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Detection of Bearing Faults in Rotary Machine using Vibration Signatures

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ABSTRACT

Bearing is one of most important and fault susceptible component of machine. Already various method of bearing fault detection has been adopted in various studied but fault data processing is yet a challenge. Bearing faults in machine produces eccentricity and pitting fault which affects the torque by providing mechanical resistance. This resistance produce vibration and for constant load and speed vibration becomes periodic and amplitude of certain frequencies increases. In this paper investigator has taken four bearing with different fault and severity level. Wavelet and FFT analysis is utilized for identifying fault frequencies.

Keywords: Fault Diagnosis, Wavelet, Rotary Machine, Vibration Signature.

I. INTRODUCTION

Condition monitoring of rotary machines have become an important part of industrial requirements. Production of industry depends on the rotary machines because these are used as prime movers. Failure in prime mover leads to increased downtime and ultimately financial losses. Therefore, researcher has described the fault diagnosis of rotary machine [1]. Failure in machines caused due to electrical (viz.-broken rotor bar fault, inter turn fault and air gap eccentricity faults) and mechanical faults (bearing and gearbox faults). Sometimes combined faults may occur in the machines. According to IEEE motor reliability study motor faults are the most dominant faults (41%) after stator faults (37%) and rotor faults (10%) which leads motor to failure. In industries the rotary machines works under labors and stress conditions and leads to fatigue, vibrations, misalignment, current distortion and loss of lubrication. Such conditions can cause serious bearing race and rolling element problems on consistent working. There are several methods that have been used for diagnosis of bearing faults (viz.-acoustic signal analysis, Motor Current Signature Analysis (MCSA) and vibration signal analysis [2].

This work deals with the recognition of localized faults occurring in bearing of rotary machines. Frequency and time-frequency domain analysis have been done on the acquired vibration signal for detecting fault frequencies for type of fault. Because of the low amplitude of modulating signal in race faults efficient signal processing technique was required. Therefore investigator made use of wavelet transform for fault detection.

II. VIBRATION AND MOTOR CURRENT SIGNATURE ANALYSIS TECHNIQUE

In industrial processes rotary machines may undergo heavy load conditions which increases load on bearings too. Increase in load leads to increase in friction as well as pressure which cause to reduce the lifetime of bearing. Bearing is made up of two rings generally called races (inner and outer) contains roller balls between them. Roller balls are made to fix in a cage so that space between contiguous balls remain same. Fault occurrence in bearing is often due to material fatigue. Every sever fault in bearing start with a crack

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and repetitive action of rolling element convert this to pitting and tearing fault, Such faults are called localized faults. These faults on race of bearing produce impulsive forces which appear in the vibration signal of supporting structure. Nature of these impact forces is periodic for constant speed operation of the shaft.

Frequency analysis of vibration signal produced as a result of periodic interaction between ball and ring can extract the information of amplitude modulation, in which mechanical resonance behave like carrier and characteristic frequency of interaction as modulating signal.

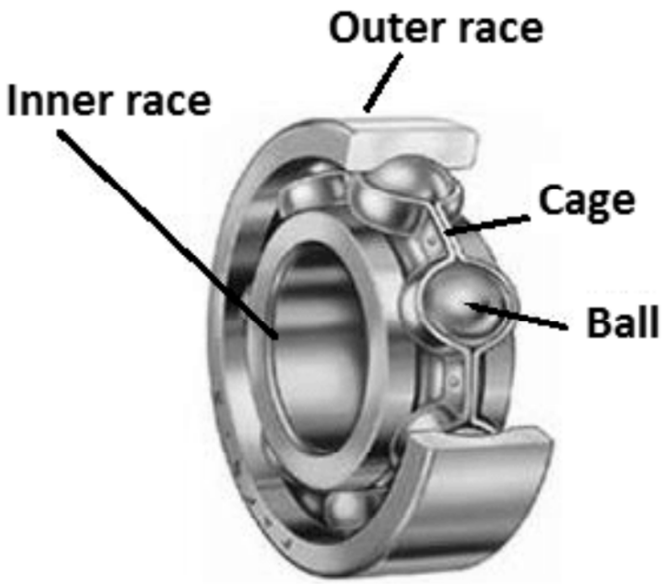

Figure 1: Ball Bearing assembaly

Localization of fault frequency depends on the geometry of the bearing and rotation frequency of shaft. For each type of fault a separate fault frequency exists [3].

