Для того щоб отримати максимальну віддачу від діяльності підприємства, операційні процеси функціональних систем оптимізують. Однак в процесі оптимізації керовані системи значну частину часу працюють в неоптимальних режимах. Крім того, зміна зовнішніх умов, якісних параметрів сировинних продуктів або вартісних оцінок вхідних і вихідних продуктів системної операції, призводить до необхідності знову запускати оптимізаційний процес.

Нерідкі випадки, коли тривалість процесу оптимізації порівнюється за часом або навіть перевищує час роботи системи. Це означає, оптимізації вимагає перехідний процес оптимізації.

При цьому в даний час інтенсивні дослідження в основному ведуться в області розробки системно обґрунтованого міждисциплінарного критерію оптимізації і методів пошуку оптимального управління. Роботи, спрямовані на методи підвищення ефективності перехідного процесу, ведуться в основному математиками, в рамках виконання завдання прискореного пошуку екстремуму. Відповідно, відомі методи можуть використовуватися для підвищення ефективності перехідного процесу в рамках параметричної оптимізації.

На прикладі періодичної системи порційного нагріву рідини розглядається рішення задачі підвищення ефективності перехідного процесу за рахунок використання методу структурно-параметричної оптимізації. Як критерій оптимізації використовується оцінний показник, який пройшов перевірку в предмет можливості його використання в якості формули ефективності.

Результати порівняльного дослідження еталонного технологічного процесу типової і модифікованої функціональних систем показали, що час виходу в область близьку до оптимальної зменшився практично в два рази.

Крім того, використання нової архітектури функціональної системи дозволяє підвищити її надійність і ефективність обслуговування

Ключові слова: ефективність перехідних процесів, структурно-параметричну оптимізація, оптимальне управління, ефективність використання ресурсів

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DEVELOPMENT OF THE METHOD FOR STRUCTURAL-PARAMETRIC OPTIMIZATION IN ORDER TO IMPROVE THE EFFICIENCY OF TRANSITION PROCESSES IN PERIODIC SYSTEMS

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1. Introduction

One of the major problems of human society is the problem of efficiency in the use of available resources [1]. This problem acutely manifests itself in the field of resource-intensive industries, where each operation requires tying up considerable financial resources and consumption of expensive energy products [2].

One of the main approaches to enhancing effectiveness is rightfully considered to be a greater degree of automation of technological processes [3]. However, automated yet ineffective operational mode can very quickly lead an enterprise's owner to the financial disaster [4].

The realization of this issue gave rise to the concept of «optimal control» [5] and optimal systems [6, 7]. An intuitive understanding of the fact that among an infinite set of available controls there is only one best control led to the rapid growth of scientific publications [8, 9] and conferences [10, 11] that addressed this issue. Thus, the actively discussed topics are those determining a variety of optimization criteria [12, 13], performance indicators [14, 15], searching for optimal control trajectories [16, 17] and the optimal structure for a functional system [18].

The fact that the number of publications about optimization is not decreasing, but increasing, indirectly indicates that the optimization problem at present is at the stage of intense development. On the other hand, the need to optimize has been the focus of principal efforts by an enterprise's owner and its top management [19, 20].

Therefore, it is an important scientific and practical task to develop the scientifically-substantiated optimization methods.

2. Literature review and problem statement

In order to achieve high economic performance indicators and stay competitive in the market, it is necessary to optimize the most resource-intensive technological processes [21]. The process of optimization itself implies that all functional systems of an enterprises operate under the best coordinated modes. This means that the central task in the theory and practice of optimization is to choose a substantiated optimization criterion.

Despite the importance and top priority of a given task, there are still different views on the strategy to select the optimization criterion.

It has been proposed to apply as the assessment criterion the minimum fuel consumption [22], displacement trajectory [23], minimization of an error or deviation [24], minimum power consumption [25] and so on.

