Importance of Vibration Parameters in Fault Diagnosis and Condition Monitoring of Bearing and Analysis of Wavelets

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Abstract— *In this paper, vibration parameters help to detect the faults generally occurred in the bearings for the bearing defect diagnosis. Bearing fault diagnosis is important in condition monitoring of any rotating machine. Early fault detection in machineries can save millions of dollars in emergency maintenance cost. Different techniques are used for fault analysis such as short time Fourier transforms (STFT), Wavelet analysis (WA), spectrum analysis, Model based analysis, etc. This Paper explains the procedure for detecting bearing faults using FFT and by using Wavelet analysis more specifically HAAR wavelet up to two levels of approximations and detail components. The analysis is carried out offline in MATLAB.*

Keywords— Bearings, Fault diagnosis, STFT, Wavelet Analysis.

I. INTRODUCTION

Because of the amplitude modulation of the bearing vibration, its vibration spectrum consists of a pattern of equal defect frequency spacing distribution around the resonance frequencies and Condition monitoring in process control industry has got now a day's very big relevance. Diagnosing the faults before in hand can save the millions of dollars of industry and can save the time as well. It has been found the Condition monitoring of rolling element bearings has enabled cost saving of over 50% as compared with the old traditional methods. The most common method of monitoring the condition of rolling element bearing is by using vibration signal analysis. Measure the vibrations of machine recorded by velocity sensor or Accelerometer continuously which is mounted on the casing of the machine. More recently by taking thermal images of bearing also we can diagnose the bearing fault. But the problem in this method is that we cannot diagnose the exact location where the problem occurs. In rotating machines mainly faults This paper focuses on vibration measurement technique and use of Fast Fourier Transformation (FFT) to obtain vibration amplitude versus frequency spectra for the study of bearing fault frequencies to detect and characterize different bearing faults. All vibration occurs at some frequency. Knowing the frequency of the vibration is paramount in diagnosing the problem. This is especially true for bearing. All roller bearings give off specific vibration frequencies, or tones, that are unique. A spectrum from FFT (Fast Fourier Transform) is an incredibly useful tool for machinery vibration analysis. If a machinery problem exists, FFT spectra provide information to help determine the source and cause of the problem. While the presence of certain defect frequencies in bearing spectrum confirms the presence of faults, the amplitude of these frequencies is an indication of bearing condition. A comprehensive review of research papers and articles related bearing fault diagnosis has been presented to showcase various techniques and methods developed in the past few decades.

II. SHORT TIME FOURIER TRANSFORM

For non-stationary machines, the Short Time Fourier Transform (STFT) of the signal should be used to clearly identify non-stationary vibration data related to speed variation, from vibrations caused by the inception of anomalies, Indeed, the PSD may not provide sufficient information about the presence of transient effect, since abrupt change in the time signal is spread out over the entire frequency range. Time-frequency Analysis results are displayed in a spectrogram, which shows how the power of a signal is distributed in the time-frequency domain. Narrow-band, periodic signals, transients and noise appear very distinctly on a spectrogram. The STFT is based on the following mathematical operations,

$$PS(t,f) = \left| \int_{-\infty}^{+\infty} x(t')w_2(t'-t)e^{-j2\pi f t'}\,dt' \right|^2$$

PS is the power spectrogram of the signal $s(t)$ and $2w\,(t)$ is a real and symmetric window translated by *t*. *t* and *f* are the instantaneous time and frequency.

III. FAULT DIAGNOSIS

When a bearing spins, any defect or irregularities in the raceway surfaces or the rolling elements such as indentation, spalls, crack, flaking or irregularities in roundness of the rolling element excites periodic frequencies called fundamental defect frequencies. A machine with a defective bearing can generate at least five frequencies [4]. These frequencies are:

1. Rotating unit frequency or speed (f): This is the frequency at which shaft on which bearing is mounted rotates. It is expressed in RPM, cycle per second (cps) or hertz (Hz).

2. Fundamental train frequency (FTF): It is the frequency of the cage. FTF seldom appears in vibration spectrums as the train hardly carries any load.

3. Ball pass frequency of the outer race (BPFO): It is the rate at which the ball/roller passes a defect in the outer race.

4. Ball pass frequency of the inner race (BPFI): It is the rate at which a ball/roller passes a defect in the inner race. The level of BPFI is often slightly lower than BPFO as the vibration is generated further away from the transducer.

5. Two times ball spin frequency (2 X BSF): It is the circular frequency of each rolling element as it spins. When one or more of the balls or rollers have a defect such as a spall (i.e., a missing chip of material), the defect impacts both the inner and outer race each time one revolution of the rolling element is made. Therefore, the defect vibration frequency is visible at two times (2X) the BSF rather than at its fundamental (1X) frequency.

