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LIFETIME ANALYSIS OF ROLLING ELEMENT BEARINGS

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Abstract: In several cases a rolling element bearing lifetime is under its intended limit. That may be caused by the insufficient lubrication, the higher loading (than the predefined value), the improper handling or something else. The following paper presents the vibrational analysis of a rolling element bearing.
Keywords: rolling element bearings, vibrational analysis, bearing failure frequencies.

1. Introduction

Rolling element bearings are one the most widely used machine parts and are critical to almost all forms of rotary machinery, such as machine tools, electric motors, generators, etc. Most defects of these machineries are deriving from the damage of the built-in rolling element bearings. Bearing failures may cause breakdown and might even lead to catastrophic failure or even human injuries [1]. In order to prevent unexpected bearing failures should be detected as early as possible.

When the appraisal of a rolling element bearing is performed by vibration analysis, many signal processing techniques can be considered. These methods can be performed within either the frequency or the time ranges. Perhaps the most commonly used process is the spectral analysis.

2. Bearing test machine

Rolling bearings condition monitoring can be accomplished with using test instrument. Such a device is located at University of Miskolc, Department of Machine Tools. This equipment is used to perform the bearing fatigue and measurement investigations. The main engineering parts of the bearing test device illustrated in Figure 1. During the bearing fatigue tests the 7F shaft works at the given rotational speed, while the 6 hydraulic cylinder exerts artificial load for the 4F bearing. After the fixed-term fatigue cycles, the bearing is put over to the 7M measuring axis. During the measurement investigations the 7M shaft works at the given rotational speed, while the 6 hydraulic cylinder exerts artificial load for the 4M bearing.

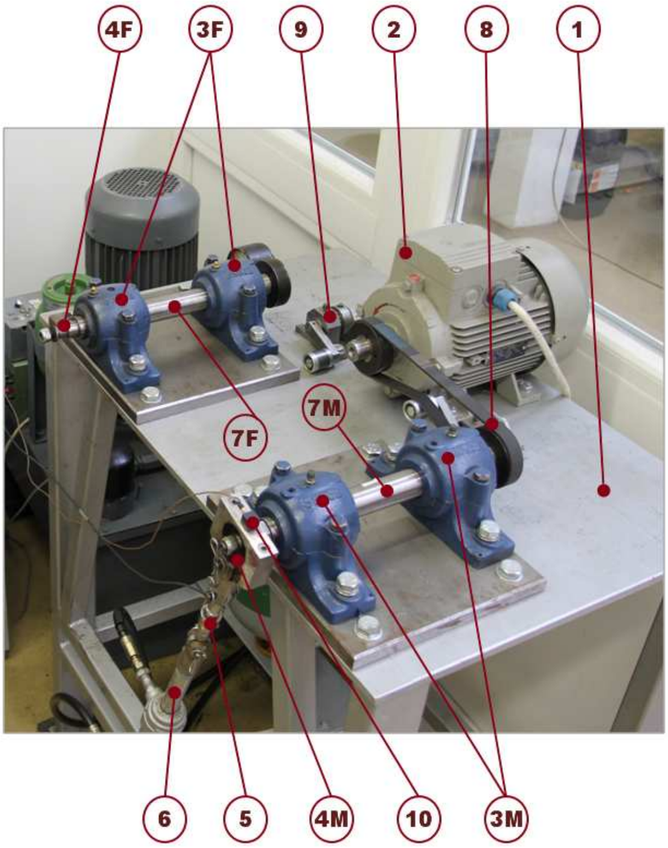

Figure 1: The main engineering parts of the bearing test device in measuring position

The individual symbols have the following meanings:

1	rigid table
2	three-phase motor
3F	supporting bearings of fatigue side
3M	special supporting plain bearings of measurement side
4F	fatigued bearing position
4M	measured bearing
5	load cell, the adjustment of hydraulic load
6	double-acting hydraulic cylinder
7F	fatigue test shaft
7M	measurement test shaft
8	length ribbed belt
9	belt tensioner
10	piezoelectric vibration accelerometer.

The measuring chain which used at vibration tests is shown in Figure 2.

