A PRELIMINARY ESTIMATION OF ANALYSIS METHODS OF VIBRATION SIGNALS AT FAULT DIAGNOSIS IN BALL BEARINGS

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Abstract

In this paper a preliminary estimation of the most common analysis methods of the vibration signals of a ball bearing is tried. The tested methods are the typical statistic analysis method, the Fourier transform, the frequencies spectrum analysis and the Wavelet method. Further testing under variable and/or radial loads is under investigation by the present research team before a final conclusion can be made.

Key words: bearings vibration, vibration analysis methods

1. Introduction

The last decade has been spent a lot of money in the development of fault diagnosis in systems and machines. Big part in this development has played the growth of microprocessors as well as the development of digital signal processing software that allows the growth dynamic, effective and economic systems. These systems watch the machine's situation as well as its individual elements as axes, gears, bearings e.t.a. The use of these systems helped the engineers to improve the performance of each machine and extend duration of useful life, depreciated thus the duration of purchasing and maintenance cost. Most of the older systems use the control method of the vibration of the moving parts of machines to diagnose a befalling damage. The older systems could watch only the changes in the level and type of vibration. These systems were not in place to locate the cause of each particular vibration. However, with the development of fault diagnosis sector were created methods and then systems which can detect and rate the possible vibrations causes increasing thus the reliability, productivity and finally the duration of systems life.

One of the commonest machine elements are the ball bearings. Bearings could be found in machines that are used mainly in industrial but also in domestic environment. The right operation of the above machines depends to a large extent from the right operation of sub elements such as the bearings. Specifically in industrial applications the bearings are considered one of the most important mechanic parts and a fault in them if it is not located in time it can cause serious glitch or even shutdown of the machine during the operation. These faults can be caused during the production cycle or during the operation cycle. For this reason the convenient and valid detection of such faults is very important for the further following of machine's operation but also for its qualitative inspection.

2. Methods of fault diagnosis.

There are various methods for the following and diagnosis of faults in bearings which can be classified in categories such as [1,5,7,22]:

- Vibration methods,
- Acoustics methods,
- Temperature methods,
- Optical methods

The methods of fault diagnosis with following the vibration level of faulty parts are very common mainly in industrial applications. There are many techniques using as input signal the vibration pulse or the acoustic emission of defective bearings in the time and/or frequency domain using the pressure or emitted sound level, the shock oscillations e.t.a. The two previous decades has been published a remarkable number of researches for the previous methods and particularly for the detection of damage with vibrations control. [1-23]

3. Instrumentation and Test Procedure

The instrumentation and experimental setup that was used for the needs of the present work is presented in Figure 1. The dynamic load setup of the bearings for the acquisition of data includes the following parts: 1) the loading device, that in our case the role undertakes a conventional lathe, 2) two pieces of one-axe accelerometers (for x and y vibration axes) (type 8702

B25by Kistler) (Figure 2), 3) a load cell for the measurement of charge (type LD5 A1) (Figure 2), 4) a DAQ card for import data (type PCI-1710 HG by Advantech) and 5) the coupling circuit for the accelerometers. The ball bearing that was used for charging was a common angular ball bearing with single mounting (type 7200 B by Nachi). It was adapted in a metal cylindrical frame. The frame was placed in the turned machine (lathe) and charged axial. The accelerometers were placed peripherally the bearing's frame in two main directions (x and y axes), while load cell was placed in the axial direction to sense the charge (Figure 2). The bearing charged with a continuous axial load equal to 500N. The sensors signals were of altered tendency and with suitable processing circuitry levelled to the host computer for further processing with the LabView program.

