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DEVELOPING OF ADAPTIVE MODEL PREDICTIVE CONTROL SYSTEM FOR HEAT TREATMENT OF IRON-ORE PELLETS WITH USING RECURSIVE LEAST SQUARE ALGORITHM FOR ONLINE PARAMETER ESTIMATION

Розроблено модель для дослідження ефективності застосування рекурсивного алгоритму найменших квадратів у складі системи адаптивного прогнозуючого керування процесом термічної обробки обкотишів та виконано її моделювання у пакеті Simulink. Отримана система продемонструвала високу якість оперативного оцінювання параметрів процесу, що дозволяє рекомендувати розроблений метод формування адаптивного прогнозуючого керування для автоматизації процесів термічної обробки обкотишів.

Ключові слова: *адаптивне прогнозуюче керування, термічна обробка обкотишів, рекурсивний алгоритм найменших квадратів.*

1. Introduction

Enrichment of iron ore in mining enterprises (ME) often ends with sintering of concentrate in sintering machines or straight grate induration machines (indurating furnaces). In terms of features of smelting process in blast furnace the end product of indurating furnaces — pellets — has a number of advantages compared with sinter, namely high durability during prolonged storage, transportation and transshipment, more uniform particle size distribution that provides better gas permeability of layer of charge materials in the blast-furnace and, consequently, leads to increasing the productivity of iron smelting and reduction of slag production. In addition, as the raw material for the production of pellets are often used finely powdered concentrates, whose share in the domestic ore-dressing plants are growing in recent years, due to the decrease of reserves of rich ore and increasing the share of poor kinds of ores. Straight grate induration machine (SGIM), in which the heat treatment of pellets is conducted, is the basic unit that affects to the productivity of the pelletizing plant and quality of the finished product. Analysis of technical and economic performance and results of the modernization of pelletizing plants of potential competitors shows that domestic SGIM have the reserves of increasing of productivity up to 10–15 % and reduction of specific consumption of natural gas by 15–20 % [1]. Improvement of the methods and systems of control of heat treatment of pellets is one of the most promising directions of solving these tasks.

2. The object of research and its technological audit

The object of research — the processes of automatic control of iron ore pellets heat treatment on induration machines during pelletizing of iron ore raw stock on mining enterprises.

To increase performance, obtaining high quality parameters of pellets, reducing specific energy consumption it is necessary to provide the desired temperature distribution along the induration machine by stabilizing the temperature of the gas in each gas-air chamber. Thus, the main technological purpose of the control of firing temperature regime will be considered temperature stabilization in each gas-air chamber of induration machine with minimal deviations from preset values and with minimum outlay of heat carrier. For heated zones of SGIM (heating and firing) it is advisable to carry out the temperature stabilization by changing the gas flow to the burners with a simultaneous maintaining a specified ratio «gas-air» to complete gas combustion. At the same time it is necessary to maintain a uniform distribution of temperature field to the width of pallet car. When implementing of individual temperature control circuits in the gas-air chamber on both sides of SGIM, there is a significant impact of burners on the readings of thermocouple from opposite side, adversely affect the uniformity of thermal field to the width of pallet car. So usually the control circuit is realized in such a way that, depending on the average temperature measured at two points of the heart of furnace, gas flow to the burner of one side of SGIM is changed, the gas flow to the burner is automatically duplicated on other side. For each burner the individual control circuits also support a given ratio «gas-air» by measuring the actual gas flow to the burner. With this approach for a given program of temperature changes in the individual gas-air chamber of SGIM it is very important to provide a formation of preset value to subordinate circuit of control of gas flow of leading side. The direction of solving this problem may be the use of adaptive system that provides online estimation of parameters of pellets heat treatment and formation of control actions on the basis of Model Predictive Control (MPC) methods.

3. The aim and objectives of research

The aim of research — to develop a control system for the pellets heat treatment process for providing a given temperature regimes in technological zones of indurating machine under conditions of uncontrolled disturbances.

