Synthesis of extreme control system of coal cleaning in jigs

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Received May 19.2014: accepted May 29.2014

Summary: The research of the behavior of the extremum of the quality criterion. A method for finding the extremum of the criterion of efficiency for the example of jigging. Made extreme synthesis and simulation control system. The dynamics of extreme systems and identify indicators of quality.
Key words: Jigging, coal cleaning, density, yield of fractions, performance criterion, extremal system

INTRODUCTION

The most important and complex processes concentrators are coal processing different engine classes in jigs and flotation machines, heavy media gravity separation and hydrocyclones.

In accordance with technological scheme of processing of coal are three levels of management [14, 15]: lower level provides management regime parameters most closely correlated with the quality of enrichment products (density separation bed height breed, specific consumption of reagents, etc.), medium – provides process control (separate concentrator machine or group of machines of the same type, for example, a few jigs), upper – provides management of the complex processes of coal preparation (all jigging, flotation machine, separators and hydrocyclones operating on a common product.)

As you know, each level of the hierarchy of control should be carried out by a given criterion when extremalization general criterion. This should be observed hierarchy of criteria: lower levels of management must obey superiors. As a criterion of control is advisable to choose a criterion that could be quickly calculated on the basis of information received from automatic devices have a physical meaning, uniquely determine the effectiveness of the factory and does not contradict the generally accepted criteria [26].

MATERIALS AND METHODS

Synthesis of extremum search criterion of efficiency is made by the method of measuring the sign of the derivative [16, 24, 32].

RESULTS, DISCUSSION

In general, coal beneficiation process can be represented as the transformation of raw coal input stream to the output stream of commodity products and wastes:

$$Y = L\{X, V, Z\},$$
$$A_{k\min}^{d*} \le A_k^d(t) \le A_{k\max}^{d*}, \ A_0^d(t) \ge A_0^{d*}(t), \quad (1)$$

where: X – vector input characteristics of raw coal, V – vector control actions, Z – vector of disturbances, Y – vector output characteristics of products, $A_k^d(t)$, – ash content, $A_k^d(t), A_{k\min}^{d*}, A_{k\max}^{d*}$ – specified minimum and maximum ash content, $A_0^d(t)$,– current ash waste, $A_0^{d*}(t)$ – given ash waste, L – оператор преобразования.

For practical application given criterion can be simplified by considering the amount of output per unit of time. Then, given the constancy of the list price and coal washability curve approximation of second-order polynomial [8, 25], we obtain a mathematical expression control objectives as follows:

$$I(A_{k\Sigma}^d) = \sup M\left\{\sum_{i=1}^{n} G_i\left[a_{0i} + a_{1i}A_k^d + a_{2i}\left(A_k^d\right)^2\right]\times \right. ,$$
$$\left. \times\left[1-\lambda\left(A_{ki}^d - A_{ki}^{d*}\right)\right]\right\}, \quad (2)$$

where: G_i – initial performance of i-th class machine, a_{0i}, a_{1i}, a_{2i}– approximating polynomial coefficients of i-th class machines, A_{ki}^d, A_{ki}^{d*} – given the current (list price) ash concentrate for the enrichment i-th engine class, $A_{k\Sigma}^d$ – total ash content of coal concentrate, λ – rate discounts or surcharges on the price of coal concentrate at a deviation of ash coal concentrate from the list price.

This should be the following restrictions on ash content and losses:

$$A_{k\Sigma\min}^{d*} \le M\left\{A_{k\Sigma}^d(t)\right\} \le A_{k\Sigma\max}^{d*}, \quad (3)$$
$$M\left\{A_0^d(t)\right\} \ge A_0^{d*}, \ \nu_n(t) \le \nu_n^*, \quad (4)$$

where: $A_{k\Sigma\min}^{d*}, A_{k\Sigma\max}^{d*}$ – allowable minimum and maximum total ash content of the concentrate, $\nu_n(t), \nu_n^*$ – current and allowable losses concentrate tailings

$$A_{k\Sigma}^d = \frac{M\left\{\sum_{i=1}^{n}\gamma_{ki}A_{ki}^d\right\}}{M\left\{\sum_{i=1}^{n}\gamma_{ki}\right\}}, \quad (5)$$

where: γ_{ki} – concentrate output of i-th class machine.

