About increasing informativity of diagnostic system of asynchronous electric motor by extracting additional information from values of consumed current parameter

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Abstract. This article is devoted to expanding the possibilities of assessing the technical state of the current consumption of asynchronous electric drives, as well as increasing the information capacity of diagnostic methods, in conditions of limited access to equipment and incompleteness of information. The method of spectral analysis of the electric drive current can be supplemented by an analysis of the components of the current of the Park's vector. The research of the hodograph evolution in the moment of appearance and development of defects was carried out using the example of current asymmetry in the phases of an induction motor. The result of the study is the new diagnostic parameters of the asynchronous electric drive. During the research, it was proved that the proposed diagnostic parameters allow determining the type and level of the defect. At the same time, there is no need to stop the equipment and take it out of service for repair. Modern digital control and monitoring systems can use the proposed parameters based on the stator current of an electrical machine to improve the accuracy and reliability of obtaining diagnostic patterns and predicting their changes in order to improve the equipment maintenance systems. This approach can also be used in systems and objects where there are significant parasitic vibrations and unsteady loads. The extraction of useful information can be carried out in electric drive systems in the structure of which there is a power electric converter.

1. Introduction

The efficiency of industrial production is directly related to the reliability of the operation of technological equipment, one of the structural links of which are electrical systems with an electric drive. These systems are realized today on the basis of an asynchronous electric motor with a squirrel-cage rotor. The wide application of the electric drive in electrical systems is caused by the simplicity of their design and low cost. The problems of large inrush current, relatively low power factor and the use of reactive power from the network [1,2] are solved using power frequency converters, in particular converters with active rectifiers [3]. Despite these qualities, the effects of various types (thermal, electrical, mechanical, environmental, etc.), determined by operating conditions, lead to the appearance and development of defects that characterize the degree of depreciation of the electric drive [4, 5]. The untimely detection of defects at the stage of their origin and development leads to subsequent malfunctions in the coupled nodes of electromechanical equipment and to a decrease in its
technical and economic indicators, and their high degree leads to disruption of the technological cycles or significant damage to the enterprise [6,7].

2. General requirements for the development of diagnostic systems

When choosing diagnostic parameters, priority is given to those that meet the requirements of reliability and redundancy of information about the technical state of the system under real operating conditions. In practice, several diagnostic parameters are used at the same time. Diagnostic data of the asynchronous motor can be electrical parameters (power, voltage, current, etc.), vibroacoustic (vibration, noise, beats, etc.), the temperature of the frame or the strength of insulation. In this case, the diagnostic parameters must have the following properties:

1) sensitivity;
2) the wide range of changes;
3) uniqueness;
4) stability;
5) informative;
6) the possibility of periodic registration.

The number of diagnostic parameters will largely depend on the following factors:

1) complexity of the technological process;
2) the use or absence of semiconductor frequency converters;
3) the possibility of direct access to the electric drive;
4) economic viability;
5) the degree of danger of the development of an emergency situation.

Under the most difficult operating conditions of the electric drive, the assessment of the technical state allows the implementation of methods based on the analysis of the currents consumed by the motor. Analysis of the stator current spectrum makes it possible to determine appearance of a defect of both electrical and mechanical parts at an early stage. It has a form of peaks at characteristic frequencies. However, this analysis does not allow one to determine quantitative assessment of the level of a defect and its growth in future. The presence of peaks in the current spectrum caused by vibrations and noises of the mechanical part of an asynchronous electric drive, duplication of peaks on both sides of the carrier frequency (50 Hz) in the low-frequency part, and distortion when using semiconductor frequency converters reduce the efficiency of spectral analysis of current.

3. The method of analysis of the Park's vector

In this method, components $i_d$ and $i_q$ of the stator current vector are used to represent the stator current time curve, i.e., the $i_d = f(i_q)$ curve, which is calculated using the Park transform based on the stator currents of the asynchronous motor ($i_A$, $i_B$, $i_C$), [8, 10] as follows:

$$
\begin{align*}
    i_d &= (\sqrt{2/3})i_A - (1/\sqrt{6})i_B - (1/\sqrt{6})i_C, \\
    i_q &= (1/\sqrt{2})i_B - (1/\sqrt{2})i_C.
\end{align*}
$$

(1)

where $i_A$, $i_B$, $i_C$ - effective values of phase currents.

Under ideal conditions, with symmetry of the currents corresponding to the operation of an asynchronous motor without defects, the field in an electrical machine has circular form, and the components of the Park's vector [3] are expressed as:

$$
\begin{align*}
    i_d &= (\sqrt{6}/2)i_M \sin(\omega t) \\
    i_q &= (\sqrt{6}/2)i_M \sin(\omega t - \pi/2).
\end{align*}
$$

(2)

Representing the components of $i_d$ and $i_q$ as the real and imaginary parts in the complex plane, one obtains:

$$
\vec{V} = i_d + j \cdot i_q.
$$

(3)

In this case, the vector will describe the hodograph (the Lissajous curve) when (2) is executed, which is a circle centered at the origin and with a diameter equal to $(\sqrt{6}/2)i_M$, and the current modulus
spectrum contains only a constant component. Since the diameter of the hodograph curve is proportional to the amplitude of the current, its shape becomes thicker when the engine load increases.

