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CREATING A CONCEPT AND AXIOMATIZATION OF THE APPLIED THEORY OF EFFICIENCY OF COMPLEX TECHNICAL SYSTEMS WITH DISTRIBUTED PARAMETERS OF INPUT AND OUTPUT PRODUCTS

The object of this study is the processes of optimal control over complex technical systems with input and output products distributed in time.

The automatic formation of optimal control trajectories of technical systems that ensure maximum efficiency of production processes is limited by the insufficient development of the applied theory of the efficiency of complex systems.

This work considers the development of the conceptual base and axiomatization of the applied theory of the efficiency of technical systems.

A system of definitions and a system of axioms describing the indicators of the functioning of the cybernetic model of a technical system have been developed. The resulting system of axioms formalizes the technique and methods for determining various indicators, as well as obtaining the current value of the performance indicator of the technical system. The obtained expressions make it possible to form a subsystem for assessing the effectiveness of a technical system, invariant with respect to its internal structure and the characteristics of the transformation processes implemented by it. The universality of the proposed indicators and the structural unity of the performance evaluation subsystem make it possible to express an opinion on the cybernetic level of these decisions.

An example of the practical application of the proposed system of axioms of the applied theory of efficiency is given.

The proposed method for determining the efficiency indicator can be applied to arbitrary technical systems with a distributed nature of the change in input and output products. The cybernetic level of abstractions used to determine the effectiveness of complex systems makes it possible to proceed to solving the problem of formalization and full automation of the processes of optimal control over complex technical systems with distributed input and output products

Keywords: cybernetic indicators, efficiency criterion, formalization, axiomatization, optimal control over complex systems

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1. Introduction

The modern scientific and technological revolution has led to a colossal growth in the productive forces of society, has changed the tools of production, materials, technologies, both the production processes themselves and control over them.

This requires significant costs for updating and improving production equipment, creating complex and expensive systems and industrial facilities, for scientific research and practical implementation of their results. Given the limited resources available, there is a problem of finding funds for such costs. The answer to this question under modern conditions is one: these funds are in the industrial production itself. The way to mobilize them is to increase the efficiency of production and the productivity of the resources spent on it. With increasing constraints on resources of all kinds, it is necessary to strive for their optimal use.

That is why the optimal control over complex technical systems is given great attention in the modern scientific world. It should be noted that the optimization function is not currently automated. This is due, first of all, to the fact that indicators are used as an optimization criterion, the possibility of application and reliability of which are not systematically justified.

Therefore, for the further development of optimal control over complex technical systems, it is necessary to devise a method for assessing the efficiency of individual production processes, sensitive to the nature of global input and output functions, the creation of reference models of operations with distributed parameters.

Speaking of efficacy, researchers face serious terminological and qualimetric problems. The term «efficiency» is one of the most used, although today there is no universal and generally accepted in the scientific community definition of the concept of «effectiveness» and indicators for its evaluation.

For example, according to the results of an Internet search of the term «effectiveness meaning», the Google search engine finds five billion 20 million articles – a result that amazes the imagination.

Scientific research in the field of conceptual base and axiomatization of the applied theory of the efficiency of technical systems is important as it creates conditions for designing optimal control systems for complex production systems. The results of the conducted research are necessary for practice as they will contribute to improving the efficiency of production and the productivity of the resources spent on it.

2. Literature review and problem statement

In modern scientific and technical literature, various definitions of efficiency are used, depending on the subject area and the conditions of operation of the technical system. The definitions of efficiency used quite often replace the well-known technical indicators: energy consumption, reliability indicators, and other, most unexpected, performance indicators of technical systems. As a result of this discrepancy, the concept of efficiency has acquired many meanings, due both to the diversity of its definitions and to an even greater variety of quantitative characteristics of performance indicators. At the same time, the latter, as a rule, are postulated without substantiation of their structure and analysis of the basic properties, which casts doubt on the legitimacy of their use.

Work [1] is an interdisciplinary study addressing the general principles of representing production processes in the form of individual operations. However, the cited work does not define any technical and economic characteristics of the production operation, making it possible to proceed to the assessment of its effectiveness.

Study [2] considers the problem of assessing the effectiveness of humanitarian assistance as this concept has gained momentum in the agenda of international politics. Study [2] gives only descriptive characteristics of effectiveness and gives a very tautological definition: «Aid effectiveness generally refers to how effective aid is in achieving expected outputs and stated objectives of aid interventions». In [2], there are no numerical characteristics or measures to assess the effectiveness of processes and indicators.

