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Simulation Model of a Chemical-Technological Complex with Continuous Character of Production from Interaction Technological and Storage Nodes in Information - Control Systems

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Abstract:
An approach to solving the problem of compensation for losses from perturbations of the chemical–technological complex is proposed, which consists in calculating control actions based on the results of forecasting the consequences of expected perturbations and implementing these effects before the perturbation occurs, while the control object still has sufficient resources to ensure that possible losses do not lead to the failure of planned tasks in information and control systems. A conceptual model of a chemical-technological complex consisted of interacting technological and storage nodes with a continuous nature of production is proposed. An algorithm for simulating the functioning of a chemical-technological complex has been developed, which allows predicting the changing characteristics of its nodes, taking into account perturbations and control actions.

Keywords: *uncertainty conditions, information and control systems, conceptual model of the object, simulation, technological units and complexes, operational and dispatching control of chemical and technological complexes and nodes, interference-signal distortion, unbalance.*

Introduction

Due to the significant improvement in the quality and capabilities of electronic computers, the scope of their application in the management of chemical enterprises has now expanded and deepened, in particular, it has become possible to predict the results of individual divisions and technological complexes under various conditions of their operation, using simulation methods. In this case, the simulation of the functioning of the control object is based on its conceptual model in the form of a system of quantitative ratios and dependencies between the values that characterize the real production process [1].

In control theory, special attention has been paid and continues to be paid to the problem of synthesis of mathematical models of dynamic objects and control algorithms under conditions of useful signals and interference acting on them [2]. This interest has recently increased in connection with the study of poorly formalized complex systems and the development of principles and algorithms in order to manage them.

The experience of creating automated control systems for complex technological objects in conditions of uncertainty and incomplete knowledge about the object, fuzzy descriptions indicates a low efficiency of using only formal classical methods of automatic control theory in information and control

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systems. The increased interest in improbability models of fuzziness and uncertainty can be explained with this factor. L. Zadeh's theory of fuzzy sets, Sevidge's subjective probability, Dempster's upper and lower probabilities that characterize uncertainty in probability theory, Schaeffer's likelihood and confidence [3, 4] are not an exhaustive list of directions focused on modeling dynamic objects based on experimental knowledge and decision – making in the conditions of fuzzy and uncertain initial information about the system under study.

Computer technology is widely used for managing chemical, oil and gas processing plants with continuous nature of technological processes. These and related industries are characterized by the presence of a large number of different types of installations (aggregates), connected to each other in accordance with the technological scheme of material, energy and information flows.

The problems of managing such a class of industrial production can be divided into the problems of maintaining the specified modes of operation of individual technological units, solved by local control systems with fixed input and output flows, and the problems of operational coordination of the work of units with each other, taking into account both internal and external perturbations for the entire complex under study.

Analysis of existing control systems of this class shows that the effectiveness of their functioning is determined primarily by solving the tasks of operational dispatch management. Solving these tasks of operational and dispatching management, which meet significant difficulties among the entire complex of problems of planning and managing the main production facilities of an industrial enterprise. At the same time, operational control algorithms are often unsatisfactory, because they are based on widely used linear models and methods of linear programming and do not take into account the real complexity of production processes, the dynamics of resource changes, the presence of uncertain, but significantly affecting the course of the technological process factors such as, for example, disturbances, noise-signal distortions, etc.

Attempts to construct stochastic models of industrial production and develop methods for solving stochastic programming problems are faced with the fact that: first, the distribution laws obtained for a limited amount of statistical data are not always reliable and stable; second, multidimensional distributions used in these models and problems are difficult to implement on a computer; third, it is not always possible to obtain the distribution law of the parameter under study.

Thus, the task of managing complex industrial production is very difficult because of lacking of knowledge about the features of technological processes; the latter cannot put in accordance with an adequate and at the same time simple model that would allow solving this problem using the methods of conventional control theory [5].

Recently, positive results in applied problems of control of some not completely defined processes have obtained based on the mathematical apparatus of the theory of fuzzy sets by L. Zadeh [6]. However, in general, methods for solving problems of managing complex chemical and technological processes and productions in conditions of uncertainty of initial information and risks remain not developed with exhaustive completeness; there are no universal algorithms for solving such a complex of problems.

