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АЛГОРИТМИЧЕСКИЙ СИНТЕЗ ОПТИМАЛЬНЫХ РЕГУЛЯТОРОВ БУРОВЫХ КОМПЛЕКСОВ НА СТРУКТУРЕ ДИНАМИЧЕСКИХ МОДЕЛЕЙ

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ALGORITHMIC SYNTHESIS OF OPTIMUM REGULATORS OF BORING COMPLEXES ON STRUCTURE OF DYNAMIC MODELS

Представлены исследования применения алгоритмического синтеза оптимальных регуляторов, с использованием принципа симметрии на основе динамических моделей, к буровым комплексам. Результаты моделирования обеспечивают стабилизацию режимов оптимизации величины нагрузки на породоразрушающий инструмент и частоты его оборотов для обеспечения рабочих режимов объемного разрушения горной породы, а по гидродинамической подсистеме стабилизацию оптимальных значений расходов и давления промывочной жидкости на уровнях интегрированной величины трения в подсистеме «породоразрушающий инструмент-порода».

Представлені дослідження застосування алгоритмічного синтезу оптимальних регуляторів, з використанням принципу симетрії на базі динамічних моделей, до бурових комплексів. Результати моделювання забезпечують стабілізацію режимів оптимізації величини навантаження на породоруйнівний інструмент та частоти його обертів для забезпечення робочих режимів об'ємного руйнування гірської породи, а по гідродинамічній підсистемі стабілізацію оптимальних значень витрат і тиску промивальної рідини на рівнях інтегрованої величини тертя в підсистемі «породоруйнівний інструмент-порода».

Real motion of the Boring Complex (BC), as well as any other object of control of Mining Electromechanical Complexes (MEMC) as a first approximation can be presented as an equation where coefficients for the tasks of technological and technical control through the energy consumption of the drive will reflect the given moments of inertia of the Boring Complex (BC). For the standard modes of the BC at the synthesis of the control systems those coefficients are recognized as random selective average as unbiased estimates of the general average appropriate fluctuations of the dynamics of the given moments of inertia in the operating conditions of the BC elements. While considering BC as simply connected objects, that is, with one influence of control, for example, with the axial load (L) or frequency of revolution of the Drill Bits and Diamond Tools (DBDT) (ω), which can be considered as the scalar functions in the form of the sliding random selective average real fluctuations of the random functions of time of the controlling influences, which can be separately denoted in terms of expression $m_n U$ [1].

With that the coincidence of the real change of the moments of inertia $y(t)$ and desirable change of moments of inertia $y^*(t)$ of those, which have the same dimensions due to the perturbed change of the moments of inertia $\eta(t)$ according to the concept of perturbed-unperturbed motion is provided with stabilizing control $U(t)$, that is, real control $u(t)$ is synthesized with the desirable $u^{*}(t)$ and stabilizing $U(t)$.

Methodology of structural and algorithmic synthesis of the systems of the automated control (SAC) on the basis of the principle of symmetry [1] according to BC stipulates definition of the laws of control by motion of the last ones through stabilization $U(t)$. It is necessary to note that the main idea of the inverse of the dynamics operation, formations of the sought-for quantity of control are reverse to the corresponding operations, which are determined by the structure of the mathematical model of BC. According to the principle of symmetry on the block diagrams, which are used for technological and technical control, the block diagrams of the controlling parts of such systems are synthesized as a result of operations and corresponding variables. The controlling part of the system here must compensate BC's own dynamics completely and provide reproduction of the set step influence as much as possible close to the ideal. With that it is necessary to take into consideration the real natural limitations depending on the dynamic characteristics and on the values of the controlling influences.

On the basis of the carried out theoretical and experimental research of the structures and dynamic characteristics of BC [2, 3, 4, 5, 6] it is possible to draw a conclusion about acceptability of representation of the majority of BC while solving the tasks of their control in the form of analytical description by the systems of the fourth order, when the perturbed motion is described by the equation in the form of

$$\begin{aligned} p\eta_1 &= b_{11}\eta_1 + b_{12}\eta_2 + b_{13}\eta_3 + b_{14}\eta_4; \\ p\eta_2 &= b_{21}\eta_1 + b_{22}\eta_2 + b_{23}\eta_3 + b_{24}\eta_4; \\ p\eta_3 &= b_{31}\eta_1 + b_{32}\eta_2 + b_{33}\eta_3 + b_{34}\eta_4; \\ p\eta_4 &= b_{41}\eta_1 + b_{42}\eta_2 + b_{43}\eta_3 + b_{44}\eta_4 + m_4 U. \end{aligned} \tag{1}$$

