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CYBERNETIC ESTIMATION OF RESERVE UTILIZATION EFFICIENCY

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This study relates to the field of verification of cybernetic estimates of the use of reserves as criteria for the effectiveness of transformative class systems with a continuous supply of a technological product.

The task set here attracted even more attention after the advent of improved approaches that make it possible to automatically change the control trajectories of technological systems in real time. In such cases, the assessment of the current status of the process and the efficiency of stock management has become an integral part of the operation of the management subsystems. Therefore, the development and verification of cybernetic assessment of effectiveness for such control systems is a relevant issue.

The first stage of the reported research involved the development of a cybernetic model of operation with distributed parameters. Four formal features have been proposed. Finding integral functions of these features has made it possible to obtain an idea of some quantitative characteristics of the process while finding the second time-dependent integral characteristic has made it possible to represent the physical and cybernetic parameters of the process.

At the second stage, formulas for calculating the main assessment indicators were proposed; their verification was carried out under three different control trajectories, which showed the adequacy of the devised approach.

The final step was to develop three variations of the efficiency formula, which is calculated at set points in time throughout the entire production cycle.

Thus, cybernetic assessment of the effectiveness of the use of reserves makes it possible to formalize and fully automate the processes of optimization and adaptation of the functional systems of an enterprise

Keywords: continuous process, verification, efficiency system, efficiency criterion, management lever

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1. Introduction

From the point of view of cybernetics, the goal of any process is to obtain a high-quality product at the output from the system in the required quantity, taking into consideration the rational utilization of reserves. To achieve the set goals, control subsystems of a different nature are used. Optimization criteria make it possible to assess the effectiveness of a particular control trajectory that best corresponds to the owner's (supersystem's) idea of the best scenario. One such development, of course, is the rational use of inventories in order to minimize production costs.

Most production processes consist of conversion class systems with a continuous supply of technological product. When evaluating such systems, it is necessary to take into consideration the time-distributed nature of binding and releasing, respectively, the input and output products of the operation.

The only possible option for the operation of conversion class systems with a continuous supply of the technological product was to establish rigidly fixed starting control effects. And, to make any changes to the control subsystem, it was necessary to pause the process in order to reconfigure the systems.

However, with the advent of the possibility of increasing the number of degrees of freedom of control over technological mechanisms, it became possible for technological processes to work with a parallel change in control trajectories under the dynamically changing external environmental conditions [1, 2]. That made it possible to make adjustments to the production process in real time [3].

Thus, with the advent of self-adjusting, continuously operating technological systems, the importance of control interventions and the assessment of their effectiveness deserves even greater attention and requires devising scientifically-based approaches. Therefore, the development of a cybernetic assessment of the effectiveness of the utilization of reserves is a relevant task.

2. Literature review and problem statement

Inventory control in multi-part, resource-intensive production is always seen as critical management to continuously improve production efficiency. After all, it has long been a well-known fact that the dependence of the Ukrainian economy on the conjuncture is precisely in its energy sector [4]. And the task of efficient use and distribution of available energy resources for many countries is one of the fundamental.

For example, article [5] improves energy efficiency by optimizing the drying process. A new mixed-flow dryer geometry has been developed, which should equalize the drying process and thus be more energy efficient. However, the cited research tackles only the improvement of the energy efficiency of production and does not take into consideration, when optimizing, other types of inventories used, which make up a considerable percentage of the total cost of production.

Attempts to take into consideration other types of stocks were reported in [6], which proposed a comprehensive accounting of the cost of the output product, material, and time costs. The method of optimization of management, which is considered in the cited article, uses a verified performance indicator; the experimental evidence of its performance is given. However, the approach was intended for portion heating of the liquid; its application for continuous processes is not justified.

Article [7] assessed the effectiveness of the continuous method of operation of the decanter centrifuge for the processing of olive oil. The possibility of changing the operational modes without stopping the entire process and assessing the energy and functional efficiency of the decanter are described. However, according to the results of the cited article, only preliminary results were obtained; the final verification of the performance assessment was not performed.

Paper [3] reports experimental research and mathematical modeling of a continuous, highly efficient process of separating coal seam methane from a porous suspension. The results of the experiments and the simulation of the process described in the paper provide basic data for the design and operation of the pilot and industrial plants. However, the assessment of the effectiveness of the process is again only for energy costs.

Paper [8] gives a model of the system of continuous processing of raw materials, which provides a quantitative assessment of the parameters that directly affect the efficiency. The overall efficiency of the process is calculated according to a verified criterion, taking into consideration the total costs and the cost of the finished product. To such costs, the author includes cost estimates of energy used and the resource of the processing and transporting parts, cost estimates of the volume and quality of output products. However, it is not always necessary to take into consideration only these types of reserves used.

Accounting for the reserves used as units of value, such as raw materials, resources, and energy of the processing and transporting part of the installation is shown in work [9]. However, all models are described specifically for the technological line of drying of granular products in a drum furnace with zone and axial burners using various types of fuel. This suggests that the author does not guarantee the applicability of efficiency assessment and optimization of operating modes for other classes of continuous processes.

Article [10] describes the method of automatic search an extremum of efficiency in multi-stage processing of raw materials. Within the framework of the method, an algorithm for calculating the efficiency coefficient of using the resources of the system and an algorithm for searching for the extremum are proposed. However, due to the limited number of degrees of freedom for the control system, the search for the efficiency extremum occurs on a limited number of control trajectories, which would not necessarily lead to finding the optimal solution.

Paper [11] proposes to manage the pumping system according to the criterion of maximum income, which does not correspond to the purpose of the paper, namely the optimal management of continuous technological processes according to the criterion of the minimum reserves used.

Thus, there is a large choice of options for assessing the effectiveness of technological continuous processes. However, detailing a specific type of process does not make the developed approaches cybernetic. Alternatively, the use of non-verified estimates does not reveal the real picture of the effectiveness of resource utilization, and, in some cases, leads to additional financial losses. Therefore, it is necessary to develop and verify the cybernetic assessment of effectiveness.

