize supports of making decision in the developed system.

4. The worked out conceptual model of the system of support of making decision, leaning against single informative space of arrangement of electronic vehicle, operative management designer preproduction and control system by the resources of enterprise, allows to provide the required properties, quality, reliability, resonant and oscillation stability of electronic vehicles on condition of minimization of material and technical production inputs, achievement of cost expended on retraining and on effectiveness.

5. Worked out informative and algorithmic providing of management, including the criteria of arrangement and management quality designer preproduction of electronic vehicles, designer preproduction of electronic vehicles, it is necessary to realize supports of making decision in the developed system.

6. Worked out algorithms of management designer preproduction, choice of types of objects and construction of model of electronic vehicle, including the stages arrangements, constructing, preproduction and tests of electronic vehicle, support intercommunication with the experimental setting with the corresponding rigging, allow to get failing information about the object of designer preproduction and estimate his parameters and arrangement without producing of pre-production model of good.

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КОНЦЕПЦИЯ УПРАВЛЕНИЯ КОНСТРУКТОРСКОЙ ПОДГОТОВКОЙ ПРОИЗВОДСТВА ЭЛЕКТРОННЫХ АППАРАТОВ

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Аннотация. В результате проведенных исследований разработана новая концепция управления конструкторской подготовкой производства электронных аппаратов, опирающаяся на единое информационное пространство компоновки электронного аппарата, оперативного управления конструкторской подготовкой производства и системы управления ресурсами предприятия, позволяющая повысить эффективность управления конструкторской подготовкой производства электронных аппаратов.
Ключевые слова: конструкторская подготовка производства, электронный аппарат, концепция управления, информационное пространство, компоновка электронного аппарата, оперативное управление, ресурсы предприятия, система поддержки принятия решений.

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The ways of improving performance of industrial risk and working conditions

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S u m m a r y .The article reviews the main features of the existing methods for assessing occupational risk and issues with their improvement.

K e y w o r d s . working conditions, injury, occupational diseases, indicators of industrial risk, harmful and dangerous production factors (HDPF).

INTRODUCTION

Academician-Secretary of Economical department in NAS of Ukraine V. Heyets in his report "Prediction of scientific, technological and innovational development: the state program of Ukraine and the world experience" (2006) at the XXI Kyiv International Symposium on Science and the scientific and technological forecasting, defining the picture of the day on the economy of our country in terms of technological level, said that the third and the fourth technological modes are now dominant in Ukraine, and the leader countries develop the fifth and the sixth ones, and stated that the facts are retarded by two technological modes [9]. Speaking of technological perspective in comparison with developed countries, the creation of one post in the field of high-tech economy is 100 thousand dollars currently. To accelerate the transition to the innovative economical background that will be competitive, we must multiply this amount by million potential workers, that results in a multibillion dollar amount Ukraine doesn’t dispose of, so this is inappropriate. And to ensure the economical growth it is possible to use both: the actual domestic resources and the ones coming from abroad.

Concerning forging production (FP) the usage of obsolete and worn-out equipment should be considered as a necessity, but not to the detriment of security staff, accuracy, product quality and competitiveness. The results of studies carried out in developed countries show the relevance of the problems associated with impact on harmful and dangerous production factors (HDPF). And engineering production focuses on rolling, forging and pressing shops, including issues like the effects and preventive measures against the negative influence of noise [31,28,32,8,20], increased by smoking [24,18], dust [15,29,7,16] local high temperature thermal radiation directly and in combination with work intensity and stress [5,1,4]. To do this, the International Labour Organization in 1999 introduced in the Directive or the so-called "technical and hygienic management of hygienic monitoring employees» ILO OSH № 72 [12], which requirements must be performed in the study of the negative impact of poor conditions.

So nowadays the issues of creating safe working conditions for people with limited economic opportunities become topical. Therefore, the continuous improvement of safety management system (SMS), as required by European standards [21, 22], from the point of view of prevention occupational injuries and diseases can provide such decisions made that would already lead to significant social impact. This willl happen when the development of safety measures are based on the use of quantitative risk indicators of workers' health with the specifications such as technology, equipment, building and planning solutions to industrial districts and objective human capabilities etc. At present a qualitative transition minds of ordinary workers and employees to accept existing for more than 20 years thesis in developed countries, that absolute security does not exist [2,17,34], is required. Therefore, improvement of SMS based on social-hygienic monitoring and evaluating production risk in enterprises, will help not only to establish parameters HDPF in job evaluation, but also to make prediction and prevention measures based on health occupational diseases and injuries.

It is necessary to note the major contribution to improving the methodology of production risk by scholars, such as V.Vlasov, S.Belov, G.Hohitashvili, M. Izmyerov, V.Minko, G.Faynburg, G.Suvorov, K.Tkachuk, P.Pashkovskyi, O.Zaporozhets, V.Sevrikov, Y.Bulgakov, A.Belikov, V.Kuzin, V.Holinko, O.Izmailova, M.Dulyasova, O.Golyshev, A.Fomochkin, I.Panfyerova, O.Kruzhylko, O.Revuk, Y.Glebova, O.Levchenko and others.

OBJECTS AND PROBLEMS

The analysis indicates the need to improve existing methods for assessing working conditions and production risk, including and forging shops that have the worst HDPF in the engineering industry.

Materials and findings. Impact on people in a production environment HDPF always represents a risk. The current concept of production risk is a common belief system and theoretical propositions about the possible diversion of health as a consequence of it's influence. Despite the differences in the approaches and methods of evaluation, taking into account the specific features of traumatic risk occupations aimed at assessing human health due to the recommendations [20,22], it should be simultaneously in three areas (Fig. 1).

At that they are linked, and their joint implementation aloows to find a definition of risk hazard class conditions (2–valid, 3.1–3.4–bad, 4–dangerous) for their health "Public health standards microclimate production facilities" PHS 3.3.6.042-99 [26] and "safety classification of work in terms of environmental hazard and danger of environmental factors, severity and intensity of the work process" EH 3.3.5-8.6.6.1 -2002 [10], through an assessment of the working conditions and health workers. In the first area of risk assessment the data, obtained as a result of job evaluation as well as special studies of HDPF and conditions, is used.

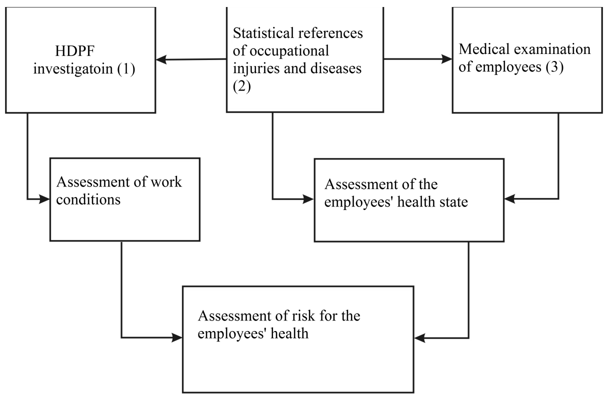

Fig. 1. Production risk assessment scheme

However, this method of assessing production risk loses its relevance due to the fact that the European standards [21,22] indicate its definition as a possible loss.

Over the past 15 years in Russia, compared to Ukraine, much more research has been done, that formed the basis of a number of regulations relating to various aspects of the production risk. And the approach mentioned in [13] allows a graphical method (Fig. 2) for determination of the occupational diseases risk depending on length of service of the employee, that is rediscovering probation areas risk. Using this method Cr (category of risk) for diagnosed cases of occupational diseases and Cs (category of severity) in April are determined via Table. 1 and 2.

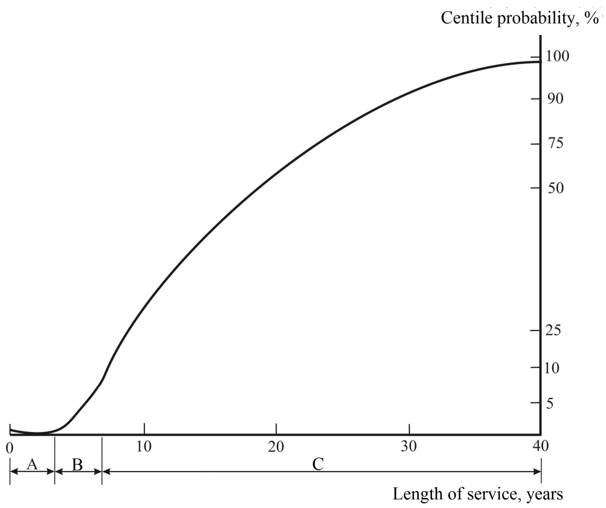

Fig. 2. Graphical interpretation of probation areas of occupational diseases (possible cases in %), where the zones: A – Safe, B – terminal, C – dangerous

Table 1. Category of risk for diagnosed cases of occupational diseases and their characteristic features

Category Cr	Probability, %	
	Diagnosed cases of occupational diseases	Diagnosed cases of early symptoms
1	>10	>30
2	1-10	3-30
3	<1	<3

Table 2. Category of severity for occupational diseases

Categor Cs	Category of severity based on medical prognosis and eventual forms of disability.
1	Disability that progresses even without further exposure and causes a change of profession
2	Permanent incapacity for work or need to change the profession
3	Constant moderate disability
4	Heavy temporary disability or sick leave for more than 3 weeks
5	Moderate disability or sick less than 3 weeks

Defined in the tables 1 and 2, the value of Cr and Cs allow you to deduce suggested in [13] the so-called single numerical indicator of risk:

$$i_{ir} = \frac{1}{Cr \cdot Cs}, \quad (1)$$

which takes into account the probabilistic measure of risk along with the severity of occupational disease. And reciprocal value of the product $Cr \cdot Cs$ can qualitatively and quantitatively evaluate its features as an integrated parameter that varies for one disease ranging from 0 to 1, i.e. 0 < iir <1. Table 3 shows the interrelation between classes of working conditions in [11] with the same numerical measure of risk iir where "MTD level" stands for the level of morbidity with temporary disability and ΔT indicates a change in biological age relative to passport.