Decision of tasks. A conceptual model of a complex chemical-technological complex without recycling

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complexes under various conditions of their operation, using simulation methods. In this case, the simulation of the functioning of the control object based on its conceptual model in the form of a system of quantitative relations and dependencies between the values that characterize the real production process.

Following the authors of works [7,8], the conceptual model of the chemical-technological complex will be understood as a descriptive model that reflects the essence of the object's functioning when considering this process within the boundaries of the goals and objectives of the study.

Characteristic features of a chemical-technological complex with continuous technology are continuity of feed of raw materials and intermediate products to technological nodes; a large (measured in tens) number of technological and storage nodes; interconnection of technological and storage nodes with material flows.

The main purpose of operational dispatch management of production is to perform a shift production task. The main works and calculations that are typical for the operational management system include of assessment of the actual state of the control object at the current time; forecasting the behavior of the object in the planned period; coordination and distribution of resources between the nodes of the control object.

These operations and calculations are complex dynamic tasks in which the dynamics of control is determined by the presence of storage tanks and the dynamic characteristics of technological units.

Let the considered technological complex consist of M technological nodes $\Pi_i (i=1,\dots,M)$ and N storage nodes $C_j (j=1,\dots,N)$. At each moment of time, the technological node Π_i will be characterized by its current performance $g_i(t)$and the maximum possible performance g_i^{max}.In this case, the value of the latter depends on the state of raw materials available to the dispatcher, as well as on the state of the equipment and the regulations of the technological process. The state of the storage node $C_j$at the current time t will be characterized by the value of its fill level $S_j(t)$.

Technological and storage nodes are considered as dynamic links that convert input signals into output signals. Control actions are applied to the input of technological nodes and represent new load values. At the same time, the transition to new loads occurs gradually, over a certain time.

We will assume that technological nodes that produce or consume several types of products produce or consume them in a certain ratio that persists over the entire time interval under consideration.

Under this assumption the structural relationships between the process and storage nodes can be set as a matrix

$$D=(d_{ij})\ (i=1,\dots,M;\ j=1,\dots,N) \qquad (1)$$

The coefficient d_{ij} will be positive if the output node is the input of the drive C_j (i.e., the product produced by the host Π_i), and d_{ij} is negative when the output of the drive C_j is the input of technological $\Pi_i$node (i.e., this product is consumed by node Π_i). If there is no direct connection between the nodes Π_i and C_j, the corresponding element d_{ij}=0. The values of non-zero elements of the matrix D row reflect the existing relationship between the products of the input or output streams of the corresponding technological node.

The current value of the unbalance $B_j(t)$between the receipts of the product to its consumers with the entered symbols set by the expression:

$$B_j(t)=\sum_{i=1}^{M} d_{ij} g_i(t) \qquad (2)$$

The activity of any enterprise is always planned, i.e. a certain program is drawn up that determines the quantity of products that should be released by a certain date. This program is issued to the dispatcher in the form of scheduled tasks $A_i(i=1,\ldots,M)$ for each technological node for the interval of the dispatcher's shift *[D,T]*. At the current time t_1, it is possible to judge the progress of planned tasks by the values of technological units' $G_i(t_1)$ developments. The values of $G_i(t_1)$ are calculated using the formula

$$G_i(t_1) = \int_0^{t_1} g_i(t)dt \qquad (3)$$

The production process is subject to disturbances. When the perturbation associated with the displacement of the optimum production process or when you have to put in place a reserve for replacement of building equipment system control is to maintain the technological nodes, the predefined loads, i.e. control actions that are treated as a change in a previously installed load is not performed.

When perturbations are accompanied by a decrease in the value of the maximum possible production of g_i^{max} to a certain value of g_i^B (lack of raw materials, equipment failures that require some time to restoret_i^B), it becomes necessary to conduct control actions. This need may be related to the output of the storage level interacting with the perturbed process node to one of its boundaries S_j^{max} (overflow) or S_j^{min} (emptying) because of the perturbation-induced increase in the unbalance between the receipt and consumption of the product of this storage. In this case, the control action is carried out in order to reduce the unbalance of the overflowing or emptying storage to "zero" and consists in reducing the loads of the corresponding technological nodes associated with the considered storage devices.