3. The aim and objectives of the study

The aim of this work is to devise cybernetic evaluation indicators as criteria for the effectiveness of using stocks of conversion class systems with a continuous supply of a technological product.

To accomplish the aim, the following tasks have been set:

– to identify formal features suitable for use in the future in assessing the effectiveness of continuous technological processes;

– to justify the choice of the main estimates of the operational process of converting a constant flow of input products into outputs, with the help of which it is possible to make judgments about the operational process;

– to derive the formulas for calculating the cybernetic assessment of the effectiveness of the use of reserves;

– to verify the evaluation indicators as performance criteria for three different control trajectories of continuous transformative processes.

4. The study materials and methods

To define the cybernetic assessment of the use of continuous process reserves at certain points in time, it is necessary to constantly monitor the input and output parameters of the operational process.

For different processes, the input and output products of the operation may differ slightly. However, bringing the studied process to a technical-cybernetic model, one can talk about such input products as the input product of directed action, the energy product that is necessary for the operational process, the intensity of the use of technical equipment.

The use of a multi-section technological mechanism, proposed in [1, 2], makes it possible to take as a basis the assessment of the operation of systems with a portioned supply of a technological product and improve the proposed approach. Thus, a continuous technological process undergoes short-portion processing with the number of sections depending on the specificity of the process.

When evaluating the operation of conversion class systems, it is necessary that the quantitative parameters of all input and output products of the operation are comparable to each other. Given that the natural scaling factor in economic systems is the cost of a unit of system product (C/S), this category was chosen, which was verified for its adequacy to the formula for resource efficiency [12].

This paper proposes to estimate the use of reserves in three different control trajectories using modified parameters and additional variables that characterize the dynamics of a continuous technological process.

At the first control trajectory (hereinafter referred to as control trajectory No. 1), after the start of the converter process, stocks are immediately supplied to the system input. The rate of change in the number of inventories over time $\left(dre^{*}_{s_1}/ds\right)$ and their valuation is shown in Fig. 1, where s are certain points in time at which current information about the process is collected. Depending on the type and nature of the continuous process, the monitoring intervals of the current state of the process are selected individually. Given that the continuous process is transformed into a short-portion process, with the help of structural changes, Fig. 1 demonstrates the tooth-shaped trajectory of stock consumption.

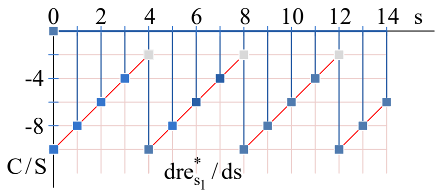

Fig. 1. Integral function of inventory valuations in control trajectory No. 1

The use of inventories of one operational process is described in more detail below (Fig. 2).

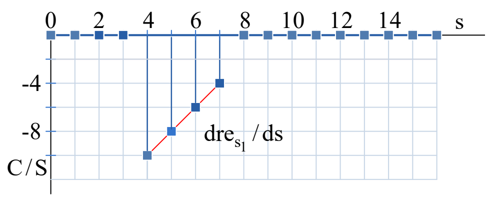

Fig. 2. Integral inventory utilization function for a single operational process under control trajectory No. 1

The result of the movement of the input and output products of the conversion class system at the moments of information registration (n) was described as a set of functions re_n and pe_n, respectively:

$$re_n = C\begin{cases} re_{n_i}, n = n_i, \\ 0, n \neq n_i, \end{cases} \quad (1)$$

$$pe_n = C\begin{cases} pe_{n_i}, n = n_i, \\ 0, n \neq n_i, \end{cases} \quad (2)$$

where re_n is the cost estimate of input technological products at the n-th point in time for the i-th control trajectory; pe_n is the cost estimate of output technological products at the n-th point of time of the i-th control trajectory; C is the unit cost of the system product for the i-th control trajectory.

As a result of the operation of the conversion class system, at the tenth registered point in time, information was obtained on the cost estimate of the output technological product at the n-th point in time for the i-th control trajectory (Fig. 3).

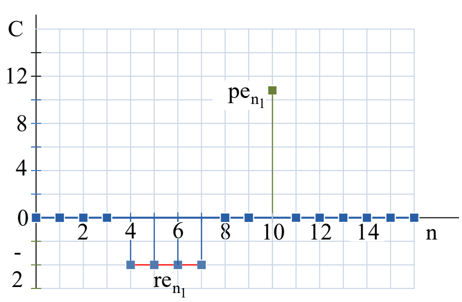

Fig. 3. Graphical representation of the operation with distributed parameters in control trajectory No. 1

It is obvious that any change in control leads to a change in the re_n and pe_n parameters described above. Given this, one can talk about the possibility of assessing the effectiveness of the use of continuous process reserves precisely according to the parameters of such a global operation model (GOM).

Consequently, such an operation model contains all the necessary information for a comparative assessment of the processes of the conversion class with a continuous supply of the technological product regarding the efficiency (rationality) of the use of reserves.

Thus, a model of the operation of the type (re_n, pe_n) is obtained, which is cybernetic for a continuous process with distributed parameters.

Based on certain parameters of the operational process, in order to assess inventory usage, further analysis of the system is described below.

It is obvious that a decrease in the number of stocks used and a stable amount of high-quality output product would make it possible to argue about a more rational operation of the production system. Given the continuity of the process, a method for calculating reserves must be determined to estimate the use of reserves.

Since the process of using stocks does not take place in an even manner and depends on the specificity of the production line and the currently chosen control trajectory, multiplying time by the amount of inventory used per unit of time is not appropriate. Integration is therefore more appropriate.

To obtain integral comparable estimates of the input and output operation, the following formulas for calculating the integrated functions of the result of the movement of input (ire_n) and output (ipe_n) products at w_g point in time for a continuous technological process are proposed:

$$ire_{w_g} = re_{n_i}\left(n_i - n_{i-1}\right) + ire_{w_g-1}, \text{ CW}; \quad (3)$$

$$ipe_{w_g} = pe_{n_i}\left(n_i - n_{i-1}\right) + ipe_{w_g-1}, \text{ CW}. \quad (4)$$

The dynamics of obtaining integral comparable estimates of the input and output operation are shown in Fig. 4. As Fig. 4 demonstrates, after the 9th fixed time point, one can see the profitability of the process since the valuation ire_n exceeded ipe_n and continued to subsequently maintain this advantage.

