Possibility of Extended Analysis of Operating Efficiency of Rotary-Type Machine Roller Bearings

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Abstract. A wide application of the rotary-type machines as actuating mechanisms and driving units in the oil&gas industry stipulates for a special approach towards the diagnostics of the current state of their elements. Roller bearings of such machines are the most critical joints as they are under constant action of significant power and oscillatory loads. Generally, failures of roller bearings cause the destruction of not only the bearings but also the contacting parts. Modern dynamic methods of diagnosing the unit and machine technical state, in particular, vibration diagnostics, allow avoiding emergency and hazardous situations, unreasonable and unscheduled stops and expensive visits of the manufacturer’s specialist.

The article considers the existing methods of diagnosing the rolling bearings state by vibration parameters. As a rule, most modern methods are based on quite precise mathematical calculations of vibration components, require the application of specialized and expensive software and do not provide a possibility to make a precise conclusion on the researched object technical state at practice.

The article considers the method of detecting the technical state of roller bearings which can be applicable in most cases. This method reveals the general forms of spectral modulations, reflecting the presence of incipient and developing faults, and defines the real values of a diagnostic sample - test spectrum, uses very few mathematical calculations and does not require all the standard bearing geometrical parameters during analysis.

1. Introduction

Recently, one can observe a wide application of the rotary-type machines as actuating mechanisms and driving units in the oil&gas industry and other areas, and such machines use rolling bearings as bearing supports [1, 9].

Bearings are operated in various conditions: high rates, increased temperatures, significant loads and with different media. Frequently, rolling bearings fail earlier than a set period of life stipulated for them. [3,6]

In compliance with the requirements to the operation and maintenance system set by the manufacturers as of today, most units, especially those operated during the warranty period, are not subject to the repair by the customer while in case of any defect occurrence or failures it is recommended to invite the manufacturing plant representatives to detect the causes of the unit failure and take a decision on its further use. However, the user can independently conduct diagnostic research without bringing the system in the state of emergency. [8,11]
2. Relevance literature review
The main operation mode of rolling bearings in these units is their operation under forced lubrication supply into the friction area. This lubrication not only withdraws heat from the friction area but also provides a possibility to reduce the friction factor between contact surfaces due to the lubrication layer formation. As a result, the contact area has boundary or semi-liquid friction.

The occurrence of various defects in a bearing causes a harsh growth of vibration level at certain spectrum frequencies. [1,2,4,6]

The analysis of causes of rolling bearing failures shows that it is necessary to control the processes of change of the machine elements technical state more carefully judging by the conditions of their operation.

Most parts of defects and changes of bearing mechanical properties in the rotor machines used in the oil&gas industry [1, 4] are similar and occur as a result of high voltages at operating surfaces and, consequently, can manifest in the following forms:
- fatigue flaking;
- abrasive wear of rolling bodies and bearing tracks;
- occurrence of local cavities at bearing tracks;
- bearing ring edge and shoulder chipping off;
- failures caused by the change of gaps and fits between bearing parts and rotor supports.
- wear of the bearing parts exceeding the permitted level, especially the rolling bodies and ring surfaces. [3,4,5,7,10,13]

The vibration control methods applied today to detect the technical state and defects of bearing supports are not suitable at all for the existing conditions of rotor machine operation as it is clear from the analysis of machine efficiency. As a rule, such methods are based onto quite precise mathematical calculations of spectral vibration components [19, 20]. As an example of large mathematical computations necessary for modern vibration diagnostics methods one can provide such dependences [1,2,18] – to detect the temporal changes of the orbit of \( \Omega_{\mu} \) and actual angular velocities of ball rotation \( \Omega_i \):

\[
\begin{align*}
\Delta \Omega_{\mu} &= \sum_{q=1}^{3} \left[ \left( \frac{\partial \omega_{\mu}}{\partial \gamma_q} \right) \Delta r_q + \left( \frac{\partial \omega_{\mu}}{\partial \beta_q} \right) \Delta \beta_q \right] + \left( \frac{\partial \omega_{\mu}}{\partial r_q} \right) \Delta r_q \\
\Delta \Omega_i &= \sum_{q=1}^{3} \left[ \left( \frac{\partial \omega_i}{\partial r_q} \right) \Delta r_q - \left( \frac{\partial \omega_i}{\partial \beta_q} \right) \Delta \beta_q + \left( \frac{\partial \omega_i}{\partial \gamma_q} \right) \Delta \gamma_q \right]
\end{align*}
\]

where
- \( r_q \) – geometric dimension (radius) of the roller path of a ball bearing.
- \( \beta_q \) – geometric dimension (radius) of the bearing rolling body.
- \( \gamma_q \) – geometric dimension (radius) of the bearing separator.
- \( \Delta r_q \) – deviation of the bearing tracks of ball bearings at defects.
- \( \Delta \beta_q \) – deviation in the form of the rolling bodies of a ball bearing, i.e., their defect.
- \( \Delta \gamma_q \) – deviation in the form of the bearing separator, i.e., its defect.

