efficiency and quality of carried out works, provided necessary accuracy, interchangeability and reliability. Research of «new technology», in conjunction with the integrated systems and laser means of measurement allows to raise considerably competitiveness of the integrated adaptive through system of stamps manufacture.

References

1. Patent "Method of integrated through preparation of manufacturing and producing of stamp pieces", No 48027 dated 10.03.2010 Bulletin No 5. Kvasnikov V. P., Kolomiets L. V., Kleshhev G. M., Kiev, 2010.
2. Kleschev V.P. Adaptive through computer technology of control of manufacturing and production of stamp pieces on the base of stamps-semifinished items. Under the editorship of Kolomiets L.V., Odessa, 2010, 283 p.
3. Kleschev G.M. Investigation of "new technology" of manufacturing of stamp pieces on the base of usage of lazer measuring devices. Collection of scientific papers of Odesa state academy of the technical adjusting and quality. No 1(6), 2015, p.p. 125-129.

Distributed control of ore beneficiation interrelated processes under parametric uncertainty

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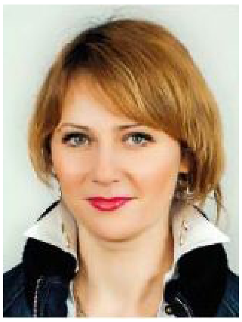

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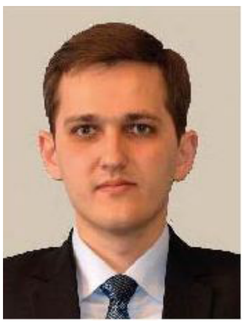

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Abstract
A method of distributed control forming of ore beneficiation interrelated processes under parametric uncertainty using robust control techniques is proposed.
Key words: DISTRIBUTED AND ROBUST CONTROL, ORE DRESSING

Problems of technological processes control synthesis of iron ore raw material beneficiation as the complex objects with a large number of parameters and disturbing influences are discussed in a significant number of works.

In particular, in papers [1-4] there noted that under parametric uncertainty and considerable spatial extent of ore beneficiation technological lines, the control effectiveness is greatly reduced.

It should be noted that a significant impact on the results of the beneficiation process have the characteristics of individual mineralogical and technological ore varieties and their relationship in the factory process flows [5-9].

The changes in these characteristics, along with the wear of technological units mechanisms, leads to the drift of control objects parameters. Under these conditions, during the control formation of ore-dressing plant technological lines it is advisable to use the methods of distributed and robust control [1-2].

Thus, ore beneficiation technological line as the control object must be represented as a system with concentrated inputs and output distributed in time and space. In this case, the concentrated system inputs are the effects on the individual technological units, the most common of which is the regulation of the ore - water ratio.

The distributed output is the distribution function of the mineral content by ore material size classes in technological units and conveyor lines, which are linking them.

In accordance with the formulation proposed in [1], the problem of distributed control of iron ore beneficiation technological line is the following. It is necessary to form a specific sequence of control actions $\overline{Q}(k)$, which set the ratio of ore and water for local technological units. Thus, it is necessary to provide a minimum deviation of the iron content in size classes $\beta(x,k)$ from a given value $\beta^*(x,\infty)$

$$\varepsilon(x,k)=\beta^*(x,\infty)-\beta(x,k), \qquad (1)$$

which will have a minimum value $\varepsilon_{\min}(x,\infty)$ under the quadratic norm

$$\varepsilon_{\min}(x,\infty)=\min\left\|\beta^*(x,\infty)-\beta(x,k)\right\| \qquad (2)$$

At the initial stage, it is necessary to obtain the problem solution of approximation in the block of spatial control synthesis. During the beneficiation technological line control, this problem, will take the following form according to [1]

$$\min\left\|\beta^*(x,\infty)-\sum_{i=1}^{n}\beta_i(x_i,\infty)HR_i(x,\infty)\right\| \qquad (3)$$

where $\{\mathrm{H}R_i(x,\infty)\}_i$ – are the steady values of given transfer characteristics of beneficiation units; $\{\beta_i^*(x_i,\infty)\}_i$ – are the approximation parameters. The resulting vector of optimal approximation $\{\breve{\beta}_i^*(x_i,\infty)\}_i$ is supplied to the input of the temporal synthesis, which consists of a single-channel control circuits with concentrated parameters. A typical circuit comprises a control object with zero-order predictor and controller with concentrated parameters (Fig. 1).