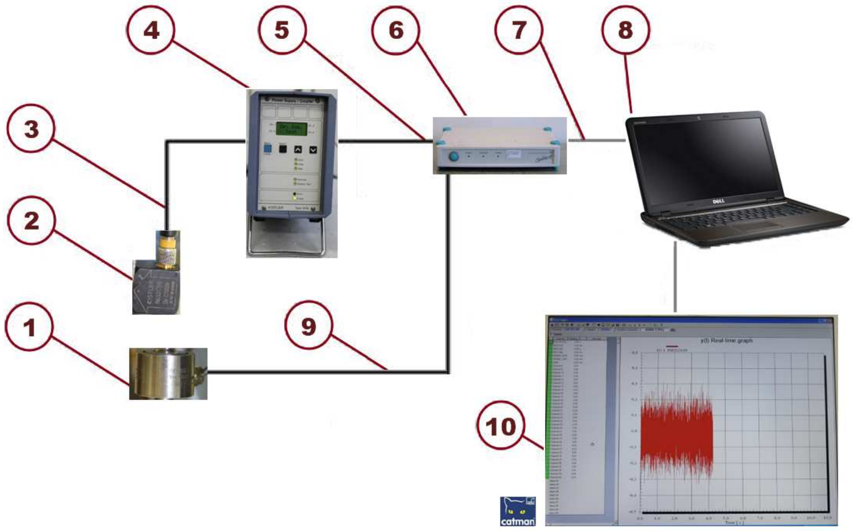

Figure 2: The measuring chain

The measuring chain elements are given in Table 1.

Table 1

The elements of the measuring chain

Code	Element of chain	Type
1	Load cell	HBM U9B
2	Piezoelectric vibration accelerometer	Kistler 8632C50
3	Connecting cable to the power supply coupler	176B cable
4	Power supply coupler	Kistler 5134
5	Connecting cable to the measuring amplifier	BNC-15PIN cable
6	Measuring amplifier	HBM Spider8
7	Connecting cable to the PC	USB cable
8	Visualization and analysis equipment	Dell Inspiron laptop
9	Connecting cable to the measuring amplifier	15PIN cable
10	Evaluation software	HBM Catman 4.0

3. The test bearing

The above-described bearing investigation device is used up to analyse an FAG 6303-2RSR, single row, deep groove ball bearing. The said bearing with some important dimensions are given in Figure 3, all the values are in mm.

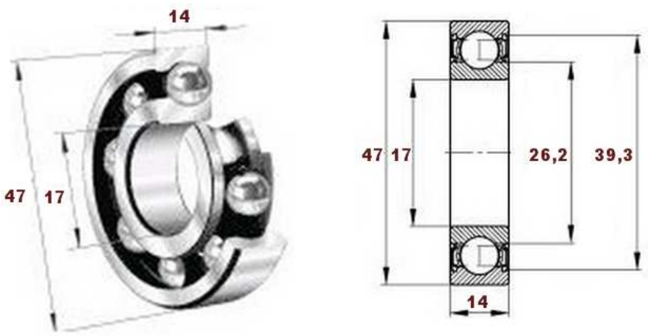

Figure 3: FAG 6303-2RSR ball bearing

Rolling bearing lifetime is finite, unfortunately one or more typical bearing failure sooner or later occurs. The finite life-time of rolling bearings may be associated with some factors, such as rotational speed, lubrication condition, load, and temperature. The length of time, until the first signs of material fatigue appear, depends on the magnitude of the load and bearing speed.

If the rotational speed is constant, the basic rating life can be expressed in operating hours, using the equation [4]:

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right)^p \tag{1}$$

where:

- L_{10h} basic bearing life in operating hours [h],
- n rotational speed [min^{-1}],
- C basic dynamic load [N],
- P equivalent dynamic bearing load [N],
- p life equation exponent (p = 3 for ball bearings).

During the experiments, the equivalent dynamic bearing load is 6000 N and always set on 1500 min^{-1} rotational speed. The 6303-2RSR ball bearing basic dynamic load is 14400 N [3].

Using these parameters, the bearing life is as follows:

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C}{P}\right) = \frac{10^6}{60 * 1500\left[\min^{-1}\right]} * \left(\frac{14400[N]}{6000[N]}\right)^3 = 153,6\,[h] \tag{2}$$

Accordingly, the examined FAG 6303-2RSR ball bearing – with the set values – will have circa 154 hours lifetime.

4. Bearing investigations with spectral analysis

Spectral analysis plays an important role in the detection and diagnosis of machine faults. We can use effectively in order to identify the location and the relative size of the bearing defects. Each bearing element has a characteristic rotational frequency. With a defect on a particular bearing element, an increase in vibrational energy at this element's rotational frequency may occur.

As we have already discussed the explorations concentrate on the 6303-2RSR ball bearing. The ball bearing frequencies [3] with the used settings are given in Table 2. The tested ball bearing's rotational frequency is 22,85 Hz [3].

