Comparison of Rolling Bearings' Diagnosing Methods – Procedures of Damage Introduction

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Abstract

The rolling bearings' diagnosing methods used in exploitation diagnostics are not usually dedicated to the postproduction control. However, this does not mean, that they cannot be used there. A comprehensive comparison of the sensitivity of rolling bearings' diagnosing methods to occurrence of faults and damage should be based on measurements of new, undamaged bearings and bearings with defects. An accurate determination of the location, size and origin of defects is expected from a set of testing bearings. The paper presents a comparison of three methods of damage introduction: sandblasting, pickling and spark erosion. Procedures for introducing damage into bearing's races have been described. In addition, race's geometries and vibration signals generated by operating bearings were compared.

Keywords: tapered roller bearings, postproduction control, bearing faults, bearing damege

1. Introduction

The rolling bearings are one of the most common components within machinery and devices. Their failure can cause machine breakdown resulting in high economic and environment costs. Vibration signals generated by bearings have been widely studied over past years. Despite that, new condition monitoring techniques are still developed in order to increase trustworthiness of diagnostic and prognostic inference.

Currently, many methods, that have been developed over many years, are used in rolling bearings' diagnostics. These include broadband vibration measurement, spectral analysis of noise and vibrations, cyclostational analysis [1-4], wavelet analysis [5], measurement of acoustic emission [4, 6], measurement of kurtosis [2-4], crest factor [1, 7], Shock Pulse Method [1, 7-9], XSK [10], REBAM - Rolling Element Bearing Activity Monitor [11, 12], artificial neural networks [12, 14], methods based on energy indicators such as TKEO [15-18] or Empirical Mode Decomposition [19].

These methods have been successfully applied at various phases of technical degradation of the bearing, but they are used mainly in the stage of exploitation. At this stage an increase of vibration accelerations is associated with the bearing's wear and is observed along with the time of exploitation [1-4, 20]. However, none of previously mentioned methods is dedicated in the first place to postproduction diagnostics. At the last stage of production, during classification in categories of good / faulty, the broadband measurement of the root-mean-square value of vibration velocity v_{RMS} has been most useful so far [4, 21].

2. Introduction of damage

Three methods of introducing damage to the bearings were used and compared Tapered roller bearings type CBK 171/63174 (SKF) were selected to create a testing bearing set. The selection of tapered roller bearings was dictated by the possibility of their dismantling. A spot sandblaster, abrasive of 0.2 - 0.5 mm and an air compressor were used for sandblasting, which was carried out sequentially under pressure from 8 to 6 bar. The duration of one sequence was approx. 20-second-long. The surface of the outer ring that was not meant to be damaged was protected by an insulating tape. Spark erosion was introduced by hand using two autotransformers (230V/50V, 50V/12V) and a copper wire erode. Already at the early stage, it was possible to state that the intensity of damage caused by spark erosion is random. Below in the figure 1 there are pictures of outer races of damaged bearings in magnification.