Work [3] considers improving the efficiency of three-phase inverters with pulse width modulation. However, work [3] does not consider general ideas about the efficiency of industrial equipment. The main result reported in [3] is a decrease in the level of higher harmonics in the output voltage. To assess the level of higher harmonics, there is a universally recognized technical term – THD (total harmonic distortion).

Paper [4] analyzes the developed computational model based on the concept of NK-fitness landscapes to assess the effectiveness of the organization under the mode of alternative variants of the organizational structure. Evaluation of the effectiveness of the organization is carried out on the basis of the method of multicriteria decision-making (MCDM). Thus, the criterion of efficiency in [4] is theoretically unreasonable. This is due to the subjectivity of the choice of particular criteria for evaluating the organization. The procedure for determining the weighting coefficients also remains subjective.

Work [5] considers the analysis of the effectiveness of grinding processes using data coverage analysis (Data Envelopment Analysis, DEA). The input and output parameters for the various grinding schemes were processed using cluster analysis techniques. Evaluation of the effectiveness of the grinding process was carried out by comparing the following indicators: the duration of the process, the average roughness of the surface, the value of the gloss. The methods and research results applied in [5] cannot be directly applied to other production processes.

Study [6] considers the analysis of energy generation, power quality, and the state of operability of a wind turbine with misalignment in the direction of the wind flow (yaw misalignment). Improving the efficiency of a wind turbine in operation refers to an improvement in the method of detecting yaw displacement based on the MPC (Maximum Power Capture) indicator. Thus, in [6], instead of the efficiency of the wind turbine, a specific aspect of the operation of this equipment is considered.

Work [7] considers the problem of improving the efficiency of the valve-inductor motor (SRM) by improving the control system.

A detailed analysis of the cited work shows that the concept of efficiency is considered declaratively. The effectiveness of SRM, according to the authors of [7], is determined by the values of known static and dynamic control indicators. The work does not contain a special definition of the concept of efficiency and the indicators defining it.

Paper [8] considers electric motors and electric drives designed to improve the energy efficiency of production processes. Study [9] reports the results of an assessment of energy consumption at six facilities commissioned by the Indiana Department of Transportation (INDOT). Energy saving projects are identified, evaluated, and ranked.

However, in [8, 9], the term «energy efficiency» refers to a decrease in the electricity consumed. In fact, instead of energy efficiency, energy saving in production processes is considered. Changes in the initial cost of the equipment are not taken into consideration. Nor does it take into consideration the potential impact of innovation on production results.

Work [10] considers determining the optimal operating conditions of heating furnaces of oil refineries in order to reduce energy costs. The influence of the environment, structural dimensions, and production conditions on the efficiency of the furnace is considered. The work does not consider the impact of the proposed solutions on the performance of the installation. The results obtained cannot be extended to other production processes.

In [11], the effectiveness of a membrane condenser of water (MC) is estimated only by the amount of moisture captured by membranes with different coatings. This approach does not take into consideration the cost of membrane coating and the cost of finished products of the water condensation process. Therefore, the definition of the efficiency of the production process by its productivity is unsatisfactory.

Paper [12] deals with the problem of improving the efficiency of solar power plants under low light conditions through the use of supercapacitors in the electricity storage system. Changing the structure of the equipment and the control mode makes it possible to increase the power taken from the solar panel. The efficiency of the solar battery is estimated by the amount of power received, which is a terminological error. The results obtained cannot be used to assess the operation of other types of generating equipment.

There are studies tackling the application of the theory of efficiency of technical systems to the optimization of control over various production processes and systems: the movement of goods, the launch of powerful electric drives, etc.

Study [13] substantiates the formulation of the optimization problem of controlling the process of starting powerful electric drives, proposes the structure of the search optimal start control system based on the efficiency indicator.

Work [14] relates to the field of control optimization for displacement systems based on the efficiency of the movement process. Within the framework of the proposed method, the contribution of the acceleration process to the movement process is determined.

Our review reveals that at today there is no single generally accepted opinion in the scientific community about the content of the term «efficiency». Accordingly, there are no sufficiently universal characteristics of the efficiency of complex production systems.