A reasonable approach is the one that employs the optimization criterion based on an integrated estimate, with the possibility to compare the input and output of the examined operation [26]. An important factor in favor of the use of such a criterion is its verification for use as an indicator of efficiency [27–30]. The optimum, however, can be reached in different ways. Therefore, the transition process for attaining the optimum must also be optimized.

In the process of optimization, a functional system operates by default under a suboptimal mode. In this case, a change in external conditions, change in the quality of raw materials, or price volatility, lead to the need to determine a new optimum. Very often, the optimization process itself takes longer than the system's operation under optimal regime. In this regard, the optimization criterion used for the transitional process itself is the stabilization time [8], duration of the response time from a PID-controller [9]. Since the time of attaining an optimum mode is linked to the instability in parameters of the technological product, the optimization criterion traditionally used is the magnitude of overcontrol [31].

Thus, the studies whose findings are aimed at improving the effectiveness of transitional processes apply the non-verified optimization criteria.

On the other hand, the possibilities for parametric optimization are limited by the features of the technological equipment utilized. The parameters of this equipment affect duration of a technological operation. By changing the structure of a technological mechanism, it is possible to significantly accelerate the process at the expense of paralleled systemic processes.

Therefore, there is reason to believe that the development of the method for structural-parametric optimization is the research tool that would make it possible to resolve the task on improving the effectiveness of the transition process.

3. The aim and objectives of the study

The aim of this study is to increase the number of degrees of freedom in periodic systems using a method of structural-parametric stabilization, which would make it possible to improve the functional efficiency of technological processes under transitional modes.

To achieve the set aim, the following tasks have been solved:

– to develop a reference model for the heating system and to define parameters for the reference optimization operation;

– to construct a model of the examined system that would enable the structural-parametric optimization in the process of control;

– to experimentally investigate processes at the restructured system and to search for the optimal controls based on the developed method.

4. Increase in the number of degrees of freedom of the periodic system

The proposed method is based on the hypothesis according to which attaining a mode of optimal control could be implemented more efficiently in the case of modular implementation of the technological part and part of quality management. In this case, an optimization module must ensure the coordination of functioning of these modules. In that case, management tools can resolve the task on the optimization of the optimization process itself.

To test a hypothesis and devise a method to improve the efficiency of optimization process, we used the structure consisting of several managed systems: supply systems of technological products (SSTP), supply systems of energy products (SSEP), examined systems (ES), system of consumption, and the transition process optimization systems (TPOS).

The examined system performs the function of partial transformation of the input technology product. Such processes are defined as periodic in the scientific literature. The term «periodic systems» is also often used, meaning the periodicity of these processes [32].

Because the developed method implies dividing ES into two identical independent systems, we also divided the reference ES into two identical systems ES1 and ES2 to conduct a control study. Each such system consists of the technological subsystem (TS) and the control subsystem (CS). In this case, characteristics of the technological subsystems are the same, and, therefore, parameters of technological processes in such systems are identical.

In control study, two periodic systems of the reference ES synchronously operate as a single system. Originally, the input of the transition process optimization system receives two signals: a signal of primary control (STR) and a control change step (STP). When TPOS is enabled, an STR signal is sent to the output and then, in the form of signals Z_{P1} and Z_{P2}, is sent to the inputs of control subsystems CS1 and CS2.

Since the systems ES1 and ES are identical, we shall consider the operation of ES using the work of structure ES2 as an example (Fig. 1).

