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SED AND FFT METHODS FOR ANALYSIS OF ROLLER BEARING VIBRATION

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ABSTRACT
Vibrations are becoming an increasingly important phenomenon that accompanies the operation of bearings with rolling elements and also an important indicator for determining the overall quality of each plant, and they are often used for analysis for the purpose of predictable maintenance. Vibrations produced by the roller bearings can be very complex and could also be the result of geometrical irregularities during the production of the bearing itself, damage to rolling surfaces or geometrical errors in the associated components from the bearing environment.
This article shows the sources of vibration and the most important frequency of defects that may be present in the operation of bearings with rolling elements. Examples of SED and FFT vibration analysis methods are also presented to provide diagnostic and prognostic recommendations for the overall technical condition of the machine, which also have such bearings in their construction.
Keywords: envelope spectrum, FFT spectrum, bearing defect frequency

1. INTRODUCTION
Damage to bearings with rolling elements usually begins with the appearance of smaller cracks or tiny particles of material due to internal temperature. They appear on contact surfaces in the bearing, fractures or cracks, causing very strong impulses when rolling elements pass over them. Damage causes changes in the geometry of the bearing elements, resulting in strong impulses when it comes to contact with damaged surfaces, i.e. increased vibrations and sound pulses, which are transmitted outside the outer ring and the bearing casing [1,2].

Impulse impacts in the damaged bearing are different based on the rate of expansion, i.e. it can be said that the impulse period is very small compared to the intensity of the impulse or the time interval between the two impulses, which affects the so-called frequency of bearing damage.
As the absolute vibration of the bearing reflects the condition of the machine and its components, the impact impulses contain important information about the condition of the entire bearing and its parts: the outer ring, the inner ring, the rolling elements and the casing.

Therefore, the choice of estimating the complete bearing or the condition of its parts or not depends on the width of the frequency bandwidth, which is selected by the hardware and software instrument for vibration measurement, i.e. narrowband (single) or broadband (overall) method.
Since impulses of such bearings are rather short, they contain very high frequency energy, which causes resonance problems. Therefore, detection of irregularities in the bearing is performed by detecting resonance rise and machine construction on higher frequency band (2-14 kHz).

Estimation of the bearing condition is performed by measuring at the measuring positions which are as close to the bearing as possible, directly on the outer ring of the bearing, although radial measurements on the bearing housing may also give clear results. Larger distance between the actual source of the impulse and the measurement position gives a weaker signal, because there is a pass through different materials. Part of the impulse signal is lost because each measuring position in which the signal passes through different materials causes signal damping.
Estimating the condition of individual bearing elements is particularly difficult because vibration indicators depend on the intensity of damage to the bearing elements. It is important to highlight some of the methods for vibration analysis on bearings due to the importance of assessing the size of damage by an analyst. [3,4,5]

2. SED AND FFT METHOD FOR ANALYZING VIBRATION

Selective envelope detection (SED) (also known as the envelope spectrum or amplitude modulation) is a type of analysis used for modulation detection and as such allows the detection of modulation of bearings at an early stage.
Envelope spectrum is used to detect bearings because it is more susceptible to the energy of the impacts generated and developed by the defect at the positions in the bearing (the impulses that appear when the rolling element passes through the damage). Envelope spectrum of vibration velocity and acceleration use a high-frequency range between 5 kHz and 20 kHz (30000 rpm-120000 rpm). Vibration signal representation in the time domain is more used for lower rotational speed.
For the diagnosis of bearings, the FFT (Fast Furier Transformation) velocity spectrum is used more because it allows an easier way of monitoring the progression and intensity of the damage that occurs within the bearing. The only advantage of using the FFT acceleration spectrum is a more accurate representation of vibration indicators in the mid-frequency domain
Indicators of damage at roller bearings at the initial stage of their formation are defects which cause friction or impulses that result in high frequency vibrations.
The impacts of damage to the bearings are shown earlier on the envelope spectrum. The signal envelope spectrum contains harmonic at equal distances of the frequency axis corresponding to the defect frequency (Fig.1).
The signal **at** the FFT frequency spectrum vibration velocity shows the harmonics **at** the defect frequency with extremely low amplitudes (which are sometimes not even recorded) in the initial phase of the damage (Fig. 2). There is usually no harmonics at the 1x defect frequency of the FFT spectrum vibration velocity, but other harmonics of the same frequency may appear.

