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JUSTIFICATION OF THE CONTROLLER PARAMETERS IN AUTOMATIC THERMAL CONTROL SYSTEM OF ELECTRIC THERMAL AGGREGATE

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Abstract On the basis of the structural diagram of the thermal aggregate temperature ACS with structural limitations and assumptions liberalized the control system. Parameters of the PID controller were optimized in accordance with the required quality parameters. Check of the adequacy of the Simulink-model showed good convergence between the results of mathematical modeling and full-scale experiment. Due to the presence of dead zones in the characteristic of the thyristor voltage regulator: delayed transient rise of temperature in the thermal aggregate, the growth process is oscillatory. Presented the transient graphs with the following results: good coincidence of natural experiment and mathematical modeling results (rms error is 5.7 °C); because of the dead zone in the characteristics of the thyristor voltage regulator: delayed transition process growth temperature in the thermal aggregate and the growth process is oscillatory; transients rise in the temperature of the furnace takes place without overshoot. Identified options PID-controller, providing specified quality parameters. Developed the Simulink-model ACS furnace temperature with the structural restrictions. Check of the adequacy of Simulink - model showed a good convergence of results of mathematical modeling and natural experiment.

Keywords: electrical furnace, temperature control, analog regulator

Introduction. In [1-3] described laboratory facility and mathematical model of the automatic control systems (ACS) temperature electric heating furnace. Structural diagram ACS temperature in the thermal aggregate based on the transfer function of the control object (the electrical heating furnace and the temperature sensor) is illustrated in fig. 1 [4].

Figure 1. Structural diagram ACS temperature electric heating furnace with structural limitations

For the justification of the controller parameters accept indicators of the quality of temperature control system.

ACS temperature furnaces must provide the following quality parameters when developing a task to a temperature equal to \( T_z = 80 \, ^\circ C \) (voltage at the terminals of the furnace \( U_{nt} = 70 \, V \)):
- allowable overshoot \( \delta_z = 6 \% \);
- permissible static error \( \Delta_z = 0 \, ^\circ C \);
- regulation time \( t_{pz} = 2400 \, s \).

Structural diagram ACS temperature shown in fig. 1, it is nonlinear. For its research methods of linear systems, linearize control system. We use the following assumptions:
- controller \( W_p(p) \) output unlimited;
- characteristic of the thyristor voltage regulator linear in all range changes input signal.

The corresponding structural diagram is shown in fig. 2.
The transfer function of the connection of the phase regulator and thyristor voltage regulator in view of the assumptions, V/mA

\[ W_{np}(p) = K_{np} = \frac{U_m}{I_{\text{pmax}}} = \frac{70}{20} = 3.5, \]  

where \( I_{\text{pmax}} = 20^\circ \text{mA} \) - output current of the regulator, whereby the voltage at the terminals of the furnace \( U_n = U_m = 70^\circ \text{V} \).

The equivalent transfer function of the controlled system.

\[ W_c(p) = W_{np}(p)W_n(p) = K_{np} \frac{K_n}{T_p}p + 1 = \frac{3.5 \times 2.46}{2400_p + 1} = \frac{8.61}{2400_p + 1} \]  

To calculate the controller is used the Matlab program package [5].

The initial transfer control function can be written as:

\[ W_p(p) = K_p \frac{T_p}{T_p + 1} \]  

Taking \( K_p = 1, T_p = 1 \), obtain:

\[ W_p(p) = \frac{p + 1}{p} \]  

In the command line Matlab introduce equivalent transfer function of the controlled system \( W_c = \text{tf}([8, 61], [2400, 1]) \) and the initial transfer control function \( W_p = \text{tf}([1, 1], [1, 0]) \).

\[ >> W_c = \text{tf}([8, 61], [2400, 1]) \]

\[ >> W_p = \text{tf}([1, 1], [1, 0]) \]

Transfer function:

\[ \frac{8.61}{2400s + 1} \]  

Transfer function:

\[ \frac{s + 1}{s} \]

Open the application SISO Design Tool [6, 7]. Import transfer functions \( W_c \) and \( W_p \) in a generalized system structural diagram. Correction controller until obtain the desired control time \( t_p = t_{\text{max}} = 2400^\circ \text{s} \) and with overshoot \( \delta \leq \delta_c = 6\% \). We can do it using either root locus (left box in fig. 3) or logarithmic frequency response and phase frequency response of a logarithmic open loop (right box in fig. 3).
As a result of setting the transfer function obtained by PI-regulators:

\[ W_p(p) = 0.00048931 \left(1 + \frac{1}{1300p}\right) \]

The coefficients of PI-regulators are:

\[ K_p = 0.636, \quad T_p = 1300. \]

The transition process in the system corresponding to controller configuration parameters is shown in fig. 4.

The transition process in the system, the corresponding controller configuration parameters

Check of the adequacy of the mathematical model. Structural diagram ACS temperature in the furnace with numerical values of controller parameters and including all of nonlinearities is depicted in fig. 5.

Check of the adequacy of the mathematical model. Structural diagram ACS temperature in the furnace with numerical values of controller parameters and including all of nonlinearities is depicted in fig. 5.

Materials and methods. To check the reliability of the results made the mathematical modeling of temperature ACS taking into account nonlinearities (fig. 5), and also made a full-scale experiment in a laboratory facility.

Scheme Simulink-model corresponding ACS furnace temperature with structural limitations shown in fig. 6. The diagram consists two subsystems:

- temperature control subsystem with limitation (limited by the output value of 20 mA) [2, 8];
- subsystem phase regulator and a thyristor voltage regulator (implemented in accordance with the nonlinear characteristic given in [2,9, 10]).

Dead zone of the thyristor voltage regulator

\[ TPH : \quad I_{pc} = \frac{U_{nc}I_{p_{max}}}{U_{ns}} = \frac{40 \cdot 20}{70} = 11.43. \]  

(6)
a task to a during full-scale experiment
\[ T_z = 80 \, ^\circ C, \]
a task to a temperature in the mathematical
model \( T_{zm} = T_z - T_{cp} = 80 - 14 = 66 \, ^\circ C \)
\( (T_{cp} = 14 \, ^\circ C \) - ambient temperature).

Set the following parameters of the PID-
regulator settings in the control unit regulators
TZN4W [8]:
\[ P = \frac{1}{K_p} = \frac{1}{0,636} = 1,572 \]
\[ I = T_i = 1300. \]

Figure 6. Simulink-model ACS temperature in the furnace with all nonlinearities

Fig. 7 shows a graph transition obtained in
Simulink-model ACS temperature (curve 2), and a
graph of transient in a real system (curve 1). The
graphs are constructed based on deviations in the
ambient temperature \( T_{cp} = 14 \, ^\circ C \).

**Figure 7.** Comparison of the results ACS temperature mathematical modeling (2) and
natural experiment (1)

**Results.** The transient graphs (fig. 7) show
as following:
– good coincidence of natural experiment
and mathematical modeling results (rms error is
5.7 OC).
– because of the dead zone in the
characteristics of the thyristor voltage regulator:
– delayed transition process growth
temperature in the thermal aggregate,
– the growth process is oscillatory.
– transients rise in the temperature of the
furnace takes place without overshoot.

**Conclusions.** Thus, as a result of the present
work we can make the following conclusions
1. Linearized the structural diagram ACS
temperature in the furnace with the structural
restrictions for the calculation of the controller
parameters;
2. Identified options PID-controller, providing specified quality parameters.
3. Developed Simulink - model ACS furnace temperature with the structural restrictions;
4. Check of the adequacy of Simulink - model showed a good convergence of results of mathematical modeling and natural experiment.