The equations related to bearing fault frequencies are presented below. These equations are used for Calculating Frequency Factors:

Frequency Factor for inner race:

$$F_{IR} = Z(1+\frac{d}{D}Cos\alpha) \quad \ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

Frequency factor for outer race:

$$F_{OR} = \frac{Z(1-\frac{d}{D}Cos\alpha)}{2} \quad \ldots\ldots\ldots\ldots\ldots \textbf{(2)}$$

Frequency factor for cage or train when inner race rotating

$$F_{CIRR} = \frac{Z(1-\frac{d}{D}Cos\alpha)}{2} \quad \ldots\ldots\ldots\ldots \textbf{(3)}$$

Frequency factor for cage or train when outer race rotating

$$F_{CORR} = Z(1+\frac{d}{D}Cos\alpha) \quad \ldots\ldots\ldots\ldots \textbf{(4)}$$

Frequency factor for ball spin:

$$F_{BS} = \frac{1}{2}\frac{D}{d}(1-\frac{d}{D}Cos\alpha)^2 \quad \ldots\ldots\ldots\ldots \textbf{(5)}$$

Above factors when multiplied with Shaft speed (*f*) gives

Specific Bearing Vibration Frequencies:

BPFI □□f □FIR

BPFO □□f □FOR

FTF □□f □FCIRR

BSF □□f □FBS

Where,

f =Shaft Rotational Speed (Hz)

BPFI =Ball pass frequency inner race

BPFO=Ball pass frequency outer race

FTF =Fundamental train frequency

BSF =ball spin frequency

Z =Number of Rolling Element or Ball

D = pitch circle diameter of the bearing

d =Rolling Element or Ball Diameter

□□=Contact Angle

IV. EXPERIMENTAL WORK AND OBJECTIVES

Condition of bearing has a great impact on power transmission. Defects in bearing may lead to decrease in transmission efficiency, jerk and noise. We have implemented method based on acoustics to identify looseness in bearing arrangement. A proper methodology is selected for this experimental work. The experiments are done on the bearing in a shaft under loading conditions. The bearing contains 13 balls. The outer shell of ball bearing is connected to a motor of range 160 watt and 1400 rpm. A mike is used to record the acoustic signal generated by the bearing assembly. In one set of reading the bearing is without fault. In the other set of reading the looseness in bearing is given. The experiments are done at different defects. The acoustic signal generated by the bearing recorded for 0.1 sec duration by placing the mike near the apparatus .After recording the signal in computer the signal is filtered. After recording the signal in computer the signal is processed. Then proper spectrogram is shown at different conditions for the raw signal, STFT (Short Term Fourier Transformation).

This work shows the ability and feasibility of the application of Short Term Fourier Transform in the diagnostic of faults inserted in the rotating machinery using the vibrations signals during machine run-up. The applications of wavelet analysis using real data, as well as its theoretical and practical aspects of implementation with Matlab and labview software are discussed.

V. EXPERIMENT AND RESULT

In our project we are dealing with four analyses of wear at inner race of the bearing arrangement. Arrangement is tested for different defect conditions. The bearing which is mounted over the motor shaft is our main area of concern because from here we have to record our signal and following is the list of equipment required:

Fig.5.1: Experimental setup

Table.1:

S. NO	EQUIPMENT/ APPARATUS/ SOFTWARE	SPECIFICATION	MAX RPM	OUTER RACE DIA IN MM	INNER RACE DIA IN MM	APPLIED LOAD IN KG
1.	MOTOR	160 watt	1400	NA	NA	NA
2.	BEARING(ARB)	7205B	14000	52	25	NA
3.	MIKE(LOGITECH)	20 Hz to 16000 Hz	NA	NA	NA	NA
4.	MATLAB	Version 7.8.0	NA	NA	NA	NA
5.	LABVIEW	Version 8.5	NA		NA	

Now firstly we took a bearing with no wear at inner race. The bearing got rotated with the help of motor shaft. The RPM is checked with the help of Tachometer and the audio signal was recorded for 0.1second with the help of mike. The signal duration of 0.1 second was ample for our diagnosis. The MIKE used was connected to the Central Processing Unit with the help single pin slot. Certain wave disturbances are clearly visible by this time on the monitor screen. The recorded readings at different speeds got analyzed. STFT is drawn for their particular speeds.

We introduced wear of 0.5mm at outer race and the corresponding signals are drawn and identified in the MATLAB & LABVIEW with the help of certain programs as done in the case of no fault conditions. STFT are drawn at the same speed.

