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IDENTIFICATION AND MODELING OF PROCESSES FOR AUTOMATED CONTROL OF FUNCTIONAL DIAGNOSTICS OF METAL STRUCTURES

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Summary. *The issues of control and identification of multidimensional and closed systems of metal structures diagnostics have been considered. The main varieties of identification and modeling of processes for managing the functional diagnostics of metal structures dealing with the improvement of the input information quality due to limited restrictions satisfaction, searching for additional a posteriori information in the process of dynamic changes of the controlled object, forecasting changes in the internal structure of the material have been specified and discussed in detail. The scheme of a priori information in the form of parameterized mappings of inputs and outputs interactions of the diagnostic system has been presented. The results of simulation are associated with the selection of variables measured diagnostic parameters. A methodology for quantitative estimations of posterior inflow information due to entropy values has been developed. Using the marked apertures of modelling and forecasting at each stage of identification, it is possible to obtain a mathematical model adequate to the real situation.*
Key words: *management, identification, diagnostics, forecasting, a priori, a posteriori information, modeling.*

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Problem statement. Due to the development of informatics and computer science it is necessary to develop and apply some new principles of management models construction and observation results formalization similar to the real situation taking into account a posteriori information. Under diagnostic system functioning conditions the continuous information inflow is taking place dealing with both the change of object material properties whilst its performance and with changes in the requirements to the diagnostics quality, including the specification of permissible defects, their location, configuration, detecting the most dangerous areas, forecasting and detected defects evolution. All the above-mentioned operations aim at the improvement of operated equipment quality and reliability. The economic aspect of metal structures diagnostics involves the equipment residual lifetime evaluation.

The efficiency of management systems of metal products functional diagnostics is determined taking into account different input and output variables in the dynamic range characterized by uncertainty and unpredictability. The results of the above-mentioned management are the basis for parameters identification of metal products diagnostics processes. Identification of complex production objects is the set of methods of mathematical models construction according to the observation data whose adaptability to the environmental changes is provided despite incomplete a priori information and processes non-stationary state. Nowadays, it is impossible to forecast neither responds to the actions in general nor to the development of the very object under diagnostics without solving the problems of identification. The forecast models based on expertise and extrapolation of the tendencies under observation have been widely used. Nevertheless, they can be applied only for univariate time series, while the process of metal structures state diagnostics presupposes a complex analysis of various characteristics of the controlled object. In this way, the identification is connected with the selection of measured diagnostics parameters aimed at having an idea of the controlled object state. The development of methodological aspects of modeling of processes for automated control of functional diagnostics of metal structures is one of the unsolved tasks of the theory of complex dynamic objects automatic control.

Analysis of publications on the topic under discussion. The temporal and frequency methods of useful signals optimal filtration are used for target management of an object behavior in states space [1–5]. A great number of papers on systems identification deal with temporal series and their different applications [6–9]. Identification of multidimensional closed systems is connected with the real model approximation within the class of models [10–12]. In identification using to the modeling of processes for automated control of functional diagnostics of metal structures the very task of identification is defined as determination of the measured diagnostic parameters in the system output which describe the controlled structures state in the best possible way.

Under uncertainty and unpredictability conditions, caused by the equipment operational conditions, the problems of identification and modeling of the processes for automated control are especially urgent.

The aim of the paper is to identify and simulate the processes for automated control of functional diagnostics of metal structures.

Main material statement. To find out about the structure and properties of the object under diagnostics one should carry out the modeling of these processes on the basis of identification close to real production environment and specify the correspondent means of active influence on the process of management.

Most modern technological objects are complex multi-element systems with their own internal structure. Nevertheless, diagnostic system modeling considers them as the whole entity. In this way, any diagnostic system based on the measurement and analysis of different characteristics of the controlled object, in its state space, having various types of readings with their own dimensions, can be considered as a closed and multidimensional one.

