Formalization and frequency analysis of robust control of ore beneficiation technological processes under parametric uncertainty

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Abstract
A method of the robust control system formalization of ore beneficiation technological processes on the example of wet magnetic separation is proposed. The control system frequency analysis under parametric uncertainty of the control object is also performed.

Keywords: ORE BENEFICIATION AUTOMATION, ROBUST CONTROL, FREQUENCY ANALYSIS

The mineral processing is currently focusing on the optimization of technological processes. This approach requires qualitative information about the process, formation the corresponding database, and their subsequent processing for the construction of adequate and effective mathematical models of processes and systems [1-10].

Technological aggregates of concentrating plant as a control object are described with sufficient accuracy by transfer functions of the first and second order with delay [1, 2]. The paper presents an approach according to which the main control action - is the ore flow rate as well the controlled indicator – is the iron content in the concentrate and tailings. In general, the transfer function of wet magnetic separation without net delay has the form [2]

$$W_{MS}(p) = \frac{K_{MS}}{(T_{MS1}p+1)(T_{MS2}p+1)} \qquad (1)$$

where K_{MS}=0,1 – is the gain; T_{MS1}=2, T_{MS2}=4 – are the time constants.

However, during operation there is a change of technological units parameters, and thus the object response on the certain control action is changing. The parametric uncertainty of the control object has a significant impact on the quality and accuracy of control [4-10]. After the inverse Laplace transform we get

$$\mu \frac{d^2x(t)}{dt^2} + \theta\frac{dx(t)}{dt} + \kappa x(t) = u(t) \qquad (2)$$

Since in a real beneficiation process control system the model parameters $\bar{\mu}$, $\bar{\theta}$, $\bar{\kappa}$ does not known exactly, let's assume that their values can deviate from the nominal values for the corresponding values: $p_\mu=p_\theta=p_\kappa$=0,2; $-1\le\delta_\mu,\delta_\theta,\delta_\kappa\le1$, which are determined, including the characteristics of the processed iron ore raw materials. The influence of the uncertainty of the control object model parameters on the quality of the transition process is shown in Fig. 1

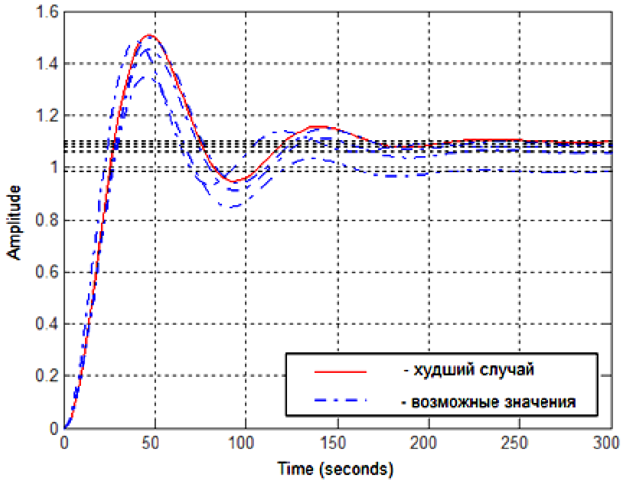

Figure 1. The family of the control object transition functions

Considering the uncertainty of the parameters μ, θ, κ it is advisable to present them in the form of two blocks obtained by using a linear fractional transformations and connecting the respective blocks δ_μ, δ_θ, δ_κ from the top [11,12], for which the next conversion should be performed

$$\frac{1}{\bar{\mu}} = F_U(M_\mu, \delta_\mu) = \frac{1}{\bar{\mu}(1+p_\mu\delta_\mu)} = \frac{1}{\bar{\mu}} - \frac{p_\mu}{\bar{\mu}(1+p_\mu\delta_\mu)}$$

(3)

where

$$M_\mu = \begin{bmatrix} -p_\mu & (\bar{\mu})^{-1} \\ -p_\mu & (\bar{\mu})^{-1} \end{bmatrix} \qquad (4)$$