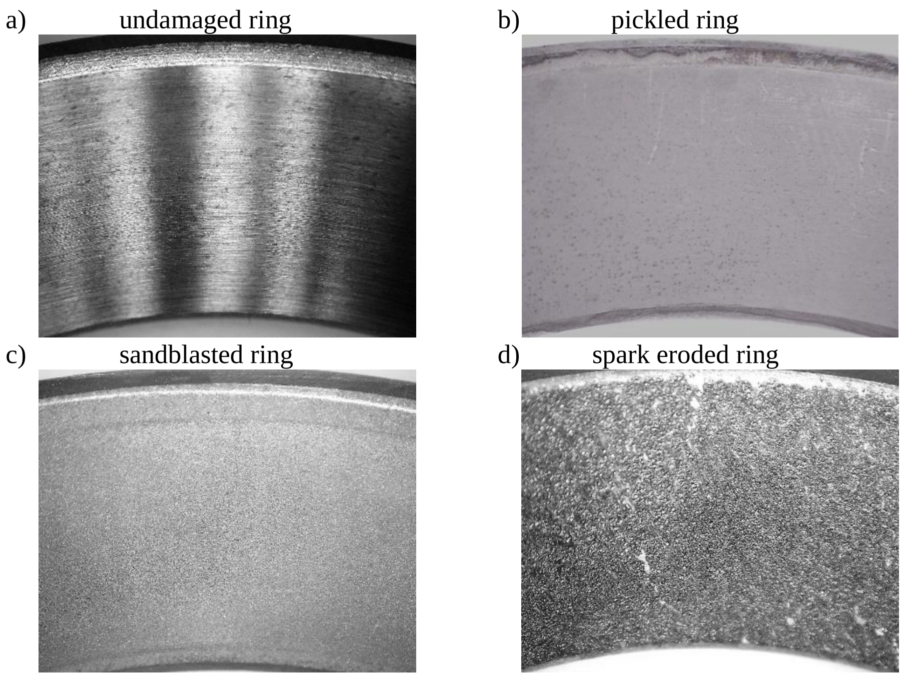

Figure 1. Outer races of the set of testing bearings, magnified view

Among methods of the surface treatment, pickling is the most appropriate, from the point of view of evenness and repeatability of damage introduction (in the micro scale) [22]. Prior to pickling, the bearings were degreased by inserting into an ultrasonic bath with acetone (POCH Avantor, Poland) for 10 min. The outer surface of the rings was protected by covering it with molten stearin. For pickling of the race, concentrated 36% hydrochloric acid (POCH Avantor, Poland) was used in a 1:1 dilution (v/v) with distilled water. The process was carried out by immersing the bearings in acid solution at 22 ± 1 °C for two hours. At the end of digestion, the bearings were washed with distilled water and the stearin layer was removed from the protected fragments.

Figure 2. Rollers of dismantled CBK 171 tapered bearing treated with acids

The choice of hydrochloric acid was dictated by the most desirable properties of the digested surface [23], which remained homogeneous without the formation of uneven layers of iron compounds observed during digestion with solutions of nitric, sulfuric and phosphoric acids. Figure 2 presents a view of the pickled rollers to show how large the loss of material can be with the use of various acids. In the picture from the left there is an intact roller, a roller pickled with nitric acid and a roller pickled with sulfuric acid. It is easy to notice the loss of material and change in the dimensions of the pickled rolls.

3. Comparison of geometries

Before testing, the outer races were parameterized on a coordinate measuring machine. The roundness and the roughness deviations (Table 2) were measured with specialized instrument Hommel-Etamic roundscan 535. The machine was equipped with Turbo Form software for the analysis of shape errors by the contact method. In this case, the measurements of the roundness deviation were carried out by a non-floating method.

Four rings were used in the research. The results of tests carried out on the undamaged ring were presented in the form of a polar diagram of roundness deviation in the Figure 3a. The triangular shape and the roundness total *RONt* = 16 µm were obtained. Figure 4a shows the roughness profile. The arithmetic mean deviation of the roughness profile *Ra* was equal to 3.85 µm. The introduced damage caused changes in the values of both roundness roughness deviations. Measured profiles are shown in Figures 3 and 4.