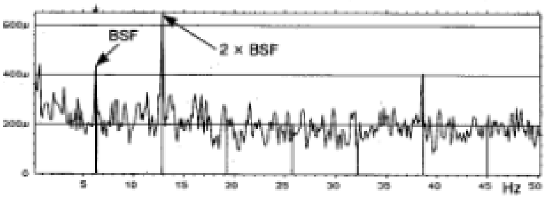

Figure 1. Envelope spectrum at the early stage of defect

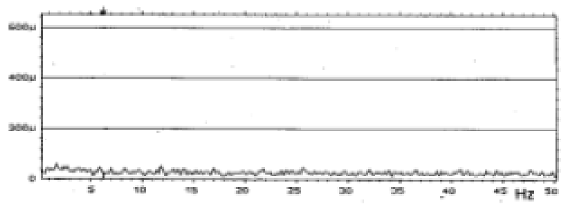

Figure 2. FFT spectrum at the early stage of defect

Figs. 3 and 4 show actual examples of the same signal on the envelope spectrum and the frequency spectrum of the vibration velocity. There is a difference, i.e. the lower amplitude on the FFT spectrum relates to the appearance of detected friction forces but it only allows insight into the bearing condition (that the bearing is damaged!). Demodulated harmonics occurring on specific frequencies on the envelope spectrum also detect impact intensity (how fast the damage spreads!). [6]
Sharper impacts occur at the later stage of the defect of a bearing, but these impacts may be of lower intensity due to increased wear and the appearance of a larger gap in the bearing.
Fig. 5 shows an envelope spectrum with vibration defect indicators at a later stage, at which harmonics may be lower amplitudes due to increased wear within the bearing.

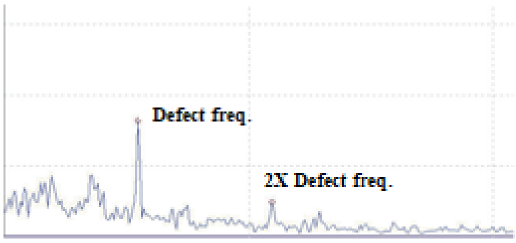

Figure 3. Example of envelope spectrum at the early stage of defect

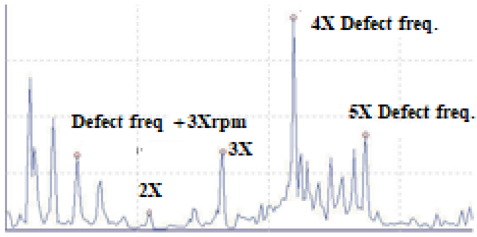

Figure 4. Example of FFT spectrum at the early stage of defect

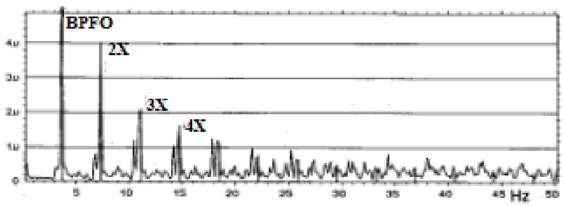

Figure 5. Envelope spectrum at the latter stage of defect

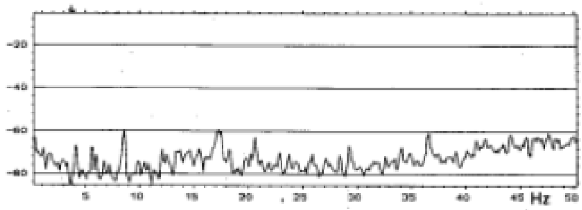

Figure 6. FFT spectrum at the latter stage of defect

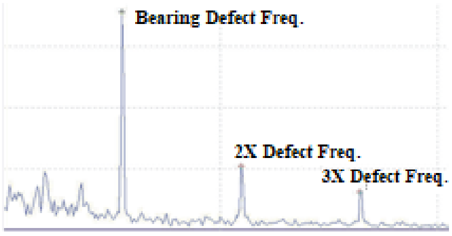

Figure 7. Example of envelope spectrum at a latter stage of defect

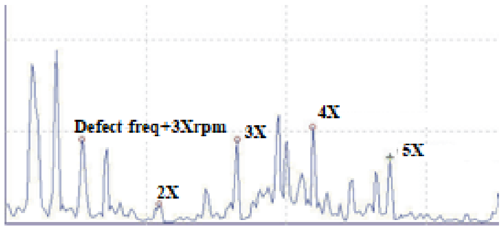

Figure 8. An example of the FTT spectrum at the latter stage of defect

Fig.6 shows the FFT frequency spectrum of vibration velocity with indicators relative to advanced defects on the bearing, where the 1x frequency of the defect becomes more visible. There is a significant increase in amplitude frequency defects (harmonics of defect frequency), which indicate the much worse condition of the bearing.

