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Selection of the Most Priority Parameters of the Mathematical Model of Multi-Stage Processes

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Due to the presence of a large number of heterogeneous disturbing influences, the multi-stage process control systems (PCSs) are difficult to maintain the operation of the control object with the required quality and reliability. This problem is especially aggravated for multi-stage production processes with a continuously discrete and continuous nature, where the control cycle is limited from below by the speed, quality and reliability of the measuring path, and from above by the speed, quality and reliability of computer equipment and communication channels.

Often, the direct determination of the values of process parameters in a production environment presents a certain difficulty. The complexity of solving the problem of constructing a mathematical model is due to the fact that existing sensors and measuring instruments do not have the required reliability, they are difficult to install on a functioning object, and their cost is also high.

In order to solve such problems, the following algorithm is proposed:

Let there are many technological parameters

$$G = G\{x_1, x_2, \dots, x_n\},$$

consisting of two subsets:

$$G_1 = G_1\left\{x_1^{(1)}, x_2^{(1)}, \dots, x_k^{(1)}\right\}, G_1 \in G,$$

readily identifiable values, and

$$G_2 = G_2\left\{x_1^{(2)}, x_1^{(2)}, \dots, x_s^{(2)}\right\}, G_2 \in G,$$

where the values are difficult to determine.

Moreover, the relation

$$G_1 \cap G_2 = \Phi\,, \quad G = G_1 \cup G_2 и k + s = n.$$

If it is possible to determine the values of the parameters of the set G_2, then with its help it is possible to build a system of models with respect to those parameters whose values are determined with a large time delay and costs.

In operator form, the model system can be represented as

$$G_2 = \varphi(G) \ ,$$

Where φ is a functional operator selected from an arsenal of mathematical equations and methods that satisfy the requirements of specialists in solving specific problems. The system of models is embedded in the memory of computer technology and at each control cycle it is used to estimate and predict the values of difficult to determine parameters.

The essence of the proposed approach lies in the application of the “flexible synthesis” methodology / 1-3,5 /, which consists in using information and its organization quality at the stage of development and implementation in the procedures for generating control actions in control cycles at the stage of development and implementation of experimental data on production dynamics process.

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For a more detailed analysis of the proposed algorithm, suppose that there is a matrix of experimental data X_0 of dimension (n × m) taken over the (t_0, t_1) time interval, the elements of which are$\widehat{x_j} = \{x_{1j}, x_{2j}, \dots, x_{nj}\}$; are input and including control, *Y* output variables. Moreover, *j*-means the number of the variable, and *i*-the number of the measurement. The relation between these variables is satisfied.

$$Y = F(x, u), \quad (1)$$

where x are the values of state variables among, u is the state of control variables, Y are the output values of state variables, F is the transformation operator.

We introduce the vector $\widehat{x_j} = \{x_{1j}, x_{2j}, \dots, x_{nj}\}$, which determines the set of measured values $\widehat{x_o}$can be represented as a set of columns $\widehat{x_j}$, $j = \overline{1,m}$ .Based on the statistics of experimental data $\widehat{x_o}$collected, the correlation matrix R is constructed and the correlation relationship is analyzed (the relationship between the variables at $0 \le \mathcal{R}_{ij} \le 0.3$ for$\forall_i , j = \overline{1,m}, i \ne j$ is weak, at $0.3 \le \mathcal{R}_{ij} \le 0.7$- average and $0.7 \le \mathcal{R}_{ij} \le 1.0$. - strong), the results of which reduce the dimension of the description of the production process to$\widehat{x_o'}$.

Thus, as a result of this procedure, a subset $\widehat{x_j}$with $\mathcal{R}_{ij} \le 0.7$ matrix $\widehat{x_o}$ takes the form $\widehat{x_o'}$ with the dimension$[n \times l, l \le m$and by analogy with (1) we have

$$Y = F_1(\widehat{x^1}, U). \quad (2)$$

Simultaneously with the above systematization of the statistics of experimental data in order to improve the quality of operational control at each cycle of the control cycle, the remaining set $\widehat{x_j}$ and $\widehat{x_o'}$ are classified as low inertia (usually quickly determined) $\widehat{x_j'}$and highly inertial variables $\widehat{x_j''}$, and in order to further reduce the dimension of the task of describing the state of the production process, a relationship is established (determined) between them

$$\widehat{x_j''} = \varphi_{j-s}(\widehat{x_1'}, \widehat{x_2'}, \dots, \widehat{x_s'}), j = \overline{s+1, l}. \quad (3)$$

Systematization in this case is carried out according to the following algorithm. Let vectors $\widehat{x_o'}$ be grouped in the matrix $\widehat{x_j'}$so that the first ones from the vector $\widehat{x_j'}$, $j = \overline{s,1}$, corresponding to low-inertia variables, are located first, and then the vectors $\widehat{x_j''}$, $j = \overline{s+1, l}$, respectivelystrongly inertial variables in real time.