3. Problem statement
The application of lengthy mathematical calculations is quite difficult not only due to the absence of more detailed characteristics of machine bearing assemblies but also because of the presence of quite a significant fluctuation of rotor rotation frequencies in real time, especially in heat engines which leads to large spectrum deviations thus making a real vibration situation rather different from a design one. In this case one should not make mathematical calculations, which are not efficient for stable bench-scale tests and are rather different from a real situation, but start searching for zonal cumulative spec-
tral manifestations of defect groups and detecting them not for some specific defect group having vir-
tually the same effect, such as the change of radial gap, destruction of contact surfaces, etc. [3]. To
analyze their technical state, it is not necessary to have precise geometric assembly parameters - it is
enough to know general forms of bearing spectra obtained mainly empirically. Thus, simply compar-
ing the reference spectra with a real situation, one can detect key defects of such elements with 75% confidence. [1,4,7,10,11]

Although ball and roller bearings consist of rolling elements, in the operation conditions they are
also subject to wear caused by slipping, and these kinds of bearing supports have the same manifesta-
tions of defects, which means the causes of such defects are the same as well. In addition, as the study
of technical documents shows, operating radial gaps of rolling bearings in most rotor units, used by
the oil&gas industry, are quite comparable with radial gaps of high-precision friction bearings. [1.5].

That is why, taking this assumption as a basis, the authors conducted some series of experiments on
the measurement and analysis of rolling bearing vibration similar to the experiments with friction
bearings. [1,12]

4. Theory experimental studies
The vibration processes, occurring in bearing supports, can be analyzed by means of spectral analysis
(analysis of vibrational records) based upon the decomposition of a complex oscillating process into
different components, having various frequencies and amplitudes. Besides, they can be used for defect
detection. Such method can be used both for any types of rotor machines of the oil&gas industry [1,
2].

The authors study 22 objects (more than 2,450 measurements) before stopping their for the repair
which gives the possibility to investigate the defects of rolling bearings and correlate them with the
amplitude-frequency characteristics of the obtained vibration spectra. The study objects include: gas-
turbine drives, gas compressor units, the drives of beam units, crude oil booster pumps as well as a
experimental unit with a reducing gear box of general purpose. The authors study the defects of all
assemblies, and then make a histogram of the distribution of the number of failures on rolling bearing
assemblies (Figure 1) [2].

To use the method of spectral analysis, the authors suggest using the amplitude-frequency sample -
test spectrum - which allows making a re-calculation of corresponding frequencies with the binding to
the rotational frequency of the machine rotor shaft and the method of imposition them on a vibration
record to define the location of high-amplitude modulations, characteristic for certain defects of the
studied assembly.

As a result of the analysis of the most significant vibration records (Figure 2), reflecting the defects
of bearings, the authors develop a universal method based upon test spectra for the extended analysis
of the bearing element technical state: detecting the defects of the internal and external rings, rolling
elements and a separator without specification of the defect nature. The test spectrum is provided in
Figure 3. Here one can clearly observe the manifestations of amplitude modulations (frequency
peaks) at the region 1/2 and the rotation frequency area, the increase of the first and second rotation
frequencies, the noise level in the area as well as the occurrence of modulations in the region of rota-
tion rates of rolling bodies.
Figure 1. Ratio of rolling bearing defects causing failures.

Figure 2. Significant vibration record at the defective separator, rolling bodies and defects at the tracks of a ball bearing.

1 – modulation of rotation frequency, 2 – modulation of the frequency of a defective separator, 3- modulation of the frequency of the defective rolling bodies, 4 – 1st,2nd harmonics of the defective internal track, 5 – 1st,2,3-d harmonics of the defective external track, 6 – 1st,2-d harmonic of the rotation frequency (rotor disbalance).

5. Practical relevance. Production approbation

Similar analysis is conducted on the bearing elements of an aeroderivative. It shows the increased vibration comparing with a normal one (at the plants of Gazprom, LLC) before disassembly and shipping to the manufacturing plant.

According to the data obtained from the plant representative the drive actually had the defect in the internal ring of the radial rolling bearing with cylinder short rollers as it was specified at the comparison of the reference test spectrum with those obtained at the drive by experiment [2].
Such drives have a rotation frequency of approx. 8,000 min⁻¹ and the capacity – 12 MW.

In addition, such method is checked at the drives of reducing gear boxes of beam units (number of drive rotations n=3,000 min⁻¹, gear reduction rate U=27.5, the drive capacity Nдв=40 kW).

Here the authors also make a conclusion that the suggested method completely corresponds to the level of confidence of the conclusions drawn on the technical state of rolling bearings.

\[ A \text{ – Modulation amplitude, } f_{mod} \text{ – modulation frequency of the unit rotor, } f_{cen} \text{ – modulation frequency of the bearing separator, } f_{mod}, k \text{ – modulation frequency of the rolling bodies, } k \text{ – modulation harmonics of the roller paths.} \]

Figure 3. Generalized test spectrum for detecting the defects of rolling bearings.

The statistical analysis and accumulation of such information on rolling bearings can be used by manufacturing plants of bearing supports with various designs – it can help in the selection and development of new materials for its elements, defining the operation modes and mean time to failure, recommended operation conditions and application of lubrication materials.

6. Conclusions
1. The authors prove the possibility of using the approach to the vibration diagnostics of rolling bearings similar to the approach applied for journal bearings and gears.
2. The authors develop a test spectrum allowing for detecting the technical state of the bearing rolling element by vibration parameters.
3. In addition, the article confirms the applicability of this method at the site virtually on any rotor units used as bearing components of rolling bearings.

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