Detection of outer race defect in bearing using signal processing techniques

Manpreet Singh*, Rajeev Kumar*, Sumit Shoor*, Piyush Gulati*, Jaiinder preet Singh*, Harpreet Singh**

*School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab-144411

**Planning and Quality department, Nettbuss AS, Oslo, Norway

Abstract

Bearing is an important element in any machine as most of the failures are happening due to bearing failure. Therefore, bearing needs to be inspected for its faults regularly to verify its health so that shutdown of the machine should not occur during its repair. This paper aims to review the trending techniques used in the detection of bearing faults using signal processing of the vibration signal. The main advantage of using these techniques is that one needs not to dis-mental the bearing for the purpose of inspection. The paper is mainly structured in two parts. In the first part the main signal processing techniques are discussed. In the second part signal was taken from the defective bearing and results were drawn in context by using signal processing techniques.

Introduction of Bearing

Bearing is a machine element made of highly precision which enable to take extremely high speed and for taking high load's at good efficiency for machine component. It generally supports rotating shaft with high precision and reliability. Therefore, bearing is having vast number of applications such as construction machinery, automobiles, machines, turbines, motors and many more applications [1-2]. The main function of bearing is to ensure stability of rotating shaft with having various loads acting in different directions. In addition to this bearing has to provide frictionless rotation of shaft without slip.

1.1 Bearing failure

In any machine bearing failure is highly significant because there may be a complete failure in machine because of it. So, the bearing is highly substantial part to be taken care through predictive maintenance so that we can predict the failure before it occurs [9-11]. The main failure characteristics of the bearing can be in the form of bath tub curve (BTC). The BTC is shown in Figure 1.

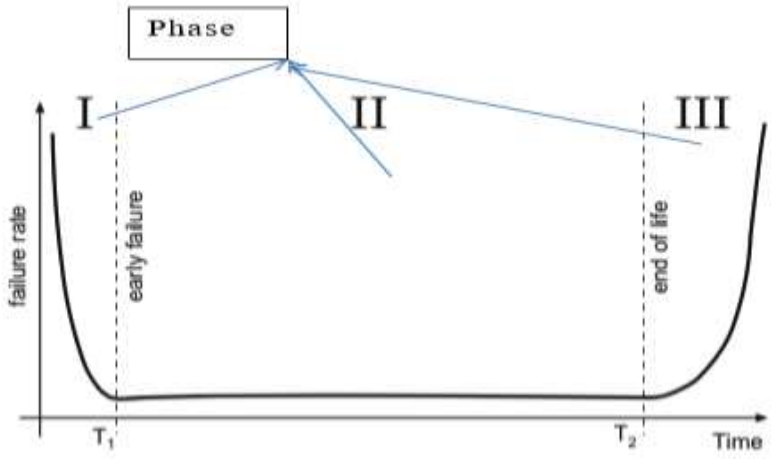

Figure 1: Bath tub curve

There are three regions in this BTC that define the failure rate of bearing according the time.

1) Phase-1: Infant mortality (initial running-in) phase 2) Phase-2: Useful (normal operating) phase 3) Phase-3: Wear out phase

Infant mortality phase basically shows the premature failure in the bearing. This is the main phase where the studies the prominently applied. In this region of highly concern for the person doing failure study. Second phase is basically smooth where rate of failure is minimum but after crossing this phase normally wear and tear occur in bearing and bearing enters in wear out phase. In the wear out phase bearing in general fails after spending its normal life. In the early phase bearing in general fails because of the crack initiation which grows with the normal usage and as a result bearing fails. There are number of signal processing techniques through which we can detect the defect location and even its size and type [6,7,10].

1.3 Signal processing

Bearing is one of the crucial components in any rotating machinery because this part is under heavy loads. Bearing is a kind of fault initiation, in bearing is very crucial and it has to be detected before bearing completely fails. From the raw signal it is difficult to identify the fault at incipient stage because of its weak signature. So, signal processing techniques are applied to identify the fault. In our case study we have selected induced outer race defect to be analyzed by using different signal processing technique and hence we will check their effectiveness.

