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THE FORMING OF THE ADAPTIVE PROCESS CONTROL OF IRON ORE DEGRADATION IN CONDITIONS OF CHARACTERISTICS UNCERTAINTY

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Abstract. The article presents the results of the analysis of the methods of the automatic control of the technological process of iron ore disintegration in conditions of iron-ore raw material characteristics and technological process parameters uncertainty._The articles and works about the principles of mill control and the methods of the shredding analysis were analyzed. The analysis the library of adaptive controllers is represented. The model of the ball mill was created in the simulation environment MATLAB / Simulink. In this work are represented the principles of using the PID controller, the work of adaptive controllers based on the Ziegler-Nichols methods. The results of using the adaptive controllers based on differential filtering component with usage of Tastin approximation (Ziegler-Nichols controller with D-component filtration) and the methods of rectangular and trapezoidal discrete sampling are represented. The results of the simulation show that the adaptive Ziegler-Nichols controller for the 3-order processes based on differential filtering component with usage of Tastin approximation is the most efficient controller for the control of the grinding process of the various types of iron-ore raw material. Comparing to the classical PID-controller it provides the smaller measure of inaccuracy, which is 0.01%-0.81%. This controller provides the following results: overshoot - 16.7, the installation of the transition process - 69.5 seconds.

Keywords: automation, adaptive control, ore degradation, PID controller.

Introduction. Degradation is the most power-consuming process among the technological processes of the ore-dressing plant. During this process the ore is constantly disintegrating to the required size (-0,074mm, -0,05mm, 0,045mm) according to the stage of ore degradation. The first stage of degradation is determinative in the matter of the following quality of the product; therefore, the increase of effectiveness of the automatic control and the updating of the equipment (the mill, the power modules, the piping) is the main task for the quality assurance and the reduction of the prime costs of the concentrate [1]. As a general criterion of efficiency of grinding ore typically use quantity of material required class size in the shower classifier that works in closed loop with the mill. This figure depends on a number of factors which are constantly changing, in particular, the characteristics of raw materials, operational management settings.

The ball mill requires the efficient and adjusted algorithm of raw material filling, which grants the efficient use of the input raw material and the mill itself [2]. One way to increase the effectiveness of degradation is usage of the adaptive control methods. Adaptive control systems adapt regulatory controls to the changes in the system parameters and control the object taking into the account the new conditions and changes of such parameters as for example variability characteristics of iron ore, that is supplied to the ball mill for grinding [3]. The operating experience with adaptive systems shows the efficiency of their implementation in the technological processes in mining factories, that permits to improve the accuracy and stability of the control systems and, as a result, to improve the quality factors of the technological processes of iron-ore degradation [4-8].

Materials and Methods. The methods of the operational control of the raw material quality on the different stages of its processing are highlighted in the works [9, 10]. During the process of raw material mining the heterogeneous ore is formed, that leads to the instability of the mineral raw materials, which is sent for the following dressing [11, 4 ,7-8]. The process of control with due regard for the efficient energy use, ecological safety and economical production of the ore-dressing plant is represented in the work [4-8, 12-14].

For effective work of ball mills must comply with certain correlation between the size of bullets and pieces of ore, loaded to the working capacity of the mill [13, 14]. For ball mill control action is the performance by the original ore, water consumption. The change in the raw material properties (hardness, breakage, particle-size analysis), sand consumption, the state of the objects, fetting can be an energizing influence. Operated variables grinding process: slurry density, the structure of the finished material (class %–0,074mm), efficiency according to the class in the waste hole of the mill, engine power [14-15]. In the article [4] the technological process of the magnetite quartzite dressing is proposed to be considered as a many-dimensional discrete system in matrix-vector form. To determine the technological processes (TP) of dressing as multiply nonlinear dynamic objects it was suggested to use the multidimensional analogues of neural predictors: NNARX, NNARXMAX, NNOE. The inverse dynamic models are used for the automatic control of the local processes, mainly ones with the schemes of the circuit type SISO (single input - single output).

The difference ADL (p, q) models structures are the base of the method of synthesis of the adaptive ARMA-process control systems [6]. The adaptive properties of such models are derived due to the usage of the designed method of neuromorphic control of weight numbers γ_0, γ_1, γ_2,..., γ_n in the discrete adaptive structure ARMABiS, which was developed on the basis of the output coordinate reference value $y^*(t)$ determination in the discrete MA(q)-model with the distributed lag order (0, q).