In Frobenius form the system (1) assumes the form of:

$$\begin{aligned} p\eta_1 &= \hat{\eta}_2; \\ p\eta_2 &= \hat{\eta}_3; \\ p\eta_3 &= \hat{\eta}_4; \\ p\eta_4 &= -a_1\eta_1 - a_2\hat{\eta}_2 - a_3\hat{\eta}_3 - a_4\hat{\eta}_4 + M_4 U. \end{aligned} \tag{2}$$

With that the coefficients a_1, a_2, a_3, a_4 are determined by the known way of comparison of the characteristic determinants (1) and (2) and coefficients at even degrees p.

In the structure of BC the controlling influences, for example, by loading on Drill Bits and Diamond Tools (DBDT) (L) or by the change of frequency of its revolutions (ω) or by the discharge of the flushing fluid (Q) for the system of the fourth order of minimization of functional (3)

$$\hat{I}_4 = \int_0^\infty \left(\sum_{i,k=0}^{4} \hat{w}_{ik} \hat{\eta}_i \hat{\eta}_k + cU^2 \right) dt, \qquad w_{ik} = w_{ki}, \tag{3}$$

it can be represented in the form of the following expression

$$\begin{aligned} U &= -\frac{M_4}{c}\left(\hat{v}_{04}\eta_0 + \hat{v}_{14}\eta_1 + \hat{v}_{24}\eta_2 + \hat{v}_{34}\eta_3 + \hat{v}_{44}\eta_4\right) = \\ &= -\frac{M_4}{c}\left(\hat{v}_{04}\eta_0 + \hat{v}_{14}\eta_1 + \hat{v}_{24}p\eta_1 + \hat{v}_{34}p^2\eta_1 + \hat{v}_{44}p^3\eta_1\right) = \\ &= -\frac{M_4}{c}\left(\frac{\hat{v}_{04}}{p} + \hat{v}_{14} + \hat{v}_{24}p + \hat{v}_{34}p^2 + \hat{v}_{44}p^3\right)\eta_1, \end{aligned} \tag{4}$$

where $v_{44} = 1$, $v_{34} = a_4$, $v_{24} = a_3$, $v_{14} = a_2$, $v_{04} = a_1$ are determined according to the system (2), which is extended to the form

$$\begin{aligned} &p\eta_0 = \eta_1; \\ &p\eta_1 = \hat{\eta}_2; \\ &p\hat{\eta}_2 = \hat{\eta}_3; \\ &p\hat{\eta}_3 = \hat{\eta}_4; \\ &p\hat{\eta}_4 = -a_1\eta_1 - a_2\hat{\eta}_2 - a_3\hat{\eta}_3 - a_4\hat{\eta}_4 + M_4U. \end{aligned} \tag{5}$$

of the system (5) Lyapunov function is described by the expression

$$\begin{aligned} \hat{V}(\eta) = \sum_{i,k=0}^{n=4} \hat{v}_{ik}\eta_i\eta_k &= \hat{v}_{00}\eta_0^2 + 2\hat{v}_{01}\eta_0\eta_1 + 2\hat{v}_{02}\eta_0\eta_2 + 2\hat{v}_{03}\eta_0\eta_3 + 2\hat{v}_{04}\eta_0\eta_4 + \hat{v}_{11}\eta_1^2 + 2\hat{v}_{12}\eta_1\eta_2 + \\ &+ 2\hat{v}_{13}\eta_1\eta_3 + 2\hat{v}_{14}\eta_1\eta_4 + \hat{v}_{22}\eta_2^2 + 2\hat{v}_{23}\eta_2\eta_3 + 2\hat{v}_{24}\eta_2\eta_4 + \hat{v}_{33}\eta_3^2 + 2\hat{v}_{34}\eta_3\eta_4 + \hat{v}_{44}\eta_4^2. \end{aligned} \tag{6}$$

Equating with zero the expressions which are at $\eta_i\,\eta_k$ $(i,k = 0,1,...,n)$ in order that a total derivative of Lyapunov function to be negative and solving the system of algebraic equations as a result, it is possible to find the coefficient of Lyapunov function

$$\begin{aligned} &v_{00} = a_1^2; \quad v_{01} = a_1 a_2; \quad v_{02} = a_1 a_3; \quad v_{03} = a_1 a_4; \quad v_{04} = a_1; \\ &v_{11} = a_2^3; \quad v_{12} = a_2 a_3; \quad v_{13} = a_2 a_4; \quad v_{14} = a_2; \quad v_{22} = a_3^2; \\ &v_{23} = a_3 a_4; \quad v_{24} = a_3; \quad v_{34} = a_4; \quad v_{44} = 1. \end{aligned} \tag{7}$$

