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Fault detection of conditioned thrust bearing groove race defect using vibration signal and wavelet transform

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ABSTRACT

Rotary machine elements plays an important role in rotating machinery. During Operation machine elements like bearing are subjected to heavy loads. Under heavy loading conditions, the defects are gradually induced in the bearing. Due to these defects it is required to detect, locate and analyse the faults for reliable operations. This defect generates vibration along with noise. Vibration signals helps to find severity of fault. An effort is made to study the performance of deep groove thrust bearing. Vibration analysis technique is used to detect the faults in the thrust bearing. FFT (Fast Fourier Transform) detects the frequencies of faults present during vibration analysis. After the vibration signal from FFT, the processing of the signal is done by magnifying the signal, Four types of bearing were tested with one of them remains good condition and other three having own type of defect.

Keywords— **FFT (Fast Fourier Transform), Thrust bearing, Vibration analysis, Wavelet toolbox.**

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I. INTRODUCTION

Ball bearing is the most basic component used in a machinery like machining tools, industrial turbo machinery, and aircraft gas turbine engines etc. It is observed that majority of the maintenance capital expenditure is spent on bearings. Even a newly manufactured bearing may also generate vibration due to components running at high speeds, heavy dynamic loads and also contact forces which exist between the bearing components. Bearing defects may be classified as localized and distributed. The localized defects include cracks, pits and spalls caused by fatigue on rolling surfaces. The distributed defects include surface roughness, waviness, misaligned races and off size rolling elements. The sources of defects may be due to either manufacturing error or abrasive wear.

The occurrence of a fault must be identified as early as possible to avoid fatal breakdown of machines, hence it is possible to increase the reliability of the system so as to rationalize costs, by developing new management models and new algorithms based on on-line monitoring of several parameters, namely vibrations, electrical variables, temperature, among others. In order to prevent bearing failure there are several techniques in use, such as, oil analysis, wear debris analysis, vibration analysis and acoustic emission analysis. Among them vibration is most commonly accepted techniques due to their ease of application. The time domain and frequency domain analysis are widely accepted for detecting malfunctions in bearings. The frequency domain analysis is more useful as it identifies the exact nature of defect in the bearings.

Feature extraction of bearing faults from its vibration signals is a difficult task in engineering due to non-stationary and non-linear nature of the signal along with strong noise interference.

II. LITERATURE SURVEY

Manpreet Singh, Rajesh Kumar[1] Experimental measurement and subsequent analysis have revealed that decomposition of pre-processed vibration signal by using Symlet5 mother wavelet is suitable for measuring outer groove race defect width in thrust bearing. In normal raw signal entry and exit points of the groove are not identifiable because signal at these points is weak. Xinsheng Lou and Kenneth A. Loparo [2] developed a new scheme for the diagnosis of defects in ball bearings. The technique is based on statistical analysis, the discrete wavelet transform, and pattern classification techniques such as neuro-fuzzy inference. Jyoti K. Sinha[3] proposed a wide spectrum of the role of vibration measurements and vibration-based diagnosis used in the nuclear plants based on the author experience has been summarised briefly through few typical cases.

P.K. Kankar, Satish C. Sharma, S.P. Harsha[4] Aiming at the characteristics of the vibration signal of rolling bearing with fault, the Complex Morlet wavelet is selected based on Minimum Shannon Entropy Criterion to extract the fault feature shown that among a wide variety of mother wavelets, Complex Morlet wavelet have satisfactory performances for both bearing and gear fault identification, which is verified by obtained results. Hai Qiu, Jay Lee, Jing Lin, Gang Yu[5] De-noising and extraction of the weak signature from the noisy signal are crucial to fault prognostics, in which case features are often very weak and masked by the background noise.

Prognostics is achieved by detecting the defect at its initial stage and alerting the operator or maintenance personnel before the defect develops into a catastrophic failure. This method is well suited for detecting the weak signature from a defective bearing signal where defect features are impulse-like. By applying the minimal Shannon entropy criterion, an optimal wavelet shape factor b with optimal time frequency resolution capability can be obtained. Sadettin Orhan, Nizami Aktu¨rk Veli¸ elik [6]. In this study, diagnosing techniques of the ball and cylindrical roller element bearing defects were investigated by vibration monitoring and spectral analysis as a predictive maintenance tool. Ball bearing looseness, a ball bearing outer race defect and a cylindrical bearing outer race defect were successfully diagnosed. Yuh-Tay Sheen[7] investigated to the resonance frequencies in the resonance modes of mechanical systems, an envelope estimation algorithm is carried out to retrieve the envelope signals from the bearing vibrations.

