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Experimental Investigation of Fault Detection in Ball Bearings using Vibration Signature Analysis

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ABSTRACT

Ball bearings are machine elements used in rotary machines to reduce friction and support radial and axial loads. During operation there are chances that these elements develop localized faults most probably on the races. To avoid catastrophic failure it is required to monitor the condition of the bearings and detect faults in it. Vibration Signature Analysis is widely used for condition monitoring of mechanical elements such as bearings, gears etc. Envelope detection is a signal processing technique for demodulation of vibration signals, it is a useful tool for the identification of faults. Time domain signals and order spectrum of healthy and faulty bearings were investigated. Statistical parameters such as Kurtosis and Root Mean Square of the time domain signals are also used to identify the presence of faults.

Keywords -Bearing, Envelope detection, Kurtosis, Root Mean Square, Spectrum Analysis.

1. INTRODUCTION

Bearings are machine elements widely used in industrial machineries. Ball Bearing provides support in radial and axial directions. In Ball bearings, faults can arise in the various elements such as races, balls or cage. There are two types of faults, they are localized and distributed faults. Spalls, brinelling etc. are localized faults .Surface roughness, waviness etc. are distributed faults. As faults arise in the mechanical elements, vibration of the machine is influenced.

As the rolling elements pass over the localized fault there would be an impact and ringing sound. The periodicity of impacts is depended on the geometry of the bearing which is known as the characteristic defect frequencies. So measuring and analyzing vibration of mechanical elements helps to detect incipient faults and its location. Vibration Analysis is widely accepted and has been used for decades for condition monitoring of machines. By investigating the time domain signals and the spectrum the bearing characteristic frequencies can be identified. Theoretically, in FFT spectra the characteristic defect frequencies should be present corresponding to the bearing defect. But experimental results show that these frequency components are not present in the spectra because the impulses generated by the defects are hidden by noise. To solve this problem signal processing techniques are used such as technique based on the averaging technique [1], adaptive noise cancelling [2] and High frequency resonance technique [3].

Statistical analysis of vibration signals acquired provides values which on comparison with the standard values would yield information on the condition of the bearing. This is relatively simple technique for fault detection but cannot be used for fault location identification. Dyer et.al [4] found that the kurtosis of healthy bearing vibration signals yielded values close to kurtosis of Gaussian signals, this was found to be valid even at speed and load variation. In the present work along with time domain analysis, statistical analysis and spectrum analysis, envelope detection is used for fault detection in bearings.

1.1 Envelope Detection

The Bearing Characteristics Fault frequencies are found in narrow band spectrum using FFT. It is observed that practically the spectrum would not be clearly revealing these fault frequencies due to the presence of higher frequencies. In vibration signal of a defective bearing the presence of amplitude modulation was found. Envelope detection is a signal processing technique to demodulate and obtain the low frequency envelope signal. Demodulation is done by either band pass filter or by Hilbert transform. This allows the detection and isolation of bearing characteristic frequencies and clear indication of the fault frequencies and its harmonics.

1.2 Kurtosis

Kurtosis is a statistical parameter used to quantify the distribution of signals relative to the Gaussian. It signifies the distribution of the signal. Kurtosis is found by the formula for discrete signals:

$$\text{Kurtosis} = \frac{\sum_{k=1}^{N} (x_k - \bar{x})^4}{N\sigma_4} \quad (1)$$

where $\bar{x}$ is the mean value of the signal and x_k denotes the discrete points of the signal.

σ_4 Denotes the standard deviation with power 4:

$$\sigma_4 = [\frac{\sum_{k=1}^{N} (x_k - \bar{x})^2}{n}]^2 \quad (2)$$

1.3 Root Mean Square (R.M.S)

R.M.S is the square of the second order central moment which indicates the intensity. It is related to the energy of the signal. For discrete signals R.M.S value is calculated by the formula:

$$\text{R.M.S} = \sqrt{\frac{\sum_{k=1}^{N} {x_k}^2}{N}} \quad (3)$$

2. EXPERIMENTAL SETUP

In this study faults were introduced on the inner and outer races using wire Electro discharge Machining cut. The cut size was same for both inner and outer races with 10mm length, 1mm width and 0.5mm thickness. The ball bearings were tested one by one in the T.I.E.R.A Machinery fault Simulator .The preferable bearings that can be used is deep groove and angular contact bearings. A static mass was used, inducing load in the shaft for measuring the vibrations at the loaded conditions. Experiments were done at constant speed of 660rpm with inner race rotating and outer race stationary. An accelerometer was used for measuring vibrations, by mounting on the bearing holder. A retro reflective type IR sensor was used for measuring the speed of the shaft and displayed in pulse meter. NI data acquisition system that has inbuilt anti-aliasing filters and the ability to acquire data with a very high sampling rate (51.2 KHz) was used.

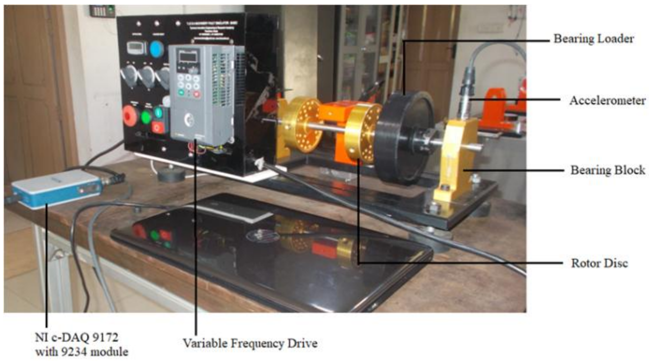

Fig. 1 Experimental setup

Figure 1 shows the setup used for experimental studies.

3. RESULTS AND DISCUSSIONS

The good and defective bearings had the following specifications:

Bearing classification=6201-2z
Ball diameter(B_d)=5.935mm
Pitch diameter (P_d) =22mm
Number of balls(N_b) =7
Contact Angle (α) =0

The characteristic defect frequencies are calculated by using the formula:

Ball Pass Frequency Inner (BPFI) =

$$\frac{N_b}{2}\left[1 + \left(\frac{B_d}{P_d}\right) cos\alpha\right] f \quad (4)$$

Ball Pass Frequency Outer (BPFO) =

$$\frac{N_b}{2}\left[1 - \left(\frac{B_d}{P_d}\right) cos\alpha\right] f \quad (5)$$

where f is the rotating frequency of the spindle (11Hz).At a speed of 660 rpm the characteristic defect frequencies of inner race and outer race were 48.4Hz and 28.2Hz respectively(which were 4.44 and 2.62 orders respectively).

3.1 Time Domain Signal Analysis

The raw time domain vibration signals were acquired for bearings at 660rpm.The time domain signals were investigated. The faulty bearings were found to have impacting in the time domain signal. The periodicity of impacting was calculated. The frequency of impacts was found to be in relation with the formula of bearing characteristic defect frequencies.