To achieve this aim it is necessary perform the following tasks:

1. To develop a method of forming of adaptive predictive control of iron ore pellets heat treatment with online estimation of process parameters.
2. To develop a structural diagram of the adaptive predictive control system for pellets heat treatment with online estimation of process parameters.
3. To conduct an experimental research of estimation effectiveness of process parameters when forming adaptive predictive control of iron ore pellets heat treatment.

4. Literature review

In the works [2–5] it is indicated that to meet the challenges of improving the systems of automatic control of nonlinear inertial objects, including the technological processes of enrichment and processing of iron ore, recently widely used methods of Model Predictive Control (MPC). Methods of control using predictive models belong to the class of algorithms in which the dynamic model is used to predict and optimize the process in real time. The advantages of these methods are relatively simple circuit formation feedback and high adaptive properties, which allow to implement quasi-optimal control of nonlinear nonstationary objects with complex structure in real time considering constraints on control and output variables, and to take into account changes in criteria of control quality during the operation, etc. [2, 3]. Positive experience of practical use of Model Predictive Control methods allows considering them as an alternative to classical parametric PI- and PID-controllers [2].

In the basic version of Model Predictive Control [6, 7] linear model of control object is used, eliminating necessity of solving of the quadratic programming problem in real time and enables to find optimal control law analytically. But according to testimony of authors [8], the efficiency of MPC algorithms with using linear models is insufficient for significantly nonlinear and non-stationary processes. Therefore, in recent years there has an active development of control methods based on nonlinear predictive models (Nonlinear Model Predictive Control, NMPC), and as a result, there are many published works are devoted to their usage for automation of iron ore enrichment processes [2, 8, 9]. Also, one of the most promising solutions to the problem of formation predictive control for nonlinear non-stationary processes is the use of adaptive predictive control. In accordance with [10], adaptive predictive control can be considered as one embodiment of the adaptive optimal control that represents an aggregate of interconnected algorithms for estimation of control object parameters, estimation of its state and directly algorithm of the formation of control law. Formation of the control law is carried out by solving the optimization problem using predictive model of process directly during the functioning of the control system (in real time). Predictive models of various classes and complexity can be used for solving this task. In particular, in [8] it is proposed to use Wiener models in the scheme of NMPC-control, in [9] — to use models based on radial basis functions, in [2, 11] — Hammerstein models, in [1, 12] — ANFIS models, in [13] — block-oriented hybrid models based on Wiener and Hammerstein-Wiener models with system of Laguerre orthonormal basis functions. Since for the implementation of the schemes NMPC-control it is necessary to solve the problem of nonlinear programming, the computational load on the microprocessor controls is significantly increased that can lead to inadmissible increase of the sampling period during forming the control signals. For block-oriented models this disadvantage can be eliminated by applying method of inversion of static nonlinearity, as proposed in [13, 14]. However, for a wide range of control objects that long time operate in modes close to the nominal, for formation of adaptive predictive control the variant of nonlinear model's linearization around the operating point can be used followed by using of algorithm of the formation of control actions in accordance with the methods of linear MPC-control. This approach can be used for control of process of pellets heat treatment in heating zones of indurating furnace because productivity of supplying of raw pellets, and thus the speed of pallet cars and height of pellets layer are supported sustainable for long periods of functioning of SGIM.

In [10] it is shown that formation of adaptive predictive control can represent a coupled combination of synthesis of optimal control of stochastic object to the assumption of accurate measurement of state variables and parameters of control object, with the estimation of state variables and parameters.

5. Materials and methods of research

Thus, the structure of adaptive predictive control of the temperature regime pellets heat treatment in a certain gas-air chamber should consist of four parts: the control object with sensors, the bloc for object parameters estimation, state observer for estimation of uncontrolled state variables and the bloc for calculating the optimal control action on the prediction horizon. One possible structure of adaptive predictive control of the temperature regime of pellets heat treatment in certain gas-air chamber of SGIM is shown in Fig. 1. In accordance with the principles of model predictive control the generalized quadratic functional with a moving interval of optimization could be used for evaluating the quality of control at the prediction interval:

$$J_n = \sum_{j=1}^{P} \left[\begin{aligned} &\left(T_{gac}^{sp}[n+j] - \hat{T}_{gac}[n+1]\right) \cdot R[n+j] \times \\ &\times \left(T_{gac}^{sp}[n+j] - \hat{T}_{gac}[n+1]\right) + \\ &+ Q_{lb}[n+j-1] \cdot S[n+j-1] \cdot Q_{lb}[n+j-1], \end{aligned} \right. \quad (1)$$

where $\hat{T}_{gac}[n+1]$, $T_{gac}^{sp}[n+j]$ — predictive and preset temperature accordingly at step $n+j$; $Q_{lb}[n+j-1]$ — value of control action — consumption of gas to the burner of leading (left) side; $R[n+j]$ — weighting coefficients that assess the degree of desirability of temperature deviation in step $n+j$ from the preset value; $S[n+j-1]$ — factors that take into account the cost of control actions energy; P — prediction horizon.

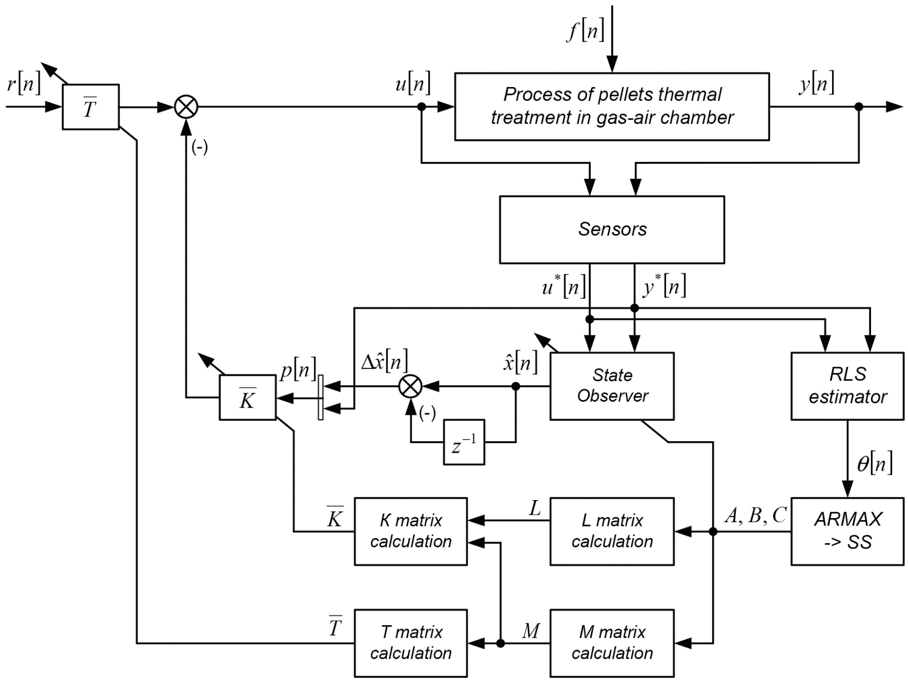

Fig. 1. Structure of adaptive predictive control of the pellets heat treatment with using recursive least square algorithm for online parameter estimation

Thus, according to the put aim of the control, the problem of finding the optimal program of control actions at the prediction horizon P can be formulated as a problem of finding a vector function:

$$\bar{Q}_{lb}[n+1]=\left[Q_{lb}[n],Q_{lb}[n+1],\cdots,Q_{lb}[n+P-1]\right]^T, \tag{2}$$

which minimizes the functional (1):

$$J_n\left(Q_{lb}[\cdot],P\right)\rightarrow\min_{Q_{lb}\in M}, \tag{3}$$

where M is allowable set of control actions.

