Comparison of Selected Point Estimators of Vibration Signals for Purposes of Fault Detection in Rolling Bearings

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Abstract

Most of machine breakdowns relate to bearing failures thus it is very important to diagnose bearing conditions. The main purpose of the study was to classify the condition of bearings and identify defective ones based on visual inspection and the values of classic parameters of the acceleration signal vibration, such as Peak, RMS, Kurtosis. The results were compared to parameters provided by the SPM method. All vibration parameters were estimated for high pass filtered signals where filters had following cut-off frequencies 0.5; 1, 2, 5 and 8 kHz. Bearings were tested on the laboratory test bench being built at the Silesian University of Technology. Based on the signal analysis and visual inspections it can be stated that there is agreement in the assessment of the conditions between the parameters of the SPM method and the Peak and RMS parameters. It was observed that the sensitivity to the existence of low-intensity defects increases when the vibration parameters are determined for signals in the band above 2kHz.

Keywords: vibration, analysis, bearings, defects, diagnosis

1. Introduction

Rolling bearings are used in almost every type of rotating machinery. Most of machine breakdowns relate to bearing failures thus it is very important to diagnose bearing conditions and predict moment of failure occurrence [3]. Many bearings fail prematurely due to contamination, poor lubrication, misalignment, temperature extremes, poor fitting/fits, shaft unbalance and misalignment. All these factors lead to an increase in bearing vibration therefore, in diagnosing the condition of rolling bearings, measurements and analysis of vibration signals are most often used [4]. Current bearing fault detection methods can be classified into time-domain and frequency-domain groups [2]. Frequency domain or spectral analysis methods are very effective in diagnosing bearing failures but require qualified and experienced personnel [2]. Time-domain techniques are mainly based on the determination of simple numerical parameters like RMS, Peak, Kurtosis, Skewness or Crest Factor which are very useful for trend building and analysis. The simple diagnostic parameters are used in many smart vibration sensors appearing in the market due to popularity of Industry 4.0 concept [5]. The main goal of the presented research was to assess the usefulness of simple vibration parameters for effective assessment of rolling bearings condition. Bearings were tested on the laboratory test bench being built at the Silesian University of Technology. Bearing condition assessment was made based on simple parameters determined for vibration signals in various frequency bands and with use of SPM (Shock-Pulse Method) implemented in commercial measurement device.

Results were compared and discussed in order to indicate most reliable method for bearing faults detection purposes.

2. Investigated bearings and testing procedure

There are many theoretical and practical studies on the rolling bearings fault detection with use of vibration signal analysis. Most of the research are based on the vibration signals acquired from prepared artificially defective bearing and compare it with the new bearings. Another more time-consuming approach is to perform the run to failure tests and monitor bearing condition until bearing failure occurs [1]. The research carried out by the authors was based on a different approach. A set of 209 used type 6303 bearings dismantled from car alternators of various and unknown condition was used for the research purposes. Tested bearings came from various manufacturers and were selected randomly. According to that an assumption was made that selected set of bearings is statistical representation of the population.

Testing and vibration measurement of bearing was performed on a dedicated test bench, designed and manufactured in the Department of Fundamentals of Machinery Design. Vibration signals were acquired and processed simultaneously by two measurements setups (Fig. 1). The first one was consisted in an accelerometer (SLC144TB-MB) connected to SPM Intellinova device that delivers advanced vibration analysis and shock pulse (SPM) monitoring algorithms. Accelerometer measurement range and sensitivity was 2 Hz-10 000 Hz and 100 mV/g respectively. The second measurement setup used raw sensor signal from auxiliary output of SPM Intelinova device. Signal was acquired by NI data acquisition card NI-USB-4432 connected to the PC and controlled by software developed in NI LabView environment. Whole test procedure was controlled by the Siemens S7-1200 industrial PLC.

