HIGH FREQUENCY VIBRATION MONITORING AND DIAGNOSTICS OF HIGH-SPEED PUMP ROLLING BEARINGS

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Abstract: Evolution of modern industry makes great demands to reliable work of pump equipment with large revolutions number of rotating parts. Under special supervision must be the centrifugal high-speed pumps. One of the major and hardly loaded units of high-speed pump equipment are rolling bearings, therefore it is very important to conduct monitoring and early diagnostics works to find out defects in them. For the high-frequency vibration detection and analysis it is possible to use both stationary and portable systems of monitoring and diagnostics. This diagnostics advantage is early detection of aberration from normal operation of rolling bearings and transition from equipment service and repair on-schedule to real situation service and repair, which is determined on periodic diagnostics results.

1. INTRODUCTION

Pumping equipment of various enterprises as well as any other equipment is subject of disrepairs and failures, which result in a substantial economic loss. From the large variety of technological equipment, pumps are taking a one of
lea-ding places. All of pumping equipment requires the permanent supervising after its work. But under the special supervision there must be centrifugal pumps (Fig. 1) with the high-speed coefficient $n_s \geq 150$, which is determined by:

$$n_s = 3,65 \cdot n \cdot \sqrt{\frac{Q}{H^{\frac{3}{4}}}} \; ; (1)$$

where: Q - complete pressure (m^3/h); H - feed of pump (m); n - revolutions amount of working shaft (rpm).

From a formula (Eq.1) evidently, that the impeller of centrifugal pump, intended for work with defined Q and H, possesses the greater high-speed, than anymore its rotation frequency. Large rotation frequencies set conditions for small sizes and mass of pumps and drive engines at high output of aggregates. Therefore application of working impellers with high n_s (Fig.1 pos. 1; 2; 3) economically feasible.

At the determined rotation frequency high-speed the higher, than anymore feed and less pressure, developed by working impeller. Therefore centrifugal pumps having working impellers with the high coefficient of high-speed have a low-pressure and give a large feed (Черкасский, 1984).

Consequently, to provide this type pumping equipment reliable and trouble-free work, it is necessary, that this equipment constantly be under control.

The most important and high-loaded units of high-speed pumps are rolling bearings; therefore it is very important to conduct works for monitoring and early diagnostics to find out defects in it already on the early stage.

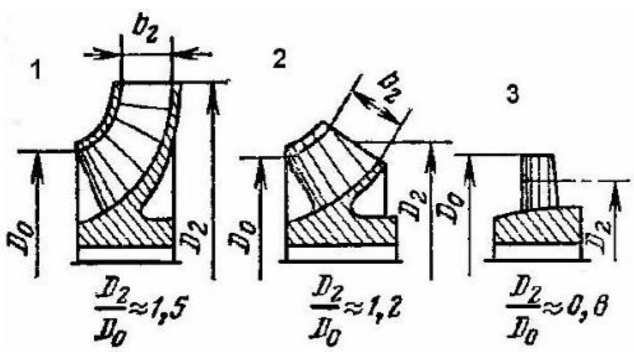

Fig. 1. Types of high-speed pump working impellers: 1 - High-speed impeller, $n_s = 150 \div 300$; 2 - diagonal impeller, $n_s = 300 \div 600$; 3 - axial impeller, $n_s = 600 \div 1200$

One of bearing incipient wear signals is a high-frequency vibration. It is the vibration in frequency range from above 20 kHz. Difficulties during the diagnostic information selection from low frequency and middle frequency vibrations, possible its distortions and complications of defect's localization it is all defined the promoted interest to the high-frequency vibration. Advantage of this diagnostics is an early acquisition of deviations from rolling bearings normal work and transition from equipment's maintenance and repair on regulation to maintenance and repair on the actual state.

The basic high-frequency vibration discovery and analysis method is a narrow band spectral analysis of signals, got from bearings, with large permission on frequency. This analysis is carried out by Fourier discrete transformation.
In the transformation the probed function is periodic, has an eventual period of repetition, and is discrete and actually allows presenting a discrete function as an eventual number of frequencies with the defined values of amplitude and phasing (lays out a function in its spectrum).

$$\operatorname{Re} X[k] = \sum_{i=0}^{N-1} x[i] \quad \cos\left(\frac{2\pi \cdot k \cdot i}{N}\right); \qquad (2)$$

$$\operatorname{Im} \quad X[k] = -\sum_{i=0}^{N-1} x[\ ] \quad \sin\left(\frac{2\pi \cdot k \cdot i}{N}\right) \qquad (3)$$

Where: Re$X[x]$ - an array, containing cos values; Im $X[x]$ - an arrayy, containing sin values.