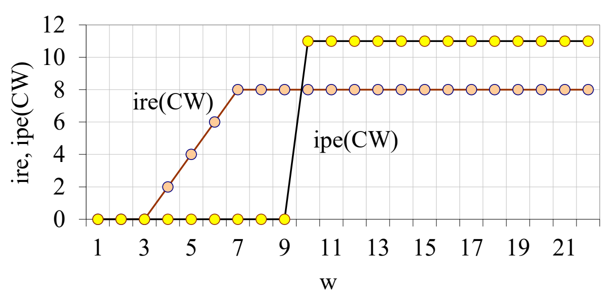

Fig. 4. Dependence of the values of the integral function of cost estimates of input and output products on time

Sensitivity to the time of capturing a certain amount of cost estimates is demonstrated by the second integral function vre_{u_f} of the input function ire_{w_g}:

$$vre_{u_f} = ire_{w_g}\left(w_g - w_{g-1}\right) + vre_{u_f-1}, \text{ CWU}; \quad (5)$$

$$vpe_{u_f} = ipe_{w_g}\left(w_g - w_{g-1}\right) + vpe_{u_f-1}, \text{ CWU}. \quad (6)$$

Finding the second integral characteristic for time has made it possible to represent the physical-cybernetic process parameters. Fig. 5 shows the sensitivity to the time of capturing a certain amount of valuations.

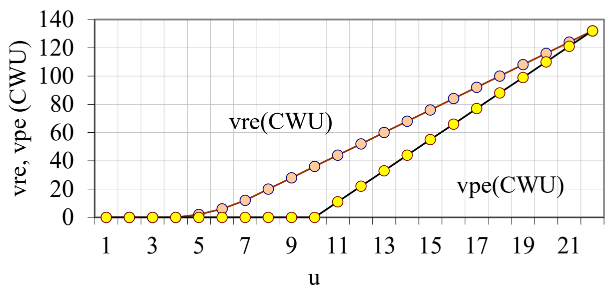

Fig. 5. Change in the values of the second cumulative series of input (*re*) and output (*pe*) products dependent on time

Since the GOM parameters respond to any change in control, cybernetic indicators would make it possible to evaluate the system under study with a continuous supply of the technological product from the maximum number of aspects.

One of the cybernetic indicators is the integral added value function dif_{uf}, which can be calculated as the difference between vre_{uf} and vpe_{uf} at the u_f-th point in time:

$$dif_{u_f} = vre_{u_f} - vpe_{u_f},\ \text{CWU}. \quad (7)$$

The dynamics of the change in the proposed cybernetic indicator on time, namely the added value indicator, can be seen in Fig. 6.

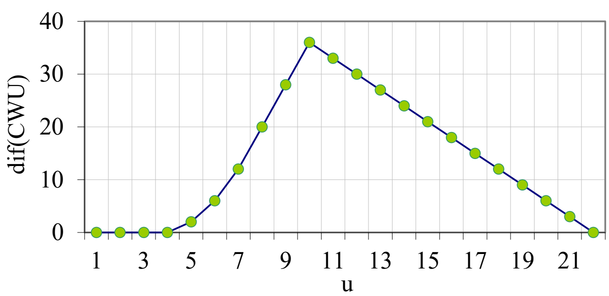

Fig. 6. Dependence of the integral added value function on time

The value of accumulated added value at the V_j-th point in time can be calculated as:

$$r_{v_j} = dif_{u_f}\left(u_f - u_{f-1}\right) + r_{v_j-1},\ \text{CWUV}. \quad (8)$$

The amount of accumulated added value dependent on time is shown in Fig. 7.

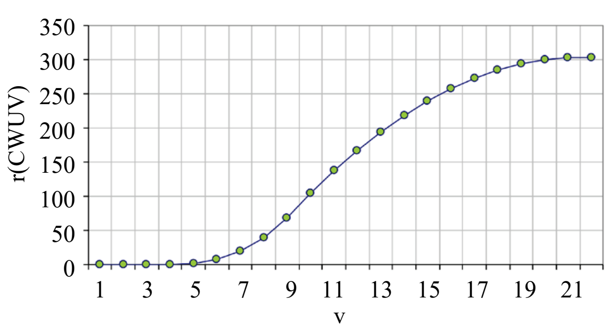

Fig. 7. Amount of accumulated added value over time

Based on the analysis of the system at the first control trajectory, it can be concluded that the main indicators for assessing the effectiveness of the conversion class system with a continuous supply of the technological product for a certain control trajectory include:

– potential effect of the operation:

$$A = \left(PE - RE\right)/2,\ \text{CWUV}, \quad (9)$$

where *PE* is the function of the results of the movement of the output products of the operation in cases where the distributed nature of the function pe_n can be neglected; *RE* is the function of the results of the movement of the output products of the operation in cases where the distributed nature of the function re_n can be neglected;

– resource intensity of the operational process:

$$R = dif_{u_f}\left(u_f - u_{f-1}\right) + r_{v_j-1},\ \text{CWUV}; \quad (10)$$

– efficiency of operation resource utilization:

$$ELF = A/R. \quad (11)$$

Thus, having analyzed and assessed the dynamics of the study process, it became possible to move on to the next stage of research.

5. Results of studying the quantity of consumption of stocks in continuous conversion production

5. 1. Definition of formal features of continuous technological processes

In the case when production systems of a continuous class can change the control trajectory, the task arises of comparing the number of stocks used and determining the effectiveness of each of them. For these purposes, it may be necessary to introduce additional formal features and a more detailed analysis of the process under study.

Below is another option for controlling a conversion class system with a continuous supply of a technological product. As can be seen from Fig. 8, in one of the cycles, the rate of change in the number of stocks over time was changed compared to the previous control trajectory. Red markers show the checkpoints at which the operation of the system differs in the first and second control trajectories. This case is described in more detail below (Fig. 9).