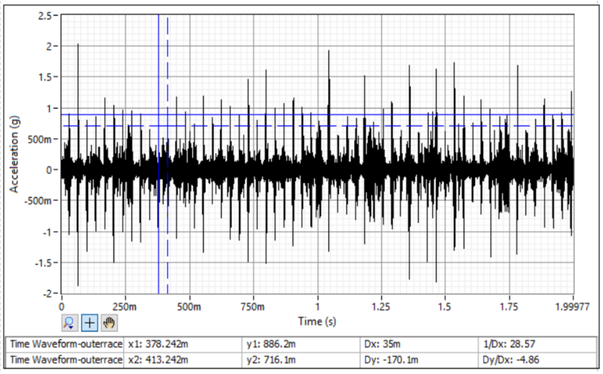

Fig. 2 Time domain signal of outer race faulty bearing

Period of impact (T)=35m

Frequency of impact= $\frac{1}{T}$ =28.57 Hz

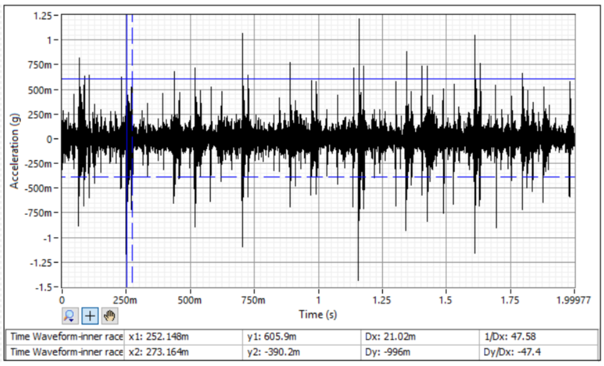

Fig. 3 Time domain signal of inner race faulty bearing

Period of impact (T) = 21.02m

Frequency of impact = $\frac{1}{T}$ =47.58 Hz

On investigating the inner race faulty bearing signals, modulation of the signal was found at that of running speed. This occurs since the inner race is coupled to the shaft.

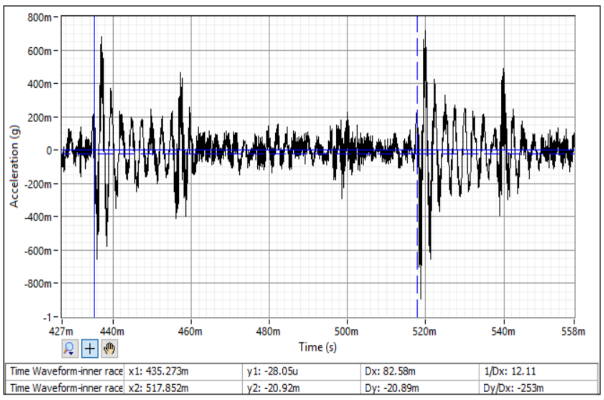

Fig. 4 Time domain of inner race faulty bearings

Period of modulation (T)=82.58m

Frequency of modulation= $\frac{1}{T}$ =12.11 Hz

3.2 Statistical Analysis

The statistical analysis of the vibration signals were done for the good and defective bearings at three different speeds .The healthy bearings were having kurtosis close to the Gaussian value (i.e. =3),it was insensitive to speed variation which was used as the criteria for the detection of defective bearings. The R.M.S velocity of the bearings was found to have a trend for the healthy bearings; there was an increase in the value with speed. The value was comparatively larger for defective bearings than healthy bearings at different speeds.

Table1 Statistical Parameters for bearings

Bearing Type	**Speed**	**RMS Velocity mm/s**	**Kurtosis**
Healthy	11.25 Hz	0.39	2.698
	25.3 Hz	1.062	2.941
	30.6 Hz	2.034	2.696
Inner Race Fault	11.25 Hz	2.590	14.740
	25.3 Hz	1.126	48.380
	30.6 Hz	2.236	25.881
Outer Race Fault	11.25Hz	3.660	52.146
	25.3 Hz	1.130	47.201
	30.6 Hz	2.238	26.245

3.3 Order Spectrum Analysis

Order Spectrum was obtained for the signals. In Faulty bearings as the rolling elements pass the localized fault there was impact. Frequency of impacts was depended on the location of the fault. The characteristic fault frequencies and its harmonics were calculated in terms of orders. The spectrum was investigated for peaks at the characteristic defect frequencies.

In both the inner and outer race faulty bearings the higher harmonics of Ball Pass Frequency inner and Ball Pass Frequency Outer were identified from the spectrum. It was found that there were no peaks at these frequencies for the healthy bearings. This reveals the fault and its location. For the inner race faulty bearings, vibration signals were modulated at running speed therefore presence of sidebands was at 1X to the fault frequency harmonics was observed.

