THE PROBLEM OF OPTIMAL CONTROL OF PROCESSES OF ORE SIZE REDUCTION

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Minerals at concentrating factories undergo a series of sequential processing, which can be divided into three groups according to their purposes in the technological cycle of the factory: preparatory, properly concentrating and supporting. Preparatory processes include crushing, grinding, screening and classification, during which separation of minerals and division of the processed mineral into categories by size take place, which is necessary for successful implementation of concentration. The processes of crushing and particularly grinding are very energy-consuming. At concentration factories these processes consume more than half of the energy consumed. Therefore, an urgent problem is to find the optimal mode of getting the final product with minimal energy costs.

The issue of optimization and control is based on the study of the models of major technological processes. Despite a multitude of all the processes at concentrating factories, there are generally considered the standard ones: material transportation, concentration change, and change in material size. These processes can be described by the first and the second order differential equations with good approximation. For example, the following equation can be used for the transport system:

$$F\frac{\partial x}{\partial t} = -Q\frac{\partial x}{\partial l};$$

This one can be used to describe concentration changes of a certain size category in an ideal mix:

$$V\frac{dx}{dt} = Q(x - x_0).$$

If one considers material size as content of a certain size category, then the process of size change can be regarded as analogous to the process of concentration change. The mechanism of ore grinding in a mill is characterized by the second order equation:

$$T_0^2\frac{\partial^2 x}{\partial t^2} + T_1\frac{\partial x}{\partial t} + x = x_0,$$

wherein $x-$ is content of the i^{th} size category;

$\frac{dx}{dt}$ – is grinding speed; $\frac{d^2x}{dt^2}$ – is grinding slowdown.

The grinding process is generally described with the help of equations, which tie content of the ready category in the derived product with duration of grinding, and physical and mechanical characteristics of ore.

To formulate the problem of optimal control, let us move to Cauchy equations in the normal form:

$$\dot{\bar{x}} = f(\bar{x}, \bar{u}, t).$$

As the original equation is normally of the second order, then the state vector $\bar{x}$ will also be of the second order. If we consider that x – is content of the i[th] size category, then $x_1 = x$, $x_2 = \dot{x}_1$.

Thus, the model in the state space will look like:

$$\dot{x}_1 = x_2,$$

$$\dot{x}_2 = \frac{x_0}{T_0} - \frac{x_1}{T_0} - \frac{T_1}{T_0} x_2.$$

Boundary conditions are: $t = 0$, $x = x_0$, $x(t_f) \in x_f$, $x_f = x_{-0.074}$, where t_f – time, during which size reduction takes place; x_f – limit of the size category. Quality requirements can be formulated in the form of restrictions on the state vector components.

Analysis of physical and mathematical models makes it possible to obtain the following dependences

$$\dot{x}_1 = f_1(x_1, x_2, E, Q, t),$$

$$\dot{x}_2 = f_2(x_1, x_2, E, Q, t),$$

where E – is energy expended during grinding; Q – is ore consumption.

The problem of selecting the optimal control criterion has been considered by many authors, but an unambiguous solution has not been obtained. On the one hand, in terms of energy saving it is an important criterion to minimize energy consumption. On the other hand, studies have shown that economic indicators are determined by maximization of the output of the finished product of the specified quality and, consequently, ore consumption. Thus, from the point of view of solution of the set problems, it is advisable to use two optimality criteria:

$$E \to \min, \; Q \to \max .$$

The set problem is solved by Bellman's dynamic programming method.

References:

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