In vibration analysis signal is being captured from the vibrating machine by transducer and with help of data acquisition system (DAQ). Signal is stored in the computer system. Signal processing techniques can be applied on the signal to extract the useful information. The main defect or failure occurs in rotating part in any machinery like in bearings or gears.

The main working of signal-processing based techniques is shown in Figure 2. In this firstly raw signal was recorded using transducer which converts physical signal into voltage. Then signal in the form of voltage goes to Data acquisition (DAQ) device and signal gets converted into readable values format. Then analog signal is converted into digital for the purpose of processing in analog to digital convertor (ADC). After processing signal again gets converted from digital to analog form in digital to analog convertor (DAC). Then signal gets analyzed for final results.

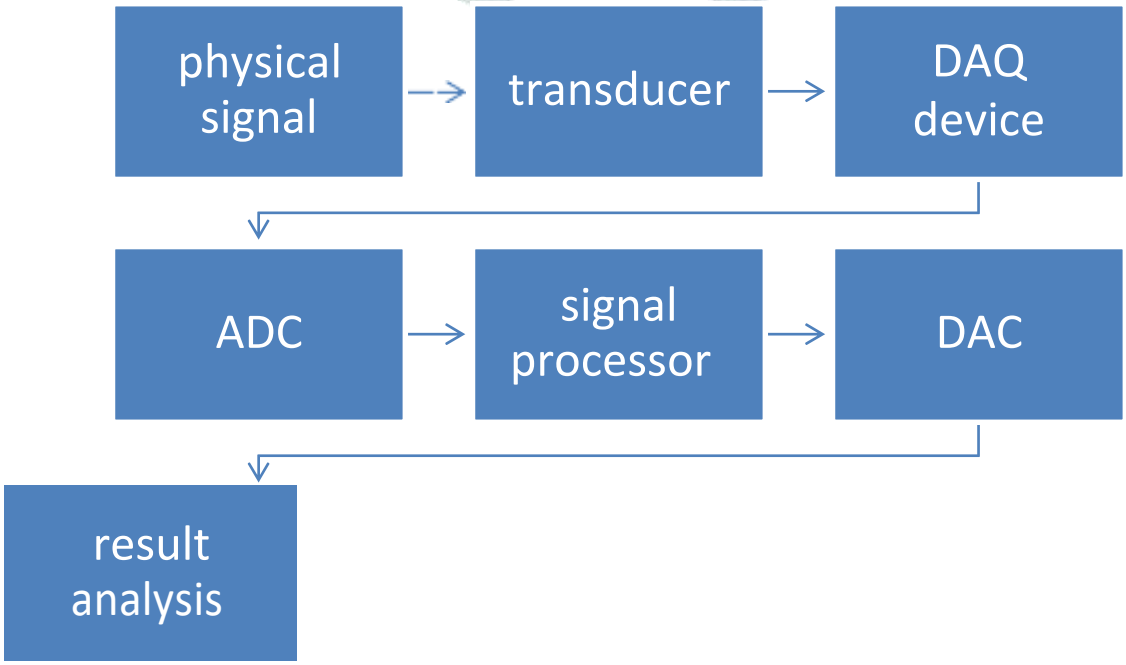

Figure 2: Signal processing technique

Transducer

Piezoelectric transducer is used to capture the vibration signal from the bearing and it cannot be recalibrated or adjusted. It contains piezoelectric crystal and whenever, stress is applied it start producing current. High level of stress and temperature can damage it so it is always specified with the temperature and load range by the manufacturer. In carrying out the experimentation we have used PCB make transducer with model number 353b34. The mounting of this transducer requires smooth, flat contact surface for proper operation.

Data acquisition

Data acquisition systems, basically interface between machine and computer that record the physical signal from machine by transducer and convert that signal into computer readable language that can be processed in the computer. We have used NI make data acquisition system model no. USB-4431 for experimentation.

Analog to digital Convertor (ADC)

The computer software that we use for analyze the recorded signal or raw signal cannot understand the electrical signal. Electrical signal is not processed by software so we require changing the electrical signals into digital signal that can be understand by the computer.

