Diagnostics of electromechanical equipment by electrical power consumption parameters

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Abstract. The relevance of problems of diagnostics and monitoring of the technical condition of electromechanical equipment is shown. An overview and analysis of specialized methods and technical tools designed to solve these problems are given. The main problems that arise in the practical application of modern methods and diagnostic tools are identified. The main advantages of using methods of diagnostics by electrical power consumption parameters are considered and the results of an analytical review of these methods are presented. A variant of the practical implementation of a stationary diagnostic complex for electromechanical units and the results of the development of functional schemes of the main components are proposed.

1. Introduction

Diagnostics of the current technical condition of electromechanical equipment can prevent the occurrence of failures and, thus, reduce the economic costs of maintenance and repair of such equipment. Currently, there are various methods and tools designed to solve this problem:

- vibration diagnostics [1—4];
- electromagnetic diagnostics [5, 6];
- thermal diagnostics [1, 7];
- diagnostics by partial discharge measurements [5, 8];
- diagnostics by electrical power consumption parameters [3, 5, 8—15].

The most widely used methods and means of vibration diagnostics. For example, only these methods are officially used for diagnostics of pumping units’ condition [4]. Methods of vibration diagnostics are highly effective in the detection of certain types of electromechanical equipment faults, and, at the same time, have a number of significant drawbacks, such as [1—4]:

- the need to install a large number of sensors directly on the diagnostic object vibration diagnostics;
- the dependence of vibration diagnostics system settings and sensor layout on the specific type of equipment being diagnosed;
- the strict requirements for sensor mounting conditions;
- the sensitivity to vibration effects of nearby equipment.

Methods of electromagnetic and thermal diagnostics also require the installation of appropriate sensors, and, in some cases, not only outside, but also inside the body of the unit being diagnosed [1, 5—7].
From the point of view of connecting the diagnostic system to the monitored equipment, the most universal methods are diagnostics by recording and analyzing partial discharges, as well as methods and means of diagnostics by electrical power consumption parameters. In these methods, the calculation of diagnostic parameters is based on the electrical values measured in the power supply circuits of the unit being diagnosed [3, 5, 8—15]. The method of partial discharge analysis requires the use of specialized circuits with high requirements for measurement accuracy over a wide frequency band (up to 3 MHz and higher [5, 8]). At the same time, methods of diagnostics by electrical power consumption parameters use standard current and voltage measurement schemes with the upper limit of the bandwidth not much higher than the maximum rotor speed [3, 5, 8].

The use of methods and diagnostic tools for electromechanical equipment based on the parameters of electrical power consumption is simpler and more promising from the point of view of its implementation and application in practice.

2. Problem statement
Technical implementation of methods and diagnostic tools for electromechanical equipment based on the parameters of electrical power consumption is currently limited mainly to installations for laboratory (experimental) research and portable measuring complexes of piece production for use on industrial facilities [16—17]. It should be noted that the use of portable complexes is not widely used due to the following reasons:

- the high cost of the diagnostic complex;
- the complexity of interpreting diagnostic results requires the mandatory presence of a specialist to form a conclusion about the technical condition of the unit being diagnosed;
- the remoteness of individual control objects (for example, pumping units) from each other requires the organization of travel to the object of specialists, which increases the overall cost of diagnostics;
- the organizational complexity of approval of the access process for connecting the complex to the power supply chain of the unit with the security and safety departments directly at the industrial facility.

The above-mentioned complexity of interpreting the diagnostic results is due to the fact that the values of some diagnostic parameters depend not only on the degree of development of specific faults and distortions of the supply voltage, but also on the specific type of electric motor, its operating mode, and the presence and type of the mechanical load on the shaft [3, 5, 8]. In general, GOST ISO 20958-2015 recommends measuring diagnostic parameters in various modes of operation of the electric motor and monitoring changes of these parameters with a certain frequency over several years [8].

In this regard, it is expedient to develop a stationary diagnostic complex for electromechanical equipment based on the parameters of the electrical power consumed. In this case, the complex is proposed to be implemented in two parts: the unit for direct measurement of instantaneous values of electrical parameters of current and voltage (the measuring unit) and the information processing unit. In this case, the blocks are proposed to be made in the form of separate devices.

3. Theory
Existing methods of diagnostic by electrical power consumption parameters are, in fact, different ways of mathematical processing of the measured instantaneous values of current and voltage. These methods can be divided into three groups:

- the analysis of the spectrum and (or) individual harmonic components of current or active power signals;
- the mathematical transformation of signals in the power supply circuits of the diagnosed unit in order to obtain a certain set of characteristic signals that are convenient for further analysis;
• the diagnostics based on the value of parameters calculated based on measured instantaneous current and voltage values (for example, active power consumption or active resistance of stator windings).

In articles on the methods of the first group [3, 5, 8—10], it is noted that the degree of development of individual faults can be estimated by the parameters of odd harmonics of the stator current (up to the eleventh), as well as by the relative magnitude of the frequency components of the spectrum, the specific position of which depends on the frequency of the supply network, the rotor speed, sliding and design features of the diagnosed unit [3, 8—10]. For example, the breakage of the short-circuited rotor rods in an asynchronous motor leads to the appearance of components in the current spectrum at frequencies determined by the formula [8]:

\[ f_{sh} = (1 \pm 2s) \cdot f_1, \]

where \( s \) is slip of induction motor and \( f_1 \) is main frequency of the supply circuit.