$$f_{BPFO} = \frac{n\,N}{2\,60}\left(1 - \frac{d}{D} Cos\,\beta\right)$$

$$f_{BPFI} = \frac{n\ \ N}{2\ \ 60}\left(1 + \frac{d}{D} Cos\,\beta\right)$$

Where, n is number of balls, N is Rotational speed in RPM, d is ball diameter, D Bearing pitch diameter, β is contact angle with race.

It should be noted from the above equations that specific information concerning bearing construction is required to calculate exact characteristic frequency. However, these characteristic frequencies can be approximated for most bearing with six to twelve balls [4].

$$f_o = 0.4\ N_b f_r$$
$$f_i = 0.6\ N_b f_r$$

Where, N_b is number of balls and f_r is rotor frequency.

In various studies researchers conclude that motor current signatures can be used to diagnose the bearing faults. Different researcher's attempts to correlate effects of vibration signal on the current. Researchers have stated that vibration component containing fault frequency of bearing can acts as a torque ripple for a rotary machine and it induces as a speed ripple in motion. This means that fault frequency in vibration can produce a chain of current fault frequencies by the formulae:

$$F_b = | f_s \pm m \ f_{fault} |$$

Where, f_s= Supply frequency, m= Integer 1,2,3.., f_{fault}= f_{BPFI},, f_{BPFO}

A study show that effect of vibration signal on the current is modeled as static eccentricity faults which is combination and backward eccentricity. In outer race and inner race fault bearing, when ball pass over the defected area a resistance is offered to rolling element. When ball every time pass over defected area load torque changes and add extra torque to machine. Various researcher have studied this phenomena and they conclude that this cause the increase in amplitude in stator current periodically.

III. WAVELET TRANSFORM

Wavelet transform have become a dominant signal processing tool for signal analysis in rotary machines and other applications. Although there are other several tools like STFT (Short Time Fourier Transform) and Gabor transform for time series decomposition of signal but investigator have used wavelet transform because dilation in wavelet allows the resolution of analysis to very as mentioned in literature [5]. Wavelet Transform is a tool which decompose the samples or data function in to certain level of frequencies which depends on the sampling frequency of the acquire signal and examine each of the level with its scale [6]. Continuous Wavelet Transform (CWT) is another approach to STFT and other time-frequency techniques which is used to overcome resolution problems. Idea behind CWT is to scale and translate the basic wavelet signal by very small steps in relation to a continuous signal for computation of wavelet coefficient at each step [7].

Many types of wavelet functions are available for different purposes, like Gaussian, Meyer, Mexican Hat, Morlet, Haar and Daubechies. Presently Harr and Daubechies wavelet are prominently used for feature extraction and wavelet functions like these are generally called mother wavelet. Although there is no particular formula in selecting a wavelet and its order but foremost system used is to detect signal visually and match the shape of fault to base wavelet. In this experimentation, investigator has used Daubechies 'db6' at level seven for Discrete Wavelet Transform (DWT) analysis, and the Meyer wavelet is used for CWT decomposition.

IV. EXPERIMENTAL SETUP AND PROCEDURE

Experimental setup of fault detection technique contains 0.25 kW three phase four pole induction motor. Motor mounting was foot mounting type with load arrangement. Motor containing four poles and maximum speed is 1400 rpm. The bearing experiment was done with healthy bearing and faulty bearing (inner race defect and outer race defect). The alignment of rotor shaft was checked every time because misalignment may lead to induction of other faults and vibration and current spectrum indicate false frequencies [8]. It was ensured that the system remain free from defects like unbalance and rubbing of bearing.