Coefficients $\hat{w}_{ik}$ Lagrangian functional (3) are stipulated according to the expressions (8)

$$\hat{w}_{00} = \frac{M_4^2}{c}\hat{v}_{04}^2; \qquad \hat{w}_{01} = \frac{M_4^2}{c}\hat{v}_{04}\hat{v}_{14}; \qquad \hat{w}_{02} = \frac{M_4^2}{c}\hat{v}_{04}\hat{v}_{24}; \qquad \hat{w}_{03} = \frac{M_4^2}{c}\hat{v}_{04}\hat{v}_{34};$$

$$\hat{w}_{04}=\frac{M_4^2}{c}\hat{v}_{04}\hat{v}_{44};\quad \hat{w}_{11}=\frac{M_4^2}{c}\hat{v}_{14}^2;\quad \hat{w}_{12}=\frac{M_4^2}{c}\hat{v}_{14}\hat{v}_{24};\quad \hat{w}_{13}=\frac{M_4^2}{c}\hat{v}_{14}\hat{v}_{34};$$

$$\hat{w}_{14}=\frac{M_4^2}{c}\hat{v}_{14}\hat{v}_{44};\quad \hat{w}_{22}=\frac{M_4^2}{c}\hat{v}_{24}^2;\quad \hat{w}_{23}=\frac{M_4^2}{c}\hat{v}_{24}\hat{v}_{34};\quad \hat{w}_{24}=\frac{M_4^2}{c}\hat{v}_{24}\hat{v}_{44};$$

$$\hat{w}_{33}=\frac{M_4^2}{c}\hat{v}_{34}^2;\quad \hat{w}_{34}=\frac{M_4^2}{c}\hat{v}_{34}\hat{v}_{44};\quad \hat{w}_{44}=\frac{M_4^2}{c}\hat{v}_{44}^2. \tag{8}$$

With implementation of the reverse transformation of the system (6) to the form of the system (1) the finite representation of the controlling influence U is possible, which is formed after the formula

$$U=-\frac{m_4}{c}\left(v_{04}\eta_0+v_{14}\eta_1+v_{24}\eta_2+v_{34}\eta_3+v_{44}\eta_4\right). \tag{9}$$

And for BC of the type ЗІФ-1200 the perturbed motion is described by the equations in the form of

$$\begin{aligned}
p\eta_0 &= \eta_1;\\
p\eta_1 &= b_{11}\eta_1+b_{12}\eta_2+b_{13}\eta_3+b_{14}\eta_4;\\
p\eta_2 &= b_{21}\eta_1+b_{22}\eta_2+b_{23}\eta_3+b_{24}\eta_4;\\
p\eta_3 &= b_{31}\eta_1+b_{32}\eta_2+b_{33}\eta_3+b_{34}\eta_4;\\
p\eta_4 &= b_{41}\eta_1+b_{42}\eta_2+b_{43}\eta_3+b_{44}\eta_4+m_4U.
\end{aligned} \tag{10}$$

In maximum integrated representation with the help of the operators of the continuous fractions, the basic structure of any MEMC from the positions of its technological and technical identification and control can be represented in the form, which is presented in Fig.1, where the first and foremost role of the technical state of every MEMC relatively to its technological state is evident.

With that, rational expression of the transfer function for BC, which represents structure of Fig. 1, is formalized in the form of

$$W[B_n^{[0]}(j\omega)]=\frac{c_{5,1}\omega^5+c_{4,1}\omega^4+c_{3,1}\omega^3+c_{2,1}\omega^2+c_{1,1}\omega-c_{0,1}}{c_{10,2}\omega^{10}+c_{9,2}\omega^9+c_{8,2}\omega^8+c_{7,2}\omega^7+c_{6,2}\omega^6+c_{5,2}\omega^5+c_{4,2}\omega^4+c_{3,2}\omega^3+c_{2,2}\omega^2-c_{1,2}\omega+c_{0,2}}. \tag{11}$$

