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# SELF-ADJUSTING FILLING CONTROL SYSTEM FOR SELF-GRINDING DRUM MILLS

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# САМОНАСТРОЮЮЧА СИСТЕМА УПРАВЛІННЯ ЗАПОВНЕННЯМ БАРАБАННИХ МЛИНІВ САМОПОДРІБНЕННЯ

**Purpose of work** is an improvement of the controlling efficiency for the processes of self-grinding ores in drum mills by using adaptive settings for the perimeters of the control part of the system.

**Methodology.** For the self-grinding process, the degree of filling of the mill drum is a critical technological variable, i.e. this parameter not only has a direct impact on the efficiency of the grinding unit in terms of the newly formed finished product, but also determines the trouble-free operation of the mill. It is known from the referenced literature that during the decay time of the autocorrelation function for the processes of original ore's main characteristics change is on the order of several hours or more. At the same time, the inertia of the crushed aggregate is measured in tens of minutes. Under such conditions, one should assume that quasi-stationarity and the rational use of the control system for a wide scope of self-grinding take place.

**Research results.** Using the method of auxiliary operators, the law for setting the parameters of the main circuit of the self-adjusting system was generated, and the block diagrams of the adaptive control system for filling ore self-grinding mills were determined. The transient processes in the control system are calculated, which proves the expediency and effectiveness of the proposed approach.

**Scientific novelty.** A new approach is proposed using an adaptive control system to regulate the degree of filling of autogenous ores mills, based on the use of the method of auxiliary operators.

**Practical significance.** While calculating the tuning processes in the control system for the filling degree of the mill, it was found that even with a simultaneous abrupt change in the object's parameters $K_0$, $T_1$ ,$T_2$ to the maximum value, the adaptive system completes tuning the parameters of the controller $C_1$, $C_2$, $C_3$ for a time of about 230 ÷ 270 minutes, which indicates the practical feasibility and effectiveness of this approach to control the filling level of ore self-grinding mills.

***Keywords:*** *adaptive system, self-grinding ores, drum mill, self-tuning circuit, sensitivity function, method of auxiliary operators, technological variable, control system, self-adjusting system.*

**Topic relevance**. It is a well-known fact that the main part of all capital and operating costs in the enrichment of ores falls on the grinding process. This fact indicates that the control actions, applied to the grinding unit, to the greatest extent affect the final economic performance of the enrichment production and, therefore, determine the relevance of the tasks of optimizing the grinding control.

**Problem formulation.** For the self-grinding process, the degree of filling of the mill drum is a critical technological variable, i.e. this parameter not only has a direct impact on the efficiency of the grinding unit in terms of the newly formed finished product [1], but also determines the trouble-free operation of the mill. At the same time, any change in the feed properties (fineness, physical and mechanical parameters) directly affects the rate of reduction in the size of the material in the grinding zone and causes a change in the degree of filling of the autogenous grinding mill.

**Problem setting.** It is known from the referenced literature that during the decay period of the autocorrelation function of the processes of changing the main characteristics of the original ore supplied for grinding is on the order of several hours or more. At the same time, the inertia of the grinding unit is measured in tens of minutes. Under such conditions, it should be assumed that the conditions of quasi-stationarity are satisfied, and it is advisable to use an adaptive control system for the degree of filling of the autogenous grinding mill [2].

**Problem investigation.** Let us consider a local system for stabilizing the filling of the mill at the set level $\varphi_{set}$ by controlling the feed of the initial material (Fig. 1).

In this case, we will assume that the calculation of the value of $\varphi_{set}$ is performed by a system of a higher level of the hierarchy.

