Diagnostics of emergency conditions of the engine DC

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Abstract. The article presents the results of an experimental study of the diagnostic process and mathematical processing of diagnostic information using logarithmic spectral analysis of the values and shape of the current in the DC armature circuit with various damage to the armature winding. Diagnostics of the state of DC electric machines is an important practical task. Failure to detect timely violations of the operation of individual components of the machine, in particular, damage to the armature winding can lead to serious accidents at work. Most of the currently used diagnostic systems have been developed based on studying the design of electrical machines and physical processes of converting electromagnetic energy, both experimentally and by analyzing mathematical models. Today’s available measuring and computing technologies have made it possible to use many previously studied phenomena in diagnostics. They have also become the basis for searching for new signals that enrich diagnostic information.

1. Introduction

In the works [1, 2] it is found that the best information has the current spectrograms in the circuit of the armature windings of the electric motor.

The purpose of this work is to analyze the results of diagnosing the technical condition of the armature windings of a DC motor using logarithmic spectral analysis of current components in the armature circuit and digital signal processing. The logarithmic spectral method for diagnostics of DC motor armature windings is based on spectral analysis of armature current values and eigenvectors of the diagnostic signal correlation matrix.

2. Object and method of research

Experimental studies of the diagnostic process were carried out on DC motors of the P11UHLA220 series (Figure 1) with technical characteristics: power $P = 0.45$ kW; supply voltage $U = 220$ B DC; the rated speed of the armature shaft $n = 3300$ rpm; rated current of the armature $I_a = 3.05$ A.
3. Results and discussion

As a result of experimental studies of electric machines of a continuous current of the P11UHLA220 series, diagnostic values of the value and shape of the current in the armature circuit depending on the type of fault of the armature winding are obtained, which are shown in Figure 2.

![Figure 1. Electrical diagram of the stand for tests of parallel excitation engine type P11U HLA220](image1)

![Figure 2. Current Waveform in the armature circuit with an inter-turn signal by closing the armature winding section of the motor P11U HLA220](image2)

For mathematical processing of the received diagnostic signals, non-periodic armature current curves, we use the graphical method to decompose the oscillogram shown in Figure 2 anchors when the armature winding section of the engine P11U HLA220 breaks.

The armature current waveform shown in Figure 2, has symmetry with respect to the ordinate axis, we divide the abscissas axis, which corresponds to two periods. Hence, the function of armature current values can be written.
$$I(x) = A_0 + A'_1 \cdot \sin (x + \psi'_1) + A''_1 \cdot \sin (3x + \psi'_1).$$

Thus, the image of the non-sinusoidal curve of the current waveform can be written next to Fourier

$$S(t) = 37,7 + 5,782 \sin(\omega t + (\psi'_1 + 90^\circ)) + 4,7 \sin(3\omega t + \psi'_1).$$

For spectral analysis of a diagnostic signal that is the sum of several sinusoids, you can use the MUSIC (Multiple Signal Classification) method in the MATLAB 7 software package [3, 4].

The diagnostic signal of the current in the armature circuit can be represented as the sum of complex exponents whose initial phases are random, with white noise in the form of electromagnetic interference:

$$s(k) = n(k) + \sum_{m=1}^{M} A_m \exp(j\omega_m kT + j\phi_m),$$

where - samples of discrete white noise, , - respectively the amplitudes, frequencies and initial phases of complex exponents contained in the diagnostic signal, T – the sampling period.

The initial phases are distributed over the interval 0.....2. The graph of interpolation of logarithmic spectral components of the current in the armature circuit by the p11uhla220 motor with inter-turn closure of the armature section depending on the time over the period is shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** Interpolation Graph for logarithmic spectral lines current components in the armature circuit by the p11uhla220 motor with inter-turn by closing the armature section depending on the frequency

Each real component of the diagnostic signal can be represented by the sum of complex exponents using Euler’s formula. The correlation function of such a diagnostic signal has the form:

$$R(k) = \sigma^2 \delta_k(k) + \sum_{m=1}^{M} A_m \exp(-j\omega_m kT),$$

where is the unit pulse function equal to 1 for \(k = 0\), is the noise dispersion.

According to the root music function in the MUSIC method, the harmonics of the frequencies contained in the diagnostic signal are extracted, as well as the inter-turn closure of the armature winding, which can be recorded as a frequency matrix [4]:

$$W(\omega) = \begin{bmatrix} 283.58 & 0 \\ -283.58 & 546.57 \\ 0 & -546.57 \end{bmatrix}$$

For rice. 4 shows the oscillogram of the p11uhla220 engine in steady mode when one of the sections of the armature winding is broken.
The armature current waveform shown in Figure 4, has symmetry with respect to the ordinate axis, which corresponds to two periods. Hence, the function of armature current values can be written
\[
I(x) = A_0 + A_1' \sin(x + \psi_1) + A_3' \sin(3x + \psi_3) + .
\]

Thus, the image of the non-sinusoidal curve of the current waveform can be written next to Fourier
\[
S(t) = 27.88 + 5.724 \sin(\omega t - 3\psi) + 2.7 \sin(3\omega t + 3\psi).
\]

For improving the efficiency of diagnostics of electric machines, two methods can be used to obtain a logarithmic spectral component of the current [2–4]: this is the application of the Fourier transform to the linear spectrum or logarithmic spectrum.