The presence of defects in the stator of the electric machine causes changes in its magnetic field, it becomes of elliptical or more complex shape (when using the converter, for example). Depending on the stator defect, the hodograph changes in shape from the circumference to the ellipse. The values of the axes of the ellipse, as well as the angle of inclination of the major axis of the ellipse to the positive coordinate axis, depend on the degree of defect and the combination of defects in the phases [9, 10].

An increase of the information capacity of the method of the Park's vector allows spectral analysis of the variable component of the module of a current of the Park's vector $M$, defined by the formula:

$$M = \sqrt{i_d^2 + i_q^2}.$$  \hspace{1cm} (4)

4. Analysis of the hodograph of the Park's vector
When an asynchronous motor operates from a semiconductor frequency converter, the hodograph takes on the elliptical shape (Figure 1 a) that orients by a major axis in the first and third quadrants. When changing the load and the frequency of the supply voltage, the geometric parameters change, such as: $a$ - the semimajor axis, $b$ - the semimajor axis, $c$ - the hodograph width of the Park's vector, the geometric shape of the inner and outer ellipse, $\phi$ - the angle of shear between the major axis of the ellipse and the axis of the real values complex plane.

![Figure 1. The hodograph of the Park’s vector (a) and the module of the Park’s vector with time $M=f(t)$ (b)](image)
Let us accept the diagnostic parameters according to Table 1, without taking into account the maximum permissible values of the current and voltage of the regulated electric drive, limiting its working capacity.

5. Experiment
In order to study the changes in the hodograph parameters of the Park's vector, the asymmetry of the stator currents was modeled according to the structure diagram (Figure 2). The circuit consists of an asynchronous motor (AM) operating from a semiconductor frequency converter, which includes a rectifier (R), a DC link (DCL), and a stand-alone voltage inverter (AVI). The monitoring of motor currents is carried out with the help of UA1-UA3 current and voltage sensors, and subsequent recording on a data acquisition board (DAB).

![Figure 2. A block diagram of an asynchronous electric drive](image)

The magnitude of the asymmetry in phase B of the induction motor was created by changing resistance R2 with changes in the hodograph of the Park's vector (Figure 3), as well as an increase in the amplitude of the magnitude of the Park's vector as a function of time \( M = f(t) \) (Figure 4).

![Figure 3. Evolution of the hodograph with asymmetry (a) - 10% asymmetry in phase B, (b) - 30% asymmetry in phase B, (c) - 60% asymmetry in phase B](image)
Table 1. The hodograph parameters of the vector of the stator current park of an asynchronous electric drive

| Measurement No. | defect % | a (°, e) | b (°, e) | c (°, e) | φ     |
|-----------------|----------|----------|----------|----------|-------|
| 1               | asymmetry in phase B – 10% | 0.619536 | 0.308355 | 0.0231  | 47.96836 |
| 2               | asymmetry in phase B – 30% | 0.734983 | 0.340462 | 0.0412  | 56.12217 |
| 3               | asymmetry in phase B – 60% | 0.992975 | 0.407833 | 0.0824  | 62.43436 |

Assuming that the currents of the asynchronous electric drive are in accordance with Figure 3 (b) (30% current asymmetry in phase B), according to Figure 4 (a) by means of fast Fourier transform, an amplitude-frequency spectrum of the current of the synchronous motor was constructed, in which there is no manifestation of a defect at the design frequency according to [12]. Consequently, it can be concluded that the method of spectral analysis of the current consumed by an asynchronous motor is insensitive to certain defects. In this case, analyzing the modulus of the Park’s vector and its spectrum, one can note the pulsations of the amplitude values of the module of the Park’s vector (Figure 4 (b) characterizing the asymmetry of the currents in the motor phases. The amplitude-frequency spectrum of a module of the current of the Park’s vector allows one to get rid of the components of the carrier frequency (50 Hz) and reflects only the peaks corresponding to various defects of the electric motor.
Figure 4. (а) – The amplitude-frequency spectrum of the current of an asynchronous motor, (b) – the module of the current of the Park’s vector; (c) – the amplitude-frequency spectrum of a module of the current of the Park’s vector

6. Conclusions
An increase of informativeness is achieved due to the use of complex analysis of currents consumed by an asynchronous electric drive, including a spectral analysis and analysis of the components of the Park’s vector (geometric shape of the hodograph, amplitude of the current module of the Park’s vector, etc.) in conditions of limited access to equipment and incompleteness of information. The use of combined diagnostic methods makes it possible to improve the quality of the assessment of the technical condition of the monitored facility. This will allow timely repair of equipment and therefore a reduction of various types of damage in general.

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