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DIAGNOSTICS OF MECHATRONIC SYSTEMS

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Abstract: The features of diagnostics of mechatronic systems are reviewed. A logical-linguistic model of diagnosis and prediction of residual life of mechatronic systems has been developed. The proposed model is a complex consisting of a description of the initial linguistic variables diagnostic parameters and technical conditions, the laws of the physical processes of degradation in mechanical, electrical, electromechanical, electronic devices, changes in patterns of diagnostic parameters in the event of defects in view of the functioning and modes of mechatronic systems. Identified patterns are presented in the rule base of fuzzy inference to determine the technical condition and calculation of residual life and intervals of diagnosing MS. Experimental studies have confirmed the adequacy of the logical-linguistic model of mechatronic systems. A direction of further research will be improvement of the model accuracy for chosen mechatronic object.

1 Introduction

Modern mechatronic systems (MS) are becoming more intelligent. MS should define its technical condition and to predict the residual life of the work. The diagnosis techniques are still being explored by many researcher, some of them as in [1] - [10]. Currently, promising directions of development of methods of diagnosis are the methods of artificial intelligence based on fuzzy logic and neural networks. Fuzzy logic can significantly simplify the description of the object model of diagnosis and are easier for hardware implementation [11] - [13]. Neural networks are used to identify objects, recognition and forecasting of MS [14] - [19]. Advantages of the classifier built based on neural networks, to traditional valuation methods lies in the following factors: the independence of the noise, self-learning, and the possibility of parallel processing. An important step in any method of diagnosis is to build a mathematical model, giving adequate information on the functioning of MS.

2 Logic-linguistic model of diagnosing mechatronic systems

Analysis of the known systems of diagnosis showed that there is no common approach to the construction of systems of diagnosing MS on artificial intelligence. As a rule, building a system of diagnosing MS is based on a mathematical model of the object of diagnosis. These models are very complicated, even for simple components such as bearings. Due to the diversity of mathematical models of functional elements, modules MS problem is pairing disparate mathematical models together. Furthermore, in this model, there is no mechanism of defects and failures, and without concern for their impact on the function of the target MS. The model object of diagnosis should be suitable for the various functional elements of the physical nature and take into account the emergence of these random defects.

For diagnosing mechatronic objects considered logical-linguistic model. This model is based on the description of input linguistic variables and technical conditions, the degradation of the physical processes in the mechanical, electrical, electromechanical, electronic units, regularities between defects and diagnostic parameters, knowledge of the functioning of MS algorithms for self-learning and knowledge.

Logic-linguistic model of diagnosis MS and calculation intervals diagnosis based on fuzzy logic is represented by a system of equations:

$$\begin{cases} x(t) = F(x(t_0), t), \\ D(t) = G(x(t_i), t), \\ Z(t) = H(x(t), D(t), t), \\ R(t) = W(x(t), D(t), Z(t), t), \\ \Delta t = V(x(t), D(t), R(t), t), \end{cases} \quad (1)$$

where $x(t) = F(x(t_0), t)$ – equation of diagnostic parameters;
x(t) – vector of diagnostic parameters;
$x(t_0), t$ – a set of diagnostic parameter measurements;
$D(t) = G(x(t_i), t)$ – equation to calculate the trend vector of diagnostic parameters;
t – utilized lifetime;
$Z(t) = H(x(t), D(t), t)$ – equation to evaluate the technical condition;
$R(t) = W(x(t), D(t), Z(t), t)$ – equation residual life assessment at the point in time t;
$\Delta t = V(x(t), D(t), R(t), t)$ – equation for calculating intervals diagnose.

A feature of MS as hierarchical structures is that the technical condition of the MS is determined by the condition of the elements in the worst condition and residual life is determined by the minimum residual life of the elements. Model diagnosing and forecasting facilities process equipment is implemented in the software product package MatLab Fuzzy Logic Toolbox. Fuzzy inference system technical condition assessment is realized on the basis of knowledge of fuzzy Mamdani type with three input variables *x*, *D*, *t*. As the membership functions of the linguistic variable term M can be selected trapezoidal function. In terms of membership functions as L, H linguistic variable chosen z, s functions.

