Model Based Misalignment Prediction by Wavelet Approach

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Abstract
In all kind of rotating machinery application misalignment is the major concern with machinery health monitoring. Usually, misalignment effects are seen at coupling, bearing and at support. In major of previous attempt, the misalignment is predicted by analyzing vibration signals in frequency domain using Fast Fourier Transform (FFT). The analysis of signal using FFT is possible up to single level of decomposition as it loses time domain information. Therefore, to analyze vibration signals at different level of decomposition in both time and frequency domain Discrete Wavelet Transform (DWT) is proposed in this paper. Different mother wavelets are available in DWT which shows different result of analysis for same signals. Selection of mother wavelet is based on characteristics like vanishing moments, symmetry etc. But different mother wavelet may have same characteristics. In such case, shape of mother wavelet matching with shape of original signal is selected for analysis. In this work, under healthy and misalignment conditions vibration signals are collected to extract features using suitable mother wavelet. It is observed that selected mother wavelet, level of decomposition and extracted features are most useful for prediction of misalignment.
Keyword: Misalignment, vibration signal, discrete wavelets transform.

1.INTRODUCTION

Rotating components and rotating machinery are in major stake for industry and industry based application. Though the rotating parts are in aligned state in stationary condition, in due course of time it get slowly added with misalignment when subject to working condition. Mainly misalignment is of two kind i.e. offset and angular misalignment [4]. As rotating parts are in major stake, their condition monitoring becomes vital important task for healthy operating condition of all rotating machinery. Condition monitoring of rotating machinery is majorly practiced with machine vibrations. Vibration signals are identified separately for their unique frequency pattern corresponding to a particular defect. (Such as misalignment, unbalance, crack, bent shaft etc.) The ignored or unattended cases of misalignment results into major downtime. Hence, continuous condition monitoring of aligned condition is necessary in all rotating machinery.

In literature survey, different methods are available for detecting misalignment of shaft. But these methods are generally based on FFT analysis. Ashish Darpe, et.al [16] modeled coupled rotor system using Timoshenko beam elements with six degree of freedom (DOF). The responses for misalignment at coupling and vibrations in bending, longitudinal and torsional modes are studied. Marangoni, et.al has presented studies for misaligned shaft with universal joint [19]. They concluded with observations that harmonics observed with misalignment are even multiple frequencies of motor rotational speed. P.N. Savedra et.al [7] calculated and obtained vibration pattern with misaligned condition for different coupling typesviz.three pin and love joy typerespectively and shown experimental results depicting 1X and 3X vibration signals as misalignment fault frequency. A.W.Leesproposed kinematics of the connecting bolt of coupling with 3-pin and obtained 2X vibration response for introduced misalignment [4]. I.Redmond,et.al [5] have developed a mathematical model representing two rotor –misaligned system considering lateral and torsional vibration. They have developed entire force analysis of system with Lagrange’s method. This study does not claim any second order harmonics present which is a common claim of similar kind of other work. Prabhuet.al[17] proposed theoretical model with two rotor consisting flexible diaphragm coupling. The analysis revealed 2X response for combined unbalance and misalignment and 1X response only for unbalance present in system. The effects are verified for both type of misalignment. They ascertained proportional increase in harmonics with misalignment by FEM analysis.

The above mentioned methods are based on FFT analysis. In FFT, only one level of decomposition is possible as it losses information in time domain. Different methods of transformations are used to convert original time signal from time to frequency domain, dq plane, etc [9]-[15]. For detail analysis of vibration signals during misalignments, multiple level of decomposition is proposed in this paper. Multiple level of decomposition also helps in effective segregation of combined mode of fault diagnosis. In this article offset, angular and combined effect of both misalignments is analyzed using DWT.

