The intelligent system for monitoring and technical diagnostics of complex technological equipment in the agro-industrial complex

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Abstract. The article considers the intelligent system of control and technical diagnostics of complex technological equipment and flexible production systems developed by the authors. The provision of automatic selection of important parameters from the entire set of input and output parameters is due to the additional training of the neural network in the process and perhaps by increasing-decreasing the number of active neurons that do not lead to deterioration in the quality of technical diagnostics, but also due to the choice of excess neurons and their activation by retraining or failure of the neurons of the network. Diagnostic systems may include sensors, a computer system, and diagnostic signal display devices. The computational part of the system can contain modules implemented with the possibility of intelligent analysis and containing a dynamic model that is implemented on a trained neural network, and a module implemented with the possibility of additional training of the neural network and the selection of active and redundant neurons.

1. Introduction
In technical diagnostics systems, there are decision-making elements that allow classifying the technical condition of the controlled object either as serviceable or as faulty. If a fault is detected, such systems identify the faulty element and determine the cause of the failure.

2. Materials and methods
Known systems for admittance control of functional states of technical devices, which contain a group of memory blocks, a differentiating element, a trigger, a group of memory registers, the group of items, group of compare units, each of which contains three memory registers, four adders, eight blocks of elements And block elements OR, comparator, inverter, OR-element. Moreover, the second and third groups of inputs of each comparator receive the values of the lower and upper limits of the range of acceptable parameter values. In the comparator, the condition (1) is checked:

$$P_i^b \leq P_i \leq P_i^a,$$

(1)
where $P_{i}^-$ - respectively, the lower and upper limits of the range of values of the j-th parameter.

If the condition (1) when the second comparator output, the signal output of which provides an extension region of parameter access at $3\sigma$ with respect to the lower and upper bounds. the reliability of decision-making (D) based on the results of tolerance control is determined by the probability of control error:

$$D=1-P_{os}$$

(2)

where $P_{os}$ - probability of error.

The probability of error is equal to the sum of two terms:

$$P_{os}=\alpha+\beta$$

(3)

where $\alpha$ is a type I error, the probability of erroneous recognition of the object of inspection is defective, and $\beta$ - error of the second kind, the probability of erroneous recognition of the object of control healthy.

Such devices have disadvantages. With the tolerance control of parameters according to the formula (1), it is assumed that the parameters $P_i$ are distributed according to the normal law $N(\mu, \sigma^2)$, where $\mu$ is the mathematical expectation, $\sigma^2$ is the variance. It is known that with a normal distribution of the parameter, 99% of the measurements fall within the confidence interval $[\mu\pm3\sigma]$. The assumption about the normal law of parameter distribution is not always valid and needs additional verification. In case of failures of the object of control, both the law of statistical distribution and the values of the controlled parameters can change. The analog of the claimed device does not take into account the possibility of changing the law of statistical distribution of parameters before and after failure. In complex technical systems, the number of elements is measured in hundreds. The degree of influence of failures of individual elements on the performance of a complex technical system varies. The tolerance control of the elements is not sufficient for technical diagnostics of the entire system.

For example, there is a method for analyzing the operation of a multi-stage gas turbine compressor with a certain number of compressor stages, in which one or more neural networks are trained based on the normal operation of the gas turbine, while measuring at least one dynamic pressure signal by means of at least one pressure sensor in or on the gas turbine compressor, and also measuring one or more operating parameters of the gas turbine by means of one or more other sensors in the normal operation of the gas turbine and/or a dynamic pressure signal, as well as one or more other operating parameters that are measured in the normal operation of the gas turbine, the dynamic pressure signal is subjected to frequency analysis, whereby one or more parameters of the frequency spectrum of the pressure signal are determined; based on one or more measured operating parameters and one or more parameters of the frequency spectrum of the pressure signal, as an output value have at least one diagnostic indicator, which represents a measure of probability for the presence of a normal gas turbine operation mode depending on the input values, characterized in that, that as a parameter of the frequency spectrum for each compressor stage, a characteristic frequency band is determined based on the number of revolutions of the gas turbine and the number of guide vanes and working vanes of the corresponding compressor stage.