Under new necessary information inflow conditions the very concept of controlled object is changing. Dynamic management object is an object whose output depends not only on the current value of input signals but on their values in previous moments of time as well. A scheme of the process of functional diagnostics management is shown on Figure 1.

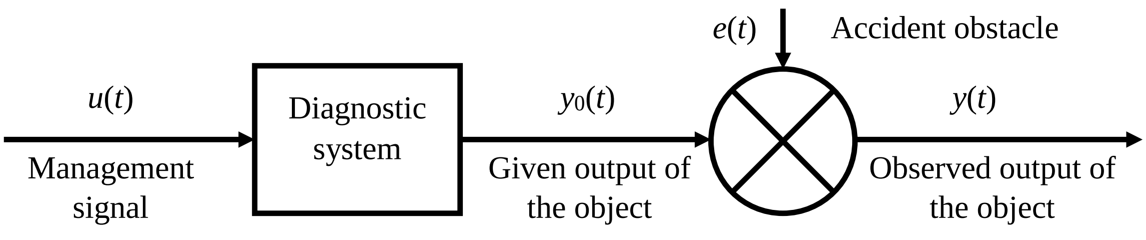

Figure 1. Scheme of the process of functional diagnostics management

The necessity of identification and its specialization is determined by the management goals which can be implemented by making impact on the managing object.

To achieve management goals one should pay special attention to their statement in all management stages as local goals undergo some changes after obtaining information of the analyzed processes dynamics. Initially the goal is specified as an oral statement and does not require any substantiation. The goal is updated at the further stages of management.

Labor intensity of dynamic processes automation is considerably influenced by the a priori information support about technological features of the controlled objects, their static and dynamic characteristics.

There are three basic options of automated control of functional diagnostics:

– increasing the quality of incoming information due to the more complete data on the controlled object, records and removal of the restrictions on the incoming a priori information, specification of objects operation conditions.

– searching any additional a posteriori information which corrects the existing information during the dynamic changes of the object state.

– forecasting of any possible changes of internal structure of the material in the operation of the objects.

Identification of objects of management processes automation starts from the collecting information of the controlled object. A priori information is the basis of the process model connecting the engineering intuition with formal properties of probabilistic models aimed at making decisions and has the form of parametrized representations of inputs and outputs interaction. Block diagram of a priori information of multidimensional closed diagnostic systems is shown on Figure 2.

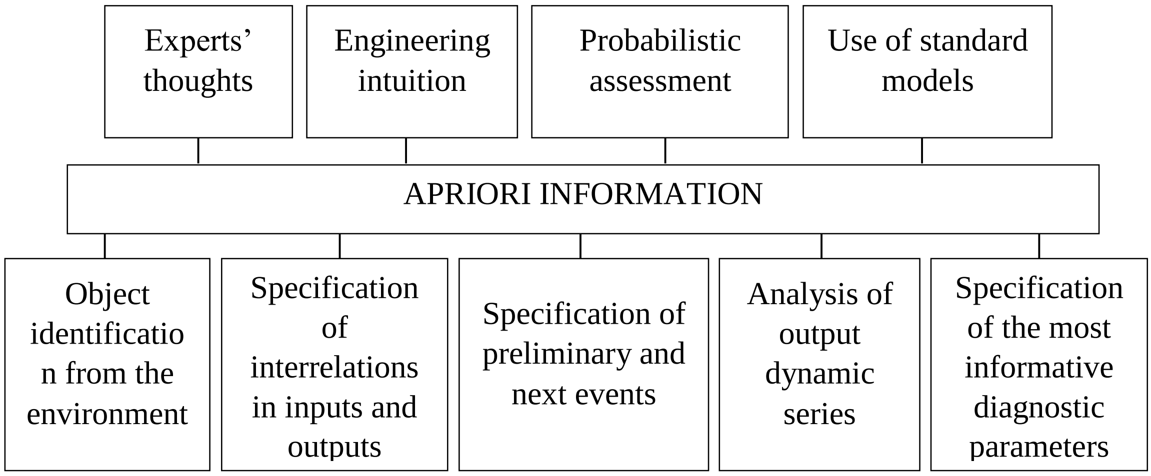

Figure 2. Block diagram of a priori information of multidimensional closed diagnostic systems