Not hard to see that (2) for each class has an extreme high-drifting in the vertical and horizontal directions with changes in productivity and coal washability. In the absence of constraints (3), (4) the maximum of (2) takes place at the maxima for each machine class, ie particular criteria are additive to the total.

In the case of restrictions on the ash content, which usually has a more stringent requirement of the form $A_{k\Sigma}^d \le A_{k\Sigma}^{d*}$ ($A_{k\Sigma}^{d*}$ – given the total ash content of the concentrate), the maximum of (2) takes place at the optimum values ash content of each class of machine, different from their extreme values [27]. In this case, the problem of determining the optimal values of ash content of each class of machine can be reduced to a linear programming problem.

Depending on the location of the extremum of target function along the axis of ash content of the concentrate can be used and the appropriate management strategy separation process.

Consider the criterion (2) for the plant as a whole. For this we represent (2) as a function of ash content mixture of concentrates:

$$I(A_{k\Sigma}^d) = \sup M\left\{\sum_{i=1}^{n} G_\Sigma\left[a_{0\Sigma} + a_{1\Sigma}A_{k\Sigma}^d + a_{2\Sigma}\left(A_{k\Sigma}^d\right)^2\right]\times \right.$$
$$\left. \left[1-\lambda\left(A_{k\Sigma}^d - A_{k\Sigma}^{d*}\right)\right]\right\}, \quad (6)$$

where: G_Σ– total load on the section of the factory, $a_{0\Sigma}, a_{1\Sigma}, a_{2\Sigma}$ – approximating polynomial coefficients of total β-curve of mix all engine classes.

Extremum-maximum criterion (6) drifts in the horizontal direction, as when changing raw coal washability and also change the coefficients of the polynomial approximating β-curve [7, 20]. And an upgrade washability extremum shifted to higher ash content as β-curve is approximated by a convex function. The maximum of criterion (6) also drifts in the vertical direction when changing coal washability and load the initial product.

For example, for coking coal of the Donets Basin (factory "Sukhodilska") plot of the optimality criterion on the ash content of the concentrate mixture has an extreme-maximum in the $A^d_{k\Sigma} = 14\%$. The norm of ash concentrate for this plant is 8.5%, so the work in this mode is not acceptable. This is due to the low value of the coefficient λ. In the case of its increase extremum of the criterion is shifted to lower ash content.

This indicates that the management of the complex at the existing price system should be implemented at the boundary permissible region. Must take into account constraints (3) due to the inability in many cases provide an extremum of the objective function at the average, difficult and very difficult categories of coal washability.

If concentrates different engine classes do not mix (for example, anthracite coal concentration), the ash content of each class is limited to a range of $A^d_{k\min} \div A^d_{k\max}$. Extremum efficiency criterion (2) takes place at extremes of this criterion for each of the classes. Since the implementation is carried out by grades of anthracite, if restrictions on its ashes must consider this limitation in concentration of each class.

For practical applications, it is advisable to the objective function of complex control processes of coal preparation expressed through the performance of each department to concentrate:

$$I(A^d_k, G_k) = \sup M\left\{\sum_{i=1}^{n} G_{ki} \cdot \left[1 - \lambda\left(A^d_{ki} - A^{d*}_{ki}\right)\right]\right\}, \quad (7)$$

with constraints (3) and (4).

In view of the above criteria's property management factory unprofitable to work with $M\left\{A^d_{k\Sigma}(t)\right\} < A^{d*}_{k\Sigma}$, so it is advisable to use the above limitation of the equal sign. This means that the restrictions on the ash content is almost always forced to work in the ash stabilization modes. Then the maximum value of sales equivalent to the maximum specified output concentrate ash content, ie criterion "concentrate output" is a special case of performance criteria.

Thus, the automatic control system to individual coal preparation process, in most cases the ash content should provide stabilization of the concentrate and it sometimes optimization. Control system for coal preparation processes should also stabilize the ash mixture concentrates all engine classes or to provide optimization of the complex. At the heart of optimization systems can be used stabilizing system, which targets are set on the basis of objective function extremalization.