Thus, it is obvious that the interconnectedness of the complex nodes can lead to a situation when changing the program of operation of one technological node requires restructuring the modes associated with it of other nodes. In general, a process called by one node can affect all other nodes.

After the t_i^B recovery time expires, all process nodes can be returned either to the operating modes set before the disturbance occurred, i.e. the control actions in the above sense are not performed, or output to new load values that provide compensation for the resulting losses. In the latter case, it is required a necessary calculation for purpose control actions.

Summarizing the above, it should be noted that by the absence of control actions at any time interval $[t_0, t_1]$, we understand the maintenance of the set values of the loads of technological units $g_i(t_0)$ during all this time, except for periods of recovery or forced work at a lower load associated with the preservation of storage levels within acceptable limits.

When constructing a simulation model of the operation of the control object, we will consider only those disturbances that entail a decrease in the value of the maximum possible production of technological nodes. Other types of perturbations will not be considered in the model, since they do not require the introduction of control actions in the sense we have assumed above.

So, failures of the technological node Π_i can be characterized by the following parameters: $\tau_i, g^B_{i,k_i}, t^B_{i,k_i}$ $(k_i = 1,\ldots,K_i)$, where τ_i– the moment of failure; g^B_{i,k_i} – the value limiting the maximum possible output during the recovery time t^B_{i,k_i}.

The k_i index indicates that a process node may be subject to K_i types of disturbances associated with failures of various types of equipment. Note that in our designations, the failure-free operation of the technological node Π_i at the dispatcher shift interval *[D, T]* corresponds to the value $\tau_i = T$.

High requirements for the reliability of chemical units involved in a continuous technological process, as well as equipment redundancy, allow us to justify the assumption that no more than one failure from the K_i types of failures of this node is possible in

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each technological node during the considered time interval. The results of practical studies of the reliability of $G_i(t_1)$ equipment for chemical production [9, 10] also support the adoption of this hypothesis. However, the assumption that an arbitrary number of perturbations may occur in the interval [D, T] for each of the technological nodes seems more natural. However, frequent failures do not allow the dispatcher to effective manage the course of a continuous technological process, since in this case it would be constantly busy eliminating the consequences of disturbances. In such situations, the problem of solving any other management tasks loses its real meaning.

If there are rare failures, it is unlikely that several perturbations will occur in a single node for a short time in a row. Therefore, the results of our calculations based on the assumption that no more than one failure is possible for each technological node during the dispatcher shift interval should differ little from the results of the same calculations obtained taking into account an arbitrary number of failures. In addition, the assumption that an arbitrary number of failures is possible significantly complicates the computational procedures used in the model.

Thus, at the interval of the dispatcher's shift *[D, T]* in the technological complex, a certain set of failures of technological nodes is implemented, which can be set using a set of x characteristics of these failures

$$x = \left\{\tau_1, g^B_{1,k_1},\ t^B_{1,k_1}, \dots, \tau_M, g^B_{M,k_M}, t^B_{M,k_M}\right\} \quad (4)$$

We denote by *X* the set of sets of characteristics x that describe possible sets of failures of technological nodes during a single dispatcher shift.

Let us turn now to the question of modeling the behavior of the dispatcher. Recall that the main purpose of the developed simulation model is to obtain estimates of situations and expected control actions in terms of the ability to perform planned tasks. Therefore, the most important indicators that are determined using the model are the values of product developments during the dispatch shift$G_i(T)$. Thus, when modeling dispatcher actions, we proceed from the need to maximize the values of$G_i(T)$, if all previously accepted assumptions about the conduct of control actions met.

This can be explained by the example of reducing the load of the process node when the storage of the product consumed by this node is emptied. In the described case, the load of the consumer of the limiting product is reduced to the level of production of this product by its supplier. This is equivalent to "zero" the unbalance for the limiting product.

