Overview of existing methods of asynchronous motor diagnostics

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Abstract. The paper provides a review, analysis and research of existing diagnostic methods such as a vibroacoustic method based on the analysis of damped oscillations arising from dynamic loads of the system in friction nodes, the thermal method based on the analysis of thermal fields created by the object under study and the acoustic emission method, which includes an assessment of acoustic emission occurring in metals and welded joints. The advantages and disadvantages are identified and the conditions and areas of use of these methods are described. The applicability of these methods to such an electromechanical system as an asynchronous motor is also described. Vibroacoustic diagnostics can be used to assess shaft fatigue and wear of rolling bearings; thermal diagnostics can be used to diagnose the operation of the cooling system and assess the degree of aging of the insulation of the windings; the acoustic emission method is applicable in cases where it is necessary to assess the progressive wear of the shaft and bearing assemblies, as well as fatigue of gear elements in the gearbox.

1. Introduction
Electromechanical systems (like any other technical systems) are exposed to dynamic loads during their operation, differing in such a set of factors as the place of impact of the load, the duration of the load, the nature of the load, etc. One of the important parts of operation is diagnostics, i.e. assessment of the current state and its residual life [1, 4, 18]. This paper reviews, analyzes and analyzes the existing diagnostic methods and their applicability in technical systems in general, and, in particular, describes the applicability in such an electromechanical system as an asynchronous motor [5, 11-13].
2. Materials and methods
There are various methods of technical diagnostics.

2.1. Vibroacoustic method
This diagnostic method is used in the steady-state operation of the object. The measurement of vibroacoustic parameters is presented in the form of periodic damped oscillations (Figure 1). Such in some cases are observed in electrical circuits.

![Figure 1. Vibroacoustic curve](image)

The main cause of fluctuations and oscillatory processes is dynamic loads. Due to the fatigue of the surface layer, fatigue wear occurs, which results in an increase in gaps and an increase in the vibration level. Vibration vibrations on the body parts of machines are usually a consequence of the action of shock loads. Variable loads in the elements of the mechanisms leading to the collision of these parts, which causes vibration of the parts of the mechanisms and the entire unit. In the undercarriage of the rolling stock, vibrations are caused by the collision of the teeth of gears, rolling elements in bearings, etc.

The advantages include the ability to monitor the technical condition of the equipment at any time, as well as the ability to predict the time of transition of the equipment or its element to the limit state [1, 14, 15].

In the method of vibroacoustic diagnostics, two large groups are distinguished time-domain analysis (time signal analysis) and frequency domain analysis (spectral analysis). Diagnostic methods based on the parameters of the time signal include analysis by the RMS value of the vibration velocity and the peak factor method.

The RMS value is determined by the formula:

$$X_{RMS} = \sqrt{\frac{1}{T} \int_{t_0}^{t_0+T} [X(t)]^2 dt}$$

2.2. The RMS method
This method detects defects in bearing assemblies at the last stages of their development, with a significant increase in the overall vibration level. The implementation of the method in practice does not require large monetary costs and specially trained specialists. Usually, this method is implemented in vibrometers, budget means of vibration control.

The peak factor method for its implementation requires a simple vibrometer, which allows you to register such parameters of the vibration signal as the RMS value of the vibration level (SCR) (i.e., the vibration energy) and peak vibration amplitude.

The peak factor is defined as:
The peak factor is a parameter that reacts to the appearance of individual short pulses. Thus, a random signal without shock pulses has a typical peak factor value of 3–4, and when rare but strong pulses appear, they can have values of 20-30 and exceed them. Despite the simplicity of implementation, the method has a disadvantage in the form of weak noise immunity.

Spectral analysis is based on the Fourier transform, which allows for a frequency analysis of the measured signal. The Fourier transform involves representing a periodic function as a sum of sines and cosines:

\[ S(t) = S_0 + \sum_{k=1}^{\infty} a_k \cos \omega_k t + \sum_{k=1}^{\infty} b_k \sin \omega_k t, \]

where \( \omega_1 = \frac{2\pi}{T} \) is the circular frequency corresponding to the repetition period of the signal;

\( \omega_k = k \omega_1 \) is harmonics.

The spectral analysis includes methods of broadband spectrum, direct spectrum, and envelope spectrum.

2.3. Broadband spectrum method
To implement the broadband spectrum method, an appropriate analyzer with good resolution and trained personnel (Figure 2). The method is quite often used in practice because in addition to bearing malfunctions, it detects other equipment malfunctions. The disadvantages include the fact that the method allows you to evaluate only the general condition of the object being diagnosed.

2.4. Diagnostics on the direct spectrum
This method consists of analyzing the vibration spectrum – identifying the frequency (frequency) of the appearance of amplitude bursts (Figure 3). The frequency composition of the spectrum can identify the occurrence and development of bearing defects. Each malfunction on the bearing elements corresponds to its own frequencies, which depend on the kinematics of the bearing, its rotation speed, as well as the geometric features of the bearing. The advantages include the high information content of the method and a high level of noise immunity. The disadvantages include the high cost of equipment and the fact that the method is insensitive to incipient defects.
The envelope spectrum is diagnosed by analyzing the high-frequency components of vibration and identifying the low-frequency signals modulating them (Figure 4). The high-frequency signal changes its amplitude over time, i.e., modulation occurs by a low-frequency signal. This method is based on the extraction and processing of this information.