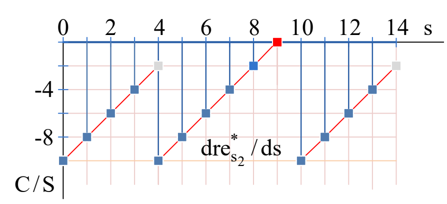

Fig. 8. Integral function of inventory valuations in control trajectory No. 2

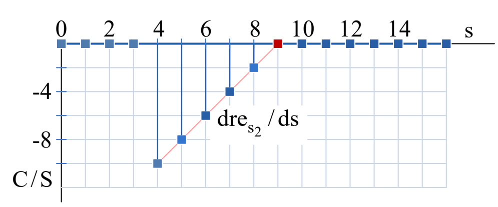

Fig. 9. Integral inventory utilization function for a single operational process in control trajectory No. 2

Assessing the changes in the cost estimates of the output product under the second control trajectory, one can talk about two control moments in time. The first reference point in time (n=8) is when changes in inventory usage are already visible but the values of the output product have not yet changed (Fig. 10). At the second checkpoint, while continuing to use additional stocks, there is a jump in the amount of value of the output product (Fig. 11).

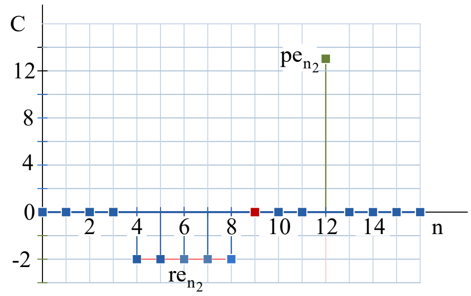

Fig. 10. Graphical representation of the operation with distributed parameters in control trajectory No. 2 at the first control point in time

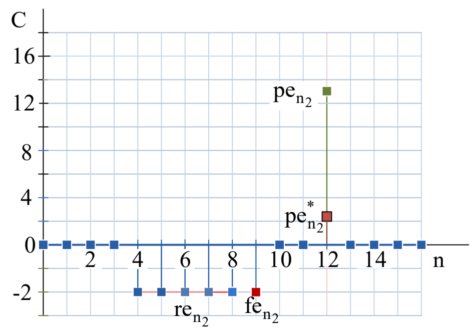

Fig. 11. Graphical representation of the operation with distributed parameters under control trajectory No. 2 at the second control point in time

Thus, to assess the change in the number of stocks used and as a result, the change in the valuation of the output product, it is necessary to introduce additional formal features: fe_{n_i} – the function of the results of the movement of an additional number of value estimates of input technological products at the i-th point in time, and $pe^*_{n_i}$ – the cost assessment of the output technological products at the i-th point in time when using fe_{n_i}.

An improved model of the operation of the type (re_n, fe_n, pe_n, pe^*_n) is obtained, which is cybernetic for a continuous process with distributed parameters with the ability to change control trajectories.

In such cases, the integrated functions are calculated as follows:

$$ire_{w_g} = re_{n_i}\left(n_i - n_{i-1}\right) + ire_{w_g-1}, \text{ CW;} \tag{12}$$

$$ife_{w_g} = fe_{n_i}\left(n_i - n_{i-1}\right) + ife_{w_g-1}, \text{ CW;} \tag{13}$$

$$ipe_{w_g} = \left(pe_{n_i} + pe^*_{n_i}\right)\left(n_i - n_{i-1}\right) + ipe_{w_g-1}, \text{ CW.} \tag{14}$$

The calculation of the double integral would make it possible to find the value of the second cumulative series of input (re_n and fe_n) and output (pe_n and pe^*_n) products of the continuous technological process where:

$$vre_{u_f} = ire_{w_g-1}\left(w_g - w_{g-1}\right) + vre_{u_f-1}, \text{ CWU;} \tag{15}$$

$$vfe_{u_f} = ife_{w_g-1}\left(w_g - w_{g-1}\right) + vfe_{u_f-1}, \text{ CWU;} \tag{16}$$

$$vpe_{u_f} = ipe_{w_g-1}\left(w_g - w_{g-1}\right) + vpe_{u_f-1}, \text{ CWU.} \tag{17}$$

To test the proposed improved model, the third option for controlling the conversion class system is considered (Fig. 12). In this case, the number of used stocks per production process was changed again (Fig. 13).

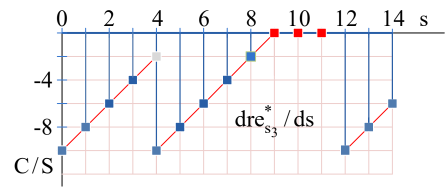

Fig. 12. Integral function of inventory valuations in control trajectory No. 3

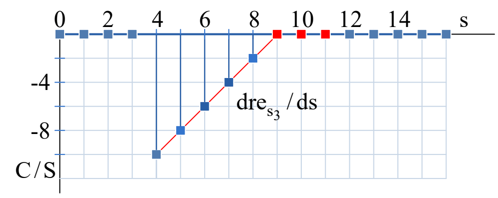

Fig. 13. Integral inventory utilization function for one operational process in control trajectory No. 3

As can be seen in Fig. 14, with a slight increase in the amount of inventory used, the proposed distributed parameters operation model does not show a response at the output of the system. However, with further positive dynamics of the increase in stocks, changes also occur in the function of the results of the movement of the output products of the operation (Fig. 15).

Comparing the graphical representation of the operation with the distributed parameters in control trajectory No. 2 (Fig. 11) and control trajectory No. 3 (Fig. 15), it is possible to see the dependence and dynamics of changes in the cost estimates of the output products of the operation on the input ones. This shows the efficiency and adequacy of the selected formal features of the operation model, starting from which, it is possible to make a judgment about the operational process.