Table 3. Performance of occupational risk assessment

Hygienic assessment of working conditions according to D 2.2.755-99 (D 2.2.2006-05)	Medical and biological indicators		
	Indicator iir	MTD level	ΔT augmentation, years
Harmful (grades 3.1-3.2)	<0,3	More than average	Up to 3-5
Especially harmful (grades 3.3-3.4)	0,3-1	High	5-10
Dangerous (extreme) (Class 4)	>1	Very high	>10

In mentioned study [3] it is suggested to use the total risk summary, while the influence of several HDPF:

$$i_{ir}^{sum} = \sum_{i=1}^{n} i_{ir_i}, \quad (2)$$

where: n – number of simultaneously active HDPF, i_{ir_i} – risk performance for the i-th factor.

But approaches to defining risk are outdated because they take into account the negative effect of HDPF on a person as effects that have occurred with sufficiently large intervals. Besides, they ignore the intensity of the process, equipment depreciation, resulting in increase of factor of severity – Fs, of the growing parameters of HDPF.

And what about the so-called "Delayed" negative effect of HDPF when it's manifestations occur late in time, but the effects are rapid and severe. That is, this method can not correctly determine the risk of professional morbidity.

There is another known method for assessing the risk of occupational diseases with regard to length of service for a particular region [30]. Its basis is a mathematical model based on Ferhyulst's equations for various occupational diseases that allows to approximat the empirical dependence, obtained in their analysis. In particular, the regression equation was obtained according to the accumulated probability P of vibration disease on length of service in years X for grinders, operating under the influence HDPF for metalworking enterprises in St. Petersburg:

$$P = \frac{98}{1+10^{(2,19-0,16x)}}, \quad (3)$$

where: 98, 2.19 and 0.16 – parameters of equations that determine the type of dependence.

This method allows to determine via the equation the 25% th and 50% of the risk and the average length of time before the official registration of occupational diseases that the exposure to the risk of these options will be equal at the experience of 10 years - 14 years for 25% th and risk 12 years for 50% of the first, respectively. But it ignores the tensions of work and intensity of exposure of HDPF, including vibration and synergy in their collective action. Thus, in [23] pointed out that the development of vibration disease must take into account the effect of concomitant risk factors (group and individual). If, for example, with the acceptable vibration and seniority of 10 years vibration disease probability is 1%, then the additional effect of noise at 100 dB (without MIP) should expect an increase of vibration disease in 1.5. With intensive cooling, especially with damp hands, there is an increased risk of 3-5. A heavy physical activity in the workplace (WP) with concomitant psychophysiological HDPF, such as smoking, increases the risk of vibration disease in approximately 2-fold.

Besides, there is a recent increase of occupational diseases cases on the background of other existing, and the conditions of its occurrence and impact of the negative effect the above approaches do not consider. In practical terms, these methods do not allow to define the consequent risk at the design stage or upgrading of production processes.

It should be noted that other methods for determining various indicators of risk for occupational diseases exist and new ones appear. In particular [14] determins Iod, the integral index of frequency and severity of occupational diseases in which the severity of the disease is estimated to 5 m categories based on his medical prognosis, and type of disability to which it leads (temporary, permanent, professional, general). This figure takes into account every case of its occurrence in a particular professional group:

$$i_{od} = \frac{\sum_{j=1}^{m} n_j \cdot K_j}{L \cdot \sum_{j=1}^{m} n_j}, \quad (4)$$

where: nj – number of occupational diseases of j category in the group, Kj – j category score of occupational diseases severity, $\sum_{j=1}^{m} n_j$ – number of occupational diseases in all categories of severity m, L – number of years of observation.

There are other developments, such as presented in [14,6,12] for determination the production risk. For example, in [12] is an approach to assess the occupational risk indicator as a temporary disability, which is the summary lost during the working time due to professional or professionally-caused disease. This method is more advanced because it determines whether total disability or death consequences, the study is equivalent to 6,000 man-days of disability. This allows to determine the number of days of disability due to known percentage of disability. Although these indicators are used in the famous methodology of assessment the levels of occupational risk in terms of health (Table 4) in the Russian Federation as a temporary standard [33], we can conclude that they are comprehensive, such as the above reasons in particular, "delayed" effect.

Table 4. Criteria of occupational risk in terms of health

№	Performance	Levels of occupational risk					
		Minimum	Low	Average	More than average	High	Very high
1	Classes of conditions due to the degree of hazard and risk	2	3.1	3.2	3.3	3.4	4
2	Integral performance of disability	<30	30-100	101-300	301-1000	301-3000	>3000
3	Integral performance of occupational diseases iir	<0,1	0,1-0,5	0,51-1,5	1,51-5,0	5,1-15	>15
4	Performance of occupational diseases iir	<0,05	0,05-0,1	0,11-0,25	0,26-0,5	0,51-1,0	>1,0
5	Occupational incidence (number of cases per 10,000 workers of the profession, production) for the year	≤1,5	1,6-5,0	5,1-15,0	15,1-50	>50	
6	The incidence of TD for all diseases (per 100 employees): - Cases of disability, - Days of disability	66,4-72,3 867-938	72,4-84,6 939-1081	84,7-90,7 1082-1153	90,8-96,8 1154-1225	96,9-102,9 1226-1281	>102,9 >1281

In table 4 TD stands for Temporary Disability

There are other methods of determining the production risk, including aimed at finding a correlation between the levels of dependency SHNVCH and frequency of disease, as shown in [25], when the latter is determined by the sum of the coefficients of regression dependence ai, showing an increase incidence of each HDPF multiplied by their actual value xi:

$$y = a_0 + a_1x_1 + a_2x_2 + ... + a_nx_n, \quad (5)$$

where: y – frequence of diseases.

But, according to the formula, for setting via coefficients a_i and Fisher's the exact specific contribution of each indicator HDPF in % to forming health indicators, it is necessary to have a basic value of the coefficient a_0, which depends on the production features.

All of the noted methods are aimed at determination of occupational risk, primarily related to the possibility of occurrence of occupational diseases. In contrast, in [27,35,36] showed that professional risk R is composed of the risk of damage to health due to:

– injuries of varying severity Rin,

– occupational diseases Rod,

– hazardous working conditions, severity and intensity of the work process that has taken the name "hidden" risk Rhid.

Dependence for the determination of risk has the form:

$$R = (N_{dth}/N)\cdot Y_{dth} + (N_{dis}/N)\cdot Y_{dis} + \\ + (N_{od}/N)\cdot Y_{od} + (N_{hid}/N)\cdot Y_{hid} \quad (6)$$

where: N – total number of employees at the station, N_{dth}/N, N_{dis}/N, N_{od}/N and N_{hid}/N - the frequency of damage to health from the deadly consequences, of the disability for one day or more, of the occurrence and frequency of occupational diseases and for working in hazard classes 3.1 ... 4 during the year, respectively, Ydth, Ydis, Yod and Yhid - damage to health in the such cases.

The mentioned hazard classes of work conditions correspond to the operating in Russia normative document [11], which provides a universal scale (Table 5) for assessment the damage injury conditions depending on the class of hazard.

Thus, the last of the method allows to determine the integral index of occupational risk R, which is a combination of actual and hidden risk of injury as a result of professional activities. And because the value of the loss of the last HDPF and conditions are determined by the reduction in days of life (24 hours), then the loss of fatal injury or disability for a day or more and occupational diseases can be expressed in the same units. And from the days of disability it's possible to transfer to the definition of occupational risk in monetary terms. This method represents a significant step forward, as it eases the adaptation of normative documents that are being adopted both in Russia and Ukraine, according to the requirements of the European standard [21,22]. It, unlike others, takes into account the risks of injury, occupational diseases and also a work injury.

Table 5. Scale of loss injury, depending on the class of hazard conditions

№	The degree of hazard conditions according to D 2.2.013-94	Term reduction of life, days per year	
		Range	Average
1	3.1	2,5-5,0	3,75
2	3.2	5,0-12,5	8,75
3	3.3	12,6-25,0	18,75
4	3.4	25,1-75,0	50,0
5	4	>75,0	

CONCLUSIONS

1. This research determines that all of the methods of assessment determine the performance of production risk by the impact of HDPF on the human body. At the design stage of various stations, shops and when they upgrade, retooled they can not give the correct answer to what would be a professional risk at a particular workplace or even at the station. They do not consider how the range and degree of deterioration of equipment and physiological feature of the employees affect.