References
SYSTEM APPROACH TO FINDING HYDRODYNAMIC RESISTANCE COEFFICIENT OF A NASAL CAVITY

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Abstract The purpose of the paper is the development of system approach to finding hydrodynamic resistance coefficient of nasal cavity, which takes into account the regimes of flow through nasal cavity and also specific anatomico-physiological features of a person’s nasal cavity. The physics of the phenomenon causing formation of airflow in a nasal cavity at breathing is considered. The actuality of theoretical and practical researches of flow regime is shown. The analysis of existing methods of nasal breathing assessment is carried out. The new methodology of receiving hydrodynamic resistance coefficient of a nasal cavity, differing from existing by lack of dimension is offered. Value of critical airflow rate allows splitting breathing cycle on 6 phases with identification of automodel zone. The 6-Phase Rhinomanometry is an extension of a 4-Phase Rhinomanometry. The separation on phases happens considering the structure of airflow that is directly connected with the performance of physiological functions. It allows investigation physiology of nasal breathing. Automodel zone of turbulent regime of flow as a marker of norm breathing will be investigated in further works. Also, future research will be connected with assessing a work of nose for different regimes of exploitation: calm breathing, breathing during physical exertion, investigation of nasal cycles.

Keywords: System approach, Rhinomanometry, software/hardware system, medical decision support, hydrodynamic resistance coefficient, Reynolds number, dimensionless coefficient.

Introduction. Patients with diseases of the nose and paranasal sinuses in most cases have nasal obstruction. Some of the common causes are acute chronic inflammatory diseases of the nose, vasomotor and allergic Rhinitis and nasal polyp Rhinitis, various nasal tumors, post-traumatic nasal septal deviation [1,2].

For an objective assessment of nasal breathing, Rhinomanometry [3-5] is widely used in modern medicine. This method measures the ratio of airflow rate through nasal cavity \( Q \) and intranasal differential air pressure \( \Delta p \).

The most of rhinomanometric tests are based on the active anterior rhinomanometry (AAR), the result of which is nasal resistance coefficient \( R \) [6, 7].

One of the concepts of AAR analysis is the division of the breathing cycle by 4 phases, it is presented in Fig. 1. The 4-phase concept distinguishes the ascending and descending phases of inspiration (the 1st and the 2nd), and also ascending and descending expiratory phase (the 3rd and the 4th). Nasal resistance \( R \) is calculated for the 1st inspiratory and the 4th expiratory phases [8]. The fullest review and the criteria analysis of nasal breath assessment is provided in work [9].

In most cases in clinical practice the calculation of nasal resistance coefficient is calculated by using (1)

\[
R = \frac{\Delta p}{Q}. \tag{1}
\]

In accordance with the recommendations of the International Committee on standardization of an objective assessment of nasal breath [10, 11], nasal resistance coefficient or nasal resistance to an airflow \( R150 \) is calculated with fixed differential pressure 150 Pa. In case the differential pressure 150 Pa is not achieved, coefficients \( R100 \) or \( R75 \) can be defined with differential pressure 100 Pa and 75 Pa respectively [12]. This method is constructed on the assumption of linear dependence between airflow rate \( Q \) and differential pressure \( \Delta p \) that corresponds to a laminar flow regime in a nasal cavity, whereas turbulent flow regime through a nasal cavity takes place together.

In works [13, 14] along with the
determination of the nasal resistance by (1) the resistance coefficient is analyzed which is determined by the equation:

\[ O = \frac{\Delta p}{Q^2}. \]  

(2)

This ratio called the obstruction coefficient. In the turbulent flow the coefficient \( O \) decreases while the airflow rate \( Q \) increases and tends to some constant in a completely turbulent flow. From the point of view of Hydromechanics and Physics of the phenomenon Rohrer [15] method is considered to be the fullest as it describes in the most adequate way hydrodynamic characteristics of the breathing process. As it can be seen from the diagram showing the changes of differential pressure \( \Delta p \) depending on \( Q \) losses in Fig. 2, the differential pressure is calculated by equation

\[ \Delta p = k_1 Q + k_2 Q^2. \]  

(3)

where \( k_1 \) – the coefficient of the laminar flow, \( k_2 \) – the coefficient of the turbulent flow.

The calculation of coefficients \( k_1 \) and \( k_2 \) by Rohrer equation is presented in works [16, 17]. It should be noted that all coefficients given above have a number of dimension: \( R = [\text{Pas/m}^3] \); \( O = [\text{Pas}^2/\text{m}^6] \); \( k_1 = [\text{Pas/m}^3] \); \( k_2 = [\text{Pas}^2/\text{m}^6] \).

The last fact reduces the diagnostic value of the received coefficients, and doesn’t allow systematizing biological norm indicators for a nasal cavity. It is necessary to note that to the analysis of dimensionless resistance coefficient \( \lambda \).
which is equivalent of the friction losses coefficient, the work [18] was devoted. However, as it is seen from the diagrams presented in this work in Fig. 3, the identification of a flow regime in nasal cavity was carried out by the fixed range of changes of the coefficient $\lambda$, which is not correct, as in a zone of turbulent self-similarity (automodel zone) the resistance coefficient has to accept constant value.

![Figure 3. Dependence of the resistance coefficient on losses [18]](image)

The purpose of the paper is the development of calculation methodology of the hydrodynamic resistance coefficient of nasal cavity, which takes into account the regimes of flow in the course of breath, and also specific anatomico-physiological features of a person’s nasal cavity.

**Materials and methods.** Bernoulli’s equation for channel of an irregular form.

From the point of view of classical mechanics of liquid the measurement of the differential pressure $\Delta p$ depending on $Q$ losses are standard while determining the hydrodynamic resistance coefficient (further in the text the resistance coefficient), which takes place in liquid movement (incompressible gas) inside internal channels. We will obtain a theoretical equation for the resistance coefficient of a nasal cavity $z$.

Let us consider the nasal cavity as the channel of an irregular form (Fig. 4). Intranasal differential pressure $\Delta p$, on the one hand, represents a difference between the total pressure in a nasopharynx $p_1$ and the external pressure $p_2$:

$$\Delta p = p_1 - p_2$$

On the other hand, the differential pressure $\Delta p$ is the result of losses of pressure upon friction $\Delta p_{fric}$ and vortex formation $\Delta p_{vort}$, independent of a regime of flow in a nasal cavity:

$$\Delta p = \Delta p_{fric} + \Delta p_{vort}.$$  

We will write down Bernoulli’s equation for two sections 1-2:

$$p_1 = p_2 + \xi_{fric} \frac{p_2 V^2_{av2}}{2} + \xi_{vort} \frac{p_2 V^2_{av2}}{2}, \quad (4)$$

where $p_2$ – air density, $V_{av2}$ – average speed of an airflow through a nostril, $\xi_{fric}$ and $\xi_{vort}$ – coefficients of losses on friction and vortex formation, respectively.
Figure 4. Motion of airflow in a nasal cavity

Laminar and turbulent flow.

During a breathing cycle the regime of flow can change from laminar to turbulent on an airflow rate change through a nasal cavity $Q$.

In case when the regime of flow is laminar, the coefficient of losses on friction is inversely proportional to Reynolds number $\xi_{\text{fric-lam}}=A/\text{Re}$. Thus the coefficient of losses on vortex formation can be accepted as constant $\xi_{\text{vort-lam}} \equiv \text{const}$. Such vortex formation is common with a laminar regime of flow behind a shelf bone which is the hamulus in a nasal cavity. In case of a turbulent regime of flow both coefficients accept constant values:

$$\xi_{\text{fric-turb}} \equiv \text{const}, \quad \xi_{\text{vort-turb}} \equiv \text{const}, \quad [19]$$

Thus, accepting that the sum of constant coefficients is the constant value

$$\xi_{\text{vort-lam}} + \xi_{\text{fric-turb}} + \xi_{\text{vort-turb}} = B.$$  

The equation can be expressed like that (4):

$$\Delta p = \frac{A}{\text{Re}} \frac{\rho_2 V_{av2}^2}{2} + B \frac{\rho_2 V_{av2}^2}{2}, \quad (5)$$

where $A$ and $B$ – dimensionless constants.

Average speed of a flow through the nostril, expressed in the (5), is connected with an airflow rate through a nasal cavity $Q$ in the ratio

$$V_{av2} = \frac{Q}{S_{\text{nostril}}} \quad (6)$$

where $S_{\text{nostril}}$ – cross section area of nostril.