So ash content and performance at coal concentrate of local processes selected by minimizing the cost of enrichment:

$$I_{11} = \sum_{i=1}^{n_\phi} C_{\Pi i} G_i \left[0{,}01 \sum_{p=0}^{k_\phi} a_{pi} \left(A^{d*}_{\kappa i}\right)^p\right] \times \left[1 + \sum_{v=1}^{m_\phi} \lambda_{vi}\left(W_{vi} - W^*_{vi}\right)\right] \to \min, \quad (8)$$

where: $I_{11} \in \mathbb{R}$ – total cost of coal preparation UAH/h., $C_{\pi i} \in \mathbb{R}$ – cost of coal preparation class i, UAH/t (in general depends on the output of concentrate), $n_\Phi \in \mathbb{Z}$ – the number of machine classes, $m_\Phi \in \mathbb{Z}$ – the number of corrective parameters rates (ash content, moisture, sulfur, etc.), $k_\Phi \in \mathbb{Z}$ – order approximating polynomial [20], $p,v,i \in \mathbb{Z}$ – auxiliary parameters, $p=1,\ldots,k_\Phi$, $v=1,\ldots,m_\Phi$, $i=1,\ldots,n_\Phi$, $G_i \in \mathbb{Z}$ – load the i-th class machine, t/h, $A^{d*}_{\kappa i} \in \mathbb{R}$ – calculated ash content of i-th engine class, %, $a_{pi} \in \mathbb{R}$ – coefficients of the polynomials, $W_{vi}, W^*_{vi} \in \mathbb{R}$ –current and set values of the parameter v-th (ash, moisture, sulfur, etc.) of i-th engine class, $\lambda_{vi} \in \mathbb{R}$ – weighting parameter deviation of i-th class machine (ash, moisture, sulfur, etc.) from setpoint.

Criteria for quality control of coal preparation for local processes must not contradict the global criterion controls the coal preparation plant (2.1) [14]. On the lower level criteria used stabilization regime parameters.

Perform synthesis system of extreme control of the local coal jigging process. Jigging efficiency to the greatest extent determined by the height of bed H and its coefficient of looseness R. Dependence of the efficiency criterion I of the H and the R has an extreme character [17, 29, 30]. A significant portion of the useful components lost waste at low altitude bed. Weediness of the product of high-components increases at high altitude bed, which leads to an increase in the ash content of the concentrate.

Carried out in [31] analysis showed that the most effective control is to change the setpoint height of bed H:

$$G_n = 108 - 719H_n + 1192H_n^2, \qquad (8)$$

$$\gamma_n = 30{,}7 - 182H_n + 276H_n^2, \qquad (9)$$

$$G_{nn} = 7{,}25 - 31{,}1H_{nn} + 99{,}9H_{nn}^2, \qquad (10)$$

$$A_k^d = -7{,}62 + 235H_{nn} - 885H_{nn}^2, \qquad (11)$$

where: G_n, G_{nn} – respectively discharging device performance in the first and second branch of the jigger, H_n, H_{nn} – respectively bed height, γ_n – rock weediness.

Dependence of the efficiency criterion I of the height of the coal bed H was obtained after substituting (8) - (9) and (10) - (11) (for given values $\gamma_{nз} = 2{,}2\%$ and $A_{kз}^d = 6{,}3\%$), respectively, in the equation:

$$I_2 = 2{,}2 + 0{,}3G_{ï} - \Delta\gamma_{ï}^2,$$

$$I_3 = 6{,}5 - 0{,}7G_{nn} - 2{,}5(\Delta A_к^d)^2,$$

where: $\Delta\gamma_{ï} = \gamma_{ï} - \gamma_{ïç}$, $\Delta A_к^d = A_к^d - A_{кз}^d$.

Performance criteria for the first and second branch of the jigger respectively have the form:

$$I_2 = 3{,}09 - 1{,}58 \cdot 10^4 H_n^{\ 2}, \qquad (12)$$

$$I_3 = 3{,}56 - 2{,}48 \cdot 10^3 H_{nn}^{\ 2}. \qquad (13)$$

As can be seen from the dependence of the efficiency criterion from control for both branches of the jigger is of an extreme nature and has a positive extremum-maximum.