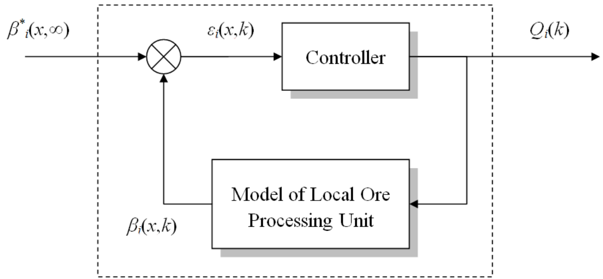


Figure 1. Single-circuit control system of ore beneficiation line local technological unit

In control problems solving the beneficiation technological line units, in the most general case, excluding net delay are present in the form of differential equations of the first and second orders [10]

$$\mu\frac{d^2\beta(t)}{dt^2}+\theta\frac{d\beta(t)}{dt}+\kappa\beta(t)=Q(t). \qquad (2)$$

The nonstationarity characteristics of iron ore raw materials and technological units mechanisms wear in the process of their work should be taken into account in the model. For this, let's assume that the values of its parameters μ, θ, κ can deviate from the nominal values $\overline{\mu}$, $\overline{\theta}$, $\overline{\kappa}$ on certain values $-1\le\delta_\mu,\delta_\theta,\delta_\kappa\le 1$. Considering the parameters uncertainty μ, θ, κ it is advisable to present them in the form of two blocks obtained using linear fractional transformation and connecting to the top of the respective blocks δ_μ, δ_θ, δ_κ [2, 11]. As a result, the output signals of the parameters blocks with model uncertainty of local technological units of iron ore beneficiation line can be written as [2]

where $Q_\mu = \delta_\mu y_\mu$, $Q_\theta = \delta_\theta y_\theta$, $Q_\kappa = \delta_\kappa y_\kappa$.

$$\begin{bmatrix} y_\mu \\ x'' \end{bmatrix} = \begin{bmatrix} -p_\mu & 1/\mu \\ -p_\mu & 1/\mu \end{bmatrix} \begin{bmatrix} Q_\mu \\ Q - v_\theta - v_\kappa \end{bmatrix}; \begin{bmatrix} y_\theta \\ v_\theta \end{bmatrix} = \begin{bmatrix} 0 & \bar{\theta} \\ p_\theta & \bar{\theta} \end{bmatrix} \begin{bmatrix} Q_\theta \\ x' \end{bmatrix}; \begin{bmatrix} y_\kappa \\ v_\kappa \end{bmatrix} = \begin{bmatrix} 0 & \bar{\kappa} \\ p_\kappa & \bar{\kappa} \end{bmatrix} \begin{bmatrix} Q_\kappa \\ x \end{bmatrix}, \quad (3)$$

In general, the model of local technological units of beneficiation line with uncertain parameters can be written as [2, 11]

$$\beta = F_Q\left(G_{SM}, \Delta_{(\mu\theta\kappa)}\right)Q, \quad (4)$$

where $\Delta_{(\mu\theta\kappa)}$ – is the diagonal matrix of uncertainties (δ_μ, δ_θ, δ_κ).

To minimize the error energy for the most unfavorable value of the input disturbance it is advisable to use H_∞- norm as an optimality criterion. The calculation of H_∞-norm is performed on the basis of the matrix in the state space [11].

$$H = \begin{bmatrix} A & BB^T \\ -CC^T & -A^T \end{bmatrix}. \quad (5)$$

Problem solution of formation of local concentrating units control, was carried out by the synthesis of the controller transfer function, which minimizes the function [11, 12]

$$T_{y1u1} \overset{\Delta}{=} \left[W_1 S \quad W_2 R \quad W_3 T\right]^T, \quad (6)$$

where $W_1(s)$, $W_2(s)$ and $W_3(s)$ – are the weighting functions depending on the frequency; S – is the sensitivity function; T – is the supplementary sensitivity function; R – is the control sensitivity function. The above functions are defined from the corresponding expressions [11]

$$S = (I + GK)^{-1}; R = K(I + GK)^{-1}; T = GK(I + GK)^{-1}. \quad (7)$$

Choosing of weighting functions was carried out in accordance with the recommendations outlined in [13].

Thus, the values of sensitivity functions must satisfy the following conditions

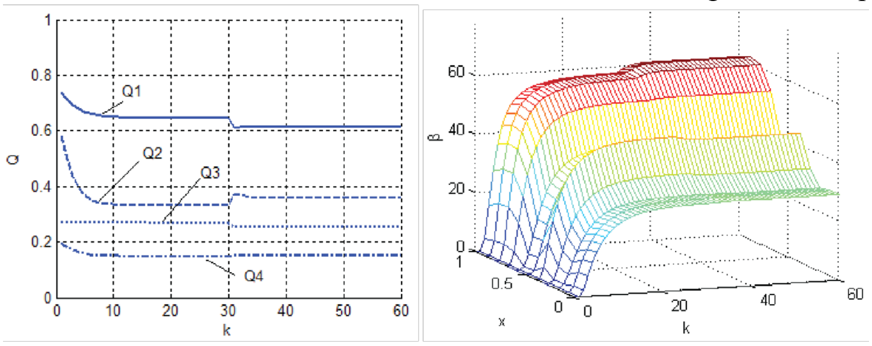
$$\bar{\sigma}(S(j\omega)) \le \gamma \underline{\sigma}\left(W_1^{-1}(j\omega)\right); \bar{\sigma}(R(j\omega)) \le \gamma \underline{\sigma}\left(W_2^{-1}(j\omega)\right); \bar{\sigma}(T(j\omega)) \le \gamma \underline{\sigma}\left(W_3^{-1}(j\omega)\right), \quad (8)$$

where γ – is the positive number.