Reynolds number in relation to a nasal cavity can be expressed in terms of the equivalent diameter of a nostril

$$\text{Re} = \frac{V_{av2} d_{eq}}{\nu} \quad (7)$$

where $d_{eq}=4S/\pi$ – equivalent diameter of a nostril, $\nu$ – kinematic coefficient of air viscosity.

The total coefficient of the resistance.

Define the total coefficient of the resistance of a nasal cavity $\zeta$. For this purpose divide the differential pressure $\Delta p$ by an dynamic pressure $\frac{p_1 V_{av2}^2}{2}$. Dividing (5) by a dynamic pressure we get the general expression for resistance coefficient, irrespective of the regime of flow, for both the laminar and the turbulent:

$$\zeta = \frac{\Delta p}{\rho_2 V_{av2}^2} = \frac{A}{\text{Re}} + B. \quad (8)$$

Thus, the ratio between the first and the second summands in the (8) depends on a shape of nasal cavity and Reynolds number, and dimensionless constants $A$ and $B$ will tie among themselves noses of various configurations which, however, have to carry out similar physiological functions.

There is a connection between the coefficients in equations (3) and (8)

$$A = k_1 \frac{4S^2}{\rho\nu^2}; \quad B = k_2 \frac{2S^2}{\rho}. \quad (9)$$

The received equations (9) show that the physical content of coefficients $A$, $K_1$ and $B$, $K_2$ doesn’t change. However, as it was noted above coefficients $A$ and $B$ are dimensionless constants, therefore hydrodynamic coefficient of resistance
of a nasal cavity $\zeta$ is also a dimensionless value. The analysis of dependences $\zeta=f(Re)$ for inspiratory and expiratory breath allows to define norm indicators for nasal breath.

Method and procedure of measurements. The measurement of differential pressure and airflow is carried out using the Rhinomanometer. Functionally Rhinomanometer comprises software/hardware system, which consists of the measuring module, a mask and the software (Fig. 5).

The operation principle of system for rhinomanometric measurements is based on the method of an Active Anterior Rhinomanometry. This method is based on simultaneous registration of two parameters: differential pressure $\Delta p$ and an airflow rate through a nasal cavity $Q$. The total pressure in a nasopharynx $p_1$ is measured in an obstructed part of a nose, and pressure $p_2$ in the space under the mask, in a point where there is no airflow speed. The scheme of measurement of a differential pressure $\Delta p$ is shown in Fig. 6 [21].

Thus, the measurements of parameters are carried out for each side of a nose separately.

The measurements result are the values of the differential pressure $\Delta p$ [Pa] and the airflow rate $Q$ [cm$^3$/s] on a time $t$ [s], presented in Fig. 7.

Data are collected and analyzed by software module (C#, SQLite, platform «.NET») in real-time mode. Sampling rate of measurement signals is 100 Hz. Software system consists of input data recording module, data analysis module, data storage module as a stages of information technology of decision-support system for differential diagnosis in rhinology. System was tested and got certificate of state registration № 14777/2015 from 06.12. 2015. Details about the design of software/hardware system for rhinomanometric measurements can be found in [20].
Basic data for the analysis have to be considered in the form of dependence $\Delta p=f(Q)$ for repeating cycles of breathing. Using the method of least squares the data set is fitting by function (3) as it is shown in Fig. 8 and the coefficients $K_1$ and $K_2$ are defined.

**Results and discussion.** In our methodology we consider the nasal cavity as a channel of an irregular form. We applied a basic hydrodynamics and obtained an equation for the resistance coefficient of a nasal cavity. To obtain the dependence $\zeta=f(Re)$ it is necessary to use a proposed above technique. The qualitative diagram of this dependence is shown in Fig. 9.
The obtained dependence is hyperbolic. On this dependence it is possible to see that from a Reynolds number \( Re_{cr} \), the coefficient of resistance becomes almost constant for Reynolds different numbers, and the regime of flow passes from laminar flow to turbulent flow. Reynolds numbers \( Re > Re_{cr} \) are in conformity with a turbulent automodel zone in which the law of change of differential pressure \( \Delta p \) from an airflow rate \( Q \) is nonlinear. Reynolds critical number \( Re_{cr} \) is determined by a derivative \( \frac{\partial \zeta}{\partial Re} \) where an absolute magnitude has to be less or equal to some preset value \( \varepsilon \):

\[
\frac{\partial \zeta}{\partial Re} \leq \varepsilon. \tag{10}
\]

After equation (2.5) differentiation with regard to the statement (8) we get:

\[
Re_{cr} = \sqrt{\frac{A}{\varepsilon}}. \tag{11}
\]

Ratio \( A/\varepsilon \) is modulo as the derivative is negative.

The received Reynolds critical number \( Re_{cr} \) allows defining the critical airflow rate \( Q_{cr} \). The critical airflow rate \( Q_{cr} \) will allow to split nasal breathing cycle on 6 phases [22]. Let’s name the separation of nasal breathing cycle on 6 phases as the 6-Phase Rhinomanometry. The 6-Phase Rhinomanometry is an extension of a 4-Phase Rhinomanometry. It is based on the separation of phases by time periods within one respiratory cycle. However the separation is not carried out by ascending/descending pressure/flow. In our case the separation on phases happens considering the structure of that airflow that is directly connected with the performance of physiological functions.

Also, we have to pay attention that air density \( \rho_2 \) and a coefficient of air viscosity \( \nu \) (which are part of the equations above) depend on the temperature of the inspired and expired air. The average temperature of the expiratory air equals to \( \approx 33^\circ C \) [23, 24], regardless of the temperature of inspired air. We have to consider this fact during the determination of the dynamic pressure and a Reynolds number for inspiration and expiration.

The error for the dynamic pressure will equal to 5% and the error for Reynolds number will equal to 10% when temperature difference \( (\Delta t) \) is 13\(^\circ\)C. Thus it will affect the accuracy of determination of the coefficient of hydrodynamic resistance of a nasal cavity \( \zeta=f(Re) \).

As a result we obtained a preliminary classification of unilateral nasal obstruction. Initial data set consists of 148 patients. Correlation between critical values of Reynolds number and patient’s subjective sensing of obstruction for the level of significance \( p=0.01 \) (using Pearson coefficient) is 0.6460978. The results are shown in the Table 1.

<table>
<thead>
<tr>
<th>Classes</th>
<th>( Re_{cr} )</th>
<th>Obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;=300</td>
<td>without</td>
</tr>
<tr>
<td>2</td>
<td>300-500</td>
<td>low</td>
</tr>
<tr>
<td>3</td>
<td>500-800</td>
<td>moderate</td>
</tr>
<tr>
<td>4</td>
<td>800-1500</td>
<td>high</td>
</tr>
<tr>
<td>5</td>
<td>&gt;1500</td>
<td>very high</td>
</tr>
</tbody>
</table>

So, such an approach is suitable for any configuration of nostril and it doesn’t depend on race differences. Proposed methodology will be used in information technology of decision support system on a stage of models design for differential diagnostics of rhinology pathologies.

Conclusion. Thus, as a result of present work we can make the following conclusions.

1. To determine the dimensionless coefficient of hydrodynamic resistance of a nasal cavity differential pressure \( \Delta p \) should be associated with a dynamic pressure \( \frac{\rho_2 V_{av}^2}{2} \) in the entrance of a nasal cavity. Thus it is necessary to take into account changes of density depending on the temperature of the inspiratory and expiratory air.

2. In general, the flow regime in a nasal cavity changes from laminar flow to turbulent one depending on an airflow rate or on Reynolds number. Also it has distinct automodel zone as evidenced by the equation \( \zeta=f(Re) \).

3. The proposed system approach to processing rhinomanometric data allows to switch to dimensionless coefficients of the hydrodynamic resistance which define nasal cavity aerodynamics for development of standard indicators.

