

DETERMINATION OF THE EXPERT KNOWLEDGE BASE ON THE BASIS OF A FUNCTIONAL AND DIAGNOSTIC ANALYSIS OF A TECHNICAL OBJECT

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ABSTRACT**:** This paper presents a method to control an operation process of a complex technical object, with the use of trivalent diagnostic information. Also, a general diagram of the complex technical object was presented, and its internal structure was described. A diagnostic analysis was conducted, as a result of which sets of the functional elements of the object and its diagnostic signals were determined. Also, the methodology of the diagnostic examination of the technical system was presented. The result was a functional and diagnostic model, which constituted the basis for initial diagnostic information, which is provided by the sets of information concerning the elements of the basic modules and their output signals. The theoretical results obtained in the present study were verified in practice on the example of a complex and reparable technical object. It belongs to the group of technical equipment for which a short time of shutdowns is required (an ineffective use of the object).
KEYWORDS**:** expert systems, knowledge base, technical diagnostic, electronics systems, algorithm, artificial intelligence.

1. INTRODUCTION

In an improvement of the maintenance process of a technical object, the knowledge and the description of the methods to create a maintenance base of expert knowledge constitute one of the important factors (elements) of this process. In the authors opinion, this problem concerns the difficult tasks related to the development of the methodology and the description of the method of specialists' work. The issues concerning the construction of maintenance rules and the creation of the data base has been fairly well studied in the literature [1, 2, 7, 8, 10, 11, 18, 19, 21]. It is also important to study the methods of the experts' work and the manners of expert inference. The issues concerning the description including in what way an expert builds specialist knowledge has not been studied as yet. There is no description of the overall principles of specialists' work in the maintenance process of a technical object. Regarding the problems described concerning the use of diagnostic information in the development process of specialist knowledge bases, a new trend in the research is being developed by one of the paper authors. The theory of operation of technical devices concerns the regeneration of the resources of the functioning of technical devices, description of the operation process of technical devices, as well as determination and investigation of the operating conditions of technical objects.

There are no studies which would combine the theory of operation of technical devices and diagnostic testing into one whole by enriching this process of combination with other fields of knowledge such as expert systems and artificial neural networks.

The basic criterion for the selection of literature for the purpose of the present article was its significance in its field as well as the contribution to the issues dealt with in this article. 16 studies presented in the references included in this article were selected for an analysis of the literature proposed. The authors own studies constitute a significant portion of this literature. They present the author's research path to the solution of the issue covered by this article.

The literature in the references concerns papers which were written after the year 1985 as well as later studies up to the year 2015.

The papers published by Barlow, Birolini, Nakagawa, Pokoradi [1, 2, 18, 19, 20, 21, 22] present the theoretical background of the reliability of technical devices in the operation process. The authors presented mathematical basis of the policy rules of the organization of repairs (replacement of components (constructional elements)) of devices. Another important practical problem which was solved in the study is the representation of the ways and methods to set periods of repairs (replacements of functional parts) of devices and their optimization. The paper also covers preventative maintenance procedures including drawbacks of this type of maintenance. A large part of the paper deals with the issues of the development and verification of the maintenance policy strategy. The study is also of a large practical importance as regards the organization of the development of theoretical models of technical devices' maintenance processes as well as the conditions and rules of their modification.

The paper published by Duer (2012 and 2013), Kobayashi (2011), Rosiński (2010) [5, 6, 7, 8, 10, 11, 23, 24] constitutes the first item in the references. It covers the theory of operation of technical devices. It includes a mathematical description of a model of a technical object as regards its reliability and operation. The paper also presents an organization of the operation process with the use of the object's models presented. The authors also possess a lot of experience in diagnostic testing of technical devices, the effect of which is their previous studies.

The studies developed by Hojjat (1995), Buchannan (1985), Kacalak (2012), Madan (2003), Waterman (1986), Zurada (2007) [3, 7, 12-14, 20, 25, 26, 27] includes theoretical and mathematical grounds of the functioning of artificial intelligence and export systems. The authors presented and characterized the difference between these fields of knowledge. The papers constitute a guide as regards the elaboration of the set of inferring rules, knowledge representation, its collection and ways of analysis. To a large extent, the papers assist practical problems connected with the creation of expert knowledge, including its application in the diagnostics and operation of technical devices.