According to the method of synthesis [3], the main stages of which are described below, for the linear model of control object the solution of the problem (2), (3) which additionally provides astatism of closed-loop system, can be represented as:

$$\bar{\upsilon}=\bar{K}p[n]+\bar{T}\bar{r}[n], \tag{4}$$

where $p[n]=\left(\Delta x[n]\vdots T_{gac}[n]\right)^T$ – vector of predictive model state; $\Delta x[n]=x[n]-x[n-1]$; $\bar{r}[n]=T_{gac}^{sp}[n]$ – preset value of temperature in the corresponding gas-air chamber at step n;

$$\bar{K}=-\left(M^TRM+Q\right)^{-1}M^TRL,\ \bar{T}=-\left(M^TRM+Q\right)^{-1}M^T\mathrm{R}. \tag{5}$$

Matrix M and L are calculated by the following formulas [3]:

$$L=\left[\bar{C}\bar{A}\quad \bar{C}\bar{A}^2\ldots\bar{C}\bar{A}^P\right]^T, \tag{6}$$

$$M=\begin{pmatrix}\bar{C}\bar{B} & 0 & \cdots & 0\\ \bar{C}\bar{A}\bar{B} & \bar{C}\bar{B} & \ldots & 0\\ \cdots & \vdots & \ddots & \vdots\\ \bar{C}\bar{A}^{P-1}\bar{B} & \bar{C}\bar{A}^{P-2}\bar{B} & \cdots & \bar{C}\bar{B}\end{pmatrix}, \tag{7}$$

where matrices $\bar{A}$, $\bar{B}$, $\bar{C}$ are defined by the following expressions:

$$\bar{A}=\begin{pmatrix}A & 0_{n\times r}\\ AC & E_{r\times r}\end{pmatrix},\ \bar{B}=\begin{pmatrix}B\\ CB\end{pmatrix},$$
$$\bar{C}=\left(0_{r\times n}\ \vdots\ E_{r\times r}\right), \tag{8}$$

where $0_{n\times r}$ – zero matrix of dimension $(n\times r)$; $E_{r\times r}$ – identity matrix of dimension $(r\times r)$.

Because the object parameters A, B and C are changed in the functioning, it is needed to implement recalculation of matrices $\bar{K}$ and $\bar{T}$ that are used to calculate the control action according to the expression (4) on the basis of results of online parameters estimation provided by the identification bloc. One of the known algorithms of online parameter estimation can be used for this task. In this paper, a Recursive Least Square Estimation Algorithm (RLS) is proposed to be used to determine model parameters of pellets heat treatment process in a certain gas-air chamber of SGIM.

In accordance with an RLS algorithm, vector of estimated system parameters $\theta[n]$ at step n can be calculated by the formula [15]:

$$\theta[n]=\theta[n-1]+\gamma[n-1]\left(y[n]-\varphi^T[n-1]\theta[n-1]\right), \tag{9}$$

where $y[n]=T_{gac}[n]$ – the current value of controlled variable – temperature in a certain gas-air chamber of SGIM;

$$\gamma[n-1]=P[n]\varphi[n], \tag{10}$$

and the matrix P[n] is calculated by the recurrence formula:

$$P[n]=P[n]-P[n-1]\varphi[n]\left(1+\varphi^T[n]P[n-1]\varphi[n]\right)^{-1}\times$$
$$\times\varphi^T[n]P[n-1], \tag{11}$$

with initial conditions:

$$P[n_0]=\left[\phi^T[n_0]\phi[n_0]\right]^{-1}, \tag{12}$$

$$\theta[n_0]=P[n_0]\phi^T[n_0]\Upsilon[n_0]. \tag{13}$$

Matrices $\phi[n_0]$ and $\Upsilon[n_0]$, that are used for calculation of initial conditions, have the form:

$$\phi[n_0]=\begin{bmatrix}\varphi[0]\\ \varphi[1]\\ \vdots\\ \varphi[n_0-1]\end{bmatrix}=$$

$$=\begin{bmatrix}-T_{gac}[N_a-1] & \ldots & -T_{gac}[0] & Q_{lb}[N_b-1] & \ldots & Q_{lb}[0]\\ -T_{gac}[N_a] & \ldots & -T_{gac}[1] & Q_{lb}[N_b] & \ldots & Q_{lb}[1]\\ \ldots & \vdots & \ldots & \ldots & \vdots & \ldots\\ -T_{gac}[N_a+n_0-1] & \ldots & -T_{gac}[n_0-1] & Q_{lb}[N_b+n_0-1] & \ldots & Q_{lb}[n_0-1]\end{bmatrix},$$

$$\mathrm{Y}[n_0]^T = [Q_{lb}[N_a]\ Q_{lb}[N_a+1]\ \ldots\ Q_{lb}[N_a+n_0+1]],$$

where N_a, N_b – accordingly the maximum delays of output and input variables in the ARMAX model, which is used to approximate the dependence of the temperature in a certain gas-air chamber from the gas consumption to the burner of leading side of SGIM.