2. During the intensification of production with new technologies with simultaneous operation of morally and physically obsolete equipment, it is necessary to improve existing methods and approaches for the determination of production risk, thereby, instead of ever increasing damage compensation for injuries and occupational diseases, to direct funds sprecifically for technical upgrading and improvement of cultural production and the creation of healthy and safe working conditions.

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ПУТИ УЛУЧШЕНИЯ ВЫПОЛНЕНИЯ ИНДУСТРИАЛЬНОГО РИСКА И РАБОЧИХ УСЛОВИЙ

Дмитрий Вишневский, Николай Касьянов, Виктор Медяник

Аннотация. Статья рассматривает главные особенности существующих методов для оценки профессионального риска и выходит с их усовершенствованием.
Ключевые слова: рабочие условия, повреждение, профессиональные болезни, индикаторы индустриального риска, вредные и опасные производственные факторы(ОПФ).

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Disk induction motor free rotor stability criterion

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Summary. Mathematical model of disk induction motor free rotor motion has been enhanced. This model accounts for the effect of moving electromagnetic forces and the forces, counteracting the movement, such as viscous friction force and sliding friction force. Based on new equations of free rotor movement, the criterion of its steady motion, including design-engineering characteristics of the electrical machine, has been specified.
Key words. Free circular rotor, stability criterion.

INTRODUCTION

One of the upcoming trends in modern machine-building industry is generating machines with direct drive of working tool or operating device [11, 18]. Using a special structure disk induction motor (DIM), circular tool can be set in steady rotational motion and kept in space without mechanical support and electrical contact through the magnetic forces [24, 25]. Such an electrical machine will enable to enhance direct drive constructions efficiency through combining rotor functions of the motor with working tool or operating device of technological machine. The problem of operating device stability control arises when developing technological machines based on DIM with no mechanical support rotor [2, 5]. When a rolling rotor is under the action of external forces, which generate its mass-center displacement, it should resist them, and when external force is not applied the rotor should return in equilibrium position. Since perturbing factors are always present in reality, the research of stability gains the utmost theoretical and practical importance.

METHODS OF RESEARCH

Stability theory has been created by many mathematicians, mechanics and physicists. Mathematician A.M. Lyapunov [2, 12] made significant contribution in the stability theory.

We suggest to use displacement of the mass center from its initial position as a parameter to evaluate circular operating element (COE) motion stability. Let the initial position be the one at which symmetry axis of the operating element and the end stator of electric machine coincide.

We denominate real variable determining DIM rotor displacement as e. We assume that rotor motion (i.e. change of e with time t) is described with independent differential equation, i.e. the equation that doesn't contain independent variable [5, 14]:

$$\frac{de}{dt} = f(e), \qquad (1)$$

where: $f(e)$ – is a known function of the variable *e*.

Function $e(t;e^0)$ is the solution of this equation at $e\big|_{t=0} = e^0$. Then, according to Lyapunov's definitions, equilibrium position e_0 is called stable if there is such a $\delta_0 > 0$, that at $\left|e^0 - e_0\right| < \delta_0$ there is a solution $e(t;e^0)$ on the whole distance $0 \le t \le \infty$. Also, for any $\varepsilon > 0$ there must exist such a $\delta_0 = \delta(\varepsilon) > 0$ that if the condition $\left|e^0 - e_0\right| < \delta_0$ is fulfilled, then $\left|e(t;e^0) - e_0\right| \le \varepsilon$ [7, 13, 14].

It means that if COE mass center in the initial time point is located close enough to the equilibrium (i.e. value $\left|e^0 - e_0\right|$ is little), then describing a path in all subsequent time points it will remain close to the equilibrium position.

Equilibrium e_0 is called asymptotically stable if it is stable according to Lyapunov's definition, and if at sufficiently small $\left|e^0 - e_0\right|$ the following condition is fulfilled [7, 13]:

$$\lim_{t\to\infty} e(t;e^0) = e_0 . \qquad (2)$$

That is, if COE mass center is displaced in relation to equilibrium, then it will tend to return in the equilibrium position with the course of time.

According to Lyapunov's motion stability theorem it is essential to know when the real components of roots of characteristic equation will be negative. The solution of this problem not involving the direct calculation of characteristic equation roots, is of the greatest interest [14].

This problem was first put by D. Maxwell, and it was he, who gave solution to third-order equation, but in general this problem was solved by E. Raus. His solution is algorithmic. The analytical solution was obtained by A. Hurwitz [14].

Stability theory includes other methods and criteria allowing to evaluate mechanical systems motion stability based on qualitative analysis of motion differential equations. E.g., the methods of Vyshnegradskiy and Michailov are based on graphical representation of stability conditions [9, 16]. Unlike the mentioned above methods, Hurwitz criterion is algebraic, thus is more convenient to use and has become widely spread.

Works [23, 27] studied free circular rotor mass center motion through differential equations taking into account environment resistance forces. Their values are in direct proportion to rotor motion speed. The criterion, determining the range of variation of certain system parameters that affect stability, has been obtained. This criterion is of little informativity since it doesn't account for engineering-design characteristics of electromagnetic system.

The second disadvantage of this criterion is that it leaves out of account sliding friction forces that often take place in technical systems. The work [30] shows that when rotor moves over the work space in air, coefficient of sliding friction significantly exceeds coefficient of air resistance. Moreover, the impact of rotor spin motion on viscous and sliding friction forces is not taken into account.

The purpose of current research is to obtain functional dependance of DIM free rotor stability criterion on design-engineering factors, which electric machines are characteristic of, and also on viscous friction and sliding friction forces.

It is necessary to allow for the forces acting upon rotor, their values, direction and law of variation to research motion stability of electromechanical system.

RESULTS OF RESEARCH

The research of forces and torques acting on circular rotor in rotating field has demonstrated that rotor center displacement vector and its feedback do not coincide in direction [22].

When rotor center is displaced in relation to stator axis by the value *e*, the DIM rotor is under the action of tangential $\overline{F_\tau}$ and radial $\overline{F_r}$ components of electromagnetic forces $\overline{F}$ main vector [22, 28]. The line of action of the force $\overline{F_r}$ passes through rotor rotation center and, thus, doesn't generate torque. If the direction of $\overline{F}_r$ is opposite to the offset, the force stabilizes rotor motion, i.e. it will tend to return the rotor in equilibrium. The force $\overline{F}_\tau$ is directed perpendicularly to the displacement and is always destabilizing.

We consider the movement of free circular rotor with depth *h*, outer radius R_{RO} and inner radius R_{RI}, under the action of spinning axisymmetrical magnetic field of stator with outer and inner radiuses R_{SO} and R_{SI} correspondingly. We also assume that $R_{RI} - R_{SI} > e$ and $R_{SO} - R_{RO} > e$. Rotor depth *h* is much less than its outer radius R_{RO}.

Fig. 1 shows the position of circular rotor over the stator surface at any given time *t*. Coordinates *x* and *y* determine the current position of rotor center O_1 in fixed coordinate system connected with stator center *O*.

The moment of electromagnetic forces $M_{o\tau}$ set rotor in spinning motion with constant angle velocity ω_r in regard to its mass center O_1. Under the action of electromagnetic force $\overline{F}$ the rotor moves with velocity $\overline{v}$ in relation to stator.

According to the definition, elastic system stiffness is force-motion ratio [19], where motion is caused by that force. As in the investigated system an argument is rotor center motion causing its feedback, then the notion of stiffness is remains the same.

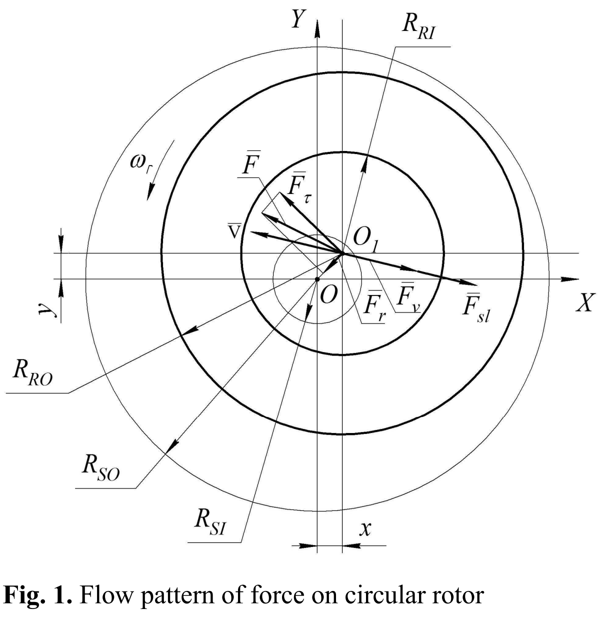

Fig. 1. Flow pattern of force on circular rotor

Radial $\overline{F}_r$ and tangential $\overline{F}_\tau$ components of the main vector of electromagnetic forces $\overline{F}$ are determined by radial D_r and tangential D_τ stiffness:

$$D_r = \frac{dF_r}{de}, \tag{3}$$

$$D_\tau = \frac{dF_\tau}{de}. \tag{4}$$

Taking into account the fact that force $\overline{F}_r$ counteracts the rotor displacement, whereas $\overline{F}_\tau$ is always perpendicular to the displacement direction, we determine the projection of vector $\overline{F}$ on coordinate axes OX and OY [22, 28] as follows:

$$F_x = -D_r x - D_\tau y, \tag{5}$$

$$F_y = D_\tau x - D_r y. \tag{6}$$

Aside from the considered moving electromagnetic forces the rotor is under the action of rotor environment viscous friction force $\overline{F}_v$. Also, when circular rotor is moving on horizontal surface it is under the action of gravitation force that causes normal feedback and, as a result, generates sliding friction force $\overline{F}_{sl}$ counteracting motion [28].

