BEARING FAULT DIAGNOSIS USING SPECTRAL ESTIMATION

Rahul Dubey[1], Dheeraj Agrawal[2]

[1,2] Electronics and Communication, Maulana Azad National Institute of Technology, Bhopal- (India)

ABSTRACT

The property of wavelet transform to detect the discontinuity in the signal is useful in many application of signal processing. An effect occurred in the bearing generally has an impulsive nature. A Morlet wavelet is useful in such a condition to detect the defects occurred in the bearing. This paper proposed a scheme to detect a faults in the bearing which is based on the two stages, the first stage is preprocessing of acquired signal through a soft thresholding wavelet filter. Then the output of first stage followed a Morlet wavelet analysis to detect the faulty frequencies in the power spectrum of vibrating data.

Keywords: ***Fault detection, Wavelet Filter, Morlet Wavelet, DAS***

I. INTRODUCTION

There are various Life Cycle Phases of Software as well as Hardware. Repair and Maintenance is one of the important phases of this Life Cycle. Machine fault problems are broad sources of high maintenance cost and unwanted downtime across the industries. The prime objective of maintenance department is to keep machinery and plant equipments in good operating condition that prevents failure and production. Rolling Element bearing supports and locates rotating shafts in machine. The term rolling element bearing includes both ball bearing and roller bearing. Rolling element bearing operate with a rolling action whereas plain bearing operates with a sliding action.

There are various methodologies for bearing fault detection namely Vibration Signature Analysis, Lubricant Signature Analysis, Temperature Monitoring. The Vibration Signature Analysis is one of the best techniques. Vibration is the oscillation of an object around an Equilibrium Position. The appearance of any of the most usual faults that affect this type of machinery will markedly influence the composition and shape of the vibration time signal measured at its critical points [1].

The Geometry of the ball bearing is shown in Fig. 1. With reference to Fig. 1, F_o is the Outer Frequency, F_c is the Cage Frequency, F_i is the Inner Frequency. F_s are the Shaft Rotation Frequency, F_B is the Ball Rotational Frequency, F_{BPIF} is the Ball pass Inner Raceway Frequency, F_{BPOF} is the Ball pass Outer Raceway Frequency.

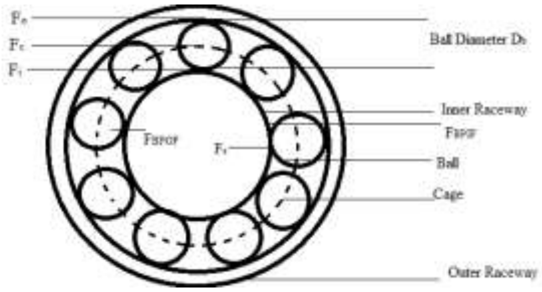


Fig. 1 A Typical Bearing Structure

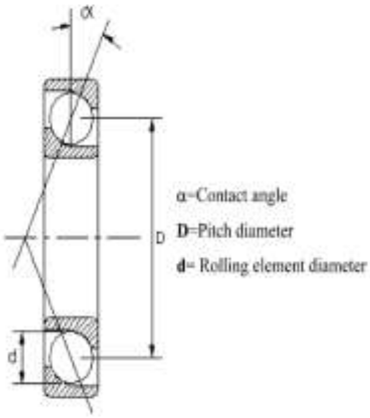


Fig. 2 A Bearing Geometry

The frequencies are to be calculated by following formula:

$$w_c = \frac{n}{2}[1 - \cos\alpha] \quad (1)$$

$$w_{bpi} = \frac{n}{2} N_b[1 + \frac{d}{D}\cos\alpha] \quad (2)$$

$$w_b = \frac{n}{2}(\frac{d}{D})[1 - (\frac{d}{D})^2 \cos^2\alpha] \quad (3)$$

$$w_{bp} = \frac{n}{2} N_b[1 - \frac{d}{D}\cos\alpha] \quad (4)$$

These Frequency indicates that the rate at which the ball pass a point on the track of inner raceway or Outer raceway. The Vibration analysis can be done in two ways either by Time domain analysis or by Frequency domain analysis. The Frequency domain analysis involves the analysis of spectral component presents in the frequency spectrum, as each component in the power spectrum belongs to one specific part within a machine. There are two methods generally employed for this vibration signature analysis namely Fast Fourier Transform, and Wavelet packet Transform.