By another words it is possible to say that this transformation is laid out by the probed signal on the base functions of sine (Eq.2) and cosine (Eq.3). They are analogues of two mutually perpendicular vibrations, because on a phase displaced in relation to each other on 90 degrees (http://shack
master.narod.ru/fourier.htm)

2. NATURE OF ROLLING BEARING'S VIBRATION

Rolling bearing's work in high-speed pump composition and at presence faults in it can influence on a vibration and modulating it processes with the followings fundamental frequencies:

- Rotation frequency of movable ring in relation to immobile: $f_{\gamma ot}$;
- Rotation frequency of separator in relation to an outer ring:

$$f_r = \frac{1}{2} \cdot f_{rot} \cdot \left(1 - \frac{d_{sr}}{d_r} \cdot \cos(\alpha)\right); \qquad (4)$$

Where: $d_{s\gamma}$ - solid of revolution diameter; $d_\gamma \approx 1/2(d_{out} - d_{in})$ - diameter of separator; d_{out} - diameter of outer ring; d_{in} - diameter of inner ring; αcontact angle of bodies and rolling paths;

- Rolling frequency of sol - id of revolution on an outer ring:

$$f_{out} = \frac{1}{2} \cdot f_{rot} \left(1 - \frac{d_{sr}}{d_r} \cdot \cos(\alpha)\right) \cdot z = f_r \cdot z\,; \qquad (5)$$

Where: z - solid of revolution number;

- Rolling frequency of solid of revolution on an inner ring:

$$f_{in} = \frac{1}{2} \cdot f_{rot} \left(1 + \frac{d_{sr}}{d_r} \cdot \cos(\alpha)\right) \cdot z = \left(f_{rot} - f_r\right) \cdot z\,; \qquad (6)$$

- Rolling frequency of solid of revolution in relation to the surface of rings:

$$f_{sr} = \frac{1}{2} \cdot f_{rot} \cdot \frac{d_r}{d_{sr}} \left(1 - \frac{d_{sr}^2}{d_r^2} \cdot \cos^2(\alpha)\right); \qquad (7)$$

Expressions (Eq. 4, Eq. 5, Eq. 6, and Eq. 7) are evaluating only basic harmonics frequencies in the vibration spectrums and envelope of its high-frequency components at the different types of defects (Барков et al., 2000)

3. METHODS OF MONITORING AND DIAGNOSTICS

Among the monitoring and diagnostics different methods of the high-speed pump's rolling bearings state it is possible to select two basic:

3.1. High-frequency vibration form analysis, excited short shock impulses

This method is sensible to microshocks appearance at the friction elements contact in rolling bearings. It got the name «Method of shock impulses». For such type of high-frequency vibration analysis implementation the specialized measuring devices were created.

To illustrate this method, on Fig. 2 the rolling bearing's high-frequency vibration signals are resulted without defects (Fig. 2a), with the friction surface wear (Fig. 2b), and with a shell on the friction surface (Fig. 2c). Shock impulses arise up in third case, at the rotation of bearing with a shell on any of rolling friction surface. They are revealed by the size of signal maximal value relation to its RMS value. This relation is named by pick factor and at rare shock impulses appearance can exceed a value ten. In default of shock impulses it, as a rule below to five.

Utilizing this method it is possible to find out the engendered microscopic greasing defects at which the oil tape breaks take a place rarely and irregularly, and also mechanical micro faults of bearings, on unstable rotation frequencies, for short time (for 2-3 turns). Thus, in practical diagnostics, method of shock impulses not using separately, in the aggregate with the *high frequency vibration power checkout* only (Maurice and Adams, 2001).

3.2. High-frequency vibration power oscillations spectral analysis

This method possesses more high possibilities on control after the rolling bearing's state of high-speed pumps on the high-frequency occasional vibration envelope spectra, excited by friction forces in oil tape of bearing, and also by shock impulses at its breaks.

Occasional signal envelope spectra gives information about periodic changes of high-frequency vibration power in the frequency range, which is preliminary selected from the vibration signal by one third octave band filter (narrow band filter).

In the Fig. 3 the vibration spectrum of bearing unit is resulted in a range from 10 kHz to 25.6 kHz, where is shown the frequencies range of filter, utilized for a high-frequency casual component selection with the envelope consequent forming.