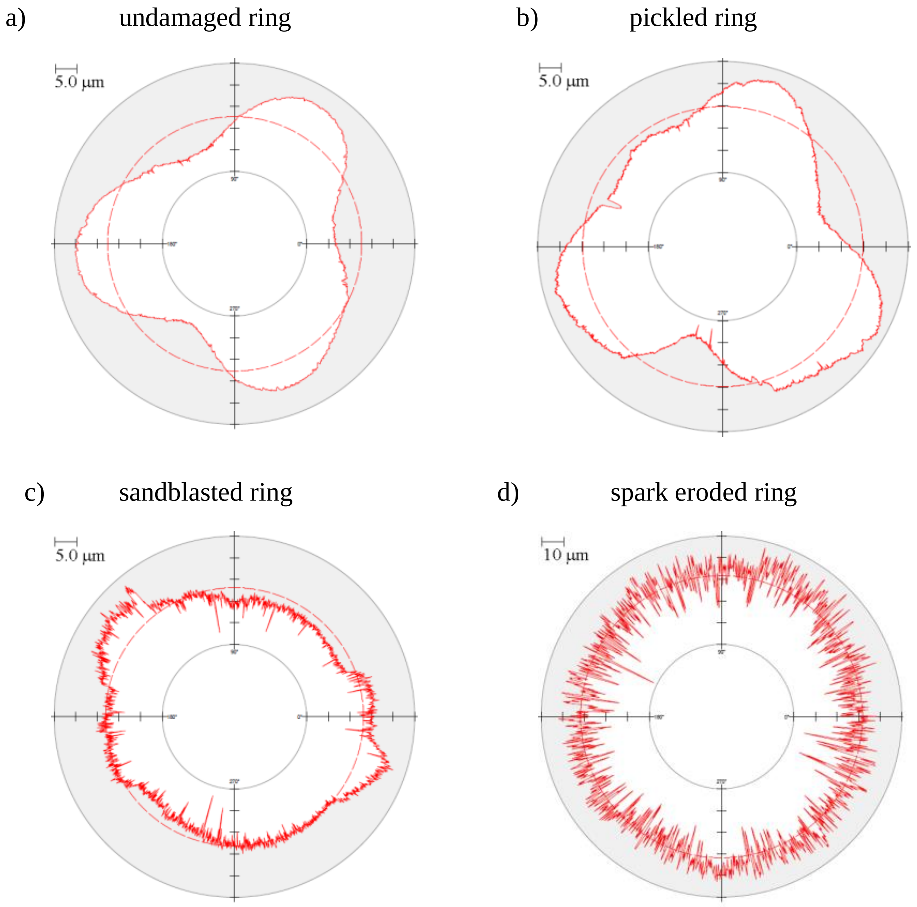

Figure 3. The roundness profiles of outer races of testing bearings

Although pickling caused an increase in deviations, the triangular shape is still visible (Fig. 3b). In this case, *RONt* increased to 21.42 µm (Fig. 3b), and *Ra* increased to 8.04 µm (Fig. 4b). After sandblasting the roundness profile was distorted. Spark erosion also caused a change in the shape of the bearing's race. In the case of sandblasting, the *RONt* increased to 20.50 µm, *Ra* increased too to 15.87 µm (Fig. 4c). In the case of spark erosion the largest changes were obtained in relation to the original values and they were respectively *RONt* = 40.12 µm and *Ra* = 50.34 µm (Fig. 4d). The introduced changes simulating the damage caused an increase in the values of roundness total by 27%, 22% and 138% respectively, while the roughness deviation value increased by 108%, 312% and as much as 1207%.