Thus, changes in the fractional composition and ash content of raw coal has a significant impact on output variables jigging process that leads to the drift maximum efficiency criterion.

Perform synthesis system of extremum search for the example of jigging [4, 5, 9]. The transfer function of a control object (second division) for the channel performance unloader G_{nn} – height of the bed H_{nn} is [12,13]:

$$W(P) = \frac{K\exp(-p\tau)}{Tp+1},$$

where: $K = 2{,}2 \cdot 10^{-4}$ – transfer coefficient m/kg, $T = 75$ – time constant, sec, $\tau = 50$ – transport delay, sec.

Fig. 1 is a functional diagram of ACS jigging [33].

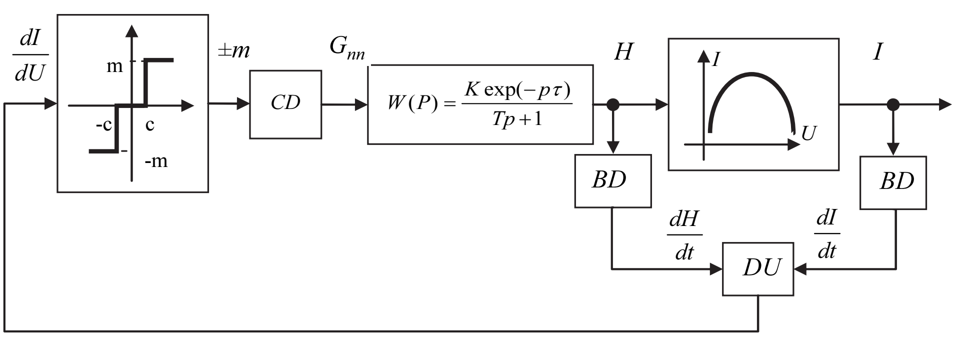

Fig. 1. Functional diagram of a process control system

This schema contains two blocks of differentiation *BD*, division unit *DU*, that defines the derivative dI/dH, and relay element *RE*, which determines the sign of the derivative [10,11,18]. Depending on the sign of the derivative control device *CD* provides movement of control object in the direction of extreme. Derivative changes sign when passing through an extremum, relay element switches and a control device changes the sign of the output signal to the other $\pm m$, which ensures the system returns to the point of extreme. Value of the derivative dI/dH is determined from the expression:

$$\frac{dI}{dH}=\frac{dI}{dt}/\frac{dH}{dt}. \qquad (14)$$

Fig. 2 shows a timing diagram illustrating the operation of the extremal system [19, 23, 28]. Let the initial state of the system is determined by the point M_1 located on the left of the extremum. In this case $dI/dH>0$ and the signal $+m$ is input to the *CD*. H-value increases at a constant rate. Quality Score I will rise first, and then after the extremum point - decrease. Derivative dI/dH before an extremum positive, derivative is zero at the extremum point, and after the extremum point becomes negative. The derivative is negative to the point M_2 because of the dead zone in the ER. When $dI/dt=-kc$, where $1/k=dI/dt$, *RE* witches and changes sign at input *CD*. Thereafter H decrease at a constant rate and quality score I increase until it enters the extremum point, etc. The system established by oscillations with a period T.

Fig. 3 shows the implementation of control systems in Simulink application [6].

The control device is implemented as a function of Matlab (Fig. 4).

The simulation results of the extremal system shown in Fig. 5-10.