It is more difficult to solve the same question if the empty drive has several consumers. Reduce the amount of the workings of the group of process units can be achieved in several ways, in particular, a decreased production of one of the group nodes, with decreased production of several or all process units of the group in a certain proportion. The choice of a particular method and the determination of the proportion is based on specific technological information about the process implemented by a specific technological complex. When this is taken into, account the economic value of each product: its cost, price and other economic indicators, performance, use technological equipment, availability of resources, stocks of spare capacity for production of this product and other considerations. In other words, there is a certain decision rule (or set of decision rules) that may change over time, which allows the dispatcher to control the chemical-technological complex when the storage devices reach the emergency limits (S_j^{min}or S_j^{max}). For our research, it is sufficient to suggest the existence of the above-mentioned decisive rules and the possibility of their use in the developed simulation model.

Study of simulation of changing characteristics of the object's state

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When modeling the functioning of the considered technological complex, a continuous approach to the construction of a simulation model of social and industrial objects was used. Forrester. In his works, the modeled object, regardless of the actual observed nature of its functioning, is formalized as a continuous abstract system, between the elements of which continuous flows circulate. At the same time, the system elements are abstract, characterized by their volume and levels of content contained in the object. A characteristic of the effect of one element on another is the rate of the flow that binds them. In the considered model of the chemical-technological complex, "reservoirs" are storage nodes, and the intensity of flows is determined by the production of technological nodes.

In accordance with earlier notation we characterize the state of technological node with the values of generation $g(t)$and groundwork from the start of the shift$G(t)$, and status of cumulative capacity values of the level of its filling and unbalance between the input and output streams$B(t)$.

The change in the level $S_j(t)$ of stocks of the accumulative node C_ (j) at the time interval $[t_0,\ T]$ is described by the ratio

$$S_{j(t_1)} = S_{j(t_0)} + \int_{t_0}^{t_1} B_j(t)\ dt, \qquad (5)$$

Where $B_j(t)$ is the value of the unbalance between the input and output flow of the storage node.

The change in time of the values of the technological node output is determined by the control actions, characteristics of disturbances and the state of storage devices directly connected by material flows to this technological node.

In accordance with the approach proposed in [11, 12], the change in the workings $g_i(t)$ of the technological node *Пi* during transients will be modeled using a piecewise linear function of the form

$$\bar{g}_i(t) = \begin{cases} g_i^0 \text{при} t_0 \le t \le t_0 + B_i, \\ g_i^0 + (t - B_i) \text{при} t_0 + B_i < t_0 + t_i^g, \\ g_i^1 \text{при} t \ge t_0 + t_i^g, \end{cases} \qquad (6)$$

where t_0- the moment when the load changes; g_i^0- the value of output before the transition process begins; g_i^1 - the value of output that is set after the transition process ends; B_i- the time of net delay; P_i^g- the rate of change in the value of output during the transition process; t_i^g- the duration of the transition process, i.e.

$$t_i^g = B_i + \frac{|g_i^1 - g_i^0|}{P_i^g}. \qquad (7)$$

The values B and $P_i^g$are determined based on two conditions. The first of them is the equality of the value of the production time during the transition process, calculated using the function$\bar{g}_i(t)$, and to the real number of products produced during this period, i.e.

$$\int_{t_0}^{t_0+t_i^g} \bar{g}_i(t) dt = \int_{t_0}^{t_0+t_i^g} g_i(t) dt. \qquad (8)$$

The second condition is that the functions $\bar{g}_i(t)$and$g_i(t)$ simultaneously reach the value of g_i^1 that is set after the end of the transition process.

$$t_i^g = g_i^{-1}(g_i^1). \qquad (9)$$

Because of solving the approximation problem (6)-(9) for the values $B_i$andP_i^g, the following expressions are obtained such as:

$$B_i = \frac{(g_i^0 + g_i^1) g^{-1}(g_i^1) - 2 \int_{t_0}^{t_0+t_i^g} g_i(t) dt}{g_1 - g_0}, \qquad (10)$$

$$P_i^g = \frac{|g_i^1 - g_i^0|}{g_i^{-1}(g_i^1) - B}. \qquad (11)$$

The values of the function $g_i(t)$, required to determine the parameters of approximation $B_i$andP_i^gin [9, 10] are proposed to calculate the speed of load change P_i^Rset by the dispatcher using

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the dynamic characteristics of the technological node presented as a weight function on the «load-output» channel.

