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CONCEPTS OF HYDRO GEOLOGICAL OBJECTS ON THE CONSTRUCTION OF THE MACRO MODE OF A MULTI-STAGE PROCESS

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Annotation

The issues of constructing a mathematical model of a multistage process are considered using the decomposition method, dividing the general technological system into interconnected control loops. A procedure for constructing an integrated macro model of a multistage process using a system of material balance equations for each control loop is presented.

Keywords: multistage process, decomposition, aggregation, simulated object, material balance equations, integrated macro-models, material resource.

1. Introduction. Building a unified mathematical model of a complex multistage production system (MPS) as a whole is impossible because of the multi-factor, multi-criteria and complexity of its functioning. In these cases, it is necessary to decompose the modeled object into a finite number of subsystems, preserving the connections between the subsystems, which take account of the interaction of the subsystems. We continue the procedure of partitioning subsystems until obtaining such subsystems that, under the conditions of the problem we are considering, will be recognized as fairly simple and convenient for direct mathematical description, reflecting the properties of any one class of phenomena. These subsystems, not subject to further dismemberment, are called elements of a complex system.

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When choosing a mathematical apparatus that forms the basis for modeling, an important role is played by the characteristic properties of this class of systems, its elements, their interconnection and interaction.

A mathematical model of a complex multistage system consists of mathematical models of elements and a mathematical model of interaction between elements.

2. Method. The complexity of the construction and use of optimization models in the management of the IPU is that, firstly, the implementation of optimization models will occur under the conditions of the existing control systems, secondly, the main processes of a multistage system are continuously discrete and continuous, and, thirdly, non-linearity is characteristic of many of them.

The difficulties associated with the diversity of the composition of management tasks at individual levels and the need to consider them as a whole with the diversity of the characteristics of the elements and their modes of operation and the resulting hybrid integrated nature of mathematical models pose as priority questions of structuring a multi-stage system, developing principles for modeling and systematizing the models of elements and the entire system. The definition of the optimal structure of the model is closely related to the problem of determining the periodicity of control, the frequency of correction of models of non-stationary subsystems of the complex, as well as the number of levels of the hierarchical system of flexible control. The hierarchical model is a set of system models built for all levels of SU MPS.

The structure of the system model is closely related to the degree of consolidation of technological areas as subsystems of the system. A quantitative measure of aggregation of aggregates can be the degree of aggregation a quantity characterizing the number of system subsystems allocated in the construction of an integrated macro model. The degree of aggregation, in general, is represented by the ratio:

$$S = k_s * m^{-1} ,$$

where m is the number of subsystems allocated during the construction of the integrated macro model; k_s– is the coefficient associated with the structural properties of the system.

The mathematical model of a multistage process is a set of operators (systems of equations) that reflect the models of individual local subsystems and circuits, i.e. the process model follows from the mathematical description of the technological operations involved in the process. Regardless of the nature of the technological scheme and the devices used, the type of material resource and its quality for each of its contour and the entire process, the law of material balance for the overall product and its components is valid. In [1-5] it is noted that to control the technological process of studying the properties of a material resource, it is necessary to know the qualitative and quantitative characteristics of each type of product obtained according to the technological scheme. Such a determination is made on the basis of the balance calculation of schemes, which is reduced to identifying the distribution of the material resource received in the process and its constituent components along the branches of the scheme. In mathematical terms, the balance calculation of schemes is reduced to solving a system of algebraic equations. For each circuit circuit, you can make the following balance equations for the mass of the product [1,2,4].

$$\sum_{s=1}^{k_{i1}} \gamma_{is}^{ent} = \sum_{s=k_{i2+1}}^{k_{i2}} \gamma_{is}^{out}, \qquad i = \overline{1,n} \;;\; s = \overline{1, k_{\iota 1} + k_{\iota 2}}$$

and mass balance of ego components

$$\sum_{s=1}^{k_{i1}} \gamma_{is}^{ent} d_{ijs}^{ent} = \sum_{s=k_{i2+1}}^{k_{i2}} \gamma_{is}^{out} d_{ijs}^{out}, \qquad j = \overline{1,m}.$$

Here i is the circuit contour number; n is the number of contours; j is the component number; m is the number of components; s is the contour product number; k_{i1}, k_{i2} is the number of products at the inlet and outlet of the circuit.