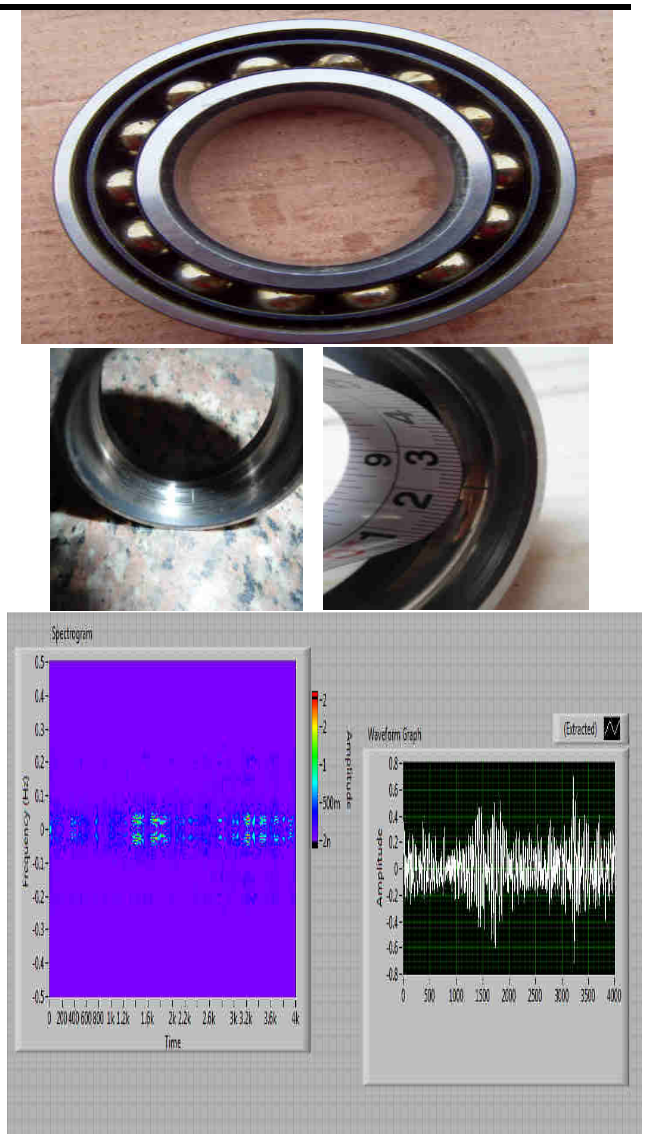

Fig.5.2: Bearing with wear of 0.5mm at outer race with corresponding STFT Spectrum

Next analysis we introduced wear of 1.0mm by width and 0.2mm thickness at outer race and the corresponding signals are drawn and identified in the MATLAB & LABVIEW with the help of certain programs as done in the case of no fault conditions. STFT are drawn at the same speed as done earlier.

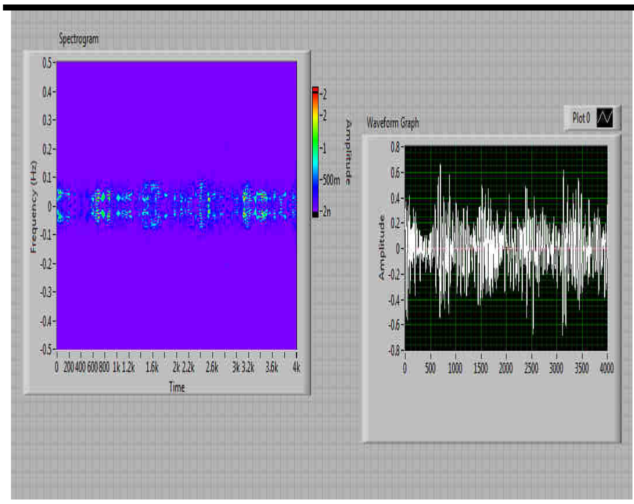

Fig.5.3: Bearing with wear of 1.0mm at outer race with corresponding STFT Spectrum.

Next analysis we introduced wear of 0.5mm by width and 0.2mm by thickness at inner race and the corresponding signals are drawn and identified in the MATLAB & LABVIEW with the help of certain programs as done in the case of no fault conditions. STFT are drawn at the same speed as done earlier.