The main characteristics of a priori information of automated control under ambiguity conditions are as follows:

– stochasticity, specified by non-controlled accidental sources;

– responsiveness, where the knowledge of the analyzed factors depend on the previous incoming parameters;

– discreteness, specified by discrete time intervals;

– non-linear feature, characterized by the fact that the reaction on different actions is not the equivalent to the sum of reactions on each of these impacts.

An object is identified when the a priori information is received and on this basis a cognitive model is developed representing the mechanism of diagnostics object functioning. It looks like in the following way according to formalization form:

$$Y = F_m(X), \qquad (1)$$

where F_m – an operator of transformation the cause X into the result Y.

Interrelation of information situations, levels of uncertainty and managerial actions is characterized by the following set of values: X – a set of management alternatives, Y – a set of controlled object states, $P(x)$ – probability of defect detection in the products material.

Situation Y needs diagnostics described by the distribution $P(x)$ in the states space.

Similar to the above-mentioned situation one can imagine the connection between X and Y in a real object using the object operator F_0. The process of synthesis of operator model F_m must be the maximum close to the operator F_0. The aim of the identification is to construct such operator F_m that is the maximum close to the operator F_0. The level of their approximation defines the quality of a priori information.

The type of management modeling can be different after a posteriori information incoming, i.e. during the observation of the diagnostic system behavior under different values of specifying factors.

A posteriori information incoming to the diagnostic system input allows us to analyze the interrelation between input and output in certain ranges of their change.

A posteriori information about the state of the object of diagnostics is residual uncertainty of data after receiving additional messages.

It's necessary to have the access to the information of every structural element of the object under diagnostics for the quality of the specified information use. To monitor the dynamics of their change and determine the probability of an event taking place on the basis of knowledge of others' possibilities Bayes formula is proposed to be used.

Using the known information and data of new observations one can calculate the whole probability of the event A under carrying out the events $B_1, B_2, \dots, B_n$ conditions:

$$P(A) = P(B_1)P(A \mid B_1) + P(B_2)P(A \mid B_2) + \ldots + P(B_n)P(A \mid B_n), \qquad (2)$$

where $P(B)$ – a priori probability of event A when the event B takes place,
$P(A|B)$ – conditional probability of event A when the event B takes place

Events probabilities $B_1, B_2, \dots, B_n$ are changing when the event A takes place and they are calculated by the formula of a posteriori probability:

$$P(B_i \mid A) = \frac{P(B_i)P(A \mid B_i)}{P(A)}. \qquad (3)$$

Probability formula $P(B_i|A)$ shows the reassessment of the events probable occurrence $B_1, B_2, \dots, B_n$.

Bayes formula is used in those cases when the probabilities of structural components changes of the controlled object are known and they are reflected in the dimensions by other methods of diagnostics. Using Bayes formula one can find the specified value of a posteriori information necessary for the mathematical model construction of processes for automated control of functional diagnostics of metal structures.

Qualitative characteristic feature that there is enough a posteriori information is the value of its entropy H

$$H = \frac{I}{n} = -\sum_{i=1}^{m} P_i \log_2 P_i, \qquad (4)$$

where P_i – probability of a diagnostic system occur in the given state, I – information volume, m – number of possible states of the system, n – number of analyzed characteristics.