The testing procedure was as follows. Tested bearing was mounted on the test bench shaft. Then it was blocked by the specially designed holder, mounted on the rod of the horizontal electric actuator. Accelerometer was mounted on a platform moved in vertical plane, which assure proper contact between sensor and bearing outer ring. Measurement was made in four angular positions of bearing (offset 90 degrees) In each position the speed of shaft was 3000 rpm, and time of measurement was 10 s (Fig. 2).

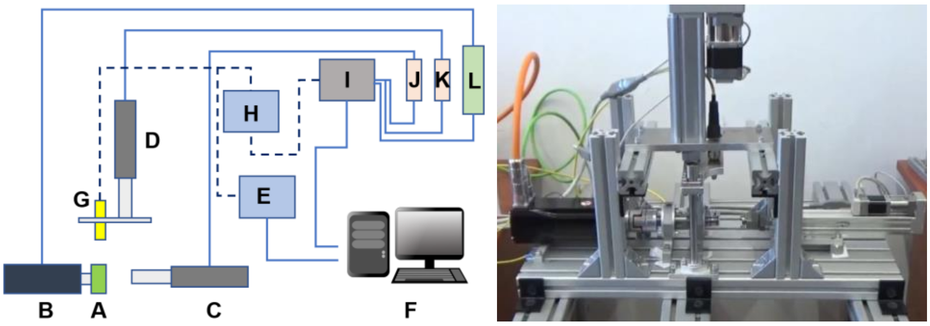

Figure 1. Test bench scheme. A – bearing, B – servo drive, C,D – linear actuators, E – NI Signal analyser, F – PC, G – Accelerometer, H – SPM vibration analyser, I – PCL, J,K – actuators controllers, L – servo drive controller

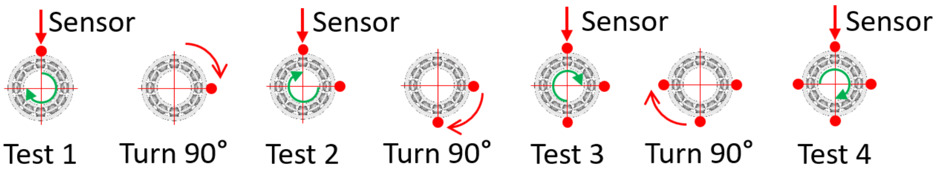

Figure 2. Idea of bearing testing

2.1. Signal processing and considered signal estimators

During the test vibration signal from the sensor was processed and vibration parameters according to scheme presented in fig. 3 were estimated. Peak, RMS and Kurtosis parameters were calculated for acceleration signal after filtration with use of high pass filters with following cut-off frequencies: 0.5kHz; 1kHz; 2kHz; 5kHz; 8kHz. Results of measurements were pre-processed for further analysis. Vibration parameters estimated for 4th measurement taken for each bearing were averaged and value of standard deviation was also estimated.