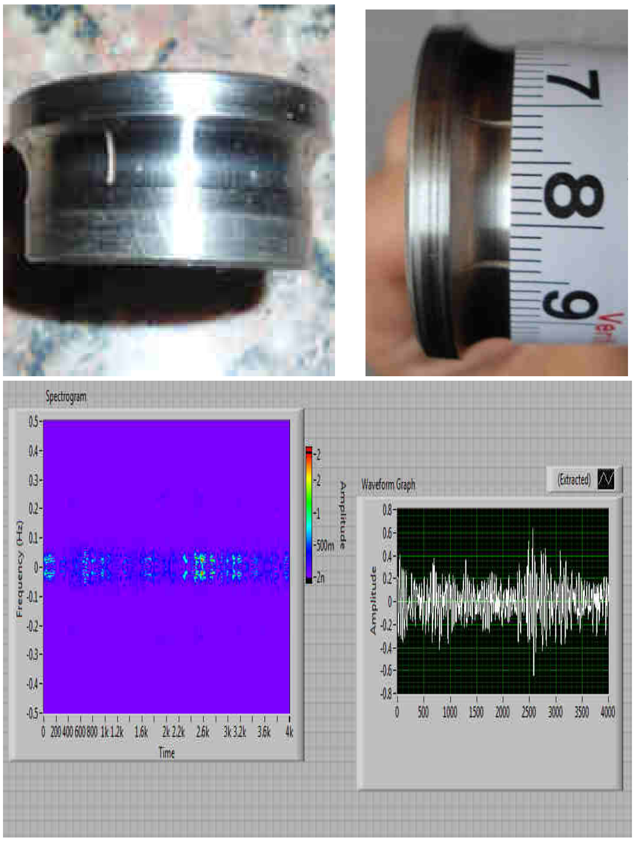

Fig.5.4: Bearing with wear of 0.5mm at inner race with corresponding STFT Spectrum.

Final analysis we introduced wear of 1.0mm by width and 0.2mm by thickness at inner race and the corresponding signals are drawn and identified in the MATLAB & LABVIEW with the help of certain programs as done in the case of no fault conditions. STFT are drawn at the same speed as done earlier.

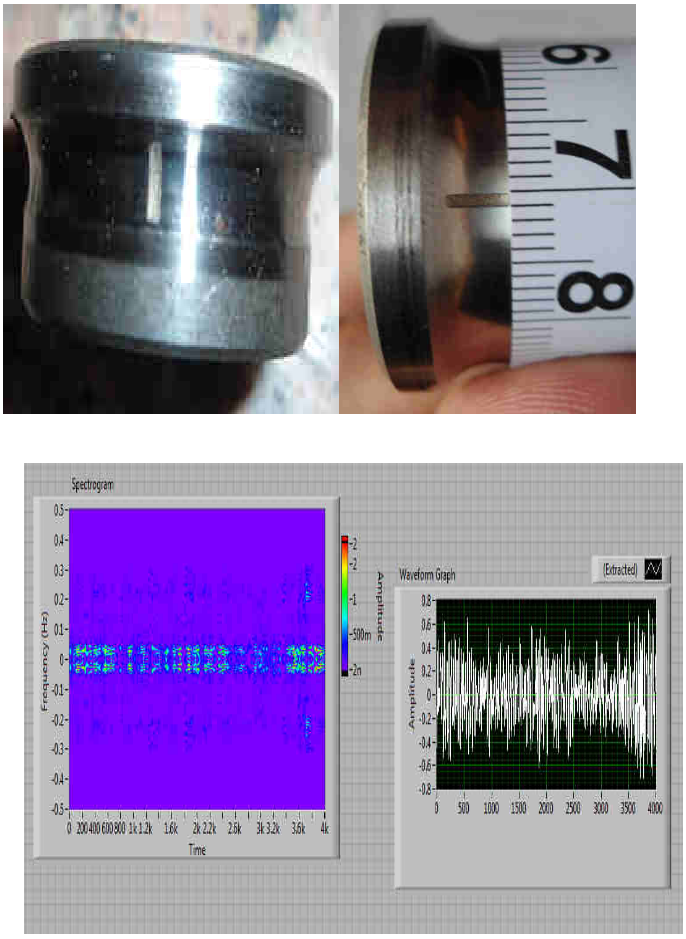

Fig.5.5: Bearing with wear of 1.0mm at inner race with corresponding STFT Spectrum.

These are basically STFT plots for the minimum speeds of all the four signals. Here also the value of the first peak and last peak is given in the graph itself, through which the value of the speed may be calculated.

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Here we feed the data in this place then click on calculate. Our result will be appear in a second which is given below:

Where

d = bearing bore diameter [mm]

D = bearing outside diameter [mm]

P = pitch diameter of rolling element assembly [mm]

D_w = rolling element diameter [mm]

z = number of rolling elements per row

α = angle [degree]

n_i = rotational speed of inner ring [r/min]

n_e = rotational speed of outer ring [r/min]

f_i = rotational frequency of inner ring [Hz]

f_e = rotational frequency of outer ring [Hz]

f_c = rotational frequency of rolling element assembly [Hz]

f_r = rotational frequency of a rolling element [Hz]

f_{ip} = over-rolling frequency of one point on inner ring [Hz]