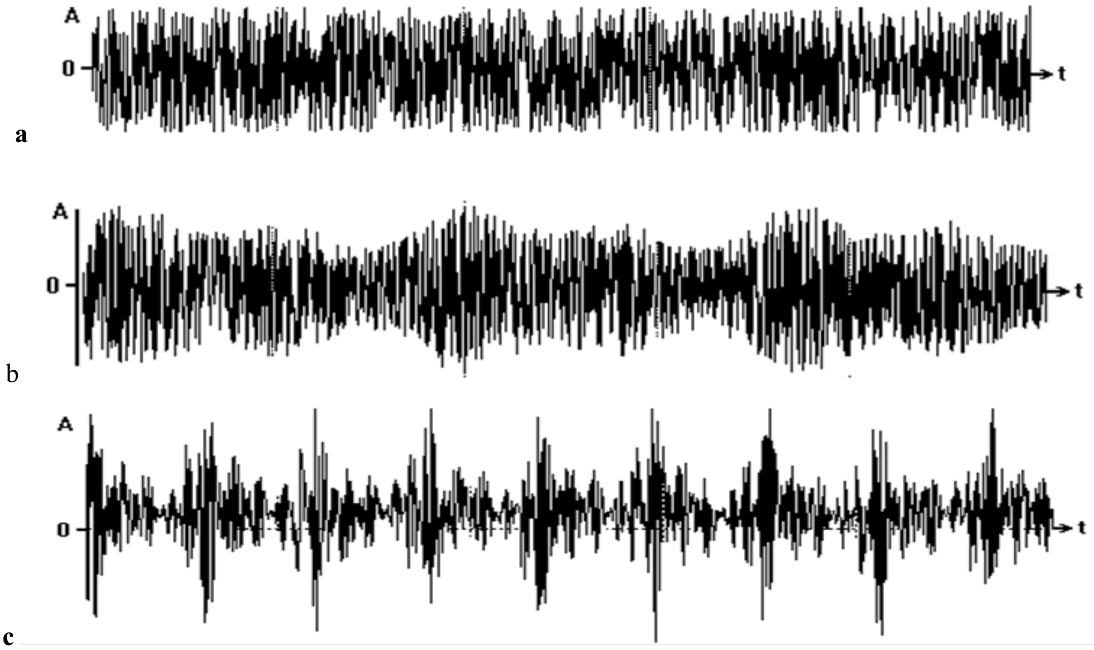

Fig. 2. High-frequency vibration of rolling bearings: a – without defects; b – with the friction surface wear; c – with a shell on a friction surface

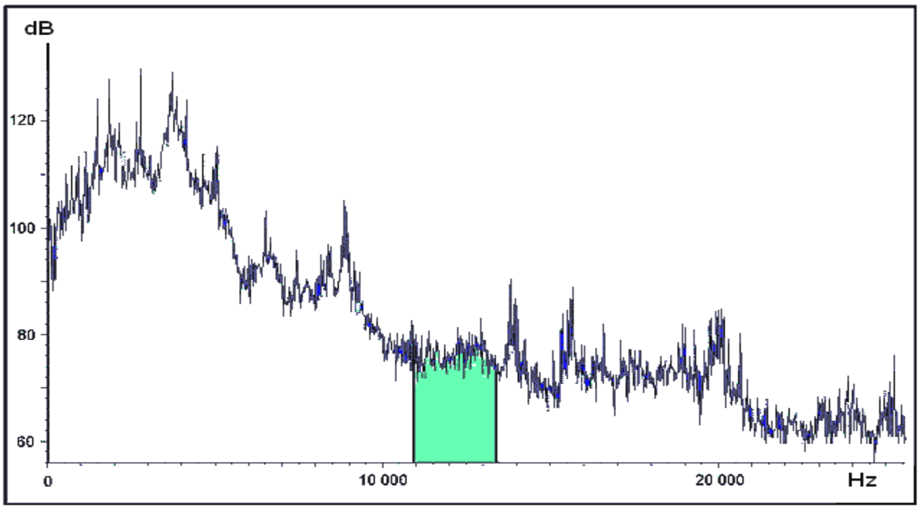

Fig. 3. Rolling bearing's vibration spectrum of high-speed pump with selected of one third octaves frequency band