The article [8] proposes the hybrid mathematical model of the iron-ore degradation closed loop; its analytical part describes the ore-flows and the changes of the grain size distribution of the iron-ore in the technological units. The fuzzy Takagi-Sugeno rules are used for the forming of the functions of division and fragmentation. It is noted, that the main task of the control of the mineral processing equipment, for example, the hydrocyclones, is to provide such mode of operation that guaranties the particle-size distribution, which is necessary for the efficient derivation of the impregnations.

Thus, the usage of the adaptive systems with complex operation algorithms in the control processes of iron-ore reprocessing is provided by the high level of the development of modern computer equipment. However, this approach does not exclude the difficulties of providing the reasonably qualitative control of the efficiency indexes of the technological processes and the necessity of the system stability assurance during the change of parameters. Therefore, it is appropriate to review the methods of adaptive control that uses the on-line data about the internal state of an object and a priori information about the patterns of grinding along with classical methods of regulation.

The analysis of the adaptive controllers while controlling the ball mill simulation model. The analysis of the controller in the conditions of parametric and coordinate disturbances.

Results. The ball mill automatic control system (ACS) works on principle of the difference between the desired value and the actual outgoing value. The mathematic model of the iron ore degradation was taken as an object and presented in the article [14].

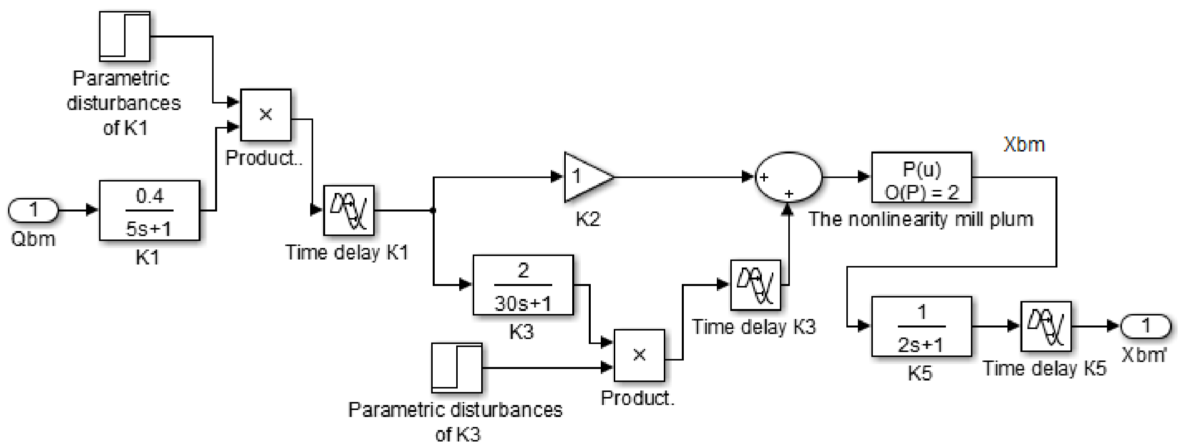

Figure 1. The object model of ball mill in Simulink

The relation between the output of the required class of coarseness and the ore consumption is nonlinear. The designations on the scheme: Qbm – is the mass flow rate, Xbm – is the quantity of the 0.074 mm class in the ground ore (fig.1). As a definition we use the quantity of the required class in the slurry of the waste hole. One of the ways of the ball mill control in the factories of ore dressing is using the proportional-integral-derivative (PID) controllers.

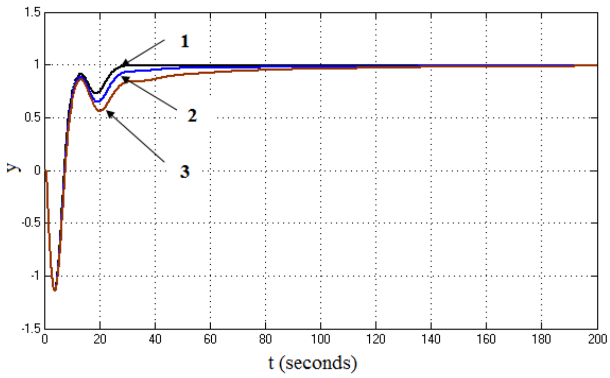

Figure 2. The control of the ACS degradation process with the change of the coefficients K1 and K3:
1 – minimum value, 2 – medium value,
3 – maximum value

Fig. 2 represents the state of the transient process of the iron ore degradation using the PID controller in the control loop in the conditions of parametric and coordinate disturbances. The parametric disturbances are shown as the change of the coefficient in the transfer functions K1and K3. The values changed within the limits mentioned in the work [14].

In cases when the values of K1 and K3 are close to the maximum the work of PID controller is more efficient. Under the influence of the parametric disturbances the system is out of balance. The simulation of the random changes of the coefficients within the certain limits (±10%), namely the changes of «K1» and «K3» of the transfer functions are represented on the fig.1 in the boxes “Parametric disturbances of K1” and “Parametric disturbances of K3”.