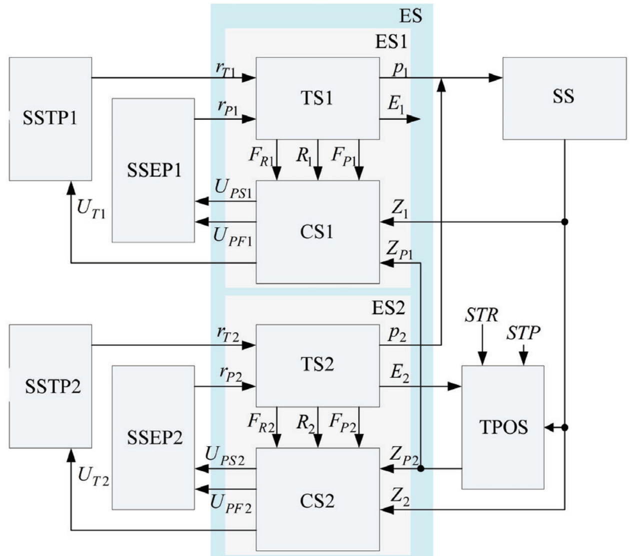

Fig. 1. Structural diagram of generalized production structure within which a periodic system consists of two synchronously working periodic systems

The system of consumption, which is a system for inventory control [18], sends an assignment signal Z_2, which arrives at the input of control subsystem CS2. Upon receiving, CS2 generates a job signal U_{T2}, which arrives at the input of SPTP2.

A given signal differs from a binary signal Z_2 in that it carries information about the required level of a technological product.

In turn, SPTP2 enables arrival of a technological product r_{T2} at the input of TS2.

At the time when a technological product arrives in full, TS2 sends a signal F_{R2}, which arrives at the respective input of CS2.

Upon receiving this signal, CS2 triggers a signal U_{PS2}, which initiates the start of supply of the energy product. The intensity of energy product supply is determined by the magnitude of signal Z_{P2} from the system of optimization.

At the time when signal $U_{PS2,}$ numerically equal to Z_{P2}, arrives at the input of SSEP2, there starts the transformation process of a technological product. At the moment when the transformed product reaches the specified quality parameter, TS2 triggers a signal R_2, which arrives at CS2.

Upon receiving this signal, CS sends a signal U_{PF1} to terminate the supply of an energy product, and the output product p_2 arrives at the input of SS.

At the time of the completion of discharge of a ready product, TS2 sends a signal F_{P2}, after which ES2 is ready for the next operation.

After completion of each operation, TS2 sends a signal E_2, which characterizes the efficiency of the performed technological operation. This signal is sent to the input of TPOS. The optimization of the transition process ends at the time when the efficiency indicator ceases to grow.

Given the equivalence of the processes occurring in ES1 and ES2, the value for efficiency was received by TPOS from the output of one ES.

Constructing a reference model of the transformational process was carried out using a simulation of the process of heating two cubic meters of liquid, from 20 to 50 °C.

Results of mathematical modeling are shown in diagrams (Fig. 2, 3).

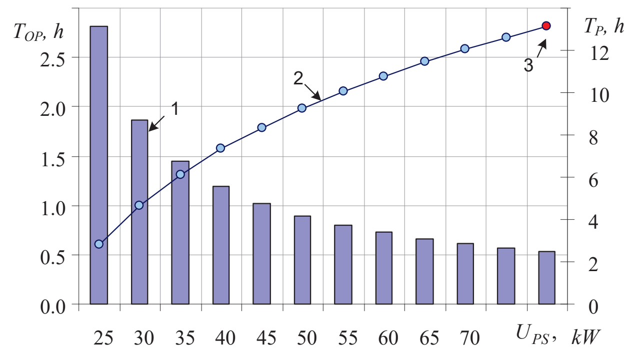

Fig. 2. Diagrams:
1 — change in the operation duration due to control;
2 — change in the time of the transition process due to control (cumulative); 3 — completion time of the transitional process

Fig. 2 (designation 1) shows that the operation time (T_{OP}) decreases with an increase in the supplied energy power.

Control switching time (T_P) is shown in Fig. 2 (designation 2).

