Diagnostics of journal bearings in mining equipment

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Abstract. The issues of diagnostics of the state of friction units of mining equipment are considered. Mathematical modeling of the situation of “oil wedge” violation in the journal bearing was carried out and its influence on the stator current of the electric motor was estimated. The analysis of the simulation results using the apparatus of the “window” Fourier transform with the corresponding conclusions is made.

1. Introduction
Journal bearings are used in friction units of heavily loaded mining equipment. Such equipment includes mine hoisting machines, underground crushing complexes, centrifugal compressors. The use of journal bearings in equipment for various technological purposes is determined by their universal set of properties, which makes it possible to use:
- for high-speed shafts when the rolling bearings are unsuitable (at rotation speeds > 10 000 rpm);
- in low-speed cars (due to the simplicity of design and low cost);
- for shafts of large diameters, for which there are no rolling bearings.

However, along with the indicated advantages, journal bearings have disadvantages, of which the following should be noted:
- significant heat generation, heating, wear in case of insufficient lubrication;
- uneven wear of bushes and trunnions.
- the need for constant supervision during operation due to the high requirements for lubrication and the danger of overheating.

2. Technological features of journal bearing wear
Journal bearings operate practically without wear, as long as the lubrication regime is not disturbed. The main criterion for their performance is the minimum thickness \( h \) of the lubricant layer, which excludes contact of microroughnesses of the trunnion and the brass. In practice, to control the friction process and the state of the bearing unit, continuous measurements of the average heating temperature of the lubricant in the working area are used.

Abrasive wear occurs during boundary and dry friction at low speeds, starting and stopping, as well as due to the ingress of abrasive particles into the lubricant (figure 1).

Seizing occurs when the bearing is overheated due to the decrease in oil viscosity when the temperature reaches \( t = 120-130 \) °C. Boundary films disappear and zones of metallic contact between rubbing surfaces appear. The latter leads to the occurrence of centers of their seizure and bearing failure.
Wear and seizing are the main causes of bearing failure with boundary and semi-fluid friction. In this regard, seizing resistance and wear resistance are used as the main indicators of the bearings performance with boundary and semi-fluid friction.

![Figure 1. Wear grooves (a) and uneven wear (b) of the working surfaces of the journal bearing brass.](image1)

Failure of a journal bearing is accompanied by partial or complete destruction of the babbitt layer (figure 2).

![Figure 2. Babbitt layer damage of a journal bearing.](image2)

To diagnose journal bearings in operational conditions, the levels of vibration, noise, temperature are measured [1]. However, these parameters do not only depend on the condition of the bearing. Indirect methods are used for non-demountable diagnostics of sliding bearings (fluoroscopy, vibration diagnostics, etc.) [2]. The characteristic feature of the listed methods is the inability to make prompt decision in case of violation of technological parameters of device operation, up to emergency shutdown of mechanisms.

The control systems currently used in the mining industry do not provide a complete diagnosis of malfunctions of friction units, therefore, it is advisable to develop additional methods for diagnosing their condition. To diagnose the state of the sliding bearings of mining equipment in real time, the method for monitoring the electrical parameters of the drive motor can be used [3,4].

3. **Mathematical modeling**

To confirm this possibility, an electromechanical complex is considered in the article, which includes an air centrifugal turbocompressor K-250 and a drive synchronous electric motor STD – 1600. To
compile the mathematical description, an expression for the friction moment in sliding bearings was used.

The frictional moment of a fluid friction bearing is described [5]:

\[
M_{b,\text{fric}}(t) = \frac{\pi \mu \omega(t) l d}{\psi} R_s
\]  

(1)

Where \( \mu \) is the dynamic viscosity of the liquid lubricant; \( \omega(t) \) – angular speed of the rotor shaft; \( R_s \) – radius of the rotor shaft spike; \( l, d \) – stud length and diameter, \( \psi \) – bearing clearance.

For the electric motor, it is convenient to choose a description in rotating d-q coordinates (2) [6]:

\[
\begin{align*}
U_{sd} &= R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega_{0x} \psi_{sq}; \\
U_{sq} &= R_s i_{sq} + \frac{d\psi_{sq}}{dt} - \omega_{0x} \psi_{sd}; \\
U_f &= R_f i_f + \frac{d\psi_f}{dt}; \\
0 &= R_{sd} i_{sd} + \frac{d\psi_{sd}}{dt}; \\
0 &= R_{sq} i_{sq} + \frac{d\psi_{sq}}{dt}; \\
\psi_{sd} &= L_{sd} i_{sd} + L_{msd} i_f + L_{md} i_{kd}; \\
\psi_{sq} &= L_{sq} i_{sq} + L_{msq} i_f; \\
\psi_f &= L_f i_f + L_{msd} i_{sd} + L_{md} i_{kd}; \\
\psi_{kd} &= L_{kd} i_{kd} + L_{md} i_{sd} + L_{msd} i_f; \\
\psi_{sq} &= L_{sq} i_{sq} + L_{msq} i_f; \\
U_{sd} &= U_{s\text{max}} \sin \theta(t); \\
U_{sq} &= -U_{s\text{max}} \cos \theta(t); \\
\theta(t) &= \int \left( \omega_{0x} - \frac{1}{k_r} p \omega_x(t) \right) dt; \\
M_{en}(t) &= \frac{3}{2} P \left( i_q \psi_{sd} - i_s \psi_{sq} \right).
\end{align*}
\]  

(2)

where \( k_r \) is the gear ratio of the gearbox, that is, the angular velocities and the angle \( \theta(t) \) of the engine are given to the compressor shaft; \( U_{sd}, U_{sq} \) – components of stator voltage along the axes; \( \psi_{sd}, \psi_{sq}, \psi_f, \psi_{kd}, \psi_{sq} \) – components of the winding flux linkages along the axes; \( R_s, R_f, R_{sd}, R_{sq} \) – components of winding resistances along the axes; \( i_{sd}, i_{sq}, i_f, i_{kd}, i_{sq} \) – components of the winding currents along the axes; \( L_{sd}, L_{sq}, L_{msd}, L_{msq}, L_{md}, L_{kd}, L_{sq} \) – components of inductances and mutual
inductance of windings; \( \theta(t), \omega_{0\text{ref}}, \omega_s(t) \) – the angle of rotor rotation, synchronous and angular speed of the machine; \( M_{em} \) – electromagnetic moment of the electric engine.

The mechanical torque of the compressor on the shaft of the electric motor was assumed constant during simulation.

As a result of the simulation, a dependence was obtained for the deviation of the stator current component for friction in the bearing when an additional moment of resistance occurs, associated with a violation of the thickness of the oil “wedge”. The dependence graph is shown in figure 3.

![Figure 3](image-url)

**Figure 3.** Deviations of the stator current component for friction in the bearing when the thickness of the oil “wedge” is disturbed.

### 4. Analysis of simulation results

To evaluate the simulation results, the “window” Fourier transform was used [7,8]. The harmonic composition was investigated in different parts of the signal. The “window” moved along the course of the disturbing impulse. In this case, a window width of one and ten periods of the basic signal was used.

The results for the site before the start of the disturbance are shown in figure 4.

![Figure 4](image-url)

**Figure 4.** Harmonic composition of the original signal before disturbance: there are no higher harmonics.

The harmonic composition at the beginning of the disturbance is shown in figure 5.
The beginning of the disturbance changes the harmonic composition of the signal: the third and fifth harmonics are at the level of 32 and 18%; constant component of 5% due to the transient process of the growth of additional disturbance.

Figure 6 shows the analysis of the disturbance signal with a wide window for 10 periods. For a signal during the period of disturbance: the third and fifth harmonics are at the level of 22 and 13%; there is no constant component. The first harmonic has additional subharmonics and some broadening of the spectrum associated with a change in the amplitude of the main disturbance modulated by a low-frequency factor.
Figure 7 shows the analysis of the signal from the initial value to the maximum of the disturbance by a wide window of 10 periods.

For the period under consideration: the third and fifth harmonics are at the level of 14 and 8%. The wide spectra at the fundamental harmonics are explained by the width of the window, which captures a part of a non-noisy signal and a part of a signal with disturbance.

The study of changes in signal values using the “window” Fourier transform allows a graph of the presence of the corresponding harmonics to be obtained (figure 8) and the dynamics of their change to be evaluated. The window width is chosen for the fundamental harmonic of the carrier signal 50 Hz.

For a full cycle of the normal signal and the disturbance in figure 8, the amplitudes of the harmonics are: 0.18 of the main undisturbed signal; 0.4 at the peak reaches the fundamental harmonic together with the disturbance; 0.07 – third harmonic; 0.04 is the fifth harmonic.
5. Conclusion
The performed modeling and analysis of its results show changes in the harmonic composition of the stator current signal of the drive electric motor in the event of defects in the bearing assemblies of mining equipment. The practical value of the results obtained lies in the possibility of developing an automated system for diagnosing friction units of mining equipment, which will allow emerging malfunctions to be identified at an early stage and mechanisms from emergency operating modes to be protected.

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