The adaptive control for intensity of ultrasonic influence on iron ore pulp

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Abstract
A method for the intensity control of the high-energy ultrasound influence on the iron ore pulp using Lyapunov and gradient methods based on MRAC system is described.
Key words: HIGH-ENERGY ULTRASOUND, PULP, CONTROL, MRAC, INTENSITY

The fluctuations of the feedstock characteristics and condition of the technological equipment, as well as changes in the reference value in the closed loop automatic control systems (ACS) cause the transient processes, during which the particle size distribution of output products of grinding and classifying aggregates varies widely. This leads to additional losses of useful components.

The duration of transient processes depends on how accurately the current state of the control object (its static and dynamic characteristics) corresponds to the controller settings in the ACS. This implies the need for periodic adjustment of controller parameters. It is best implemented in adaptive ACS. In [1-8] and the other the various algorithmic and technical approaches for constructing of the technological processes adaptive control are proposed. However, the most effective advantages of adaptive ACSs can be realized only considering the characteristics of a specific control object and their means of information support. The promising direction for effective beneficiation process control is the high-energy ultrasonic influence with a given intensity to the pulp flow.

The purpose is the adaptive control formation for the intensity of high-energy ultrasound influence on the iron ore pulp based on model reference adaptive control system.

Model reference adaptive control (MRAC) system diagram is shown in Fig. 1. This system has an internal feedback loop consisting of the control object and the controller, and an external feedback loop to adjust the control parameters. Parameters vary basing on mismatch errors between the output of the system – the actual intensity I_{act}, and the output of the reference model - a reference intensity, I_{ref}. Let's consider two separate parameterization mechanisms [9]. The first mechanism is based on the Lyapunov stability theory and gives a regulatory mechanism, which guarantees the stability of the adaptive system with feedback. The second mechanism is based on the gradient method [10] for tuning controller parameters.

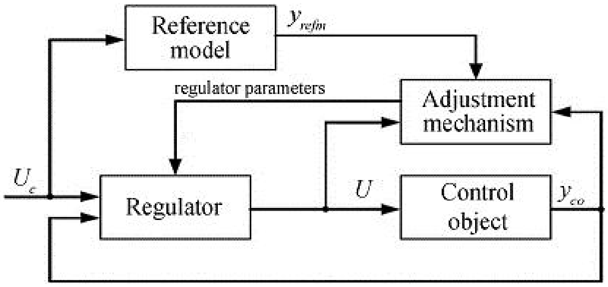

Figure 1. A block diagram of the MRAC system

Let's consider the Model Reference Adaptive Controll (MRAC). For the model reference adaptive control formation let's represent the process of high-energy ultrasonic influence on iron ore pulp using a state space model, which can be represented as follows [11]

$$x(k+1) = Ax(k) + Bu(k), \qquad (1)$$

where *x(k)* – $n \times 1$ – is the state vector (intensity); $u(k)$ – $m \times 1$ – is the vector determining the amplifier power; *A* – $n \times n$ is the system matrix comprising a conductivity terms and the pulp flow rate, *B* – $n \times m$ input matrix, which represents the effect of power *m*.

It is desirable that ultrasonic influence closed loop response *x(k)* corresponds to an response $x_m(k)$ of the reference model, which can be represented as follows

$$x_m(k+1) = A_m x_m(k) + B_m u_c(k), \qquad (2)$$

where $x_m(k)$ – is the state vector representing the intensity of the model; $u_c(k)$ – is the input vector defining the command input into the model. The polinomials A_m and B_m – is the model state matrix and input matrix.

The MRAC system inner loop uses a common linear adjustment, which can be represented as follows:

$$u(k) = M(\theta) \cdot u_c(k) - L(\theta)x(k), \qquad (3)$$

where *M* and *L* – is the gain controlling matrices with adjustable parameters of θ. Considering (1) – (3) the MRAC internal circuit dynamic model can be represented as follows

$$x(k+1) = (A - BL(\theta))x(k) + BM(\theta)u_c(k) = A_c(\theta)x(k) + B_c(\theta)u_c(k), \qquad (4)$$

Let's suppose that *e* – the error between the *y* output from the closed-loop system and y_{ref} model access. To minimize the error of *e*, the θ parameters were adjusted so that the function

$$J(0) = \frac{1}{2}e^2, \qquad (5)$$

was minimal.

