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EXAMINATION OF CONDITION OF ROLLING BEARINGS

DÁNIEL TÓTH

University of Miskolc, Institute of Machine Tools and Mechatronics
3515, Miskolc-Egyetemváros
toth.daniel@uni-miskolc.hu
https://orcid.org/0000-0001-8928-4633

Abstract: Bearings operating properties impact the function of the whole machine therefore their investigation is an important topic. Early detection of failure of bearings allows for the replacement of them during planned maintenance, thus avoiding sudden downtime or unexpected accidents. There are several methods for monitoring the operating conditions of bearings, which help determine the residual lifetime of the bearings. This paper focuses on a test procedure which can be used to determine the condition of rolling element bearings.

Keywords: *condition monitoring, rolling bearings, vibration diagnostic*

1. INTRODUCTION

According to environment-conscious approach of our days the purpose primarily is the more efficient extraction of the reusable raw material during the annihilation of industrial products. At the same time the certain number of extracted materials during the recycling processes could be recycled on higher preparation level. Voltage regulators and generators, starters, bearings disassembled from the cars and other industrial products are counted in this class, which can be even built into a new product if it has well defined and sufficient remanent lifetime (Patkó, et al., 2010). Research group of the Department of Machine Tools at the University of Miskolc gained extensive experiences in development of special precise machine details and producing machines (Takács, Patkó, Csáki, Szilágyi, & Hegedűs, 2006). One of the preliminary works in this field was the cooperative project of the University of Miskolc with the Hungarian Roller Bearings Works (MGM) in framework of which a cooperative linear motion guide developer and analyser laboratory was operated and a new precise linear motion roller guide family was worked out.

2. Vibration analysis

There are many different techniques for condition monitoring of rotating machinery, most of the bearing testing methods are based on vibration measurement. The current state and features of a bearing, and its deterioration can be assessed by vibration analysis. During the condition monitoring of equipment units and components, two important conditions are usually observed: one is the detection of possible defects, and the other is the frequency of defect occurrence, which also informs us about the service life of the component (Tóth, 2022). This latter aspect is especially important in the case of components that operate in continuous mode for a certain period. The balls and rollers rotating inside the bearing generate broadband noise and vibration, which is increased by poor lubrication of the bearing, overloading (for example, misalignment), or by damage to the raceways or rolling element surfaces. Since the noise and vibration generated by the bearings (which are otherwise high-frequency) are broadband, it is difficult for instruments measuring the effective value to define any specific frequency or narrow frequency band with which the condition of the bearing can be characterized (Szilágyi, Takács, Kiss, & Tóth, 2016). This is also impossible because the specific bearing failure frequencies depend, among other things, on the bearing type and the current speed of the machine. In practice, the method that has proven successful is to determine the value characteristic of the bearing condition based on the effective value of the vibration acceleration measured in the frequency range between 2 kHz and 20 kHz. The frequency domain techniques involve analysing or display of vibration data based on the frequency. One advantage of the method is that the repetitive nature of the vibration signals is exactly displayed as peaks in the frequency spectrum at the frequency where the repetition takes place. Time domain vibration signals are processed into the frequency domain by the adaptation of Fourier transform, typically in the shape of fast Fourier transform (FFT) algorithm. FFT is an algorithm to calculate the discrete Fourier transform and its inverse (Tóth, Szilágyi, & Takács, 2014). In a frequency spectrum the horizontal axis is generally the frequency, and the vertical axis is the amplitude of displacement, velocity or acceleration. Figure 1 shows a spectrum from a late stage in the life of a ball bearing. It is striking that the acceleration values have increased around 1000 Hz.

Time-frequency domain analysis can evince the signal frequency components, identifies their time variant features. These techniques have facility to handle both, non-stationary and stationary vibration signals (Tóth, 2016). These methods for instance the short time Fourier transform, the Wavelet transform and the Wigner-Ville distribution. One of the most widely used time-frequency techniques is the short time Fourier transform (STFT). STFT distributes the original signal into segments with short-time window and then apply the Fourier transform to each time segment to ascertain the frequencies that existed in that segment. The Wavelet transform (WT) is a favoured method to diagnosis bearing faults. One advantage of WT over the STFT is that it can achieve high frequency resolutions with sharper time resolutions (Tóth, Szilágyi, & Takács, 2018).