Let us set up differential equations of circular rotor movement when it is under the action of electromagnetic and motion resistance forces [3, 20]:

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= F_{vx} + F_{slx} + F_x, \\ m\frac{d^2y}{dt^2} &= F_{vy} + F_{sly} + F_y, \\ I\frac{d^2\varphi}{dt^2} &= M_v + M_{sl} + M_{o\tau}, \end{aligned}\right\} \tag{7}$$

where: *m* – is rotor mass kg, *I* – second moment of circular rotor kg m^2, F_{vx} and F_{vy} – projections of viscous friction forces on coordinate axes OX and OY *N*, F_{slx} and F_{sly} – projections of sliding forces on coordinate axes OX and OY *N*, M_v – moment of forces of viscous friction *Nm*, M_{sl} – moment of forces of sliding friction *Nm*, $M_{o\tau}$ – spinning moment of electromagnetic forces *Nm*.

Since the relationship $h/R_{RO} \ll 1$ is correct for the considered circular rotor, the motion drag forces are insignificant and not taken into account.

We assume that elementary force $d\overline{F}_v$ of viscous friction of rotor surface (fig. 2) elementary deck *A* on liquid or gaseous environment is proportional to the first degree of velocity and is always directed oppositely to movement. This force is derived from the expression [17]:

$$d\overline{F}_v = -\nu \overline{\mathrm{v}}_{\mathrm{A}} dS_r \,, \tag{8}$$

where: ν – is a drag factor $kg/_{s \cdot m^2}$, $\overline{\mathrm{v}}_{\mathrm{A}}$ – rotor surface elementary deck *A* motion velocity m/s, $dS_r = \rho d\rho d\varphi$ – elementary deck *A* area m^2.

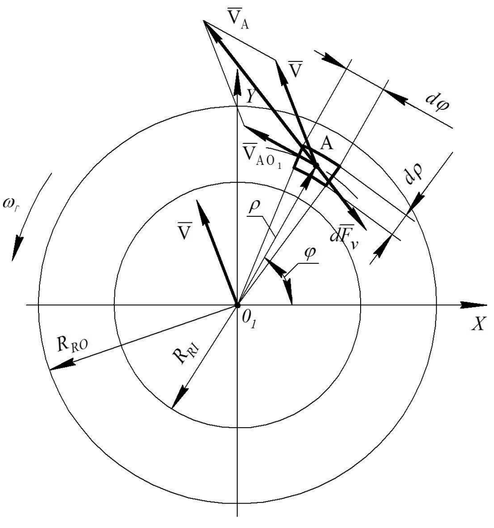

Fig. 2. Design pattern for determining the forces and torques of viscous friction

Since the rotor is in plain-parallel motion, the elementary deck *A* speed in relation to stator will be determined by the expression [3, 19, 20]:

$$\overline{\mathrm{v}}_{\mathrm{A}} = \overline{\mathrm{v}} + \overline{\mathrm{v}}_{\mathrm{AO_1}} \,, \tag{9}$$

where: $\overline{\mathrm{v}}_{\mathrm{AO_1}}$ – is relative speed of deck *A* around rotor rotation center $m/_s$.

Having denominated velocity vector $\overline{\mathrm{v}}$ projections on coordinate axes OX and OY as $\mathrm{v_x}$ and $\mathrm{v_y}$ correspondingly, we find projections $\mathrm{v_{Ax}}$ and $\mathrm{v_{Ay}}$ of vector $\overline{\mathrm{v}}_{\mathrm{A}}$ on the same axes, allowing for the fact that $\mathrm{v_{AO_1}} = \rho\omega_r$:

$$\mathrm{v_{Ax}} = \mathrm{v_x} - \rho\omega_r \sin\varphi \,, \tag{10}$$

$$\mathrm{v_{Ay}} = \mathrm{v_y} + \rho\omega_r \cos\varphi \,. \tag{11}$$

Taking into account (Eq. 10) and (Eq. 11), we also obtain projections of vector $d\overline{F}_v$ on axes OX and OY from the expression (Eq. 8):

$$dF_{vx} = -\nu(\mathrm{v_x} - \rho\omega_r \sin\varphi)\rho d\rho d\varphi \,, \tag{12}$$

$$dF_{vy} = -\nu(\mathrm{v_y} + \rho\omega_r \cos\varphi)\rho d\rho d\varphi \,. \tag{13}$$

Having integrated the expression (Eq. 12) and (Eq. 13), we determine the projections of viscous friction force acting on the rotor [15]:

$$F_{vx} = -\nu S_r \mathrm{v_x} \,, \quad F_{vy} = -\nu S_r \mathrm{v_y} \,, \tag{14}$$

where: $S_r = \pi(R_{RO}^2 - R_{RI}^2)$ – is circular rotor surface area m^2.

From the expression (Eq. 14) it is seen that viscous friction force depends on environment properties, rotor area and its motion speed in relation to stator, but doesn't depend on rotation frequency.

Let us find torque dM_v of viscous friction elementary force $d\overline{F}_v$ in regard to rotor rotation center:

$$dM_v = -dF_{vx}\rho\sin\varphi + dF_{vy}\rho\cos\varphi \,. \tag{15}$$

Having put expression (Eq. 12) and (Eq. 13) into (Eq. 15), we obtain:

$$\begin{aligned} dM_v = \nu((\mathrm{v_x} - \rho\omega_r \sin\varphi)\rho^2 \sin\varphi - \\ -(\mathrm{v_y} + \rho\omega_r \cos\varphi)\rho^2 \cos\varphi) d\rho d\varphi \end{aligned} . \tag{16}$$

Having integrated (Eq. 16), we get:

$$M_v = -\frac{1}{2}\nu\omega_r S_r (R_{RO}^2 + R_{RI}^2). \quad (17)$$

At $h/R_{RO} << 1$, distribution of standard pressure, which the moving rotor exerts on insulating substrate, is close to equilibrium. In this case sliding friction force, acting on rotor, is derived from the expression [6, 21]:

$$\overline{F}_{sl} = -\frac{\mu mg}{S_r}\int_0^{2\pi}\int_{R_{RI}}^{R_{RO}} \frac{\overline{v} + \overline{\omega}_r \times \overline{\rho}}{\left|\overline{v} + \overline{\omega}_r \times \overline{\rho}\right|} d\rho d\varphi, \quad (17)$$

where: μ – is sliding friction ratio, which we will consider as constant, m – circular rotor mass *kg*, g – gravitational acceleration m/s^2.

In works [6, 21] the expression (Eq. 17) has been integrated, based on this we can write the following:

$$F_{sl\,x} = -F_{sl}\frac{v_x}{v}, \; F_{sl\,y} = -F_{sl}\frac{v_y}{v}, \quad (18)$$

where: $v = \sqrt{v_x^2 + v_y^2}$ – rotor mass center speed vector modulus m/s, F_{sl} – sliding friction force vector modulus *N*.

Having denoted the ratio between circular rotor inner radius and its outer radius as $\alpha = R_{RI}/R_{RO}$ and having done the transformations [10, 15], we obtain projections of sliding friction force on coordinate axes:

$$F_{sl\,x} = -\frac{\mu mg}{\omega_r R_{RO}(1+\alpha)} v_x, \quad (19)$$

$$F_{sl\,y} = -\frac{\mu mg}{\omega_r R_{RO}(1+\alpha)} v_y. \quad (20)$$

From (Eq. 19) and (Eq. 20) it is obvious that as rotor spin angle frequency rises, the sliding friction force falls, at simultaneous rotation and motion of the circular rotor.