Digital to analog convertor

This type of convertor takes up the data from computer in the binary form to convert it into analog data. This is facilitating the user to read the data easily and in understandable mode.

Signal processor

Vibration signal is a carrier of useful information in terms of amplitude , phase, frequency and shape. Signal processor processes the signal to refine and analyzing the recorded raw signal and give the useful information about the signal.

1.4 Signal processing techniques

Broadly signal processing techniques can be classified in three types Time domain, Frequency domain and Time-Frequency domain.

Time domain techniques

The signal recorded from any machine component through DAQ device has to be processed and drawn in simple amplitude vs time graph. This graph is known as the raw signal which gives the information of the events in the time domain. A typical raw signal is shown in Figure 3. The one can have the information about amplitude vs time graph and can measure the statistical parameters to extract the useful information [11]. Each statistical parameter is having its own characteristic. These types of techniques are widely used for the distributed kind of defects such as wear out surface and also defects like misalignment and loading conditions [9-11].

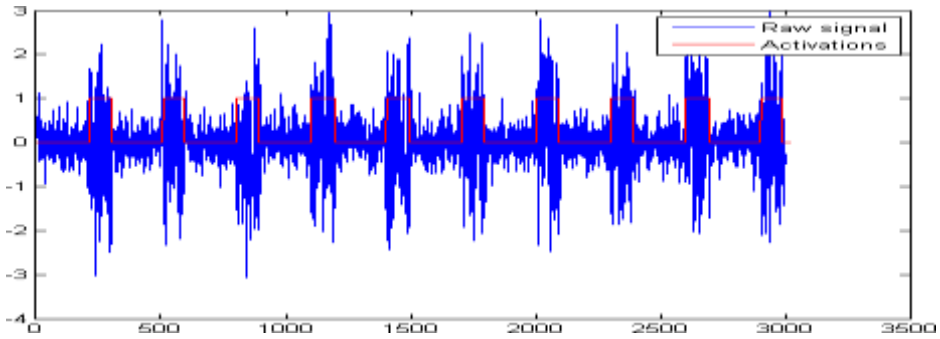

Figure 3: Raw signal

Frequency domain techniques

The most prominently used technique for frequency domain is Fast Fourier Transformation (FFT). The FFT of raw signal changes the time domain signal to frequency domain and during this time domain information is completely lost. It generally converts the signal into two part real and imaginary and in general real part is plotted for the representation. The frequency contents of raw signal are displayed in the graph and one can see the frequency contents strongly present in the signal [6-9]. It is possible to re-construct the raw signal from the FFT graph by using the function inverse fast Fourier transform IFFT. The application of FFT and IFFT is shown in Figure 4.