The papers published by Duer (2010-2012) [4-7], make the use more specific (and improved) of the results of diagnostic testing in the organization of a technical object's maintenance system. The papers present the mechanism of a negative change of states in a technical object, as a result of which there occurs in the object a reduction of its operational properties: a change of the state. The author also presented a diagram and a description of artificial neural network structures and mathematical dependencies which express the idea of the functioning of the network in compliance with the algorithm developed for it. The paper also presents theoretical grounds for diagnosing of technical objects in trivalent logic with the use of an artificial neural network. The results of the study were supported with an example of a diagnostic information database for the device tested.

The study by (Barlow 1995, Rosiński 2008) [2, 23] covers mathematical basis for the reliability and the quality of operation of technical devices in probabilistic and statistical approaches. Methods of an analysis and testing of reliability with the use of Markow's method (among others) were discussed. The paper includes well-developed mathematical models of reliability for technical, medical etc. devices (products).

One of the paper authors used his experience in the area of the construction of a specialist knowledge base in the formal description for the needs of the maintenance process (Fig. 1).

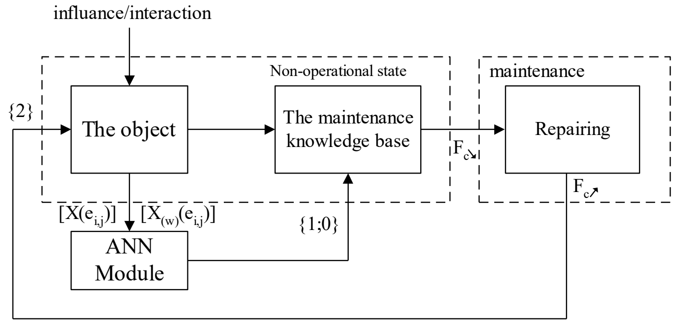

Figure. 1. Diagram of operation process for technical object utilizing artificial neural network, where: $X(e_{i,j})$ – diagnostic signal in jth element of ith set, $X_{(w)}(e_{i,j})$ – model signal for $X(e_{i,j})$ signal, {2, 1, 0} – value of state assessment logics for the technical object, where: "2" – the state of full operation; "1" – the state of incomplete usability; "0" – the state of non-operation (defect), F_C - function of the use of the object

One of the authors of this paper systematically describes in his papers [4-11] the improvement methods of the preventive procedures of technical objects (Fig. 1). A functional and diagnostic analysis constitutes the basis for the designing of every maintenance system of any technical object. The result is information obtained about the object, including usability, diagnostic, functional, maintenance-specialist and any other data.

2. FUNCTIONAL AND DIAGNOSTIC ANALYSIS OF TECHNICAL OBJECT

The technical object {O} used for tests in the present study is a reparable complex technical object of an analogue class. While preparing a diagnostic model of this class of an object, its internal structure was divided into four levels of the maintenance structure (Fig. 2): level one: object {O}, level two: assemblies (in object {O}), level three: subassemblies (in each assembly $\{E_i\}$), level four: modules-basic elements (in each subassembly, of each assembly of the object).

The first level of the maintenance structure of the object is constituted by the object itself. It is a set of functional assemblies $\{E_i\}$. The assemblies of the object constitute the second level of the object's maintenance structure, while each of them is a set of operation subassemblies. Subassemblies in assemblies constitute the third level of the object's maintenance structure. The lowest level, i.e. the fourth level of the structure, is constituted by the basic elements:

modules. Each functional subassembly of the object consists of basic elements, which are the smallest and indivisible functional element in the object. It was assumed in the paper that such an element is understood as a basic element in the object where there is an output (diagnostic) signal on its output. If object {O} has been divided into *i* structural levels, and in each of them, there are *j* basic elements, then each of the object's structural levels constitutes a set of operating elements $\{e_{i,j}\}$, which was presented in the form of the following dependence:

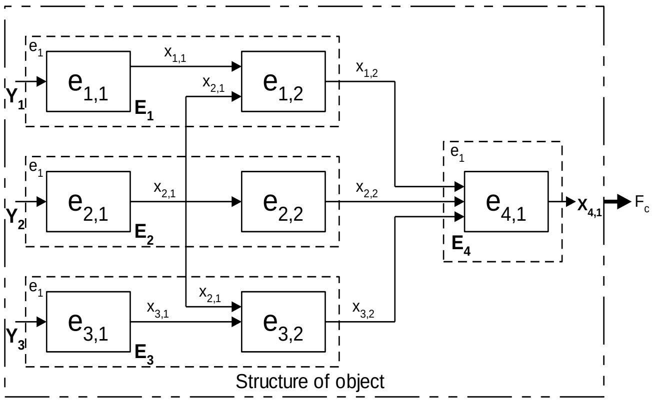

Figure. 2. Functional and diagnostic model of the object, where: E_i - ij[th] functional assembly in the object, e_i - j j[th] subassembly or functional element in a given assembly, $Y_{1,2,3}$ – input signals in the object