2.METHODOLOGY

The proposed method of shaft misalignment is shown in Fig.1. Motor shaft and output are coupled by means of rubber bush coupling. An artificially created misalignment in set up induces forces in system. These forces are measured in terms of vibration at bearing position 2 using accelerometers. The vibration signals are sensed by accelerometer in x, y and z coordinates. The obtained signal is processed and analyzed using DWT.Vibration signals are non-stationary in nature. Non-stationary signals are generally analyzed using DWT [1]. It is required to know whether and also when an incident was happened. Therefore, detailing of non-stationary vibration signals is essential. Such detailing of signals is carried out using DWT. In DWT, analysis of the information signal is converted into scaled and translated version of mother wavelet which is very irregular in nature. Hence, DWT is more suitable for stationary and non-stationary signal. In DWT, original vibration signals are passed through low pass filter (LPF) and high pass filter (HPF). The output of LPF is called as detail coefficients (C_D) and output of high pass filter is called as approximate coefficients (C_A). C_D carries information in frequency domain and C_A carries information in time domain. For further level of decomposition C_A are used. In DWT the C_D and C_A can be expressed as Eq. 1 and Eq. 2.

$$C_D = \sum_{i=0}^{j} V_n(i) \,.\, h(m-i) \quad (1)$$

$$C_A = \sum_{i=0}^{j} V_n(i) \,.\, g(m-i) \quad (2)$$

Where i and m are shifting and scaling parameter of DWT. $V_{(n)}$are vibration signals in three direction x, y and z, therefore n= x, y and z. DWT gives completeanalysis of original information in time and frequency domain. Hence, in common behavior of different operating conditions it may be faulty or healthy. For locating exact fault DWT is more suitable. In this proposed system suitable mother wavelet and decomposition levels is selected by analyzing maximum feature of C_D.

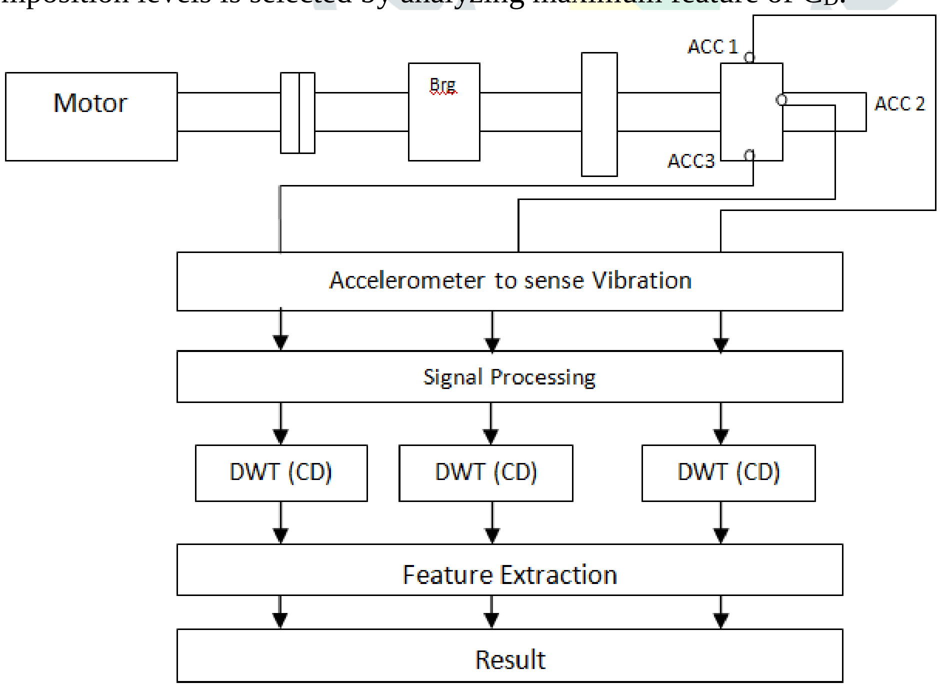

Fig.1. Proposed methodology

3. EXPERIMENTAL SET UP

The experimental setup is shown in Fig. 2. A three phase, A.C. induction, 1 H.P motor is used in experimental set up. A shaft with central load is supported between two bearings to simulate condition with rotating machinery. An arrangement facilitates to have lateral displacement of motor side part to induce artificial misalignment as required.