Table 1
Experiment components along with specification

Component	*Specification*
LabVIEW	2013
cDAQ NI-9178	8-slot , USB chassis
NI-9234	4 Ch, ±5 V
Induction motor	0.25 hp,4 pole, foot mounted
Accelerometer (piezoelectric type) – 2Nos.	Sensitivity:100mV/g, 93mV/g

Figure 2: Ball bearings with inner race and oute race defects

For acquiring vibration signal two bi axial accelerometers of sensitivity 93mV/g and 100mV/g were used. They were mounted as x and y axis. Four channel NI-9234 data acquisition card was used for data acquisition along with cDAQ NI-9178. Belt pulley arrangement was provided for applying different loads to motor. Other data acquisition setup is shown in Table 1 along with other specifications.

For present study faulty bearings were installed in machine and faults are modeled to induce artificially. Faults were induced in inner race as well as outer race with different dimensions as shown in Figure 2. The ball bearing utilized for this particular experimentation was SKF 6204-2Z. The specifications of bearing are given in Table 2(a) and (b).

Table 2
Ball Bearing 6204

(a) Specifications of 6204-2Z (SKF) deep grooved ball bearing

No. of balls	8
Shaft Speed	12-25Hz
Ball diameter	7.93mm
Pitch diameter	34.49mm
Contact angle	**0^0**

(b) Bearing with induced fault dimensions

Healthy	No Defect
Inner race	2mm, 4mm
Outer race	**2mm, 4mm**

V. DATA ACQUISITION AND ANALYSIS METHODOLOGY

Data acquisition of different bearings under different load conditions was done utilizing accelerometer (piezoelectric type) at two axes. Sampling rate of data acquisition was 12800 and other specifications are given in Table 3.

Table 3
Data acquisition parameters

Parameters	*Data*
Scan rate	12800
Number of samples	48000
Time Record	3.75 sec.
Window	7 Term B- Harris
Sensor Sensitivity	100mv/g, 93mv/g

The data for healthy bearing was acquired initially and bearing was replaced by faulty bearing at drive end. The same process was repeated for other bearings with different faults. The bearing installation in machine was checked every time because other fault could be induced due to bad workmanship. Each bearing with different faults was tested under different load conditions as no load, half load and full load conditions.

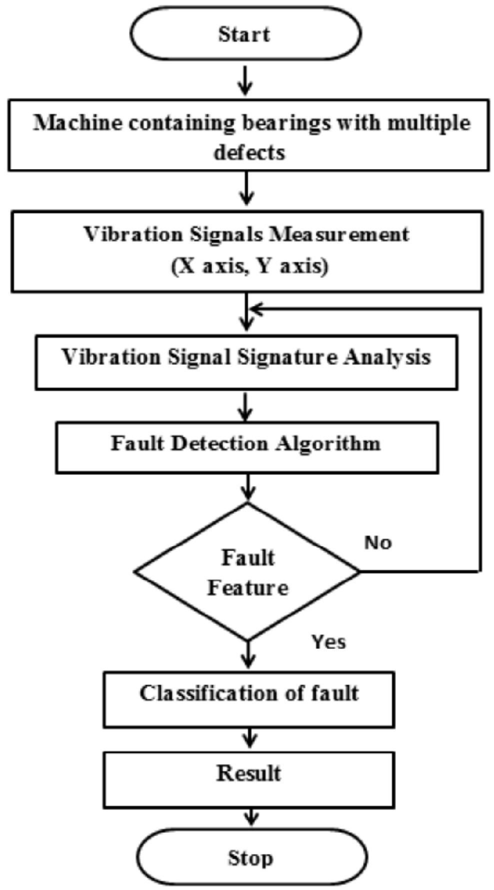

Figure 3: Vibration signal fault detection methodology

The frequency of rotation for different conditions was measured approximately between (12-25) Hz. Signal analysis was done on MATLAB wavelet tool box and FFT was done at particular level of decomposition to locate fault frequencies. Methodology of fault identification is shown in Figure 3.

VI. EXPERIMENTAL RESULTS

Baseline data for healthy and faulty bearing was acquired at 12800 sampling rate and motor was run at full load. Characteristic frequency values for different faults depend on the geometry of the bearing. DWT (1-D) was applied for level seven as shown in Figures 4 to 7, because the characteristic frequencies were in range of 1-100 Hz as given in Table 4. FFT analysis was applied on detailed 7 level to catch the fault frequencies.