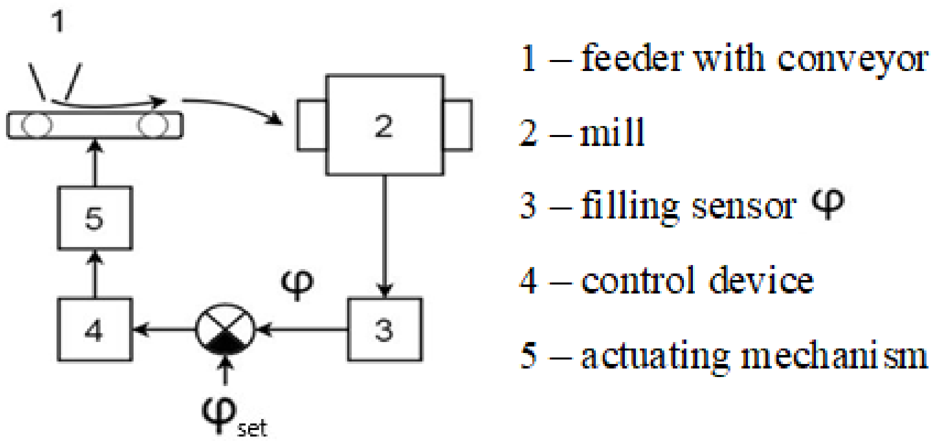


Fig. 1. Functional diagram of the system for stabilizing the filling of the mill.

The self-grinding mill with a feeder as an object of control of the OC can be represented as an inertial link of the second order [3]. Then it is advisable to use the PID-controller as the main loop controller and the structure of the main control loop will correspond to Fig. 2a.

In the transfer function of the controller:

$$W_{ctr}(p) = K_1 + K_2 p^{-1} + K_3 p = \frac{K_1 p + K_2 + K_3 p^2}{p} = K_2\left(\frac{K_3}{K_2}p^2 + \frac{K_1}{K_2}p + 1\right)p^{-1}$$

let us denote: $K_3/K_2 = C_1$; $K_1/K_2 = C_2$; $K_2 = C_3$.

Then the transfer function of the open main control loop will have the form:

$$W_{main}(p) = W_{contr}(p)\cdot W_{oc}(p) = \frac{K_0 C_3\left(C_1 p^2 + C_2 p + 1\right)}{p\left(T_1 p^2 + T_2 p + 1\right)}, \quad (1)$$

and the block diagram will correspond to Fig. 2b.

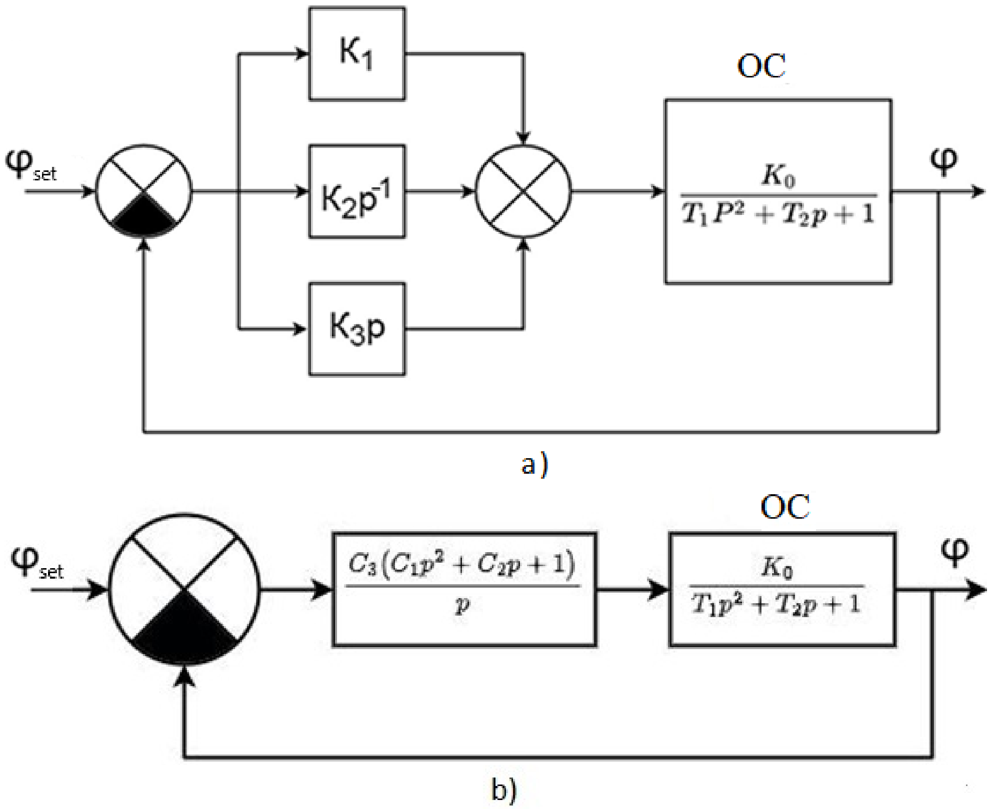


Fig. 2. Structural diagrams of the main circuit of the control system

Under fulfilling the equalities $C_1 = T_1$; $C_2 = T_2$ the expression (1) takes simpler form:

$$W_{main}(p) = \frac{K_0 C_3}{p}.$$

Then the transfer function of the closed main loop corresponds to an aperiodic link with a time constant $(K_0 \cdot C_3)^{-1}$:

$$\Phi(p) = \frac{W_{main}(p)}{1 + W_{main}(p)} = \frac{K_0 C_3}{p + K_0 C_3} = \frac{1}{(K_0 C_3)^{-1} \cdot p + 1}.$$

Let the desired inertia of the main closed circuit of the system be determined by the parameter $\alpha$, i.e. time constant $\alpha^{-1}$. Then the goal of self-tuning of the adaptive system will be to maintain the equalities:

$$\begin{gathered} C_1 = T_1 \\ C_2 = T_2 \\ K_0\, C_3 = \alpha \end{gathered} \tag{2}$$

It should be noted that the desired value of the parameter α will be limited in real conditions by the technical possibilities for implementing the limiting values of the control action on the object, which in this real system is the flow of material into the mill.

Obviously, this parameter cannot exceed a certain limit value and cannot be negative.

An enlarged block diagram of an adaptive self-adjusting system with a reference model (RM) for the purpose of self-adjustment (2) is shown in Fig. 3

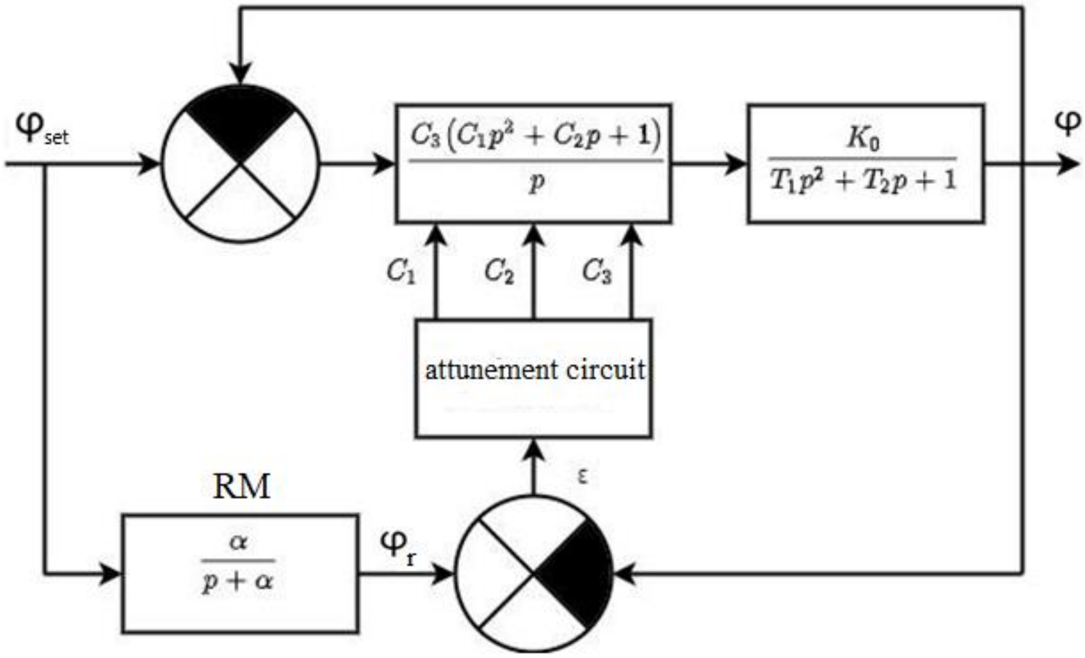


Fig. 3. An enlarged block diagram of an adaptive system.

The self-tuning criterion is chosen as the square of the discrepancy between the desired $\varphi_r(t)$ and the actual $\varphi(t)$ processes of changing the level of filling:

$$I = \frac{1}{2}\varepsilon^2 = \frac{1}{2}(\varphi_r - \varphi)^2 \tag{3}$$

The controller parameters are adjusted according to the gradient law:

$$\frac{dC_i}{dt} = -\gamma_i \frac{\partial I}{\partial C_i}; \quad i = 1, 2, 3, \tag{4}$$

where $\gamma_i$ is a coefficient determining the speed of setting the corresponding parameter $C_i$. It should be taken into account that if the value of $\gamma_i$ is too high, the system may lose its stability.