It is advisable to conduct a study on the definition of quantitative characteristics of the efficiency of production operations in relation to technical systems with time-distributed flows of input and output products.

Solving this problem will give new directions for the development of the theory and practice of optimal control over complex technical systems according to the criterion of efficiency, will improve the technical and economic performance of production systems.

3. The aim and objectives of the study

The purpose of this study is to create a system of definitions and methods for calculating performance indicators of a production operation, invariant with respect to the type and features of the technical system.

Achieving this goal will make it possible to assess the efficiency of various production processes from a single position, to unify the structure of optimal control devices for complex technical systems with time-distributed parameters of input and output products.

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

– to formalize the system of basic definitions of the applied theory of the efficiency of technical systems;

– to formalize the methods for calculating the main indicators of the transformation operation of a complex system with a time-distributed nature of the change in input and output products;

– to devise an example of the use of the developed system of basic definitions and axioms of the applied theory of the efficiency of technical systems to determine the performance indicators of the production system.

4. The study materials and methods

The object of this study is the processes of optimal control over complex production systems with a time-distributed nature of the change in the input and output products of the transformation process.

The main hypothesis of the study is the assumption of the invariance of the indicator of the efficiency of resource conversion and methods for determining the necessary indicators on the physical nature and features of the transformation process.

The described results of previous studies cover a wide range of issues that formalize the theory of efficiency in relation to complex technical systems. All this makes it possible to take the next step in the formalization of the theory of efficiency – to formulate the basic definitions and axiomatic basis of the applied theory of efficiency of technical systems.

The applied theory of efficiency is based on the obvious fact that complex technical systems and their individual subsystems are created with the aim of increasing the value of output products in relation to input products in the process of transforming the latter. Such a transformation is considered as a time-distributed process of consuming input resources and generating output products, and, in order to overcome the problems of dimensionality, input and output products are brought to a single system of expert estimates. For technical systems, such a system of expert assessments is the valuation of the input and output products of the conversion process.

An equivalent estimation scheme of the conversion process with distributed parameters of input and output products, in relation to the process of starting a powerful electric drive of a production mechanism, [13], is shown in Fig. 1.

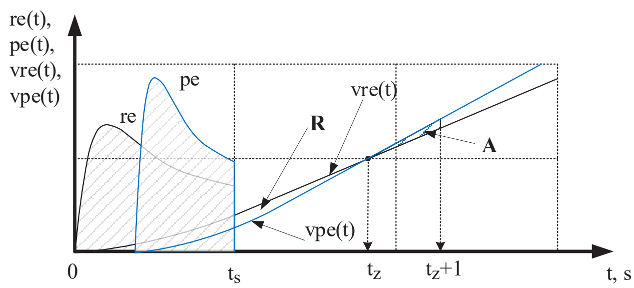

Fig. 1. Quantitative characteristics of the efficiency of the start-up process with time-distributed parameters of input and output products: *re* – a total signal for recording the cost estimates of input products; *pe* – the total signal of registration of cost estimates of output products; *vre* – integral function of resource consumption; *vpe* – integral resource efficiency function; t_S – the moment of completion of the start-up process; t_Z is the moment of logical completion of the start-up process; *A* – potential effect of the start-up process; *R* – resource intensity of the start-up process

The operation of the obtained model of the optimal control system was verified using the specialized software package EFFLY [15].

5. Results of studying the conceptual base and axiomatization of the applied theory of efficiency

5. 1. Formalization of the system of basic definitions of the applied theory of efficiency of technical systems

For the transformation process with distributed parameters of input and output products, we shall give the following basic definitions.

Definition 1. A managed product transformation process in which the supply of input and output product flows is distributed over time is called a distributed product flow parameter operation.

Definition 2. A cybernetic system is an object that continuously generates operations with distributed parameters of product flows.

Definition 3. An operation is called a system operation if it involves similar operations, each of which uses its own input intra-system products, the transformation of which is aimed at achieving a single system goal.

Definition 4. A system operation is called an operation with distributed parameters of product flows if the cumulative expert evaluations of the input $re(t)$ or output $pe(t)$ products of the operation are functions of time.

Definition 5. The start time of an operation with distributed parameters of product flows (v_0) is determined by the moment when its first input product flow is registered.

Definition 6. The completion time of an operation with distributed product flow parameters (w_0) is determined by the time when its last output product stream is registered.