For example, for the universal ladder circuits of the hierarchical dynamic diagnostic models of the elements of MEMC of BC of the type ЗІФ-1200, Fig. 1, the normalized values of coefficients of the polynomials of numerator and denominator $c_{i,j}$ in relative units to the nominator of the transfer function by the circuit load on the Drill Bits and Diamond Tool (DBDT) with the type of the

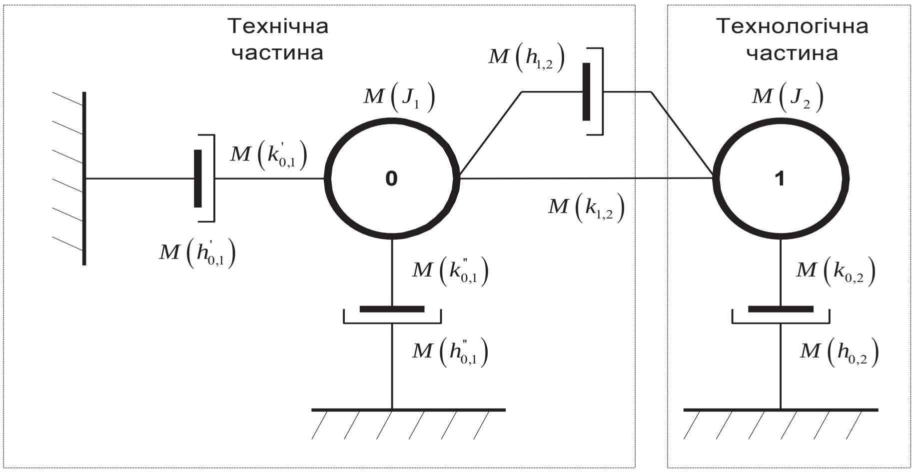


Fig.1. Integrated chain general structures of the dynamic models of BC

diamond drill bit (01АЗД20К30 – 14А4Д50К50, D=76 мм) adopt the following analytical and numerical values:

$$c_{0,1} = e3; \qquad c_{0,1} = 2.699E - 011;$$

$$c_{1,1} = J0 \cdot e3 - k \cdot h \cdot e3 - 1; \qquad c_{1,1} = -7.875E - 007;$$

$$c_{2,1} = k \cdot h \cdot J0 \cdot e3 - k \cdot h + J0; \qquad c_{2,1} = -3.928E - 001;$$

$$c_{3,1} = k \cdot h \cdot J0 + e3 \cdot J0; \qquad c_{3,1} = -7.856E - 001;$$

$$c_{4,1} = k \cdot h \cdot e3 \cdot J0 - J0^2 \cdot e3; \qquad c_{4,1} = 5.001E - 001;$$

$$c_{5,1} = -k \cdot h \cdot J0 \cdot e3; \qquad c_{5,1} = 1.000E - 000,$$

and for the denominator

$$c_{0,2} = 0;$$

$$c_{1,2} = -h;$$

$$c_{2,2} = -J0 - h \cdot e3;$$

$$c_{3,2} = h \cdot J3 \cdot e3 - J0 \cdot k \cdot h + h \cdot e3 \cdot J0 - e3 \cdot J0;$$

$$c_{4,2} = J0 \cdot J3 \cdot e3 + h \cdot e3^2 \cdot J3 - J0 \cdot k \cdot h \cdot e3 + h \cdot J3 + h \cdot J0 + J0^2 \cdot e3; \qquad (12)$$

$$c_{5,2} = e3^2 \cdot J0 \cdot J3 + h \cdot e3 \cdot J3 + h \cdot e3 \cdot J0 + J0^2 - h \cdot e3^2 \cdot J0 \cdot J3 + J0 \cdot k \cdot h \cdot J3 \cdot e3 + \\ + J0 \cdot J3 + J0 \cdot k \cdot h \cdot J3 \cdot e3;$$

$$c_{6,2} = -h \cdot e3 \cdot J0^2 + J3 \cdot e3 \cdot J0 + e3 \cdot J0^2 + J0 \cdot k \cdot h \cdot J3 + J0^2 \cdot k \cdot h - J0^2 \cdot e3^2 \cdot J3 - \\ - 2 \cdot h \cdot e3 \cdot J0 \cdot J3 + J0 \cdot k \cdot h \cdot e3^2 \cdot J3;$$

$$c_{7,2} = -h \cdot e3^2 \cdot J3 \cdot J0 - 2 \cdot J0^2 \cdot e3 \cdot J3 + J0^2 \cdot k \cdot h \cdot e3 - J0^3 \cdot e3 + J0 \cdot k \cdot h \cdot e3 \cdot J3 - \\ - J0^2 \cdot k \cdot h \cdot e3^2 \cdot J3;$$