Similarly, the next conversion is performed $\bar{\theta} = F_U(M_{\theta i}, \delta_\theta)$; $\bar{\kappa} = F_U(M_\kappa, \delta_\kappa)$, where

$$M_\theta = \begin{bmatrix} 0 & \bar{\theta} \\ p_\theta & \bar{\theta} \end{bmatrix}, \quad M_\kappa = \begin{bmatrix} 0 & \bar{\kappa} \\ p_\kappa & \bar{\kappa} \end{bmatrix}. \qquad (5)$$

Considering the performed transformations the parameters blocs output signals with the model uncertainty of the first stage of iron ore raw materials grinding can be written as [11]

$$\begin{bmatrix} y_\mu \\ x'' \end{bmatrix} = \begin{bmatrix} -p_\mu & 1/\bar{\mu} \\ -p_\mu & 1/\bar{\mu} \end{bmatrix} \begin{bmatrix} u_\mu \\ u - v_\theta - v_\kappa \end{bmatrix}; \qquad (6)$$

$$\begin{bmatrix} y_\theta \\ v_\theta \end{bmatrix} = \begin{bmatrix} 0 & \bar{\theta} \\ p_\theta & \bar{\theta} \end{bmatrix} \begin{bmatrix} u_\theta \\ x' \end{bmatrix}; \qquad (7)$$

$$\begin{bmatrix} y_\kappa \\ v_\kappa \end{bmatrix} = \begin{bmatrix} 0 & \bar{\kappa} \\ p_\kappa & \bar{\kappa} \end{bmatrix} \begin{bmatrix} u_\kappa \\ x \end{bmatrix}, \qquad (8)$$

Where $u_\mu = \delta_\mu y_\mu$, $u_\theta = \delta_\theta y_\theta$, $u_\kappa = \delta_\kappa y_\kappa$. After replacing $x_1=x$, $x_2=x'$, $y=x_1$ and eliminating the variables v_c and v_κ we obtain

$$\begin{bmatrix} x_1' \\ x_2' \\ y_\mu \\ y_\theta \\ y_\kappa \\ y \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ -\overline{\kappa}/\overline{\mu} & -\overline{\theta}/\overline{\mu} & -p_\mu & -\overline{p_\theta}/\overline{\mu} & -\overline{p_\kappa}/\overline{\mu} & 1/\overline{\mu} \\ -\overline{\kappa}/\overline{\mu} & -\overline{\theta}/\overline{\mu} & -p_\mu & -\overline{p_\theta}/\overline{\mu} & -\overline{p_\kappa}/\overline{\mu} & 1/\overline{\mu} \\ 0 & \overline{c} & 0 & 0 & 0 & 0 \\ \overline{\kappa} & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x \\ x_2 \\ u_\mu \\ u_\theta \\ u_\kappa \\ u \end{bmatrix}. \quad (9)$$

Designating by $\Delta_{(\mu\theta\kappa)}$ the diagonal matrix of uncertainty [11, 12]

$$\Delta_{(\mu\theta\kappa)} = \begin{bmatrix} \delta_\mu & 0 & 0 \\ 0 & \delta_\theta & 0 \\ 0 & 0 & \delta_\kappa \end{bmatrix}, \quad (10)$$

we obtain

$$\begin{bmatrix} u_\mu & u_\theta & u_\kappa \end{bmatrix}^T = \Delta_{(\mu\theta\kappa)} \begin{bmatrix} y_\mu & y_\theta & y_\kappa \end{bmatrix}^T \quad (11)$$

Consequently, the dynamic model of the first stage of grinding on the channel "performance - the iron content in the tailings" considering the uncertainty of parameters would have four input variables $(u_\mu, u_\theta, u_\kappa, u)$, four output variables $(y_\mu, y_\theta, y_\kappa, y)$ and two state variables (x_1, x_2).