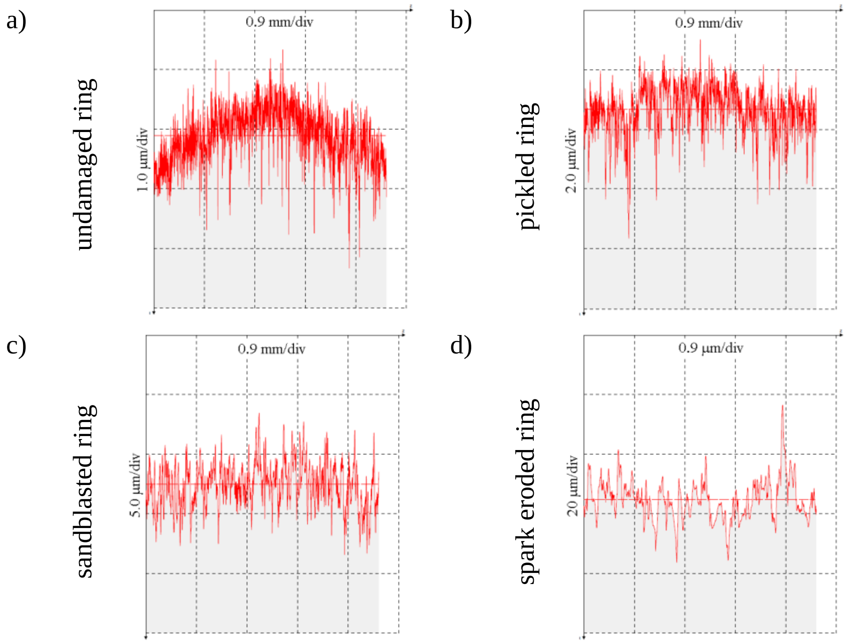

Figure 4. The roughness profiles of outer races of testing bearings

4. Vibration measurements

Prior to the tests, the bearings were carefully prepared in accordance with the previously developed procedure [24]. The bearings were cleaned (duration 3 min) in an ultrasonic cleaner filled with kerosene and then rinsed in petroleum ether. Before each test the cleaning procedure was repeated twice.

The acquisition of vibration signals was made on a test stand that enabled conducting Experiments have been performed with specified operating parameters such as: radial load equal to 15 N, axial load equal to 55 N and rotation speed of inner ring equal to 1450 rpm. The measurements and analyses of vibrations generated by bearings were performed for three damaged in various ways bearings and for an undamaged reference bearing. The bearings were lubricated with ISO VG 32 oil (0.25 ml of oil was injected with a syringe). Before the beginning of each test the shaft was turned by hand several times to distribute the lubricant.

The vibration accelerations were linearly recorded (up to 50 kHz). Signal sequences (120-second long) have been acquired. The ICP ® M352A60 (PCB) accelerometer was used for vibrations measurements. The acquisition module VibDAQ 4+ was used for the analogue-digital conversion of vibration and tachometer[2] signals. Digital signal processing was performed using a dedicated application elaborated in DASYLab software.

[2] The tachometer signal has been acquired to check the rotation speed of the bearing.

Figure 5a shows the temporal waveforms of the instantaneous root-mean-square values of vibration accelerations a_{IRMS}, in addition the maximum $\hat{a}_{\mathrm{IRMS}}$ and the minimum $\check{a}_{\mathrm{IRMS}}$ instantaneous root-mean-square values of vibration accelerations in the comparison to the root-mean-square value of vibration accelerations a_{RMS} in the form of a column chart are shown beside (Fig. 5b).

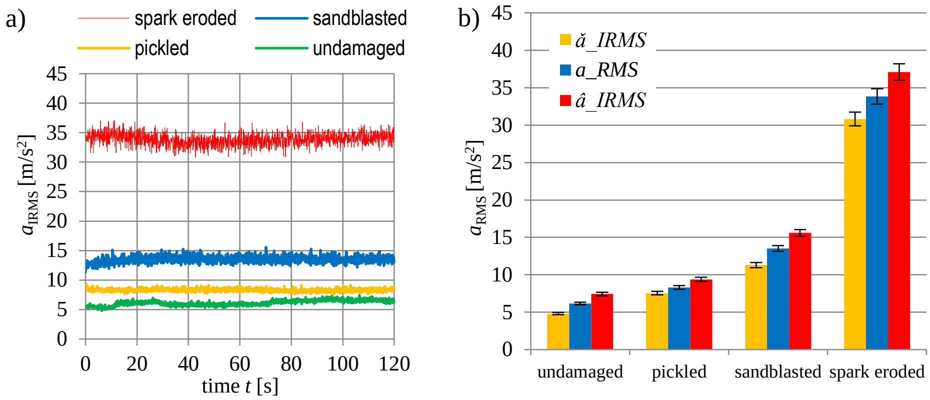

Figure 5. The instantaneous root-mean-square values of vibration accelerations a_{IRMS}; a) temporal waveforms of a_{IRMS}; b) a_{RMS} in the comparison to the maximum and the minimum a_{IRMS}

The bearing vibration values depend on race damage [4]. The relationship between a_{RMS} and the deviation Ra is shown below in the Figure 6.