Identification of weight functions $W_i(t)$, based on the use of data on the normal functioning of the object, is performed using the algorithms given in [13, 14]. At the end of the transition process, the process node retains the steady value of output for the entire remaining interval, except for the time of action of disturbances. In this case, disturbances can occur both in this technological node, and be transmitted to it from other technological nodes through empty or overflowing storage nodes directly connected to this node. During the action of disturbances, the technological node retains the greatest possible output in the current situation. The value of the operating time of the technological node is calculated using the formula (3). The balance between input and output for the storage node is calculated using the formula (2). The change in time in the storage level C $_j$ is expressed in terms of the calculated unbalance according to the expression (1).

To reproduce (simulate) the changing characteristics of the model state on a computer, it is necessary to proceed to finite-difference equations with describes the functioning of the model elements in discrete time. In this case, the assumption is made about the constancy of the values of the workings of technological nodes during each step of the simulation. Due to this, the dependencies between the characteristics of the States of the elements of the considered continuous model are presented in the form of simple finite-difference equations.

Let $g_i(t), G_i(t), (i = 1,2, \dots, M)$ и $S_j(t), B_j(t), \ (j = 1, \dots, N)$ be the current values of the state characteristics of the model elements. Then their values at the next moment $(t + \Delta t)$ of the model time can be determined from the following first-order finite-difference equations.

Change in g_i output in the absence of any impacts is:

$$g_i(t + \Delta t) = g_i(t). \qquad (12)$$

The change in g_i output during the transition process is due to the control action

$$g_i(t + \Delta t) = \begin{cases} g_i(t) + P_i^g \Delta t, & \text{если} (t + \Delta t) > t_0 + B_i, \\ g_i(t), & \text{если} (t + \Delta t) \le t_0 + B_i, \end{cases} \qquad (13)$$

Where B_i and P_i^g are the characteristics of the transition process calculated by formulas (10) and (11) t_0– the initial moment of the control action.

Changing the production time of G_i by the process node:

$$G_i(t + \Delta t) = G_i(t) + \frac{g_i(t+\Delta t) + g_i(t)}{2} \Delta t. \qquad (14)$$

The change in the magnitude of the unbalance B_j. In accordance with the expression (2), we obtain

$$B_j(t + \Delta t) = \sum_{i=1}^{M} dij g_i\,(t + \Delta t). \qquad (15)$$

Changes in the level S_j not:

$$S_j(t + \Delta t) = S_j(t) + \frac{B_j(t) + B_j(t+\Delta t)}{2} \Delta t. \qquad (16)$$

Let be given the initial values of the state of the engineering and features expected in the interval of dispatching the change process units $(\tau_1, g_1^B, t_1^B, \dots, \tau_M, g_M^B, t_M^B)$, where τ_i – moments of occurrence of cracks, g_i^B - the maximum generation value during the time of the action indignation t_M^B.

Algorithm for calculating the changing characteristics of the state of the technological complex (Fig. 1) includes the following main blocks.

Block 1. Calculation of balance values for storage devices using the formula (15). The input parameters are the current values of the workings $g_i(t), (i = 1, \dots, M)$, the result of the block – the values of the unbalances $B_j(t), (j = 1, \dots, N)$.