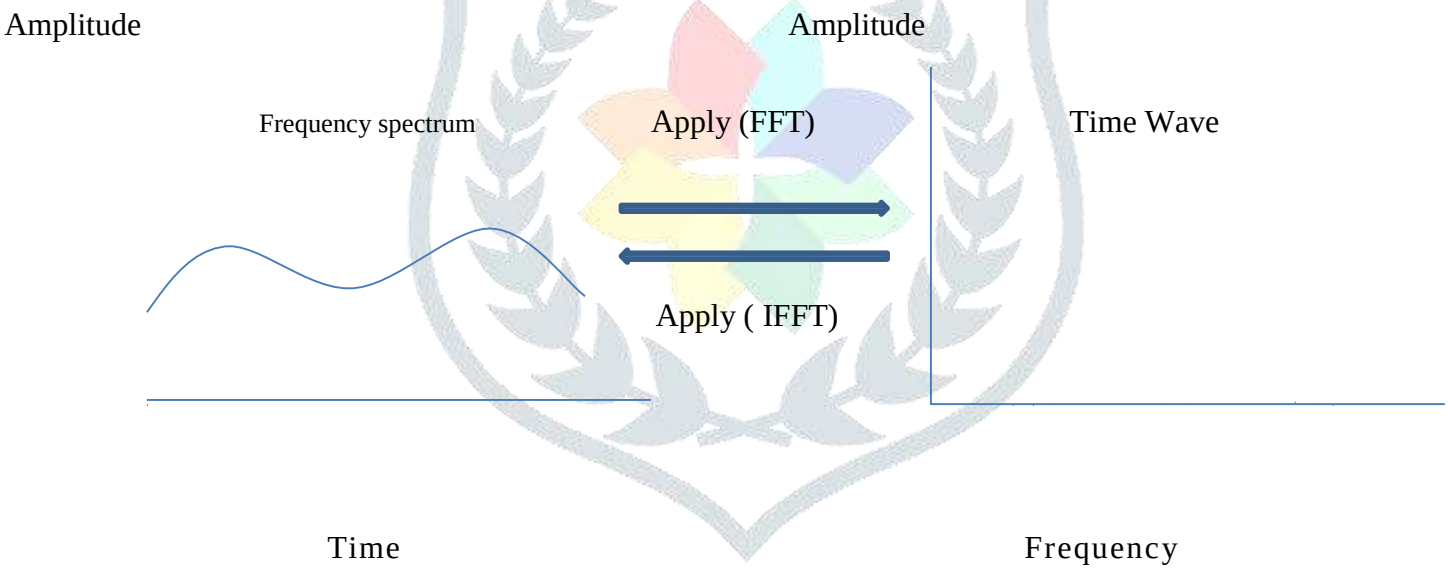

Figure 4: FFT and IFFT application

FFT is defined by this function

$$f_{(x)} = \int_{-\infty}^{\infty} x(t) \cdot e^{iwt} \cdot dx$$

Here x(t)= Signal function

For inverse FFT

$$x(t) = \int_{-\infty}^{\infty} f_{(x)} \cdot e^{-iwt} \cdot dx$$

Time-Frequency techniques

In time-frequency techniques both time and frequency domain information are maintained [4-6]. There are many transforms used in the time-frequency techniques but most common transform is continuous wavelet transform (CWT). This function is operated by scaling function and translation function through mother wavelet. The scaling function is diving the frequency components for the presentation for example high frequency components of the signal goes to the low scale and low frequency to the high scale. The equation for CWT is as follows

$$X_b(a,b) = \frac{1}{|a|^{\frac{1}{2}}} \int_{\infty}^{-\infty} X_{(t)}\, \bar{\mu}\left\{\frac{t-b}{a}\right\} dt$$

$X(t)$ = signal function

$\bar{\mu}$ = mother wavelet

1.5 Methodology used in experimentation

Methodology is the systematic analysis of the methods applied to study a system or process. Here we are doing study on defects in tapper roller bearing for a local defect.

Different methodology has been adopted in the field of signal processing for extracting useful information. Mainly signal is acquired from the vibrating component and its useful characteristic are extracted with help of different transforms. In our study we are mainly using (FFT) and (CWT) to extract the information of the crack defect on the outer race. The flow chart of main methodology for using FFT and CWT are present below in Figure 5 and Figure 6 respectively:

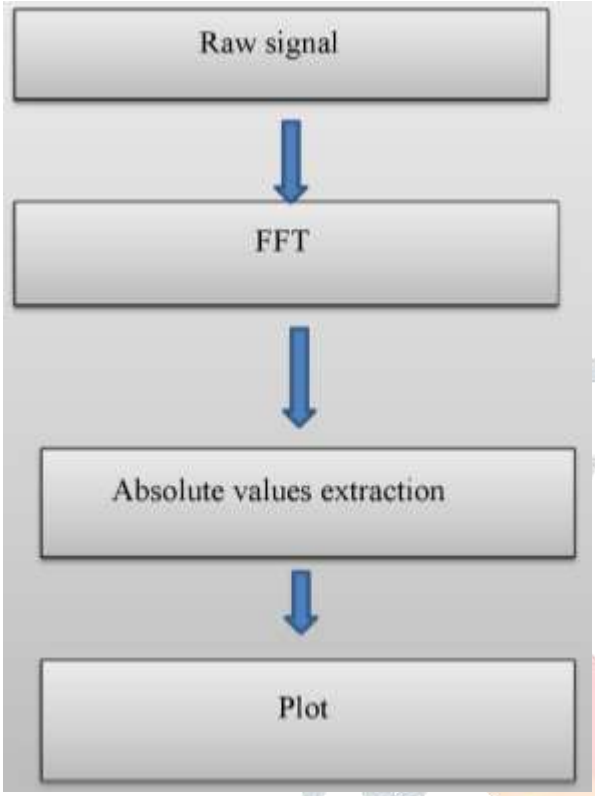

Figure 5: Methodology for using FFT

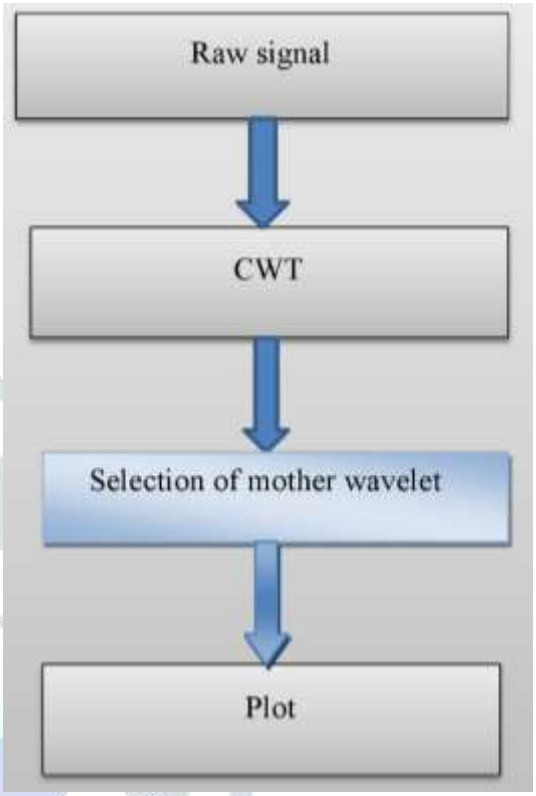

Figure 6: Methodology for using CWT

1.6 Result and discussion

Tapper roller bearings are most common type of bearing for the application of automobile axles. These bearing are generally subjected to high amount of radial as well as axial load and it also supports rotating shaft with low friction. In this experimentation vibration signal was captured at sampling rate of 70000 for the defective bearing and results are presented. An outer race defect in taper roller bearing is selected due to its easy installation and de-installation. Vibration signal is captured for the defective bearing and signal processing is carried out using different types of techniques. The outer race defect is shown in Figure 7. defect A taper roller bearing is made to run in the bearing test rig shown in Figure 8. The shaft carrying the main bearing is driven by an alternative current motor with the help of v-belt and pulley arrangement. The experiments were carried out on 2050 rpm.

The raw signal for defective bearing at 2050 rpm is shown in Figure 9. First and fourth consecutive peaks are marked with time domain is coming out to be 277 & 1134 in terms of data points. The average data point can be calculated as 285.66 [(1134 -277)/ 3] between two consecutive peaks. The frequenc y of defect is coming out to be 245.04 Hz [70000/285.66]. The theoretical frequenc y of outer race defect is measured as 244.54 Hz for the given set of bearing at 2050 rpm [6]. This signifies that the defect presence

in the outer race.