Taking into account (3) the expression (4) can be written as follows:

$$\frac{dC_i}{dt} = -\gamma_i \frac{\partial I}{\partial \varepsilon} \cdot \frac{\partial \varepsilon}{\partial C_i} = -\gamma_i \varepsilon \frac{\partial(\varphi_r - \varphi)}{\partial C_i}; \quad i = 1, 2, 3.$$

Reference model output $\varphi_r$ does not depend on the controller parameters $C_i$. Therefore we have:

$$\frac{dC_i}{dt} = \gamma_i \varepsilon \frac{\partial \Phi(p, c)}{\partial C_i} \varphi_{set}; \quad i = 1, 2, 3. \tag{5}$$

Now the task is to determine the sensitivity functions $\partial \Phi(p, c) / \partial C_i$ [4 – 8]. If conditions (2) are violated, the transfer function of the closed main loop will be equal to:

$$\Phi(p,c) = \frac{K_0 C_3 \left(C_1 p^2 + C_2 p + 1\right)}{p\left(T_1 p^2 + T_2 p + 1\right) + K_0 C_3 \left(C_1 p^2 + C_2 p + 1\right)}$$

and sensitivity functions will have a following form:

$$\frac{\partial \Phi(p,c)}{\partial C_1} = \frac{K_0 C_3 p^3 \left(T_1 p^2 + T_2 p + 1\right)}{\left[p\left(T_1 p^2 + T_2 p + 1\right) + K_0 C_3 \left(C_1 p^2 + C_2 p + 1\right)\right]^2}$$

$$\frac{\partial \Phi(p,c)}{\partial C_2} = \frac{K_0 C_3 p^2 \left(T_1 p^2 + T_2 p + 1\right)}{\left[p\left(T_1 p^2 + T_2 p + 1\right) + K_0 C_3 \left(C_1 p^2 + C_2 p + 1\right)\right]^2}$$

$$\frac{\partial \Phi(p,c)}{\partial C_3} = \frac{K_0 p \left(C_1 p^2 + C_2 p + 1\right)\left(T_1 p^2 + T_2 p + 1\right)}{\left[p\left(T_1 p^2 + T_2 p + 1\right) + K_0 C_3 \left(C_1 p^2 + C_2 p + 1\right)\right]^2}$$

When the self-tuning conditions (2) are met, the expressions for the sensitivity functions are simplified:

$$\begin{aligned} \frac{\partial \Phi(p,c)}{\partial C_1} &= \frac{\alpha p^3}{(p+\alpha)^2} \frac{1}{\left(C_1 p^2 + C_2 p + 1\right)} \\ \frac{\partial \Phi(p,c)}{\partial C_2} &= \frac{\alpha p^2}{(p+\alpha)^2} \frac{1}{\left(C_1 p^2 + C_2 p + 1\right)} \\ \frac{\partial \Phi(p,c)}{\partial C_3} &= \frac{\alpha p}{C_3 (p+\alpha)^2} \end{aligned} \quad (6)$$

Taking into account sensitivity functions from (6) the law of setting the parameters of the regulator of the main circuit has the following form:

$$\begin{aligned} \frac{dC_1}{dt} &= \gamma_1 \varepsilon \frac{\alpha p^3}{(p+\alpha)^2} \frac{1}{\left(C_1 p^2 + C_2 p + 1\right)} \varphi_{set} \\ \frac{dC_2}{dt} &= \gamma_2 \varepsilon \frac{\alpha p^2}{(p+\alpha)^2} \frac{1}{\left(C_1 p^2 + C_2 p + 1\right)} \varphi_{set} \end{aligned} \quad (7)$$

$$\frac{dC_3}{dt} = \gamma_3 \varepsilon \frac{\alpha p}{C_3 (p+\alpha)^2} \varphi_{set}$$

Expressions (7) determine the structure of the self-tuning loop and, therefore, the block diagram of the entire adaptive system (Fig. 4).

