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Vibration Signal Denoising And Fault Diagnosis Of Rotating Machine: A Review

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Abstract **- Vibration signal plays very important role in fault diagnosis of machine because it carries dynamic information of the machine. Signal processing is essentially needed to process and analyse signal but it is difficult to process and analyse the noisy signal. In many cases the noise signal is even stronger than the actual vibration signal, so it is important to have some mechanism in which noise elimination can be effectively done without affecting the actual vibration signal. This paper presents two robust techniques for denoising of vibration signals corrupted by Additive White Gaussian Noise. The proposed method uses the Stationary Wavelet Transform (SWT) and the Dual Tree Complex Wavelet Transform (DTCWT). The proposed methods are very efficient due to their shift invariance property and have reduced aliasing effect than other methods such as Discrete Wavelet Transform (DWT), Continuous Wavelet Transform (CWT), Short Time Fourier Transform(STFT) etc.**

Keywords- **SWT, DWT, DTCWT, Thresholding, Minimaxi.**

I. INTRODUCTION

A vibration signal based condition monitoring analysis is very well-liked for fault diagnosis of rotating machine. It carries dynamic information of machine thus it is important to make sure that vibration signal should be ruined by noise .Vibration signal acquired and recorded, directly from the outer cage of machine, can be used in fault diagnosis. Vibration signal is non-stationary in nature and when fault occurs in machine, the characteristics fault frequency alters the vibration spectrum. The fault frequency is characterized by sharp peaks at periodic interval of the signal but these are of low frequency.

These signals are modulated by number of high frequency harmonics due to this, characteristics frequency is lost in them and thus an effective denoising technique is needed before using it in fault diagnosis by the means of characteristic fault frequency retrieval. Noise is a carried by the signal. There are different types of noise such as white noise, random noise, coloured noise, impulsive nose etc. This work emphasis on the elimination of the Gaussian white noise from the vibration signal because the characteristic frequency of different fault is impulsive in nature, should not be eliminated from the signal.

A discrete wavelet transform (DWT) is basically multi resolution analysis of signal in both time and frequency domain.[3] Use of wavelet in the field of de-noising the Vibration signal is relatively new, automatic denoising Facility and availability of different thresholding technique, enable it to separate the noise from the signal. A Hard thresholding method based on “keep and kill” reported in reference [4], is applicable to remove the bumpy and impulsive noise from the human body vibration signal. This scheme removes a signal above the threshold value to eliminate the impulsive noisy component from the signal. As it is already mentioned that the characteristic fault frequencies (specially for bearing related fault of machine) are impulsive in nature and if this method is applied for the denoising of machine vibration signal then characteristic fault frequency will be get lost. Characteristics fault frequency is a basic frequency of interest for the fault diagnosis, loss of characteristics fault frequency will mislead the fault diagnosis procedure thus this method cannot be used here to remove the noisy component from the machine vibration signal.

II. LITERATURE SURVEY

During recent years many different ideas have been proposed for fault detection and denoising in which vibration signals are corrupted due to additive white gaussian noise. A brief literature about such methods is furnished here. Arun et Al [1] proposed ensemble empirical mode decomposition (EEMD) based denoising method and discrete wavelet transform and Fourier transform for fault diagnosis of rolling bearing. The denosing result was compared on the basis of RMSE of both Raw-EEMD vibration or TSA-EEMD vibration signal. Wang et al. [2] suggested the Dual Tree Complex

Wavelet Transform (DTCWT), a shift invariant wavelet transform for multiple fault detection. Mortazavi et al. [3] compared the noise performance of various denoising techniques like DWT , WPT, SWT, DT-CWT for partial discharge signals.

Naveed et al. [4] proposed a signal denoising framework algorithm which employs goodness of fit (GOF) test on complex wavelet coefficients obtained via dual tree complex wavelet transform (DT-CWT). The GOF test is used to identify the noisy DT-CWT coefficients whereby statistics based on empirical distribution function (EDF), namely Anderson Darling (AD) statistics, is employed to quantify the distance between the EDFs of local wavelet coefficients and reference white Gaussian noise (WGN) distribution. Abdelkader et al. [5] proposed method is based on a Complete Ensemble Empirical Mode Decomposition with an Adaptive Noise (CEEMDAN) associated with an optimized thresholding operation.