$$\{O\} \Rightarrow (\{E_i\} \Rightarrow \{e_j\}) = \{e_{i,j}\} \tag{1}$$

where: {O} – object's internal structure, $\Rightarrow$ – relation of result (division), E_i – i[th] functional assembly of the object, e_j – j[th] subassembly in i[th] assembly of the object, $\{e_{i,j}\}$ – set of basic elements in the object (structure of the object).

The object's state is determined on the basis of an examination of the set of output (diagnostic) signals $\{X(e_{i,j})\}$(Table 1) [4-11, 22-24]. The set of its functional elements $\{e_{i,j}\}$ determined during a diagnostic study of the object constitutes the basis for the list included in the table of a set of diagnostic signals (Table 1).

Table 1. Table of object's input diagnostic signals

Object	Level of object E_i	Vector of initial diagnostic signals $\{X(e_{i,j})\}$				
		X(e1,1)	...	*X(ei,j)*	...	*X(ei,J)*
O	E_1	$X(e_{1,1})$	...	$X(e_{1,j})$	...	$X(e_{1,J})$
	⋮	⋮	...	⋮	...	⋮
	E_i	$X(e_{i,1})$	...	$X(e_{i,j})$	...	$X(e_{i,J})$
	⋮	⋮	...	⋮	...	⋮
	E_I	$X(e_{I,1})$	...	$X(e_{I,j})$	...	$X(e_{I,J})$

where: $X(e_{i,j})$ – diagnostic signal of j[th] element in i[th] assembly.

The issue of the recognition of the object's states (Table 2) for the purpose of a regeneration of usable properties in the operating system (Fig. 2) is constantly developing. More and more effective (modern) diagnostic systems of technical objects are being sought, also with the use of artificial neural networks (Fig. 5).

For this purpose, on the basis of the object's diagnostic model (Fig. 1), an optimum number of check paths is determined. Each check (d_i) covers a certain set of elements (e_j) in a given assembly (E_i), which means that a subset of elements $\{e_j \; \varepsilon \; E_i\}$ is assigned to diagnostic check (d_i); therefore, the check path is determined, which is described with the following dependence:

$$\underset{\substack{d_i \in D \\ i=\overline{1,I}}}{\forall} \left(d_i \mapsto \rangle e_j \langle d_i\right) \;\; ; e_j \in E_i \tag{2}$$

where: $\mapsto$ – assignment relation, $\rightarrow$ – relation of result, $\rangle e_j \langle d_i$ – subset of basic elements ($e_{i,j}$) covered by check d_i.

Diagnostic decision rules for a trivalent assessment of the object's states were presented in the form of the following dependence:

$$\underset{e_j \in E_i}{\exists} \left(\left(\varepsilon\left(e_{i,j}\right)=0\right) \Leftrightarrow \left(D_i\left(\varepsilon\left(e_{i,j}\right)=0\right)=0\right)\right) \tag{3}$$

$$\underset{e_j \in E_i}{\forall} \left(\left(\varepsilon\left(e_{i,j}\right)=1\right) \Leftrightarrow \left(D_i\left(\varepsilon\left(e_{i,j}\right)=1\right)=1\right)\right) \tag{4}$$

$$\underset{e_j \in E_i}{\forall} \left(\left(\varepsilon\left(e_{i,j}\right)=2\right) \Leftrightarrow \left(D_i\left(\varepsilon\left(e_{i,j}\right)=2\right)=2\right)\right) \tag{5}$$

where: $(\varepsilon(e_{i,j})) = 0$ – non-operational state of element ($e_{i,j}$); $(\varepsilon(e_{i,j})) = 1$ – state of incomplete usability of element ($e_{i,j}$);$(\varepsilon(e_{i,j})) = 2$ – state of non-operation of element ($e_{i,j}$); $(D_i(\varepsilon(e_{i,j}) = 0)$ – result of check with non-operational element ($e_{i,j}$); $(D_i(\varepsilon(e_{i,j}) = 1)$ – result of check with an incompletely operating element ($e_{i,j}$); $(D_i(\varepsilon(e_{i,j}) = 2)$ – result of check with an operational element ($e_{i,j}$).

