Technical diagnostics functioning machines and mechanisms

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Abstract. Article discusses the machines and mechanisms technical state monitoring problem. Approaches for estimating mechanical systems current technical state, defects detection and evaluation of mechanical elements degradation levels are considered. The paper analyzes the traditional methods offered in international and national standards, especially vibrodiagnostics. An advanced phase method is presented which is based on registration the kinematic parameters of the mechanism running cycle. The result of coupling the phase method and mathematical modeling is shown, and simulation comparison with the experimental data is presented.

1. Introduction

Machines and mechanisms technical state monitoring is an important part of maintenance process. The principal tasks are the current state monitoring, the degradation degree evaluation and emergency protection.

The current state of art is given in international standards, also applied in Russia [1-5]. These standards provide general approaches, methods, procedures and methodology used to determine the strategy of monitoring the current state of functioning machines and mechanisms, as well as the interpretation of measurement results. The data processing includes the parametric diagnostics, for example, vibration parameters, temperature, power, operating speed, contaminant content.

Approaches to monitoring consist in the analysis of a design, identification of diagnostic signs at faults and breakages and tracing the links between cause and effect which led to defect. Also the operating experience of the similar equipment is used. It is acknowledged that when using traditional approaches it is very hard to obtain quantitative assessment of degradation degree of cyclic mechanism and to provide the emergency protection.

The monitoring and diagnostics strategy main stages are:
- identification of the most critical components of machines and mechanisms,
- analysis of failures during operation,
- forming the list of measured parameters required for monitoring,
- faults and defects diagnostic signs identification,
- monitoring strategy development.

For development of monitoring strategy the operating experience for long periods of time is required in order to accumulate the score for defects and results of their analysis. And only after that the development of monitoring and diagnostics systems becomes possible. However not all defects are
manifested at the initial stage of operation. Such long preparatory process is unacceptable for the expensive equipment at high costs of its maintenance.

The analysis of methodology of diagnostics stated in the international and national standards shows that the level of obtained information is not insufficient for reliable assessment of functioning of machines and mechanisms. For traditional approaches the insufficient level of information is characterized by lack of quantitative estimates and wide use of qualitative categories for defect probability detection: "low," "average," "high" and "reliable".

Also it is claimed that monitoring of technical condition of machines and mechanisms carried out by the developer of the equipment. However, as a rule, developers and manufacturers do not develop the system of diagnostics (hydroelectric units, turbine units, the main pumps, rolling mills, etc. are the examples). The systems of diagnostics, as a rule, are developed by specialized firms since specific knowledge and experience are needed for this purpose.

The most critical elements of technical diagnostics are the reliable diagnostic signs which are not to be affected by operating conditions and modes. Currently, as shown by many years of practice, vibrodiagnostics cannot fully solve this problem [6-9]. The vibro-acoustic signal contains the natural vibrational background of the device and information on the interaction of the parts of the operating mechanism. A high level of interference and relatively small changes in the measured signal caused by defects significantly complicate the detection. Besides, using the vibrodiagnostics parameters (for example, vibration speed and vibration acceleration), it is not possible to establish a reliable relationship between the measurement results and the mathematical models of machine structure elements and parts and defects to be detected.

So, the problems of traditional diagnostics methods are:
- the lack of automatic and automated systems for assessing the machines and mechanisms current technical state,
- predominance of qualitative evaluations,
- shortening of time between repair intervals,
- big unproductive maintenance costs,
- complexity of detecting nascent defects and providing emergency protection,
- reducing the competitiveness of products.

For the processing of measurement information and decision-making in machines and mechanisms state monitoring, various approaches are currently used: methods of system analysis and synthesis, the theory of pattern recognition, the theory of neural networks, Bayesian methodology, probability theory, reliability theory, wavelet transformations, methods of game theory, methods of artificial intelligence, theory of optimization and decision making, fuzzy sets, fuzzy logic, etc. This wide variety of methods confirms the lack of a unified approach to obtaining information for functioning machines and mechanisms technical state diagnostics.

Thus, in connection with the reasons considered, the traditional methods fail to fully solve the problem of obtaining reliable information on the diagnostic features of cyclic machines and mechanisms for reliable assessment of the current technical state, emergency protection and degradation degree evaluation.