Figure 7: Outer race defect in taper roller bearing

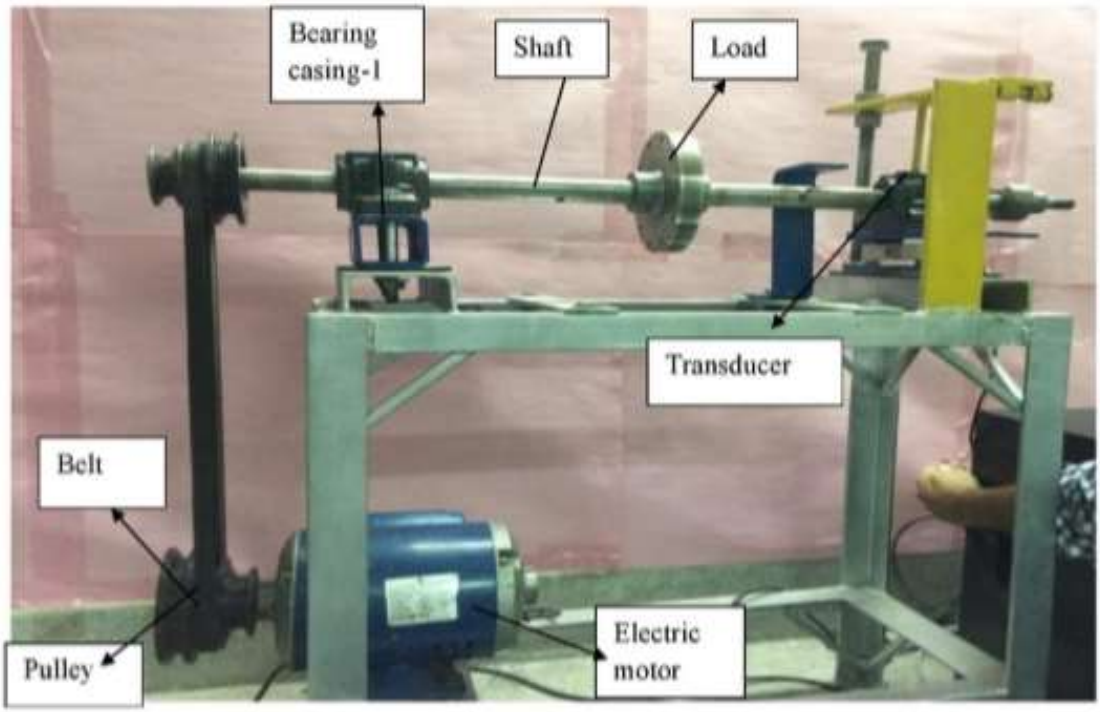

Figure 8: Bearing test rig

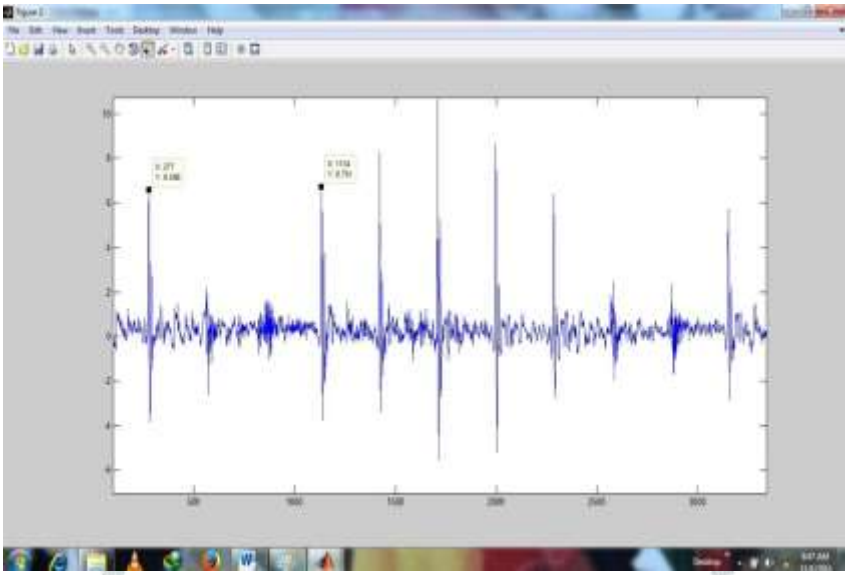

Figure 9: Raw signal for defective bearing

The FFT of the same raw signal shown in Figure 9 is shown in Figure 10. This technique only represents the frequency contents present in the signal. The harmonics of the frequencies are clearly visible in the FFT graph. In the same way frequency between the two consecutive peaks was measured as [(1456 -971)/ 2] = 242.5 Hz. The frequency measured from the FFT graph again signifies the presence of defect in the outer race.