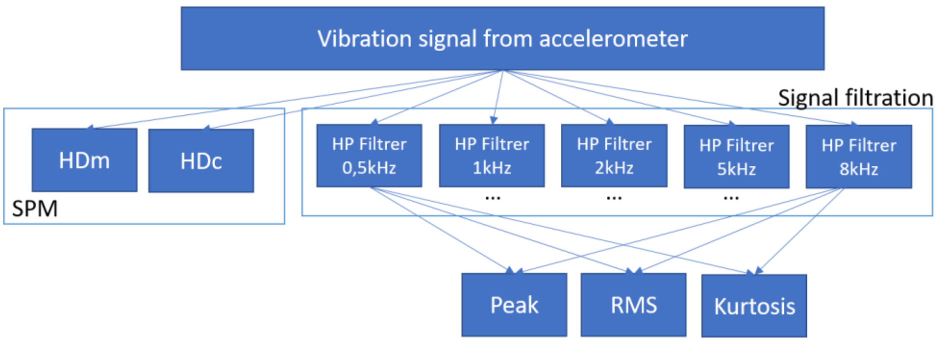

Figure 3. Schema of vibration signal processing and analysis

2.2 Bearing selection for further investigation

The first step of the research was assessment of the bearings condition and selection of bearings for its visual inspection. Aim of visual inspection was confirmation of the bearings condition identified based on vibration parameters. The parameter values ordered from the lowest to the highest value were used to bearings selection. Based on these ordered values, the condition of the bearings was divided into three classes: bearings in good condition, bearings in satisfactory condition and bearings in poor condition. The division was made in the same way for all vibration parameters, if bearings from the first quartile are in good condition than bearings from the last quartile are in poor condition. Bearings from the other two quartiles represented a satisfactory condition. Exemplary plot of mean values of Peak amplitude and kurtosis of acceleration signal with indicated standard deviation is presented in figure 4 and 5 respectively. In the figure 4 indicated considered classes. For the selection of a representative group of bearings, each tested bearing was assigned a rank depending on the bearing's belonging to a given class. The rank of bearings in good condition was 0, the bearings in satisfactory condition got rank 1 and the bearings in poor condition rank 2. A representative group of bearings was selected from those which received the same rank for each of the considered vibration parameters. Finally a group of 24 bearings for further investigation have been selected.

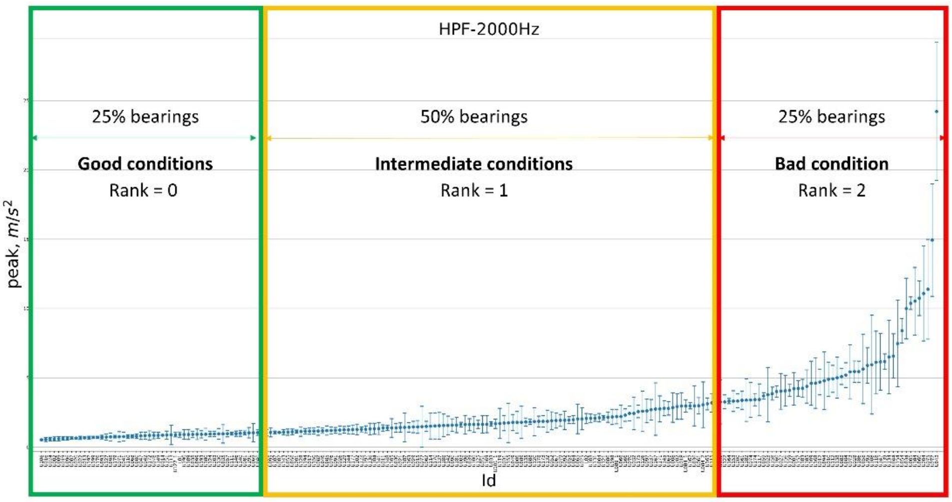

Figure 4. Plot of mean values and standard deviations of Peak amplitude and idea of assessment of bearing conditions

Analysing standard deviation values one can see that increasing proportional to mean value of a vibration parameter. It is clearly visible in fig. 5 for kurtosis values.

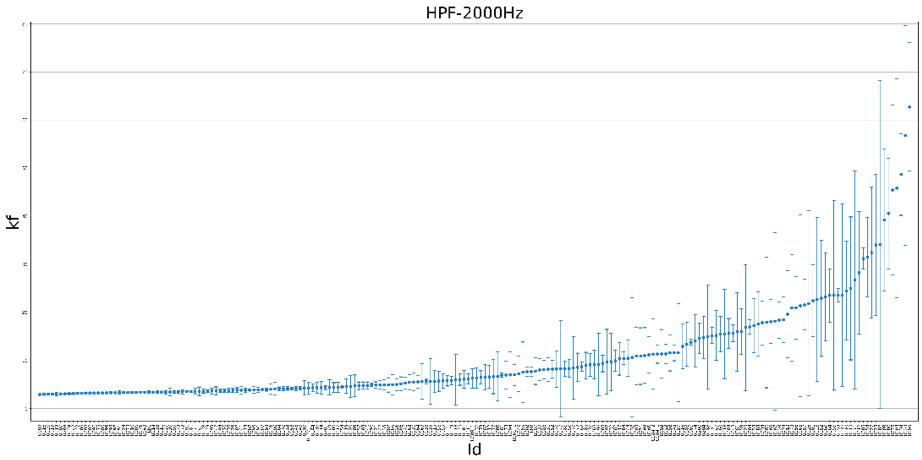

Figure 5. Plot of mean values and standard deviations of Kurtosis estimated for signal filtered with use high pass filter 2000 Hz