$$c_{8,2} = -e3^2 \cdot J0^2 - J0^3 \cdot k \cdot h \cdot e3 + h \cdot e3^2 \cdot J0^2 \cdot J3 - 2 \cdot J0^2 \cdot k \cdot h \cdot e3 \cdot J3;$$

$$c_{9,2} = J0^3 \cdot e3^2 \cdot J3 - J0^2 \cdot k \cdot h \cdot e3^2 \cdot J3;$$

$$c_{10,2} = J0^3 \cdot k \cdot h \cdot e3^2 \cdot J3,$$

where

$c_{0,2} = 0;$

$c_{1,2} = 1.886E-008;$

$c_{2,2} = -2.567E-003;$

$c_{3,2} = -5.133E-003;$

$c_{4,2} = 5.839E-003;$

$c_{5,2} = 3.496E+002;$

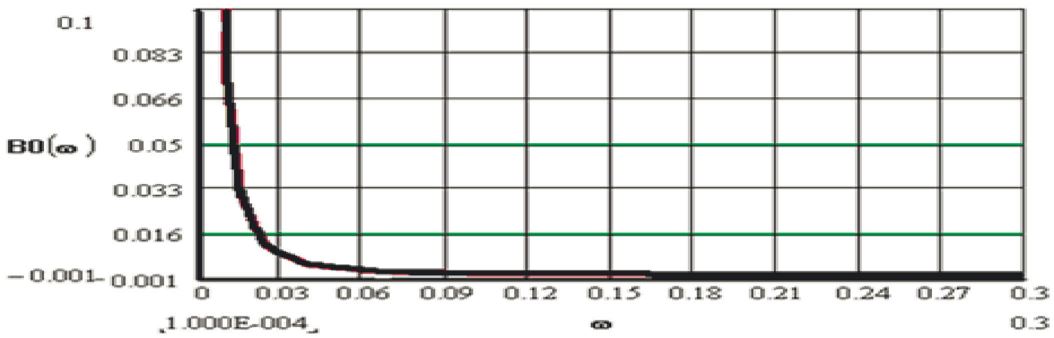
$c_{6,2} = 6.993E+002;$

$c_{7,2} = -4.454E+002;$

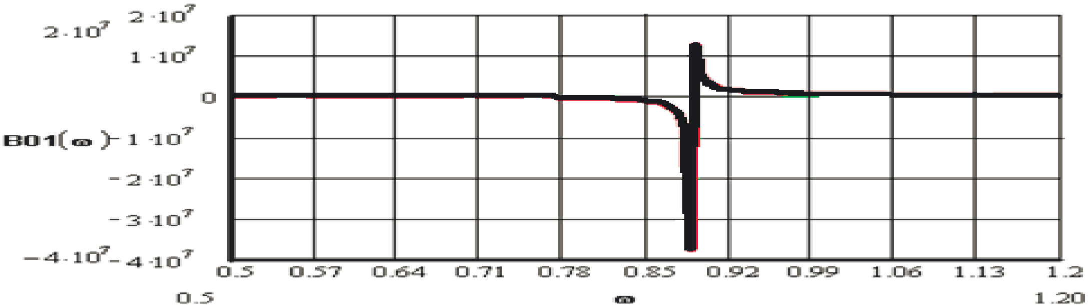
$c_{8,2} = -8.909E+002;$

$c_{9,2} = 5.001E-001;$

$c_{10,2} = 1.000E+000.$



a



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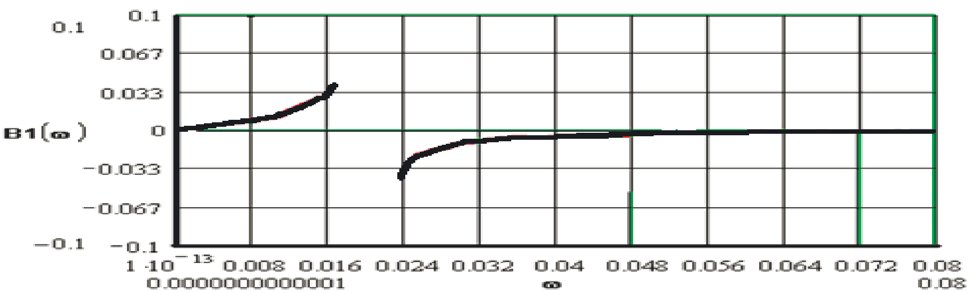