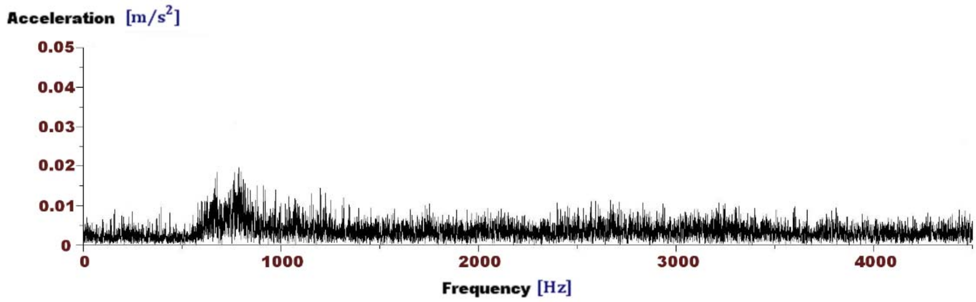

Figure 1. *Frequency spectrum of a ball bearing*

3. CONDITION MONITORING OF BEARINGS

It is advisable to estimate the residual life of a used bearing as result of a comparative experiment. In this case, the condition of the used bearing is compared with the condition of a specified number of journal bearings of the same type as the used bearing but subjected to specified operating conditions. Specified operating conditions can be achieved, for example, during a bearing fatigue test. In this case, a used bearing of the same type as the bearing to be tested is fatigued under predetermined conditions. The fatigue is continued until the nominal life determined from the specified conditions. A bearing test equipment is used to perform the bearing fatigue and measurement investigations. Figure 2 shows this equipment, which is located at University of Miskolc, Department of Machine Tools.
The above-mentioned bearing test device used to examine ball bearings (type: 6303). During the experiments, the vibration patterns measure from bearing using piezoelectric vibration accelerometer (Kistler 8632C). During bearing fatigue tests the left, fatigue shaft works at the given rotational speed, while the hydraulic cylinder exerts artificial load (6 kN) for the bearing. The fixed-term fatigue cycles on average 4 hours long. After the fixed-term fatigue cycles, the bearing is put over to the right, measuring axis. During the measurements the shaft works at the given rotational speed, while the hydraulic cylinder exerts artificial load (1 kN) for the examined bearing. 5 vibration samples and 16 384 element samples were taken within each

cycle. The spindles are driven by a Siemens frequency converter controlled electric motor. During fatigue tests and measurements always set on rotational speed 1500 min^{-1}, which corresponds to a frequency of 25 Hz. Consequently, the tested bearing has a lifetime of nearly 150 hours with described data. Typical failure frequencies of 6303 bearings are summarized in the Table 1, considering that the inner ring rotates.

Figure 2. *Bearing test rig in measurement position*

Table 1
Typical failure frequencies

Name	Abridgment	Value [Hz]
Inner ring frequency	BFSI	≈ 110,62
Outer ring frequency	BFSO	≈ 64,37
Rolling element frequency	BSF	≈ 44
Cage frequency	FTF	≈ 9,12

Fast Fourier transform was used to represent the recorded vibration patterns in spectrum form. The program code (see Figure 3) written in symbolic language, used both Maple and Matlab mathematical softwares.

$$with(Matlab)$$
$$a := readdata(\text{"1.txt"})$$
$$V := convert(a, list)$$
$$num := 16384$$
$$Time := \left[seq\left(\frac{1}{9600}(h), h = 1..num \right) \right]$$
$$ft := Matlab[fft](V)$$
$$setvar(\text{"FT"}, ft)$$
$$setvar(\text{"n"}, num)$$
$$evalM(\text{"result=FT.*conj(FT)/n"})$$
$$pwr := getvar(\text{"result"})$$
$$pwrlist := convert\left(\frac{pwr}{num}, list \right);$$
$$pwrlist1 := \left[seq\left(2 \cdot \sqrt{pwrlist_w}, w = 1..num \right) \right];$$
$$pwr\_points := \left[seq\left(\left[\frac{h-1}{Time_{num}}, pwrlist1_h \right], h = 1..\frac{num}{2} \right) \right]$$
$$plots[pointplot](pwr\_points, style = line, view = [0..4500, 0..0.05])$$