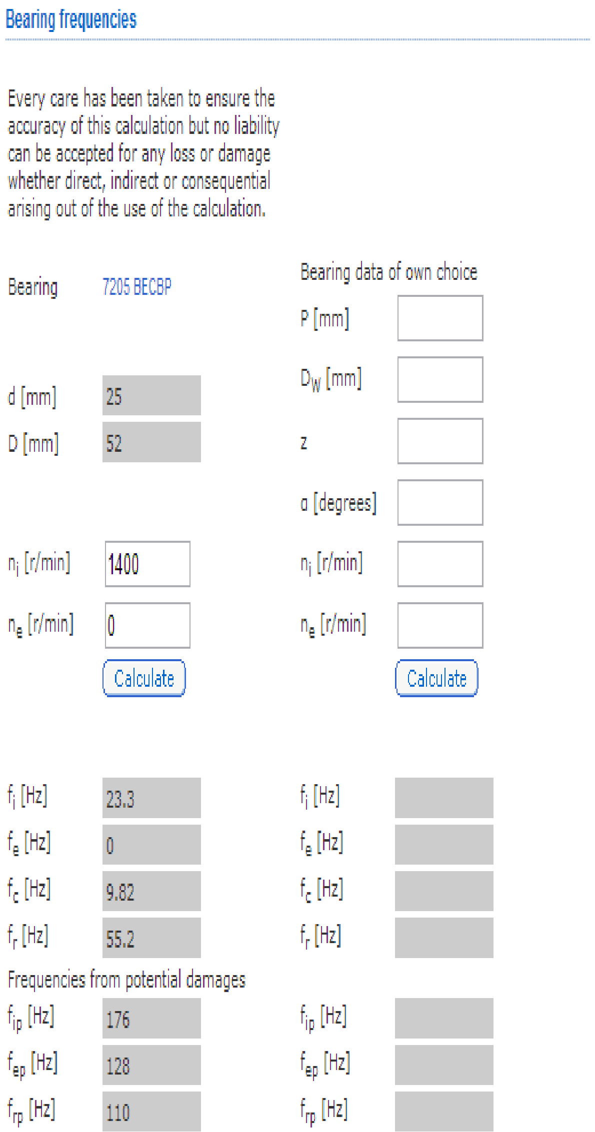
(frequency when one point on inner raceway is damaged)

f_{ep} = over-rolling frequency of one point on outer ring [Hz]

(frequency when one point on outer raceway is damaged)

f_{rp} = over-rolling frequency of one point on rolling element [Hz]

(frequency when one point on a rolling element is damaged. A ball may change its rotational axis and thus not always be overrolled at the same point)



So now we can observe that wear increases the wave shows more disturbance (more up and down) this is because of increase in energy at each individual ball of the bearing because of the wear.

So we can say after observing these graphs we obtained the conclusion that as the wear increases on the shaft the peaks are staggering in the time plot and there is also a significant rise in the frequency obtained in each vibration signal.

VI. CONCLUSION AND APPLICATION

In this project work we have analyzed the effect of wear in bearing system on the spectrum of acoustic and vibration signal and developed a method to identify such defects.

From the experiments following conclusions are drawn.

1. It is demonstrated that, although the environment influences acoustic signal for condition monitoring, it does not significantly reduce the extraction of useful diagnostic information. It has been demonstrated that acoustic condition monitoring can effectively be used for fault detection in bearing arrangement.
2. It shows the STFT and Decomposition spectrum for the cases of misalignment responded equally.
3. In vibration monitoring using acoustic signal have certain advantages over the conventional vibration measuring techniques. Firstly in this sensors do not alter the behavior of the machine due to its non contact nature. And time based information is not lost in this method.
4. Acoustic based method provides considerable freedom in positioning of the microphone. For instance, in this application, small variations in distance and plane of the microphone with respect to the bearing had a little influence in detecting the main characteristics of the bearing acoustics. On the other hand, small change in the location of the accelerometers based method had a bigger impact in detecting the main characteristics of the bearing vibration.
5. The method developed in the project can be used for the condition monitoring and for predictive maintenance of the ball bearing for the wear.

   This process can be used for live analysis of other machines, example internal combustion engines, Compressors, Turbines etc. we will use our this topic of vibration and acoustics for fault diagnosis in the higher studies as here a very vast scope is available.

1. Condition Monitoring of lathe using decomposition (an application)

Condition of wear of tool in the machining has a great impact on surface finish. I have implemented methods based on acoustics to identify defects due to wear The proper methodology is selected for this experimental work. The analyses are done on machine tool under varying wear conditions.. A mike is used to record the acoustic signals generated by the machine assembly. The acoustic signals generated by the set-up are recorded by placing the mike in front of the rotating job . In this way we are analyzing the effect of wear on the spectrum of acoustic signals and developed a method to identify such defects.

2. Decomposition

The decomposition process can be iterated, with successive approximation being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called the wavelet decomposition tree.