Table 2

6303-2RSR ball bearing frequencies on 1500 min^{-1} rotational speed

Frequency name	**Abbreviation**	**Special abbreviation**	**Value [Hz]**	**Divided by the rotational frequency [–]**
Ball Pass Frequency of Inner ring	BPFI	I	101,1	4,425
Ball Spin Frequency	BSF	G	40,21	1,76
Fundamental Train Frequency	FTF	K	8,4	0,368
Ball Pass Frequency of Outer ring	BPFO	O	58,84	2,575

After the fixed-term fatigue cycles we take vibration specimens from the test bearing. Fast Fourier Transform is used to illustrate the recorded spectral specimens as spectrum. The program code, which runs in Maple software, is seen in Figure 4. The measurement cycles are always perform at 9600 Hz sampling frequency. We generally take five vibration samples and 16,384-element samples within each measurement cycle.

$$with\ (Matlab)$$

$$a := readdata(\text{“1.txt”})$$

$$V := convert\ (a, list)$$

$$num := 16384$$

$$Time := \left[seq\left(\frac{1}{9600}(h),\ h = 1..num \right) \right]$$

$$ft := Matlab\,[\,fft\,](V)$$

$$setvar\ (\text{“FT”},\ ft)$$

$$setvar\ (\text{“}n\text{”}\ num)$$

$$evalM(\text{“}result = \text{FT.} * \text{conj(FT)} / n\text{”})$$

$$pwr := getvar(\text{“result”})$$

$$pwrlist := convert\left(\frac{pwr}{num}, list\right);$$

$$pwrlist1 := \left[seq\left(2 \cdot \sqrt{pwrlist_w}, w = 1..num\right)\right]$$

$$pwr\_points := \left[seq\left(\left[\frac{h-1}{Time_{num}}, pwrlist1_h\right], h = 1..\frac{num}{2}\right)\right]$$

$$plots[pointplot](pwr\_points, style = line, view = [0..4500, 0..0.05])$$

Figure 4: The FFT program code in Maple software

Figure 5 shows the nature of vibrations after 23 operating hours. During this period, the bearing was running safely.

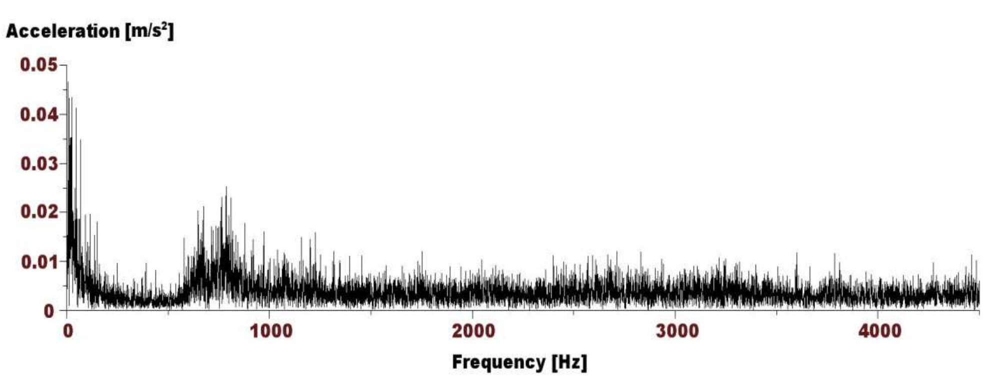

Figure 5: Vibrations spectrum at 23 operating hours

Figure 6 shows the nature of vibrations after 70 operating hours. It is conspicuous that the acceleration values have increased substantially at this bearing lifetime period.

Most of the typical machine errors belong to the rotation frequency or its integer multiples. A widespread method is to scale the frequency axis into rotational speed units. In this case, the horizontal spectrum frequency axis is divided by the bearing rotational frequency. Consequently dimensionless frequency value is received, where “1” corresponds to the rotational frequency. Some literature [2] also called this to order-number. The typical bearings failure frequencies linear depend on the rotational speed.

Some bearing frequencies appeared after 36 operating hours, which illustrated in Figure 7. The marking of the frequency codes are realized according to the abbreviations of Table 2.