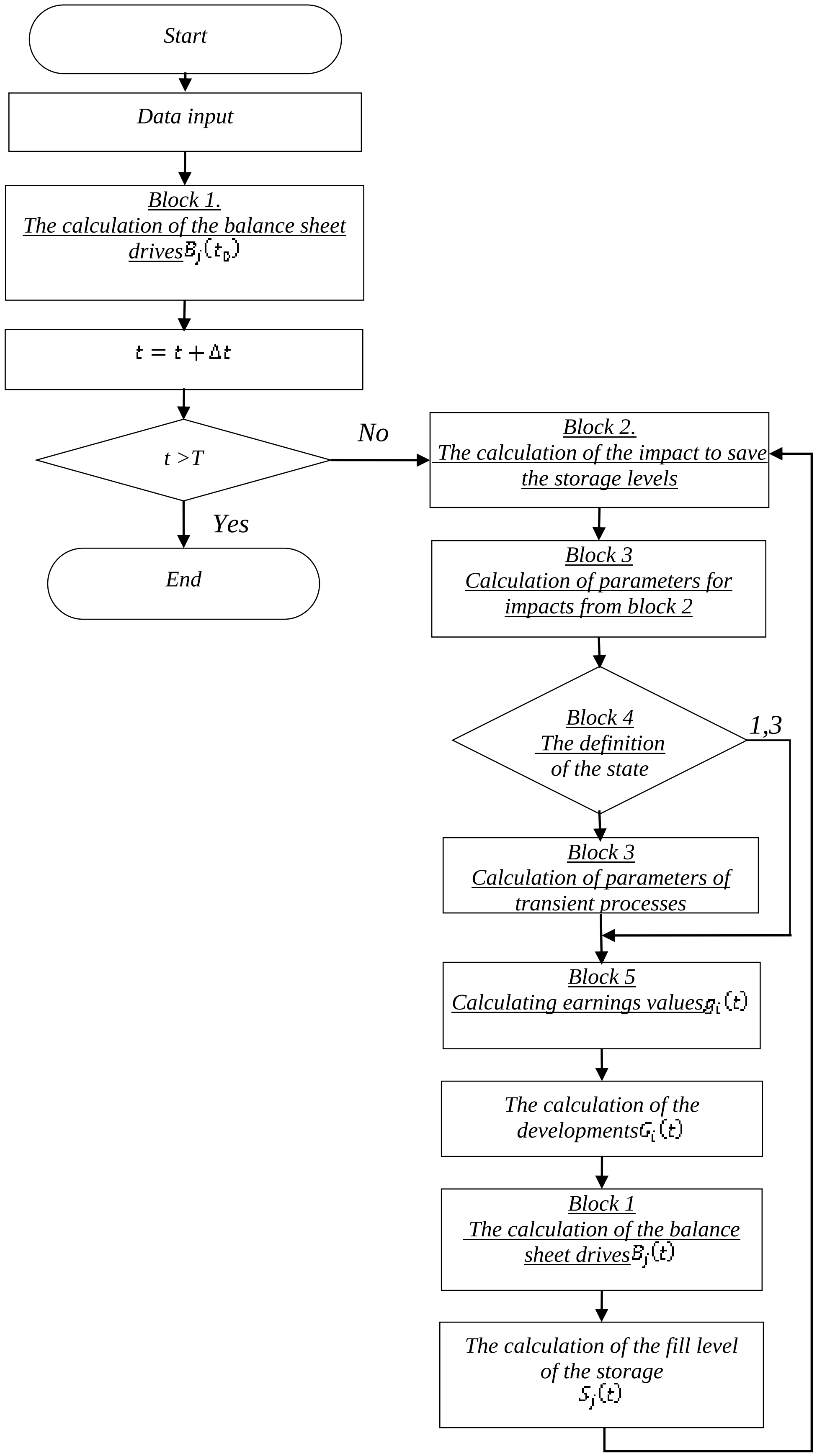

Fig. 1. *Block diagram of the algorithm for simulating the functioning of a chemical and technological complex*

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Block 2. Determining the amount of control actions to keep the storage levels within acceptable limits. The calculation is performed using the following formulas

$$t_j^{г} = \frac{S_j^{ext} - S_j(t)}{B_j(t)}, (j = 1, \dots, N), \qquad (17)$$

where

$$S_j^{ext} = \begin{cases} S_j^{max}, & \text{если }) > 0, \\ S_j^{min}, & \text{если} B_j(t) < 0, \end{cases}$$

$t_j^{г}$ – time when the storage level reaches one of its allowed limits.