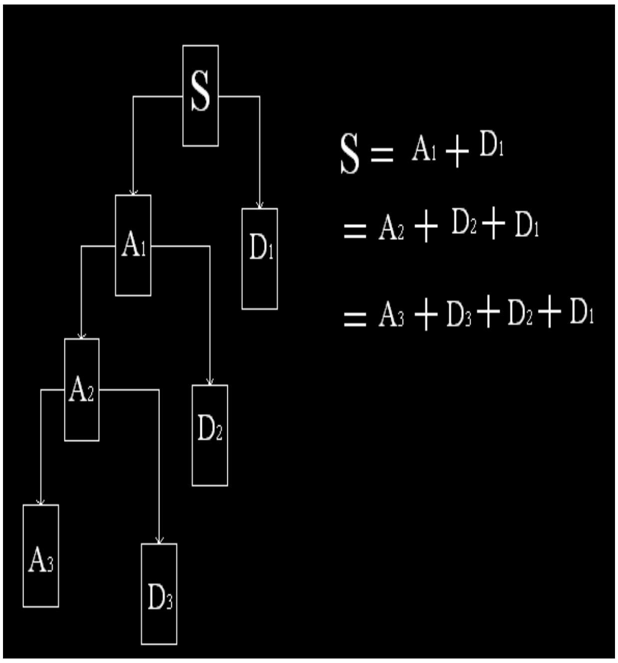


Fig.6.1: Decomposition Tree

3. Experimental Setup

The setup consists of rotating work piece on lathe and condition monitoring is done for different wear condition of the tool. The signal is recorded by placing mike 2cm away from the tool. The signal is recorded for different condition of the tool after recording the signal processing is done on the mat lab. Decomposition is done up to 6th level and from the decomposition tree condition is monitored.

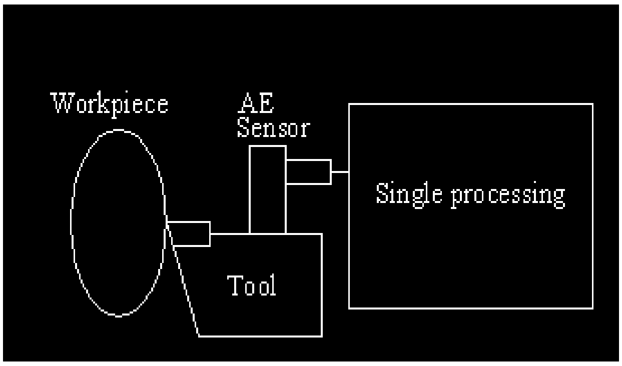


Fig.6.2: Experimental Representation

4. Decomposition diagram

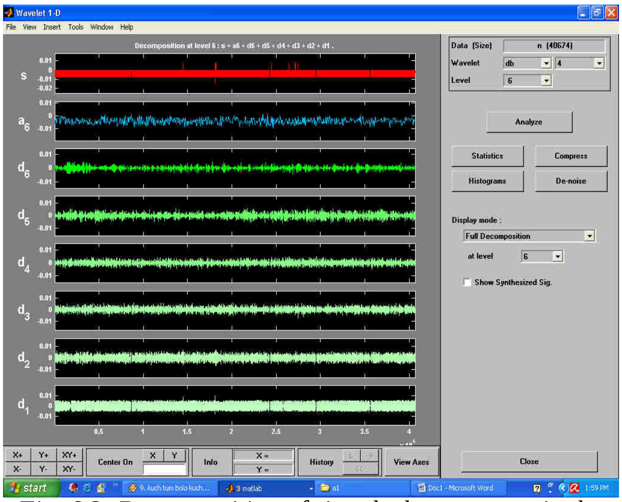


Fig .6.3: Decomposition of signal when no wear in the tool.