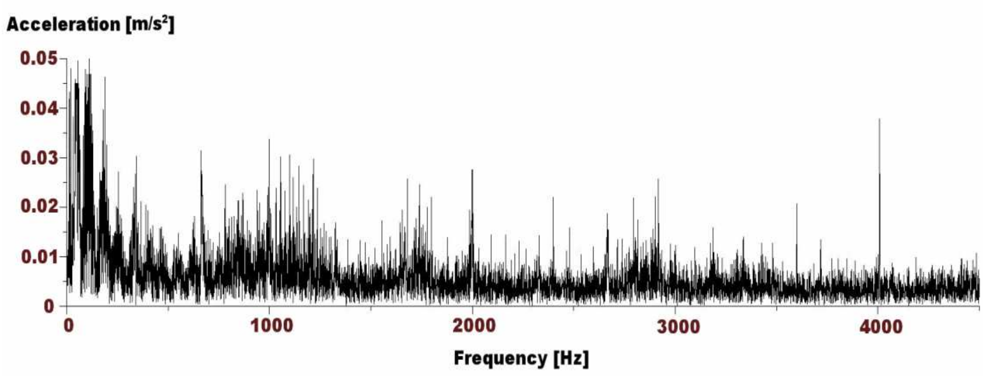

Figure 6: Vibrations spectrum at 70 operating hours

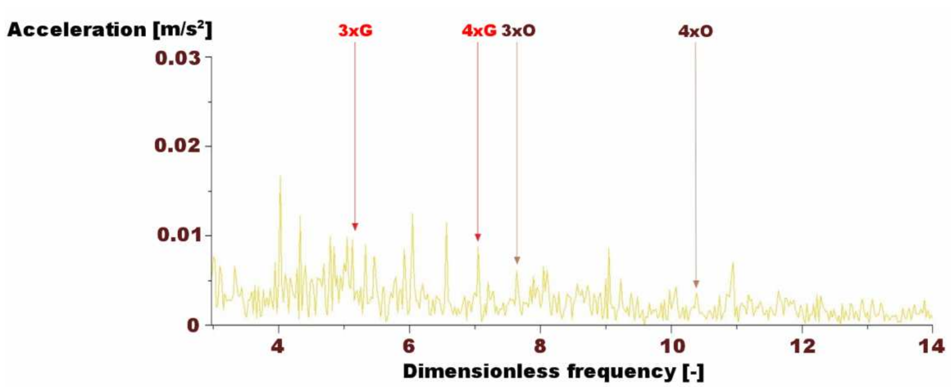

Figure 7: Vibrations spectrum with bearing failures at 36 operating hours

Figure 8 shows some bearing failures grew after 60 operating hours.

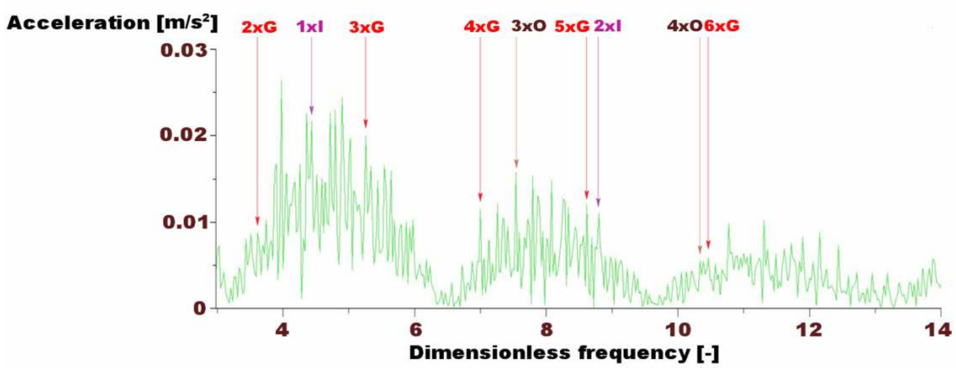

Figure 8: Vibrations spectrum with bearing failures at 60 operating hours

It is conspicuous that the passage of time the acceleration values grew materially. It is also apparent, that more and higher upper harmonic frequencies appeared as the time progressed.

The evaluation of the experiments, it was concluded that the Ball Spin Frequency and the Fundamental Train Frequency (frequency of the cage) give the most striking change. The following figures (Figure 9 and Figure 10) show the change of these frequencies and upper harmonic frequencies parallel with the operating hours.