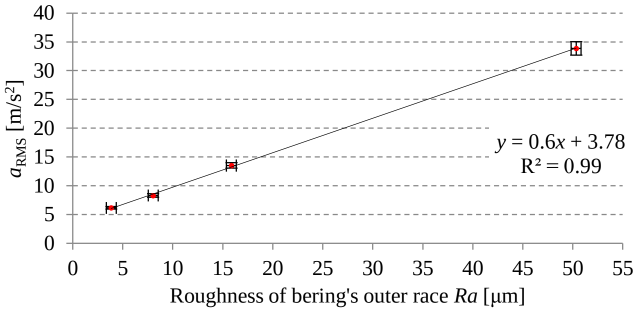

Figure 6. The root-mean-square value of vibration accelerations a_{RMS} in relation to the arithmetic mean deviation of the roughness profile Ra of bearing's outer race

The relationship between bearing vibrations and roughness of the race, which in this case simulates bearing wear, has been expected to be an increasing function. However, such a high coefficient of determination $R^2 = 0.9997$ has not been expected. The regression of relation between a_{RMS} and Ra is defined by the following equation:

$$y = 0.6x + 3.78. \tag{1}$$

None the less the number of points on the graph is small, therefore, the statement that this relationship is linear is uncertain and requires further tests.

5. Summary

The tests carried out allowed to formulate the following conclusions. Bearing vibrations depend on the roughness of the race and this relationship is likely to be linear and increasing. For the purpose of creating the set of bearings and comparing the methods of bearing diagnosing for postproduction control three methods of introducing damage were tested. Spark erosion introduces too severe changes in the profiles of the race and they have too much random nature to be taken into further account. However, sandblasting and pickling proved to be much better in this matter. The introduced changes in deviations of roughness and roundness total can successfully simulate production defects. Pickling is a way of introducing damage which intensity depends on the time of process and is therefore controllable. The same as in the case of spark erosion, sandblasting introduces random damage. But their intensity also depends partly on time. Therefore, pickled bearings will be used for further tests.

Acknowledgment

The results presented are results of the research that was funded with grant 02/21/DSMK/3501 for education allocated by the Ministry of Science and Higher Education of the Republic of Poland.

References

1. S. Radkowski, *Diagnozowanie Łożysk Tocznych* in *Inżynieria Diagnostyki Maszyn* Ed. B. Żółtowski, C. Cempel, Polskie Towarzystwo Diagnostyki Technicznej Instytut Technologii Eksploatacji – PIB, Radom 2004, 529 – 544.
2. R. B. Randall, J. Antoni, *Rolling element bearing diagnostics—A tutorial*, Mechanical Systems and Signal Processing, **25** (2010) 485 – 520.
3. R. B. Randal, *Vibration-based Condition Monitoring: Industrial, Aerospace and Automotive Applications*, Wiley, New Delhi 2011, 200 – 202.
4. C. Cempel, *Podstawy wibroakustycznej diagnostyki maszyn*, Wydawnictwo Naukowo Techniczne, Warszawa 1982, 156 – 177.
5. B. T. Holm-Hansen, R. X. Gao, L. Zhang, *Customized Wavelet for Bearing Defect Detection*, Transactions of the ASME, **126** (2004) 740 – 745.
6. N. Tandon, A. Choudhury, *A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings*, Tribology International, **32** (1999) 469 – 480.
7. T. Williams, X, Ribadeneira, S. Billington et al., *Rolling Element Bearing Diagnostics In Run-To-Failure Lifetime Testing*, Mechanical Systems and Signal Processing, **15** (2001) 979 – 993.
8. D. E. Butler, *The Shock-pulse method for the detection of damaged rolling bearings*, Non-Destructive Testing, **6** (1973) 92 – 95.