Definition 7. The target product of an operation with distributed parameters of product flows is a part of the exchange product, the value of which is numerically equal to the added value of the operation.

Definition 8. Synchronized operations with distributed parameters of product flows are operations in which:

– expert estimates of input and output product flows are equal;

– the parameters of the integral evaluation of the input function are equal;

– the parameters of the integral evaluation of the output function are not equal.

5. 2. Axiomatization of methods for calculating performance indicators of a complex system

Basic statements that do not require proof within the framework of this theory can be formulated in the form of the following system of axioms. For the formal recording of the basic statements, the mathematical apparatus of the theory of predicate algebra was used.

Axiom 1. For any system operation with distributed parameters of product flows, the moment of supply of the first input product flow and the moment of completion of the issuance of the last output product stream can be determined as:

$$(\forall x \in M)\left[A(x) \rightarrow B(x) \wedge C(x)\right], \tag{1}$$

where x is an operation with distributed parameters in time of input and output product flows, defined on the set of M operations implemented in the complex system in question; $A(x)$ is the predicate «a cybernetic operation is an operation with distributed parameters in time of input and output product flows»; $B(x)$ – the predicate «the operation x has defined the moment of its beginning», the moment of the beginning of the operation x is recorded according to Definition 5; $C(x)$ is the predicate «the operation x has defined the moment of its completion», the moment of completion of the operation x is recorded by definition 6.

Axiom 2. For any system operation with distributed parameters of product flows, quantitative estimates of input and output product flows can be determined as:

$$(\forall x \in M)(\forall r \in R)(\forall p \in Z)\begin{bmatrix} A(x) \wedge R(x,r) \wedge \\ \wedge P(x,p) \rightarrow D(r) \wedge \\ \wedge D(p) \end{bmatrix}. \tag{2}$$

where $r=(r_1, r_2, r_3,...r_n)$ – input products of the operation defined on the set R; $p=(p_1, p_2, p_3, ..., p_n)$ are the output products of the operation defined on the set Z; $D(a)$ – the predicate «product a has a quantitative definition»; $R(x, r)$ – the predicate «product r is the input technological product of operation x»; $P(x, p)$ is the predicate «product p is the output technological product of operation x».

Axiom 3. To carry out a system operation with the distributed parameters of product flows, it is necessary to use a finite number of input raw materials, each of which can be quantified as:

$$(\forall x \in M)\left[A(x) \rightarrow \exists(r_i \in R)\left(D(r_i) = rq_i\right)\right], \tag{3}$$

where $rq_i=(rq_1, rq_2, rq_3, ..., rq_n)$ are the quantitative estimates of input commodities defined on a set of real numbers.

Axiom 4. The result of the system operation with the distributed parameters of the product flows is the formation of the finite number of output consumer products of the operation, each of which can also be given a quantitative assessment:

$$(\forall x \in M)\left[A(x) \rightarrow \exists(p_j \in Z)\left(D(p_j) = pq_j\right)\right], \tag{4}$$

where $pq_j=(pq_1, pq_2, pq_3, ..., pq_n)$ is the quantitative estimates of output consumer products, defined on a set of real numbers.

Axiom 5. 1. For each commodity product r_i of the set R, there is an expert assessment of the value of the r_{si} unit defined on the set V:

$$(\forall r \in R)\left[R(x,r) \rightarrow V(x,r)\right], \tag{5}$$

where $V(x, r)$ is the predicate «the product r of operation x at the input of the operation has expert evaluation».

Axiom 5. 2. For each consumer product p_j of the set Z, there is an expert assessment of the value of the unit of consumer product p_{sj}, defined on the set V:

$$(\forall p \in Z)\left[P(x,p) \rightarrow V(x,p)\right], \tag{6}$$

where $V(x, p)$ is the predicate «the product p of operation x at the output of the operation has an expert assessment».