Moment of friction is determined by the expression [6, 21]:

$$\overline{M}_{sl} = -\frac{\mu mg}{S_r}\int_0^{2\pi}\int_{R_{RI}}^{R_{RO}} \rho \times \frac{\overline{v} + \overline{\omega}_r \times \overline{\rho}}{\left|\overline{v} + \overline{\omega}_r \times \overline{\rho}\right|} d\rho d\varphi. \quad (21)$$

According to works [6, 21], after being integrated the expression (Eq. 21) looks like:

$$\overline{M}_{sl} = -M_{sl}\frac{\overline{\omega}_r}{\omega_r}. \quad (22)$$

After the calculations have been done friction torque is determined according to the following expression [1, 15]:

$$M_{sl} = -\frac{2}{3}\mu mg R_{PH}\frac{1-\alpha^3}{1-\alpha^2}. \quad (23)$$

Having introduced the following denominations: $\vartheta = \nu S_r$, $\upsilon = \frac{\mu mg}{\omega_r R_{RO}(1+\alpha)}$ and $\beta = \frac{1}{2}\nu S_r (R_{RO}^2 + R_{RI}^2)$ we put down the system of equations (Eq. 7), with allowance for the obtained above forces and moments of viscous and sliding friction, as well as electromagnetic forces and their torque:

$$\left.\begin{aligned} & m\frac{d^2x}{dt^2} + (\vartheta + \upsilon)\frac{dx}{dt} = -D_r x - D_\tau y, \\ & m\frac{d^2y}{dt^2} + (\vartheta + \upsilon)\frac{dy}{dt} = D_\tau x - D_r y, \\ & I\frac{d^2\varphi}{dt^2} + \beta\frac{d\varphi}{dt} + M_{sl} = M_{o\tau}. \end{aligned}\right\} \quad (24)$$

Rotational moment $M_{o\tau}$ of electromagnetic forces is determined from the expression [22]:

$$M_{o\tau} = \pi C_\tau B^2 (R_{RO}^4 - R_{RI}^4)\left(\frac{1}{2} + \frac{e^2}{R_{RO}^2 + R_{RI}^2}\right), \quad (25)$$

where: $C_\tau = C\sin\psi$ and $C = \frac{(\omega_s - \omega_r)h}{2\rho_r}$, B – is averaged value of induction density in the working zone of DIM stator *tesla*, ψ – angle between the normal line to stator slot and the radius of the DIM working zone *radian*, ω_s – angle velocity the electromagnetic field of the stator s^{-1}, ρ_r – DIM rotor resistivity constant $Ohm m$.

Since the displacement $e << R_{RO}$ and $e << R_{RI}$, then it is possible to assign the addend $\frac{e^2}{R_{RO}^2 + R_{RI}^2} = 0$ with quite high precision. Then the third equation of the system does not depend on the x and y coordinates and thus does not affect the rotor motion trajectory.

The first two equations of the set (Eq. 24) include only coordinates x and y of rotor mass center current position. Solution of these two equations determines rotor trajectory and, consequently, its displacement in relation to stator. The third equation of the set does not depend on x and y coordinates and thus doesn't affect rotor trajectory. Besides, as rotor rotates with constant angle frequency ($\omega_p = const$), the product $I\frac{d^2\varphi}{dt^2} = 0$ and resistance forces torque are balanced by electromagnetic forces torque. Since the resistance torque values does not depend on displacement e, electromagnetic torque $M_{o\tau}$ remains unchanged.

In this case, it is enough to consider the first two equations of the set (Eq. 24) to analyze rotor motion stability. As this set of equations is linear and independent, we use Hurwitz criterion [14] to analyze its stability.

For this purpose we convert the first two equations of the set (Eq. 24) into the fourth-order differential equation:

$$\begin{aligned} & m^2 y^{(4)} + 2m(\vartheta + \upsilon)y^{(3)} + \\ & + (2mD_r + (\vartheta + \upsilon)^2)y^{(2)} + \\ & + 2D_r(\vartheta + \upsilon)y^{(1)} + (D_r^2 + D_\tau^2)y = 0. \end{aligned} \quad (26)$$

The characteristic equation corresponding to (Eq. 26) is as follows:

$$a_0 p^4 + a_1 p^3 + a_2 p^2 + a_3 p + a_4 = 0. \quad (27)$$

where: $a_0 = m^2$, $a_1 = 2m(\vartheta + \upsilon)$,
$a_2 = 2mD_r + (\vartheta + \upsilon)^2$,
$a_3 = 2D_r(\vartheta + \upsilon)$, $a_4 = D_r^2 + D_\tau^2$.

Let us set up Hurwitz determinant from these coefficients:

$$\Delta = \begin{vmatrix} a_1 & a_3 & 0 & 0 \\ a_0 & a_2 & a_4 & 0 \\ 0 & a_1 & a_3 & 0 \\ 0 & a_0 & a_2 & a_4 \end{vmatrix}. \quad (28)$$

According to Hurwitz criterion the system is stable when all main diagonal minors of determinant (Eq. 28) are greater than zero. If at least one minor is equal to zero, the system is in the state of indifferent equilibrium, and if it is less than zero - the system is unstable.

Let us find the minors of the matrix (Eq. 28):

$$\begin{aligned} & \Delta_1 = 2m(\vartheta + \upsilon) > 0, \\ & \Delta_2 = 2m(\vartheta + \upsilon)(mD_r + (\vartheta + \upsilon)^2) > 0, \\ & \Delta_3 = 4m(\vartheta + \upsilon)^2(D_r(\vartheta + \upsilon)^2 - mD_\tau^2) > 0, \\ & \Delta_4 = \Delta_3 a_4 > 0. \end{aligned} \quad (29)$$

The last two inequations (Eq. 29) are fair when the following condition is fulfilled:

$$\frac{(\vartheta + \upsilon)^2 D_r}{mD_\tau^2} > 1. \quad (30)$$

Having put the expressions for ϑ and υ into (Eq. 30) we obtain:

$$\left(vS_r + \frac{\mu mg}{\omega_r R_{RO}(1 + \alpha)} \right)^2 \frac{D_r}{mD_\tau^2} > 1. \quad (31)$$

Equation 31 determines the range of variation of electromechanical system parameters that provide its stability, and it is circular rotor steady motion criterion (stability criterion).

Physical meaning of the expression (Eq. 31) consists in the fact that if the inequity is realized then rotor rotation center tends to take the stator center position under the action of tangential $\overline{F_\tau}$ and radial $\overline{F_r}$ forces. At that, as the displacement value e decreases, F_τ and F_r forces and rotor mass center motion velocity falls, too, but at $e = 0$ these values are equal to zero, which corresponds to steady rotation motion. If the inequity (Eq. 31) is not realized, the opposite process takes place, i.e. the rotor mass center moves away from stator center until the rotor falls outside the action of electromagnetic forces.

Radial and tangential forces are derived from the expressions [29]:

$$F_r = \frac{\omega_s sh}{\rho_r} e\pi\left(B_O^2 R_{RO}^2 \cos\psi_O - B_I^2 R_{RI}^2 \cos\psi_I\right), \quad (32)$$

$$F_\tau = \frac{\omega_s sh}{\rho_r} e\pi\left(B_O^2 R_{RO}^2 \sin\psi_O - B_I^2 R_{RI}^2 \sin\psi_I\right), \quad (33)$$

where: s – is rotor slip, B_O and B_I – induction density nearby the outer and inner stator contours correspondingly *tesla,* ψ_O and ψ_I – angle between the normal line to stator slot and the radius on outer and inner contour correspondingly *radian*.

To evaluate the circular rotor motion stability degree we introduce the safety factor K_{sf} that shows how many times left part of the inequity (Eq. 31) is bigger than 1. The greater K_{sf} is, the more steadily rotor moves. If K_{sf} is equal to one, it corresponds to the state of motion critical stability. If that coefficient is less than one, rotor motion is unsteady, it tends to fall outside the boundaries of stator magnetic field.

Using expressions (Eq. 32) and (Eq. 33), we rewrite criterion (Eq. 31) as follows:

$$K_{sf} = \frac{\rho_r}{\pi m \omega_s sh}\left(\nu S_r + \frac{\mu mg}{\omega_s R_{RO}(1-s)(1+\alpha)}\right)^2 \times \\ \times \frac{B_O^2 R_{RO}^2 \cos\psi_O - B_I^2 R_{RI}^2 \cos\psi_I}{(B_O^2 R_{RO}^2 \sin\psi_O - B_I^2 R_{RI}^2 \sin\psi_I)^2} > 1. \quad (34)$$

Stability criterion (Eq. 34) allows for the impact of rotor mass, its radial sizes and depth, rotor slip, electrical resistance, environmental resistance, distribution of induction density values in the running clearance, DIM stator slot direction.

The stability criterion allows for the impact of operating environment through environmental resistance ν and sliding friction μ coefficients. It is obvious from the criterion (Eq. 34) that as these coefficients rise rotor stability increases, and according to expressions (Eq. 14), (Eq. 19) and (Eq. 20), environmental resistance forces F_ν and F_{sl} are proportional to ν and μ. Consequently, as the forces counteracting rotor motion increase, rotor stability rises as well.

From the rotation stability criterion (Eq. 34) and expression (Eq. 25) it is obvious that the ratio between rotor resistivity constant and its depth ρ_r/h affects the safety factor K_{sf} and driving torque $M_{o\tau}$ oppositely. As ρ_r/h rises, safety factor K_{sf} increases while torque $M_{o\tau}$ declines. To increase the driving torque $M_{o\tau}$ DIM rotor is produced from low ρ_r materials, like copper and aluminium. Rotor depth h is determined by its process value [4, 8].