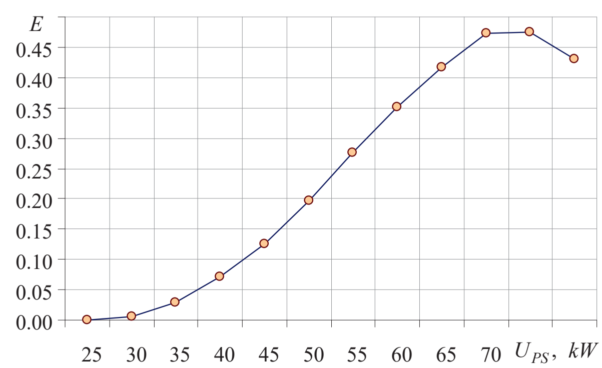

Fig. 3. Diagram of change in the effectiveness of operations due to control

When supplying a power of 75 kW, the efficiency of operation is maximum. However, it will be clarified at the next stage of control.

Therefore, the transition process time is 13.15 h (Fig. 2).

5. Development of a method for the structural-parametric optimization of transition process

At the next stage of our study, the structure of TPOS was altered (Fig. 4), and the systems ES1 and ES2 operated under autonomous individual modes in accordance with the developed method.

The feature of the method is that all functions related to the asynchronous control over technological processes are implemented within a single functional system.

Expression [26] is applied as the efficiency indicator:

$$E = \frac{(PE - RE)^2 T_P^2}{RE \cdot PE \cdot T_{OP}^2},$$

where E is a measure of efficiency, RE is the valuation of input products of the operation, PE is the valuation of output products of the operation, T_P is the time for determining the potential effect of the operation, T_{OP} is the operation run time.

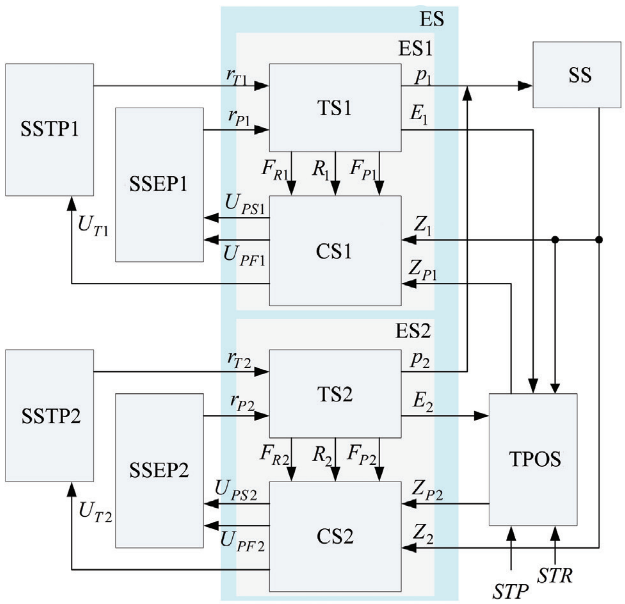

Fig. 4. Structural diagram of generalized production structure within which the periodic systems ES1 and ES2 operate independently

A procedure to determine parameters RE, PE, T_P, T_{OP} is given in paper [33].

At the initial point in time, we establish two starting controls U_{ZP1}=STR and U_{ZP2}=STR+STP.

At the time of completion of the operations, functions $F_{P1}(t)$ and $F_{P2}(t)$ accept a single value, it is recorded to the operative memory of TPOS of the foursome (Z_P, E, E_{OLD}, Z_{P_OLD}).

A new direction is determined from the rule:

If $E_{OLD1} \vee E_{OLD2} \leq E$, then:

– for ES 1 → If $Z_{P1} > Z_{P2}$, then $Z_{P1} = Z_{P1}$+STP, otherwise $Z_{P1} = Z_{P2}$+STP;

– for ES 2 → If $Z_{P1} > Z_{P2}$, then $Z_{P2} = Z_{P1}$+STP, otherwise $Z_{P2} = Z_{P2}$+STP.

The process of optimizing the transitional process is terminated if $(E_{OLD1} \vee E_{OLD2}) > (E_1 \vee E_2)$.

Such an optimal control is selected, which is matched with the maximum value of the effective use of resources.

6. Implementation of the structural-parametric optimization method

For clarity, we accept that at the input STR to the system TPOS we set the control, which ensures a 25-kW power supply at the input to a fluid heating system. At the input STP, we assign a step in the change of control, 5 units.