Table 4
Fault frequencies with fault

Figure. No.	*Rotor Frequency(Hz)*		*BPFIorBPFO*	*Observation*
Figure 4	*Healthy*	*24.3*	*-*	*Observed*
Figure 5(a),(b)	Inner race 2mm	13.4	64.4	Observed
Figure 6(a).(b)	Outer race 2mm	14.85	47.52	Observed
Figure 7(a),(b)	Inner race 4mm	13.8	66.24	Observed
Figure 8(a),(b)	Outer race 4mm	14.7	47.04	Observed

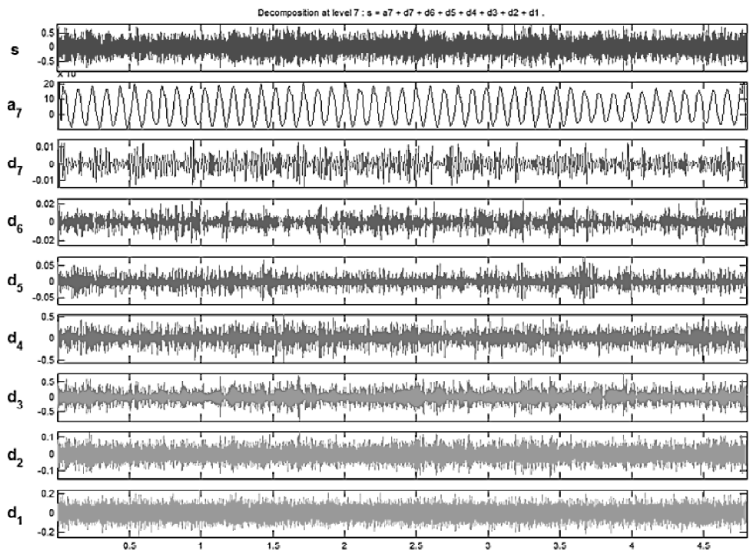

Figure 4: Wavelet Transform of healthy bearing

It is evident from the 5(b) to 8(b) that amplitude of the fault frequency increases as the severity of fault increases. Figure 9 shows that the fault frequencies become more prominent as severity increases. Figure 9(a) and 9(b) shows the prominent fault frequency areas as indicated.

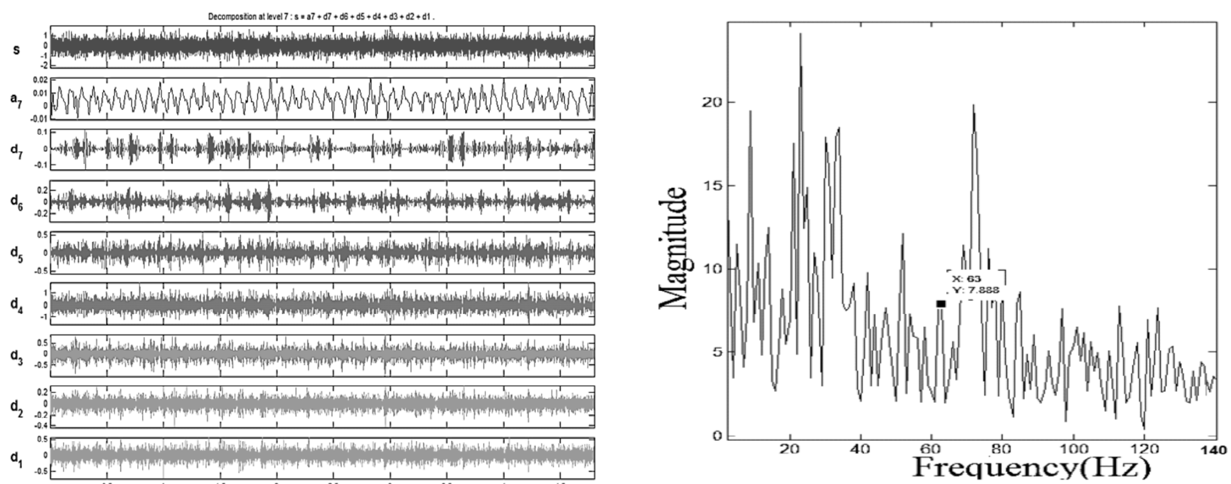

Figure 5: (a) Wavelet Transform of bearing with 2mm inner race fault Figure 5(b) FFT of Detailed level 7