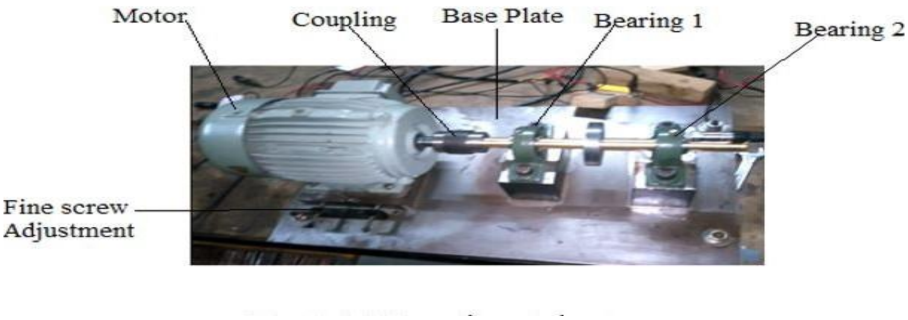

Fig.2 Experimental setup

A suitable range of speed on industrial application based is considered. The maximum permitted misalignment is verified from shaft and machinery alignment handbook. These limits are taken as permissible range for variation of misalignment in the experimental set up artificially. Motor side arrangement is given scope for introducing misalignment artificially. (Offset and angular misalignment). The experimental set up and its result obtained is validated with misalignmentfrequencies of 1X, 2X. It is also compared with vibration diagnostic chart (IS: 10816:01). A 4-channel digital power scope is used to store vibration signals collected with the help of accelerometer, in three directions i.e. X, Y and Z.A Variable Frequency Drive(VFD) (50 Hz, 1.5Amp) is used to obtain precise control and constant speed of motor. Vibration isolator pad are used to damp unwanted structure vibration.

4.RESULTS:

Actual vibration signal obtained from experimental set upare shown in Fig. 3. In this, 2500 samples are collected for different operating conditions of motor. It is seen that overall vibration level is more in the plane of offset misalignment i.e. in lateral direction i.e. 'Z'direction. Sample vibration signal of 1800 rpm with 0.03 misalignments are shown in Fig.3. The FFT is applied for validation of collected vibration signals under healthy and misalignment conditions. As accepted the result of FFT highest amplitude at 1x is obtained as shown in Fig. 4. Hence the results of FFT are authenticating that collected data under various conditions is correct.

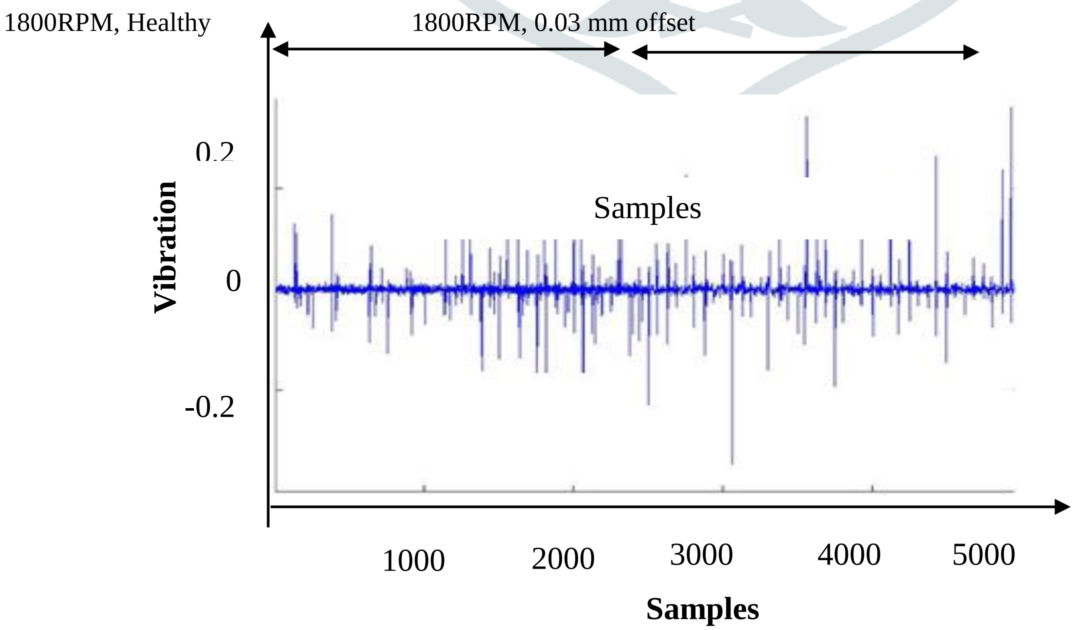

Fig.3. Vibration signal at healthy and 0.03mm offset at 1800rpm.

