A COMPARISON OF METHODS FOR THE BEARING STATE EVALUATION.

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Abstract: This paper shows a comparison of several methods commonly used for the bearing state evaluation. A brand new bearing (of the type ZKL1202) as well as a damaged one were used for the tests done at a simple rotating machine. An obvious methods, such as kurtosis, crest factor, a high frequency band RMS value, a spectral analysis of a base band signal and the envelope analysis were used. The results show, that all methods are able to detect the failure bearing with the high reliability compared to the initial state of the bearing.

Keywords: bearing state, ball bearing, kurtosis, crest factor, envelope analysis

1 INTRODUCTION

Ball bearings are one of the most used components in industrial machines. Their appropriate selection as well as suitable operational conditions are very important features for a long life time of the bearing. In the opposite case, a life time of the bearing is shortened or an unexpected failure of a machine can occurs. From the aforementioned reasons the predictive vibrodiagnostics takes a significant place in the industrial maintenance of machines [1, 2]. Bearing failures can be detected in generally four stages of its lifetime (see Figure 1). A detection of an acoustic emission signal is useful in the first

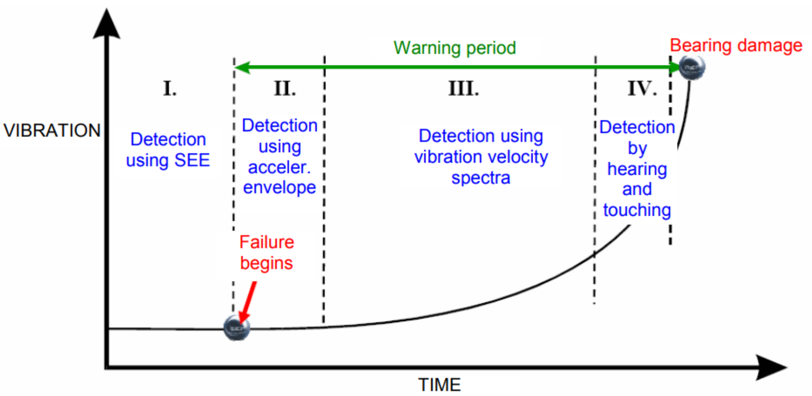

Figure 1: The course of rolling bearing defect development [10].

stage of the bearing lifetime, since no other methods can detect an increased vibration signals. There are also a lot of methods commonly used for evaluation of the bearing state in the following stages [3], such as kurtosis, crest factor, high frequency RMS value, envelope analysis etc [4]. Also a detection of bearing fault frequencies takes place in a final stage of the bearing lifetime, immediately before its failure. Big companies propose their own methodologies as well, such as bearing condition unit

(BCU) developed by Schenck Trebel [3], Shock Pulse Monitoring proposed by SPM Instruments [5, 6] etc.

1.1 KURTOSIS

Kurtosis is a statistical parameter and is a measure of the tailedness of the probability distribution of a real-valued random variable [7]. It is very often used for bearing state evaluation according to the Equation 1 [8].

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3 = \frac{\frac{1}{N}\sum_{n=1}^{N}(x(n)-\bar{x})^4}{\left(\frac{1}{N}\sum_{n=1}^{N}|x(n)-\bar{x})|\right)^2} - 3 \tag{1}$$

where $\bar{x}$ is a mean value of the data set x, N is the number of samples of the signal x and μ_4 and μ_2 are the fourth and the second central moment of the first order.

1.2 CREST FACTOR

Creast factor is a fast procedure for the detection of the failure course [2]. It can be calculated according to the Equation 2 and it is equal to the ratio of a peak value and a RMS value of the digitized signal.

$$K_v = \frac{x_{peak}}{x_{RMS}} = \frac{max(x) - min(x)}{\sqrt{\frac{1}{T}\int_0^T x^2(t)dt}} \tag{2}$$

The result is suitable mainly as a fault detection in the early stage of the bearing failure. The method is relatively fast and cheap, but the accuracy of the damage evaluation is not very high. Parasitic pulses decreases the reliability of the detection as well.