The controlling effects on technological nodes are to reduce the earnings of suppliers of overflowing storage devices and reduce the earnings of consumers of emptying storage devices. The values of these impacts are determined from the condition

$$B_j(t + t_j^{г}) = 0. \qquad (18)$$

The transition time t^g is determined by its approximation parameter from expression (7). If $(t + t_j^{г} - t_j^{g}) > T$, then you do not need to make control actions. The input parameters of the block are the values$S_j(t), S_j^{max}, S_j^{min}, B_j(t)$,, the output parameters are$g_i^{г}$, i.e. the workings to which the technological nodes need to go, t_i^{g} - the transition time.

Block 3. Calculation of the characteristics of transient processes when carrying out control actions. This calculation is made in accordance with expressions (10) and (11). The input parameters are the values $g_i(t), g_i^{y}$,and the output parameters are the approximation parametersP_i^{g}, θ.

Block 4. Determining the state of the process node. A process node can be in one of the following States:

1. The absence of effects
2. Start of the transition process
3. Transition process

The "start of transition" state is identified when:

- $t + \Delta t = \tau_i$ – the moment of the start of the perturbation (at this point begins the transition process from the generation $g_i(t)$ to develop g_i^{B}, while the value of g_i^{y} assigned the value of g_i^{B});
- $t + \Delta t = \tau_i + t_i^{B}$– the moment when the restrictions due to perturbation expire (the transition process begins from the production of $g_i^{B}$to the production of $g_i(t_0)$, and the value of g_i^{y} is assigned the value $g_i(t_0)$;
- $t + \Delta t = t_i^{г} -$ the moment when the control action begins when the storage is overfilled or emptied, and the value g_i^{y} is assigned to $g_i^{г}$.

State "transition process" $t_i^{g}$from the beginning of the transition process.

In all other cases, the "no impact" situation is identified. The input parameters of the block τ_i, t_i^{B}, $t_i^{г}$the output parameters are *k*-the number of the identified situation and the values g_i^{y}, t_i^{g}- for the situation "beginning of the transition process".

Block 5. Calculation of changes in the values of workings of technological nodes. In this block, new values of $g_i(t + \Delta t)$ for the next moment of the model time are calculated for the values of the workings $g_i(t)$in accordance with the identified situation.

In the situations of "no impact" and "beginning of the transition process", the values of $g_i(t + \Delta t)$are calculated using the formula (12).

In the "transition" situation, the values of $g_i(t + \Delta t)$ are calculated using the formula (13).

The input parameters of the block are *k*-number of the situation, I-number of the technological node and the values $g_i(t), g_i^{y}, t_i^{g}$,the output parameter is the value of the output $g_i(t + \Delta t)$.

The results obtained in the study of the properties of the proposed conceptual model of a chemical-technological complex with a continuous nature of production, allow us to draw the following conclusions.

In one-step of the simulation algorithm, the transition from the state of the technological complex at moment t to its state at moment $(t + \Delta t)$ occurs. To do this, to performed the following calculations.

Based on the current values of balances and storage fill levels, the need to make control actions to keep their levels within acceptable limits is determined. If the impact is necessary, the output value of $g_i^r$is calculated, the start time of the transition processt_i^r, and the duration t_i^g (blocks 2 and 3).

Then, in the cycle for each technological node, its state is identified (block 4), the value of $g_i(t + \Delta t)$ is calculated (block 5), and the value of $G_i(t + \Delta t)$ is calculated using the formula (14).

At the end of the cycle, first the balance values $B_j(t + \Delta t)$(block 1) are calculated for all storage devices, and then the values $S_j(t + \Delta t)$ according to the formula (16).

The accuracy of calculations and the time spent on all calculations depend on the size of the modeling step Δt. Therefore, the choice of this value should be made for each specific case.

Conclusion

The proposed approach to solving the problem of compensation for losses from perturbations of the chemical-technological complex consists in calculating control actions based on the results of predicting the consequences of expected perturbations and implementing these actions before the perturbation occurs, while the control object still has sufficient resources to ensure that possible losses do not lead to the failure of planned tasks.

The developed algorithm for simulating the functioning of the technological complex allows us to predict the changing characteristics of its nodes, taking into account the disturbing and controlling effects.

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