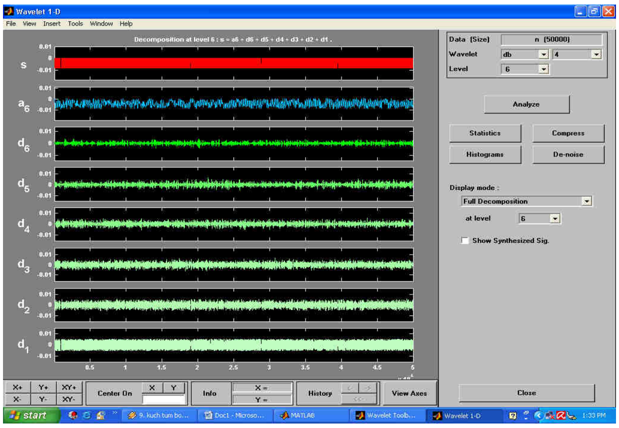


Fig.6.4 : Decomposition of signal when slight wear in the tool

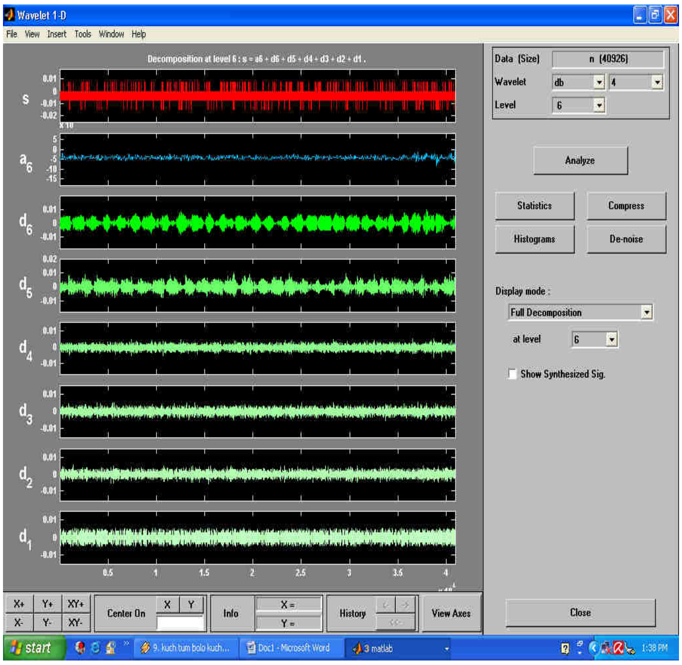


Fig.6.5: Decomposition of signal when more wear in the tool

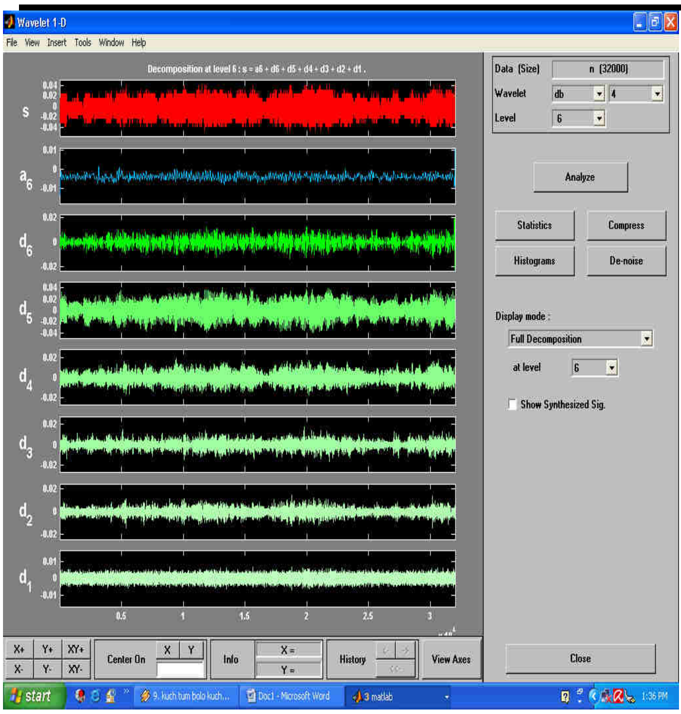


Fig.6.6: Decomposition of signal when much more wear in the tool

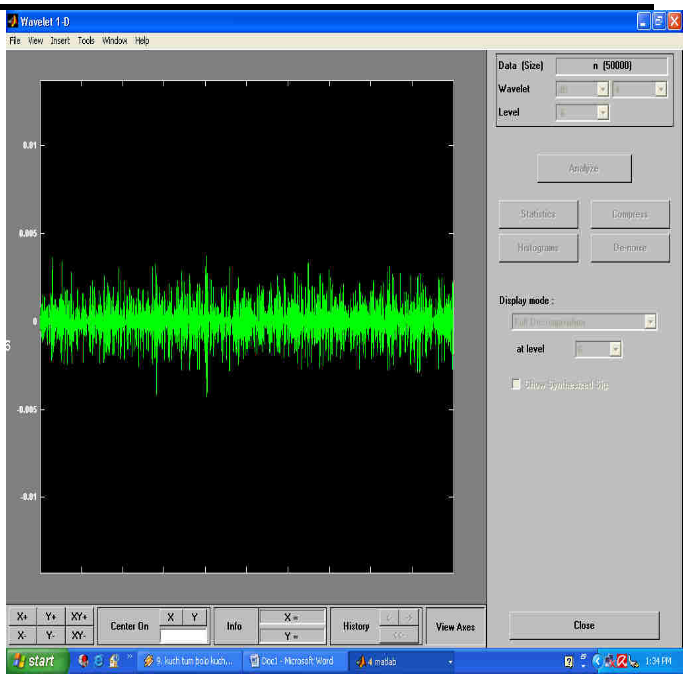


Fig.6.8: Decomposition of signal at 6^{th} level when slight wear in the tool

5. Detailed view of 6^{th} level decomposition

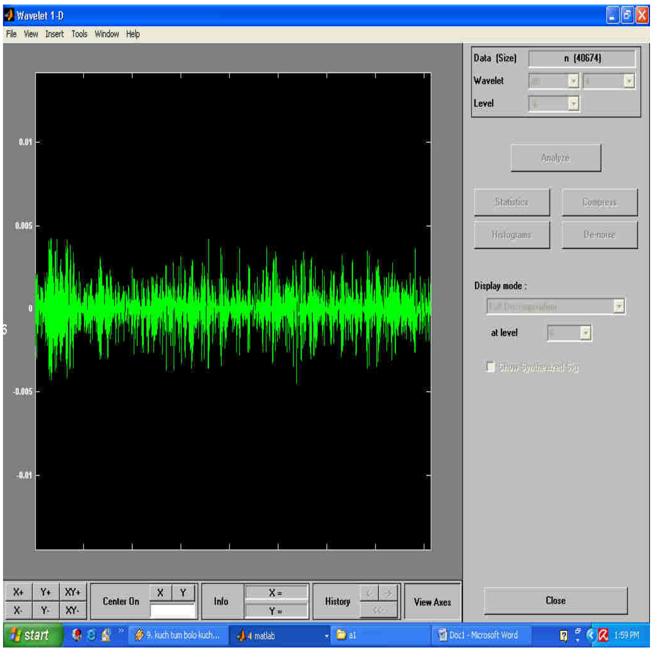