The entropy of a posteriori information source for the two states of the diagnostic system u_1 and u_2 with probability $P(u_1) = P$ i $P(u_2) = 1 – P$ is expressed by the formula

$$H(u) = -[P\log_2 P + (1-P)\log_2 P]. \tag{5}$$

For the eves $x_1, x_2, \ldots, x_n$, with equal probability $1/n$, the entropy value H_0 equals to:

$$H_0 = -\log_2 1 + \log_2 n, \tag{6}$$

Taking into account that

$$P_1 = \frac{N(x_1)}{N},\ P_2 = \frac{N(x_2)}{N},\ \ldots,\ P_n = \frac{N(x_n)}{N}. \tag{7}$$

Entropy formula looks like:

$$H = -\sum_{i=1}^{n}[P_i \log_2 N(x_i) - \log_2 N] + P_2(\log_2 N(x_2) - \log_2 N) + \ldots + P_n(\log_2 N(x_i) - \log_2 N), \tag{8}$$

where $N(x_i)$ – number of states of the diagnostic system at the moment when the event x_i took place;
N – general number of possible states of the diagnostic system.

Information structure of a priori data necessary for the entropy calculation must contain the data of the structural alternatives and diagnostics alternatives which can be found by means of statistical material processing or by analytical methods based on probabilistic ideas.

The entropy at given values of events possible occurrence has been calculated. These sources of information are considered to be completely independent.

At equally probable manifestations of analyzed dimensions x_1, x_2, x_3, the source of information will have the maximum of entropy value.

Thus, for $P_1 = P_2 = P_3$ и $i = 1,2,3$ entropy equals to:

$$\begin{gathered} H_0 = -\left[\frac{1}{3}(\log_2 1 - \log_2 3) + \frac{1}{3}(\log_2 1 - \log_2 3) + \frac{1}{3}(\log_2 1 - \log_2 3)\right] = \\ = \left[\log_2 1 - \log_2 3\right] = -\left[0 - 1.58496\right] = 1.58496\left[\text{bit}\right] \end{gathered} \tag{9}$$

For values $P_1 = 0.7$, $P_2 = 0.2$, $P_3 = 0.1$.

x_1, x_2, x_3 entropy equals to:

$$\begin{gathered} H_0 = -\left[\frac{7}{10}(\log_2 7 - \log_2 10) + \frac{1}{5}(\log_2 1 - \log_2 5) + \frac{1}{10}(\log_2 1 - \log_2 10)\right] = \\ = \left[(-0.360206) + (-0.464386) + (-0.332193)\right] = 1.156785\left[\text{bit}\right] \end{gathered} \tag{10}$$

The difference of these values characterizes the entropy changes that is the basis of its diagnostics:

$$\Delta H = H_0 - H_1 \tag{11}$$

A calculating experiment was carried out to unify and shorten the possible typical calculations dealing with the variability of indicators probability in operation. The results of the experiment are presented in the form of a posteriori entropy of the correspondent graphical charts (nomograms) (Figure 3). The values of possibilities of the last indicator are numerated on the curves $H = f(P)$