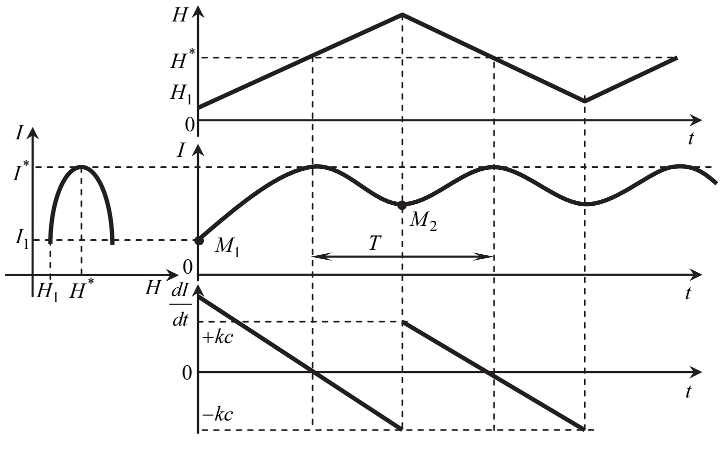

Fig. 2. System operation

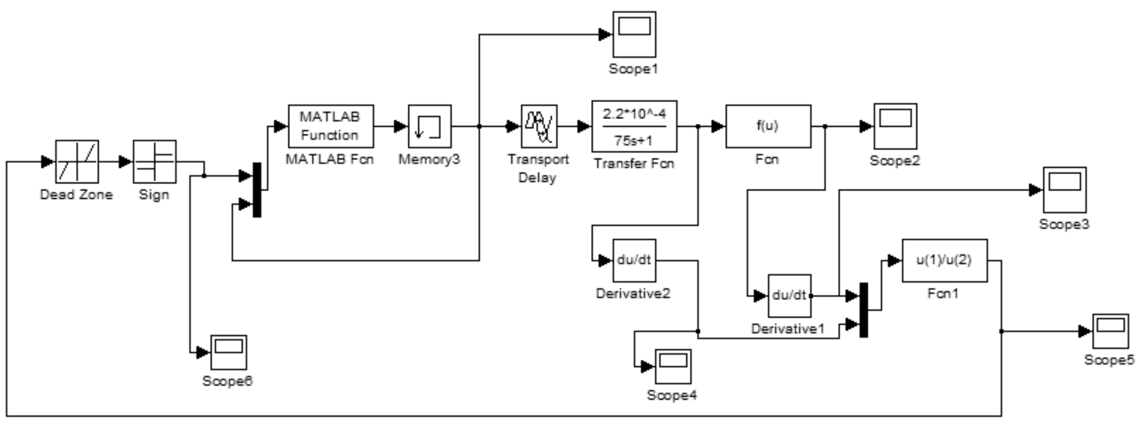

Fig. 3. Simulation of the system in Simulink

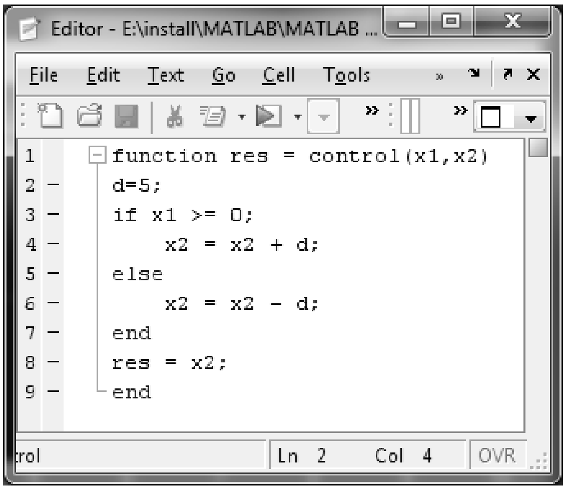

Fig. 4. Calculation of control action

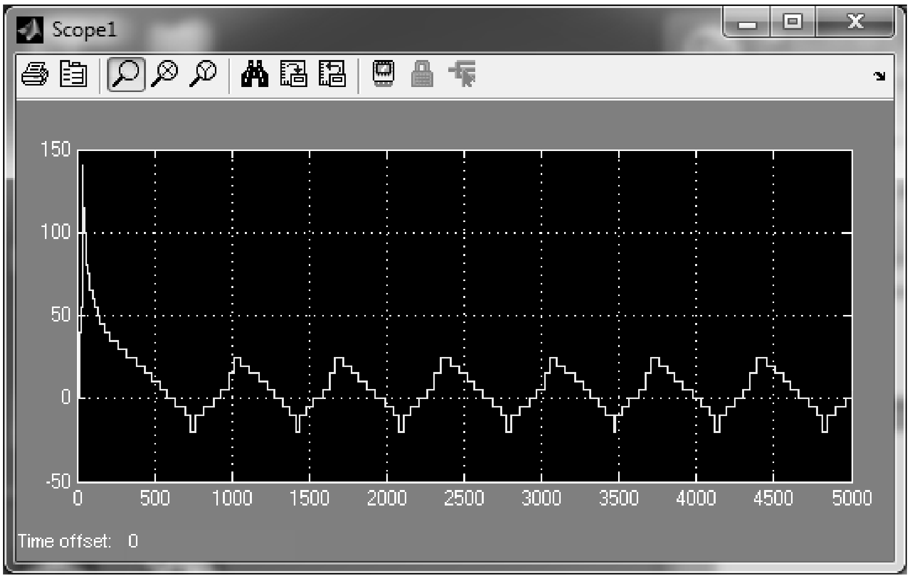

Fig. 5. Changing performance unloader G_{nn}

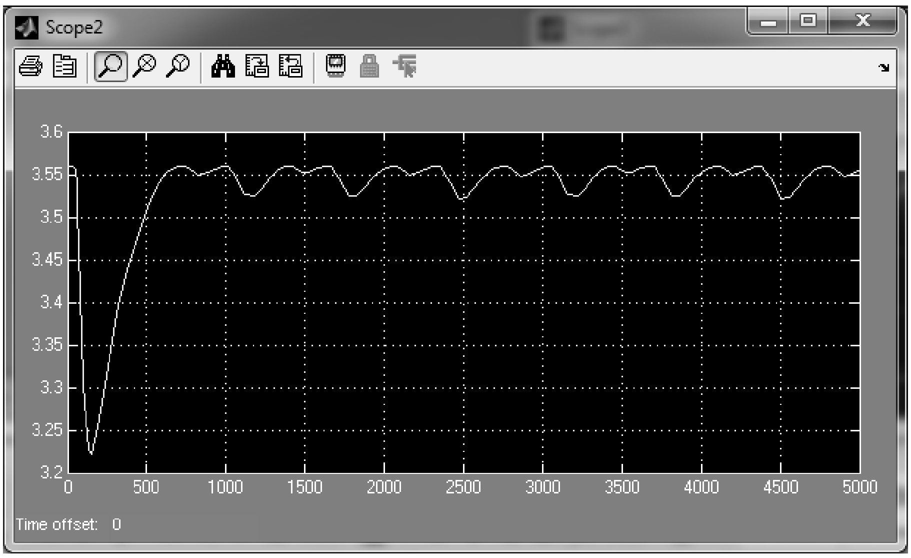

Fig. 6. Search extremum of the functional quality

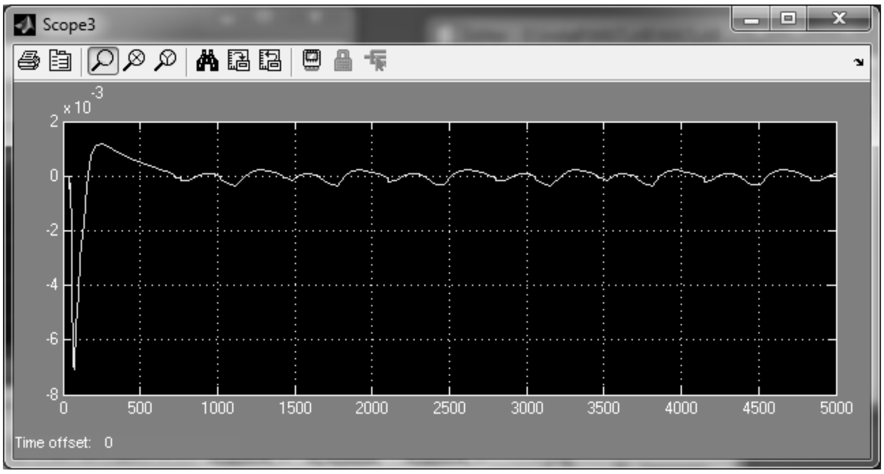

Fig. 7. Changing the value of the derivative dI / dt

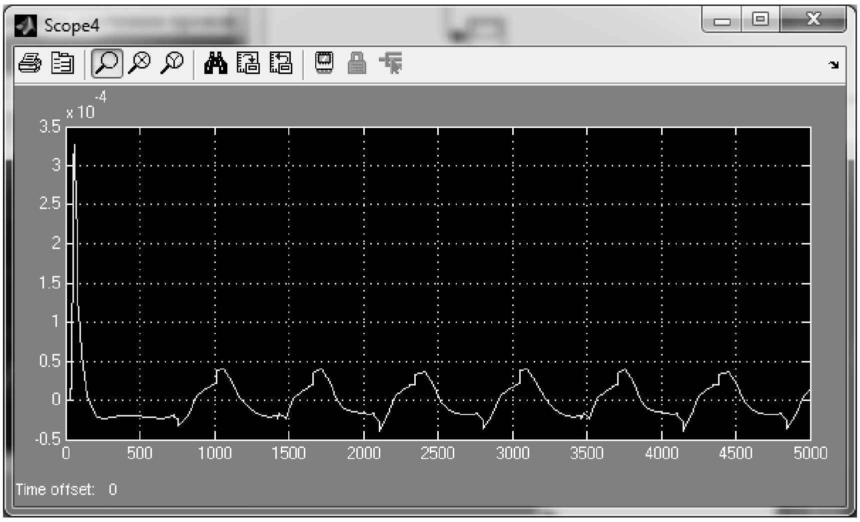

Fig. 8. Changing the value of the derivative dH / dt

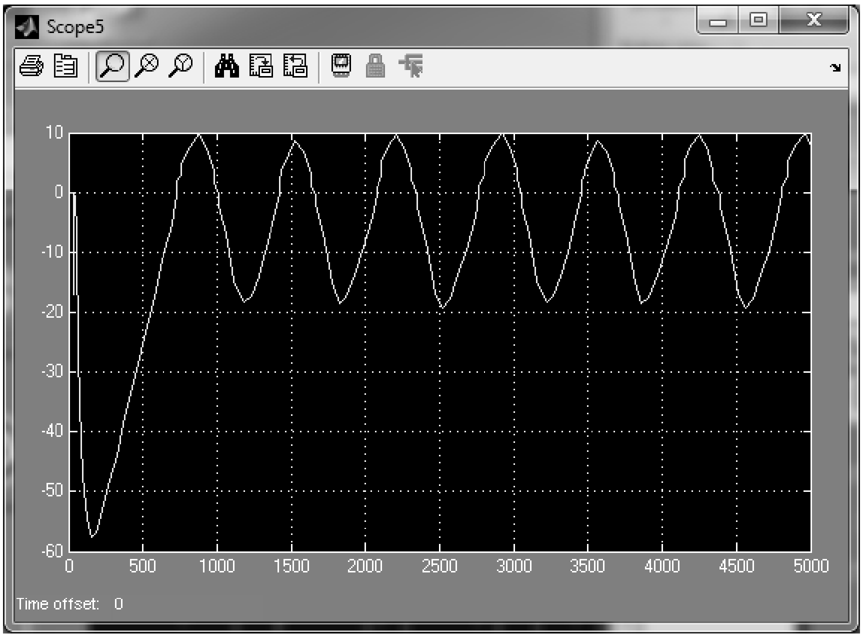

Fig. 9. Changing the value of the derivative dI / dH

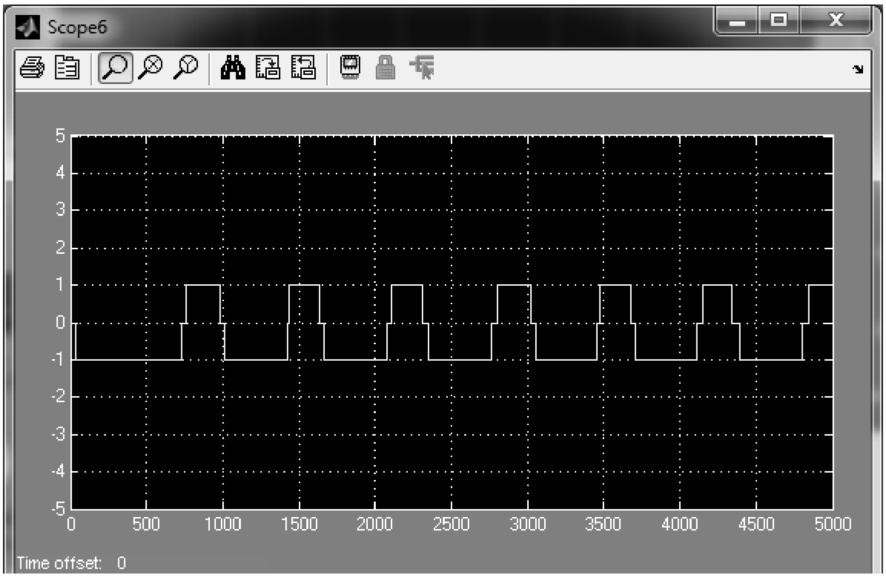

Fig. 10. Signal at the output relay element

Dynamics of systems characterized by extreme parameters such as: search costs, hunting period, the search area at the input and output of the object, time to the point of extreme [1, 3]. We define these parameters for extreme system. Relay element is the perfect three-point relay with dead zone 2 sec.