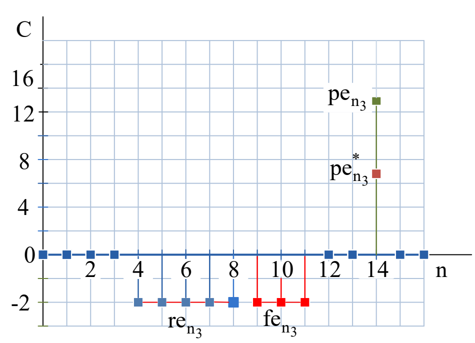

Fig. 14. Graphical representation of the operation with distributed parameters in control trajectory No. 3 at the first control point in time

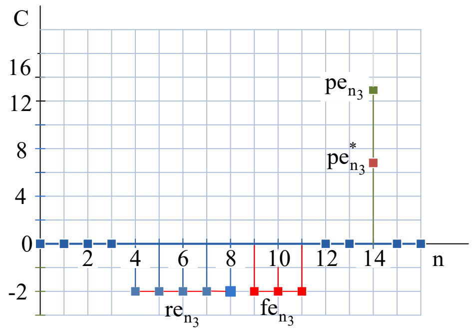

Fig. 15. Graphical representation of the operation with distributed parameters in control trajectory No. 3 at the second control point in time

Thus, the formal features of the model of operation with distributed parameters for a continuous process are determined, namely the function of the results of the movement of the input products function of the results of the movement of additional input products, at which there is a change in the function of movement of the output products.

In a general form, the formulae for calculating the integrated functions of the result of the movement of the proposed formal features can be represented:

$$ire_w = \sum_{w_0}^{w} re_n, \text{ CW;} \quad (18)$$

$$ife_w = \sum_{w_0}^{w} fe_n, \text{ CW;} \quad (19)$$

$$ipe_w = \sum_{w_0}^{w} \left(pe_n + pe_n^*\right), \text{ CW.} \quad (20)$$

The second cumulative series is just the integral function vre_u of the function ire_w for the result of the movement of the input products and the integral function vpe_u of the function ipe_w for the result of the output products movement:

$$vre_u = \sum_{u_0}^{u}\sum_{w_0}^{w} re_n, \text{ CWU;} \quad (21)$$

$$vfe_u = \sum_{u_0}^{u}\sum_{w_0}^{w} fe_n, \text{ CWU;} \quad (22)$$

$$vpe_u = \sum_{u_0}^{u}\sum_{w_0}^{w} \left(pe_n + pe_n^*\right), \text{ CWU.} \quad (23)$$

The calculation of integral functions can also be represented as:

$$ire_g(w) = \int_{w_0}^{w} \left(re_n(t)\right) dw = \{w \geq w_g, \text{ cw;} \quad (24)$$

$$ife_g(w) = \int_{w_0}^{w} \left(fe_n(t)\right) dw = \{w \geq w_g, \text{ cw;} \quad (25)$$

$$ipe_g(w) = \int_{w_0}^{w} \left(pe_n(t) + pe_n^*(t)\right) dw = \{w \geq w_g, \text{ cw,} \quad (26)$$

where *cw* are the units of value; w_0 – the start time of the continuous process.

Double integration as:

$$vre_f(u) = \int_{u_0}^{u}\int_{w_0}^{w} \left(re_n(t)\right) dw du = \{u \geq u_f, \text{ cwu;} \quad (27)$$

$$vfe_f(u) = \int_{u_0}^{u}\int_{w_0}^{w} \left(fe_n(t)\right) dw du = \{u \geq u_f, \text{ cwu;} \quad (28)$$

$$vpe_f(u) = \int_{u_0}^{u}\int_{w_0}^{w} \left(pe_n(t) + pe_n^*(t)\right) dw du = \{u \geq u_f, \text{ cwu.} \quad (29)$$

Thus, the formal features designed to assess the effectiveness of the use of continuous process stocks are the use of global input and output functions, as well as the application of a time-dependent double integration procedure.

5. 2. Substantiation of the choice of the main evaluation indicators of the operational process with a continuous supply of the technological product

Taking into consideration the introduced additional formal features, changes have been introduced to the formulas of the main evaluation indicators of the operational process. The integral added value function would consist of three components:

$$dif_{u_f} = vre_{u_f} + vfe_{u_f} - vpe_{u_f}, \text{ CWU.} \quad (30)$$

The value of the accumulated added value at the *i*-th time point is calculated:

$$r_{v_j} = dif_{u_f}\left(u_f - u_{f-1}\right) + r_{v_j - 1}, \text{ CWUV.} \quad (31)$$

Thus, the calculation of the main indicators for assessing the efficiency of the conversion class system with a continuous supply of the technological product takes the following form:

$$R = dif_{u_f}\left(u_f - u_{f-1}\right) + r_{v_j - 1}, \text{ CWUV;} \quad (32)$$

$$A = \left(\left(PE + PE^*\right) - \left(RE + FE\right)\right)/2, \text{ CWUV,} \quad (33)$$

where *FE* is the function of the results of the movement of an additional number of value estimates of the input technological products in cases where the distributed nature of the function can be neglected, PE^* is the function of the results of the movement of value estimates of the output technological products in cases where the distributed nature of the function can be neglected.

In a general form, the main estimates of the operational process of converting a constant flow of input products into outputs, with the help of which it is possible to make a judgment about the operational process, are presented below:

$$dif_u = \sum_{u_0}^{u}\sum_{w_0}^{w}\left(\left(re_n + fe_n\right) - \left(pe_n + pe_n^*\right)\right), \text{ CWU;} \quad (34)$$

$$r_v = \sum_{v_0}^{v}\sum_{u_0}^{u}\sum_{w_0}^{w}\left(\left(re_n + fe_n\right) - \left(pe_n + pe_n^*\right)\right), \text{ CWUV;} \quad (35)$$

$$R = \sum_{v_0}^{v_l}\sum_{u_0}^{u}\sum_{w_0}^{w}\left(\left(re_n + fe_n\right) - \left(pe_n + pe_n^*\right)\right), \text{ CWUV.} \quad (36)$$