In upcoming work, our efforts will focus on further validation of the proposed system approach using more clinical cases. Also we will be working on improvement of information technology of decision support system for rhinology.
References
CREATION OF THE PROGRAM OF TARGET OPERATIONS ASSESSMENT CALCULATION

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Abstract. The purpose of the paper is to develop a software product for the evaluation of simple target operations. The methods of mathematical modeling and object-oriented programming were applied during the program development. As a result, the program complex has been developed. The comparison of the studied processes is possible by means of the program of target operations calculation assessment. The software product performs assessment calculation, based on the expression of cybernetic estimative indicator that was developed in early researches. It is possible to calculate assessment value of testing operations in the training and educational systems, and also operations of software or any technical object by means of the developed software product. Also the developed method of estimation allows to get objective and correct operation assessment. The software work was demonstrated by the equipment evaluation to select the best option. As cybernetic approach of the operation description is universal and the assessment of any target operation can be calculated using three basic indicators. They are an expert evaluation of input parameters, an expert evaluation of output parameters and the time of operation. The software product of assessment calculation based on the single estimative criterion is suitable for any kind of estimation. As has been noted, the correctness of tasks decision and tasks complexity are necessary for the assessment calculation of any testing operation that is made by any person. The reduction of expert estimates values of input parameters by alignment of action directed product values is necessary for the comparative assessment implementation of the test tasks of different complexity performed by several subjects, as well as any operations.

Keywords: program of operations assessment, equipment assessment, task assessment.

Introduction. Today the main problem of successful goal achievement for system objects of the cybernetic class is connected with a possibility of identification of their procedural activities. The development of the cybernetic estimated indicator [1-3] provides scientific approach to the problem solution. However, there is a question of practical use about the developed scientific and methodical decisions. Logical development of this issue is development of software product based on technology of the universal and adequate assessment of engineering procedures of the controlled systems [4-7].

The use of the known methods of the analysis, planning and implementation of any kind of executive systems activity [8-10], does not result to achievement of maximum possibilities of supersystem [11-12] that uses the results of their procedural activities. It means that the available resources of enterprises are used with low efficiency. This reduces their competitiveness and pace of development.

The problem of creation of the single cybernetic estimative indicator is also actual in the training and educational systems [13-15]. It is connected with the fact that such indicator provides an assessment of dynamics of development of personality practical skills or entity personnel in case of accomplishment of any technological operations.

The advantages of computer estimation are speed, objectivity, consistency and visualization in forming of estimative result. And the advantages of the used technology are absence of subjectivity, universality and accounting possibility of all important parameters (speed, complexity and quality of the solved task).

Materials and Methods. It is proposed to consider the example of the two equipments evaluation presented in [3], for demonstration of the created software work. In work the operation parameters of two electric electric heaters for room warming were considered. Also the assessment of the target operations that are made by the equipment No. 1 and No. 2 has been counted. The assessment calculation is based on the brought input and output parameters for comparative assessment to make the choice of an optimal variant of the equipment.

The input products expert evaluations of the transactions are: \( \alpha_1 = 1546, \alpha_2 = 1904,24 \). The time values of warming the room space are \( TO_1 = 1, TO_2 = 0,83 \). The expert evaluation of output parameters will be as followings: \( k\alpha_1 = 2790; k\alpha_2 = 3085,7 \).

The created software product of assessment calculation has the program settlement modules control window at which it is possible to choose the class of the investigated operation (fig. 1). In our case we will consider the first module of the program where there is an opportunity to
calculate an assessment of simple target operations.

![Figure 1. Control window of estimated modules of the target operations assessment program ram](image1)

The data entry window for an assessment of simple operations (fig. 2) opens when you click the mouse left key on the “Evaluation of simple transactions”.

![Figure 2. The window of data entry and of the basic indicators of simple economic transactions calculation](image2)

After data entry in the needed cells and the last pressing of the “Enter” key the operations data are visualized in the table of operation (1). There are values of all main indicators of economic transaction including its efficiency in the left table (2). And in the right table (3) both basic operation data and the indicators are displayed by one line (fig. 3).
Figure 3. The program window of the operations assessment calculation results that displaying functioning of the equipments № 1 and № 2

Therefore, if Q1 > Q2, then the choice of the equipment No. 1 is reasonable.

**Results.** The software work was demonstrated by the equipment evaluation to select the best option.

As cybernetic approach of the operation description is universal and the assessment of any target operation can be calculated using three basic indicators. They are an expert evaluation of input parameters, an expert evaluation of output parameters and the time of operation. The software product of assessment calculation based on the single estimative criterion is suitable for any kind of estimation.

For example, as has been noted in [3], the taking into account the correctness of tasks decision and tasks complexity are necessary for the assessment calculation of any testing operation that is made by any person. The reduction of expert estimates values of input parameters by alignment of action directed product values is necessary for the comparative assessment implementation of the test tasks of different complexity performed by several subjects, as well as any operations.

**Conclusions.** Developed a program of cyber operations assessment, the calculations of which are carried out using a universal single assessment indicator $Q$. A special feature of the program is a unique opportunity to evaluate the operations performed by a system or mechanism both technical and biological origin, and functioning in any sphere of activity.

This assessment calculation is possible in the case of using the cybernetic approach to technology identification. Since the global input and output functions of the operations are unique to each control, based on a technique that allows to bring significant factors to a single expert values for assessment calculation.

Presentation of studies on assessment calculation of the operations performed by persons, using the developed software product is the subject of the following publications.

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SYSTEM ANALYSIS OF THE ACCIDENT RISK OF SURFACE MINING OBJECTS AS A BASIS FOR THEIR SAFE OPERATION

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Purpose. Making one of the reliability assessment methods of structural elements of objects surface mines as a system of risk analysis of possible defects in the construction of structures and organizational reasons that can lead to an accident, allowing to manage security in the operation.

Methodology. Developed the analytical model for determining the accident risk assessment of structures (structural collapse), in which made the diagnostics of the technical state of the object surface mines and found the value of the actual degree of survivability. To determine the risk standard levels an object is represented as a system consisting of connected groups of the same type of bearing elements. During the simulation are considered the main parameters: technical, human and organizational factors, as well as the cost of the work related to improving security.

Scientific novelty. The scientific novelty of proposed method is an adequate description of reliability degree of bearing elements of the object surface mines, which will take its place among the new modern experimental studies of the structures of the industrial site.

Practical significance. Made the methods for system risk analyses of possible structural defect, which allows to determine the reliability of an object at a particular time and safe residual life. As a result of the proposed measures increased assessment of costs and benefits from implementation of measures to reduce the risk of an accident based on the hazard identification. Developed the final recommendations for the safe operation facilities using the existing regulatory framework on labor protection.

Results. Identified three areas of risk like negligible risk, acceptable risk (which is not so small to be ignored, but not large enough to consider it excessive) and unacceptable risk (so large that it is considered excessive). Obtained the model that allows to perform systematic risk analyses of possible structural defects in construction, by comparing with its actual acceptable boundaries. The proposed method can be used in practice to assess the survivability degree and safe residual life of the object.

Key words: risk, accident, reliability, safety, residual life.

Introduction. The high level of injuries and especially accidents involving fatal injuries in Ukraine raises the issue of improving the methods of prevention. In recent years, production in the world is estimated based on safety adverse event risk. The international organizations ISO, IMO and others have developed theoretical bases and methods of risk assessment and decision on the basis of their technical solutions for the prevention from accidents and injuries in the workplace [1-3]. Experts from various industries in their reports constantly operate not only the definition of "danger" but also such a term as "risk".

In the scientific literature there are various interpretation of the term "risk" and its definitions sometimes differ from each other by content. For example, the risk in the insurance terminology is used to refer to the insurance object (industrial enterprises or firms), the insured event (flood, fire, explosion, etc.), insured sum (risk in monetary terms) or as a collective term to refer to unwanted or uncertain events. Economists and statisticians, faced with these issues, understand the risk as a measure of the possible consequences, that will emerge at some point in the future. In psychological dictionary, risk is interpreted as an action aimed at attractive goal, the achievement of which involves elements of danger, risk of loss, failure, or as a situational characteristic of activity consisting in uncertainty of its outcome and possible adverse consequences in case of failure, or as a distress measure with non-success in the activities, defined by the combination of the probability and magnitude of adverse effects in this case. A number of interpretations reveal the risk as a probability of accident occurrence, danger, accident or disaster under certain conditions (state) of production or human environment. These definitions emphasize the value of the vigorous activity of the subject and objective properties of the environment.