At the next step the ARMAX-model of pellets heat treatment in a certain gas-air chamber of SGIM, which was received as a result of estimation procedure with RLS algorithm, is transformed to the state-space representation in the canonical form of observability [16]. Further the A, B, C matrices of received model are used in the formulas (5)–(8) for calculating of matrix coefficients, which in turn are used for the calculation of the preset values of the gas consumption to the burner of leading side with using the formula (5).

6. Results of research

For study of effectiveness of RLS algorithm for online estimation of parameters in the system of adaptive predictive control of pellets heat treatment, the model is implemented in Simulink package. The study was carried out by simulation modeling on the basis of data about the dependence of temperature T_{gac34} in the firing zone under burners №№ 3, 4 from gas consumption Q_{lb} on the burner of leading side, which were obtained in a mode of passive experiment at the indurating machine OK-324 of JSC «Central GOK (ME)» in condition of constant values of pellets layer height and speed of indurating machine.

Fig. 2 shows a graph of the temperature in the furnace burning zone, calculated on the basis of parameters of pellets heat treatment model, found as the result of the identification procedures, and appropriate experimental temperature.

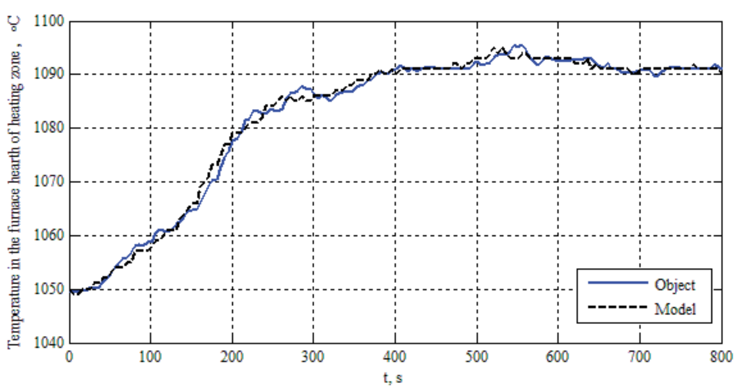

Fig. 2. The results of the research of RLS algorithm efficiency for online estimation of parameters in the system of adaptive predictive control of pellets heat treatment

Fig. 3 shows the graphics of changes of coefficients of pellets heat treatment model in the operation of the developed system of adaptive predictive control.

Analysis of the identification of parameters of pellet heat treatment using recursive least squares algorithm in the system of adaptive predictive control shows that the normalized root mean square error NRMSE of forecasting results from the experimental data does not exceed 7,32 %, coefficient of variation – 0,63 %. The speed of convergence of procedure of parameter estimation from the start of system functioning is up to 50 steps.

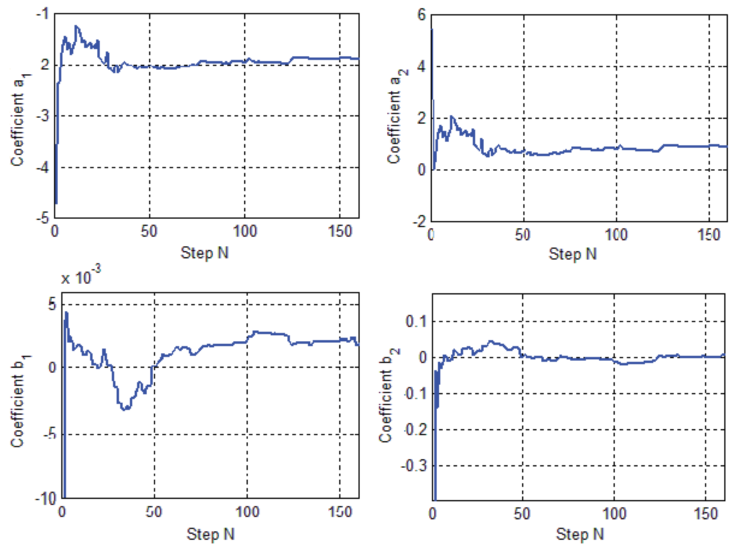

Fig. 3. The dynamics of changes of coefficients of pellets heat treatment model during the functioning of the subsystem of parameter estimation using RLS algorithm