It should be noted that the solution of the system of balance equations is associated with a number of computational difficulties: the high dimensionality of the system, poor conditionality, uncertainty, incompatibility and closeness of technological schemes for processing a material resource. A modern technological scheme for processing material resources cannot be carried out without returning circulating products, when the product is sent from subsequent nodes to the head of the scheme for revision. However, if in the balance calculation of the circuit contour, the task is a pivot to determining the output of a product according to the model described by relatively simple one- or multi component balance equations, then in the technological calculation of the circuit it is necessary to calculate the full product characteristic, which requires the use of both balance and more complex equations.

At the second stage, mathematical models are constructed for each selected contour, taking into account the tasks and limitations arising from the results of the first stage.

Consider the procedure for constructing an integrated macro model ICP.

For the *i* - th circuit of the MPS there are equations of material balance

$$\alpha_i \gamma_{\alpha_i} = \beta \gamma_i + \theta_i \gamma_{\theta_i},$$

$$\gamma_{\alpha_i} = \gamma_{\beta_i} + \gamma_{\theta_i},$$

where $\alpha_i, \beta_i, \theta_i -$ is the content of the useful resource in the diet, in the finished product and in the dump products of the *i*- th circuit; $\gamma_{\alpha_i}\ \gamma_{\beta_i}\ \gamma_{\theta_i}$ is the mass of the material resource of the i - th circuit, respectively, in food, in finished products and in dump products.

3. Results. Flows from other circuits, as well as the initial flow of a material resource, can be fed into the power supply of the *i* - th circuit. From here we get expressions.

$$\alpha_i = \frac{\sum_{j=1}^{\pi}\left(\omega_{ij}\beta_i\gamma_{\beta_i} + \aleph_{ij}\theta_j\gamma_{\theta_j}\right) + \alpha_i^0\gamma_{\alpha_i}^0}{\sum_{j=1}^{\pi}\left(\omega_{ij}\gamma_{\beta_j} + \aleph_{ij}\gamma_{\theta_j}\right) + \gamma_{\alpha_i}^0}, \qquad (1)$$

$$\gamma_{\alpha_i} = \sum_{j=1}^{\pi}\left(\omega_{ij}\gamma_{\beta_i} + \aleph_{ij}\gamma_{\theta_j}\right) + \gamma_{\alpha_i}^0 \qquad (2)$$

Where

$$\omega_{ij} = \begin{cases} I, \; if\ the\ material\ resource\ of\ the \\ j - \text{th circuit enters the input of the} \\ i - \text{th circuit} \\ 0, \; \text{otherwise,} \end{cases}$$

$$\aleph = \begin{cases} \text{I,} \quad \text{if the heap products of the} \\ \text{j} - \text{th circuit arrive at the input of the} \\ \text{i} - \text{th circuit 0, otherwise)} \end{cases}$$

$\alpha_i^0 -$ the content of the useful resource in the source stream;

$\gamma_{\alpha_i}^0 -$ output material resource in the original thread.

Changing and from i to n using equations (1), (2), we compose a system of linear algebraic equations, solving it, we find the following functions:

$$\gamma_{\beta_i} = \gamma_{\beta_i}(\alpha_1^0, \alpha_2^0 \dots, \alpha_n^0, \gamma_{\alpha_1}^0, \gamma_{\alpha_2}^0, \dots, \gamma_{\alpha_n}^0, \beta_1, \beta_2, \dots, \beta_n, \theta_1, \theta_2, \dots, \theta_n),$$

$$\gamma_{\theta_i} = \gamma_{\theta_i}(\alpha_1^0, \alpha_2^0 \dots, \alpha_n^0, \gamma_{\alpha_1}^0, \gamma_{\alpha_2}^0, \dots, \gamma_{\alpha_n}^0, \beta_1, \beta_2, \dots, \beta_n, \theta_1, \theta_2, \dots, \theta_n),$$

Where

i=1,2,..,n .

