Principles of construction of an adaptive multilevel system of monitoring and diagnostics of complex technical objects

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Abstract

This thesis is devoted to issues of development and research of the basis of the model for building an adaptive system of multi-level monitoring and diagnostics of complex technical objects. The requirements of the adaptive system of multi-level monitoring and diagnostics of complex technical objects are formulated. The scientific problem was posed, the requirements for adaptive systems were determined, taking into account the principle of maximum use of system resources.

The organization, architecture, principles of construction, work modes, technical and economic prerequisites for ensuring quality monitoring of the parameters of complex technical objects in real time, and the selection of the model of the research object were studied.

One of the distinctive features of the systems under consideration is that the function of adapting the operation modes of the diagnostics subsystem to changes in the characteristics of objects is included in the presented functional composition. A generalized structural and functional scheme of the system of multi-level monitoring and diagnostics of complex technical objects has been developed.

The paper presents the development of a generalized criterion for assessing the effectiveness of research into multi-level monitoring and diagnosis systems of complex technical objects and partial criteria for the monitoring subsystem and the diagnostics subsystem, and presents a model basis for building a multi-level monitoring and diagnosis system.

Keywords

Automated control systems, multi-level monitoring and diagnostic systems, adaptive multi-level monitoring and diagnostic systems, efficiency evaluations, the method of least squares, subsystems of control, diagnostics, forecasting and decision-making.

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1. Introduction

This thesis is devoted to issues of development and research of the basis of the model for building an adaptive system of multi-level monitoring and diagnostics (SMMD) of complex technical objects. Based on the analysis of the characteristics of controlled objects, presented in works [1, 2], a class of complex technical objects is defined, the main features of which are the complexity for monitoring and diagnosis, which is due to the stochasticity and multi-level processes, the complexity of the design, the impossibility of access to all units of the unit without its disassembly, as well as a lack of information for control. This class includes, in particular, hydroelectric power plants, thermal power plants and nuclear power plants.

Using the formalized approach of theory of automata, a functional-logical model of complex technical objects [3] was built and described, which allows to determine approaches for creating simulation models of complex technical objects, methods of their control, and to formulate requirements for multi-level monitoring and diagnostics.

Based on the analysis of works [4,5,6], the main principles of construction and properties of adaptive self-organizing technical systems are defined.

Among the large number of works aimed at solving the above-mentioned problems, it is possible to single out, for example, publications [9, 10], each of which considers certain issues related to the use of monitoring and diagnostic systems. Therefore, the main drawback of the presented multi-level monitoring systems is the difficulty of realizing their technical advantages in combination with acceptable cost and application adaptation [1, 11].

The purpose of the work is to study the organization, architecture, principles of construction, work modes, technical and economic prerequisites to ensure quality monitoring of the parameters of complex technical object (CTO) in real time, to select a model of the research object. To achieve the goal, the following scientific tasks were solved:

- analyze the subject area and determine the main characteristics of the adaptive system of multi-level monitoring and diagnostics of complex technical objects. Conduct a scientific problem statement, determine requirements for adaptive systems, taking into account the principle of maximum use of system resources;
- apply the method of two-stage modeling of the CTO automatic and simulation models of the object.

2. The main characteristics and functions of the adaptive system of multi-level monitoring and diagnostics of complex technical objects

Modern SMMDs are the result of the integration of previously existing subsystems of control, diagnosis, forecasting and decision-making for the prevention of emergency situations and liquidation of the consequences of unregulated conditions. SMMD are multi-level systems for monitoring man-made systems of complex industrial objects (CIO). Fig. 1 defines and presents a generalized structural and functional scheme of the SMMD CIO.

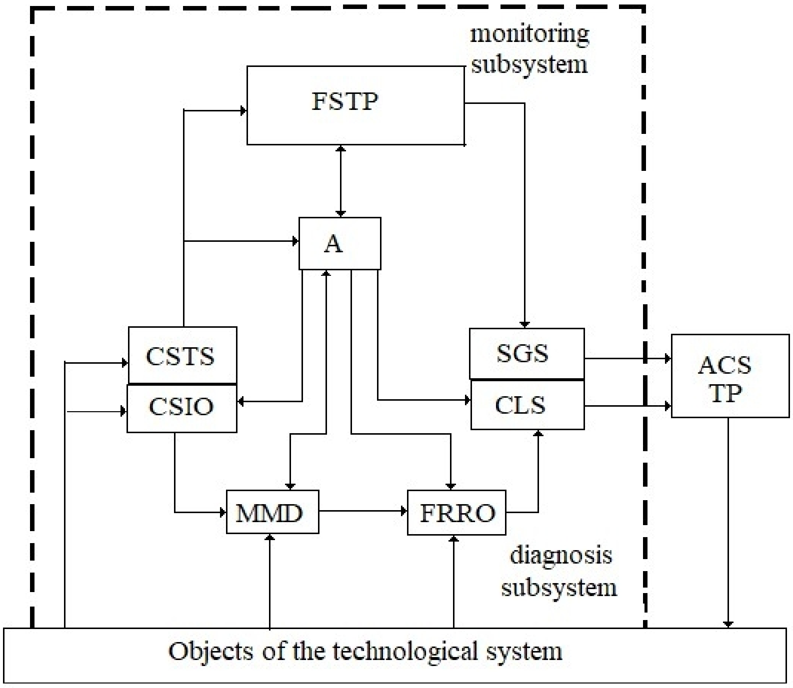

Figure 1: Structural and functional scheme of the SMMD of complex industrial facilities

The *monitoring* subsystem contains blocks to perform the following functions:

- control of the state of the technical system (CSTS);
- forecasting the state of the technical system (FSTS);
- adaptation of the modes of operation of functional blocks of the diagnostics subsystem (A) to changes in the characteristics of the CTO;
- selection of a global strategy and elimination of consequences from unregulated conditions of objects at the level of the technical system (SGS).