The capability of wavelet packet to detect the discontinuity in signal space is particularly useful in application to detect bearing faults. In this paper, an enhanced wavelet packet algorithm is proposed. An effective technique is designed based on the denoising of vibrating data in preprocessing step followed by wavelet packet algorithm. The outline of the paper is as follows. Section 2 presents a proposed preprocessing step. In section 3, a brief review of wavelet packets is presented. In section 4, the proposed algorithm for bearing fault diagnosis is presented. Section 5 presents the result of the proposed method, which is followed by conclusion in section 6.

II. PREPROCESSING STEPS

The preprocessing phase is subdivided into following steps:

A. Signal Acquire

B. De-noising of received signal

2.1 Signal Acquire

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Spectrum analysis with special phase constant averaging routines allows to determine machine specific signatures by magnitude and phase relation. By correlation analysis common information of different vibration signals is evaluated for source localization, and cepstrum analysis is used to quantify periodical information of spectral data.

2.2 De-Noising of Acquired Signal

De-noising of signal acquired from DAS done in this stage. Wavelet filtering is used in this scheme. The time-frequency representation of Discrete Wavelet Transform is performed by repeated filtering of the input signal with a pair of filters namely, low pass filter (LPF) and high pass filter (HPF), and its cutoff frequency is the middle of input signal frequency. The coefficient corresponding to the low pass filter is called as Approximation Coefficients (CA) and similarly, high pass filtered coefficients are called as Detailed Coefficients (CD) [2]. Wavelet thresholding is the signal estimation technique that exploits the capabilities of signal denoising. Thresholding methods categorizes in to two types such as hard thresholding and soft thresholding.

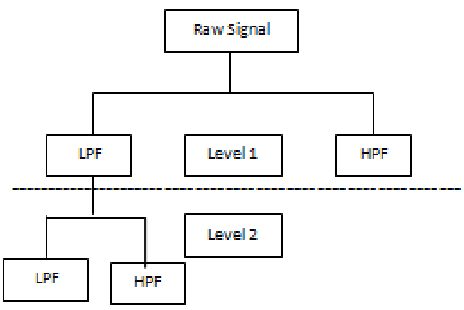


Fig 3. Filter Bank Structure

Soft thresholding is used in the proposed scheme to deny the acquired signal. It is defined as in equation 5

$$F(a,b) = \begin{cases} [sign(w)](|w| - t), & |w| \geq t \\ 0, & |w| < t \end{cases} \quad (5)$$

The signals are visually inspected after the finishing the experiment and it is found that, the signals are severely affected by using different sources of noises such as power line frequency, baseline wandering, and high frequency noises [3]. However, it is impractical to remove the noises visually on definite duration of the acquired signal and it consumes more time. Hence, robust signal processing techniques are inevitable to remove such effects of noises from the signals. On each level of wavelet decomposition, the value of threshold has been calculated by applying the threshold selection rules and the wavelet coefficient above the value of threshold has been removed (soft thresholding).

III. WAVELET BASED ANALYSIS

The ineffectiveness of the FFT analysis for low SNR signals motivates for developing high resolution techniques such as the Wavelet transform for bearing fault detection. Fourier Transforms are great if signal is a constant frequency. But if the signal varies or it has pulses or blips or anything that happens at a particular time there is a need of Wavelets. Wavelets give you information about the frequency of an interesting transient event AND also tell you when it occurred and what it looks like! Wavelets act as a "microscope" to analyze interesting data.