In cases where the distributed nature of the functions re_n, fe_n and pe_n, pe_n^* can be neglected, the object of the operation study is the five *RE*, *FE*, *PE*, PE^*, *TO*, where the potential effect of the operation is calculated:

$$A=\left[\left(\left(PE+PE^*\right)-\left(RE+FE\right)\right)\left(v_d-v_l\right)^2\right]/2,\ \text{CWUV}. \quad (37)$$

Evaluation indicators can also be represented in the form:
– an integral function of added value:

$$dif_f(u)=\int_{u_0}^{u}\int_{w_0}^{w}\begin{pmatrix}\left(re_n(t)+fe_n(t)\right)-\\-\left(pe_n(t)+pe_n^*(t)\right)\end{pmatrix}\mathrm{d}w\mathrm{d}u=\left\{u\geq u_f\right.,\ \text{cwu}; \quad (38)$$

– resource intensity:

$$r_j(v)=\int_{v_0}^{v}\int_{u_0}^{u}\int_{w_0}^{w}\begin{pmatrix}\begin{pmatrix}re_n(t)+\\+fe_n(t)\end{pmatrix}-\\-\begin{pmatrix}pe_n(t)+\\+pe_n^*(t)\end{pmatrix}\end{pmatrix}\mathrm{d}w\mathrm{d}u\mathrm{d}v=\left\{v\geq v_j\right.,\ \text{cwuv}; \quad (39)$$

– the resource intensity of the operational process during the change of the control trajectory v_1 can be found:

$$R=\int_{v_0}^{v_l}\int_{u_0}^{u}\int_{w_0}^{w}\begin{pmatrix}\left(re_n(t)+fe_n(t)\right)-\\-\left(pe_n(t)+pe_n^*(t)\right)\end{pmatrix}\mathrm{d}w\mathrm{d}u\mathrm{d}v=$$
$$=\left\{v\geq v_j, v\in\left[v_0,v_l\right]\right., \text{cwuv}, \quad (40)$$

where v_1 is the time to determine the potential effect of the operation at the time of changing the control trajectory;
– the potential effect of the operation is calculated:

$$A=\int_{v_l}^{v_d}\int_{u_0}^{u}\int_{w_0}^{w}\begin{pmatrix}\left(pe_n(t)+pe_n^*(t)\right)-\\-\left(re_n(t)+fe_n(t)\right)\end{pmatrix}\mathrm{d}w\mathrm{d}u\mathrm{d}v=$$
$$=\left\{v\geq v_j, v\in\left[v_l,v_d\right]\right., \text{cwuv}, \quad (41)$$

where $v_d=v_1+1$ is the time between the end of one control trajectory and the calculation of the potential effect [13].

Thus, the main estimated indicators have been improved, namely the integral function of added value dif_i, the resource intensity *r*, the resource intensity of the operational process *R*, and the potential effect of operation *A*. The proposed innovations make it possible to compare different control trajectories and further calculate the efficiency of inventory utilization.

5. 3. Deriving a formula for calculating the cybernetic assessment of the effectiveness of the use of reserves

Based on the developed formal features and estimates, it is possible to proceed to build a formula for assessing the effectiveness of the use of stocks in a continuous production process.

To assess the effectiveness, one can use the *ELF* indicator [14], which has passed the stages of verification for its consistency with the concept of efficiency, setting reference points for the calculation time, and constantly collecting information throughout the production cycle of work.

In general, one can argue that efficiency is the ratio of the potential effect of operation *A* to the resource intensity of the operational process:

$$ELF=A/R. \quad (42)$$

Taking into consideration the developed four formal features, the calculation of the efficiency of the use of reserves can be presented in the form:

$$ELF=\frac{\left[\left(\left(PE+PE^*\right)-\left(RE+FE\right)\right)\left(v_d-v_l\right)^2\right]/2}{\sum_{v_0}^{v_l}\sum_{u_0}^{u}\sum_{w_0}^{w}\left(\left(re_n+fe_n\right)-\left(pe_n+pe_n^*\right)\right)}, \quad (43)$$

or, in the following form:

$$ELF=$$
$$=\frac{\int_{v_l}^{v_d}\int_{u_0}^{u}\int_{w_0}^{w}\left(\left(pe_n(t)+pe_n^*(t)\right)-\left(re_n(t)+fe_n(t)\right)\right)\mathrm{d}w\mathrm{d}u\mathrm{d}v}{\int_{v_0}^{v_l}\int_{u_0}^{u}\int_{w_0}^{w}\left(\left(re_n(t)+fe_n(t)\right)-\left(pe_n(t)+pe_n^*(t)\right)\right)\mathrm{d}w\mathrm{d}u\mathrm{d}v}=$$
$$=\begin{cases}v\geq v_j, v\in\left[v_l,v_d\right];\\ v\geq v_j, v\in\left[v_0,v_l\right].\end{cases} \quad (44)$$

Thus, when technological systems operate with a continuous supply of a technological product, it has been established that the optimization criterion is the indicator of the efficiency of inventory use [13]. Formal attributes have been established; evaluation indicators have been developed. Based on them, three variations of the efficiency formula (41) to (43) of the use of stocks of a continuous technological process are proposed, the calculation of which is carried out at established points in time throughout the entire production cycle.

5. 4. Verification of estimates as performance criteria

The results of testing the proposed approach of cybernetic assessment of the effectiveness of the use of reserves in the control trajectory No. 1 are shown in Fig. 16. It demonstrates the dynamics of changes in all the proposed parameters, indicators, and the resulting values of the efficiency of the use of reserves in the first trajectory.

	8	11							302	1,5	0,00497
n	re	pe	ire	ipe	vre	vpe	dif	r	R	A	ELF
	C	C	CW	CW	CWU	CWU	CWU	CWUV	CWUV	CWUV	
0											
1			0	0	0	0	0	0			
2			0	0	0	0	0	0			
3			0	0	0	0	0	0			
4	2		2	0	0	0	0	0			
5	2		4	0	2	0	2	2			
6	2		6	0	6	0	6	8			
7	2		8	0	12	0	12	20			
8			8	0	20	0	20	40			
9			8	0	28	0	28	68			
10		11	8	11	36	0	36	104			
11			8	11	44	11	33	137			
12			8	11	52	22	30	167			
13			8	11	60	33	27	194			
14			8	11	68	44	24	218			
15			8	11	76	55	21	239			
16			8	11	84	66	18	257			
17			8	11	92	77	15	272			
18			8	11	100	88	12	284			
19			8	11	108	99	9	293			
20			8	11	116	110	6	299			
21			8	11	124	121	3	302			
22			8	11	132	132	0	302			

Fig. 16. Change in the basic parameters of the operation with a continuous supply of the technological product at control trajectory No. 1

The results of the study of the second trajectory of continuous process control, taking into consideration the additional number of cost estimates of input technological products at the i-th point in time, are shown in Fig. 17.