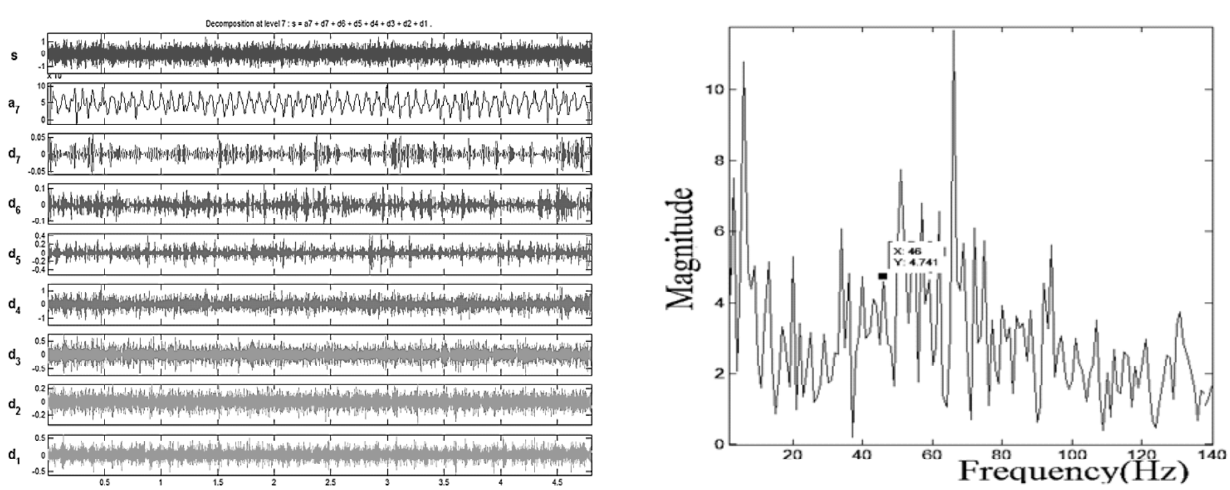

Figure 6: (a) Wavelet Transform of outer race 2mm fault Figure 6(b) FFT of Detailed level 7

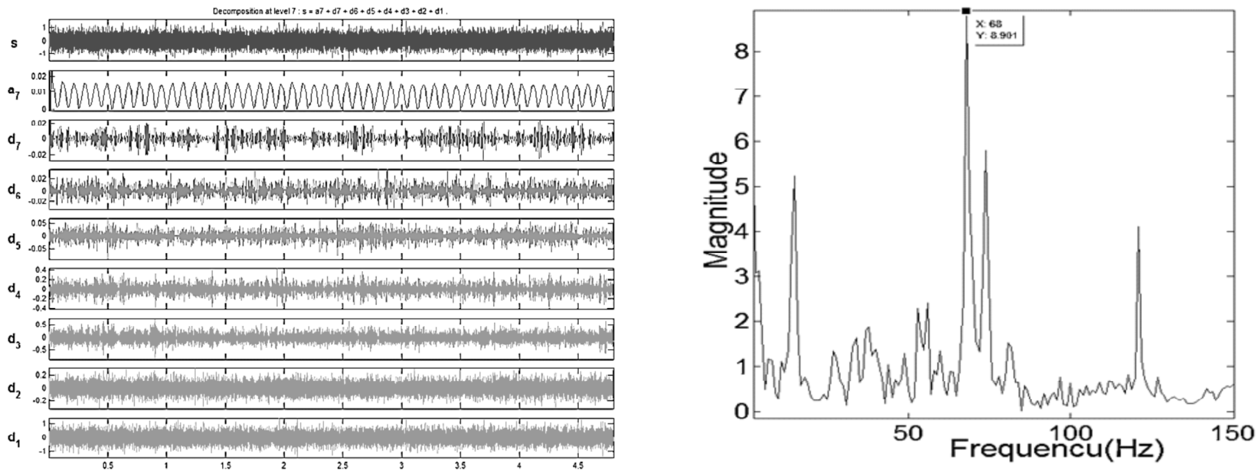

Figure 7: (a) Wavelet Transform inner race 4mm fault Figure 7(b) FFT of detailed level 7