3. Visual investigation of bearings condition

Selected bearings was dismantled to assess their condition. All bearing elements were cleaned with use of solvent and visually inspected. During inspection signs of such defects like pitting, wear, overheating, cracks and other were looking for. Any defects were photographed and described. In the table 1 summary of visual investigation results were presented. Figure 6 presents selected defects discovered during inspections. On the basis of inspection results bearings general condition were quantified with use of the same rank range like in case of assessment of vibration parameters.

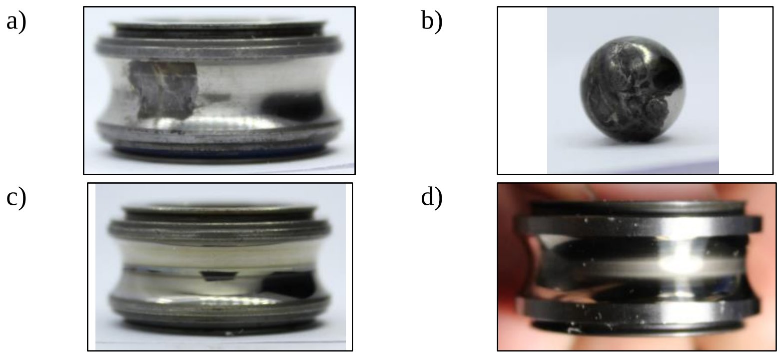

Figure 6. Images of observed defect of selected bearing
a) Most degraded bearing U043, b) Ball pitting in bearing U043
c) discolouring of inner race U028, d) wear of inner race in bearing U149

Table 1. Summary of bearing visual investigations

Bearing Id	Outer ring	Inner ring	Balls	Cage	General condition
L01	OK	OK	OK	OK	1
L02	OK	OK	OK	OK	0
U002	OK	dicolouring	OK	OK	1
U022	wear	OK	OK	OK	0
U028	abrasion	dicolouring	OK	OK	1
U029	OK	OK	OK	OK	0
U033	Dicolouring	dicolouring	pitting	OK	1
U043	pitting	pitting	pitting	OK	2
U070	OK	dicolouring	OK	OK	1
U071	OK	OK	OK	OK	0
U072	pitting	OK	OK	OK	2
U075	abrasion	abrasion	abrasion	OK	1
U084_2	scratches	OK	OK	OK	1
U112	OK	abrasion	OK	OK	1
U119	OK	OK	OK	OK	0
U142	OK	OK	OK	OK	0
U149	Wear	abrasion	abrasion	OK	1
U154	OK	Wear	OK	OK	1
U180	OK	OK	OK	OK	0
U183	OK	abrasion	OK	OK	1
U184	Multiple imprints	Multiple imprints	Multiple imprints	OK	2
U185	OK	OK	OK	OK	0
U195	OK	Dicolouring	OK	OK	1
U204	Multiple imprints	Multiple imprints	OK	OK	2

4. Analysis of vibration measurements

The main purpose of the study was to classify the condition of bearings and identify defective ones based on the values of classic parameters of the acceleration signal vibration, such as Peak, RMS, Kurtosis. The results were compared with the condition assessment based on the parameters provided by the SPM method. All vibration parameters were estimated for high pass filtered signals where filters had following cut-off frequencies 0.5; 1, 2, 5 and 8 kHz. Aim of a signal filtering was to find optimal frequency band for which vibration parameters will allow to clearly assess the overall condition of the bearing. It is worth mention that in the case of industrial bearing inspections it is important to detect damage and its severity. Exact location of the place of damage is not considered as important. Assessment of bearings condition for each filtered signal and each parameter was performed based on ranks assigned in the way described previously. Based on the ranks a maps of bearing conditions were created. Exemplary map for Peak value is presented in Fig. 7. The condition maps were the basis for determination of the general condition of each bearing as an average value of the ranks for different filter cut-off frequencies. In the Table 2 presented the results of the general condition assessment of the considered bearings. The table also allows to compare vibration parameters with the results of visual analysis.