If β_π and $\gamma_{\beta_\pi}$are taken as the content of the useful material resource in the finished product and its output, then the system of equations is determined from the general material balance according to the technological scheme:

$$\sum_{i=1}^{\pi} \alpha_i^0 \gamma_{\alpha_i}^0 = \beta_n \gamma_{\beta_n} + \theta_{omb} \gamma_{\theta_{omb}} ,$$

$$\sum_{i=1}^{\pi} \gamma_{\alpha_i}^0 = \gamma_{\beta_n} + \gamma_{\theta_{omb}} .$$

From this system we find the expression, i.e. macro models, for the maintenance of a useful material resource in dump products.

$$\theta_{omb} = \beta_\pi - \frac{\beta_\pi \sum_{i=1}^{\pi} \gamma_{\alpha_i}^0 - \sum_{i=1}^{\pi} \alpha_i^0 \gamma_{\alpha_i}^0}{\sum_{i=1}^{\pi} \gamma_{\alpha_i}^0 - \gamma_{\beta_n}}$$

Macro model regarding the content of a useful material resource in the finished product has the form.

$$\beta_\pi = \theta_{omb} - \frac{\theta_{omb} \gamma_{\theta_{omb}} - \sum_{i=1}^{\pi} \alpha_i^0 \gamma_{\alpha_i}^0}{\gamma_{\beta_\pi}}.$$

Similarly, the macro model of the extraction of a useful product in the finished product is determined as follows:

$$\mathcal{E} = \beta_\pi \gamma_{\beta_\pi} \Big/ \sum_{i-1}^{\pi} \alpha_i^0 \gamma_{\alpha_i}^0$$

Thus, at the first stage of modeling, a macro model is built for the whole process, determined using only the input and output parameters of the contours.

At the second stage, the micro model is constructed for individual local subsystems of the IPU according to the principle given in [1,3,5].

The hierarchy of beginning systems under study is described using the original global mathematical model. Then, in accordance with the accepted composition of the hierarchy, the aggregated model of the central system and the detailed micro models of the local subsystems are separated from the original macro model. The problem is reduced - to find the optimal solution to the original mathematical model by interconnecting conditionally - optimal solutions of individual models, after that a comparison of various formal decomposition methods is performed according to previously determined criteria and on this basis the most preferable one is chosen.

At the same time, the top level model is built by aggregating the micro models of the lower level in accordance with the conditionally optimal solutions previously obtained for them. In turn, the aggregated solution found using the top-level macro model is transmitted in the lower-level model and is used by them as a contour within which a detailed solution is searched.

When creating SU MPS, allowing to intensify processes and increase production efficiency, one of the most bottlenecks is the issue of modeling. At the same time, the structure and accuracy of the mathematical model largely determines the efficiency of the entire MPS control system.

Often, models act as integrating elements of control systems, combining and processing information coming from various subsystems of control systems in order to obtain analytical and forecast data from the operation of the control object. The quality of such models - their adequacy, completeness, efficiency, largely determines the level and quality of control of the object as a whole.

Multistage processes are complex modeling systems, the analysis of the dynamics of functioning and the synthesis of optimal solutions for which are possible in real situations only on the basis of the use of computer technology. Therefore, a range of requirements is placed on modeling methods related to the machine orientation of the models, with the possibility of using them in the tasks of a comprehensive analysis of the functioning of a multistage system and the synthesis of a flexible control system. In large terms, this part of the requirement is as follows: modularity, hierarchy, formalizability, machine orientation and versatility. This circumstance is due to the inherent features of mathematical modeling of the IPU.