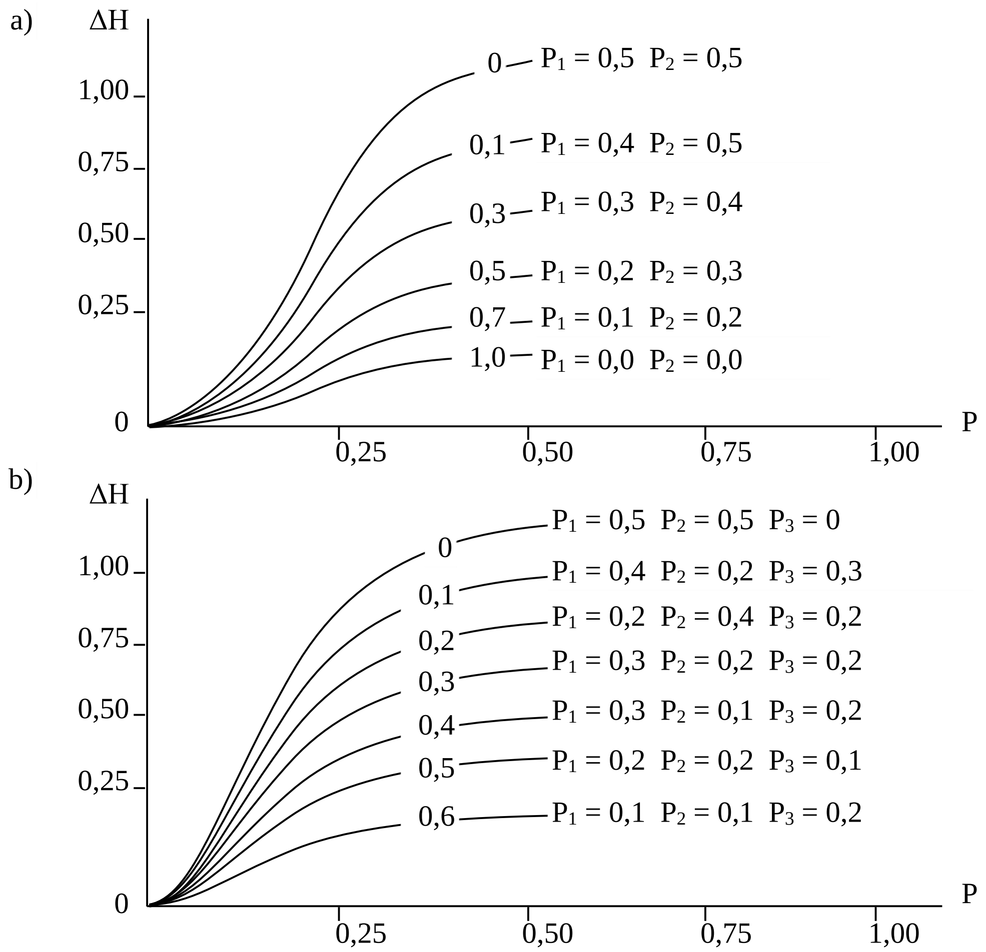

Figure 3. Nomograms for determining entropy at given probabilities for different groups of indicators: a) n = 3, b) n = 4

Entropy change is the basic criterion of quality of diagnostic system management system.

Statistical analysis, which was conducted on the initial stage of functional diagnostics management, and further specification of probability of events happening, calculations of a priori information and entropy value are able to regulate the process of storing the necessary amount of information at managerial decisions making.

Identification and forecasting from the mathematical models perspective concerning the object state diagnostics can be differentiated due to the following criteria: at identification the object state refers to the certain fixed period of time whereas at forecasting the object state is found in further periods of time.

Automation of processes on decisions making based on intellectual and information technologies and computer programs is a promising direction of increasing the efficiency of management system of object technical condition.

A considerable information flow is processed while errors are being searched and specified. The quality of the decisions made is greatly influenced by the software of technical diagnostics that involves:

- data bases of accumulated operation time, performance conditions, repair impacts
- standard values of diagnostic parameters
- results of diagnostics

– recommended actions of management

Algorithm of procedure for identification of multidimensional closed diagnostic systems has been developed on the basis of analysis of the presented statements (Figure 4).