There is a way to control a technical installation containing many systems, in particular a power plant. A device for monitoring a technical installation containing many systems, characterized in that at least one module is provided, which contains a dynamic model of at least one system of a technical installation, and the analysis module is supplied as input data with operating parameters or operating and structural parameters of the technical installation. At least one artificial intelligence-based algorithm contained in the analysis module identifies dependencies between operating parameters or operating and structural parameters of the
system in the operating parameters or operating and structural parameters through artificial intelligence methods and integrates the identified dependencies into the dynamic model as new dependencies and thereby improves it in terms of improving the accuracy of predicting the behavior of the system. Through this, the dynamic model of the system is improved in terms of improving the accuracy of predicting the behavior of the system during the operation of the system. The analysis module defines the output data that characterizes the instantaneous and/or future behavior in the operation of the system. Improving the dynamic model involves identifying inputs that have not previously been used by the dynamic model. With these inputs, the dynamic model is extensible. A dynamic system model contains one or more elements from a group:

- physical equation;
- neural network;
- fuzzy logic;
- genetic algorithm;
- graphic characteristics.

The dynamic model contains at least one neural network that is trained by the historical operating parameters of the system. The device has a set of analysis modules, which contain a dynamic model of at least one technical installation system, respectively. An additional algorithm based on artificial intelligence is introduced, which can be used to determine correlations, at least, between the input and output data of the first and the input and/or output data of the second of the analysis modules [1-7].

The dynamic model of at least one system of a technical installation is supplied as input data with the operating parameters or the operating and structural parameters of the technical installation. The dynamic model of the system during operation is improved by an artificial intelligence-based algorithm to improve the accuracy of predicting its behavior. Using artificial intelligence methods, they look for dependencies between operating parameters or operating and structural parameters of the system in the operating parameters or operating and structural parameters and integrate the identified dependencies into the dynamic model as new dependencies. By means of a dynamic model, output data is determined that characterize the instantaneous and future behavior in the operation of the system. Improving the dynamic model with respect to improving the accuracy of predicting the behavior of the system involves identifying such input data that has not yet been used by the dynamic model. With these inputs, the dynamic model is extensible. A plurality of dynamic models are provided that describe at least one system of the technical installation, respectively, and at least one subsequent artificial intelligence-based algorithm is provided by which correlations are determined at least between the input and output data of the first and the input and/or output data of the second of the dynamic models. Further outputs are determined by means of correlations that characterize the instantaneous and future behavior in the operation of the technical installation, and these further outputs contain information that goes beyond the system.

Such methods solve the problem of technical diagnostics by expanding the number of working and structural parameters of the technical installation, searching for new correlation dependencies between the parameters and including these dependencies in the dynamic model of the system. In order to implement a complex dynamic model of a technical system, an equally complex artificial neural network is required, and of a large size.

Adding new input and output parameters and new connections to the dynamic model will require increasing the number of neurons and mutual connections in the artificial neural network. The time of training and retraining of a neural network depends significantly on the number of neurons.

Thus, the "improvement" of the dynamic model will lead, at a certain step, to a decrease in the efficiency of the technical diagnostics system, due to an increase in the number of neurons in the network and the time spent on training and retraining the neural network.
The task is to optimize the size of the artificial neural network, reduce the number of neurons involved in the network and reduce the time spent on training and retraining the neural network.

The technical result can be achieved by increasing the efficiency of the technical diagnostics system by automatically selecting significant parameters from the entire set of input and output parameters used to diagnose complex technological equipment. Additional training of the neural network can be performed in the process of operation, by increasing or decreasing the number of active neurons, which does not lead to a deterioration in the quality of technical diagnostics, as well as by selecting redundant neurons and activating them during retraining or failure of neurons in the network.

During technical diagnostics of complex technological equipment, sensors are placed on it and in the working area, and measurements and signal conversions are made. The signals set the operating and structural parameters of the process equipment. Next, training signals are generated for the neural network in the form of vectors of input and output values, and these signals are used for initial training of the neural network. The trained neural network is connected to the inputs and outputs of the mining module, which contains a dynamic model implemented on the trained neural network. In the process of operation of technological equipment measurement and conversion of signals from sensors and based on these signals improved dynamic model by further training the neural network, adding new parameters, and to identify new reciprocal relationships between the mentioned parameters, after initial training of neural network thereto, the excess neurons, and in the process of training the neural network choose of the active and redundant neurons, which do not affect the result of the diagnosis, moreover, redundant neurons are activated during subsequent additional training of the neural network or when the neurons of the network fail. Criterion of excess neurons is the value of the total probability of errors first and second kind, the sum value of the scaling factors for input and output signals of a neuron trained neural network.