As a common in all the above views is that risk involves the uncertainty of whether either an undesirable event or the adverse condition will occur. Note that in accordance with modern views the risk is usually interpreted as a probability...
Risk is inevitable, concomitant factor of industrial activities. The risk is objective, it is characterized by suddenness, the unexpectedness of onset, which involves the risk forecast, its analysis, assessment and control - a number of actions to prevent risk factors or lessening the impact of hazard.

Construction, reconstruction and operation of facilities and structures on the surface of the mines belongs to the highest degrees of risk, due to the specifics of work performance (lack of permanent jobs and increased risk of production processes), as well as organizational factors. This requires the improvement of the preventive work to improve safety of construction production on the basis of existing risk assessment methods [4-9].

In this work, the aim is to use known technique for the analysis of potential accident hazards facilities (structural collapse), transforming it to conditions of construction.

Materials and methods. Human safety and environmental protection are the two related to problems of health and safety. International standardization organization (ISO) interprets safety as the absence of unacceptable risk associated with the possibility of damage [1].

On the basis of analysis and synthesis of the research results in the field of technogenic safety was developed a guide for formal safety assessment - Formal Safety Assessment (FSA) [2]. FSA is a structured and systematic methodology designed to increase security, including the protection of life and human health, of environment and property based on a risk assessment taking into account the required costs and benefits.

Most often risk is defined as the frequency of realization of the unwanted event - a quantitative risk assessment [3].

The FSA considers the term “risk” as a product of damage caused by accident, that is, the risk value can be calculated from the following equation

\[ R = \lambda \cdot Y, \]

where \( R \) - the estimated risk value, \( \lambda \) - the frequency of accidents of this type, \( Y \) - the damage caused by accident, without dimension or in UAH.

The dimension 1/year used in estimating a risk of human death (individual risk) and the
dimension of the UAH. /a year in assessing a risk of material loss or environmental risk.

In accordance with the FSA [2] the scale of risk has three areas. In first, there is a negligible risk, the second risk is so great that it is considered excessive or inappropriate. Between these two areas is an area of acceptable risk, i.e. that risk, which is not so small to be ignored, but not large enough to consider it excessive.

In the general, acceptable risk is the level of anthropogenic activities which society is willing to accept for the resulting economic and social benefits.

In accordance with the criteria adopted in the world practice [2], is considered unacceptable individual risk exceeding $1.10^{-4}$ 1/U AH. when during the year of this type of undesirable events killed 1 person in 10000.

Acceptable (valid) is the individual risk, if its level lies in the range $1.10^{-4}-1.10^{-6}$ 1/year. This area of risk requires the special measures to its control.

The risk value $1.10^{-6}$ 1/year in developed countries is considered as the acceptable level of risk. An area of risk is less than this value suggests that the safety measures, made in the field of technological activity, are at a level that does not require special interventions for their improvement.

During the risk assessment should be considered the total damage caused by both the loss of life and material losses and the environmental damage. With this purpose it is necessary to consider the compliance of the material damage in monetary terms with the damage from the human death.

The used method is based on the concept of acceptable risk, and aims to identify hazards before resulting to accidents. This takes into account technical, human and organizational factors, as well as the cost of the work related to improving security.

Assessed the risk of an accident constructions (structural collapse). Implementation of the methodology includes several stages.

The first stage is the assessment of the degree of accident risk and risk identification of its occurrence.

To estimate the risk value is used the proposed method of determining the indices of frequency and damage caused by accidents with the use of a logarithmic scale, transforming it for conditions of our problem.

According to the methodology: risk = frequency x damage or:

$$\lg R = \lg \lambda + \lg Y,$$

then

$$R = 10^{(\lg \lambda + \lg Y)} = \lambda \cdot Y.$$  (2)

By introducing the notation $\lg \lambda = (FI - 6)$ and $\lg Y = (SI - 3)$ we obtain an equation for estimating the risk value

$$\lg Y = (SI - 3).$$  (4)

where $FI$ - the frequency index of accidents (the Frequency Index); the number 6 is subtracted from the frequency index corresponds to the frequency value of 1.0 1/year (tab.1); $SI$ - the index of damage caused by the accident (Severity Index); the number 3 subtracted from the index of damage corresponds to the relative damage of 1.0 (table.2); $RI$ - the accident risk index (Risk Index), the values of which are given in table.3.

As you can see, the value of (-9) in the exponential expression $(RI - 9)$ of formula (4) corresponding to the frequency of accidents is 1 per year, with the relative damage of 1.0 is taken as the base in determining the risk $R$. The risk value for other combinations of $FI$ and $SI$ is determined on the basis of statistical data or expert method using the table.1-3 [9-13]. In table.3 accident risk indices ($RI$) are the summation of the indices of damage ($SY$) and the frequency of accidents ($FS$). Identified with the help of tables the risk index according to the formula (4), it is possible to set the numeric value of accident risk, to compare it with valid values and to make a conclusion about the level of considered risk.
In our case, on the basis of statistical data, we assume that an accident (full collapse) may occur once a year at one of the 100 structures, i.e., $F_I=4$. This accident is usually accompanied by numerous deaths and causes severe structural damage, it refers to a severe $S_I=4$. Then, on the basis of the data in the table 3 is determined the accident risk index $R_I=7$.

Substituting the found value of $R_I$ in the formula (4), we determine the risk value of an accident $R=10^{0.3\times 7} = 10^{-2}$ 1/hour

Results. Comparing the obtained value risk with its permissible limits, we conclude that the risk of an accident facilities (structural collapse) is unacceptable (10-2 1/year $> R$ acceptable 10-4 1/year) and requires for additional measures to reduce the risk [14, 15].

For this purpose, we carry out the identification of accident risk and evaluation of factors influencing the risk value. This goal can be achieved by constructing a risk-sharing tree (tree of events and hazards).

The goal of the next phase is the selection of measures to reduce the accident risk based on the hazard identification.

The third stage involves the assessment of the costs and benefits of measures implementation proposed of the previous stage.

At the final stage produced final recommendations on the management safe operation of facilities using the existing regulatory framework on labor protection.

Conclusions. Thus, a systematic analysis of the risk of possible structural defects and organizational reasons causing an accident, allows to control safety in its operation.

In this direction are conducted a lot of research and development. It is hoped that the more detailed studies carried out by us, and this methodology could be applied in risk analysis of any process in the construction, repair and maintenance of buildings and structures on the surface of the mining enterprises.
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ANALYSIS OF POTENTIAL OPPORTUNITIES AND RATIONALE OF CYBER-PHYSICAL SYSTEMS FOR MINING AND METALLURGICAL COMPLEX

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Abstract. Overview of general Cyber-Physical Systems (CPS) and technologies, analysis of potential possibilities for their application in the field of mining and metallurgical enterprises in Ukraine. The research objective is to analyze the possibilities of modern cyber-physical systems and other innovative approaches in the structure as a part of the concept “Industry 4.0” to improve the efficiency and competitiveness of domestic enterprises of mining-metallurgical complex (MMC). By applying the system analysis are investigated the main process stages and TP of domestic enterprises, identified promising areas for the implementation of the “unmanned production” on the basis of CPS. The obtained results can be applied for the implementation of projects intellectual production control. Showed the modern tendency of creating a “smart production”, “smart products”, “smart production methods” based on the concept of “Industry 4.0”. Presented a number of business processes and technological processes, automation of which is widely highlighted in the concept of “Industry 4.0”. It is primary and secondary production, logistics, marketing, procurement, maintenance control. Studied the implementation of intelligent maintenance control system on the basis of CPS and other promising approaches to the concept of “Industry 4.0” in terms of large mining companies (such as Mining Enterprise and steel company “Metinvest Ukraine”, “Arcelor Mittal Kryvyi Rih”, etc.).