The presence of dozens of harmonics of basic frequencies in the development of EMF winding insulation defects makes it difficult to find diagnostic features in spectral analysis. In this case, when evaluating the state of the equipment, nonlinear transformations are used, for example, the logarithm of the spectrum followed by a Fourier transform; in other words, the secondary spectrum or logarithmic spectral components of the armature current are obtained
\[
C_{isk}(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \ln\left[ S_i(kw) \right]^2 e^{i\omega} d\omega,
\]
where is the current spectrum in the motor armature circuit defined as
\[
S_i(kw) = \sum_{k=-\infty}^{\infty} s(k) \exp(-j\omega k).
\]

The diagnostic parameter of the current spectrum in the electric motor armature circuit in the form of a function, set on the segment, can be considered periodic, i.e., considered, where k is an integer, and-the Fourier period:
\[
S_i(kw) = \sum_{k=0}^{\infty} (a_k \cos kw t + b_k \sin kw t),
\]
where and form the complex frequency spectrum of the signal; the main circular frequency (bin-the discreteness of the spectrum); k – the number of the harmonic.

The Fourier transform determines the components of the spectrum:
\[
a_0 = \frac{1}{T_N} \int_{0}^{T_N} s(t)dt ; \quad a_k = \frac{2}{T_N} \int_{0}^{T_N} s(t) \cos kw t dt ; \quad b_k = \frac{2}{T_N} \int_{0}^{T_N} s(t) \sin kw t dt,
\]
where is the analogue diagnostic signal of the current value in the EMF armature circuit.
The graph of logarithmic spectral components of the current in the armature circuit by the p11uhla220 motor when the armature section is broken is shown in Figure 5 depending on the frequency.

![Graph of logarithmic spectral components of current in a circuit anchors with the p11uhla220 engine when the anchor section breaks](image)

**Figure 5.** Graph of logarithmic spectral components of current in a circuit anchors with the p11uhla220 engine when the anchor section breaks

From the analysis of the graph of logarithmic spectral components of the current Figure 5, it follows that the harmonics of the frequencies contained in the diagnostic signal, when the armature section breaks, can be written as a frequency matrix:

\[
W(\omega) = \begin{bmatrix} 173.58 & -13.069 \\ -173.52 & 291.94 \\ 13.069 & -291.94 \end{bmatrix}
\]

For creating an adaptive system for technical diagnostics of DC motor windings, it is necessary to have exemplary diagnostic parameters of a serviceable electric motor, which can be obtained using experimental modelling. Figure 6 shows the oscillogram of a serviceable p11uhla220 engine in steady mode.

![Current Waveform in the armature circuit serviceable electric motor P11U HLA220](image)

**Figure 6.** Current Waveform in the armature circuit serviceable electric motor P11U HLA220

To study the logarithmic spectral components of the armature current of a technically serviceable p11u XLA220 electric motor, we decompose the current oscillogram shown in Figure 6 in the Fourier series.
\[ I(x) = A_0 + A_1' \cdot \sin(x + \psi_1) + A_3' \cdot \sin(3x + \psi_3) \]

Thus, the image of the non-sinusoidal curve of the current waveform can be written next to Fourier 
\[ S(t) = 314.77 + 0.654 \sin(\omega t + \psi_1) + 0.64 \sin(3\omega t + \psi_3). \]

The graph of logarithmic spectral components of the current in the armature circuit depending on the frequency of the serviceable motor P11UHLA220 is shown in Figure 7.

![Graph of logarithmic spectral components of the current](image)

**Figure 7.** Graph of logarithmic spectral components of the current in the armature circuit depending on the frequency of the serviceable motor P11UHLA220

From the analysis of the graph of logarithmic spectral components of the current Figure 7, it follows that the harmonics of the frequencies contained in the diagnostic signal, the correct state, can be written as a frequency matrix:

\[
W(\omega) = \begin{bmatrix}
449.95 & 150.66 \\
-449.95 & -150.66 \\
0 & 0
\end{bmatrix}.
\]

4. Conclusion
The harmonics of the frequencies contained in the diagnostic signal during emergency operation have values from 283.58 kHz to 173.52 kHz for the first current harmonic and from 0 to 13.069 kHz for the third current harmonic. In an exemplary (serviceable) engine, the harmonics of the frequencies contained in the diagnostic signal have values: 449.95 kHz for the first harmonic, 150.66 kHz for the third harmonic. The logarithmic spectral components of the armature current correspond to the values of the spectrograms obtained during the experimental study of the p11uhla220 engine in the normal and emergency operation mode. They can serve for the construction of adaptive systems for technical diagnostics of DC electric machines.

References
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