The analysis of the PID controller (fig.3) shows the necessity of using the adaptive controller in the control loop. It would be able to evaluate the changeable values and correct the parameters of the controller during its work to provide the stable and efficient control under all possible modes. Therefore, we'll review the ACS (automatic systems control) with several adaptive controllers [16].

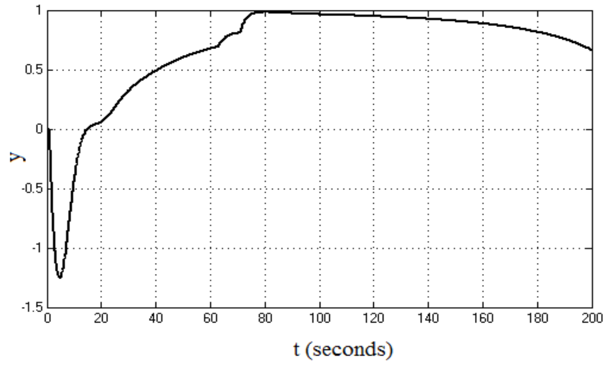

Figure 3. The transient process with the random change of the K1 and K3 coefficients

The mathematical description of the controller is represented in the following form.

Ziegler-Nichols controller for third order processes with filtration of derivative-component using Tustin approximation (ZN3FD). Control law

$$u_k = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} - p_1 u_{k-1} - p_2 u_{k-2},$$

where e_k - control error ($e_k = w_k - y_k$). Controller parameters are calculated using following equations [16]

$$q_0 = K_p \frac{1 + 2(c_f + c_d) + \frac{c_i}{2}(1 + 2c_f)}{1 + 2c_f}$$

$$q_1 = K_p \frac{\frac{\tilde{n}_i}{2} \quad 4(c_f + c_d)}{1 + 2c_f}; \qquad (1)$$

$$q_2 = K_p \frac{c_f(2 - \tilde{n}_i) + 2c_d + \frac{c_i}{2} - 1}{1 + 2c_f};$$

$$p_1 = \frac{4c_f}{1 + 2c_f}; \; p_2 = \frac{2c_f \quad 1}{1 + 2c_f};$$

$$\tilde{n}_f = \frac{T_f}{T_0}; c_i = \frac{T_0}{T_i}; \qquad (2)$$

$$c_d = \frac{T_D}{T_0}$$

$$T_f = \frac{T_D}{\alpha}; \mathrm{Kp} = 0.6\mathrm{Kpu}; \mathrm{T_I} = 0.5\mathrm{Tu}; \mathrm{T_D} = 0.125\mathrm{Tu}, \quad (3)$$

where K_{Pu}- ultimate gain, T_u- ultimate period respectively, T_0- period of surveys controller, T_D – time constant of differentiation, T_I – time constant of integration, ∝ - filtration coefficient (where usually $3 < \propto < 20$). The coefficients c_f, c_i, c_d – enter for easy image formulas [16].

Ziegler-Nichols PID controller for processes of second order (ZN2FR). Controller is based on forward rectangular method of discretization. Control law [16]

$$u_k = K_p\left[e_k - e_{k-1} + \frac{T_0}{T_I} e_{k-1} + \frac{T_D}{T_0}\left(e_k - 2e_{k-1} + e_{k-1}\right)\right] + u_{k-1}, \quad (4)$$

where e_k - control error ($e_k=w_k-y_k$). This form of control law can be transformed to feedback form

$$u_k = q_0 e_k + q_1 e_{k-1} + q_2 e_{k-2} + u_{k-1}. \quad (5)$$

Controller parameters are calculated using following equations

$$q_0 = K_p\ (1 + \frac{T_D}{T_0});$$

$$q_1 = -K_p(\ 1 - \frac{T_0}{T_I} + 2\frac{T_D}{T_0}); \quad (6)$$

$$q_2 = K_p \frac{T_D}{T_0};$$

$$Kp = 0.6K_P u; T_I = 0.5Tu; T_D = 0.125Tu, \quad (7)$$

where K_{Pu}- ultimate gain, T_u- ultimate period respectively, T_0- period of surveys controller, T_D – time constant of differentiation, T_I – time constant of integration [16].