From all has been said it follows that design-engineering characteristics improving DIM efficiency lead to decline of stability of rotor without mechanical support.

Stability criterion analysis showed that asymptotical stability condition is fulfilled when the following equation is adhered:

$$B_H^2 R_{PH}^2 \sin\psi_H - B_B^2 R_{PB}^2 \sin\psi_B = 0. \quad (35)$$

At that tangential force F_τ is equal to zero.

As it is obvious from (Eq. 35) the condition $F_\tau = 0$ is affected only by rotor radial sizes (R_{RO}, R_{RI}), elementary forces direction (angles ψ_O and ψ_I) and distribution of induction density in running clearance (B_O, B_I).

Rotor asymptotical stability always takes place when destabilizing force is absent, regardless of displacement *e* and is expressed with condition $F_\tau = 0$. At that stability criterion, regardless of other parameters, tends to infinity.

Let us consider three alternatives of DIM.

The first variant is characterized with conditions $R_{SO} - R_{RO} > e$ and $R_{RI} - R_{SI} > e$, i.e. rotor is always within stator magnetic field. Destabilizing force turns into zero when the equation (Eq. 35) is rendered.

This variant is the most common, since $F_\tau = 0$ is fulfilled in a broad range of variation for parameters included in (Eq. 35).

For the second variant we assume that $R_{SO} = R_{RO}$, and $R_{RI} - R_{SI} > e$. Then $F_\tau = 0$ will be fulfilled at:

$$\frac{R_{RO}}{R_{RI}} = \frac{B_I}{B_O}\sqrt{2\frac{\sin\psi_I}{\sin\psi_O}}\,. \qquad (36)$$

Equation $R_{SO} = R_{RO}$ reduces the number of active parameters, that to a certain extend simplifies rotor stability maintenance. From (Eq. 36) it is obvious that at constant geometric parameters of stator and rotor, zero value of destabilizing force F_τ can be achieved by changing B_I and B_O induction density values on the outer and inner contours of stator correspondingly.

The third variant of DIM construction is characterized with equation $R_{SO} = R_{RO}$ and magnetic field uniformity in the working area, i.e. $B_O = B_I = const$. Rotor rotation stability condition takes the form of:

$$\frac{R_{RO}}{R_{RI}} = \sqrt{2\frac{\sin\psi_I}{\sin\psi_O}}\,. \qquad (37)$$

The latter variant makes condition $F_\tau = 0$ absolutely stringent, in other words, the condition is set at accurate conformance of parameters that cannot be regulated in real machine.

To ensure steady motion of rotor it is necessary that center directed force F_r appears and the equation (Eq. 35) is adhered as the rotor shifts. This can be achieved if the force F_τ pattern of change along the radius will not coincide with the force F_r pattern of change [26]. At that the stator slot tilt angle ψ must functionally depend on the radius.

CONCLUSION

1. The free rotor motion mathematical model refinement enabled to specify the stable motion criterion that allows for the impact of characteristics, like: rotor mass, sizes, electrical resistance, environmental resistance and sliding friction ratios, distribution of induction density in DIM running clearance and stator slots direction. The new criterion enabled to determine the impact of DIM design and engineering characteristics on free rotor stable motion.

2. Based on the obtained stability criterion it has been detected that increase of viscous friction force and sliding friction force improves rotor motion stability. This property makes it possible to use DIM as a drive for circular operating devices of technological machines.

3. If the electric machine efficiency is preserved, free rotor stability rise is possible in such system of electromagnetic forces where the rotor shift from center doesn't lead to occurrence of tangential destabilizing force but causes only radial stabilizing force returning rotor to the center.

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КРИТЕРИЙ УСТОЙЧИВОСТИ СВОБОДНОГО РОТОРА ДИСКОВОГО АСИНХРОННОГО ДВИГАТЕЛЯ

Сергей Ерошин, Сергей Мирошник

А н н о т а ц и я . Усовершенствована математическая модель движения свободного ротора дискового асинхронного двигателя, которая учитывает действие движущих электромагнитных сил и сил, противодействующих движению, таких как сила вязкого трения и сила трения скольжения. На основании новых уравнений движения свободного ротора уточнен критерий его устойчивого движения с учетом влияния комплекса конструкторско-технологических параметров электрической машины.
К л ю ч е в ы е с л о в а . Свободный кольцевой ротор, критерий устойчивости.

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Analysis of the theoretical and applied aspects of modern it infrastructure

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S u m m a r y . Information processes of modern enterprises are implemented on a set of elements of the IT infrastructure. The complexity of the interaction of elements of the IT infrastructure does not allow them to create adequate models without additional restrictions, tools and standards for the enterprise. System features elements of the IT infrastructure is not properly investigated. This paper presents vision, challenges, and system science elements for an IT-infrastructure. In this paper it is going to be discussed criteria for IT infrastructure optimization also. The main task of the IT infrastructure is, ultimately, the management of enterprises information. In this work we discuss causes and problems of building an effective IT infrastructure, and present a analysis of IT infrastructure elements such as a hardware, operating system and virtualization on different levels including data center level. Building a private cloud solutions will unify and standardize IT infrastructure to reduce capital (CAPEX) and operating (OPEX) costs. The conclusion is that the technologies and tools for building cloud solutions IT infrastructure will be implemented in subject to such trends as BYOD, Big Data and Collaboration tools.
K e y w o r d s : IT infrastructure, Cloud, Enterprise architecture, ITIL, MOF.

INTRODUCTION. THE DEVELOPMENT OF THE THEORY OF INFORMATION NETWORKS

Evolutionary development of information processes and architectures of information networks has led to the emergence of new concepts, complementing and partially replacing the concept of the classical theory of information networks [20]. Central to the theory of information networks is the concept of the information process [14, 15]. The theory of information processes, as one of the areas of cybernetics, was developed in the service-oriented architecture (SOA) [27]. In today's information networks, information processes are implemented by IT services.

Information-processing network in the current conditions should be considered as a complex, distributed system in the corporate and territorial space that consisting of a set of local subsystems possessing computing software and hardware implementation of information processes. The necessary and sufficient conditions for the existence of information network is its belonging to a particular organization (enterprise) and/or territory, strong intra-communication, and standardized hardware and software. Moreover information-processing network is a subset of information network as it is in general, embodies a lot of information processes involving subsystems that is non-corporate and geographically specific. Proof of this is the use of cloud solutions like PaaS, IaaS and SaaS for the organization of information processes that implement the business functions of the company.

In practical terms, the trend in recent years is that the information networks became available to us in two implementations: local and distributed. Thus, the local network are typically distributed network subsystems. Classification of networks on a territorial basis (LAN, WAN, MAN) almost lost relevance in the present time. Due to the protocol stack TCP/IP and SMB protocol modern information networks have reached a very high degree of integration and convergence. In addition, we observe gradual abandonment from ring and bus topologies, the peak spreading have observed in 80-90 years. In a large, this transition is caused by objective evolutionary processes in the information society, in particular the improvement of networks (wired and wireless), the use of new communication media, the appearance of next-generation networks (Next Generation Network [5] and the Software-Defined Networking) and intelligent networks [16], increasing transmission speed.

Modern information networks and its subsystems have presented by higher level of abstraction than ten years ago. While the actual tasks were design and optimization of topological structures, data flow, access methods, determination of the routes of their static and dynamic characteristics. Some of them are now the subject of research [21, 23, 24, 30-33]. However, at present most efficient and quasi-optimal solutions are standardized and marketed, inherited for use in new and existing information-processing networks. Thus, we distinguish two lines of research: theoretical, influencing the development of quantitative indicators of hardware and software, and the practical, used for research, design and optimization of the information-processing networks.

FROM INFORMATION-PROCESSING NETWORKS TO IT INFRASTRUCTURE

Definitely practical results that obtained by vendors, have an impact on the theoretical study. Today the unthinkable to consider and study the computing (server) system separate from the networks. Local and wide area networks have become an integral component of any information and automated systems. Evolutionary processes of information technology led to the emergence of a new term in the theory of information networks - IT infrastructure. ITIL defines IT infrastructure as a term that includes all enterprise information technology, except people, processes and documentation [10]. The structure of information technology is hardware and software that implements the development, testing, provisioning, monitoring, management and support of IT services. Thus, in theory of information networks, IT infrastructure is a set of enterprise information technologies, which includes the hardware and software implementing the development, testing, provisioning, monitoring, management and support of IT services. Currently, the term IT infrastructure can be used instead of the outdated terms LAN, WAN or MAN. On the other hand, the concept of IT infrastructure includes local and wide area networks, corporate networks, computer networks, and other terms, the essential properties of which are multiple properties of information-processing networks. It should also be noted that the IT infrastructure operates (is a part of) the automated systems and enterprise level systems, which are at a higher level in the hierarchy, and include the processes, personnel, and documentation.