Axiom 6. For any system operation with distributed parameters of product flows, global input functions $re(t)$ and output $pe(t)$ can be defined as:

$$\begin{aligned}&(\forall x \in M)\left[(\forall rq_i \in R) \rightarrow \exists rs_i\right] \rightarrow \\ &\rightarrow \left(re(t) = \sum_{i=1}^{n} rs_i \cdot rq_i(t)\right) \wedge \\ &\wedge \left[(\forall pq_j \in Z) \rightarrow \exists ps_j\right] \rightarrow \\ &\rightarrow \left(pe(t) = \sum_{j=1}^{k} ps_j \cdot pq_j(t)\right).\end{aligned} \tag{7}$$

Axiom 7. For any system operation with distributed product flow parameters at the time of its completion, the value of the global input function $re(t_s)$ is greater than zero and the value of the global output function $pe(t_s)>re(t_s)$ is:

$$(\forall x \in M) \rightarrow \left[\left(re(t_s) > 0 \right) \wedge \left(pe(t_s) > re(t_s) \right) \right], \tag{8}$$

where t_s is the moment of completion of the operation, determined in accordance with axiom 1.

Axiom 8. For any system operation with distributed parameters of product flows, it is possible to define integral estimates of its global input and output functions:

$$(\forall x \in M) \rightarrow$$
$$\rightarrow \left[\left(ire_v = \int_{v_0}^{t} re(t)\mathrm{d}t \right) \wedge \left(ipe_v = \int_{v_0}^{t} pe(t)\mathrm{d}t \right) \right], \tag{9}$$

where ire_v is the integral evaluation of the input and output function; ipe_v is the integral evaluation of the output function; v_0 – the moment of the beginning of the operation, determined in accordance with axiom 1.

Axiom 9. For any system operation with distributed parameters of product flows, it is possible to define the second integral estimates of its global input and output functions:

$$(\forall x \in M) \rightarrow \left[\begin{array}{l} \left(vre_\omega = \int_{v_0}^{t} \left(\int_{v_0}^{t} re(t)dt \right) \mathrm{d}t \right) \wedge \\ \wedge \left(vpe_\omega = \int_{v_0}^{t} \left(\int_{v_0}^{t} pe(t)dt \right) \mathrm{d}t \right) \end{array} \right], \tag{10}$$

where vre_ω is the second integral assessment of the input; vpe_ω is the second integral evaluation of the output function.

Axiom 10. For any system operation with distributed parameters of product flows, it is possible to define the moment of logical completion of the operation as the moment of achieving equality of the second integral estimates of the global input and output functions:

$$(\forall x \in M) \rightarrow \left[\begin{array}{l} \exists \left(vre_\omega(x,t_f) \wedge vpe_\omega(x,t_f) \right) \rightarrow \\ \rightarrow \left(vre_\omega(x,t_z) = vpe_\omega(x,t_z) \right) \end{array} \right], \tag{11}$$

where t_z is the moment of logical conclusion of the operation.

Axiom 11. For any system operation with distributed parameters of product flows, one can determine the value of the total resource intensity of the CR operation:

$$(\forall x \in M) \left[\left(CR = \int_{v_0}^{t_z} \left(vre_\omega(t) - vpe_\omega(t) \right) \mathrm{d}t \right) \right], \tag{12}$$

Axiom 12. For each system operation with distributed parameters of product flows, it is possible to determine the quantitative characteristic of the value added (potential effect) of the operating process A:

$$(\forall x \in M) \left[A = \int_{t_z}^{t_z+1} \left(vre_\omega(t) - vpe_\omega(t) \right) \mathrm{d}t \right], \tag{13}$$

where t_z is the moment of logical conclusion of the operation, determined by axiom 10.

Axiom 13. For each system operation with distributed product flow parameters, one can define a dimensionless indicator of the resource efficiency of the ELF operation:

$$(\forall x \in M) \left[\exists (A \wedge CR) \rightarrow \left(ELF = \frac{A}{CR} \right) \right]. \tag{14}$$

The formulated axioms formalize all stages in determining the performance indicators of a production operation with distributed parameters of product flows, regardless of the structure and parameters of the physical and technological transformation processes performed by the production system.

5. 3. An example of the application of the system of basic definitions and axioms of the applied theory of efficiency

The practical application of the above system of definitions and axioms to control over a particular technical system is associated with the definition of the set of input material and energy products of the transformation, the set of output products of the transformation. Establishing the functional dependence of the input and output signals of the transformation products on time during the transformation process may require the development of methods for mathematical modeling of the process under consideration.

An illustration of the practical application of the system of developed definitions and axioms is the system for controlling the efficiency of the production process, heating the liquid, the structural scheme of which is shown in Fig. 2.