In the space of states [11, 12] the model G_{SM} п of the first stage of grinding has the next form

$$G_{SM} = \begin{bmatrix} A & B_1 & B_2 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix}; \quad (12)$$

where $A = \begin{bmatrix} 0 & 1 \\ -\overline{\kappa}/\overline{\mu} & -\overline{\theta}/\overline{\mu} \end{bmatrix}$;

$$B_1 = \begin{bmatrix} 0 & 0 & 0 \\ -p_\mu & -\overline{p_\theta}/\overline{\mu} & -\overline{p_\kappa}/\overline{\mu} \end{bmatrix};$$

$$B_2 = \begin{bmatrix} 0 \\ 1/\overline{\mu} \end{bmatrix}; \quad C_1 = \begin{bmatrix} -\overline{\kappa}/\overline{\mu} & -\overline{\theta}/\overline{\mu} & -p_\mu \\ 0 & \overline{c} & 0 \\ \overline{\kappa} & 0 & 0 \end{bmatrix};$$

$C_2 = \begin{bmatrix} 1 & 0 \end{bmatrix}$;

$$D_{11} = \begin{bmatrix} -p_\mu & -\overline{p_\theta}/\overline{\mu} & -\overline{p_\kappa}/\overline{\mu} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix};$$

$D_{12} = \begin{bmatrix} 1/\overline{\mu} & 0 & 0 \end{bmatrix}^T$; $D_{21} = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix}$; $D_{22} = 0$.

Let’s imagine the uncertainty of the grinding first stage model in two blocks, which obtained using a linear fractional transformations and connecting from the top of the diagonal block (δ_μ, δ_θ, δ_κ). Thus, the model of the first stage of grinding as the one-dimensional object with uncertain parameters can be written as $y = F_U(G_{SM}, \Delta_{(\mu\theta\kappa)})u$, where $\Delta_{(\mu\theta\kappa)}$ – diagonal matrix of uncertainties (δ_μ, δ_θ, δ_κ).

Let’s consider the frequency characteristics of a closed system with uncertainty. Analysis of Bode diagrams family for different values of uncertain parameters (δ_μ, δ_θ, δ_κ), which are shown in Fig. 2, leads to the conclusion about significant impact of uncertainty on the stability of beneficiation technological processes control.

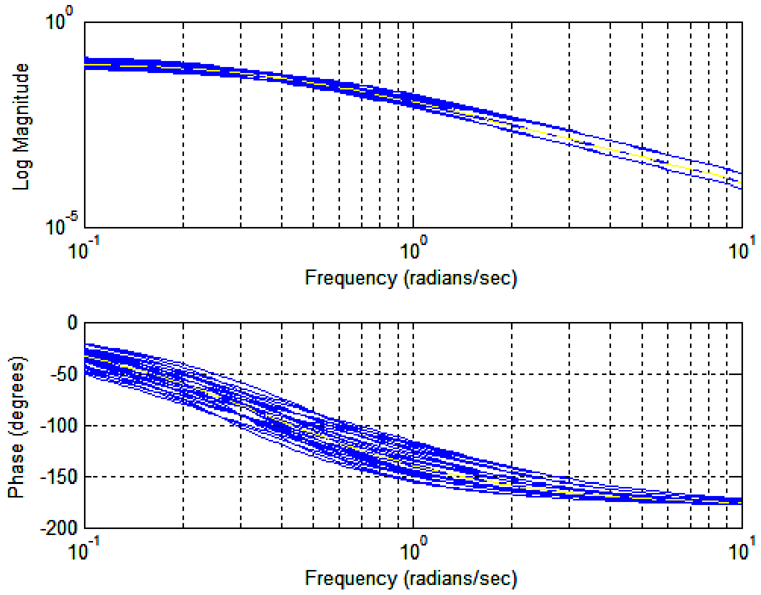

Figure 2. Bode diagram of the open perturbed control system of the first stage of grinding

Thus, the effect of model parameters uncertainty of technological processes of iron ore raw materials beneficiation is advisable to consider as model uncertainty of the first stage of grinding in the form of two blocks, obtained using a linear fractional transformations and connecting from the top of the diagonal block of deviations

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