The first group of discrete - continuous MPS modeling features is related to the special quality of these systems - flexibility, the second - to the high complexity of the modeling process, due to the large variety of elements and options for their integration, as well as the inclusion in consideration when modeling a large number of different types of elements whose coordination is a prerequisite for the organization of interaction elements. The third group of features is associated with high responsibility and laboriousness of the MPS modeling process.

The complexity of discrete-continuous MPS as objects of modeling is due to a number of objective factors, including the heterogeneity of the medium, the heterogeneity of the material on various grounds (size, shape, mineral composition of particles), the complexity of the interaction of various physic chemical factors in the production process. As a result, each technological operation has a different degree of influence on the final results of the TP, therefore, separate control loops have technological sections with a certain number of input and output material and information flows in the SU MPS. The selected contours can be viewed independently of the rest of the MEAs and it is necessary to develop control and identification algorithms for them. For each office, its mathematical model is built, goals, management tasks and technological constraints imposed on the management process are formulated.

The control circuit of the MPS can be represented as a multidimensional object (Fig. 1).

The task of building a mathematical model of a continuously functioning process is formulated as follows.

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Let the input parameter $x(t)$with the components $x_1(t)$, $x_2(t)$, ….. , $x_S(t)$ affect the input of the circuit and output r - output parameter $y(t)$ = $y_1(t)$, ….. , $y_r(t)$ /2,4/, and each of the weekend

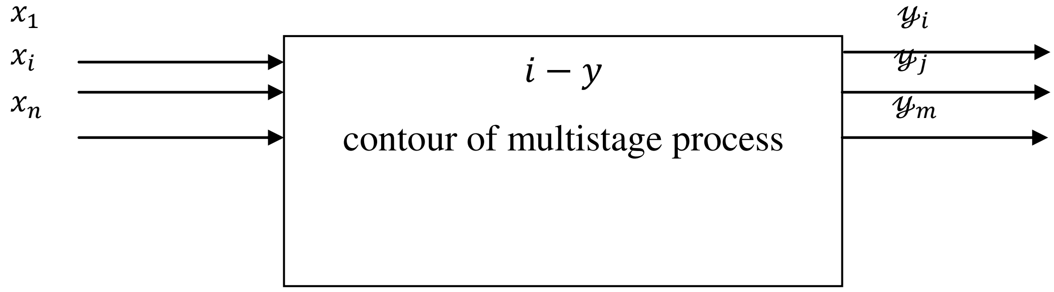

Fig .1. Block diagram of the control circuit.

parameters $y_1(t)$, $y_2(t)$, ….. , $y_r(t)$is completely determined in the probabilistic sense by all or often the input $x_1(t)$, $x_2(t)$, ….. , $x_S(t)$. At the same time, it is impossible in principle to take into account all input parameters affecting the process and output variables, practically it is necessary to confine ourselves to only a small part of the main determining input parameters, the rest are attributed to uncontrolled disturbances (noise). The task of the control system is to compensate for the effect of these disturbances. In addition, certain restrictions $g(x), g(y)$.are imposed on the input and output parameters.

In the general case, the system of equations describing the process under study is expressed as follows:

$$\mathcal{Y}_j = f_j(x_1, x_2, \dots, x_\ell, y_1, y_2, \dots y_{j-1}, y_{j+1}, \dots, y_s, a_0, a_1, \dots, a_m)$$

$$\mathcal{Y} = a_0 + \sum_{i=1}^{k} a_i x_i + \sum_{\substack{\ell,i=1,\\ \ell\neq i}}^{k} a_{\ell i} x_\ell x_i + \sum_{i=1}^{k} a_{ii} x_i^2 + \cdots$$

The function $f_j(j = \overline{1,S})$can be fairly well approximated by the functions $\hat{f}_j(j = \overline{1,S'}, S' < S$), specified up to a set of parameters $b = (b_0, b_1, \dots, b_m)$, i.e.

$$\mathcal{Y}_j \approx y_j^* = \hat{f}_j(x_1, x_2, \dots, x_r, y_1, \dots, y_{j-1}, y_{j+1}, \dots, y_s, b_0, b_1, \dots, b_m) \quad (3)$$

or

$$\mathcal{Y}_j \approx y^* = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{\substack{\ell,i=1,\\ \ell\neq i}}^{k} b_{\ell i} x_\ell x_i + \sum_{i=1}^{k} b_{ii} x_i^2 + \cdots \quad (4)$$

where $j = \overline{1,S'}$ and $b = (b_0, b_1, \dots, b_m)$, are the undefined coefficients of the mathematical model.