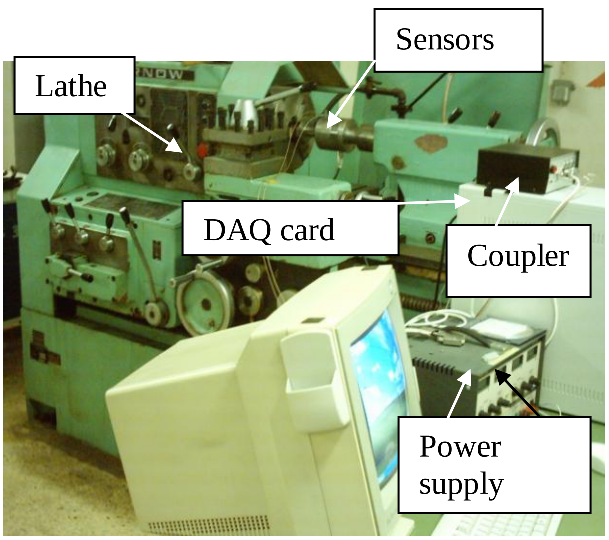

Figure 1: Experimental setup

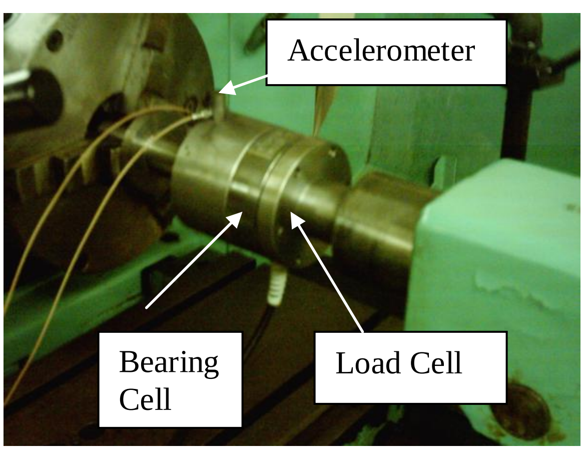

Figure 2**:** Accelerometer and Load cell sensor

4. Experimental results

The experimental data that were received during the experiments represent data of bearing's vibration from the early start of the charging up to the final fracture.
The analytical data processing became with the use of the MatLab program. A typical presentation of the vibration signal in the time domain is presented in Figure 3.

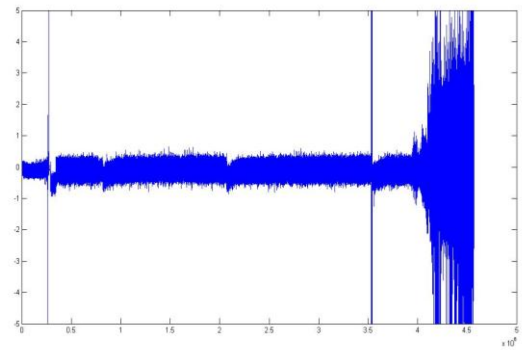

Figure 3 Signal of vibration

Observing Figure 3 it is clearly descried the threshold where the vibrations width altered intensely, leading deterministic to the fracture of the bearing.
For the vibration signal analysis were used four of the most common techniques [2-7]. 1) The statistic signal analysis that mainly contains calculations of mean value and standard deviation, 2) the Fourier transform for calculations in frequency domain, 3) the frequency spectrum analysis for each sensor with different data windows, and finally 4) the Wavelets transform

With the statistical signal analysis it is easily detected, as moreover it was expected, the quantitatively differentiation (but no qualitatively) of the measured signals in the level of vibration which it is potentially owed in some fault bearings. Varieties in the means and standard deviations signal values were observed, leading to an increase of the vibration level and to a likely fault appearance. During the signal analysis were tried some smoothing techniques as the moving average value of three and five points respectively.

With Fourier transform detected the frequencies of damage presented during the vibration of a bearing (Figure 4). Knowing, from the equations (1-4) the theoretical frequencies that a fault will appear for each part of the bearing, it is possible henceforth to locate the faulty part.

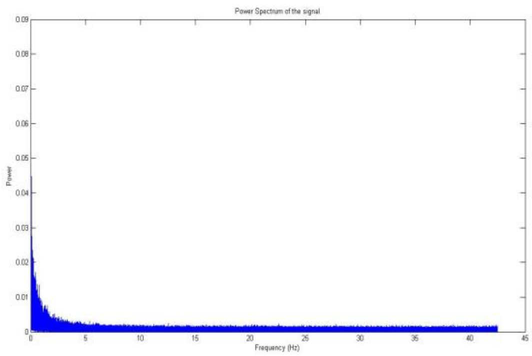

Figure 4. Fast Fourier Transform (FFT) signal analysis

It is marked that, the vibrations width is an indicator of the vibration power and depends from the speed (Rpm) and the charge (N) of the bearing. For a particular bearing geometry, inner raceway, outer raceway and rolling element faults generate vibration spectra with unique frequency components. It is these unique frequency components and their magnitudes that make it possible to determine the condition of the bearing. The bearing defect frequencies are linear functions of the running speed of the motor. Outer race and Inner race frequencies are also linear functions of the number of balls in the bearing. For a bearing shown in Figure 5, with the outer ring stationary, bearing key frequencies are calculated as follows (1-4) [24]:

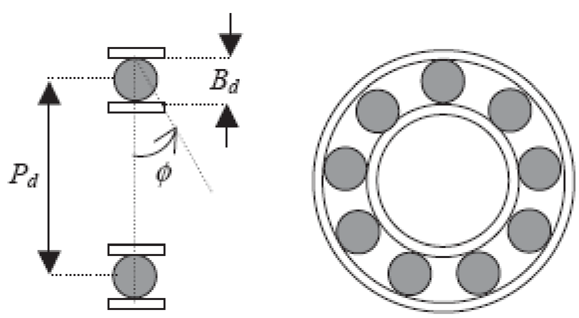

Figure 5. Ball Bearing

Fundamental Train Frequency (FTF):

$$f = \frac{f_s}{2\cdot}\left(1-\frac{B_d}{P_d}\cos\phi\right) \qquad (1)$$

Inner Race Frequency (IR):

$$f_i = N(f_s - FTF) \qquad (2)$$

Ball spin frequency (BS):

$$f_b = \frac{P_d\, f_s}{B_d\, 2\cdot}\left[1-\left(\frac{B_d}{P_d}\right)^2 \cos\ \phi\right] \qquad (3)$$

Outer Race Frequency (OR):

$$f_o = N(FTF) \qquad (4)$$

Where f_s; B_d; P_d; φ are the revolutions per second of the IR or the shaft, ball diameter, pitch diameter and the contact angle, respectively. The contact angle for the ball bearings carrying no thrust load is assumed to be zero. Manufacturers often provide these frequencies in the bearing data sheet. The measured values for the characteristic frequencies might not match the theoretically calculated ones especially when the ball bearings have significant thrust loads and internal preloads.

By the above mentioned equations it is calculated for the bearing of trials, that is turning in the machine-tool of system with speed of 1000 Rpm with φ=15^o, B_d=7,7 mm, P_d =19,7 mm and n(number of balls)=8, the defected frequencies: FTF=41,99 Hz, IR=91,32 Hz, BS=36,64 Hz, and OR=5,25 Hz. In practice, the vibrations of percussion are added in the signal of oscillations that has much higher width. These oscillations are created e.g. from bad balancing of turned axis, frequencies of clutching of gears, mechanic percussions and vibrations etc. From the analysis of Fourier diagrams (Figure 4), big concentration of energy was observed round the frequency of 30 Hz that according to the equation (3) locates fault in the balls of bearing.

With the use of spectral of frequencies of signals as well as energy that is contained in them the frequencies that were calculated by the Fourier transformation (30 Hz) (Figure 6) were substantiated. With the analysis of spectrum of energy (power spectrum analysis) the distribution of frequencies in all the spectrum of energy of signal was located. At the same time using the analysis of density of spectrum (power spectrum estimate) (Figure 7) the development of spectrum of signals energy was observed in reference to time.

At the duration of spectral analysis of frequencies, a variety of fake frequencies (existence of peaks) of the main signal was observed without any certain remarkable clue on damage. This is attributed to the existence of parasitic frequencies because of vibration of other parts of machine, as well as to non-effective elimination of phenomenon of leaking.

For the distinguishable transformation of signals with the Wavelets method was used Wavelet Toolbox of MatLab, and concretely the graphic contact of user (GUI) with name Wavemenu. In the each signal was applied analysis with use of two wavelet interrelations, Haar wavelet of level of analysis 4 and the wavelet db level 3 level of analysis 3. In Figures 8 and 9 we can distinguish the results. The Wavelet transformation is the conjunctive ring of analysis of signal between the time domain and the frequency domain. From its results it is possible to distinguish quantitatively the point (threshold) in which exists an abrupt change in the width of frequencies of corresponding signals, making thus easy the localisation of time point in which the corresponding fault is presented. It is marked that, the results of distinguishable transformation with wavelets did not draw any important conclusion with regard to befalling damage. For this reason, analysis with use continuous transformation with wavelets was used as well (Figure 10).

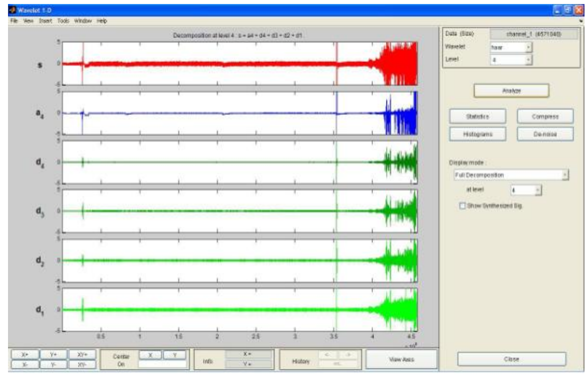

Figure 8. Haar Wavelet (level of analysis 4)