Under the assumption of stepwise functions for the envelope signals in the corresponding resonance modes, the vibration signal could be decomposed into the sinusoidal function bases with fundamental frequencies at the resonance frequencies. V.N. Patel, N. Tandon, R.K. Pandey[8], This study incorporates local defect detection on the races of test bearing (deep groove ball bearing, SKF BB1 B420205) in the presence of external vibrations.

III. BLOCK DIAGRAM

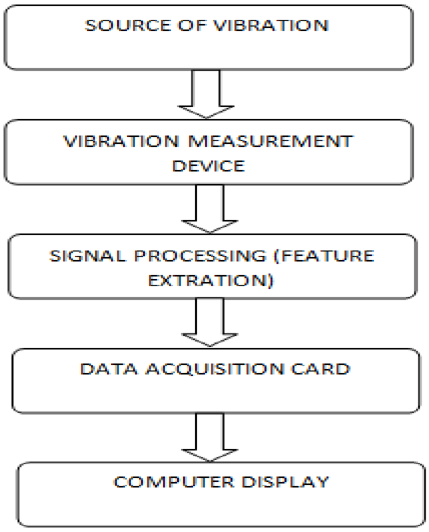

Fig. 1 Block diagram for fault detection of a thrust bearing

A. Source of vibration

Source of vibration is nothing but a vibration signal of bearing for which the defects to be detected. Thrust bearing with faults such as outer race defect, inner race defect, ball defects.

B. Vibration Measurement Device

Vibration signal is processed by accelerometer and converts analog signal into electric signal and passed for the further processing to the FFT analyser.

C. Signal Processing

Vibration signal from FFT analyser is extracted for detection of fault in the bearing.

D. Data Acquisition Card

Extracted Vibration signal is stored in Data Acquisition Card.

E. Computer Display

Final Vibration signal is displayed on computer screen.

IV. FFT ANALYSER

FFT Analyser is one of the most important instrument used in the experimental work. The fast Fourier transform (FFT) is a computationally efficient method of generating a Fourier transform. The main advantage of an FFT is speed, which it gets by decreasing the number of calculations needed to analyse a waveform. A disadvantage associated with the FFT is the restricted range of waveform data that can be transformed and the need to apply a window weighting function (to be defined) to the waveform to compensate for spectral leakage.

Fig. 2 FFT Analyzer(model no-2ch SA-78)

V. THRUST BEARING AND ITS FAULT

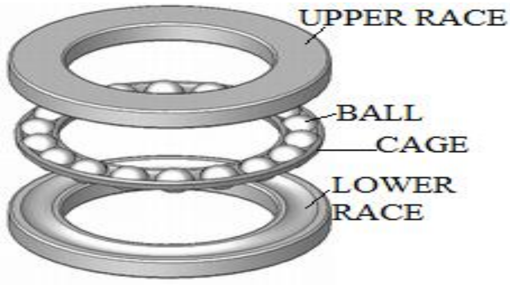

Fig. 3 Thrust Bearing

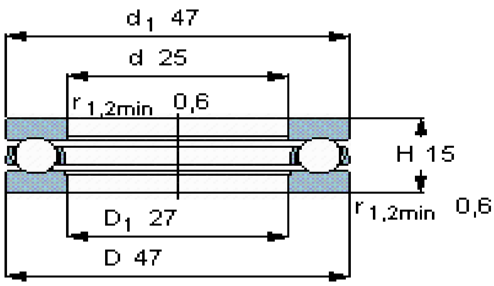

Fig.4 SKF Thrust Ball Bearing 51205

TABLE I

SKF Brand Model	51205
Types	Thrust Ball Bearings
Brands	SKF Bearings
Inner Diameter(d)	25 mm
Outer Diameter(D)	47 mm
Thickness(H)	15 mm

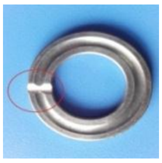

Fig. 5 Top damage

VI. EXPERIMENTATION & RESULTS

Experimental setup consists of 1 HP Vertical shaft base mounted, 3phase, A.C. motor with 1390 rpm fixed in lower disc vertically. SKF bearing with number 51205 having diameter of 25mm having ball diameter (b_d), outer race mean diameter (d_{or}), pitch diameter (p_d).

Following are the dimensions of the bearing used in the work.