As level two of decomposition is applied, 625 detailed coefficients are obtained. Packetssize of 625 is used to extract features and maximum value is obtained from each packet. The vibration signals under different conditions are obtained as shown in Fig.5.The extracted Max featureof Detailed Coefficient (C_D)are obtained using Discrete Wavelet Transform (DWT). The obtained Max features are considered for selection of different mother wavelets.

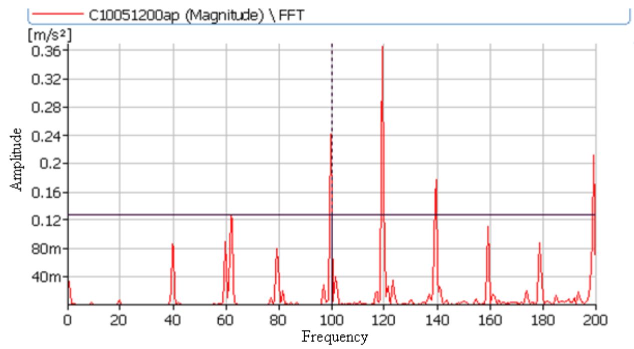

Fig.4. FFT applied to vibration signal to validate collected signals at 1800 rpm 0.03 mm offset

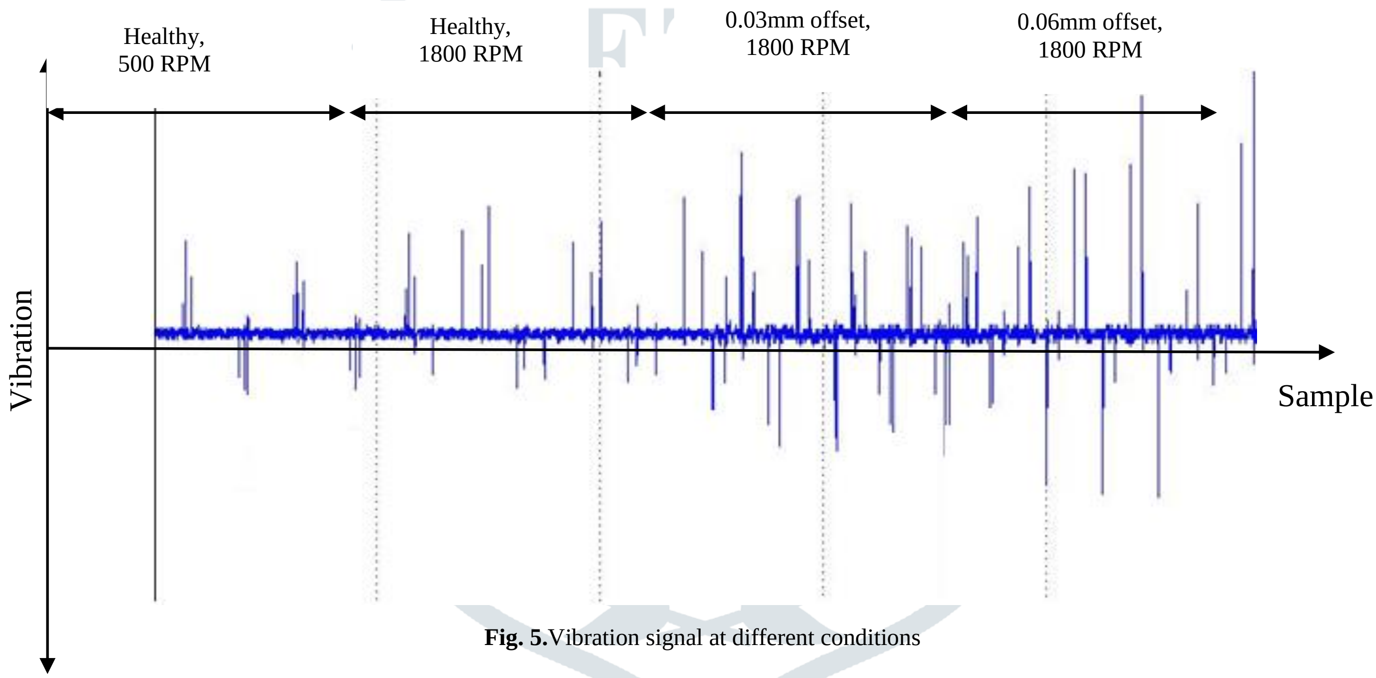

Fig. 5. Vibration signal at different conditions

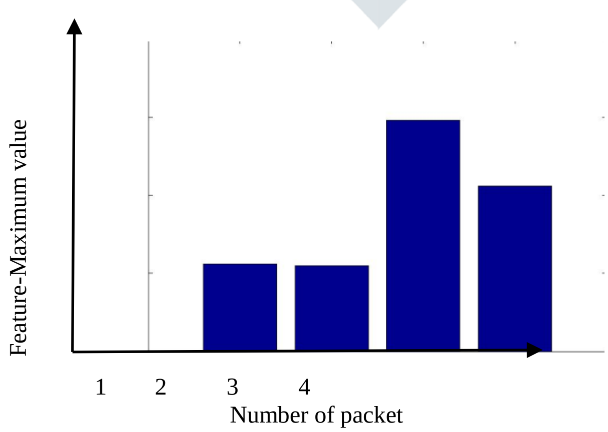

Fig. 6. Maximum features of detailed coefficients obtained using BIOR 1.1 mother wavelet

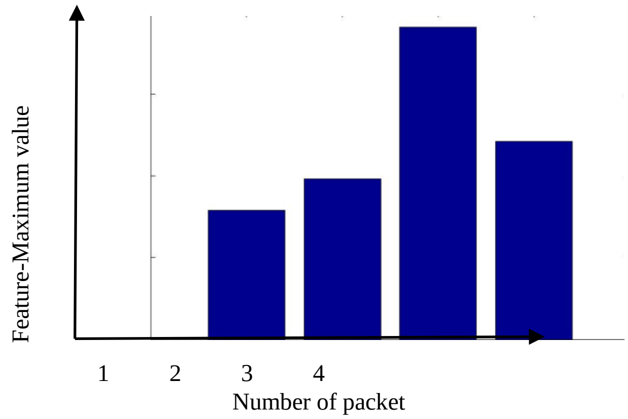

Fig. 7. Maximum features of detailed coefficients obtained using BIOR 1.3 mother wavelet

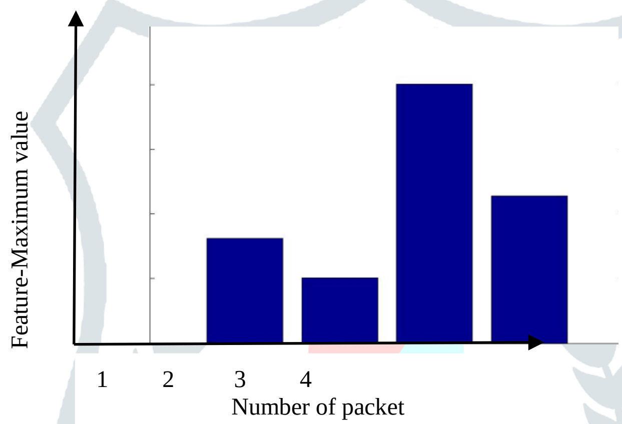

Fig. 8. Maximum features of detailed coefficients obtained using COIF 1 mother wavelet