Mamdani fuzzy inference is selected, the t-norm is maximum. Defuzzification carried out by the method of the centre of gravity, as it provides good accuracy and speed setting fuzzy knowledge base. The configurable parameters are used as the weights of rules, the coordinates of the maxima of the term of membership functions M linguistic variable.

3 Algorithms and software for diagnostics

A review of existing algorithms and software diagnosis shows no universal algorithms for diagnosing MS.

Neural networks are a promising mathematical tool for the creation of automatic diagnosing mechatronic objects. Neural networks have the following advantages: fast learning algorithms, the ability to work in the presence of significant noise, the ability to work with various information, the ability to simultaneously to solve several problems (parallelism of information processing), and reliable operation.

Statistical methods for recognizing the MS condition used in cases where the mathematical model of the physical processes is unknown or impossible to obtain. For example, when the physical processes described reliably enough known equations of mathematical physics, or the dimension of the model exceeds the capacity of existing computers. At the same time, statistical pattern recognition techniques require a substantial amount of state a priori data, i.e. Data obtained through experiments. Therefore, costly experiments, statistical methods can be detected, the small acceptable.

Diagnosing system faults using deterministic methods of recognition effectively in the presence of a mathematical model of its functioning. These models are, in most cases can be analysed only by numerical methods, which restricts their use in real-time troubleshooting and management of the technical system. Almost all real processes of functioning of technical systems have nonlinear behaviour. In these cases, experts are commonly used, that is there is human intervention in the process of diagnosis and management of the technical system. If deterministic knowledge available or mathematical modelling costly estimated time, or does not provide the required accuracy, there may be used other methods. These methods are modelling the knowledge of the operator by means of heuristic knowledge and inference strategies, such as is done in expert systems based on fuzzy logic to the implementation of hardware-based or software-algorithmic emulation of neural networks.

An important property of neural networks is that they study the dynamics of the system during a workout consisting of several training cycles, with the training data coming either from the previous cycle, consisting of a real signal. After each cycle, the neural network learns more and more about the dynamics of the object. One of the most important features of neural networks is their ability to study the dynamic behaviour of nonlinear systems automatically, if the neural network architecture comprises at least three layers. Perhaps the use of neural networks is in the problems of predicting residual service life of MS.

Algorithm of diagnosing establishes the composition and the procedure for diagnosing MS.

Generally, the following types of diagnosis:

- elementwise, consisting in diagnosing each element separately;
- modular, consisting in diagnosing individual mechatronic modules, each of which in turn consists of a number of elements;
- group comprising diagnosing a group of elements that are interrelated, but do not form a mechatronic module.

To construct a rational algorithm diagnosis is necessary:

- MS introduce a system recognized as a separate functional elements and relationships between them;
- determine a list of all possible faults and give a formal description of the system;
- create a mathematical description of the fault system.

Drawing algorithms diagnosis much simpler, if the task list of the defects indicated construction site where

possible types of defects. Often, you want to find a place where a defect and determine its cause.

Algorithm of diagnosis often involves the following sequence. First, measure the main characteristics of the MS and determine whether it works in a given mode or has excessive deviation. Further, a cause of these deviations and with the help of special tests detects a fault.

Thus, in the first stage is carried out functional diagnostics, and then - a test to find a defect diagnosis.

When diagnosing electrical and electronic elements necessary to determine the fault to the independent element (resistor, diode, transistor, etc.). In this case, to assess the performance of the system will need to test with great resolution.

Since MS are modular in their diagnosis is sometimes sufficient diagnostics module. Rectify faults in this case is achieved by replacing the faulty module serviceable.

In monitoring performance (serviceability) diagnostic system must objectively determine the defective or faulty item or unit. Verifying the operation is to determine how the module is at the current time, and whether the parameters of his work good technical condition.