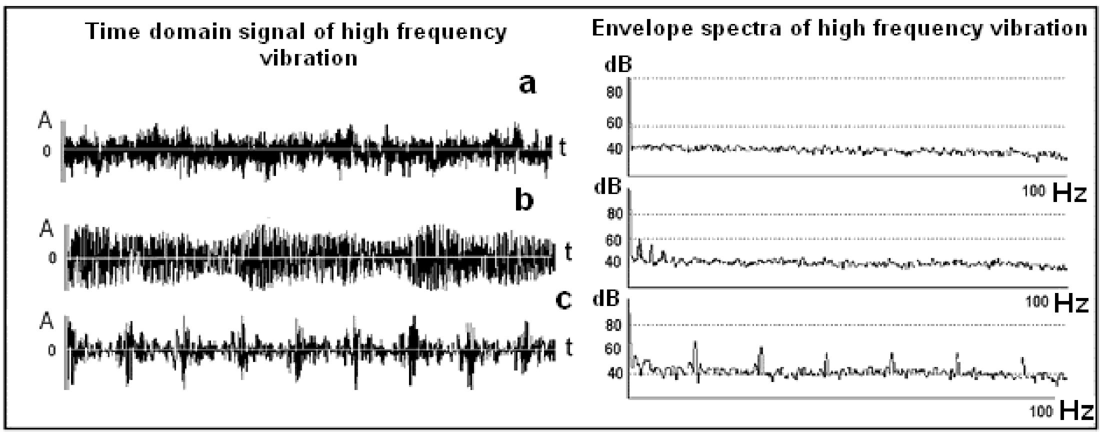

Fig. 4. Forms of the high-frequency vibration and its envelope spectrums are for three identical bearings, accordingly, without faults (a); with the fault of separator (b); with a shell on an outer ring (c)

The method gives positive results only when harmonic constituents of vibration do not get in the frequency band of filter, by power exceeding an occasional vibration. Otherwise the power oscillations sum of harmonic and occasional constituents decreases and an envelope spectrum giving the distorted information about bearing's state (Баркова, 2003).

In spite of certain complication of high-frequency casual vibration envelope spectra measuring as compared to mea-suring, executable by the «shock impulses» method, all possibilities of envelope method's realization allows to solve many important problems of high-speed pump rolling bearing's diagnostics.

4. EQUIPMENT FOR MONITORING AND DIAGNOSTICS

In technical maintenance of high-speed centrifugal pumps, the vibration monitoring and diagnostics fill the special place because of the possibilities to find out the changes in the condition long before emergency situation.

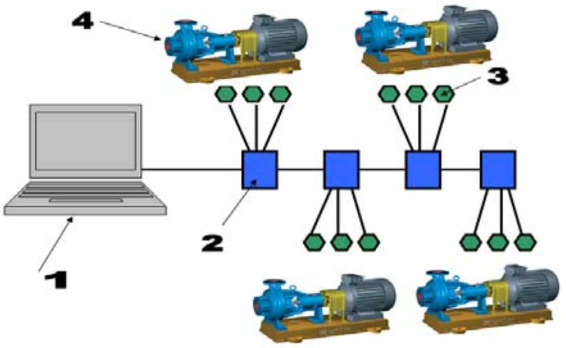

Fig. 5. The monitoring and diagnostics stationary system structure (1 - computer with special software; 2 – boards of transformation signals from sensors in digital form; 3 – sensors of vibration; 4 – centrifugal pumps)

Fig. 6. The monitoring and diagnostics portable system structure (1 – Laptop with special software; 2 – data collector-analyzer; 3 – the sensor of shaft revolutions; 4 – vibration sensor)

The modern systems of looking after pumping equipment unite in it both monitoring and diagnostics functions. These systems can be both stationary and portable.

It is expedient to apply the monitoring and diagnostics stationary systems at supervising pumps large amount presence. The generalized structure of the stationary system is shown on Fig. 5.

For necessary mobility and realization monitoring and diagnostics works providing in different situations, utilize the portable systems (Fig. 6).

Utilizing experience of both stationary and portable systems shows that a most economic effect is obtained at presence on an enterprise simultaneously both stationary and portable system.

5. SUMMARY

It is possible to draw a conclusion from all of above-stated, that high-speed centrifugal pumps equally with other rotating machinery require permanent control after their technical state. It is very important to find out defects in rolling bearings on the occurrence early stage. That is possible due to the vibration control in high-frequency range (in frequency range from above 20 kHz). Only in this range possible to find out the engendered defects of rolling bearings. All these actions are necessary for a transition from the planned repairs of equipment to repairs on the actual state.

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