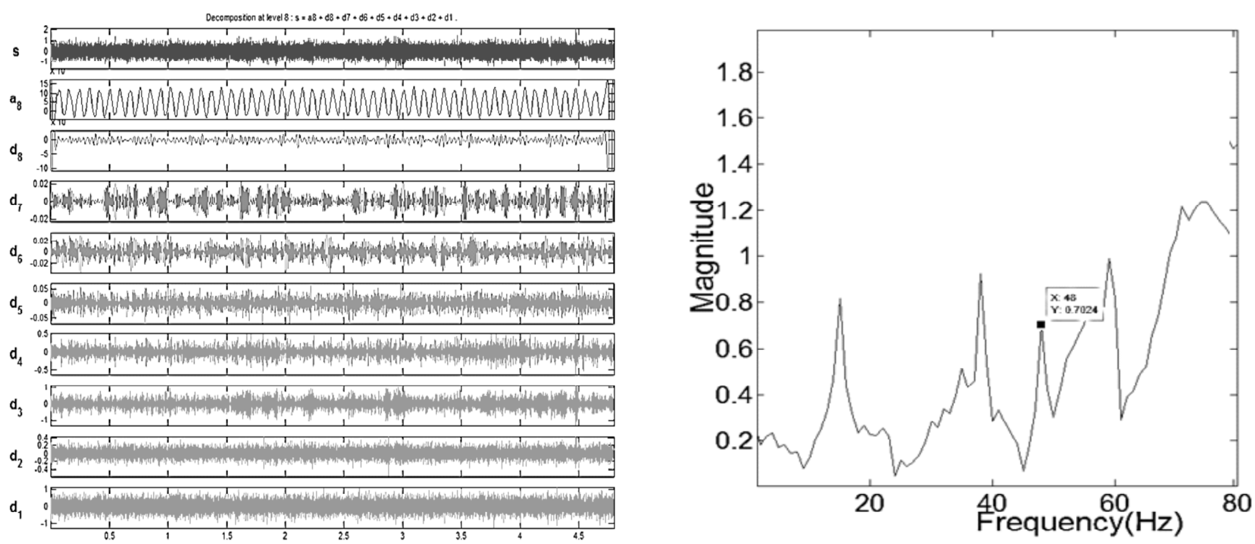

Figure 8: (a) Wavelet Transform outer race 4mm fault Figure 8(b) FFT of detailed level 7

The Figures 9(a) and 9(b) shows the plots of CWT coefficients plotted on time (samples) and scale (frequency) grid. The sampling time is 3.75 seconds corresponding to a total of 48,000 samples acquired at a sampling rate of 12800 samples/ sec. The color indicates amplitude of signal at respective point on the sample scale. The scale parameter may be considered as inverse of frequency as low scales represent the high frequency band and high scales represents the low frequencies.