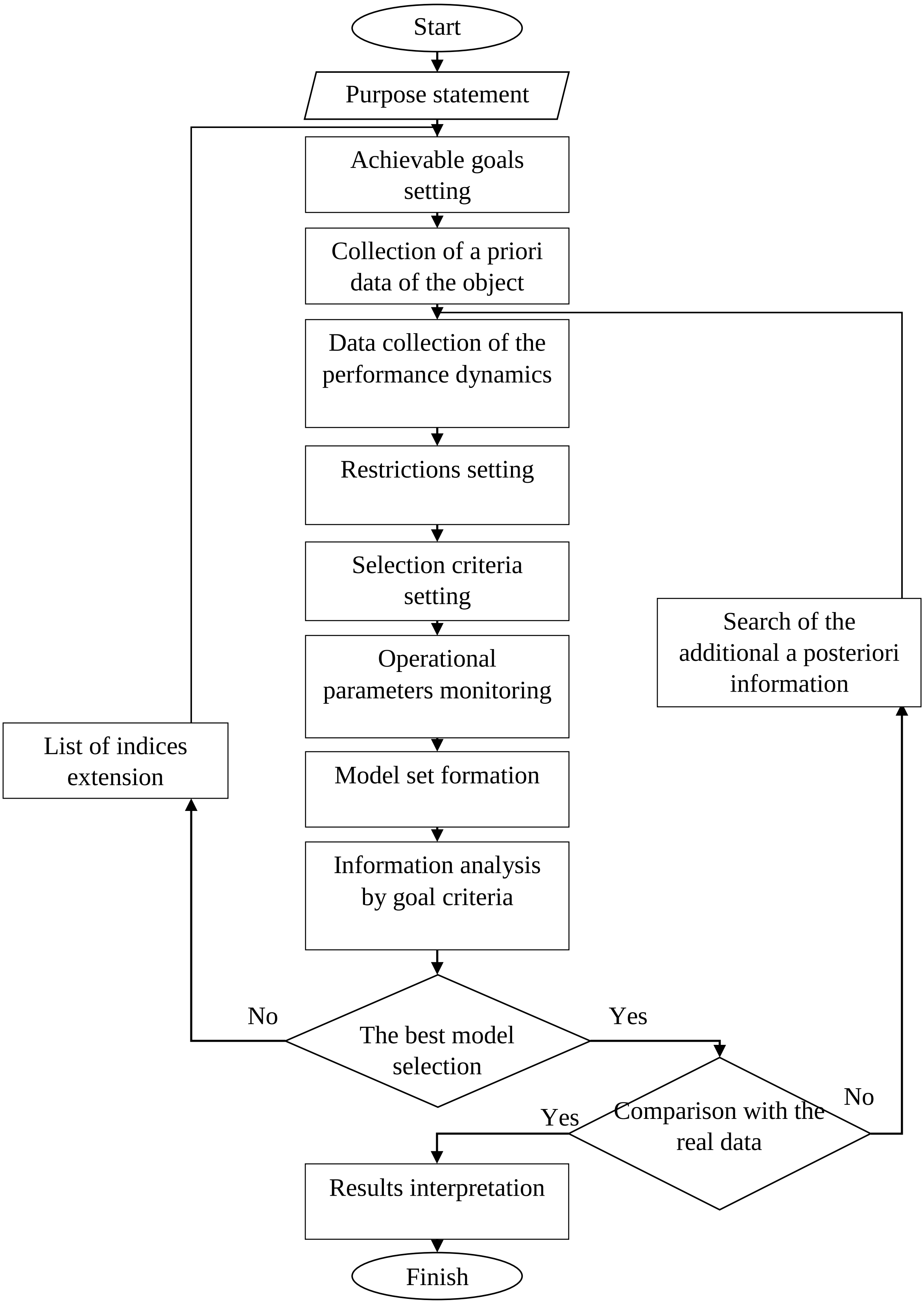

Figure 4. Algorithm of procedure for identification of multidimensional closed diagnostic systems

Interpretation of the algorithm of identification procedure as a weakly structured scheme of functional diagnostics allows us to overcome the intellectual difficulties in determining the structural changes of the material that is in operation and provides the increase of diagnostic system functioning quality.

The very technology of identification process concerning the modeling of functional diagnostics automated control involves the following iterations conducting:

– choice of mathematical hypothesis to describe the diagnostic system,
– mathematical model construction,
– determination of incoming a priori information,
– information processing according to the target criteria,
– carrying out some actions on the mathematical model parameters replacement by their empirical values,
– checking the model adequacy to the real diagnostic conditions,
– a posteriori information introduction,
– model correction,
– some practical recommendations writing.

The statements under discussion is the methodological basis of modeling of diagnostics of automated control under unpredictable changes impact conditions in operation on the structures material state. Identification of diagnostics allows us to find the components of the object dynamic state which can be automated. They can serve as the data which can be used by other researchers.