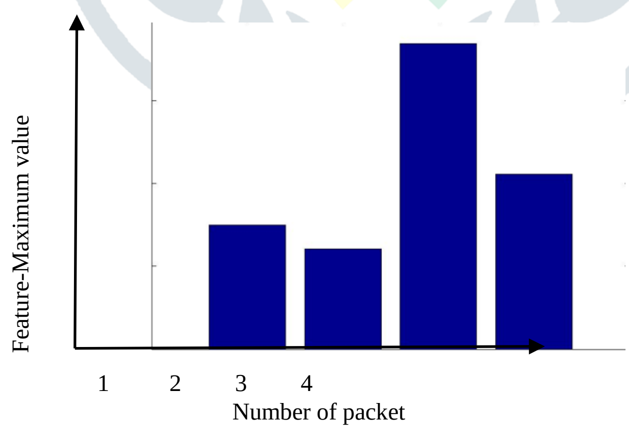

Fig. 9. Maximum features of detailed coefficients obtained using COIF 2 mother wavelet

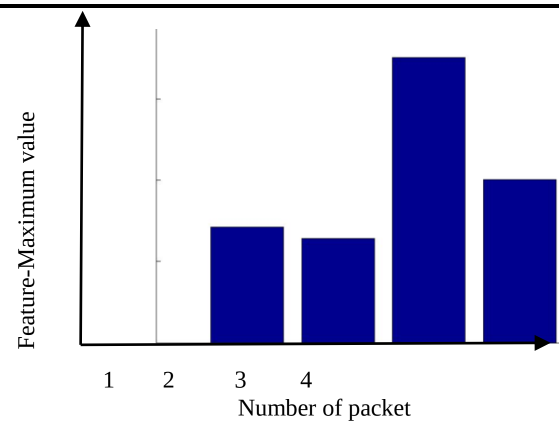

Fig.10. Maximum features of detailed coefficients obtained using COIF 3 mother wavelet

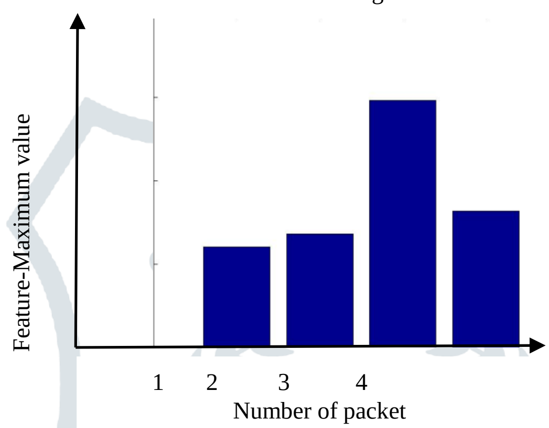

Fig.11. Maximum features of detailed coefficients obtained using DMEY mother wavelet

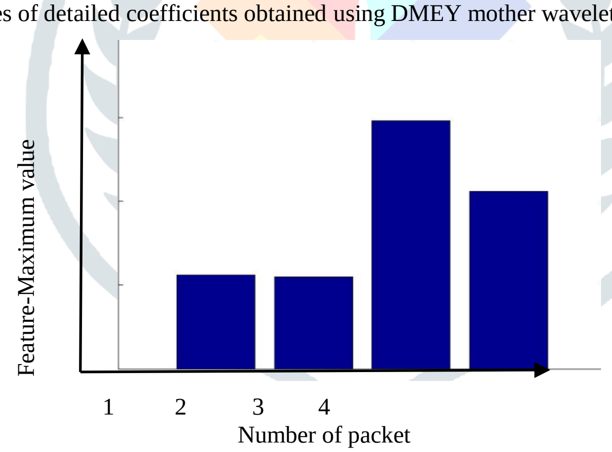

Fig.12. Maximum features of detailed coefficients obtained using HAAR mother wavelet

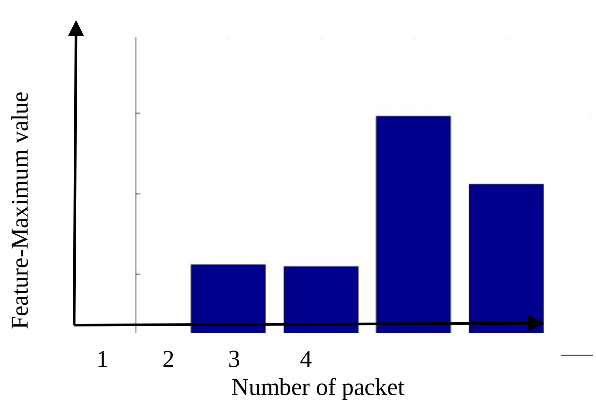

Fig. 13. Maximum features of detailed coefficients obtained using RBIO1.3 mother wavelet