Thus, as shown in [1], the parametric synthesis regulators is advisable to carry out in compliance with the following condition.

$$\left\{\lim_{k\to\infty} \varepsilon_{\min}(x_i, k) = \lim_{k\to\infty}\left(\breve{\beta}_i^*(x_i, \infty) - \beta(x, k)\right) = 0\right\}_{i,k}, k \to \infty. \quad (9)$$

The simulation results of distributed control of ore beneficiation technological line are presented in Fig. 2.



a) b)

Figure 2. Dynamics of concentrated control signals and distributed output variable: a – beneficiation units control signals; b – distributed characteristics of the iron content in the ore

Thus, the considered control laws allow forming such control signals sequences for individual beneficiation units, which provide a minimum control error of the entire technological line under parametric uncertainty.

References

1. Hulko G., Antoniova M., Belavy C., Belansky J, Szuda J., Vegh P. (2003) Modeling, control and design of distributed parameter systems (internet version of the monograph), Slovak university of technology Bratislava. Available at: http://www.dpscontrol.sk/monog_index.html.
2. Gu D.W., Petkov P. Hr., Konstantinov M. M. (2005) Robust Control Design with MATLAB, Springer-Verlag London Limited.
3. Kupin A., Senko A. (2015). Principles of intellectual control and classification optimization in conditions of technological processes of beneficiation complexes, CEUR Workshop Proceedings, Vol-1356, p.p. 153-160.
4. Morkun V., Morkun N., Tron V. (2015). Formalization and frequency analysis of robust control of ore beneficiation technological processes under parametric uncertainty, *Metallurgical and Mining Industry,* No 5, p.p. 7-11.
5. Morkun V., Tron V., Paraniuk D. (2015) Formation of rock geological structure model for drilling process adaptive control system, *Metallurgical and Mining Industry,* No5, p.p. 12-15.
6. Morkun V., Morkun N., Tron V. (2015). Identification of control systems for ore-processing industry aggregates based on nonparametric kernel estimators, *Metallurgical and Mining Industry,* No1, pp. 14-17
7. Morkun V., Tron V., Goncharov S. (2015) Automation of the ore varieties recognition process in the technological process streams based on the dynamic effects of high-energy ultrasound, *Metallurgical and Mining Industry,* No.2, pp. 31-34.
8. Morkun V., Tcvirkun S. (2014). Investigation of methods of fuzzy clustering for determining ore types. *Metallurgical and Mining Industry,* No5, p.p. 12-15
9. Azaryan A., Azaryan V. (2015) Use of Bourger-Lambert-Bera law for the operative control and quality management of mineral raw materials, *Metallurgical and Mining Industry,* No1, p.p. 4-8.
10. Nesterov G. S. Tekhnologicheskaya optimizatsiya obogatitelnykh fabric [Technological optimization of concentrating factories], Moscow, Nedra, 1976.
11. Pupkov K., Yegupov N. Metody klassicheskoy i sovremennoy teorii avtomaticheskogo upravleniya [Methods of classical and modern control theory], 2-ed. Vol.3: Sintez regulyatorov sistem avtomaticheskogo upravleniya [Synthesis of regulators of automatic control systems], Moscow, N.E. Bauman MGTU, 2004.
12. Polilov Ye., Tkachenko A., Rudnev Ye., Skorik S., Shcholokov A. (2011). Razrabotka i prakticheskaya realizatsiya robastnykh algoritmov upravleniya avtomatizirovannym sinkhronnym elektroprivodom na osnove H_2- i H_∞- optimizatsii, Yelektrotekhnichni ta kompyuterni sistemi [Development and implementation of robust control algorithms for automated synchronous electric drive based H_2- and H_∞- optimization], No3, p.p. 60-69.
13. Polilov Ye., Zelenov A., Rudnev Ye. (2009). Prakticheskiy podkhod k vyboru vesovykh funktsiy dlya H_∞-teorii robastnogo upravleniya [A practical approach to the choice of weighting functions for the H∞-theory of robust control], Vísnik KDPU imeni Mikhayla Ostrogradskogo, No3(56), p.p. 17-24.