The results of the object's diagnosis obtained from the relations (4, 5, 6) are presented in Table 2.

Table 2. Table of object's states

State of object	State of module	Vector of states of elementary components $\{e_{i,j}\}$				
		$\varepsilon(e_{1,1})$	...	$\varepsilon(e_{i,j})$	...	$\varepsilon(e_{i,J})$
$W(\varepsilon(O))$	$W(\varepsilon(E_1))$	$W(\varepsilon(e_{1,1}))$	...	$W(\varepsilon(e_{1,j}))$	...	$W(\varepsilon(e_{1,J}))$
	⋮	⋮	...	⋮	...	⋮
	$W(\varepsilon(E_i))$	$W(\varepsilon(e_{i,1}))$	...	$W(\varepsilon(e_{i,j}))$	...	∅
	⋮	⋮	...	⋮	...	⋮
	$W(\varepsilon(E_I))$	$W(\varepsilon(e_{I,1}))$	...	$W(\varepsilon(e_{I,j}))$	...	$W(\varepsilon(e_{I,J}))$

where: $W(\varepsilon(e_{i,j}))$ – value of state assessment logics for j^{th} element within i^{th} module (from the set of the accepted three-value logic of states' assessment) - {2, 1, 0}), ∅ - symbol complementing the size of table.

3. DETERMINATION OF THE EXPERT KNOWLEDGE BASE ON THE BASIS OF A FUNCTIONAL AND DIAGNOSTIC ANALYSIS A TECHNICAL OBJECT ON THE EXAMPLE OF A CAR ENGINE

The method for the expert knowledge base determination presented will be verified on the example of a reparable technical object, which is an analogue controller unit for combustion automotive engine with its peripheries. (Fig. 3). Research set-up was developed on the basis of a spark ignition engine with multi-point injection MPF1. The object was subject to a diagnostic development, as a result of which a functional-diagnostic diagram was developed. In the example, an object was used whose internal structure (Fig. 4) is composed of seven modules (E_1, E_2, …, E_7) (Tab. 3), and each one of them, up to five elements were distinguished [7].

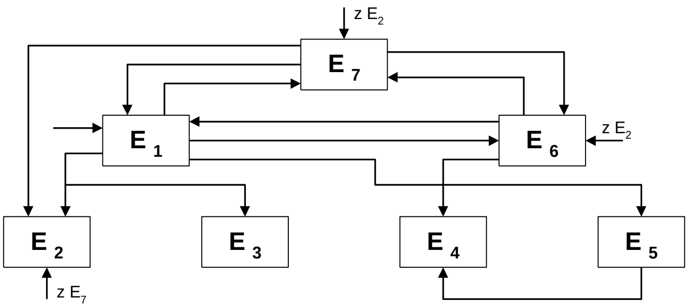

Figure. 3. Scheme of an electronic controller for an automotive engine

The object was subject to a diagnostic development, as a result of which the following was developed: a functional diagnostic diagram (Fig. 4), on the basis of which a set of maintenance elements was determined.

The presented method of diagnosing of technical objects requires the use of a uniform compliance of the designation of the elements of the object's structure. For this reason, the basic elements: modules of the object included in its functional and diagnostic model, must be "addressed" in a certain manner ($e_{i,j}$), where: j – is the number of the element in a given assembly, and (i) is the i^{th} number of this assembly of the object.

The modern diagnostic system with measurement module utilizes not only a measurement A/D converter card with appropriate signal interfaces, but also some computer tool used for proper signal registration as well as for acquiring and processing registered data. The purpose of such a process is to build a diagnostic knowledge base basing upon the analysis of both the object and the results of measurement stored [4-6, 9, 15, 18, 18, 21].