According to the method, at the initial point in time, the input of $SSEP_1$ receives a signal equal to U_{PS1}=STR=25 units, and the input of $SSEP_2$ – U_{PS2}=STR+STP=25+5=30 units.

Since SSEP2 enables the supply of an energy product with greater intensity, heating the liquid to the specified temperature occurs faster here.

Table 1 shows results of heating operations for the systems ES1 and ES2. Here S is the identifier of ES.

Table 1

Results of operation of systems ES1 and ES2

UP	*RE*	*PE*	*TS*	*TO*	*E*	*S*
30	17.9	19.6	1.939	1.939	0.021	2
25	21.37	19.6	2.81	2.77	0	1
35	15.36	19.6	3.425	1.42	0.0297	2
40	14.39	19.6	4.01	1.16	0.071	1
45	13.8	19.6	4.45	0.992	0.126	2
50	13.385	19.6	4.90	0.864	0.197	1
55	13.13	19.6	5.25	0.767	0.277	2
60	13.04	19.6	5.630	0.69	0.351	1
65	13.075	19.6	5.92	0.631	0.4179	2
70	13.205	19.6	6.242	0.58	0.473	1
75	13.575	19.6	6.483	0.536	0.475	2
80	14.14	19.6	6.775	0.5	0.43	1

Because the random-access memory does not contain the recorded previous value of ES2 operational effectiveness, E_{OLD2}=0, we determine the new control. Since $U_{PS2} > U_{PS1}$, then $U_{PS2} = U_{PS2}$+STP=30+5=35.

The next to end is the heating operation in ES1.

As the valuation for the heated liquid is lower than the valuation for the input products of the operation, the efficiency of operation is negative. Since efficiency is not defined in the region of negative values, the value at the outlet $E1$ is null.

Because $U_{PS2} > U_{PS1}$, then $U_{PS1} = U_{PS2}$+STP=35+5=40.

Subsequent controls are determined similarly.

The efficiency that matches a control of 80 is lower than the efficiency reached at a control of 75. Therefore, the optimal control is accepted to be a control of 75 kW (Fig. 5).

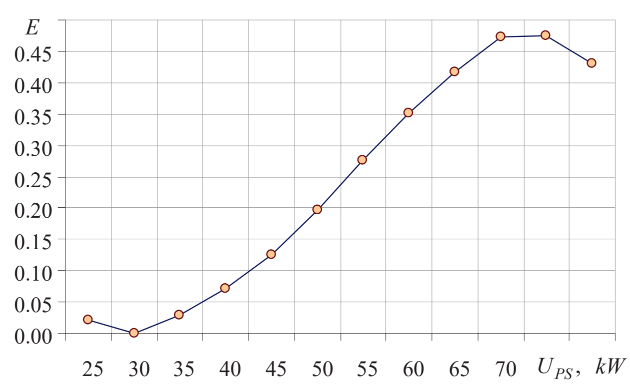

Fig. 5. Diagram of change in the effectiveness of operations due to control

Since the time for attaining an optimal control amounted, in the first case, to 13.15 h, while in the second case it was 6.77 h (Fig. 6), the control that employs the developed method is guaranteed to be effective.

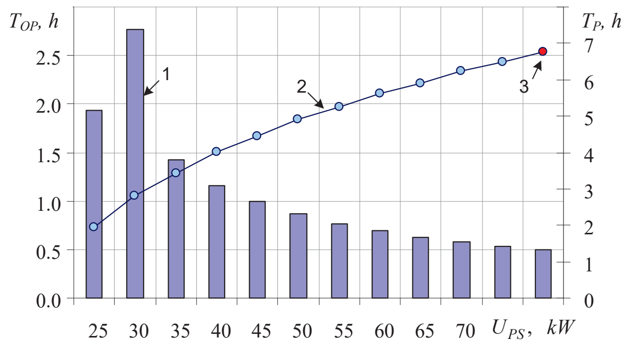

Fig. 6. Diagrams:
1 — change in the time of operations due to control;
2 — change in the time of a transition process due to control (cumulative); 3 — time of completion of the transitional process

This relates to that the time required to attain an optimal control was reduced by two times while all the remaining operations' parameters did not change.