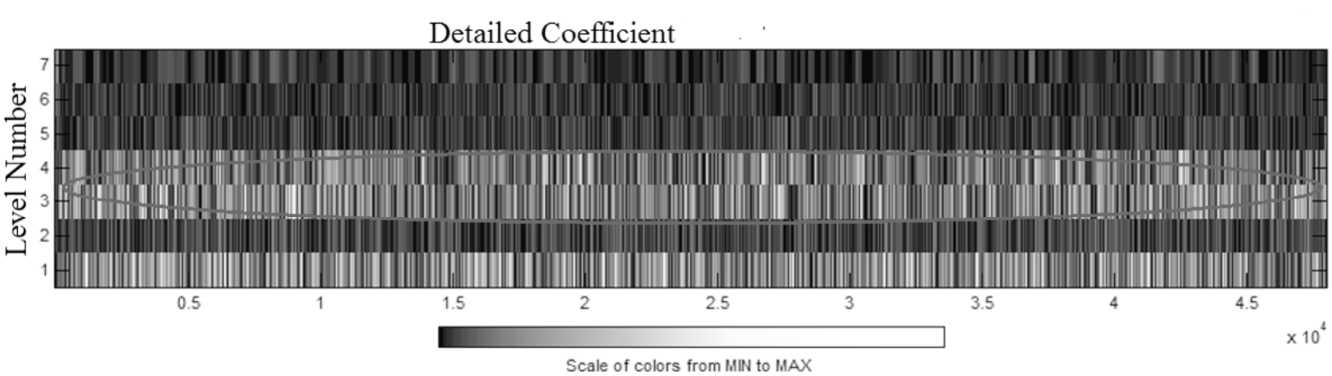

Figure 9(a): Fault spectrum of inner race 4mm fault

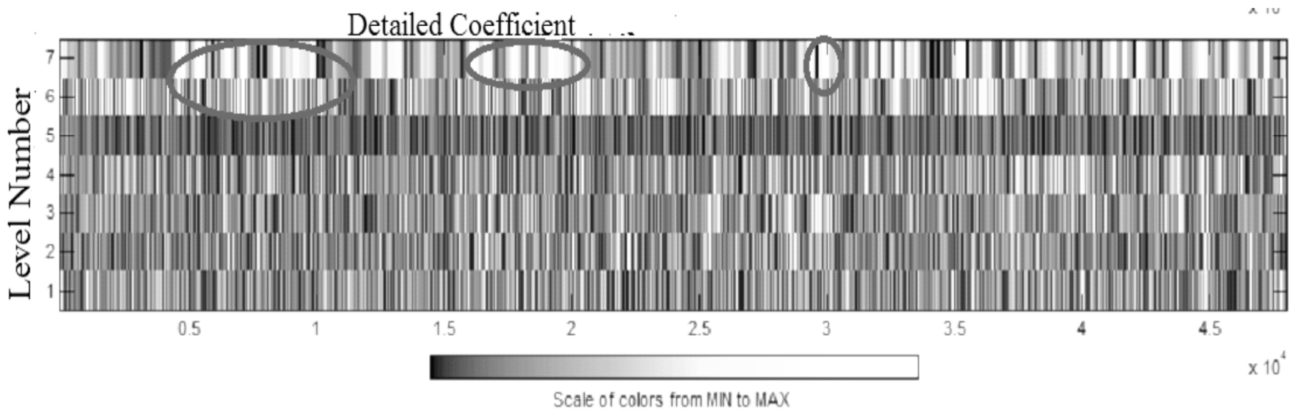

Figure 9(b): Fault spectrum of outer race 4mm fault

When a healthy bearing is operated, the energy level is low corresponding to the low frequency ranges indicated by the dark color. However in case of faulty bearing with outer race defect the structural vibrations due to surface imperfections cause the signal energy to shoot up in the low frequency ranges. This is represented by the bright colored contours in the low frequency range (level 6 and 7), Figure 9(b). The same can be observed at level 3 and 4 for the for inner race defect, Figure 9(a). Thus, the technique gives excellent results and can be used as an indispensable tool for detection of bearing problems such as inner and outer race defects.

VII. CONCLUSION

The result produced from experimentation presented in this paper confirms that bearing faults of rotary machine can be detected by vibration analysis using wavelet and FFT accurately. Wavelet transform provides liberty to control or investigate in time as well as frequency domain. Scaling property of wavelet transform provides researcher an opportunity to scale down signal or decompose the signal to a particular frequency band near to rotational frequency of rotary machine and fault frequencies. It has been ensured that no other fault exists in the system when the experiments were performed.

VIII. RESEARCH TRENDS

Future research may focus towards implementation of other time, frequency and time-frequency domain analysis techniques such as energy and power spectrum estimation and empirical mode decomposition to extract the features from the decomposed wavelet signals. This could be done using appropriate mother wavelet function with suitable analysis techniques at desired decomposition level.

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