7. SWOT analysis of research results

The strengths of the developed method can be referred the use of linear models, the adequacy of which in the current technological situation is achieved by using the procedures of online estimation of model parameter with using RLS algorithm. With this embodiment of the system the computational load on the microprocessor control units significantly decreases through lack of necessity to solve problems of nonlinear programming when forming control actions by using methods of model predictive control.

The disadvantages at this stage of research can be referred need for prior definition of rational orders of models of pellets heat treatment in various gas-air chambers of indurating machine in order to ensure acceptable performance of control system and to ensure the convergence of parameter estimation procedures. In further research it is planned to improve the proposed approach by taking into account constraints on the value of the control action on each control step.

Thus, for purposes of developing the universal system of predictive control of pellets heat treatment it is necessary to create analytical dynamic model of the process that takes into account qualitative characteristics of raw pellets, their particle size distribution and fractional void of the layer, and the availability of tools for operational control of these parameters.

8. Conclusions

The method of forming adaptive predictive control of pellets heat treatment with online estimation of process parameters using recursive least squares algorithm is suggested. This approach allows providing the maintaining given temperature conditions of pellets indurating in conditions of fluctuations of particle size distribution and fractional void of the layer, changes in the process equipment characteristics and the presence of noise in measurement channels.

The structural diagram of the system of adaptive predictive control of pellets heat treatment, which includes the control object with sensors, the block for object parameters estimation, state observer for estimation of uncontrolled state variables and the block for calculating the optimal control action on the prediction horizon. The relevant structure allows to accomplish the estimation of process parameter, the estimation of uncontrolled state variables and the formation of control actions on each step of the system functioning.

Experimental study of the effectiveness of online parameters estimation confirmed that the use of recursive least squares algorithm provides reception of a satisfactory model (normalized root mean square error (NRMSE) of prediction results with using received models from experimental data does not exceed 7,32 %, while the convergence rate of estimation procedure up to 50 steps) for the formation of adaptive predictive control of iron ore pellets heat treatment.