Wang et al. [6] presented the diagnosis of gear fault by power spectrum of vibration signal in time-frequency domain and signal was denoised by EEMD method. Liu et al. [7] used DT-CWT technique for signal denoisng and its extraction for weak gear fault diagnosis. Chaari et al. [8] employed the Short Time Fourier Transform and then Smoothed Wigner–Ville distribution for gear fault diagnosis.

Chen et al. [9] proposed a novel method for identification of gear crack from the low-frequency modulated vibration signal. Hilbert transform were used to present the envelope of the modulated vibration signal to show the modulating frequency. Dybala et al. [10] diagnosed the rolling bearing fault at early stage and employed Empirical Signal Decomposition Methods as a tool. Garde et al. [11] presented two robust techniques for denoising of vibration signals corrupted by additive white Gaussian noise. The method uses the Stationary Wavelet Transform (SWT) and the Dual Tree Complex Wavelet Transform (DTCWT).

Yadav et al. [12] proposed a method based on intra-scale and inter-scale dependency of coefficients of stationary wavelet transform for vibration signal denoising. The parent and children coefficients of the non-noisy signals show larger correlation while these are less correlated in case of noisy signals.

III. PROPOSED WORK

For denoising of signal in the proposed work, the concept of thresholding of averaging of noisy wavelet
Coefficients inside a window are used with both SWT and DTCWT. This is done due to the fact that the wavelet coefficients belonging to signal class are correlated with their neighbours, while wavelet coefficients belonging to noise are not. Thus first of all, the signal is decomposed using SWT and DTCWT which results in separate approximation and detail coefficients for each level of decomposition. The threshold value is selected using 'Minimaxi' method and is level adaptive, that is, for each level a different threshold is selected. Instead of comparing a single wavelet coefficient with the threshold, the average of noisy wavelet coefficients inside a window is compared with the threshold and the centre wavelet coefficient is replaced by the threshold value. This procedure will be repeated for every subband. As shown in Fig. 2, for a window of size 3, the coefficient Wi will be threshold if (Wi-1+Wi+Wi+1)/3 is greater than the selected threshold.

W_{i-1}	W_i	W_{i+1}	- - -	W_n

Fig.1. Noisy wavelet coefficients in a sub band.

The inverse wavelet transform of threshold coefficients provide the denoised signal.

III. DTCWT AND SWT

1. Dual Tree continuous wavelet transforms (DTCWT)

DTCWT stands for 'Dual Tree Complex Wavelet Transform'. As the name indicates, it contains two dual tree wavelet basis functions and due to this property the problem of lack of shift invariance, coefficient oscillation and aliasing effect do not occur [12]. It is very powerful and efficient transform for multiple fault detection and noise reduction. In this transform, two parallel DWTs with different lowpass-highpass filters are used for decomposition and reconstruction of signal and hence it is highly directionally selective. For ψg(t) and ψh(t) denoting two real valued wavelets used for lowpass and highpass filters respectively, the complex wavelet ψc(t) is given by

$\psi c(t)=\psi h(t)+j\psi g(t)$........ (1)

Thus two real wavelets constitute a complex analytical wavelet which is supported on positive frequency axis.

2. Stationary wavelet transforms (SWT)

SWT represents 'Stationary Wavelet Transform'. SWT is also an efficient transform as it is an inherently redundant scheme [11]. The output of each level of SWT contains the same number of samples as the input. Thus for decomposition of N levels, there is a redundancy of N in wavelet coefficients. This makes it a shift invariant transform that is not achieved by DWT. In SWT, shift invariance is achieved by removing the down samplers and up samplers in the DWT and up sampling the filter coefficient by a factor of 2(j-1) in the jth level of algorithm. Fig. 3 shows the signal decomposition in 1D stationary wavelet transform.