7. Discussion of research results related to the development of the method for structural-parametric optimization

The research results have shown that a multi-unit structure for the construction of functional system is potentially better than a mono-unit structure. This is evident in the prospect to significantly improve the effectiveness of a transitional optimization process.

Practical implementation of the proposed method could demonstrate the advantages where the resource-intensive processes are implemented using a variety of similar technological mechanisms. For example, at a production line that exploits, rather than a single large-scale technological mechanism, several mechanisms with the appropriate summary performance.

In this case, there is a possibility to launch such a structure as a single system. At the same time, coordination of the asynchronous operation of such in-systems technological mechanisms opens up the possibility of making better use of an enterprise resources.

The method, proposed in this work, was examined for the case when the efficiency of optimizing functional systems is compared, which consist of one and of two technological subsystems. In this case, increasing the number of technological subsystems is a technical challenge.

The proposed transitional process optimization technology could be implemented at those enterprises, which employ the systems of crushing, grinding, heating, extruding, melting, etc. In other words, the maximum effect might be most likely obtained where the cost of reducing the pace of a transition process, or its losses, is relatively high. These could include either the energy-intensive production or production with a high duration of the transition process and the high cost of a technological product.

A given method could be implemented at those enterprises whose structure is based on the systems that actively interact. Production lines at which technological processes are functionally interconnected, require structural changes. The functionally interconnected technological processes relate to such an interdependence of enterprises' systems at which a change in parameters for any local process necessitates a change in parameters for the entire interconnected technological chain.

In addition, a variant is possible when, in order to implement the proposed method, large technological mechanisms are purposefully replaced with several identical, smaller technological mechanisms, with an equivalent or close performance.

Of course, that does not mean that production efficiency will be improved automatically. This issue requires a separate study, though it can be assumed that an increase in the number of technological subsystems will lead to that the efficiency improves at first, only to start to decline later.

Such an assumption is based on that the reduction of dimensions of technological equipment leads to a relative increase in its cost per unit of output. On the other hand, the effective functioning of multi-unit systemic structures is enhanced through improved reliability. The failure of a single element in a multiple structure does not halt the entire process.

However, numerical justification of the efficiency of a technological process under such a standpoint requires acquisition of different statistical materials and development of a specialized estimation procedure.

If we go back to the industries with the ability to apply a method of the structural-parametric optimization of transitional processes, using it could significantly improve economic indicators. That will manifest itself in the form of lower costs at the increased productivity. In this case, an added value will not be significantly reduced due to the reasonably enhanced wear of equipment. It is also necessary to stress the need to adopt legislative acts, both at the level of executive and local self-government, and at separate enterprises, which would describe in detail the procedure (rules) for implementing the model of efficiency in the functioning of technological processes under transient modes.

8. Conclusions

1. We have developed a model of a functional system for determining the parameters for the optimization transition process. Using a liquid heating system as an example, we studied parameters of the operational optimization process. The data were obtained that characterize the stages in the process of optimization under condition of applying a traditional approach: value of control, duration of transition process, the effectiveness of operation.

The research results obtained are required to compile a comparative base for the further research. Key indicators here are the effectiveness of the final operation in the transition process and its duration.

2. The model of a two-section functional system was constructed. Technological part of such a system consists of two technological mechanisms that can be managed independently.

We have formed the structure of the control subsystem, which makes it possible to construct such controls at which technological processes can function asynchronously, and would enter an optimum mode as fast as possible and without losses in efficiency.

3. We investigated the evaluation of the effectiveness of transitional processes for a single- and two-section heating system.

It was established that the functional system, using which could enable two parallel optimization processes, ensures a two-fold decrease in the time of the transition process with the same efficiency of separate operations during this process.

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