As noted, there are two methods for the θ parameter adjustment. Consider first the gradient method, for which we will set the parameters in the direction of the negative gradient of J in the following form

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial\theta} = -\gamma e\frac{\partial e}{\partial\theta}, \qquad (6)$$

where γ – is the adaptation gain.

The relationship between variable of θ and the weight function is as follows

$$J(\theta) = |e(\theta)|$$

$$\frac{d\theta}{dt} = -\gamma\frac{\partial e}{\partial\theta\cdot c}sign(e), \qquad (7)$$

where $sign(e) = \begin{cases} 1, e > 0 \\ 0, e = 0 \\ -1, e < 0 \end{cases}$

Considering (5), let’s define a control law for the system *Y(s)/U(s) = kG(s),* where *k* is unknown. It is necessary that the expression take the following form *$Y(s)/U_c(s) = k_0G(s)$* using the object of control $G_{refm}(s) = k_0G(s)$.

Let’s choose the weight function

$$J(0) = \frac{1}{2}e^2(\theta) \rightarrow \frac{d\theta}{dt} = -\gamma e\frac{\partial e}{\partial\theta}, \qquad (8)$$

and write the equation for the error

$$e = y - y_{refm} = kGU - G_{refm}U_c = kG\theta U_c - k_0GU_c$$

(9)

The “sensitivity” derivatives calculation can be represented as follows

$$\frac{\partial e}{\partial\theta} = kGU_c = \frac{k}{k_0}y_{refm}, \qquad (10)$$

Considering (6) we obtain the adaptive control algorithm

$$\frac{\partial\theta}{\partial t} = -\gamma'\frac{k}{k_0}y_{refm}e = -\gamma y_{refm}, \qquad (11)$$

The dynamics approximation of the pulp ultrasonic treatment process as a second order system and the application of the gradient method gives the parameterization law, which can be represented as follows

$$\theta_1(k+1) = \theta_1(k) - \gamma\left(\frac{q}{q^2 + a_{m1}q + a_{m2}}U_c\right)e(k+1)$$

$$\theta_2(k+1) = \theta_2(k) - \gamma\left(\frac{q}{q^2 + a_{m1}q + a_{m2}}U_c\right)e(k+1)$$

$$\theta_3(k+1) = \theta_3(k) - \gamma\left(\frac{q}{q^2 + a_{m1}q + a_{m2}}U_c\right)e(k+1)$$

$$\theta_4(k+1) = \theta_4(k) - \gamma\left(\frac{q}{q^2 + a_{m1}q + a_{m2}}U_c\right)e(k+1)$$

(12)

The mathematical modeling results of automatic stabilization adaptive system for the intensity of ultrasonic influence on iron ore pulp is presented on Fig.2.

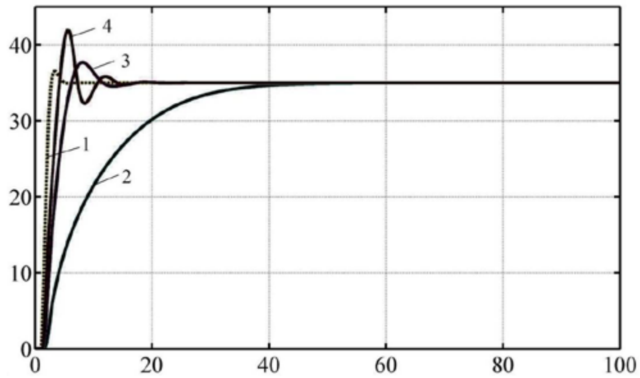

Figure 2. Mathematical modeling results of intensity control for different gains of γ: 1 – reference value; 2 – $\gamma = 0{,}0001$; 3 – $\gamma = 0{,}001$; 4 – $\gamma = 0{,}01$

Coclusions. The formation of the ultrasonic oscillations intensity automatic control using Lyapunov and gradient methods based on MRAC system led to the following conclusions. The method based on MRAC shows high speed transition process, small overshoot, and a slight mismatch.

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