Key words: Cyber-Physical Systems (CPS), Industry 4.0, Smart Factory, Key Performance Indicator (KPI).

Introduction. Mining and metallurgical complex (MMC) in Ukraine is the leading branch of Ukrainian economy, which provides more than 20% of GDP and about 30-40% of export revenues of the country [1]. It is expected this trend to be continued in the future in the short and medium term. However, in this industry in recent decades has accumulated a number of problems that negatively affect the competitiveness of domestic enterprises in the world market. These are primarily obsolete assets (depreciation sometimes up to 70-90%), technology, features of a raw-material base, ecology, and extremely low energy efficiency. So, for example, in terms of specific energy consumption per unit of finished product is spent on average 2-3 times more energy than European enterprises, USA, Japan, South Korea, etc. [2]. So in order to correct the negative tendencies of development of domestic MMC is needed highly effective innovation.

The analysis of industrial development strategies of the most developed countries of the world shows the modern tendency of creating a “smart production” (smart factory, Fig.1), “smart products”, “smart production methods” based on the concept of “Industry 4.0” (or the 4th industrial revolution, Fig.2). The idea of this concept was formulated in 2006 in Hannover (Germany), and after several years became a promising program of industrial development in Germany to 2030 approved by the government of that country [3]. To date, most of the world’s largest corporations (e.g. Siemens, Bosch, Schneider Electric, Rolls-Royce, Trumpf, Dassault Systèmes, etc.) have declared their active participation in the implementation of this concept in their projects [4].
to it industrial robots and automation since the early 1970s. Respectively, the fourth industrial revolution means the emergence of a fully digital industry based on mutual penetration of information technology and industry. This dramatically increased labor productivity and, consequently, production efficiency, competitiveness, etc.

The 4th Industrial Revolution - "Industry 4.0"

Figure 2. Evolution of scientific and technological progress

Cyber-physical systems (CPS) also belong to the fourth industrial revolution (Fig. 2). It is believed that in the future such intelligent systems will completely replace human labor. This is especially true of hazardous industries, which in the fullest extent can be attributed to MMC. Our country has a fairly large industrial and scientific potential, and, therefore, cannot be outside this process. Therefore, the aim and objectives of this article are analysis of possibilities of modern CPS and other innovative approaches in the structure of the concept “Industry 4.0”, to improve the efficiency and competitiveness of domestic enterprises of mining and metallurgical complex (MMC). Objects of research are the basic limits and the technological processes as a perspective area of the implementation of “unmanned production” on the basis of CPS [5-7].

Materials and Methods. You can list key technological trends underlying cyber-physical systems (fig. 3). Isolated they are already used in different areas, but being integrated into a single unit, they change existing relationships between producers, suppliers and customers and between man and machine.
Figure 3. Technologies of Industry 4.0

Big data and Analytics. A collection and a comprehensive assessment of data from different sources will become a standard for decision-making in real-time.

Autonomous robots. Industrial robots can already perform quite complex operations, but the computer vision systems will allow robots to interact with each other and automatically adjust their actions, and people can sit next to them, to influence them and it will be safe.

Modeling and simulation. Engineers have already been using 3D modeling in the design stage of products or processes. In the future, big data technologies allow to use different simulators in real time. For example, in the production stage the operator will be able to virtually simulate the physical process taking into account the available raw materials and people, and thereby to reduce the setup time of equipment and increase quality.

Cloud computing will require a better system integration, both horizontal between suppliers and customers, and vertical between various functions and operations. To create a platform for collaboration and data exchange between geographically distributed partners enable cloud technology.

Internet of things. Sensors and sensor readings generally fall in to the central control system of the production process, and even at this level are taken decisions. In the future, the possibilities, offered by embedded systems, will allow devices to communicate with each other and decentralize decision-making. For example, you can use RFID (Radio-frequency identification) tags for semi-automated production line, reading the label to decide for itself (in real time), what operation to apply to one or the other semis.

Information security. Many companies use the system of management and production based on traditional technology or not having access to the Internet. However, the expansion of relations with partners, the use open standards and protocols dramatically increase the risk of information security. For the protection of industrial systems are required not only high-quality and secure communications, but system account management and access control (Identity and Access Management).

3D printing. 3D printers are mainly used for prototyping or individual components. In the future, a 3D printer can be widely used for the production of small batches of specialized products. Its design advantages and the decentralized nature of production will reduce transportation costs and warehouse stocks.

Augmented reality. Technology is at the early stages of its development, but in the future will allow employees to accelerate the adoption of solutions. For example, an employee can receive instructions on how to repair or replace a broken part in a production system, when he looks at it through the glasses of augmented reality.

Figure 4. Typical organizational structure of enterprises and industrial holdings of mining and metallurgical industry in Ukraine

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Let us analyze the prospects of application of the above approaches in the context of domestic mining companies. The basis of the latter is mining and processing enterprises (MPE) and the steel mills. Fig. 4 shows a typical organizational and production structure of these enterprises and holdings in Ukraine.

Analysis of this organizational structure shows the presence of a number of business processes and the technological processes, automation of which is widely represented in the concept of "Industry 4.0". First of all, it is primary and secondary production, logistics, marketing, procurement, maintenance control etc. Let us make a feasibility study for the implementation of intelligent maintenance control system on the basis of CPS and other promising approaches to the concept of "Industry 4.0" in terms of large mining companies (such as Mining Enterprise and/or steel company “Metinvest Ukraine”, "Arcelor Mittal Kryvyi Rih", etc.). For the calculations we use a common methodology based on KPI (Key Performance Indicator) [8].

According to this method in order to calculate the performance indicators for the enterprise or production, it is necessary to analyze these items:

1. The consumption of raw material per day.
2. The volume of raw materials in warehouses and in an incomplete form.
3. The actual productivity.
4. The cost of storing finished products.
5. The amount of other expenses.
6. The required funds for the repair and maintenance of equipment.

According to the method described in ISO 22400 [9], in the process of further calculations should be used the following dependencies for the above indicators:

\[
\text{IndexKPI} = \frac{\text{Fact} - \text{Base}}{\text{Plan} - \text{Base}}, \tag{1}
\]

\[
K_{\text{Res}}(\%) = \sum_{i=1}^{N} \text{IndexKPI}_{i} \cdot W_{i}, \tag{2}
\]

where Index KPI – the value of the efficiency index for the selected random process stages; Fact, Plan, Base – the corresponding values of the adopted indicators on the articles 1-6 (actual, planned, base); KRes – final calculation index of the innovation efficiency; i – number of process stage; N – the number of analyzed stages.

Results. The calculations of Key Performance Indicators of the intelligent maintenance control project with the use of CPS [10] on the example of a private enterprise "ArcelorMittal Kryvyi Rih" (AMKR). Estimated by experts each of the components of this project provides some savings (Fig. 5).

![Figure 5. Expected economic benefits in the implementation of intelligent maintenance control in terms of AMKR (A – savings on the purchase of spare parts due to optimization of the warehouse; B – reducing idle resources through streamlined work processes and faster maintenance of measuring equipment)](image)

The main components of such a system include:

1. “Smart warehouse” is an intelligent CPS to optimize the assortment of parts, number of parts and devices. Implementation will reduce the number of required warehouses from 10% to 5%, therefore, will decrease the storage costs. To calculate the efficiency, we use KPI – “Storage and transport relation of the loss” (paragraph 8.28 ISO 22400).

2. Workplaces, operations management and intelligent CPS transportation will reduce the time of maintenance and repair to 24 hours. For example, to date, in AMKR this time is 170 hours. To calculate the efficiency of the use of KPI “Efficiency” (paragraph 8.9 of ISO 22400).

Fig. 6 shows the expected estimate indicators of economic efficiency by the above procedure.
Similar results can be obtained for other technological processes.

Conclusions. On the above we can conclude that the implementation of innovative projects “smart” (Smart Factory) with CPS based on modern scientific concept of Industry 4.0 has significant potential for growth of the competitiveness of domestic mining companies. So produced estimates of key performance indicators for such enterprises based on the ISO 22400 methodology demonstrate the reserves for optimization of KPI values in the range of 5-80%.