The methods of the second group include analysis using the Park’s vector [8, 11—13]. Instantaneous current values of all three phases of the supply network are converted to coordinates of a two-dimensional vector \((i_D; i_Q)\) using the following formulas [8]:

\[ i_D = \left( \frac{\sqrt{2}}{\sqrt{3}} \right) i_A - \left( \frac{1}{\sqrt{6}} \right) i_B - \left( \frac{1}{\sqrt{6}} \right) i_C; \]

\[ i_Q = \left( \frac{1}{\sqrt{2}} \right) i_B - \left( \frac{1}{\sqrt{2}} \right) i_C, \]

where \( i_A, i_B \) and \( i_C \) are instantaneous values of linear currents of phases A, B and C, respectively.

The trajectory described by the end of the vector \((i_D; i_Q)\) characterizes the technical condition of the equipment [8, 11]. If the equipment is functional and represents a symmetrical load, the Park vector describes a circle centered at the origin. Any difference between the trajectory and the circle indicates the presence of a certain defect [8, 11]. In the extended Park’s vector method, the spectrum of the variable component of the Park’s vector module is analyzed [8].

In [14—15], diagnostic methods for parameters of electrical power consumption related to the third group are presented. These articles note the dependence of the technical condition of the diagnosed units on the values of parameters such as active and complex resistance of the stator windings, the largest difference between the phase shift angles of each phase, and the angular dependence of the current on the frequency of the supply voltage [14—15].

The proposed implementation of a stationary diagnostic complex in the form of two separate devices can implement different diagnostic methods for the parameters of the electrical power consumed without making changes to the measuring unit.

4. Development of functional schemes
The functional scheme of the developed measuring unit is shown in Figure 1.

The measuring unit is permanently connected via measuring transformers to the power supply circuits of the unit being diagnosed. The signals of the secondary windings are converted to proportional voltage signals, after which the spurious high-frequency components are filtered, followed by analog-to-digital conversion. Further, discrete instantaneous values corresponding to instantaneous values of currents and voltages in the power supply circuits of the diagnosed unit are received at the input of the preprocessing module for input signals. The main task of the above-mentioned module is to convert the output codes of analog-to-digital converters into a format that is convenient for storing and further processing, assign a time stamp to each new set of input data, and adjust the input values in accordance with the specified tuning coefficients to minimize bias and gain errors introduced by the measuring circuit.
During each new sampling cycle, the input preprocessing module generates an array of six instantaneous values with an assigned timestamp, which is written to buffer memory. The internal device of the buffer memory assumes cyclic overwriting of the stored values with new ones so that, when the corresponding command is received, the transfer to the internal memory of both currently measured and previously accumulated data is initiated, while the total amount of information transmitted should be sufficient for carrying out spectral analysis. This solution allows you to significantly reduce the amount of memory used and reduce the load on the communication channel.
compared to the mode of permanent recording of measured instantaneous values in the internal memory.

The contents of the buffer memory are also used by the computing module to calculate the electrical parameters of the power supply circuit of the unit being diagnosed, such as, for example, the active power consumption. The values of these parameters are constantly written to the internal memory at a certain time interval (the specific recording frequency is determined when setting up the measuring unit, but not more than 10 Hz). This makes it possible to track the relationship between changes in the above parameters and the operating modes of the unit being diagnosed.

The control module, depending on the settings of the measuring unit, can generate commands that initiate data transfer from the buffer memory to the internal memory when one of the following events occurs:

- the receiving the appropriate command via the communication interface;
- the triggering the built-in timer (for example, once a day at a certain time);
- the power off of the unit being diagnosed;
- the output of the value of one of the calculated parameters beyond the set limits.

In addition, the above module is designed to store in a specially allocated section of internal memory data about events, both those discussed above, and those that can affect the correct interpretation of measurement information, such as:

- the switching on the measuring unit (the time of each new switch-on is recorded);
- changing the settings of the measuring unit (including changing the real-time clock readings).

In the device under development, it is proposed to exchange data over the Ethernet interface, while the measuring unit must support both the mode of direct control from the processing unit, and the mode of autonomous operation for a month or more.

The functional scheme of the developed information processing unit is shown in Figure 2.

![Diagram of the information processing unit](image)

**Figure 2.** The functional scheme of the information processing unit.

The information processing unit is proposed to be implemented on the basis of a personal computer. Main functions of this block:

- the remote configuration, control and monitoring of the measuring unit;
the receiving up-to-date measurement information;
the systematization and storage of all previously accumulated measurement information;
the calculation of diagnostic parameters in accordance with one of the implemented diagnostic methods selected by the user;
the filing and the archiving of the results of calculation of diagnostic parameters.

5. Conclusion
The presented development of the measuring complex reflects the initial stage of the authors’ work in the field of diagnostics of electric machine units according to the parameters of the consumed electric power and can be used in various industries to identify various types of malfunctions that occur during the operation of electric machine equipment. The use of the proposed information processing algorithms makes it possible to take advantage of digital signal processing and provide remote transmission of measurement information. Currently, a prototype of the proposed device is being manufactured and organizational issues are being resolved for the installation and experimental research of the complex on the pumping electric machine unit of the oil pumping station.

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