The final variant of the control trajectory and all the necessary values for analysis are shown in Fig. 18.

	10	2	13,25	2,25									820	4,25	0,00518
n	re	fe	pe	pe*	ire	ife	ipe	vre	vfe	vpe	dif	r	R	A	ELF
	C	C	C	C	CW	CW	CW	CWU	CWU	CWU	CWU	CWUV	CWUV	CWUV	
0															
1					0	0	0	0	0	0	0	0			
2					0	0	0	0	0	0	0	0			
3					0	0	0	0	0	0	0	0			
4	2				2	0	0	0	0	0	0	0			
5	2				4	0	0	2	0	0	2	2			
6	2				6	0	0	6	0	0	6	8			
7	2				8	0	0	12	0	0	12	20			
8	2				10	0	0	20	0	0	20	40			
9		2			10	2	0	30	0	0	30	70			
10					10	2	0	40	2	0	42	112			
11					10	2	0	50	4	0	54	166			
12			13,25	2,25	10	2	15,5	60	6	0	66	232			
13					10	2	15,5	70	8	15,5	62,5	294,5			
14					10	2	15,5	80	10	31	59	353,5			
15					10	2	15,5	90	12	46,5	55,5	409			
16					10	2	15,5	100	14	62	52	461			
17					10	2	15,5	110	16	77,5	48,5	509,5			
18					10	2	15,5	120	18	93	45	554,5			
19					10	2	15,5	130	20	109	41,5	596			
20					10	2	15,5	140	22	124	38	634			
21					10	2	15,5	150	24	140	34,5	668,5			
22					10	2	15,5	160	26	155	31	699,5			
23					10	2	15,5	170	28	171	27,5	727			
24					10	2	15,5	180	30	186	24	751			
25					10	2	15,5	190	32	202	20,5	771,5			
26					10	2	15,5	200	34	217	17	788,5			
27					10	2	15,5	210	36	233	13,5	802			
28					10	2	15,5	220	38	248	10	812			
29					10	2	15,5	230	40	264	6,5	818,5			
30					10	2	15,5	240	42	279	3	821,5			
31					10	2	15,5	250	44	295	-0,5	821			

Fig. 17. Change in the basic parameters of the operation with a continuous supply of the technological product at control trajectory No. 2

	10	6	13,25	6,75									1284	3	0,00234
n	re	fe	pe	pe*	ire	ife	ipe	vre	vfe	vpe	dif	r	R	A	ELF
	C	C	C	C	CW	CW	CW	CWU	CWU	CWU	CWU	CWUV	CWUV	CWUV	
0															
1					0	0	0	0	0	0	0	0			
2					0	0	0	0	0	0	0	0			
3					0	0	0	0	0	0	0	0			
4	2				2	0	0	0	0	0	0	0			
5	2				4	0	0	2	0	0	2	2			
6	2				6	0	0	6	0	0	6	8			
7	2				8	0	0	12	0	0	12	20			
8	2				10	0	0	20	0	0	20	40			
9		2			10	2	0	30	0	0	30	70			
10		2			10	4	0	40	2	0	42	112			
11		2			10	6	0	50	6	0	56	168			
12					10	6	0	60	12	0	72	240			
13					10	6	0	70	18	0	88	328			
14			13,25	6,75	10	6	22	80	24	0	104	432			
15					10	6	22	90	30	22	98	530			
16					10	6	22	100	36	44	92	622			
17					10	6	22	110	42	66	86	708			
18					10	6	22	120	48	88	80	788			
19					10	6	22	130	54	110	74	862			
20					10	6	22	140	60	132	68	930			
21					10	6	22	150	66	154	62	992			
22					10	6	22	160	72	176	56	1048			
23					10	6	22	170	78	198	50	1098			
24					10	6	22	180	84	220	44	1142			
25					10	6	22	190	90	242	38	1180			
26					10	6	22	200	96	264	32	1212			
27					10	6	22	210	102	286	26	1238			
28					10	6	22	220	108	308	20	1258			
29					10	6	22	230	114	330	14	1272			
30					10	6	22	240	120	352	8	1280			
31					10	6	22	250	126	374	2	1282			
32					10	6	22	260	132	396	-4	1278			

Fig. 18. Change in the basic parameters of the operation with a continuous supply of the technological product at control trajectory No. 3

Thus, the proposed cybernetic estimates of the use of reserves as criteria for the effectiveness of conversion class systems with a continuous supply of the technological product were verified. The analysis of the three variants of system operation demonstrated the adequacy of the devised approach.

6. Discussion of research results related to cybernetic assessment of stockpile efficiency

It is obvious that the assessment of the use of reserves of continuous technological processes is an important scientific task.

The application of a rigidly fixed control trajectory of such processes is often not an effective solution due to dynamically changing external conditions. With the advent of approaches that make it possible to automatically change the control trajectories of technological systems without stopping the process, the task of assessing the effectiveness of the use of reserves has become even more relevant.

However, the use of non-verified estimates does not reveal the real picture of the effectiveness of resource use, and, in some cases, leads to additional financial losses.

The benefits of using validated scorecards and a confidence performance formula are obvious. Such verified assessment methods would make it possible to fully automate the control subsystem of technological systems and, importantly, to make the transition to a different control trajectory, due to changes in external factors while maintaining the principle of using a minimum of reserves.