в

Fig.2. Mathematically expected amplitude-frequency characteristics of the universal ladder circuits of the dynamic models structural are the values of the elements of BC of the type ЗIФ-1200 according to the chart of Fig. 6.2: a – $B0(\omega)$, б – $B01(\omega)$, в – $B1(\omega)$

In Fig.2 and Fig.3 the amplitude-frequency characteristics of the transfer functions of the elements of integrated structure of BC are represented in Fig.1, which are determined for the dynamic models with the losses for friction in DBDT diamond drill bits and supports of BC of the type ЗІФ-1200 with consideration of the last one after structure with the jammed left end. According to the form and frequency parameters they are mainly characteristic for most types of MEMC with the analogues conditions of with the help of continued fractions [7].

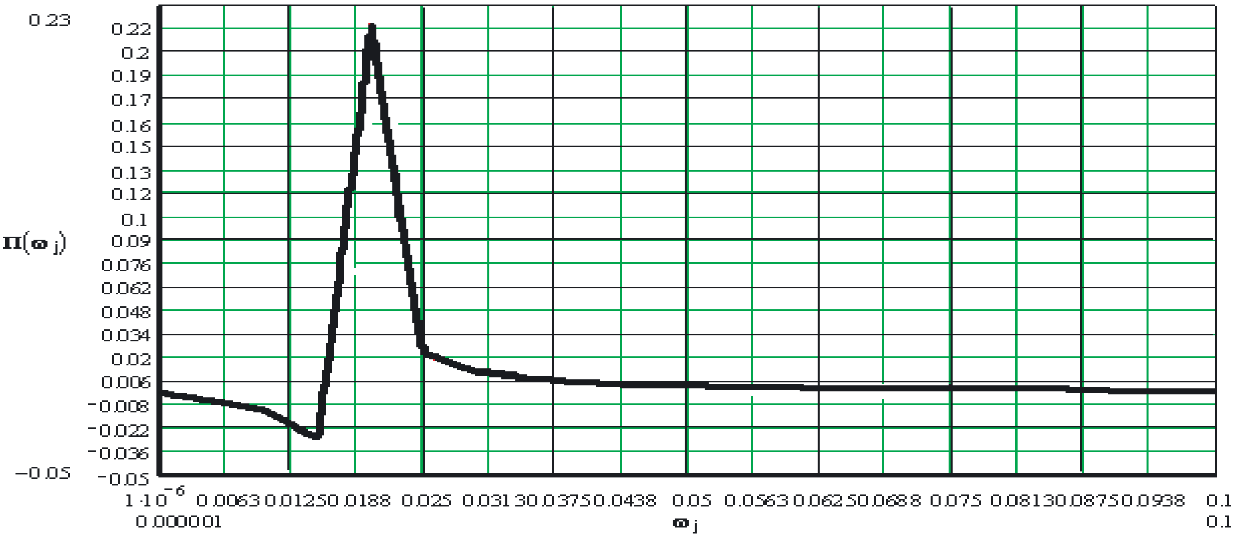

Fig.3. Mathematically expected amplitude-frequency characteristic of the transfer function of the universal ladder circuit of the dynamic model of BC of the type ЗІФ 1200