We assume that the $I = f(H)$ has the form of a parabola, then if origin of coordinates moved to the extremum point, the nonlinear part of the object is described by the equation:

$$I = -k_1 H^2 . \quad (15)$$

Assume that H varies linearly in the mode steady-state oscillation, i.e.:

$$H = \pm k_2 t, \quad (16)$$

where: the sign "+" corresponds to the time interval when $dH/dt > 0$, and the sign "-" – the time interval when $dH/dt < 0$. In this case:

$$I = -k_1 k_2^2 t^2 . \quad (17)$$

In the steady-state oscillation maximum deviation (amplitude yaw) of the quality of the extreme value is determined from the expression (14) for $t = T/2$:

$$\Delta I = -k_1 k_2^2 T^2 / 4 . \quad (18)$$

Define the derivative dI/dH, for this we write the derivative of the quality time:

$$dI/dt = -2k_1 k_2^2 t ,$$

and derivative dH/dt:

$$dH/dt = \pm k_2 .$$

Then:

$$dI/dH = \frac{dI/dt}{dH/dt} = \pm 2k_1 k_2 t.$$

Switching *RE* occurs when $dI/dH = \pm c$ and $t = T/2$ if origin of coordinates moved to the extremum point:

$$2k_1 k_2 T/2 = c,$$

Which implies that:

$$T = c / k_1 k_2 ,$$

i.e. period depends on the hunting deadband relay element, and is determined by parameters of *CD* and extreme characteristics of the object.

The average deviation of the quality for the period is called loss on the hunting D. It is determined from the integral:

$$D = \frac{1}{T}\int_0^T I(t)dt = \frac{2}{T}\int_0^{T/2} - k_1 k_2^2 t^2 dt = \frac{-k_1 k_2^2 T^2}{12} . \quad (19)$$

CONCLUSIONS

1. Studies of coal preparation in heavy media gravity separation (class 13 mm) in jigs (class 1-13 mm) and flotation machines (class 0-1 mm) lead to the following conclusions [2,21,22]:

- dependence $I(A^d_{k\Sigma})$ has a maximum, which drifts in vertical and horizontal directions,
- to increase washability extremum shifted to the right in the area of high ash content,
- operation of the process at the extremum of the functional quality within the permissible ash is only possible for the light category coal washability.

2. Therefore, in most cases, the optimal mode of any coal beneficiation processes is the stabilization mode maximum ash content of the concentrate with constraints on the ash content.

3. The results of calculations of quality extremal system: amplitude of the hunting $\Delta I = 0.025$, search costs – $D = 0{,}075$. The average value of the ash content of the concentrate $\overline{A}^d_k = 6{,}25\%$, standard deviation – $\sigma_A = 0{,}15\%$.

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СИНТЕЗ ЭКСТРЕМАЛЬНОЙ СИСТЕМЫ УПРАВЛЕНИЯ ПРОЦЕССОМ ОБОГАЩЕНИЯ УГЛЯ В ОТСАДОЧНОЙ МАШИНЕ

Алексей Письменский, Виталий Ульшин

А н н о т а ц и я. Исследовано поведение экстремума критерия качества. Предложена методика поиска экстремума критерия эффективности на примере процесса отсадки. Выполнен синтез и моделирование экстремальной системы управления. Исследована динамика экстремальной системы и определены показатели качества.

К л ю ч е в ы е с л о в а: отсадка, угольная постель, выход фракций, критерий качества, экстремальная система