Research in the direction of improved performance, in terms of achieving optimal performance of some units and functioning of information systems are increasingly attributed to the purely theoretical, since modern information networks are built and scaled based on equipment from major vendors have already implemented protocol stacks and functionality. At the same time performance of the hardware, in most cases, exceed the real needs of an enterprise in terms of ensuring the functioning of the required IT services. Management and support of IT services now have performed at higher levels than the physical (signal level) or protocol (stack TCP/IP). It should also be note that the most widely used transport networks are Ethernet and its high-speed implementations [29]. In the center of the system, except Ethernet, for connecting storages and computing systems are widely used also InfiniBand and FC. Thus, the market inherently affects the direction and topics of research in this subject area. Relevant studies have aimed not only to look for new technologies and methods of teleprocessing and telecommunications, but also taking into account the importance of the application.

Significant indicator of architecture development of information networks is a client connection method. Taking into account the latest research results can be state that in the near future fiber, copper and wireless communication channels will be dominate. Wireless networks will dominate in remote access technologies, and copper - in the information networks of all sizes and application purposes. Client connection technology went its path from development of single-user and terminal connections with low speed performance up to fiber to the desk connection. Thus, by using different methods and approaches of structural optimization of networks, networks modeling and prediction should be taken into account some heuristics, such as a topological origin, standards limitations, interoperability [28].

At present, we are witnessing the consolidation of equipment and computing in the form of medium and large systems (often distributed), implemented as a set of data processing centers (Data Center) [8]. However, their design capacity has already been selected and prepared with a reserve to high availability, performance and fault tolerance. Thus, the aim of current study is the analysis of problem of simulation and optimization of the parameters of software and hardware virtualization technologies and cloud computing in the IT infrastructure.

On the set of IT infrastructure elements two subsets are identified: a subset of the hardware (servers, storages, network equipment, client systems), and a variety of system and application software. In the first subset of the defined range of problems in synthesis, simulation and optimization, there are a number of models and software tools for their implementation, methods and research techniques often do not take into account the topology and protocol restrictions. For the second subset of items currently not enough attention is paid to the modeling, analysis and optimization techniques, theoretical base is underdeveloped, the main results obtained in the field of software engineering.

IT INFRASTRUCTURE OPTIMIZATION CRITERIA

Corporate IT infrastructure is a set of enterprise information technologies, which includes hardware and software that implements the development, testing, provisioning, monitoring, management and support of IT services [9]. Reduce capital and operating costs for the IT is one of the most important and priority areas for modern enterprises. Experts and analysts have pointed out that, on average about 70% of the IT budget is spending on maintenance and support of existing software and hardware, and only 20-30% make expenses for the development, implementation and optimization of new technology and information processes.

Because of the low level of automation of information and computing systems management increases the TCO, increases response time on incidents, reduces availability of services and their security. In such conditions, businesses are not ready to implement LOB applications, have a low ROI level, and often do not have a strategy for the development of corporate information technology.

The core of modern enterprise IT infrastructure exists as a physical server pools, physical server pools with partial virtualization and fully virtualized hypervisors based server resources. Now private cloud solutions, hybrid cloud solutions and public cloud solutions are widely used. Typically, evolving, the core of enterprise IT is in the permanent change process. The difference is in the amount of expenses incurred by the company during the transition to the new information technologies.

There are cases when the transition to the new version of the enterprise LOB applications have to perform a complete replacement of the hardware computing systems. In this case, back-end systems are quite unsuitable for use and must be replaced (virtualization, write-off, disposal).

With the rapid obsolescence of enterprise information technologies and lack of funding the actual direction is the research and development of IT infrastructure optimization criteria in its life-cycle in order to ensure business continuity. Currently, studies are performed in the direction of the network structure optimization criteria to minimize response time, availability, reliability and cost. There are also cost optimization criteria of upgrade hardware and software. Are also offering approaches to optimization in terms of "performance/cost" when implementing new network structures. Many of these approaches do not consider architectural features of the IT infrastructure, the levels of its maturity and evolving nature of the changes in information technology.

Microsoft identifies the following maturity levels of IT infrastructure: basic, standardized, rationalized and dynamic [4]. It does not specify what maturity levels are acceptable and recommended for small, medium and large size enterprises. In addition, the definition of the enterprise's size, depending on the number of client and server systems is subjective to a certain extent, and may be referring to expert estimates. IBM Corporation in the development of business solutions focus on making the data center, which defines four stages of maturity: Basic, Consolidated, Available and Strategic data center [3]. Because the basis of the IT infrastructure of large and medium-sized enterprises is the data center, the development of optimization techniques must take into account the levels and stages of maturity, proposed by vendors who are leaders in the development of cloud solutions and virtualization.

EFFECTIVE INFORMATION MANAGEMENT IS THE MAIN TASK OF THE IT INFRASTRUCTURE

The modern enterprise is a complex system processing big amount of information. Broadly speaking, an information is a data in specific context. The information includes business data, documents, images, audio, video [12].

The information in digital form has produced, consumed, handled, stored and disposed of with the use of information technology. Each year, the amount of information increases by more than 50%. This increases the requirements for IT infrastructure that provides efficient storage and retrieval of information.

One of the main trends that determine the development of the IT market in 2013, according to Gartner, are hybrid IT systems, cloud computing and big data. In particular, it has reported that the variety and complexity of the data arrays, the need for their effective treatment, require a revision of the traditional approaches to handling data across the enterprise. In this case, the concept of a single enterprise data warehouse as part of ERP-systems do not meet the requirements, and a more promising approach is the implementation of multi-level systems form logical enterprise data warehouses, which cover the physical storage systems, information management systems, specialized file systems, cloud environment.

Storage systems are a key asset of the enterprise information technology that determines the safety, reliability, availability, and fault tolerance of IT infrastructure as a whole. The modern solutions are currently available from storage industry leaders EMC, IBM, NetApp, HP, HITACHI with the latest tools and technologies for big data analytics [7, 19, 25, 26].

When the implementation of business processes, the main influence on performance indicators has the level of structured information. Structured information is information in databases, in content management systems, in ERP-systems, in document management systems. A lot of unstructured information are in data files (documents of file system, spreadsheets, presentations, multimedia, folders), a set of mail and instant messaging, set of voice messages and another figureless information.

The greatest difficulty in information using and processing occur when working with unstructured information. Typically, the unstructured data several times more than structured. In 1998, Merrill Lynch analysts have suggested that approximately 80% of potentially useful business information can be extracted from unstructured data. As a result, the average employee spends 60% of time searching for the right information, and 40% for its use. By some estimates, 80% of the world's information is unstructured and its amount will increase by several tens of times faster than a structured.

Let us consider the information processes of the modern enterprise of small and medium scale in more detail. The modern enterprise is characterized by information processes for handling heterogeneous unstructured information that relates to the manufacturing process, administration, research and development, social and humanitarian activities. Currently, information services support controllers and industrial networks, file portals, data from collaboration tools, documents from document management systems, data from ERP-systems warehouses [6].

Any changes in the direction of processability, economy and productivity of IT infrastructure are associated with the usage of efficient information storage and hardware platform. As an example, initiatives such as the transition to a new corporate information and ERP systems, implementation of information management systems, portal systems, terminal systems based on thin clients and VDI, which is actual for the modern enterprise [35]

The main challenges of information management are [11]:

- large number of separate information management systems, implemented at different stages of development,
- presence of legacy systems that require replacement or upgrading,
- poor information systems integration,
- competition between information management systems,
- lack of strategic direction of implementation of an integrated environment and open standards,
- limited or partial acceptance of existing information systems by personnel,
- poor quality of the information, including the lack of control of consistency, repeatability and obsolescence of information,
- the lack of recognition and support of information management technologies from top management,
- limited resources for deploying, managing and improving of information systems,
- lack of enterprise-wide definitions of types and value of information (no taxonomy at the level of the enterprise),
- a wide variety of business needs and problems to be solved,
- lack of clarity in the definition of strategies and development,
- difficulties in changing practices and work processes,
- the impact of domestic policies on the ability to coordinate activities across the enterprise.

In the analysis, development and implementation of new IT solutions should be considering the trends of world and Ukrainian market. A great influence on the architecture of future solutions have a trends BYOD, Virtual Desktops, Cloud-Hosted Technologies, Application Virtualization, Big Data, Collaboration tools. In the near future, more than half of all devices with which customers and employees have access to the services and enterprise information systems will be mobile (Fig.). Todays smartphones are 60 times faster than a CRAY-1 supercomputer of 1982 [17].