The wavelet transform is defined as the inner products of the signal and a family of wavelets.

$$W_{(a,b)} = |a|^{-1/2} \int_{-\infty}^{\infty} x(t) * \Psi_{(a,b)}(t)dt \quad (6)$$

Where a is the scale factor, b shows the time location, and $\Psi_{ab}(t)$ are the son wavelets generated by shifting and scaling the mother wavelets, Ψ(t) [4] . The more the son wavelets are similar to feature components, the larger are the corresponding wavelet coeffkients. This implies that a wavelet can be used for feature extraction if the mother wavelet is more similar to the feature configuration hidden in the signal. One major advantage afforded by wavelets is the ability to perform *local analysis* -- that is, to analyze a localized area of a larger signal.

wavelet analysis represents particular signal by *approximations* and *details*. The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called the *wavelet decomposition tree* [5]. Generally, the fault occurred in the bearing has an impulsive nature. To detect a signal with impulsive nature, there is a need to select a particular wavelet function. A Morlet wavelet is a wavelet with such a characteristic. It is given by

$$x(t) = C_{\psi}^{-1} \int_{-\infty}^{\infty} W(a,t) \frac{da}{a^{3/2}} \quad (7)$$

where

$$C_{\psi} = \int_{-\infty}^{\infty} \frac{\psi^*(\omega)}{|\omega|} d\omega \quad (8)$$

Where $\psi^*(\omega)$ Is the Fourier Transform of $\psi(\omega)$

A normal criterion for selecting the mother wavelet is the sparsity. Accordingly, a desirable mother wavelet is the one which generates the fewest wavelet coefficients for a given signal. Therefore, that α is optimal which leads to the lowest number of wavelet coefficients, On the other hand based on the Shannon entropy this is equivalent to obtaining the minimum entropy between the mother wavelet and wavelet coefficients.

$$E_n = -\sum_{i=1}^{M} d_i \log d_i \quad (9)$$

where

$$d_i = \frac{c_i^2}{\sum_{i=1}^{M} c_i^2} \tag{10}$$

IV. THE PROPOSED ENHANCED APPROACH FOR BEARING FAULT DETECTION

Vibrating Signal is acquired through a DAS system. The preprocessing of the acquired data is done in further steps. The acquired signal is feed to the wavelet filter for denoising. The component frequencies in the power spectrum of acquired data belong to one specific part of the machine, a rotating shaft with a constant speed generates an impulsive vibration on the spot where the ball passes over the defect. This excites the characteristic frequency of the bearing part that can be measured from the vibrating signal.

To detect a fault, the signal energy is estimated with in a sub band around the characteristic frequency of the bearing component. When this energy increases compared to the healthy one, we can conclude if the inner race or the outer race is defective.

The flow chart of the proposed work is shown below in figure 4:

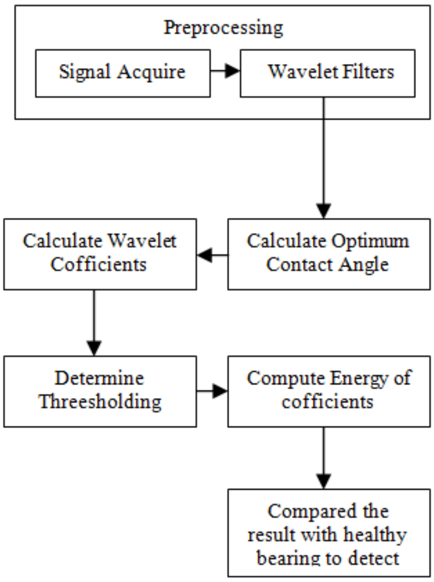
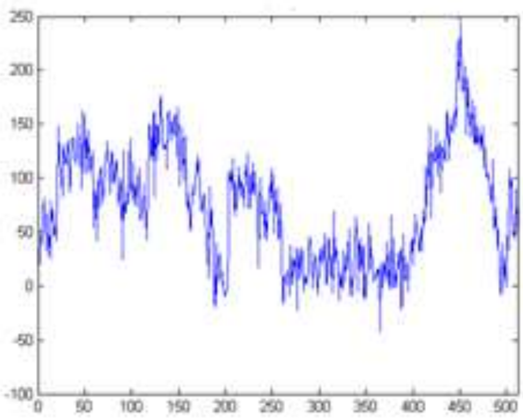


Fig 4. The Proposed Approach

V. RESULT

To find a defect in the bearing, signal acquired through a DAS system, which is get denoised in the pre-processing stage. The signal acquired from the machinery is shown in figure 5.