This model is represented by a technical description of the operational process and its cybernetic component and can be interpreted as a technical and cybernetic model of the operational process.

The liquid heating operation implemented by the model (Fig. 2) is an operation with distributed parameters of the input and output product flows due to the fact that the process of consuming the energy required for heating is distributed over time.

In the above model of the fluid heating process, the ire_v and ipe_v units perform the mathematical expressions defined in axiom 8; the vre_ω and vpe_ω units execute the mathematical expressions defined in axiom 9; units A and R perform mathematical expressions defined in axioms 12 and 11, respectively; the ELF unit implements the expression defined in axiom 13.

The formation of a set of input and output products inherent in the transformation process in question can be a complex and non-trivial task. But after its solution, the algorithm for further processing of the received signals is universal.

Obtaining numerical values characterizing the efficiency of the transformation process is guaranteed by a universal procedure that is invariant with respect to the transformation process under consideration.

The subsystem for the formation of the efficiency indicator, built using the developed definitions and axioms, has a structure that does not depend on the specific features of the transformation process under consideration, which gives this subsystem the properties of a cybernetic object.

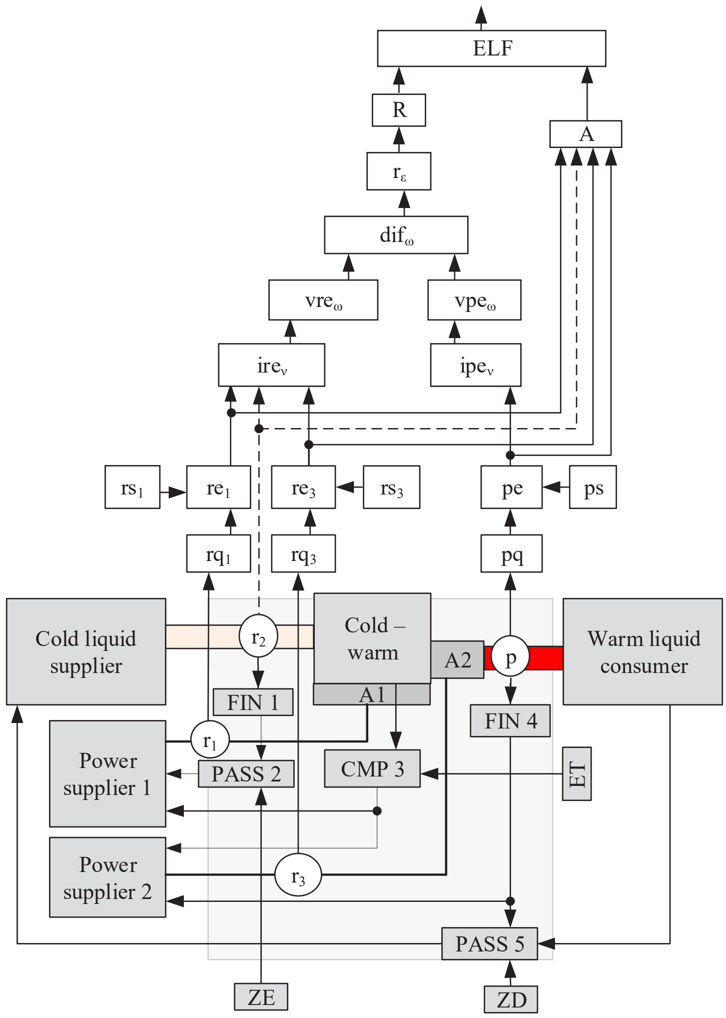

Fig. 2. Technical-cybernetic model of a controlled liquid heating system: ZD is an object that sets the required volume of a portion of cold liquid; r_1 – cold liquid supply channel; r_2 – temperature sensor; r_3 – mechanism that discharges heated liquid; A1 – channel that releases heated liquid; A2 – liquid heating mechanism; p – the channel of supply of heated liquid; FIN 1 – a mechanism that determines the moment of completion of the supply of cold liquid to the heating tank; PASS 2 – a mechanism that determines the moment of supply of the energy product, the intensity specified by the external object (ZE); CMP 3 is a mechanism that receives information from an external source (ET) regarding the final heating temperature of the liquid and signals the objects of supply of energy products to stop such a supply; FIN 4 is a mechanism that determines the moment of completion of the process of issuing a heated liquid and gives a signal about the cessation of energy supply to the mechanism for issuing a heated liquid; PASS 5 – the mechanism that completes the system operation of heating a portion of liquid

6. Discussion of results of studying the conceptual base and axiomatization of the applied theory of efficiency

Within the framework of this work, the basic definitions of cybernetic characteristics of transformation processes in technical systems were formalized. An important advantage of the development is the invariance of the proposed method for assessing the effectiveness of technical systems on the physical and technical features of the production process. This seminal work is the first step towards the creation of a terminological standard in the field of the theory of efficiency of complex technical systems with a time-distributed nature of the change in input and output products.