1.3 K(t) PARAMETER

Relatively better results can be obtained using K(t) parameter calculation method. It is based on the similar principle as crest factor and is very suitable for the bearing state evaluation [9]. The diagnostic parameter K(t) is calculated according to the Equation 3.

$$K(t) = \frac{a_{pp}(0) \cdot a_{RMS}(0)}{a_{pp}(t) \cdot a_{RMS}(t)} \tag{3}$$

where $a_{pp}(0)$ (or $a_{pp}(t)$) is a peak-to-peak acceleration in the time of the bearing mounting (or in the time t from the beginning of the bearing working) and $a_{RMS}(0)$ (or $a_{RMS}(t)$) is a RMS acceleration in the time of the bearing mounting (or in the time t from the beginning of the bearing working).

The bearing state is evaluated according to value of the K(t) parameter – see the Table 1.

Table 1: The bearing state evaluation according to the K(t) parameter [9].

K(t) value	State of the bearing
$0.00 < K(t) \leq 0.02$	wrecking state
$0.02 < K(t) \leq 0.50$	damaged bearing
$0.20 < K(t) \leq 1.00$	good bearing

1.4 RMS value in high frequency band

Since the bearing failure is detected in the higher frequency band from e.g. 500 Hz (outside of the ISO band), the RMS value is also a good marker of the bearing state. Because the RMS value changes from bearing to bearing, it is impossible to define the exact value for all bearings. From this reason a relative measurement is performed and an initial RMS calculation (at the time of the bearing mounting) is used as a reference. The ratio gives an overview about the size of the damage of the bearing compared to its initial phase.

1.5 Envelope analysis

Envelope analysis is a powerful method for bearing state evaluation. Its principle is clarified e.g. in [10]. The process consists of a high-pass filtering (due to removing the low frequency components caused by the machine natural frequencies), rectification of the signal and application of the envelope filter. The process is shown in the Figure 2. The RMS value is calculated from the envelope signal

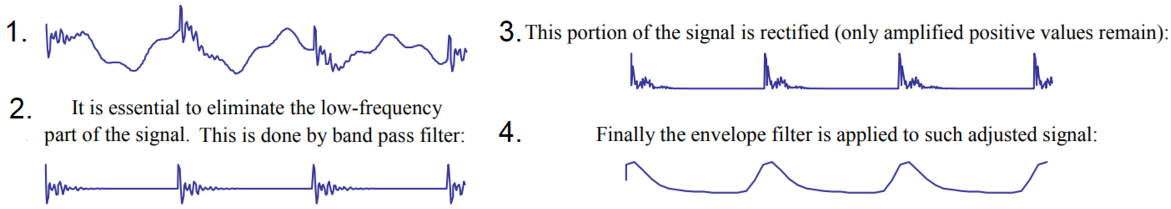

Figure 2: Creation of the acceleration envelope (modified from [10]).

very often and used as a key parameter for the bearing state evaluation. Also the ratio of the initial RMS envelope value and the value in the next time should be done and it gives an overview of the actual state of the bearing. The frequency analysis of the enveloped signal is also done very often.

1.6 Bearing fault frequencies

Values of bearing fault frequencies are increased in the last period of the bearing lifetime (see Figure 1). Their values lie in the low-frequency band (in ISO band) and can be measured from the raw signal, mainly the vibration velocity. But sometimes the noise background is too high to detect the exact frequencies, thus the spectrum is calculated from the enveloped signal. The process of enveloping do the filtering of the signal and removes the uninteresting components.

A typical bearing consists of four main parts – an inner ring, an outer ring, rolling elements and a supporting cage. Each part has its own fault frequency. If there is a fault on this particular component, then an error frequency appears in the vibration signal (or can be seen in the spectrum of the signal). Fault frequencies can be calculated using well known formulas [4] and depend only on dimensions of the bearing and its operating speed.

2 PRACTICAL RESULTS

A test bench containing of an asynchronous three-phase motor, a rigid rotor and two bearing supports has been used for the practical experiment. A self-aligning bearing of the type of ZKL1202 was used for the measurement. Two bearings were measured – the first one was a brand new and the second bearing was damaged by the drilling machine at the outer ring. The photography of the bearing can be seen in the Figure 3. A time signal in a frequency band up to 12.8 kHz has been stored using the ICP sensor PCB352C03 and a signal processing of the aforementioned parameters (creast factor,