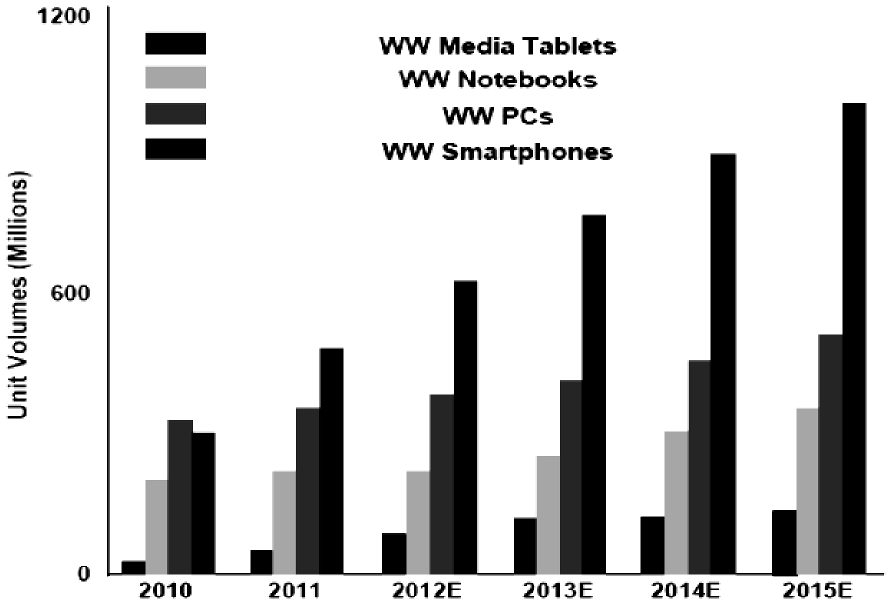

Fig. A new trend is the use of mobile devices in the enterprise. Source: Wells Fargo Securities, January 23, 2012 "Fostering the People: The Shift to Engagement Apps"

CLOUD TECHNOLOGIES AS A BASIS OF MODERN IT INFRASTRUCTURE

The basis for the functioning of cloud solution is virtualized IT infrastructure of the data center. Building a cloud solution based on the use of the following components of information technology: server pool (including virtualized), storage systems, network infrastructure, and specialized software for cloud management. The idea of virtualization and sharing of computing resources is not the product of new technologies as well as the basic principles have been implemented in the era of mainframes and large computers. Academician V. M. Glushkov was a supporter of the idea of collective computing centers in the former Soviet Union.

Currently in Ukraine put into operation many data centers, among which are the departmental (private) and public. The majority of commercial data centers in Ukraine do not meet the criteria of the standard "Telecommunications Infrastructure Standard for Data Centers" TIA 942 Tier III. Despite the construction and putting into operation of new Ukrainian data centers DeNovo (http://www.de-novo.biz/), «The park» (http://datacenter.ua/), BeMobile (http://bemobile . ua /), Datagroup, (a total of 22 data center [2]) the state of affairs in the field of implementation of private and public cloud solutions, as noted at the conference IDC Cloud Computing Roadshow 2012 is unsatisfactory, the market is not mature.

Forrester Research report said that up to 70% of private cloud systems cannot be fully considered as complete cloud solution (definition of NIST [22]), despite the availability of virtualized desktops and virtualized servers, virtual resources management portal and storage systems. At present, a characteristic feature of the information technologies of enterprise is the heterogeneity of IT infrastructure, as well as having a "zoo" of software and hardware. Building a private cloud solution will unify and standardize IT infrastructure and reduce capital (CAPEX) and operating (OPEX) costs. Despite the highly uneven implementation of cloud technologies, according to some studies it is expecting that by 2014, 80% of cloud solutions will be private or hybrid, and by 2016, 80% of servers will be virtualized.

To build a private cloud is currently used software with similar functionality from different vendors, allowing to isolate the level of service from the level of the hardware platform, while maintaining control and providing dynamic resource allocation on demand. However, there is a risk for companies become dependent on a single vendor to support their private cloud. Software-defined networks, based on the OpenFlow protocol, can partially or totally eliminate the dependence of the network infrastructure from a specific vendor's equipment; however, they have not widely used yet.

The transition to the use of cloud services related with questions of integration, scalability, compatibility, security, as well as organizational issues. Is it possible to transfer data to another vendor's cloud solution in the transition to the new platform? Will it reach the necessary level of transparency and data protection? What will happen and what actions should be taken, if you happen to leak data? Do the companies know about information leak? Is it possible to store data, which the company operates in the public cloud?

Considering the cloud technology as a necessary evolutionary stage of development of the IT infrastructure should be noted that dynamic optimization level could be achieved. A dynamic infrastructure allows full costs control, to automate processes of critical services management, to improve service levels, to achieve high competitiveness, to comply with service level agreements, to get rid of extensive development.

Cloud solutions of three basic models: IaaS, PaaS and SaaS are widely used [1, 34]. In the class of IaaS models are widely used Amazon elastic Compute Cloud (EC2), Clever, Eucalyptus, GoGrid, FlexiScale, Linode, Nimbus, Open Nebula, PerfCloud, RackSpace Cloud, IBM SmartCloud, OpenStack, Terremark. PaaS model is implemented by technologies and providers Force.com, GoGridCloudCenter, Google AppEngine, Cloud Foundry, AppJet, Etelos, Qrimp, Windows Azure Platform. The leaders in the provision of SaaS solutions are GoogleApps, Oracle On Demand, SalesForce.com, SQL Azure, Microsoft Office365 and others.

CONCLUSIONS

1. Modern information networks reached a very high degree of integration and convergence. Much of the protocols and rules of engagement are standardized. The main volumes of calculations carried over to the server side. System analysis of modern information networks has revealed new structures, the constituent elements and relationships between infrastructural elements. The exponential growth of information have being processed has led to the consolidation of the computing and storage systems in the form of a data center. The research, simulation, design and optimization of today's IT infrastructures with the use of methods of system analysis, simulation, operations research, forecasting and statistics are relevant to the current stage of development of the information networks.

2. In this paper discussed an approach to optimizing IT infrastructure using a complex criterion that takes into account the structure and configuration of the communication equipment, the scale of the corporate network, the level of automation of information management processes and computing systems, the cost of ownership and return on investment. While solving the optimization problem taken into account the level of maturity of enterprise information technology at every stage of its life cycle.

3. The factors and trends listed in this work point to the dynamic processes of enterprise informatization in the industry context. Information management problems have solved in part, or not resolved at all. Many small and medium-sized businesses variety of vertical markets of Ukraine are not ready to fully implement new solutions related to cloud technologies, mobile systems and virtualized environments [13]. Numerous attempts to match the level of international experience by retrofitting and transition to new platforms are not systemic and do not include of technological trends. More detailed analysis of platforms and examples of infrastructure solutions implementation in companies, as well as their classification, are complicated

and are available at the level of presentation, Case studies of IT market leaders and information messages of system integrators. As a result of analysis of implementation experience of the latest technology by Ukrainian enterprises that available from public sources, it can be concluded that the IT budget cannot ensure the business-continuity and scalability of enterprise information systems and its IT infrastructure.

Under these conditions, we offer IT outsourcing at different levels of service (IaaS, PaaS, SaaS) based on system integrators, consortia and other industry associations of enterprises in Ukraine with the deployment of new or existing data centers, according to legal, organizational, regional and applied features of existing information processes. In this case, the more members of the consortium of IT outsourcing, the higher the level of consolidation, lower TCO, higher energy efficiency. One embodiment of such center have presented by technology parks, innovation centers and other regional research institutions. However, their regional identity, territorial scope, departmental subordination and focus on specific educational complex with its principles of organization and obedience does not allow to fully implementing the principles of IT outsourcing across some industries or vertical market.

4. Cloud solutions will be spreading mainly in the direction of private and hybrid clouds. The transition to the use of private enterprise cloud solutions is a complex multi-criteria problem, the solution of which have accompanied by the stages of analysis, forecasting, deployment and evaluation. Existing technologies and tools for building cloud solutions will be implemented taking into account the trends BYOD, Big Data and Collaboration tools.

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АНАЛИЗ ТЕОРЕТИЧЕСКИХ И ПРИКЛАДНЫХ АСПЕКТОВ СОВРЕМЕННОЙ ИТ-ИНФРАСТРУКТУРЫ

Эдуард Жариков

А н н о т а ц и я . Информационные процессы современных предприятий реализованы на множестве элементов ИТ-инфраструктуры. Сложность организации процессов взаимодействия элементов ИТ-инфраструктуры не позволяет создать их адекватные модели без дополнительных ограничений, инструментальных средств и стандартов уровня предприятия. Системные свойства элементов ИТ-инфраструктуры не исследованы должным образом. Эта статья представляет видение, проблемы и систематизацию элементов IТ-инфраструктуры. В данной работе обсуждаются критерии оптимизации ИТ-инфраструктуры. Основной задачей ИТ-

инфраструктуры, в конечном счете, является управление информацией предприятия. В данной работе рассмотрены причины и проблемы построения эффективной ИТ-инфраструктуры, представлен анализ элементов ИТ-инфраструктуры, таких как аппаратные средства, операционные системы и виртуализированные на различных уровнях серверные системы, включая уровень центров обработки данных. Построение частных облачных решений позволяет унифицировать и стандартизировать ИТ-инфраструктуру в целях снижения капитальных (CAPEX) и операционные (OPEX) расходов. Сделан вывод, что технологии и инструменты для создания облачных решений ИТ-инфраструктуры будут применяться в условии таких тенденций, как BYOD, Big Data и Collaboration tools.
Ключевые слова: IT-инфраструктура, облако, архитектура предприятия, ITIL, MOF

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