As a result, the data matrix $\widehat{x_o'}$ is represented as two submatrices - $\widehat{x_o''}$- low inertia and - $\widehat{x_o'''}$- strongly inertial. When choosing the methodology of mathematical methods for determining the structure $\varphi_{j-s}, j = \overline{s+1, l}$special attention will be paid to the method of the modeling function / 2-5 /.

In the work / 3 /, as the proximity of the estimate of the operator of the object to its true value, the minimum criterion of a quadratic functional of the form is used:

$$R_{\kappa p} = m_E + \sum_{i=1}^{n} \xi_i \kappa_E(\tau_i), \quad (4)$$

where$\kappa_E(\tau_i)$ is the value of the correlation function of the error at the moment $\tau_i, \xi_i$are some constant coefficients satisfying the condition $\sum_{i=1}^{n} \xi_i^2 \ne 0$. Then the optimal estimate of the object operator can be sought in the class of linear integral stationary operators

$$Y(t) = AX(t) = \int_{-\infty}^{t} \omega(\tau) x(t-\tau) d\tau,$$

Where ω(t) is the weight function of A.

Further, expressing functional (4) through the initial statistical data and taking into account the physical realizability of the system $\omega(\tau) = 0$, for $\tau < 0$, $\tau > t$, we obtain

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$$R_{кр} = m_x \int_0^T \omega(\tau)d\tau - m_y + \sum_{i=1}^{n} \xi_i \left[\iint_{00}^{TT} \mathrm{K}_x \cdot (\tau_i - \lambda + \tau)\omega(\tau)d\tau d\lambda - 2\int_0^T \mathrm{K}_{xy}(\tau_i + \tau)\omega(\tau)d\tau + \mathrm{K}_y(\tau_i) \right], \quad (5)$$

where m_x, $m_y$are the mathematical expectation of the input and output signals; $\mathrm{K}_x(\cdot)$ $and\mathrm{K}_{xy}(\cdot)$are, respectively, the auto- and cross-correlation function of random processes x (t) and y (t). Expression (5) represents the functional of the weight function of a model of the type / 3,4 /.

$$R_{кр} = \iint_{00}^{TT} \Phi[t, s, \omega(t), \omega(s)]dtds.$$

The integrand in this case has the form

$$\Phi\big(\tau, \lambda, \omega(\tau), \omega(\lambda)\big) = \sum_{i=1}^{n} \xi_i \mathrm{K}_x(\tau_i - \lambda + \tau)\omega(\tau)\omega(\lambda) - \frac{1}{T}\sum_{i=1}^{n} \xi_i \big[\mathrm{K}_{xy}(\tau_i + \tau)\omega(\tau) + \mathrm{K}_{xy}(\tau_i + \lambda)\omega(\tau)\big] + \frac{m_x}{2T}[\omega(\tau) + \omega(\lambda)]$$

and is a symmetric bilinear form with respect to ω(τ) and ω(λ).

It is easy to show that the estimate of the weight function of the object in this case should satisfy the linear integral Fredholm equation of the first kind

$$\int_0^T \sum_{i=1}^{n} \xi_i \mathrm{K}_x(\tau_i - \lambda + \tau)\omega_0(\lambda)d\lambda - \sum_{i=1}^{n} \xi_i \mathrm{K}_{xy}(\tau_i + \tau) + \frac{m_x}{2} = 0\,,$$

Where $\omega_0(\lambda)$is the optimal estimate of the weight function of the object according to criterion (4). The solution to this equation can be found by the methods described in / 2,3 /.

Considering the above estimates by some generalized coordinates, we obtain an effective mathematical description of complex production processes.

As a result of the above systematization$\widehat{x_o'}$, they can be used to increase the efficiency and quality of the procedure for developing a solution in the control cycles of PCSs using information on the values $\widehat{x_j}$.

The efficiency of the decision-making procedure in the control cycle can be reduced by further systematization and ranking of the submatrixelements $\widehat{x_o''}$. For this purpose, the elements of the matrix $\widehat{x_o'}$are divided into controlled and

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uncontrolled (but controlled) parameters with their further ranking into submatrices of lower dimension according to the following scheme.

We introduce the set $J_1 = \{j\}$, consisting of numbers of unmanaged variables and the set $J_2 = \{j\}$, consisting of numbers of controlled variables. In accordance with the above procedure, using the values of the correlation matrix R_{ij}, the elements of the set J_1 are ordered. For this purpose, the interval (a_0 , a_d) is divided into d subintervals $[a_0 a_1) , [a_1 a_2) , \dots , [a_{d-1}]$.