This paper proposes a model of the operation of the type (re_n, fe_n, pe_n, pe_n^*), which is cybernetic, for a continuous process with distributed parameters with the ability to change control trajectories. A feature of the model is the presence of additional two features fe_n and pe_n^* (Fig. 11, 15), which allow for a comparative assessment of different control trajectories. Evaluation of the process is carried out with the help of formal features reduced to comparable values, which have been verified for their adequacy to the formula for the efficiency of resource use [12].

Based on formal features, formulas for finding integral functions of the results of the movement of the input ((12) to (14), (18) to (20), (24) to (26)) and output products are described, which give an idea of some quantitative characteristics of the process. As well as the second integral characteristic ((15) to (17), (21) to (23), (27) to (29)), which represents the physical and cybernetic parameters of the process over time.

To be able to make judgments about the operational process, the main estimated indicators of the process of converting a constant flow of input products into outputs have been developed. These include the integral added value function dif_i (30), (34), (38), the potential effect of operation A (33), (37), (41), and the resource intensity of the operational process R (32), (36), (40).

When technological systems with a continuous supply of a technological product operate, it has been established that the optimization criterion is the indicator of the efficiency of inventory use [13].

Based on the estimated indicators, three variations of the efficiency formula ((41) to (43)) of the use of continuous process reserves are proposed, the calculation of which is carried out at established points in time throughout the entire production cycle. Based on the calculations, one can judge the efficiency of the production process on the part of the use of stocks and choose a control trajectory with minimal consumption.

Verification of the developed cybernetic assessment of the efficiency of the use of reserves was carried out under three different control trajectories of a conversion class system (Fig. 16–18).

The limitation of the developed cybernetic assessment of the use of stocks is that a given process can be carried out only for continuous production processes with a continuous supply of a technological product, which also has a number of advantages and disadvantages:

– the generalized nature of the proposed approach would make it possible to apply the calculation to a large number of different kinds of continuous processes;

– the possibility of applying the assessment only to the technological process with a sectional-modular system, which makes it possible to increase the number of degrees of freedom, and, therefore, to more flexibly control the process.

7. Conclusion

1. A cybernetic model of continuous operation with distributed parameters has been developed, which differs from the existing ones by the presence of additional two formal features that allow for comparative characterization of different control trajectories. It is proposed to allocate from the total flow of input resources the number of reserves that are additionally spent and, as a result, the number of additional output resources that have appeared. This division makes it possible to additionally evaluate some quantitative characteristics and the physical-cybernetic parameters of the process of using additional reserves.

2. The main estimated indicators of the operational process of converting a constant flow of input products into outputs have been developed, which differ from the existing ones by taking into consideration the four formal features of a continuous process. This makes it possible to increase the quality of judgment about the operational process.

3. Three variations of the efficiency formula have been built for assessing the use of reserves of conversion processes with a continuous supply of a technological product, which differ from the existing ones in the possibility of assessing a continuous process from the point of view of the use of reserves. That makes it possible to compare possible operational options and choose a control trajectory with minimal inventory consumption.

4. Verification of evaluation indicators as performance criteria for three different control trajectories of continuous transformative processes was carried out. The current study has shown the adequacy of the process assessment, which makes it possible to carry out full automation of continuous processes, both on the side of the technological part and the side of management.

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DEVELOPMENT OF A METHOD FOR DIFFERENTIAL ANALYSIS OF DATA ON THE ARTERIAL BLOOD OXYGENATION IN HEALTHY ADULTS

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Monitoring of arterial blood saturation with oxygen (oxygenation) has gained special significance as a result of the COVID-19 pandemic. A new method for computer processing of saturation records (so-called SaO_2 signals), based on the study of differentials (increments) from signals, was proposed. Finding a differential for a time series involves calculating the difference between the pairs of its adjacent elements. The differential is non-zero only if the elements in a pair are different. The study of differentials together with primary signals for a set of records (20 subjects) shows that the spectrum of observed levels of blood saturation is discrete and limited (from 2 to 10 levels). In addition, changes in saturation levels (switches) occur only between the nearest levels.

New indicators of the variability of blood saturation were proposed. These are the frequencies of saturation level switches (event intensities) and the intervals between them. It was established that these indicators are described by statistical distributions of Poisson and Erlang, respectively. Comparison of new variability indicators with the most reliable statistical – inter-quartile range – indicates that the new indicators also provide for the division of the data set into three subgroups according to the magnitude of variability. This division is statistically significant at a confidence level of 0.99 in both approaches, however, the division into sub-groups is slightly different in these methods.

It was shown that the proposed indicators of the variability of SaO_2 signals are scale-invariant, that is, they do not depend on the length of observation interval. This is a consequence of the fractality of the positions of differentials in the observation interval. The established switch frequencies for subgroups in order of increasing variability are (0.06, 0.11, and 0.20) Hz. These frequencies are manifested on Fourier spectra of differentials of SaO_2

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1. Introduction

Studies of the levels of blood oxygenation (saturation), that is, the percentage of oxygen saturation of hemoglobin, became increasingly active as a result of the coronavirus pandemic (COVID-19). The first stage of this viral disease is characterized by «latent hypoxia» due to insufficient oxygenation of the patient's blood [1–3]. Hypoxia, or lack of oxygen, can be almost unnoticeable for saturation levels close to 90 % and below. The range of the oxygenation norm for healthy adults is (95–100) % [4].

The clinical practice mainly uses pulse oximetry – an indirect, but non-invasive, inexpensive, and convenient method for monitoring the oxygen level in the blood. Pulse oximeters are small devices that are fixed on fingers or on ear lobes. In this way, the so-called peripheral oxygenation (SpO_2) is measured [5, 6].

Much more expensive, invasive, and more complex devices, called blood gas analyzers, or CO-oximeters, allow direct, reliable, and more accurate studies [7] They specifically measure the so-called arterial oxygenation (SaO_2) and are used in equipped medical laboratories by qualified personnel. These devices are also the standards for calibrating pulse oximeters, usually based on the data for healthy patients.

There are certain differences in the results between these two methods, which depend both on the diagnosis of a patient and on the measurement range [8]. In particular, at Manchester University Hospital, for patients with