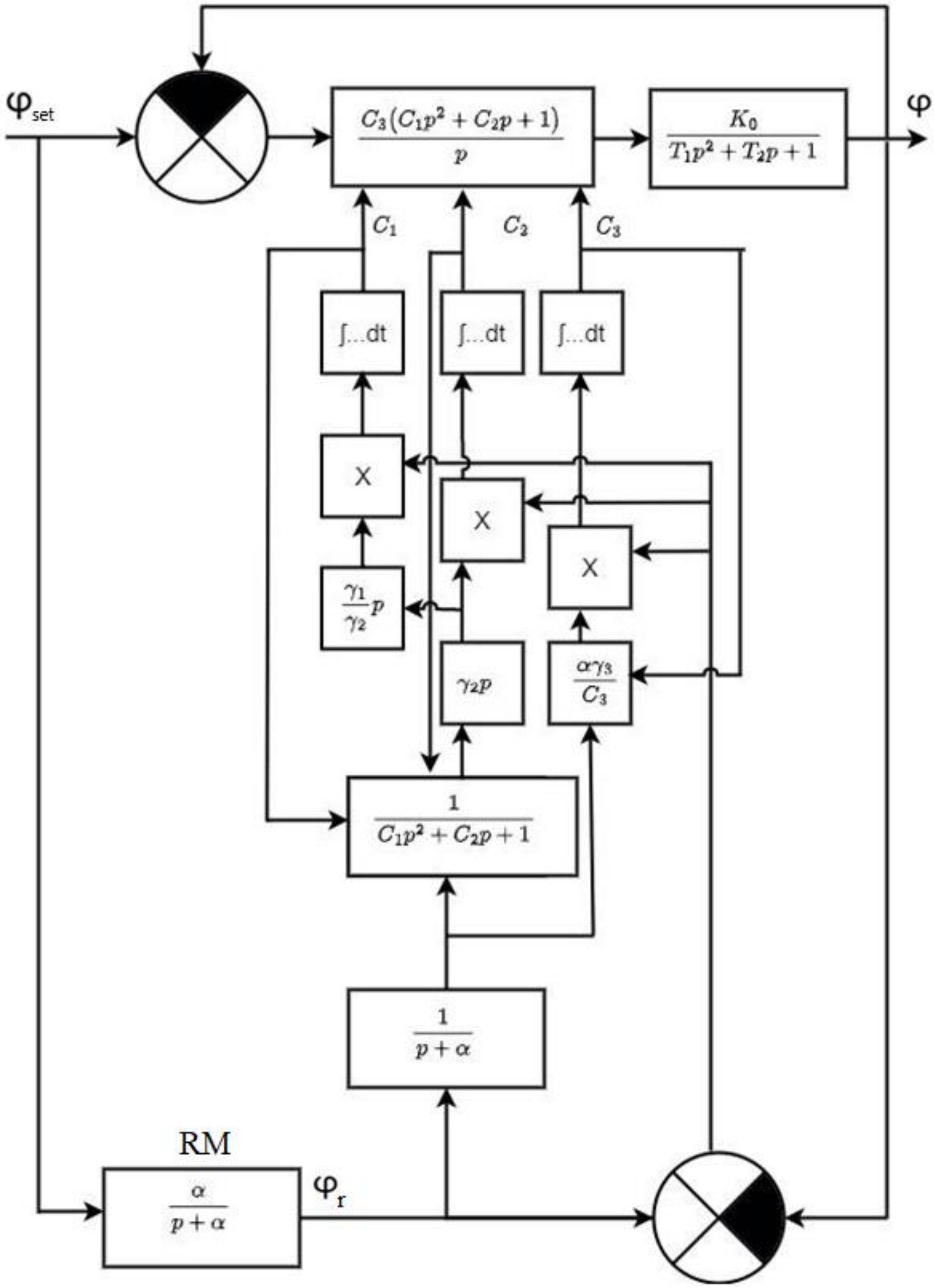


Fig. 4. Structural diagram of an adaptive mill filling control system.

The calculation of transition process in the main circuit, as well as the processes of setting the parameters of the controller $C_1$, $C_2$, $C_3$ when changing the parameters of the control object $K_0, T_1, T_2$ was performed by a numerical method $\Delta t$.

The changes in the parameters of the object were carried out by a shift in the range of $\pm 20\%$ of the nominal values, which corresponds to real conditions. The main task of the calculations was to determine the optimal values of the parameters $\gamma_1, \gamma_2, \gamma_3$, under which the tuning speed $C_1$, $C_2$, $C_3$ will be maximized.