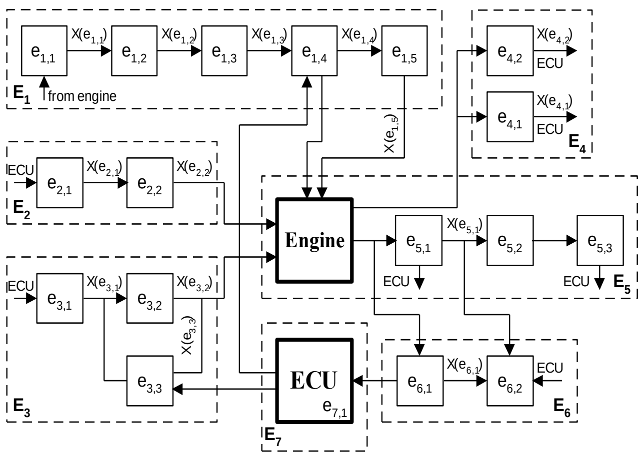

Figure. 4. Diagram of an electronic controller for an automotive engine, where: E_1 – ignition module, E_2 – fuelling module, E_3 – air-feeding module, E_4 – starting circuit, E_5 – power supply circuit, E_6 – engine block, E_7 – electronic control unit

Table 3. Internal structure of the object

Assembly of the object	Structure of the object $\{e_{i,j}\}$				
E_i	e_1	e_2	e_3	e_4	e_5
E_1	$e_{1,1}$	$e_{1,2}$	$e_{1,3}$	$e_{1,4}$	$e_{1,5}$
E_2	$e_{2,1}$	$e_{2,2}$	∅	∅	∅
E_3	$e_{3,1}$	$e_{3,2}$	$e_{3,3}$	∅	∅
E_4	$e_{4,1}$	$e_{4,2}$	∅	∅	∅
E_5	$e_{5,1}$	$e_{5,2}$	∅	∅	∅
E_6	$e_{6,1}$	$e_{6,2}$	∅	∅	∅
E_7	$e_{7,1}$	∅	∅	∅	∅

where: E_1 – ignition module: $e_{1,1}$ – automotive alternator, $e_{1,2}$ – voltage regulator, $e_{1,3}$ – battery, $e_{1,4}$ – coil ignition, $e_{1,5}$ – sparking plug; E_2 – fuelling module: $e_{2,1}$ – fuel tank ventilation valve ,$e_{2,2}$ – fuel injector; E_3 – air-feeding module: $e_{3,1}$ – air flow meter, $e_{3,2}$ – throttle position sensor, $e_{3,3}$ – idle run position controller; E_4 – starting circuit: $e_{4,1}$ – combustion knocking sensor $e_{4,2}$ – coolant temperature sensor; E_5 – power supply circuit: $e_{5,1}$ – oxygen sensor (1), $e_{5,2}$ – catalyser, $e_{5,3}$ - oxygen sensor (2); E_6 – engine block:$e_{6,1}$ – crank shaft position sensor, $e_{6,2}$ – EGR valve: E_7 – $e_{7,1}$ electronic control unit.

The use of DIAG software requires preparation of input diagnostic information on the basis of a functional and diagnostic analysis of a given object. A functional and diagnostic model of an object needs to be made. On the basis of this, the following was determined: a set of basic elements, a set of diagnostic signals $\{X(e_{i,j})\}$ (Fig. 6) and a set of their model (standard) signals $\{X_{(w)}(e_{i,j})\}$. The results of measurements [6] for chosen elements of the object are presented in Table 4 and Fig. 5.

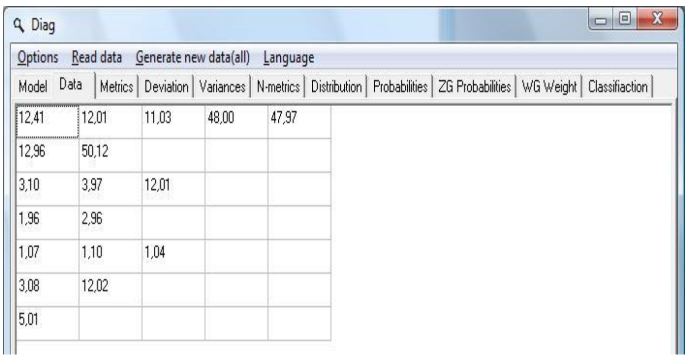

Figure. 5. Loading of input data to DIAG programme-matrix of measures of diagnostic signals from the object

Table 4. Matrix of measures of diagnostic signals from the object

Level of object E_i	Vector of initial diagnostic signals $\{X(e_{i,j})\}$ [V]				
E_i	e_1	e_2	e_3	e_4	e_5
E_1	12,41	12,01	11,03	48,00	47,97
E_2	12,96	50,12	∅	∅	∅
E_3	3,10	3,97	12,01	∅	∅
E_4	1,96	2,96	∅	∅	∅
E_5	1,07	1,10	1,04	∅	∅
E_6	3,08	12,02	∅	∅	∅
E_7	5,01	∅	∅	∅	∅

The state of the object was determined on the basis of the measurements of the diagnostic signal features processed. They were processed and analysed by an artificial neural network. The final results obtained of DIAG programme were presented in the form of a table of states (Table 5 and Fig. 6).