The *diagnostics* subsystem contains blocks to perform the following functions:

- control of the state of the industrial object (CSIO);
- multi-level monitoring and diagnostics (MMD);
- forecasting the residual resource of the object (FRRO);
- selection of a local strategy for liquidation of a specific identified unregulated state (SLS). All results are sent to the automated control system of the technological process (ACSTP).

One of the distinctive features of the systems under consideration is that the function of adapting the operation modes of the diagnostics subsystem to changes in the characteristics of objects is included in the presented functional composition [9, 12]. As a result, SMMD is provided with parametric adaptability at the system level. At the same time, the adaptation block initiates self-organization of the system to create the effect of coordinated interaction of its subsystems in order to implement the principle of maximum use of system resources.

3. A model basis for building a system of multi-level monitoring and diagnostics

The analysis of the system structure, information flows and time modes of operation, the SMMD under study was presented in the form of a single-channel multiphase mass service system and was discussed in detail in the paper [1]. In this paper, we will focus on the characteristics of the service station model. As a result of studies of modern approaches to the construction of models of complex objects [9, 11], a two-stage method of construction of CTO models was determined, according to which, at the first stage, a conceptual model of the object consisting of two subsystems is developed: • automatic;

• imitation.

The automatic one determines the algorithm of transition of object states, and the simulated one reproduces signals from the object corresponding to the transition states.

At the second stage, based on the canonical design method, a system of nested automata is developed to simulate object state transitions and signal simulators for each state [3, 7]. The model of each nested automaton (NA) is described by the following expression:

$$\mathrm{NA} = \{X, V, C, Y, S, \delta, \lambda, s_0\},$$

where X, V, C – are the corresponding vectors of controlling, disturbing and correlating parameters of the model, which collectively form a set of input data for each NA; Y – is a vector of initial values, $Y = \{y_1, y_2, \dots y_{ii}, \dots y_{NN}\}$; S – is a vector of states; δ, λ – state transition and output functions, respectively; s_0 – is the initial state of NA.

The transition functions $s(t')$ and $y(t')$ of the NA outputs in the automatic time t' mode are determined as follows:

$$s(t') = \delta\{s(t' - 1), x(t'), v(t'), c(t')\};$$

$$y(t') = \lambda\{s(t' - 1), x(t'), v(t'), c(t')\}.$$

According to the value of the vector Y of each nested automaton in the simulation subsystem, the appropriate model of the time series $P_i(t)$ of the CTO parameter is selected and adjusted in the form of the following polyharmonic polynomial:

$$P_i(t) = a_0 + \sum_{i=1}^{n} \left(a_i \cos\left(2\pi K_i \frac{t}{N}\right) + b_i \sin\left(2\pi K_i \frac{t}{N}\right)\right) + d_0 + d_1 t$$

where n is the number of harmonics during the training period of model N; K_i – is the coefficient that determines the harmonic number (i = 1, ... n; $n = N/2$); t is the time interval number, t = 1,2,3 ... . Model coefficients a_0, a_i, b_i are average statistical estimates of Fourier coefficients [13] for time series of parameters obtained experimentally, and coefficients d_0, d_1 are average statistical characteristics of the trend. All coefficients of the model are determined using the method of least squares [14].

Thus, the output signal of the model corresponding to the generalized parameter P^* for the moment tt is determined as a superposition of the simulated signals $P_i(t)$ (i = 1, ... m), i.e.:

$$P^{¿}(t)=\sum_{i=1}^{m} P_i(t)$$

The developed model has a wide range of functional capabilities, in comparison with known analogues, has flexible settings, can adapt to changes in the structure of CTO and can be implemented with available hardware [8, 15].

The main features of the presented methodological basis include the following characteristics:

- the presented methods and tools can be used at all stages of designing the SMMD, starting with the pre-project study of the system, ending with their implementation in production and recommendations for maintenance;
- the main concept of methodological developments is the synthesis of project solutions based on adaptive work modes and subsystem self-organization.

Based on the analysis of the characteristics of the studied objects, a class of complex technical objects was determined, the main feature of which is the complexity for monitoring and diagnostics, which is due to the stochasticity of the processes taking place, the complexity of the design, and the lack of information available for control. Typical representatives of CTO are hydroelectric power plants, thermal power plants, nuclear power plants, metallurgical facilities and oil refining enterprises.

With the use of the formalized approach of automata theory, a functional-logical model of CTO is built and described, which allows to determine approaches for creating simulation models of CTO and methods of their control.

The basic concept of scientific research and development for the creation of a single system of methods and means of construction of the SMMD CTO has been determined, the main aspects of which include:

- the creation of adaptive SMMD, in which the management of the operating modes of the diagnosis subsystem, which is located at the lower level, is performed at the upper level by the subsystem of monitoring the state of the objects of the entire technical system;
- diagnosis of CTO according to the principle of necessity, taking into account assessments of the real state of objects obtained as a result of monitoring;
- the selection of a strategy for the elimination of unregulated states of CTO is based on the results of the work of both subsystems;
- development of well-known and planning of new effective methods of control of CTO on the basis of modern information technologies and increasing the level of intellectualization of hardware and software tools of SMMD.

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