The resulting noise is amplified, while the shape of the signal continues being distorted due to the wear of the bearings and near assemblies.

Fig.7 and 8 show actual examples of the same signal on the envelope spectrum and the FFT frequency spectrum of vibration velocity for improved damage to the bearing. The comparison of these two spectrums shows the impact on the frequency of defect on both the FFT spectrum and the envelope spectrum, as well as the increased amplitude of the higher harmonic frequency defects in the advanced phase of bearing damage that are much more noticeable in the envelope spectrum.

As shown, the typical progression of an irregularity leads to the expansion of the defect which can be displayed on the FFT frequency spectrum and the envelope spectrum of vibration velocity. However, there are other ways of controlling the expansion of the defect on the bearing, such as the FFT frequency spectrum and the envelope spectrum of vibration acceleration (gSE spectrum-term originating from the acceleration amplitude unit and Spike Energy - gSE), as well as special bandwidths with a recorded time signal or ultrasonic noise detection (e.g. Shock Pulse), which are quite outdated methods.

3. INTERPRETATION OF ENVELOPE SPECTRUM

Interpretation of the envelope spectrum, i.e. determination of an actual peak amplitude, is not as important as its value relative to the surrounding noise level of the spectrum. What does that indicate?

The level of ultrasonic noise detected by the appropriate analyzer has a much greater effect on peak amplitude than supposed.
Unlike the vibration velocity or the unit it represents, the unit on the envelope spectrum, i.e. gSE unit shows the influence of other states such as bearing load intensity and lubricity condition more precisely. Reduced oil quality or quantity induces such a signal which forms the "surface" of the increased amplitude on the spectrum .
The vibration measurement performer notices the normal bearing operation as long as the gSE amplitude is in the range of 0.05 gSE to 2 gSE. There is no general rule for determining this area because it varies, i.e. depends on the characteristics and type of machinery, as well as the environmental influence.
Therefore, other interpretation methods are used, and the two main ones are:

1. After observing the frequency of the influence using the gSE spectrum, the vibration velocity spectrum is controlled for a very high peak frequency (which can even be a low amplitude). If there are none, the control is further carried out on the frequency axis. If there is a peak (or wider bandwidth around it-sideband), the cursor on the analyzer display is positioned at the chosen influencing frequency (even if it does not have a peak) and discrete harmonics are tried to be found set in a row that will point out certain defect deviations for a more accurate assessment. The spectrum vibration acceleration is the better option for the application of this method.
2. The gSE spectrum is used and the amplitude scale is converted to dB. Afterwards the peak amplitude on the frequency of the defect is compared to the estimated peak amplitude inside the so-called sideband areas. If the difference between the peak is within the 12-18 dB limit, there is a significant amount of vibration. The difference greater than 18 dB indicates a higher impact and an increase in vibration, suggesting faster wear in the bearing.

More attention should be paid when using the envelope spectrum identification method for two reasons:

- If the overall vibration amplitude is being used, the so-called overall vibration or increase in magnitude for a "trend" analysis without analyzing the enveloped spectrum, it must be taken into consideration that a greater number of different vibration sources due to the occurrence of machine irregularities will cause an increase in signal energy effect, which may not be relative to the real problems in the bearing.
- The envelope spectrum forms signals that are very sensitive and can point out vibration indicators and hidden problems even at the initial stage of damage in the bearing. Thus, major repair decisions at this stage can affect the credibility of this spectrum and signal interpretation program when it comes to vibration operators who are not sufficiently familiar with this technology.

4. CONCLUSION

In conclusion, the envelope and FFT spectrum of vibration velocity and acceleration are the most efficient methods for detecting defect spread on the elements of roller bearings. What led to this conclusion are harmonics of the more important frequency of the individual elements of the bearing on the spectrum, which lead to the proper making of conclusions for the diagnosis of the bearing condition, such as:

- Separate broadband bandwidth frequency, i.e. sidebands on spectrums of vibration velocity and acceleration, as an important identifying element when detecting errors, because such a frequency range corresponds to enhanced resonance, which is relative to the occurring irregularities when mounting the bearings.
- The harmonics on 3x-10x frequency defects, as frequency indicators of a very pronounced defect on the bearing. Which harmonic increases most and shows the highest amplitude depends on the resonance frequency range of the mounted bearing.

5. REFERENCES

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