Conclusions. Identification of automation processes of functional diagnostics control can be considered as a system object involving a great number of methods based on the measuring of deviations from standard parameters and as a basic component providing the equipment reliability and its residual lifetime calculating.

The scheme of a priori information structure of multidimensional closed diagnostic systems under consideration, ways of its obtaining and identification allow to create a cognitive model that will represent the mechanism of a diagnostics object functioning.

To follow the dynamics of materials properties strength, caused by their structure changes due their performance Bayes formula is proposed to be used during the a posteriori information incoming period based on the knowledge of possible changes of other related characteristics of the object. The a posteriori information has been determined to be the quantitative assessment of residual ambiguity. After receiving any additional messages this feature of a posteriori information can be used for the prediction of changes in internal structure of the material in metal structures operation.

Under multifactor and different directions conditions the quality of forecasting can considerably decrease. Thus, at forecasting of trends in materials structure changes in multidimensional closed diagnostic systems some additional operations are recommended to introduce dealing with probabilistic assessment of expected changes: detecting bad values in time series and making the dynamic series indices correct.

The developed algorithm of identification procedure of multidimensional closed diagnostic systems, generalized methodical techniques of information analysis and processing allow us to increase considerably the reliability and adequate forecasting due to the decrease of residual ambiguity of incoming variables by means of a posteriori information correcting for the period of observation and forecasting. Some promising further research will deal with the construction of a control model of material structure diagnostic systems taking into account the changes in materials mechanical properties not only by output signals but immediately in the source of structure failure.

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ІДЕНТИФІКАЦІЯ ТА МОДЕЛЮВАННЯ ПРОЦЕСІВ АВТОМАТИЗОВАНОГО УПРАВЛІННЯ ФУНКЦІОНАЛЬНОЮ ДІАГНОСТИКОЮ МЕТАЛЕВИХ КОНСТРУКЦІЙ

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***Резюме**. Розглянуто питання управління та ідентифікації багатовимірних і замкнутих систем діагностики в матеріалі металевих конструкцій. Підкреслено, що широко використовуються моделі прогнозування, які базуються на експертизі й екстраполяції тенденцій, що спостерігаються, можуть бути використані лише для одновимірних часових рядів, водночас як процес діагностування стану металевих конструкцій передбачає комплексний аналіз різноманітних характеристик керованого об'єкта. Конкретизовано й детально розглянуто основні різновиди ідентифікації та моделювання процесів управління функціональною діагностикою металевих конструкцій, які пов'язані з підвищенням якості вхідної інформації за рахунок обліку лімітованих обмежень, пошуку додаткової апостеріорної інформації в процесі динамічних змін контрольованого об'єкта, прогнозуванні змін внутрішньої структури матеріалу в процесі експлуатації металевих конструкцій Запропоновано структурну схему вимог до якості апріорної інформації. Розроблено методологію кількісного оцінювання знаходження апостеріорної інформації через значення ентропії з використанням формули Байеса. Виконано розрахунки значень ентропії для різних груп показників діагностики. Встановлено, що апостеріорна інформація являє собою кількісне оцінювання залишкової невизначеності при ідентифікації й прогнозування змін міцнісних параметрів матеріалів. Доведено, що зміна ентропії є основним критерієм якості управління системою діагностики. Розроблено алгоритм процедури ідентифікації процесів автоматизованого управління функціональною діагностикою металевих конструкцій. Використовуючи зазначені прийоми моделювання й прогнозування на кожному етапі ідентифікації, можна отримати математичну модель, адекватну реальній ситуації. Ідентифікація діагностики дозволяє виділити компоненти діагностичного стану об'єктів, які можна автоматизувати. Результати моделювання пов'язуються з підбором змінних вимірюваних діагностичних параметрів.*

***Ключові слова:** управління, ідентифікація, діагностика, прогнозування, ентропія, міцнісні властивості, моделювання.*

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