TABLE III

ball diameter (b_d)	4 mm
outer race mean diameter (d_{or})	36 mm
pitch diameter (p_d)	47 mm

Outer groove race defect width, L_d can be calculated from the vibration burst duration (Δt), which is estimated using Symlet based decomposition in MATLAB environment, fundamental train frequency (FTF):

$$FTF = \frac{s}{2} \times \left(1 - \left(\frac{b_d}{p_d}\cos\theta\right)\right) \quad (1)$$

Where,

θ - The angle of contact

s – Speed in revolutions per second

For the race defect width, L_d in mm, d_{or} must be in mm, FTF in Hz. If n_d is the number of data points between the ball entry into and exit from defect and f_s is the sampling rate, then vibration burst duration (Δt) can be calculated as:

$$\Delta t = n_d / \quad (2)$$

The groove race defect Ld can be calculated by using following equation:

$$Ld = \pi * \Delta t * d_{or} * FTF \quad (3)$$

From Eq No. 1, the fundamental frequency FTF is found to be,

FTF = 10.59 Hz

At lower race speed 1390 rpm and outer race mean diameter d_{or} = 36 mm, Eq No. 3 can be simplified as :

$$L_d = 1207.17 * n_d / f_s \quad (4)$$

The data points in the signal consists of both positive and negative values. The amplitude data helps to describe the phenomenon of destressing and restressing at entry and exit of the defect.

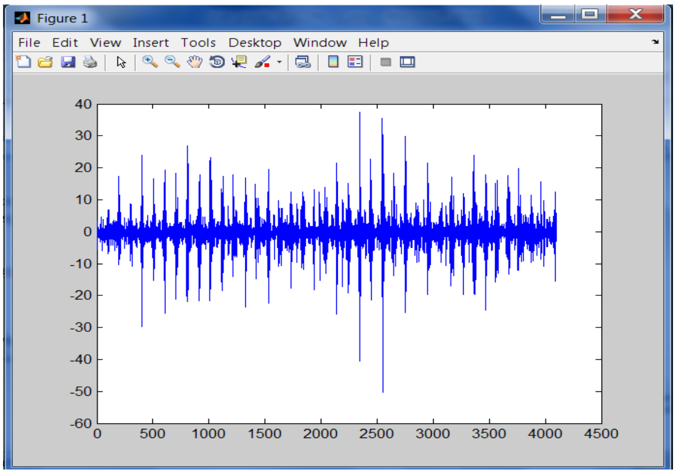

Fig. 6 A typical raw signal of 1.5 second duration for outer race defect of width 5 mm approx. under axial load of 112 N at shaft rotation 1390 rpm.

It is difficult to describe position of the ball with only positive and negative values of amplitude. To overcome this, multiply the signal by its own absolute value of amplitude, at each data point the signal amplifies more in the burst portion as compared to the other portion in the signal. This retains the original format of the signal at each data point.

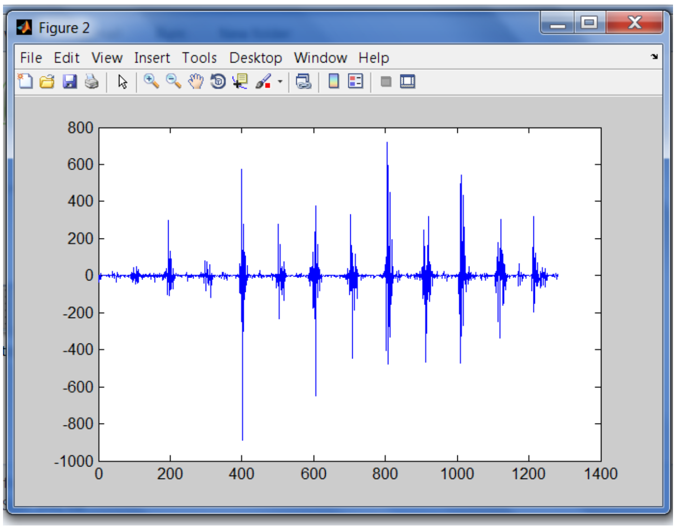

Fig. 7 Pre-processed signal for which is amplified by multiplying by its own value before applying wavelet decomposition.