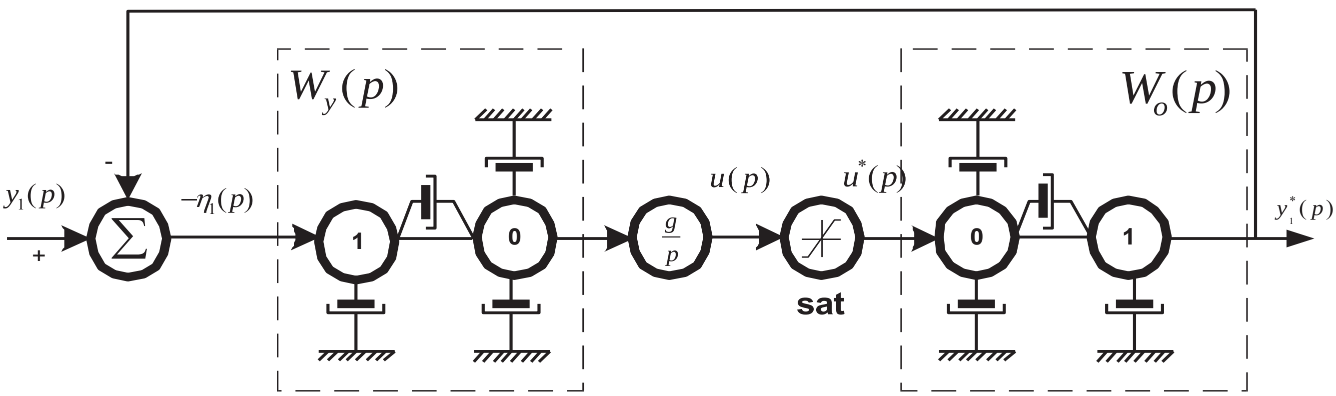

Fig.4. Basic modified structural diagram of the closed control system with compensation of own dynamics of MEMC in representation through the universal ladder circuits of the dynamic models.

The use of the effective methods of structural and algorithmic synthesis of control systems in modification of principle of symmetry to the decision of tasks of the analytical designing of regulators with the initial design of control objects with the help of operational method of the continued fractions on the first stage allows to present the closed control system in Fig. 4. Conceptually substantial here is the real requirement to the control part of the system as to the complete compensation of own dynamics of MEMC with provision of the best reproduction of the set gradation control influence in the sense of the standard-mean-square criterion. That is very important while deciding the tasks of technological and technical identification and control of BC. With that, formation of the real dynamic characteristics and limitations for the values of the control influences are provided with the chart. Presentation of the transfer functions of MEMC and the part of the closed control system with mechanism of dispersive operation form of the continued fraction allows to get to the charts presented in Fig.5 with the proper analytical description. Structural integrated technological and technical charts of the Boring Complexes of the type ЗІФ-1200 and УКБ-2000/3000 in representation through the universal ladder circuits of the dynamic models are presented in Fig. 5.

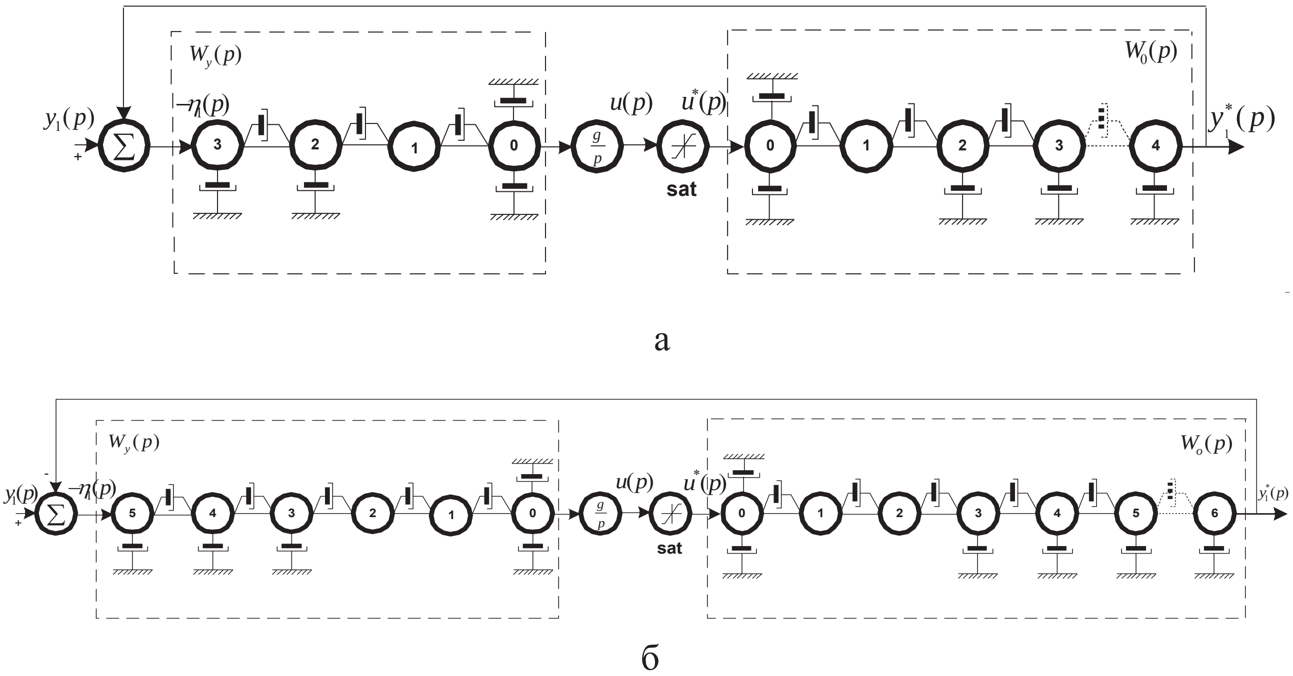

Fig.5. Structural integrated technological and technical charts of the Boring Complexes of the typeЗІФ-1200 (а) and Boring Complexes УКБ-2000/3000 (б) are represented through the universal ladder circuits of the dynamic models