Table 5. The table of object's states

State of the object	State of the module	Vector of element's states $\varepsilon(e_j)$				
		e_1	e_2	e_3	e_4	e_5
0	1	1	1	2	2	2
	1	1	2	∅	∅	∅
	0	1	2	0	∅	∅
	2	2	2	∅	∅	∅
	1	2	1	2	∅	∅
	2	2	2	∅	∅	∅
	2	2	∅	∅	∅	∅

4. CLASSIFICATION OF THE ELEMENTS OF THE INTERNAL STRUCTURE OF A TECHNICAL OBJECT

Control of the quantity of the qualitative usability function (F_C) in the operation process requires, among other things, recognition and description of an object's internal structure, the nature of its work etc. In modern systems for the servicing of technical objects, with a computer aided organization of this process, an important role is played in them by specialist (expert) databases [3, 12-14, 16, 20, 25]. This specialist set of information concerning the object of servicing is determined on the basis of a description of the elements of the object's servicing structure, grouping of them into classes, and assigning of a specific subset of preventative activities to them, which are characteristic only of a given class of the elements of the structure (Tab. 6). For the description of the elements of the object's servicing structure for a given class, some properties of the object and its functional elements were used. The results obtained were presented in Tables 6.

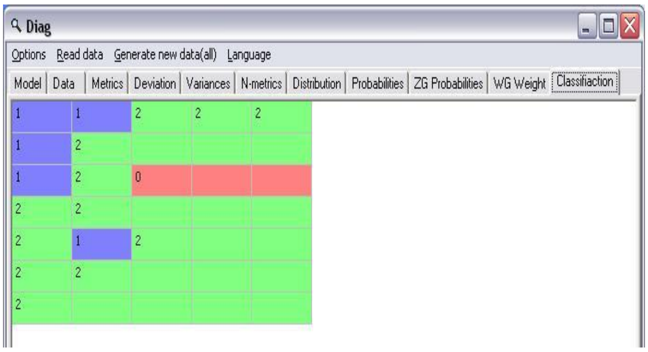

Figure. 6. The result form of DIAG programme "Table of object's states" (under servicing of object)

Table 6. Classes of operational elements of the object

Class of element s{$e_{i,j}$}	Elements of the assembly {$e_{i,j}$}						
	E_1	E_2	E_3	E_4	E_5	E_6	E_7
I - electronic	$e_{1,2}$	-	-	-	-	-	-
II – mechatronic	-	-	$e_{3,3}$	-	-	-	-
III – electric	$e_{1,1}$; $e_{1,3}$; $e_{1,4}$; $e_{1,5}$	$e_{2,1}$; $e_{2,2}$	-	$e_{4,1}$; $e_{4,2}$	$e_{5,1}$; $e_{5,2}$	$e_{6,1}$; $e_{6,2}$	-
IV – electromechanical	-	-	$e_{3,1}$; $e_{3,2}$	-	-	-	-
V – pneumatic	-	-	-	-	-	-	-
VI – mechanical	-	-	-	-	$e_{5,3}$	-	-
VII – digital	-	-	-	-	-	-	$e_{7,1}$

On the further state of the listing (development) of the set of the object's operational information, a classification (grouping) of elements was conducted in order to distinguish classes (groups) of operational elements. With the use of the manner of classification of operational elements as presented in the article, the object's functional elements were grouped into operational classes.

5. CONCLUSIONS

The article presents a method to control the operational process of a technical object. The basis of the presented system of regulation of the object's function of use (F_c) is constituted by diagnostic information which concerns the object's states. The diagnostic information is developed in a diagnostic system of recognition of the states of a reparable technical object, with the use of an artificial neural network. The accepted method of diagnosing by a neural network consists in comparing of the image of vectors of diagnostic signals with the images of their models. For this purpose, the technical object examined was subject to a diagnostic study. An important stage of the work is a functional and diagnostic analysis of the object. For this reason, the paper presents and describes the method of the division of the object's internal structure. As a result of this division, a set of basic elements and a set of diagnostic signals were determined. The grounds for the development of diagnostic decisions concerning the object's state is constituted by an analysis in the Euclidean space of elementary metrics of the distances-divergences of the vectors of diagnostic signals (measurement ones vs. their models).

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