9. G. Allenby, *Condition based maintenance* in *Condition Monitoring and Diagnostic Engineering Management* Ed. R. Rao, Chapman and Hall, Padstow 1990, 155 – 161.
10. F. Xi, Q. Qiao Sun, G. Krishnappa, *Bearing Diagnostics Based on Pattern Recognition of Statistical Parameters,* Journal of Vibration and Control, **6** (2000) 375 – 392.
11. R. G. Harker, J. S. Hansen, *Rolling element bearing monitoring using high gain eddy current transducers*, Journal of Engineering for Gas Turbines, **107** (1985) 160 – 164.
12. D. E. Bently, P. Goldman, J. J. Yu, *Rolling Element Bearing Defect Detection and Diagnostics Using REBAM Probes*, Orbit 2001, 12 – 25.
13. B. Li, M. Y. Chow, Y. Tipsuwan et al. *Neural-Network-Based Motor Rolling Bearing Fault Diagnosis*, IEEE Transactions On Industrial Electronics, **47** (2000) 1060 – 1068.
14. I. E. Alguindigue, A. Loskiewicz-Buczak, R. E. Uhrig, *Monitoring and Diagnosis of Rolling Element Bearings Using Artificial Neural Networks*, IEEE Transactions On Industrial Electronics, **40** (1993) 209 – 217.
15. A. Gałęzia, R. Barczewski, B. Jakubek, *Possibilities of faults detection of rolling bearings using energetic descriptors of vibrations signals*, Advances in Condition Monitoring of Machinery in Non-Stationary Operations: Proceedings of the 5th International Conference on Condition Monitoring of Machinery in Non-stationary Operations, Springer, 2018, 329 – 328.
16. M. Liang, B. I. Soltani, *An energy operator approach to joint application of amplitude and frequency-demodulation for bearing fault detection*, Mechanical Systems and Signal Processing, **24** (2010) 1473 – 1494.
17. R. P. Henríquez, J. B. Alonso, M. A. Ferrer, et al. *Application of the Teager-Kaiser energy operator in bearing fault diagnosis*. ISA Transactions, **52** (2013) 278 – 284.
18. I. Antoniadou, T. P. Howard, R. S. Dwyer-Joyce, et al. *Envelope Analysis Using the Teager-Kaiser Energy Operator for Condition Monitoring of a Wind Turbine Bearing*, Applied Mechanics and Materials, **564** (2014) 170 – 175.
19. J. Dybała, R. Zimroz, *Rolling bearing diagnosing method based on Empirical Mode Decomposition of machine vibration signal*, Applied Acoustics, **77** (2014) 195 – 203.
20. H. Madej, Z. Stanik, J. Warczek, *The vibroacoustic methods and their application in the diagnostics of the combustion engines's roller-bearing fittings,* Journal of KONES Powertrain and Transport, **17** (2010) 293 – 297.
21. ISO 15242-1(2015) Rolling bearings – Measuring methods for vibration – Part 1: Fundamentals.
22. T. Burakowski, T. Wierzchoń, *Inżynieria powierzchni metali*, Wydawnictwo Naukowo Techniczne, Warszawa 1995, 68 – 70.
23. N. N. Greenwood, A. Earnshaw, *Chemistry of the Elements*, Butterworth-Heinemann, 1997, 946 – 948.
24. B. Jakubek, R. Barczewski, M. Jakubowicz, *The influence of the lubrication on the vibroacoustic signal generated by rolling bearings*, Journal of Vibrations in Physical Systems, **28** (2017) 1 – 9.