References

1. Lobov, V. Y. Avtomatyzovani systemy keruvannia protsesamy termichnoi obrobky kotuniv na konveiernii vypaliuvanii mashyni [Text]: Monograph / V. Y. Lobov, L. I. Yefimenko, M. P. Tykhanskyi, S. A. Ruban. — Kryvyi Rih: Vydavets FOP Cherniavskyi D.O., 2015. — 250 p.
2. Porkuian, O. V. Keruvannia neliniinymy dynamichnymy obiektamy zbahachuvalnykh vyrobnytstv na osnovi hibrydnykh modelei Hamershteina [Text]: Dissertation of the Doctor of Technical Sciences / O. V. Porkuian. — Kryvyi Rih, 2009. — 379 p.
3. Veremei, E. Y. Upravlenye s prohnozyruiushchymy modeliamy [Text] / E. Y. Veremei. — SPb: SPbHU, 2014. — 212 p.
4. Morari, M. Model predictive control: past, present and future [Text] / M. Morari, J. H. Lee // Computers & Chemical Engineering. — 1999. — Vol. 23, № 4–5. — P. 667–682. doi:10.1016/s0098-1354(98)00301-9
5. Roubos, J. A. Fuzzy model-based predictive control using Takagi-Sugeno models [Text] / J. A. Roubos, S. Mollov, R. Babuška, H. B. Verbruggen // International Journal of Approximate Reasoning. — 1999. — Vol. 22, № 1–2. — P. 3–30. doi: 10.1016/s0888-613x(99)00020-1
6. Garcia, C. E. Model predictive control: Theory and practice — A survey [Text] / C. E. Garcia, D. M. Prett, M. Morari // Automatica. — 1989. — Vol. 25, № 3. — P. 335–348. doi:10.1016/0005-1098(89)90002-2
7. Lee, J. H. State-space interpretation of model predictive control [Text] / J. H. Lee, M. Morari, C. E. Garcia // Automatica. — 1994. — Vol. 30, № 4. — P. 707–717. doi:10.1016/0005-1098(94)90159-7
8. Gomez, J. C. Wiener model identification and predictive control of a pH neutralisation process [Text] / J. C. Gomez, A. Jutan, E. Baeyens // IEE Proceedings-Control Theory and Applications. — 2004. — Vol. 151, № 3. — P. 329–338. doi:10.1049/ip-cta:20040438
9. Pottmann, M. A nonlinear predictive control strategy based on radial basis function models [Text] / M. Pottmann, D. E. Seborg // Computers & Chemical Engineering. — 1997. — Vol. 21, № 9. — P. 965–980. doi:10.1016/s0098-1354(96)00340-7
10. Bukov, V. N. Adaptyvnye prohnozyruiushchye systemy upravlenyia poletom [Text] / V. N. Bukov. — M.: Nauka, 1997. — 232 p.
11. Fruzzetti, K. P. Nolinear model predictive control using Hammerstein models [Text] / K. P. Fruzzetti, A. Palazoglu, K. A. McDonald // Journal of Process Control. — 1997. — Vol. 7, № 1. — P. 31–41. doi:10.1016/s0959-1524(97)80001-b
12. Ruban, S. A. Avtomatyzatsiia protsesu keruvannia termichnoiu obrobkoiu zalizorudnykh obkotyshiv z vykorystanniam prohnozuiuchykh ANFIS-modelei [Text]: PhD thesis / S. A. Ruban. — Kryvyi Rih, 2011. — 20 p.
13. Mykhailenko, O. Process control of ore crushing using block-oriented predictive model [Text] / O. Mykhailenko // Technology audit and production reserves. — 2015. — № 4/3 (24). — P. 28–32. doi:10.15587/2312-8372.2015.47952
14. Patikirikorala, T. Hammerstein-Wiener nonlinear model based predictive control for relative QoS performance and resource management of software systems [Text] / T. Patikirikorala, L. Wang, A. Colman, J. Han // Control Engineering Practice. — 2012. — Vol. 20, № 1. — P. 49–61. doi:10.1016/j.conengprac.2011.09.003
15. Ljung, L. System Identification: Theory for the User [Text] / L. Ljung; by ed. Ya. Z. Tsypkin. — M.: Nauka, 1991. — 432 p.
16. Candy, J. V. Model-Based Signal Processing [Text] / J. V. Candy. — New Jersey: Wiley-IEEE Press, 2005. — 704 p. doi:10.1002/0471732672

РАЗРАБОТКА СИСТЕМЫ АДАПТИВНОГО ПРОГНОЗИРУЮЩЕГО УПРАВЛЕНИЯ ПРОЦЕССАМИ ТЕРМИЧЕСКОЙ ОБРАБОТКИ ОКАТЫШЕЙ С ИСПОЛЬЗОВАНИЕМ РЕКУРСИВНОГО АЛГОРИТМА НАИМЕНЬШИХ КВАДРАТОВ ДЛЯ ОЦЕНКИ ПАРАМЕТРОВ МОДЕЛИ ПРОЦЕССА

Разработана модель для исследования эффективности применения рекурсивного алгоритма наименьших квадратов в составе системы адаптивного прогнозирующего управления процессом термической обработки окатышей и выполнено ее моделирование в пакете Simulink. Полученная система продемонстрировала высокое качество оперативного оценивания параметров, что позволяет рекомендовать разработанный метод формирования адаптивного прогнозирующего управления для автоматизации процессов термической обработки окатышей.

Ключевые слова: адаптивное прогнозирующее управление, термическая обработка окатышей, рекурсивный алгоритм наименьших квадратов.

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