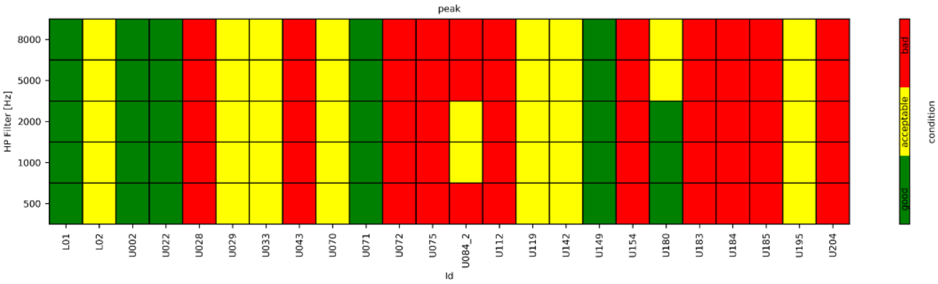

Figure. 7. Exemplary map of bearing conditions evaluated on the basis peak amplitude for different filter cut-off frequency.

Table 2. Comparison of general conditions of considered bearings based on averaged rank values. 0 – good condition; 1- acceptable condition; 2 – bad condition

Id	Basic estimators ranks			SPM parameters ranks		Visual inspection
	Peak	RMS	Kurtosis	HDm	HDc	
L01	0	1	0	1	1	1
L02	1	1	1	1	1	0
U002	0	0	0,2	0	0	1
U022	0	0	0	0	0	0
U028	2	2	2	2	2	1
U029	1	1	1	1	1	0
U033	1	1	1	1	1	1

U043	2	2	1,8	2	2	2
U070	1	1,2	1	1	1	1
U071	0	0,2	0,6	1	1	0
U072	2	2	1,2	2	2	2
U075	2	2	2	1	2	1
U084_2	1,6	2	1	2	2	1
U112	2	2	1	2	2	1
U119	1	1	0,8	1	1	0
U142	1	0,6	1	1	1	0
U149	0	0	1	0	0	1
U154	2	2	2	2	1	1
U180	0,4	0,2	0,8	1	1	0
U183	2	1,6	2	2	2	1
U184	2	2	2	2	2	2
U185	2	2	1,4	2	2	0
U195	1	1	2	2	0	1
U204	2	2	1,4	2	2	2

5. Conclusions

Based on the analysis of the test results, it can be stated that in the case of bearings for which visual inspection have shown the existence of defects, there is agreement in the assessment of the conditions between the parameters of the SPM method and the Peak and RMS parameters. Equivocal results were obtained for Kurtosis, which is not sensitive to such defects as uniform bearing wear or extensive fatigue damage (pitting). It was observed that the sensitivity to the existence of low-intensity defects increases when the vibration parameters are determined for signals in the band above 2kHz. Parameter which the best reflects the condition of bearings in the context of both mechanical damage and wear is a peak value of acceleration signal determined in a frequency band above 2000 Hz. The highest peak values indicates the worst bearing condition. One of the interesting indicator of bearing condition could be standard deviation of vibration parameter which increase according to degradation of bearing condition. Such trend observed in case of the all diagnostic parameters considered during the investigations.

For some bearings, the vibration parameters indicate their poor condition despite the fact that visual tests showed no visible mechanical damage. This effect may be caused by insufficient lubrication conditions. To confirm this thesis additional research regarding to evaluation of bearing grease conditions are required.

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