Unlike [2], a strict definition of the efficiency indicator of the production process, which has a quantitative assessment, is proposed.

In contrast to works [3–5], the formulated criterion for the efficiency of the production operation has a pronounced technical and economic character, which is associated with the use of value assessments of various types of products to bring comparable units of measurement to the system. This approach allows us to largely abstract from the physical and technical characteristics of the production process.

When developing a structural scheme for determining the effectiveness of a controlled fluid heating system, a strict system for determining both individual indicators of the technological operation and the indicator of its effectiveness as a whole was used. This makes it possible to reuse the developed solutions, provides terminological rigor of our work, which distinguishes it from studies [6–12].

In [13], the issues of determining the efficiency indicator of the process of starting powerful electric drives were considered but the nature of the change in the output product is time-focused.

A fairly powerful and universal system of definitions related to the characteristics of a complex system in the process of resource conversion is given. Using the mathematical apparatus of the theory of predicate algebra, a system of axioms is formulated – formulas (1) to (14), which formalizes the technique of calculating the efficiency index of a complex technical system for a fairly general case of the time-distributed nature of input and output products.

An example of the application of the developed axiom system to the construction of a subsystem for determining the efficiency indicators of the controlled fluid heating system is shown (Fig. 2).

An important characteristic of the resulting solution is the invariance of the subsystem for determining the effectiveness of the technical system on the technological process of transformation performed by it. This level of universality allows us to argue about the cybernetic nature of such a subsystem and the indicators used in it.

A limitation of this study is that the analysis performed is limited to a class of complex technical systems. This is due to the fact that for this class of complex systems, it is quite easy to formulate ideas about the resource conversion process and offer a system of expert evaluations of input and output products. Extending the study's results to assess the effectiveness of other classes of processes and systems (educational processes, treatment processes, etc.) is possible when developing a system for the structure of input and output products of such systems. It is also necessary to create a consistent system of expert assessments of the value of input and output products.

The disadvantages of the study are the significant complexity of the obtained expressions for determining the efficiency of the transformation process with the distributed nature of the input and output products. This may cause unjustified complication of the design of technical devices that implement the proposed solutions.

This study may be advanced by estimating the errors that occur when representing a real transformation operation with an equivalent focused operation with concentrated parameters. This will significantly simplify the design of devices for optimal control over conversion processes of complex technical systems.

The use of the cybernetic subsystem for determining the performance indicators of the technical system makes it possible to move on in the future to the creation of an invariant optimal conversion process control system with distributed parameters of input and output products.

7. Conclusions

1. The system of definitions of the applied theory of efficiency has been formulated. The main classes of operational processes have been formalized, definitions for quantitative characteristics of production processes with distributed parameters of input and output products have been introduced. The proposed system of definitions of performance indicators has a higher level of abstraction compared to technical indicators. This allows us to unify approaches to the study of the efficiency of various production processes.

2. The formulated system of consistent axioms is based on the theory of predicate algebra. Its distinctive feature is the definition of cybernetic verified characteristics of the efficiency of resource conversion processes for a class of continuous production transformation processes with distributed parameters of input and output products. This makes it possible to create a universal subsystem for determining performance indicators that do not depend on the characteristics of the production process.

3. The developed example of a system for determining the efficiency of the liquid heating process is based on the proposed system of definitions and axioms. In the developed system for determining the efficiency indicator, a subsystem is separated whose structure and functional features are invariant with respect to the type and characteristics of the production process. This makes it possible to create universal equipment designed to optimally control the transformation processes of complex technical systems. Built on the basis of the developed definitions and axioms, the subsystem for determining the effectiveness of the transformation process is a new cybernetic entity since it is universal, invariant with respect to the type and characteristics of the transformation process under consideration.

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