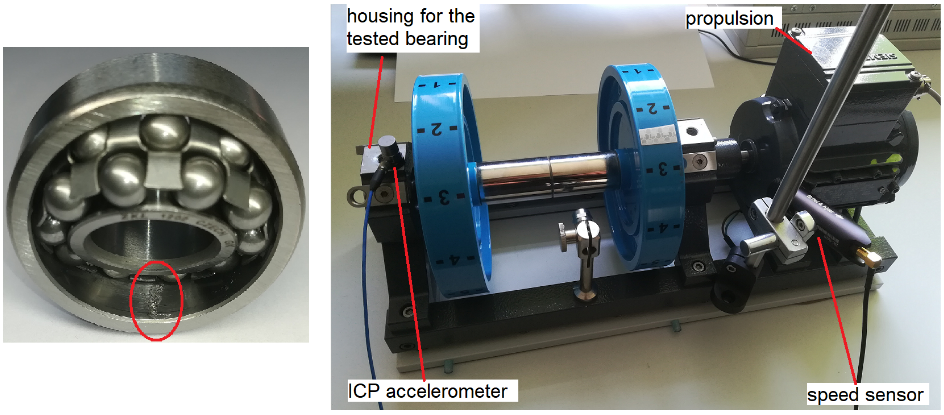

Figure 3: A view on the damaged bearing (left side) and the test stand for bearings (right side).

kurtosis, K(t), RMS envelope, overall RMS and fault frequencies amplitude) was performed using a LabVIEW application. The results can be seen in the Table 2.

Table 2: The results of the bearing fault detection on the good and the damaged bearing.

Parameter	Good bearing	Damaged bearing	Note
Crest factor [-]	3.88	10.33	
Kurtosis [-]	2.96	16.49	
K(t) [-]	1	0.0025	
RMS envelope [m/s^2]	1.37	16.14	in band 500 Hz – 12.8 kHz
RMS overall [m/s^2]	0.68	8.09	in band DC – 12.8 kHz
BPFO [mm/s^2]	0.0/0.0/0.0/0.0/0.0	5.5/4.6/3.7/2.8/2.1	1st/2nd/3rd/4th/5th harmonic

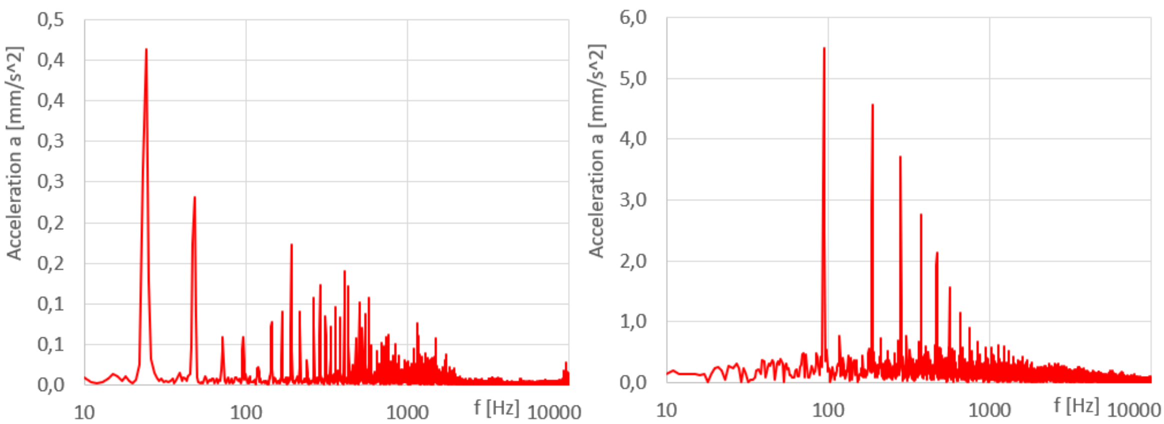

Figure 4: The spectrum of the raw vibration signal of the damaged bearing (on the left side) and the spectrum of the enveloped signal (on the right side).

3 CONCLUSION

As it can be seen from the Table 2, all used methods are suitable to detect the fault of the ball bearing. Any detailed measurement with a bigger set of bearings should be done for evaluation of particular methods sensitivities. There can be seen not a big difference between the overall RMS and the envelope RMS values, but the main advantage of the enveloping method can be seen in Figure 4 for FFT observing. Significant and clear harmonic components (on the right side) increased from the original signal (on the left side) after the enveloping procedure.

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