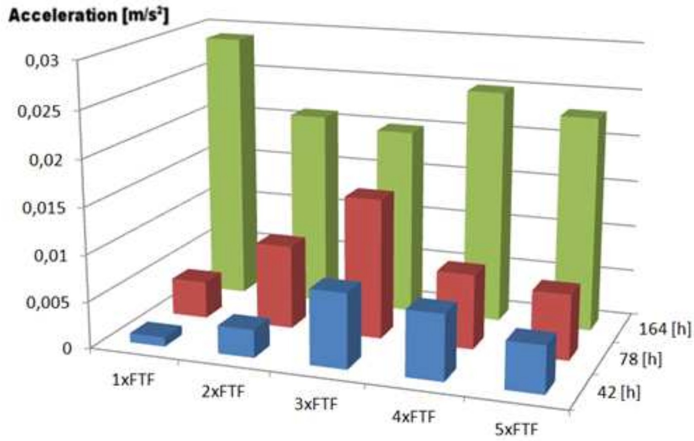

Figure 9: Cage frequency changes parallel the operating hours

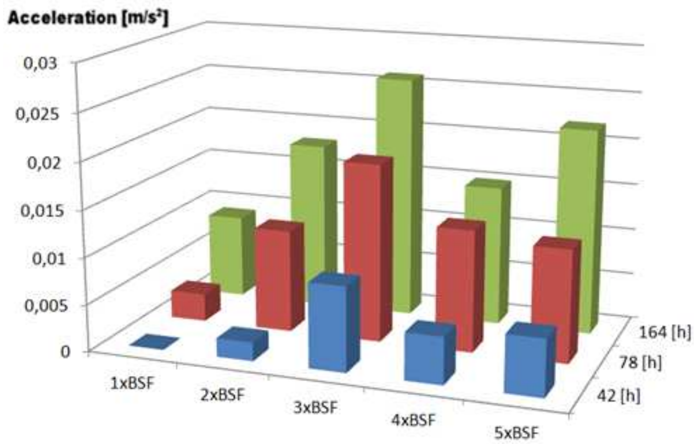

Figure 10: Ball Spin Frequency changes parallel the operating time

The bearing failure frequency peaks became well separable at the boundary of the basic bearing life.

5. Bearing damages

When the bearing noise had increased and the bearing had exceeded its nominal lifetime, the bearing was disassembled by cutting its outer ring and cage using professional angle grinder. The disassembled ball bearing – together with all elements of it – is given in Figure 11.

Figure 11: The disassembled ball bearing

As predicted the results of the spectral analysis so the bearing failure's main reasons were the damage of the cage structure and the rolling elements impairments. The broken cage structure is illustrated in Figure 12.

Figure 12. Cage structure defects

At the deterioration of the bearing, the ball rolling elements were not able to properly roll off on the inner and outer ring's surfaces. Many small damage trail visible on the rolling element (see Figure 13), so it is subjected to microscopic studies.

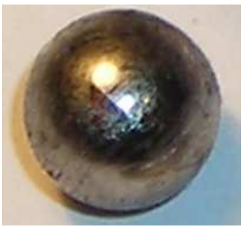

Figure 13: Damaged ball rolling element

Figure 14 shows the microscopic photo of the ball rolling element.

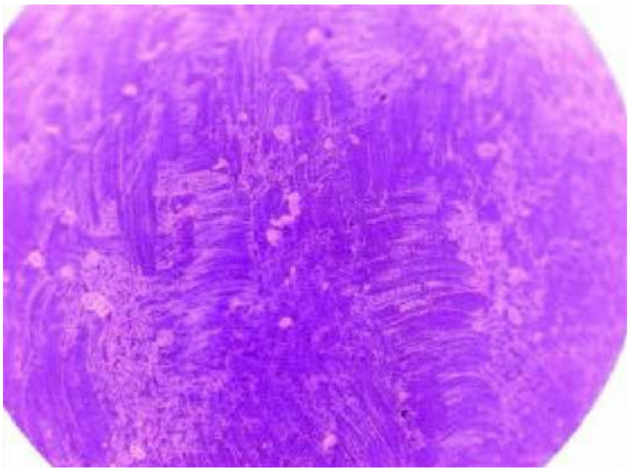

Figure 14: Ball rolling element defects (30 times magnification)

The microscopic photo clearly shows the tiny (10–55 µm) indentations, which probably caused by the metal particles, that came off from the bearing elements.

6. Conclusion

In the present paper, the authors analysed the lifecycle of an FAG 6303-2RSR single row, deep groove ball bearing. University of Miskolc, Department of Machine Tools has a bearing test device, which is used to perform the fatigue and the measurement investigations. After fatigue cycles the rolling bearing spectrum photos were presented and analyzed. When the bearing noise had increased and the bearing had exceeded its nominal lifetime, the bearing was disassembled to pieces. Having disclosed the failures of the bearing, we could realise the distraction anticipated by the previous measurements and also the efficiency of spectrum analysis.

Acknowledgement

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