Next, the first one is taken from the subset J_I, for example, with serial number I with the value of its possible values on the interval $[a_0 a_d]$.

The ordering procedure $\widehat{x_k'}$ in the subset J_1 consists in grouping the subintervals and is determined by the membership $\widehat{x_k'}$ in the corresponding subintervals. The whole set $\widehat{x_k'}$ in each of the above sub-intervals form, respectively, subsets $I_1, I_2, \dots , I_d$. In accordance with the distinguished sets $I_1, I_2, \dots , I_d$., rows in the matrix $\widehat{x_0'}$ are rearranged in such a way that all values of the vector $\widehat{x_j'}$ in the subinterval $\widehat{x_k'} \in [a_0 a_1)$, stood at the beginning (in the upper part) of the matrix, then $\widehat{x_k'} \in [a_1 a_0)$, etc.

Thus, the initial data matrix $\widehat{x_k'}$ according to the values of one of the elements of the subset J_1 is represented as several submatrices of substantially smaller dimension.

Further, for all rows with serial number $i \in I_\alpha , \alpha = \overline{1,d}$, the corresponding model (3) is constructed with respect to some pre-selected output process index. For example, let a variable with serial number q be an output exponent $\widehat{x_q'}$. Then model (3) takes the form

$$\widehat{x_{q_1}'} = f_1\left(\widehat{x_1'}, \widehat{x_2'}, \dots , \widehat{x_k'}, \dots , \widehat{x_{q-1}'}, \widehat{x_{q+1}'}, \dots , \widehat{x_s'}, \widehat{x_{s+1}'}, \dots \widehat{x_l''}\right) \text{for} \widehat{x_k'} \in [a_0 a_1),$$

$$\widehat{x_{q_2}'} = f_2\left(\widehat{x_1'}, \widehat{x_2'}, \dots , \widehat{x_k'}, \dots , \widehat{x_{q-1}'}, \widehat{x_{q+1}'}, \dots , \widehat{x_s'}, \widehat{x_{s+1}'}, \dots \widehat{x_l''}\right) \text{for} \widehat{x_k'} \in [a_1 a_2),$$

.....

$$\widehat{x_{q_d}'} = f_d\left(\widehat{x_1'}, \widehat{x_2'}, \dots , \widehat{x_k'}, \dots , \widehat{x_{q-1}'}, \widehat{x_{q+1}'}, \dots , \widehat{x_s'}, \widehat{x_{s+1}'}, \dots \widehat{x_l''}\right) \text{for} \widehat{x_k'} \in [a_{d-1} a_d).$$

An important advantage of the described approach to organizing information transformation processing technology is that the constructed models of the form (5) can also be used both for predicting the characteristics of the output indicator of an object and for managing them in the future under real production conditions.

The essence of the proposed algorithm for choosing the preferred process model taking into account technological situations is as follows. If the values of the variables of the object with the number j, $j = \overline{1,s}$ are determined on the P -th control cycle, then, when substituting their values in (5), each model determines the values of the output indicator with different accuracy. In this case, the substitution of the values of these variables in a model of type (5) is carried out taking into account their belonging to the subinterval (a_{r-1} , a_r). In this case, the error between the measured and calculated by the model value of the output indicator is determined as follows

$$\delta_r = \left| \widehat{x_{q_r}'^p} - f_r\left(\widehat{x_I'^p}, \dots , \widehat{x_k'^p}, \dots , \widehat{x_q'^p}\, \widehat{x_{q+1}'^p}, \dots , \widehat{x_s'^p}\, \widehat{x_{s+1}''^p}, \dots , \widehat{x_l''^p}\right)\right|$$

$$\text{at } \widehat{x_k'^p} \in (a_{r-1} , a_r) , \qquad \text{where } I \le r \le d.$$

However, there may be cases when the selected model with satisfactory accuracy does not approximate the statistical dependence in a real process.

Let ξ_β be some given accuracy of the desired model. If $\delta_r < \xi_\beta$, then the selected model can be used to solve subsequent optimization and control problems; otherwise, $\delta_r > \xi_\beta$ requires the introduction of adaptation.

One of the possible ways to increase the accuracy of models (4), (5) is to correct them based on the accumulation of statistics during operation.

Thus, the practical implementation of all the steps of the above methodology for choosing the most appropriate structure (type) of the process model can significantly reduce the memory of a personal computer and the time taken to process a large amount of information, and increase the reliability of the model. Consequently, the use of

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reliable models in the normal functioning of the control object leads to a significant reduction in valuable material, energy resources and thereby improves the quality of management.

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