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USE OF THE SYSTEM MOODLE IN THE FORMATION OF ECOLOGICAL COMPETENCE OF FUTURE ENGINEERS WITH THE USE OF GEOINFORMATION TECHNOLOGIES

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Abstract At present the information and communication technologies in education can be a catalyst in solving important social problems connected with increasing the educational resources and services availability and quality, real and equal opportunities in getting education for citizens despite their residence, social status and income. One of the most important education tasks is to develop students’ active cognitive attitude to knowledge. Cognitive activity in universities is a necessary stage in preparing for further professional life. The solution of task of formation of ecological competence of mining profile engineer requires the reasonable selection of the means of information and communication technologies conducing formation of ecological competence. Pressing task is constructive and research approach to preparation of future engineers to performance of professional duties in order to make them capable to develop engineering projects independently and exercise control competently. The relevance of the material covered in the article, due to the need to ensure the effectiveness of the educational process in the preparation of the future Mining Engineers. We analyze the source with problems of formation of ecological competence. The relevance of the material covered in the article, due to the need to ensure the effectiveness of the educational process in the preparation of the future Mining Engineers. The article focuses mainly general-purpose computer system support learning Moodle, which allows you to organize individual and collective work of students to master the specialized course teaching material used in teaching special course “Environmental Geoinformatics” in the implementation of educational research. Used in teaching special course “Environmental Geoinformatics” in the implementation of educational research.

Keywords: ecological competence, geoinformation technologies; future mining engineers.

Introduction.

Education must serve for the society needs. Processes reflecting current trends in society provide information technologies development and implementing. At present the ICT usage in education can be a catalyst in solving important social problems connected with increasing the educational resources and services availability and quality, real and equal opportunities in getting education for citizens despite their residence, social status and income [1, 10]. Professionals having common practical and theoretical skills of work with different information types are highly wanted.

One of the most important education tasks is to develop students’ active cognitive attitude to knowledge. Cognitive activity in universities is a necessary stage in preparing for further professional life. Teacher’s task is to seek and find the best methods and means of improving the educational process and leading to the cognitive interest development.

The main regulatory document, defining the legal and organizational principles of Mining Engineers Profile of mining operations, providing emergency protection of mining enterprises, institutions and organizations, is the Mining Law of Ukraine [2].

Due to the fact that, by definition of DeSeCo specialists, environmental sustainability (ecological sustainability) is the basis of the key competences of the individual associated with success in society (The Definition and Selection of Key Competencies), consideration of environmental competency is advantageously carried out at three levels:

– on the general level of ecological culture and environmental awareness Michael K. Stone [3], Alekseev S. V. [4], Gagarin O. V [5], Ermakov D. S.[6];

– on a social-professional level of environmental literacy Zenobia Barlow [7], David W. Orr [8], Galieva G. M. [9] Gurenkova O. V. [10];

– on the special professional level of environmental competence Bazarov E. L. [11], Bibik N. M. [12], Budnik V. F. [13], Carmel Bofinger [14], Harvey B. E. [15].

The use of means of GIS technologies in the formation of ecological competence of future mining engineers takes place in the process of education of the special course “Environmental Geoinformatics”, that requires their consideration simultaneously as an object of study, and as the means of education. First in theory the special course is reasonable and done “Ecological Geoinformatics “.
The primary objective of the special course is forming of the ecological competence through the totality of the special knowledge, abilities and skills, providing possibility to apply means of GIS technologies at first in educational to the students, also in a prospect also in professional activity.

The basic means of the general setting, which is used for teaching of the special course is the computer system of educating support system of educating support Moodle – the freely expandable system of support of educating with a comfortable interface and system of help.

Materials and Methods. In the basis of creation of the special course “Ecological geoinformatics” the principles of use of visual aids, scientific character, individualization and differentiation of educating are fixed in the system of educating support Moodle. The special course in SES Moodle comprises the information is about the special course setting working educational programme the dictionary of basic terms on discipline, methodical instructions on laboratory-calculable practical work etc. The material of the SES Moodle special course is structured into two educational modules which include: compendia of lectures on the module subjects glossary; didactic materials to the module subjects reference to the Internet resources; recommended literature; tests. The main means of the educational communication in the special course by means of SES Moodle are forums, chats and reports. The module “Forum” gives the participants of the special course opportunity to carry out asynchronous communication. The module “Chat” allows to the participants of synchronous online-discussion in the character mode. The module “Chat” allows to the participants of synchronous online-discussion in the character mode. A chat can be non-permanent or can recur at the same time every day or week. The sessions of chats are saved and can be done by accessible to all for view.

Chats are especially useful, when a group is unable to meet audience, in next cases:

– the regular meeting of students participating in online-courses, so that they can share the experience with other in the same course, but elsewhere;
– a student temporally can not be present personally on the consultation together with a teacher;
– students gather together, to discuss their experience with each other and with a teacher;
– the session of questions and answers with a teacher who is elsewhere.

Among other external means of educational communication we will distinguish Skype and WizIQ. Skype can be used for organization of the personal text chat, transmission of files, implementation of audio and video rings, realization of conferences. During online-consultations Skype is possible to use for the organization of the joint work of the participants of the special course through the possibility of receipt of access to the work mounts of interlocutors.

The module of WizIQ SES Moodle allows to work in the online-classes of WizIQ. Virtual Classroom WizIQ is the on-line instrument of educating, integrated with Moodle and gives a possibility of collaboration in real time and to bilateral connection, creating new possibilities for the synchronous educating within the framework of online-class of Moodle.

WizIQ Virtual Classroom in Moodle allows to cooperate in real-time with the following instruments:

– multilane audio and to 6 videostreams;
– an unlimited amount of participants;
– the presence of general “white board”;
– the simple loading of data;
– the sharing of screen.
The module of WizIQ Virtual Classroom gives next means of the integration with Moodle: only entrance in WizIQ and Moodle; the statistics of the use of WizIQ classes; placing of written in classes of WizIQ in Moodle; the direct editing of the content of WizIQ classes from within Moodle; general calendar of WizIQ and Moodle.

Results. Using thus special course worked out, students have the opportunity: to choose an arbitrary theme; to look over and load the compendium of lecture on the topic, the maintenance of basic determinations, concepts and facts; to seize educational material and to look over the examples, downloading files from didactic materials; to meet with multimedia (in particular, by a network) resources to the themes of the special course, using the corresponding references; to look over protocols of laboratory works, to pass testing on the chosen topic or on maintenance a few them (in the educational or the supervisory mode); to place in Moodle their individual and collective research projects, own portfolios etc.

Conclusions. Thus, the use of the worked out in SES Moodle electronic educational course allows to organize an individual and collective work of students master educational material of the special course in the process of the implementation of educational researches.

References
Purpose. The aim of the research is to increase the energy efficiency and the iron content in the concentrate during the ore enrichment process presented through mineralogical and technological species, by developing the principles and approaches to the distributed optimal control of interrelated processes concentrating production on the basis of dynamic spatial-temporal model.

Methodology. Analysis of domestic and foreign experience; systematization of the existing approaches and methods to optimize the control of ore enrichment process; methods of mathematical statistics and probability theory for processing the results of experiments; methods of analytical design and computer simulation in the synthesis and analysis of automated systems; methods of system analysis and optimal control methods in the development of process control algorithms; numerical simulation methods for the synthesis and analysis of mathematical models of optimal automated control system; computer information and software technology for the implementation of the developed algorithm for automated control software.

Scientific novelty. Developed the method for automating control processes of nonlinear dynamic objects of the technological line iron ore enrichment, which differs from the existing ones, that the technological line processing of iron ore is represented as a structure with lumped inputs: consumption of ore and water in the processing units; and distributed over the entire production line output - distribution functions of the iron content by grade of ore particle size, which allowed to redistribute the load between the stages of enrichment and to reduce electricity consumption by 2.34%.

Practical significance. The obtained results include the development of: algorithms and programs of the automated energy-saving control of ore enrichment process; software and hardware means formation of information base of automated process control over technological processes of ore enrichment.