It is currently, as a mathematical apparatus for diagnosing using methods of artificial intelligence, such as expert systems, artificial neural networks, fuzzy logic techniques and genetic algorithms.

Neural networks are non-linear model without knowledge of its structure and give results in a short period of time.

As the inputs of neural networks are the current, voltage, power, temperature, vibration, and the accuracy of spatial positions and rigidity, movement, power settings, time intervals.

The main problem encountered when using a neural network, a selection of the best features and the input parameters of the neural network, making it compact and classification of defects - accurate.

The mechanism of withdrawal of the expert system inference classifies states of the object using a database containing the history of the state of the equipment, which would describe the trends characteristic types of faults. Knowledge of trends in diagnostic parameter of any type of fault - a crucial moment, since it allows the expert system to conclude that the acceptance or disregard of a fault on the basis of a threshold value.

The key decision in the diagnosis of this condition is the choice of an efficient system of classification. They can be divided into two main groups: a model based on the knowledge and data.

Requires diagnostic tool with the ability to dynamically acquire knowledge is not demanding to the presence of examples of faults for the correct diagnosis and applicable to various typologies of equipment, at least one series of the machines.

Often, it seems difficult to collect data that reflect the whole "region error", while easier to define "area of the working values." Modern approaches are built on neural networks are trained on data taken from a properly functioning installation, and are able to detect a fault on the basis of data that lie outside the area defined during training.

Neural networks make it possible to effectively identify the cause and type of damage to mechatronic systems, working with noisy data, eliminating the need for intermediate electronic interference filters or filter by mathematical methods as well as to adapt to a particular instance.

Intelligent diagnostic system constructed as self-learning, self-tuning system with flexible decision-making procedures, as a system, based on knowledge and creates new knowledge in the operation.

The tasks of the intellectual system of diagnosing includes: assessment of technical conditions; data envelopment analysis, etc. Class intelligent diagnostic systems meet the following five principles:

- presence of interaction between the system of diagnosing the real outside world using information communication channels. Intelligent diagnostic system is obtained from his knowledge and influences it. Implementation of this principle allows organizing communication channel for knowledge extraction and organization of purposeful behaviour;
- fundamental openness of the system in order to enhance intelligence and improve their own behaviour (openness of the system is ensured by the self-tuning, self-organization and self-education). The system of knowledge of intellectual diagnostic system consists of two parts: your knowledge and proven knowledge. This principle allows organizing the completion and acquisition of knowledge;
- existence of mechanisms of functioning of the forecast changes in the environment and their own behaviour in a dynamically changing system of the outside world. In accordance with this principle, the intellectual system of diagnosing not fully intelligent, if it does not have the ability to predict changes in the outside world and of their own behaviour;
- existence of a system of building structure corresponding to the principle of IPDI (Increase of Precision with Decrease of Intelligence): the higher the control accuracy, the smaller the intelligence system. It is a way of building complex intelligent systems diagnostics when inaccurate knowledge of the model of the object or control his behaviour can be compensated by increasing the intelligence generated by the system;
- preservation operation at break ties or loss of control actions of the higher levels of the hierarchy.

For example, the intellectual system of diagnosing of CNC based on information system analysis of the technological equipment for the forming quality parameters using artificial neural networks, which are the basis of knowledge of the system and optimize the control

action (cutting mode parameters) using a genetic algorithm.

4 Conclusions

A logical-linguistic model of diagnosis and prediction of residual life of MS has been developed. The proposed model is a complex consisting of a description of the initial linguistic variables diagnostic parameters and technical conditions, the laws of the physical processes of degradation in mechanical, electrical, electromechanical, electronic devices, changes in patterns of diagnostic parameters in the event of defects in view of the functioning and modes of MS. Identified patterns are presented in the rule base of fuzzy inference to determine the technical condition and calculation of residual life and intervals of diagnosing MS. Experimental studies have confirmed the adequacy of the logical-linguistic model of MS. A direction of further research will be improvement of the model accuracy for chosen mechatronic object [20].

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