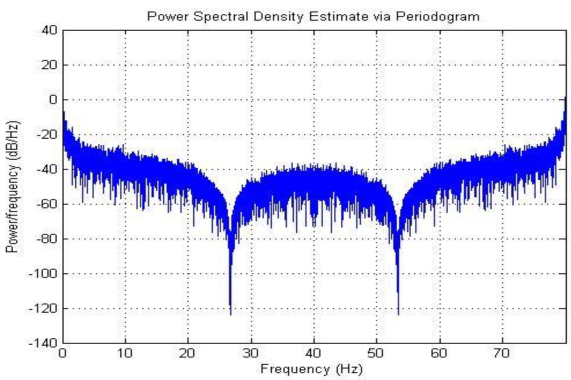

Figure 6. Frequencies Spectral Analysis

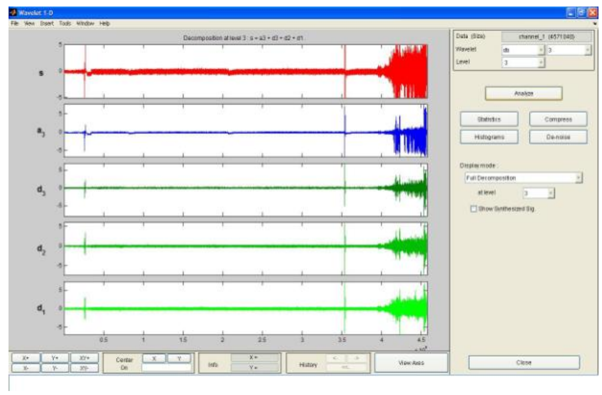

Figure 9. Wavelet db 3 (level of analysis 3)

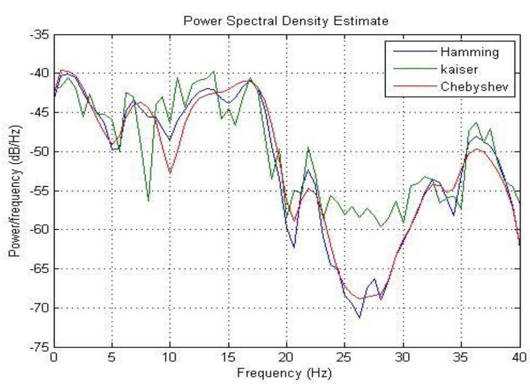

Figure 7. Spectrum Density Analysis

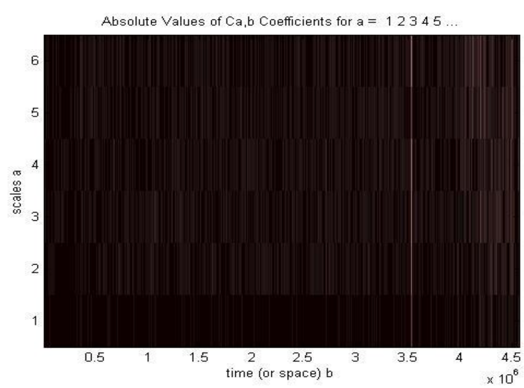

Figure 10. Continuous Wavelet transformation

While observing Figure 10, a change in the frequency of signal is distinguished. The changing point is near 35 Hz and comparing it with the defected frequencies at the specific ball bearing, a potential damage to its balls is located.

5. Results - Conclusions

The ball bearing, as all the machine elements have a characteristic natural frequency vibration. At the same time however we can also calculate the frequencies with which their components are vibrating, as the exterior ring, the internal ring or their balls. With the Fourier transformation as well as with the calculation of spectrum of frequencies we can distinguish the frequencies of ball bearing's elements and conceive if there is any damage in the particular component, so that the interruption of machine's operation will happen timely.

The statistical treatment of signals presented an increase of the level of vibrations via the increase of the average and the mean square deviation of individual signals. The studying of statistical indicators of Fourier transformation for all signals presented an increase in the width of transformation of all signals. At the same time, the study of statistical prices of continuous transformation showed a change in the frequency via the increase of prices of average and mean square deviation as well as increase of range of factor prices. The above clue was distinguished more easily in the graphic representations of factors transformation.

Interrelation FFT of MatLab does not use data windows technique which helps in the obliteration of phenomena as that of leaking. This is the main reason why such distribution of energy in the particular spectrum of frequencies is distinguished. Further testing under variable and/or radial loads is under investigation by the present research team before a final conclusion can be made.

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