Key words: system, processes, production, ultrasonic control, error, pulp.

Introduction. In modern conditions at the mining and processing plants are processed several types of ore processing. The system of mining operations does not allow to produce the same type of ore for a long time, which leads to instability of the mineral composition of the raw material supplied to the enrichment. One of the ways to reduce the negative impact of variability of the raw iron-ore on energy consumption process equipment is to increase the accuracy of object identification processing control of production, that will improve the process control quality. The final results of the processing plant depend on a complex of interrelated processes. That requires an appropriate approach to modeling the technological processes that take into account their combination and ensures optimization of the entire structure [1-6]. The analysis showed that the problems of managing interrelated processes of production and processing is advisable to solve on the basis of distributed optimal control methods based on dynamic spatial-temporal models performing the operational characteristics measurement of the technological iron ore flow through ultrasonic radiometric methods.

Materials and methods. To solve the problem of the automatic control parameters of ore solid slurries is proposed the method, which consists in measuring the intensity of the high frequency volumetric ultrasonic waves transmitted at a fixed distance in the measuring container during periods ore slurry flow to affect the suspension with ultrasonic vibrations and in their absence [7-12]. In this case, the calculated ratio of the measured values allows to determine the parameters of the solid phase of the ore slurry. Also, during the measurement are formed gamma radiation and low-frequency volumetric ultrasonic waves in the ore slurry flow and are measured the intensity gamma-radiation and low-frequency volumetric ultrasonic waves transmitted at a fixed distance in the presence of the reference fluid in the measuring chamber and the ore slurry flow during effect on the slurry flow with ultrasonic vibrations and in their absence. At the same time, the intensity of ultrasonic vibrations during their
Effect on the flow of suspension is changed under the relevant law.

Functional scheme of automation, designed according to the stated principle of operation, is shown in Fig. 1.

Scheme of automation control product processing industry (Fig. 1) consists of three circuits. The circuit 1 is designed to generate directed high-energy ultrasound and consists of elements: 1A – control device (BC); 1B – switchgear (NS) of ultrasonic phased array. The contour 2 is designed for measurement of the pulp density on the basis of the ultrasonic signal to determine the concentration of ore particles in the pulp. The circuit consists of the following elements: 2A – transducer ultrasonic signal transmitter (BE); 2B – indicating and recording secondary transducer of the ultrasonic signal (BIR); 2C – control device (BC); 2D – switchgear (NS) source of ultrasonic vibrations. Contour 3 is designed to measure the iron content in the ore particles on the basis of gamma radiation. The circuit consists of the following elements: 3A – primary transducer of gamma-radiation signal (RE); 3b – indicating and recording secondary transducer of ultrasonic signal (RIR); 3b – control device (RC); 3G – switchgear (NS) source of ultrasonic vibrations.

Consider the research results of the effect of such parameters of ultrasonic phased array as a distance between elements, a wavelength and the number of elements, on control and the efficiency of ultrasonic radiation. Ultrasonic phased array is considered as a set of point sources of ultrasound, located equidistantly (d) from each other. The ultrasonic pressure field is calculated using Huygens’ principle with properly selected values of phase and amplitude for the case \( r \gg d \) [13].

\[
(r, \theta, \tau) = \frac{\rho_0 f_0 \sin \left( \frac{\omega \Delta \tau - k d \sin \theta}{2} \right) N}{\sin \left( \frac{\omega \Delta \tau - k d \sin \theta}{2} \right)} \exp \left[ -j \left( \frac{\omega \Delta \tau - k d \sin \theta}{2} \right) (N - 1) \right] \exp \left[ j(\omega \tau - kr) \right]
\]

where \( r_0 \) – the infinitely small radius of pulsating ultrasonic radiation point-sources; \( \rho_0 \) – the pressure amplitude of ultrasonic radiation point-sources; \( k \) – the wave number; \( \omega \) – the angular frequency; \( N \) – the number of ultrasonic radiation point-sources; \( j \) – the imaginary unit.

Diagram of a point element ultrasonic phased array is shown in Fig. 2.

The required time delay between adjacent sources is needed to direct ultrasonic radiation at an angle \( \theta_s \) is given by [14].

\[
d \sin \theta_s / c,
\]

where \( c \) - the speed of a sound in the propagation medium (the standard fluid and ore pulp respectively).
The results of the calculation delay time in the actuation of point elements ultrasonic phased array is shown in Fig. 3.

The directivity of the ultrasonic radiation on the basis of an equation (1) defined as

\[
\sin \left[ \frac{\pi d (\sin \theta - \sin \theta')}{\lambda} N \right] \\
N \sin \left[ \frac{\pi d (\sin \theta - \sin \theta')}{\lambda} \right]
\]  

(3)

Figure 3. The delay time (in ms) of the ultrasonic phased array point-sources

Optimal parameters of the ultrasonic phased array are selected on the basis of the following parameters, characterizing the diagram directivity of the ultrasonic phased array (Fig. 4)

Figure 4. The diagram directivity of the ultrasonic phased array: --- total; --- point element

The width value (sharpness) of the main lobe of the diagram based on the formula (3) is determined from the equation

\[
q = \frac{1}{\pi} \left[ \sin^{-1} \left( \sin \theta + \frac{\lambda}{Nd} \right) - \sin^{-1} \left( \sin \theta - \frac{\lambda}{Nd} \right) \right]
\]  

(4)

In this case, the best directivity corresponds to the smaller value of the parameter \(q\). It should be noted that in the case where the value of the equation \(\lambda/\text{Nd}\) approaches zero, then the value also tends to zero. Thus, the best directivity can be achieved by applying a greater number of point radiating elements or increasing the distance between the elements.

On the basis of the equation describing the increased width of the main lobe of the radiation diagram it can be concluded that the increase in the number of elements of the ultrasonic phased array improves its efficiency. However, studies [11-14] show that the value of the index \(q\) is dramatically reduced by varying the number of elements in a phased array to 8 pieces. The number of elements exceeding 32 does not bring significant improvement of the parameter \(q\). Thus, the optimal number of elements in terms of the improvement in directivity of the phased array, as well as manufacturing costs, is 16 elements.

The distance between the elements is also a significant parameter that affects the directivity index \(q\) of the ultrasonic phased array radiation. In the paper [12], it is shown that the best value of directivity corresponds to a larger distance between the elements in phased array. However, it should be noted that along with the improvement of the directivity value \(q\), also increase side-lobes of the directivity. This is confirmed by the shown in Fig. 6. results of calculating the diagram directivity of ultrasonic phased array with 16 elements (4×4) while changing the distance between the elements from 0.4 mm to 0.7 mm in increments of 0.1 mm.

Therefore, it is necessary to find a compromise value for the distance between the elements of the phased array, which, on the one hand, ensures an optimal radiation directivity, and on the other, provides a reduction in side-lobe. From the equation (3) subject to \(H(\pi n/2) = 1\) we find the distance between the elements of the phased array.
As a result, obtained the optimal distance between the elements of the ultrasonic phased array \( d_{cr} = 0.47 \text{ mm} \).

The arrangement of the elements of the ultrasonic phased array is shown in Fig. 5.

Three-dimensional representation of the diagram directivity of the ultrasonic phased array is shown in Fig. 6.

**Results.** The results of laboratory tests of the developed device for ultrasonic control pulp parameters showed that the reconstruction error of the distribution function of the crushed material particles by size in standard deviation is 0.7-0.85%; the reconstruction error of the distribution function of the useful component content in the particles of the crushed material by size in standard deviation is 0.67-0.74%.

**Conclusions.** Developed a method of evaluating the distribution function of the useful component by grade of particle size iron ore pulp using a high-frequency and low-frequency ultrasonic radiation and gamma radiation, which differs from existing ones that in the process of the measurement is carried out displacement of the particles of a given grade size in the measurement area by acting on the pulp with ultrasonic radiation of high intensity; the measurement results are compared with the reference substance characteristics, which improves the measurement accuracy by 1.23%.

**References**