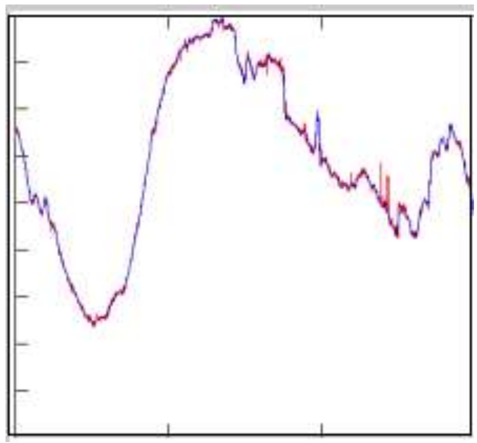


Fig 5. Acquired Noisy Signal

Fig 6. Signal Decomposed by Wavelet Filter

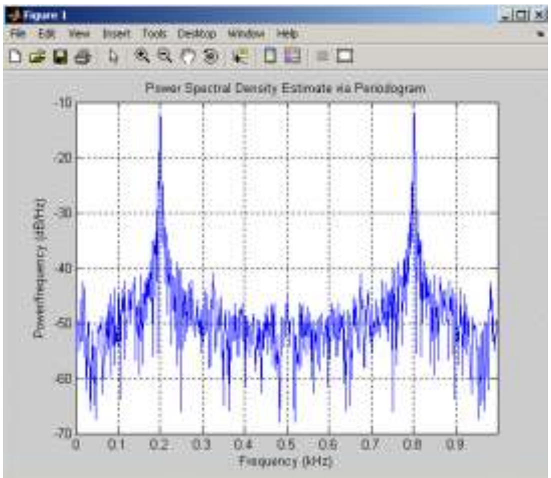


Fig 7. Power Spectral Density of Preprocessed Signal

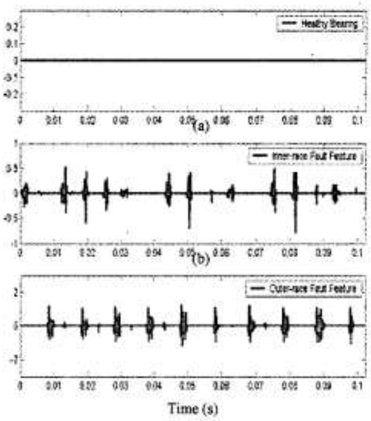


Fig 8. Inner Race Way and Outer Raceway Fault Detected

VI. CONCLUSION

In this paper, a preprocessing step is proposed for the signal acquired through DAS system by wavelet filtering. The Morlet wavelet is used in the next step to detect the noise which is impulsive in nature. This algorithm gives a high efficient result when compared to that of previous work, does not deal with the repetitive nature of noise when encountered in vibrating data.

REFERENCES

[1] Bhende.A.R, Awari.G.K, and Untawale. S.P "Assessment of Bearing Fault Detection Using Vibration Signal Analysis", VSRD-TNTJ, Vol. 2 (5), pp. 249-261, 2011.

[2] Kabir, M.A "An ECG signal denoising method based on enhancement algorithms in EMD and Wavelet domains", TENCON 2011, IEEE Region 10 Conference, p. 284-287, 2011.

[3] Cohen. R, "Signal Denoising Using Wavelet", Project report, Technion, Israel Institute of Technology, Feb-2012.

[4] Torbatiao.M, Kahaei.M.H , and Poshtan. J, "Bearing Fault Detection Using Level-Dependent Noise Reduction Technique", Signal Processing and Information Technology conference, 2003. P-146-149, ISSPIT 2003**.**

[5] Liu. J, Wang. W, Golnaraghi. F, and Kefu Liu "Wavelet spectrum analysis for bearing fault diagnostics", MEASUREMENT SCIENCE AND TECHNOLOGY, IOP Publishing, Vol.19 No.1, p.1-9, 2007.