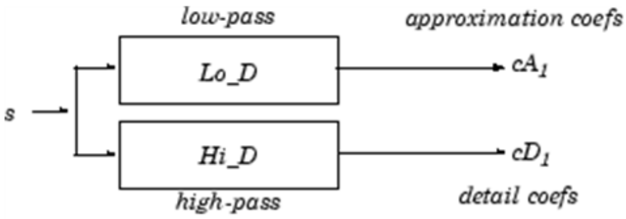

Fig.2. Signal Decomposition in 1D stationary wavelet transform.

IV. VIBRATION SIGNAL ACQUISITION

A standard set of data is collected from the test setup prepared by bearing data centre of Case Wastern Reserve University [13], it is consisting of a 2 hp motor (left) running at the speed of 1797 rpm. The motor shaft is supported by test bearings. An accelerometer is attached to the housing with magnetic bases of the machine to collect the vibration signal from it. The test bench setup for vibration signal capturing and bearing geometry is depicted in Fig. 2 and Fig. 3 respectively,

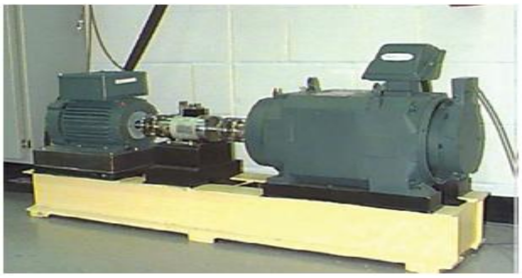

Fig.3. A test bench set-up [13].

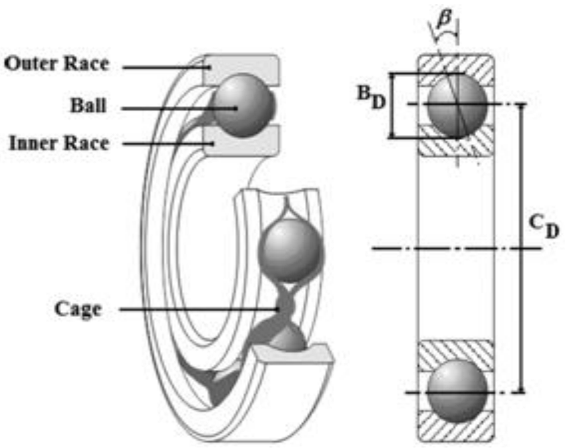

Fig.4. Geometry of a rolling bearing.

Table I: bearing geometrical dimensions

Inside diameter	Outside diameter	Thickness	Ball diameter	Pitch diameter
0.9843	2.0472	0.5906	0.3126	1.537

Vibration signals are collected from the accelerometer by using a 16 channel DAT recorder. The data is processed in a Matlab environment. Sampling frequency of the digital data is kept at 12000 samples / second. Bearing geometry and Size are detailed in Table 1. Speed and horsepower data were collected using the torque transducer/encoder and were recorded by hand.

V. IMPLEMENTATION AND RESULT COMPARISON

The proposed denoising algorithm will also be tested on real time faulty signal. The real time faulty signal is taken from CWRU bearing data Center [13]. Reliance electric motor with torque transducer, dynamo meter and control electronics constitutes the test setup. This signal contains fault in inner race at fan end side. For this signal input SNR is not known, thus for the comparison of results, statistical parameter known as kurtosis [13] is calculated, and is given by the equation

$$Kurtosis(x) = E(x-\mu)4/\sigma4 \;.........(1)$$

Here μ and σ are mean and standard deviation of signal(x).

VI. CONCLUSION

This paper proposses a new and efficient technique of denoising of noisy vibration signals. In the proposedwork, DTCWT and SWT are used instead of DWT as they are shift invariant and do not introduce aliasing. The noisy vibration signal is decomposed into subbands and at each subband coefficients are thresholded according to its average value with its neighbours inside a window. From the analysis of experiments and results, it is diagnosed that SWT gives better results than DTCWT for same window size. Also SWT is easily implemented and is fast, which is a basic need of today for practical applications whereas DTCWT contains complexity due to two wavelet basis functions instead of single wavelet basis function. Further, SWT effectively suppresses the noise and at the same time retains the characteristic frequency of the vibration signal.

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