Signals from sensors that specify the operating and structural parameters of complex technological equipment are first converted into the form of the sum of Fourier series, and a significantly larger number of series members and greater accuracy of parameter measurement are used than is required for technical diagnostics, then the remainder of the series is estimated. Then, the values of the time series coefficients are calculated and converted into binary codes and digital signals and fed to the inputs of the trained neural network.

The technical result is achieved due to the fact that the devices of technical diagnostics of complex technological equipment contain sensors, a computer system and devices for displaying diagnostic signals connected to each other in series by inputs and outputs, where the sensors are made with the possibility of placing on the technological equipment and in the working area for measuring the values of working and structural parameters of complex technological equipment and converting them into digital signals, and the computer system consists of interconnected modules, where at least one module is implemented with the possibility of intelligent analysis and contains a dynamic model that includes a trained neural network, in which the inputs and outputs are made with the possibility of generating signals from the mentioned sensors, and the dynamic model can be implemented with the possibility of improving it by increasing the number of mentioned parameters, identifying mutual connections between them and additional training of the neural network during the operation of technological equipment, at least one module is implemented with the possibility of additional training of the neural network during the operation of technological equipment and the selection of active and redundant neurons, and the inputs of the mentioned module are connected to sensors, and the outputs are connected to the inputs of one or more intelligent analysis modules.
Figure 1. Intelligent system of technical diagnostics of complex technological equipment.

The structure of the intelligent system of technical diagnostics of complex technological equipment is shown in figure 1. Structural elements are indicated by the following positions: 1 – sensors; 2 - computer system; 3 - diagnostic signal display device; 4, 5, 8 - computer system modules; 5 - intelligent analysis module; 6, 7 - trained neural network; 6 - active neurons; 7 - redundant neutrons; 8 - module for additional training of the neural network and selection of active and redundant neurons.

3. Results and discussion
It is possible to offer a system of technical diagnostics of complex technological equipment, in which the following sequence of actions is performed.

1. Sensors are installed on the technological equipment and in the working area, and measurements and conversions of signals that set the working and structural parameters of complex technological equipment are made. The number of such parameters and their accuracy are chosen significantly more than is necessary for technical diagnostics. In the process of additional training and reducing the number of active neurons in the network, insignificant parameters and excessive accuracy will be automatically detected.

2. Based on the processing of measured signals from sensors, training signals for the neural network are formed in the form of vectors of input and output values. Initial training of the neural network is carried out. A certain number of redundant neurons are added to the trained neural network.

3. The trained neural network is connected to the inputs and outputs of the intelligent analysis module, which contains a dynamic model implemented on the trained neural network.

4. During the operation of technological equipment, sensors are used to measure and convert signals that set the operating and structural parameters of complex technological equipment. These signals are fed to the input of the computer system, at the output of which diagnostic signals are generated. Diagnostic signals are transmitted to the input of the diagnostic signal display device. The computing system includes interconnected modules, including at least one
module of intelligent analysis and at least one module made with the possibility of additional training of the neural network and the selection of active and redundant neurons. During the operation of the technological equipment, additional training of the neural network is carried out, adding new parameters and identifying new mutual connections between the mentioned parameters.

5. In the process of additional training of the neural network, the computer system selects active and redundant neurons. Active neurons affect the result of technical diagnostics. Redundant neurons do not affect the result of technical diagnostics. For example, the criterion for selecting redundant neurons is the total probability of errors of the first and second kind, calculated by (3). For example, the criterion for selecting redundant neurons is the sum of scaling coefficients for the input and output signals of a neuron. Excess neurons are transferred to the reserve.

6. Redundant neurons are activated during subsequent additional training of the neural network or when neurons fail. Redundant neurons of the input layer of the neural network determine non-essential parameters for technical diagnostics and control of the operation of technological equipment. Active neurons of the input layer of the neural network correspond to the essential parameters of technical diagnostics. The possibility of optimizing the size of the neural network is due not only to an increase in the number of neurons when expanding the number of parameters, connecting additional sensors and modules of the computer system, identifying new mutual connections, but also due to the reverse process - reducing the size of the neural network and selecting redundant neurons that do not significantly affect the result of technical diagnostics.

4. Conclusion
The computing system consists of separate modules that can be implemented on the basis of a controller, a computer, as well as on the basis of a software or hardware-software implemented trained neural network, with the connection of additional expansion cards for signal input and output and converting signals from sensors into digital form.

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