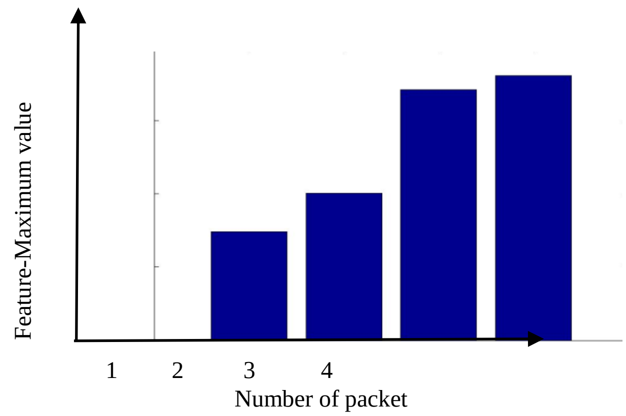

Fig. 14. Maximum features of detailed coefficients obtained using SYM2 mother wavelet

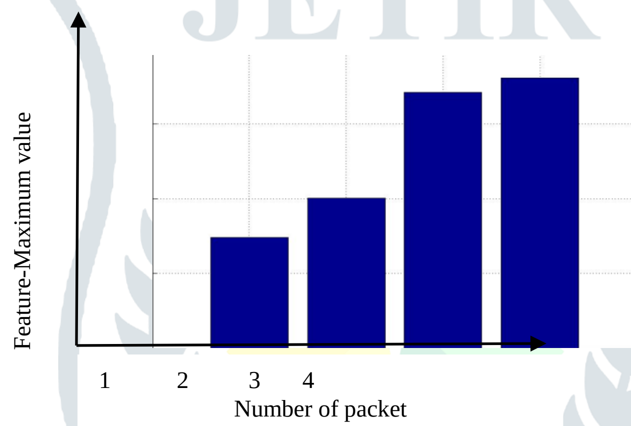

Fig.15. Maximum features of detailed coefficients obtained using DB2 mother wavelet

These wavelets are compared for various level of decomposition. The extracted Max features are compared with different mother wavelet, as shown in Table.1. In misalignment detection,**db2** and **SYM 2** wavelets are found suitable as their Max features for different condition of misalignment are same. These selected mother wavelet can be used for machine learning where monitoring of misalignment in run time condition is very essential.

Table.1. Max features at different conditions using different mother wavelet

Mother Wavelet	Operating conditions			
	500 RPM	1800 RPM	1800 RPM, 0.03 mm offset	1800 RPM, 0.09 mm offset
BIOR1.1	0.112	0.110	0.296	0.212
BIOR1.3	0.158	0.196	0.382	0.242
COIF1	0.161	0.100	0.400	0.228
COIF2	0.149	0.120	0.368	0.211
COIF3	0.142	0.128	0.350	0.200
DMEY	0.120	0.136	0.295	0.163
HAAR	0.112	0.110	0.296	0.212
RBIO1.3	0.124	0.195	0.342	0.274
SYM2	0.147	0.200	0.341	0.361
db2	0.147	0.200	0.341	0.361

I. CONCLUSION:

The offset misaligned condition and their vibration signals are considered for DWT analysis. As per selected range of shaft speed and limit of misalignment, different vibration signals are obtained by experimental set up. For validation purpose, these signal output is verified for misalignment frequency 1X, 2X on frequency. The analysis of non-stationary signals have been done effectively for misalignment detection using DWT analysis.In this analysis, different mother wavelet (db,haar,symetc) are applied. The constant values of Max features are seen withdb 2 and SYM 2 mother wavelet as shown in Table 1. Hence, db2 and SYM 2 are suitable mother wavelet in detection of misalignment.

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