2. Requirements for obtaining effective information.

For obtaining information on functioning of cyclic machines and mechanisms (mechanical and electromechanical systems) characteristic to their technical state it is necessary to meet the following requirements:

1. For assessment of functioning of machines and mechanisms there has to be a possibility of accumulating the measurement information in order to detect the slow trends caused by normal wear and crescent defects. The long observation periods are also necessary to define the diagnostic signs of diagnostic signs defects typical for machines and mechanisms operation.
2. Measuring instruments accuracy is to be sufficient for assessment of the diagnostic signs caused by wear and developing defects which are usually much smaller than the nominal measured parameters values.

3. It is necessary to implement the mathematical models for structural elements, defects and processes happening in the mechanism. It is also necessary to carry out these models identification using experimental data. This increases greatly the diagnostic signs robustness for all types of defects.

3. Phase-chronometric method for diagnosing cyclic machines and mechanisms

The most perspective for cyclic machines and mechanisms are phase methods. Phase approach is most organically connected with a running cycle of the device, and all life cycle of machines and mechanisms is connected with its realization and is supported by all maintenance operations.

Practice of application and research showed that the characteristics received on the basis of phase methods are connected directly to parameters of the mechanism functioning elements and parts[6-12].

The main idea of a phase-chronometric method is registration of kinematic parameters of the running cycle of the parts of the cyclic device. The key controlled parameter of a phase-chronometric method are time intervals corresponding to a running cycle of parts of the device, for example rotation of turbines, shaft of rotor mechanisms. As the running cycle in the normal mode of functioning of a mechanism is characterized by relative stability and repeatability of kinematic parameters at all operational phase, there is a opportunity of detection diagnostic signs corresponding slow processes of wear and growing defects [6-9]. Also, if necessary, measurements are made of the basic operating parameters of the device.

Due to the fact that time intervals are measured with an accuracy unattainable for other physical quantities, phase-chronometric measurements of time intervals variations are highly sensitive to the influence of various factors on the operation of the device, for example:
- accuracies in the manufacturing dimensions of parts and assemblies,
- influence of wear (for example, wear of rolling bearings),
- detection of emerging defects at an early stage, since the phase-chronometric measurements sensitivities is much higher than for vibro-acoustic measurements ( because there is a natural background of the machine's vibration),
- the impact of operating conditions,
- the impact of changes in modes of operation, etc.

4. The main advantages of the phase-chronometric diagnostic method

1. Practically achieved high accuracy of measuring time intervals in the conditions of operation of machines up to 1±10^{-7} s provides registration of changes in the operation of the device associated with the interaction of structural elements, processes and operating conditions.

2. The high metrological level makes it possible to obtain individual quantitative characteristics for phase-chronometric diagnostic signs of nascent defects. The metrological level achieved makes it possible to obtain a higher detail of information in comparison with vibrodiagnostics.

3. The most significant advantage of the method is the opportunity of using the mathematical models [6-12] on the basis of classic mechanic theory describing the operation of cyclic mechanical and electromechanical machines and their elements, normal and defected. It enables to evaluate the operation of the machine and identify diagnostic features of defects. The use of mathematical models and algorithms permits to process measurement data and detect defects diagnostic signs.

The mathematical model of the product is the most important factor in the relationship between measurement results and the process of functioning of parts and assemblies in the device [10,11]. In this case, the computational experiment should correspond to the results of processing the experimental data obtained with precision measurements. Comparison of the results of mathematical modeling and experimental data of the functioning of a metal-cutting machine, taken from a rotating spindle in a drive-reduction-spindle system, is presented in [12].
An example of fitting the results of the computational experiment based on mathematical model to experimental data (the intervals of the turnover time and its fractions of the spindle of the machine in the drive-reduction-bearing-spindle system) is shown in the figure 1. The defect of the front bearing of the lathe is presented.

![Experimental and settlement chronograms of rotation of a spindle of the lathe with defect of the forward bearing](image)

Figure 1. Experimental and settlement chronograms of rotation of a spindle of the lathe with defect of the forward bearing

Thus, the use of the phase method makes it possible to obtain more efficient information and to promote the diagnostics of machines and mechanisms to a new level.

The phase-chronometric method allows performing the analysis of the device operation, defect modeling and defect classification, which minimizes the costs of monitoring, diagnostics and emergency protection of machines and mechanisms.

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