![Figure 3. Direct spectrum of the time signal.](image)

The envelope spectrum in good condition is represented by a horizontal wavy line. When damage occurs, discrete components begin to appear, the frequencies of which are uniquely calculated by the kinematics and revolutions of the bearing.

The frequency composition allows you to register malfunctions, and the excess of the corresponding components over the background describes the depth of the defect, of the advantages of
noise immunity, high level of sensitivity and informativeness, of the disadvantages – the high cost of equipment, expensive metrological characteristics (Figure 5) [2, 10].

![Figure 5. The spectrum of the time signal envelope.](image)

Summarizing the above, we can say that the advantages of the method of vibroacoustic diagnostics include the possibility of monitoring the technical condition of the equipment at any time, as well as the possibility of predicting the time of transition of the equipment or its element to the limit state [1].

2.5. Thermal method
Thermal methods include the analysis of infrared radiation of an object and its elements and relate to physical methods. A serviceable product has a certain thermal radiation pattern; changes in the pattern appear in the presence of defects in mechanical, electrical, and other parts of machines. There are active and passive methods: with active heating occurs using an external source, with passive – the analysis is performed in the field of natural heat generation. The control of Ternopil is carried out with the help of thermo-, pyro-, and radiometers, infrared microscopes, thermal imagers, etc. The existing methods of thermal diagnostics include contact, non-contact and thermographic (Figure 6).

![Figure 6. Diagnostics of the cooling system by thermal imaging method.](image)

Contact methods are methods using thermocouples, temperature-sensitive paints, LCD connections. The first is simple, works out and allows to measure the temperature in point areas, the second is also
simple, but has the irreversibility of processes, the third method is based on the property of LCD compounds to acquire color depending on the temperature of the medium.

Non-contact methods are based on the properties of bodies to emit electromagnetic energy proportional to their temperature. A method with sequential registration is implemented: fixation of thermal radiation and conversion into an amplified electrical signal. Bolometers, microradiometers, and other devices are used for this purpose.

The main technical parameters of the receiving devices include the sensitivity threshold; the value of the output signal per unit of incident radiation flux; the inertia of the receiver, depending on the time constant.

Sensitivity threshold:

$$P_{\min} = \frac{ES_P}{(V_s / V_0) \Delta f}$$

where $E$ is the density of radiation incident on the receiver, $W/cm^2$;

$S$ is the area of the receiver, $cm^2$;

$V_s / V_0$ is the ratio of the output signal to thermal noise;

$\Delta f$ is the frequency of radiation, $Hz$.

The sensitivity threshold is measured when the receiver is exposed to blackbody radiation with a temperature of +300 °C for uncooled and +100 °C for cooled receivers.

Thermal imaging methods allow analyzing the condition of the object being diagnosed, its components, and mechanisms by thermal portrait. The disadvantage of thermal diagnostics is the long time required for data processing, so this method is used as an additional one to the existing ones [3].

2. 6. Acoustic emission method

The method is based on the identification and analysis of the parameters of acoustic emission signals arising during the course of dynamic processes in the metal. Acoustic emission (AE) refers to ultrasonic vibrations that occur when defects occur and develop in a controlled object under the influence of a load. Acoustic emission differs from most methods of non-destructive testing (MNC) in that:

1. The method refers to passive, i.e., the source of the signal is the material, not an external source.
2. AE detects the most dangerous defects.
3. This method is remote, and it requires the correct placement of sensors on the surface of the object.

The purpose of AE control is to track acoustic emission sources associated with defects in welded joints and the base metal of objects, to identify defects that are developing and prone to development with changes in load or the presence of leaks, to determine their location, and assess their danger. The AE method is also used to assess the rate of defect development in order to stop operation or testing in advance and prevent product malfunction. AE monitoring of the state of the objects being diagnosed is carried out only when a state is created in the design that initiates the operation of AE sources in the object material. To do this, the object is loaded with force, pressure, temperature field, etc. The choice of the type of load is determined by the design of the object and its working conditions, the nature of the tests. The method has found wide application in pneumatic tests of vessels, apparatuses, and pipelines operating under pressure [6-8].

The advantages include the fact that the method detects dangerous defects, compatibility with regular strength tests, control of the entire volume of the object being diagnosed. In addition, the method is used to assess the degree of destruction of metal in the structure. The disadvantages include
the complexity of interpreting the results and the need to attract highly qualified specialists [1, 16, 17].

3. Conclusion
The existing diagnostic methods are described. The method of vibroacoustic diagnostics based on the analysis of vibrations arising from loads acting on the object is shown, the method of acoustic emission based on the study of acoustic vibrations is presented, the method of thermal diagnostics used as an addition to the above is considered.

Vibroacoustic diagnostics can be used to analyze the condition of the bearing assemblies and the shaft of an asynchronous motor. Too high an oscillation amplitude may indicate a deflection of the shaft or wear of the bearings. Thermal diagnostics can be used to assess the condition of the cooling system and engine windings. Excess temperatures indicate that the cooling system is faulty, and overheating of the windings indicates aging insulation and thermal breakdown. The acoustic emission method can be used to detect wear of materials in friction units, both in the engine itself and, for example, in the gearbox: in this way, it is possible to determine the progressive fatigue of bearing units in the engine, fatigue of gear elements in the gearbox, etc.

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