Fig.6.7: Decomposition of signal at 6^{th} level when no wear in the tool

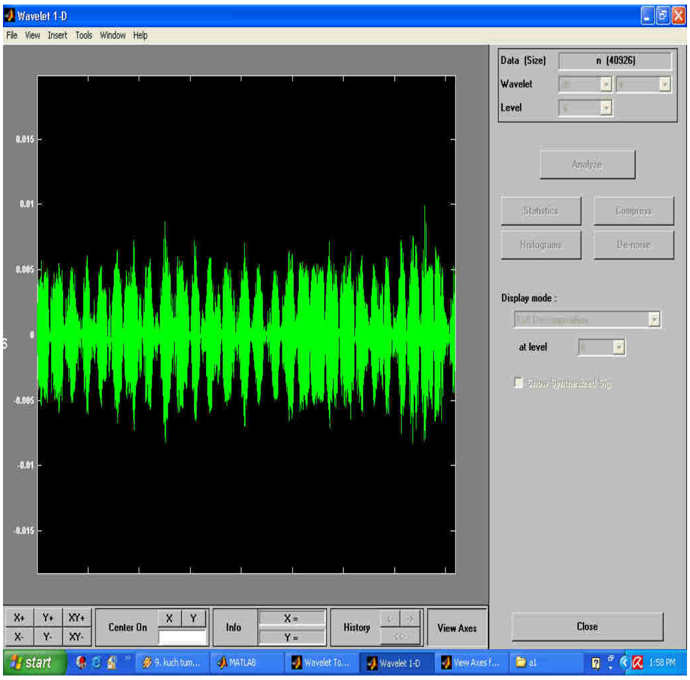


Fig.6.9: Decomposition of signal at 6^{th} level when more wear in the tool

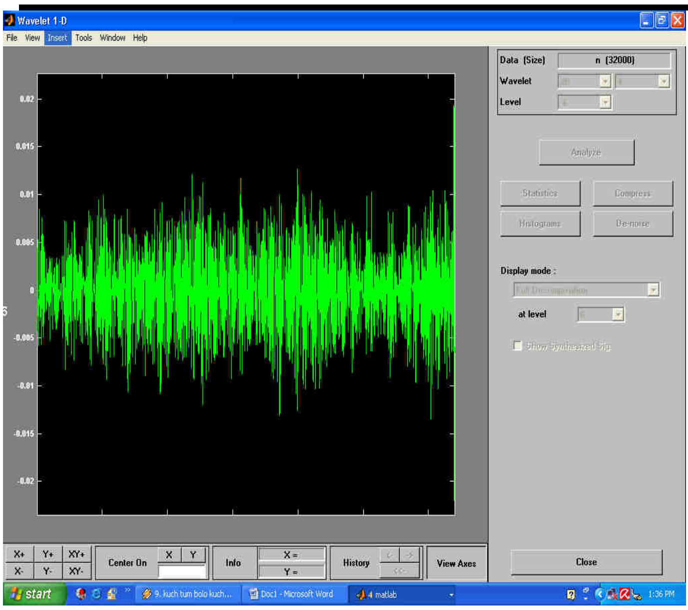


Fig.6.10: Decomposition of signal at 6th level when much wear in the tool

And from decomposition tree we can find the conclusion that as the condition of tool deteriorating the decomposition peak gives clear representation.

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