Based on experimentally obtained values $\mathcal{Y}_j \in g(y)$ and $x_{i\delta} \in g(x)$, $(j = \overline{1,S'}; \delta = \overline{1,S};\ i = \overline{1,\pi})$ parameters (3), (4) can be estimated using the least squares method / 1-3 /.

When modeling multidimensional systems, one has to operate with various factors that have different units of measurement. Therefore, it is advisable to determine the dimensionless mathematical model, since it is easily analyzed. You can also derive recurrence relations that allow you to move from a dimensionless model to a dimensional one.

For this purpose, instead of components of the initial factors, standardized (dimensionless) components are introduced:

$$C_{x_{is}} = \frac{x_{is} - \mathcal{M}_{xi}}{\delta_{x_i}},\ C_{y_s} = \frac{y_s - \mathcal{M}_y}{\delta_y},\quad \text{S}=\overline{1,m};\quad \text{i}=\overline{1,n},$$

where

$$\delta_{x_i} = \sqrt{\frac{\sum_{i=1}^{m}(x_{is}-\mathcal{M}_{xi})^2}{m-1}}, \quad \delta_{y} = \sqrt{\frac{\sum_{s=1}^{m}(y_s-\mathcal{M}_{y})^2}{m-1}} \;,$$

$$\mathcal{M}_{x_i} = \frac{1}{m}\sum_{s=1}^{m} x_{is} \;, \quad \mathcal{M}_{y} = \frac{1}{m}\sum_{s=1}^{m} \mathcal{Y}_s \;.$$

$$C_{y} = \alpha_1 c_{x1} + \alpha_2 c_{x2} + \cdots + \alpha_n c_{xn}. \quad (5)$$

After simple transformations, we obtain a system of equations for the unknown coefficients α_1, which in matrix form looks like this:

$$D_\alpha = \beta \;, \quad (6)$$

Where

$$D = \begin{vmatrix} d_{11}d_{12}\cdots d_{1n} \\ d_{21}d_{22}\cdots d_{2n} \\ \cdots\cdots\cdots\cdots\cdots \\ d_{n1}d_{n2}\cdots d_{nn} \end{vmatrix}, \quad \alpha = \begin{vmatrix} \alpha_1 \\ \alpha_2 \\ \cdots \\ \alpha_n \end{vmatrix}, \quad \beta = \begin{vmatrix} \beta_1 \\ \beta_2 \\ \cdots \\ \beta_n \end{vmatrix}$$

or

$$\mathrm{D{=}d}(i,j)\,, \;\; \alpha = \alpha(i)\,, \;\; \beta = \beta(i)\,,$$

$$d_{ij} = \frac{1}{m}\sum_{s=1}^{m} C_{x_i S}\, C_{x_j S} \;,$$

$$\beta_j = \frac{1}{m}\sum_{s=1}^{m} C_{y_s}\, C_{x_j S}\,, \qquad i,j = \overline{1,n}$$

If for a quadratic matrix D there exists an inverse matrix D^{-1}then, multiplying (6) from the left by D^{-1} we find the unknown coefficients of the system α_i:

$$\alpha = D^{-1}\beta$$

Substituting the coefficients into an approximate regression equation (5), we find a dimensionless mathematical model (on a standardized scale) to describe the multidimensional system under study.

Thus, at present, the methods of mathematical modeling are the most convenient, reliable, and relatively cheap methods for studying real MPS.

The use of the latest mathematical modeling tools and modern computer equipment mainly determines the prospects of such research.

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