Ziegler-Nichols PI controller for processes of second order. Controller is based on trapezoidal method of discretization (ZN2PI). Control law [16]

$$u_k = K_p\left[e_k - e_{k-1} + \frac{T_0}{T_I} * \frac{e_k + e_{k-1}}{2}\right] + u_{k-1}, \quad (8)$$

where e_k - control error ($e_k=w_k-y_k$). This form of control law can be transformed to feedback form

$$u_k = q_0 e_k + q_1 e_{k-1} + u_{k-1}. \quad (9)$$

Controller parameters are calculated using following equations

$$q_0 = K_p\left(1 + \frac{T_0}{2T_I}\right); q_1 = -K_p\left(1 - \frac{T_0}{2T_I}\right), \quad (10)$$

$$Kp = 0.6K_P u; T_I = 0.5Tu$$

where K_{Pu} - ultimate gain, T_u- ultimate period respectively, T_0 - period of surveys controller, T_I – time constant of integration [16].

All mentioned transient processes of adaptive controllers are represented on one diagram and shown on the fig.4.

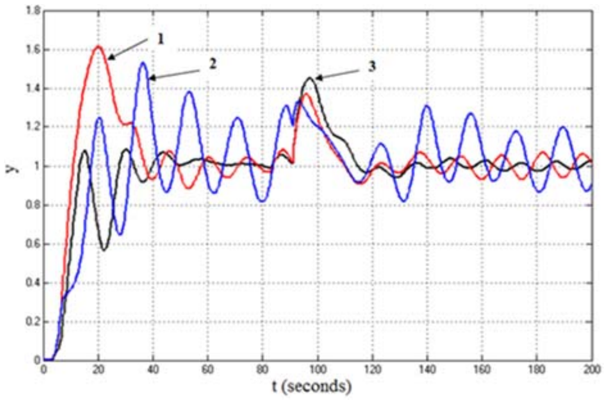

Figure 4. The example of the work of the controller with the changing of the system parameters during the functioning: 1-ZN3FD, 2 – ZN2FR, 3 – ZN2PI

Ziegler-Nichols controllers for the third-order processes with the D-component filtration and using Tustin approximation, Ziegler-Nichols PID controller for processes of second order (controller is based on forward rectangular method of discretization), Ziegler-Nichols PI controller for processes of second order (controller is based on trapezoidal method of discretization) were used to control the process of the degradation of ore raw material technological variations in the ball mill. The demonstrative results of the modelling are shown in the table 1.

Table 1. The comparison of control quality indexes using the adaptive controllers

Type controller	Values of the coefficients	t transient processes	б overshoot	h set value
1	2	3	4	5
ZN3FD	K1-0.35 K3-1;	69.5	16.7	1.004
ZN3FD	K1-0.35; K3-2;	91.1	29.8	1.005
ZN2FR	K1-0.35; K3-1;	85	53.7	1.006
ZN2FR	K1-0.35; K3-2;	146	70.4	1.006
ZN2PI	K1-0.35; K3-1;	66.9	48.4	0.9966
ZN2PI	K1-0.4; K3-1;	51.8	74.1	0.8872

After the number of researches we have defined that Ziegler-Nichols adaptive controller is most appropriate controller for the ball mill filling automatic control system for the third stage processes with D-component filtration and using Tustin approximation. This controller provides the following results: the overshoot – 16.7, the period for transient process installation – 69.5 seconds (fig.5).

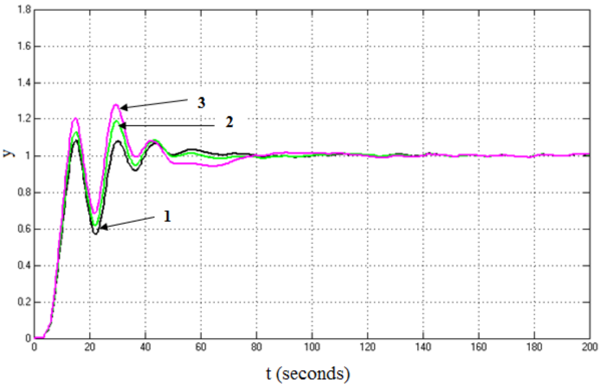

Figure 5. The transient process of Ziegler-Nichols controller for the third-order processes with the D-component filtration and using Tustin approximation with various values of K1 and K3: 1 – minimum value, 2 – medium value, 3 – maximum value

Therefore the using of this controller is well-taken in the view of better quality of the required class in the waste holeof the mill.

Conclusions. The Ziegler - Nichols controller for the third - order processes with the D-component filtration and using Tustin approximation is the most appropriate controller for mill control. In the presence of the required class in the waste hole it increases the work of the mill by 0.01%-0.81%, which is better than the classical PID controller. The improvement of the control processes of the iron-ore degradation with due regard for the multidimensionality of the real objects is the main course of the further investigations. The further analysis is dedicated to the construction of the multi-channel systems of adaptive control of the technological processes of the iron-ore degradation in the conditions of mining factories.

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