**Results and conclusions**. While calculating the tuning processes in the system of Fig. 4, it was established that even with simultaneous abrupt shifts in the object's parameters $K_0$, $T_1$, $T_2$ by the maximum value, the adaptive system completes the tuning process of the controller's parameters $C_1$, $C_2$, $C_3$ in a time of about $230 \div 270$ min, which indicates the practical feasibility and effectiveness of given approach, to control the filling level of the mills.

## References


1. Novitsky, I.V. (2000). *Automatic optimization of ore self-grinding processes in drum mills.* System Technologies.
2. Novitskyi, I., Sliesariev, V., & Maliienko, A. (2021). The basic principles of organizing prospecting procedures for managing the process of autogenous grinding of ores in drum mills. *Collection of Research Papers of the National Mining University*, *66*, 245–253. https://doi.org/10.33271/crpnmu/66.245
3. Maruta, A.N. (1991). *The theory of simulation of oscillations of the working bodies of mechanisms and its applications*. Dnipropetrovsk state University.
4. Novitsky, I.V., & Us, S.A. (2017). *Modern theory of healing: textbook for universities*. National Mining University.http://ir.nmu.org.ua/handle/123456789/150797
5. Sokur V.I., Bileskiy V.S., Vidmid I.O., & Robota E.M. (2020). *Ore preparation: fragmentation, grinding, debit card.* Kremenchuk.
6. Popovych M. G., & Kovalchuk O. V. (2007). *Theory of automatic control*. Kyiv.
7. Novitskiy I., & Shevchenko Y. (2018). Method of extreme control for ore self-crushing mills. *Contemporary Innovation Technique of the Engineering Personnel Training for the Mining and Transport Industry 2017 (CITEPTMTI'2017), 1*(4), 207-211. https://ir.nmu.org.ua/handle/123456789/156579
8. Novitskiy, I.V., & Shevchenko, Y. O. (2000). Adaptive loading control system for AG drum mills. *Collection of Research Papers of the National Mining University, 44*, 103–109. http://ir.nmu.org.ua/handle/123456789/152406


## АНОТАЦІЯ


**Метою цієї роботи** є підвищення ефективності управління процесами самоподрібнення руд у барабанних млинах шляхом застосування адаптивних алгоритмів налаштування периметрів керуючої частини системи.

**Методика дослідження.** Для процесу самоподрібнення руди ступінь заповнення барабана млина є критичним технологічної змінної, тобто, цей параметр не тільки надає безпосередній вплив на ефективність роботи подрібнювального агрегату в сенсі новоствореного готового продукту, а й визначає безаварійну роботу млина самоподрібнення. З довідкової літератури відомо, що час спаду автокореляційної функції процесів зміни основних характеристик вихідної руди, що надходить на подрібнення, має порядок кілька годин і більше. У той самий час інерційність подрібнювального агрегату вимірюється десятками хвилин. У таких умовах слід

припускати виконання умов квазістаціонарності та доцільне застосування адаптивної системи управління ступенем заповнення млина самоподрібнення.

**Результати дослідження.** Методом допоміжних операторів згенеровано закон налаштування параметрів основного контуру системи, що самоналаштовується, а також визначено структурні схеми адаптивної системи управління заповненням млинів самоподрібнення руд. Розраховано перехідні процеси в системі управління, які свідчать про доцільність та ефективність запропонованого підходу.

**Наукова новизна.** В роботі пропонується новий підхід з використанням адаптивної системи керування для регулювання ступеня заповнення млинів подрібнення руд, заснований на застосуванні методу допоміжних операторів.

**Практична значимість.** У ході розрахунків процесів налаштування в системі керування ступенем заповнення млином було встановлено, що навіть при одночасному стрибкоподібному зміні параметрів об'єкта $K_0$, $T_1$, $T_2$ на максимальну величину, адаптивна система закінчує процес налаштування параметрів регулятора $C_1$, $C_2$, $C_3$ за час порядку 230 ÷ 270 хвилин, що свідчить про практичну доцільність та ефективність застосування даного підходу для регулювання ступеня заповнення млинів подрібнення руд.

***Ключові слова:*** *адаптивна система, барабанний млин, самоподрібнення руд, контур самоналаштування, контур управління, функція чутливості, метод допоміжних операторів.*