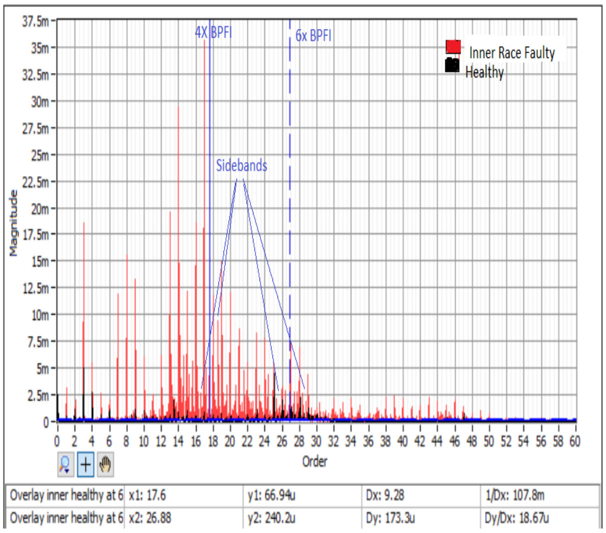

Fig. 5 order spectrum of inner race faulty bearings and healthy bearings

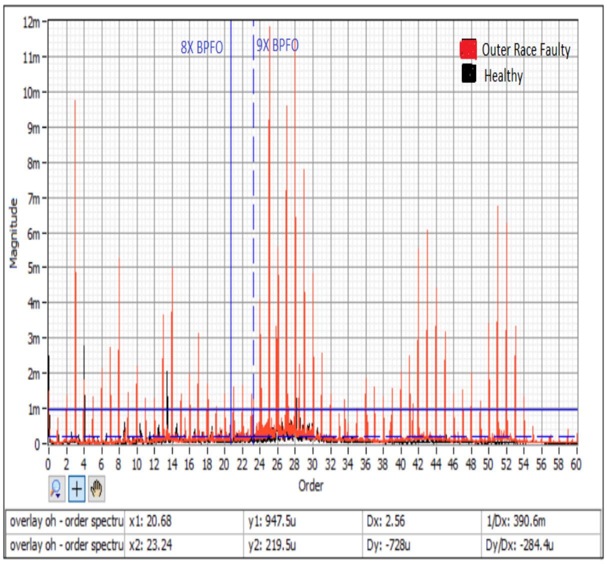

Fig. 6 order Spectrum of outer race faulty and healthy bearings

3.4 Envelope Detection

In the order spectrum of the vibration signal it was found to be difficult to identify the characteristic defect frequencies along with that of vibration of other components. It was found that few harmonics of the defect frequency was identified in the order spectrum. In the vibration signals of bearings, the defect frequencies were found to be modulated. In the envelope analysis the demodulation of the signals were done. It was found from the envelope spectrum of inner and outer race defective bearings that the BPFI and BPFO along with its harmonics respectively, were identified easily.

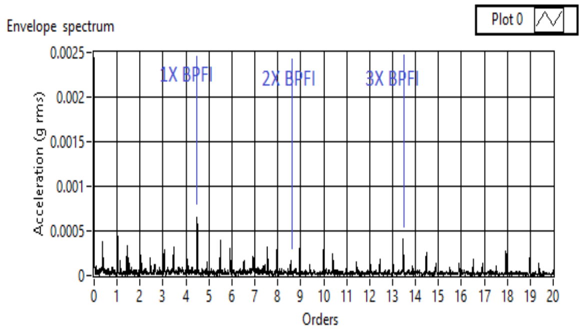

Fig. 7 envelope spectrum of inner race faulty

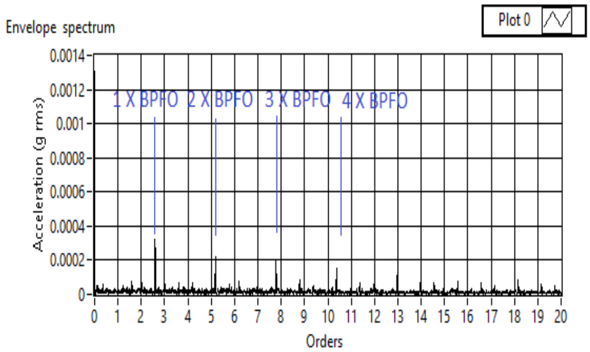

Fig. 8 envelope spectrum of outer race faulty

4. CONCLUSION

The experiment results reveal that the impacts due to the fault in bearing was identified clearly using envelope detection compared to that of order spectrum ,in which the defect frequencies were difficult to be identified.

In statistical analysis it was found that the defective bearings had higher kurtosis values compared to that of healthy, in defective bearings there was no trend found with variation of speed but the healthy bearing had kurtosis value close to three, even with speed variation. The R.M.S velocity of vibration of defective bearings was comparatively larger values to that of healthy bearings indicating the presence of fault.

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