To measure the defect width experimentally, Wavelet toolbox is used. In wavelet toolbox load the pre-processed signal which shows amplification in the amplitude of the signal at the burst and reduction at no burst. Continuous wavelet transform is performed on the signal. Once continuous wavelet transform is performed, Symlet 5 is selected instead of symlet 4 or symlet 6 because symlet 5 gives appropriate de-stressing and re-stressing of the signal which gives the smooth waveform of the signal. Signal obtained from defective bearing is analysed and found that when ball comes in contact with defect the disk pushes in upward direction and due to the effect of inertia the disc takes some time to come back its original position. When ball rotates in the groove the ball might have crossed over the defect without touching the defect which leads to missing some of the bursts.

In experiment the bursts are observed at data points interval in the range of 500-523, 610-630, 708-731.

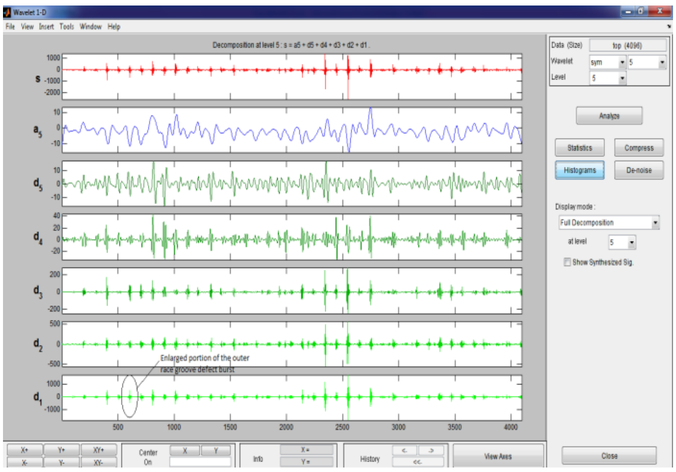

Fig. 8 Wavelet decomposition of the signal for upper race groove defect

A single burst is shown in fig. 9 using Symlet 5 for finding the width of defect L_d. The entry of the ball in groove defect is at 600^{th} data point and exit at 610^{th} data point i.e. number of data points between entry and exit of ball in race defect is 22. The 5 observable bursts in the signal were calculated for groove defect measurement. Using Eq. No.4 we found width of defect equal to 4.47 mm.

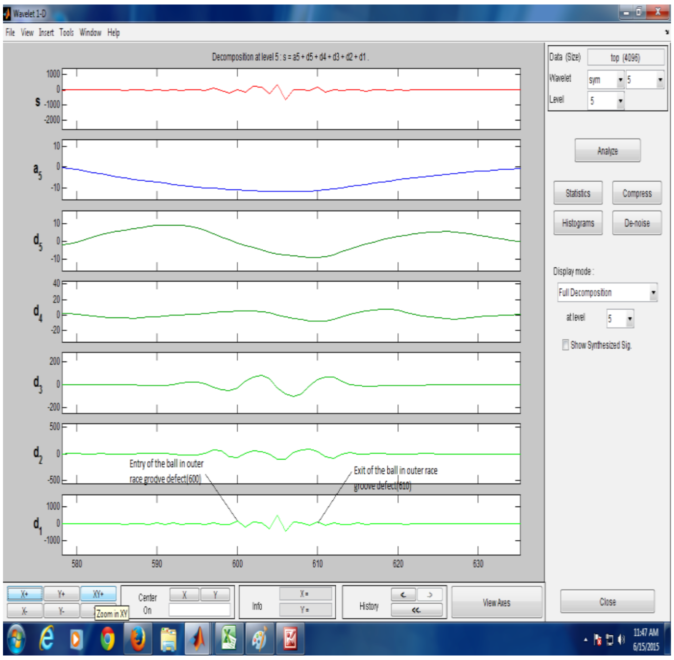

Fig. 9 Enlarged view of the signal for the burst portion

VIII. CONCLUSIONS

Experimental analysis and decomposition of preprocessed vibration signal by using Symlet 5 is suitable for measuring outer race groove defect in thrust bearing. Raw signal shows the burst at entry and exit of ball in groove but they are not suitable for analysis. To overcome this difficulty the preprocessing of the signal is done. In preprocessing the amplitude of signal is multiplied by its own absolute value, which gives large peak in the burst as compared to no burst region. This preprocessed signal is then analyzed and decomposed in wavelet 1D which gives burst at equal interval of the period. For finding the width of the defect, one of the burst is zoomed in wavelet for getting exact data points of entry and exit of the outer race groove defect. Five such bursts are used to find average burst data points of outer race groove defect. After calculating the width of the defect the deviation in the width of defect has been found to be 1.81% that of the actual width of outer race defect.

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