Thus, application of the analytical designing of regulators in the Systems of Automated Control (SAC) of BC is provided with the purpose of control and amount of a priori information in collection with the running perturbations. And the use of conception of perturbed-unperturbed motion for the structural and algorithmic synthesis of the control system on the basis of the principle of symmetry allows to form the basic algorithm of optimum evaluation and control of BC through the set of control influences, which on mechanical subsystem provide stabilization of the modes of optimization of the value of load on DBDT and frequency of its revolutions to provide operating modes of the bulk crush of the rock, and on a hydrodynamic subsystem provide stabilization of the optimum values of the losses and pressure of the flushing fluid on the levels of the integrated value of friction in a subsystem of DBDT-rock. Operative control of technological and technical states is at the same time provided on limitations in the additional circuits and pre-emergency shut-down of BC if it is found to be impossible to remove it from pre-emergency state with the help of the standard control.

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ABSTRACT

Purpose. Explore possibility of application of algorithmic synthesis of optimum regulators, with the use of principle of symmetry on the basis of dynamic models, to the management by the boring complexes.

The methods of research. Used methods of structural-algorithmic synthesis of the systems of management in modification of principle of symmetry to the decision of tasks of the analytical constructing of regulators with the initial design of objects of management by the statement method of chain shots, that allows on the first stage to synthesize the closed system of management.

Findings. Results of design secure stabilization of the modes of optimization of size of loading on the porodorazrushayushiy instrument and frequencies of its turns for providing of operating conditions of by volume destruction of mountain breed, and on the hydrodynamic subsystem stabilization of optimum values of charges and pressure of washing liquid at the levels of the integrated size of friction in subsystem «porodorazrushayushiy instrument-breed».

The originality. Consists of requirement to the handling part of the system about the complete compensation of own dynamics of mountain complex with providing of forming the best in sense of srednekvadratichnogo criterion of the set handling influence.

Practical implications. Conducted researches confirmed practical expedience of application of algorithmic synthesis of optimum regulators, with the use of principle of symmetry on the basis of dynamic models, to the management by the boring complexes.

***Keywords**: boring complexes, management, synthesis of optimum regulators, principle of symmetry, dynamic models*

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МОДЕЛИРОВАНИЕ ПРОЦЕССА РАЗМЕЩЕНИЯ ОБОГАТИТЕЛЬНОГО ПРОИЗВОДСТВА С УЧЕТОМ НЕПРЕРЫВНО РАСПРЕДЕЛЕННОГО РЕСУРСА

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MODELING PLACEMENT OF THE CONCENTRATING INDUSTRY WITH CONTINUOUSLY DISTRIBUTED RESOURCE

Рассмотрена технологическая схема работы горнодобывающего предприятия. Выполнен анализ существующих математических моделей размещения многоэтапного производства на примере горнодобывающей промышленности. Предложена новая математическая модель в смешанной постановке для многоэтапной задачи размещения обогатительного производства. В качестве критерия задачи оптимального размещения выбрана суммарная стоимость доставки продукции.

Розглянуто технологічну схему роботи гірничодобувного підприємства. Виконано аналіз існуючих математичних моделей розміщення багатоетапного виробництва на прикладі, гірничодобувної промисловості. Запропоновано нову математичну модель в змішаній постановці для багатоетапної задачі розміщення збагачувального виробництва. В якості критерію задачі оптимального розміщення обрана сумарна вартість доставки продукції.

Введение. Горнодобывающая промышленность Украины отличается высокой степенью концентрации и большими масштабами производства, позволяющими удешевлять стоимость добычи и применять современную технику. Однако, в последнее время, в центре внимания всего мира и Украины, в частности, все чаще становятся задачи повышения конкурентоспособности за счет снижения затрат и улучшения качества показателей реализации продукции.

Характерным для развития этой отрасли является необходимость развития новых предприятий (например, разработка новых месторождений) и модернизации или реорганизации имеющихся, в связи с чем возникает задача оптимального размещения предприятий на данной территории.

При решении этой задачи необходимо учитывать различные факторы (экономические, социальные, экологические) и особенности отрасли, что в совре-