***Figure 3.** Program code for fast Fourier transform*

During the tests, more and more failure frequencies appear as time progresses, and their values increase exponentially. The largest changes were in the harmonics of error frequency of the cage and the outer ring. Figure 4 shows the evolution of failure frequencies of cage.

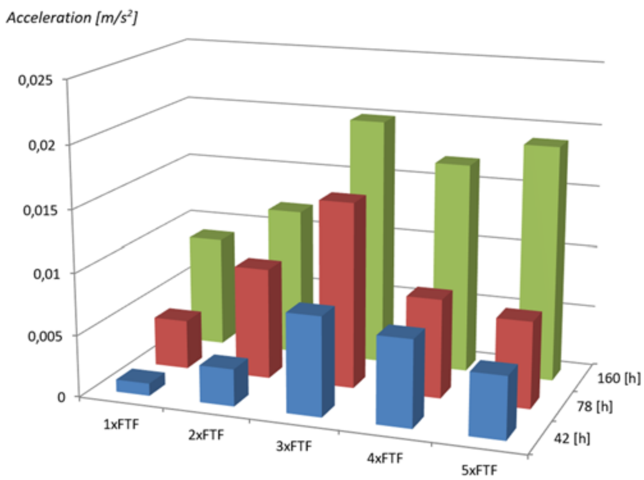

***Figure 4.** Evolution of failure frequency of cage*

At the limit of the previously calculated lifetime, the fault frequency peaks in the vibration spectrum have become clearly visible. Figure 5 shows the temporal evolution of the fault frequency harmonics of the outer ring.

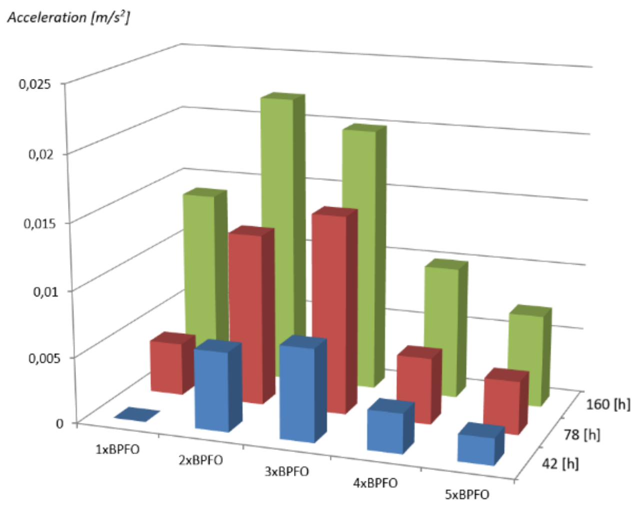

Figure 5. *Change of failure frequency of outer ring*

After the results of the frequency domain analysis indicated and the bearing noise increased, the bearing was taken apart to pieces. As predicted the frequency domain analysis after 161 fatigue hours the bearing indeed had a defect. The main reason of bearing failure was the failure of cage (see Figure 6).

Figure 6. *Failure of cage*

As expected from the results of the spectral analyses, it can be concluded that the main cause of the failure of the tested bearing is damage of the cage structure. The high load force certainly contributed to the development of the defect.

4. SUMMARY

Accurate and trustworthy measuring methods and devices are necessary for rotary and bearing condition monitoring. The investigation of vibration signals is an important technique for monitoring the condition of machine components. The present paper shows that the frequency domain techniques can be effectively used in condition monitoring and fault diagnosis of ball bearings. These methods are reliable tools, and they make fast data processing possible.

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