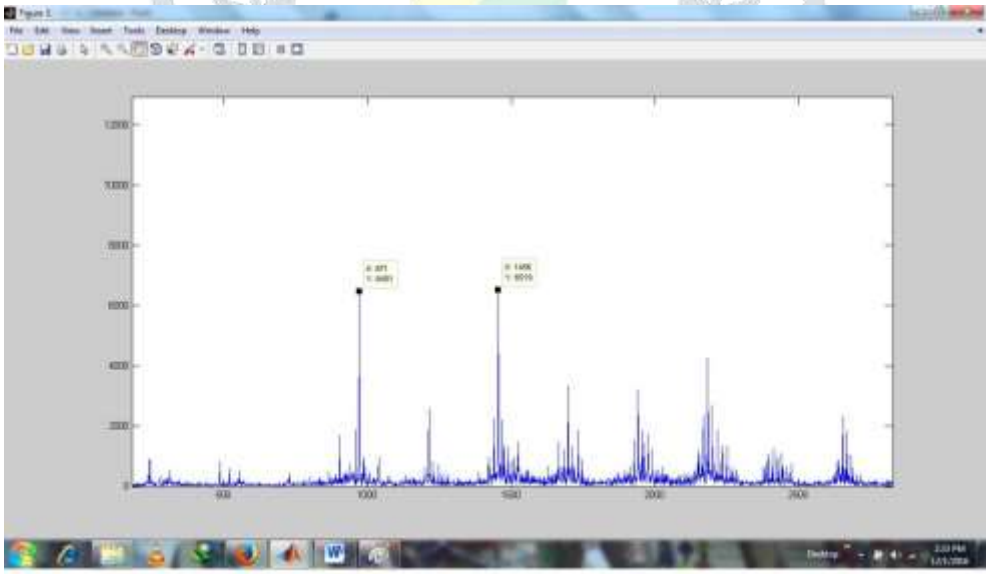

Figure 10: FFT of the raw signal shown in Figure 9

The CWT of the raw signal shown in Figure 9 is shown in Figure 11. The high frequency bands are clearly visible in the signal. The data points between two consecutive high frequency bands is measured as 289.50[(14418 -13837)/2] and corresponding frequency as 241.79 Hz. This also signifies the frequency matching with the outer race defect frequency so defect is present on the outer race. It can be observed that all the techniques are capable of detecting the defect location and its type.

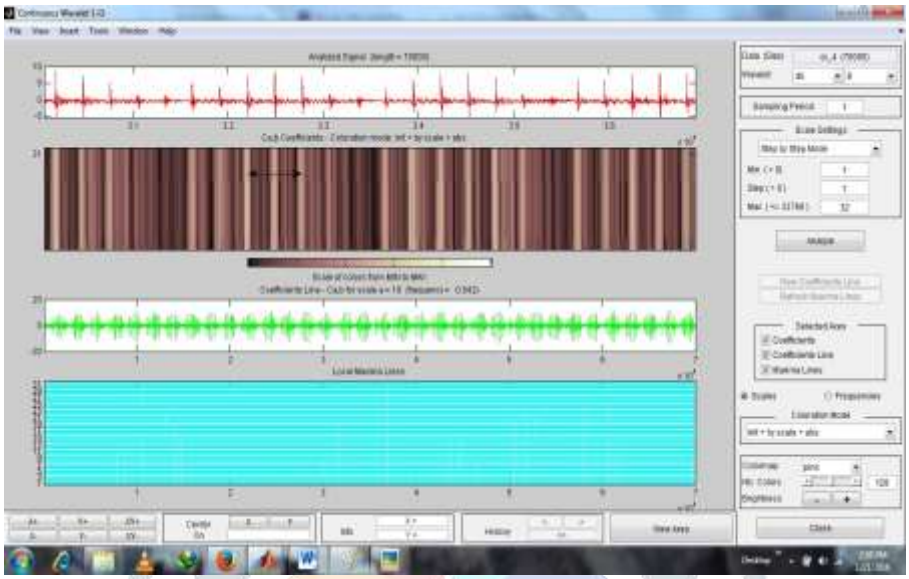

Figure 11: CWT of the signal shown in Figure 9

Conclusion:

The use of signal processing techniques in predicting the health of bearing are widely used. The main advantage of using signal processing for monitoring is that one need not to dis-mental the bearing for the purpose of inspection. Therefore, this paper has presented the general bearing introduction along with reasons for defect origination. Then after a raw signal is recorded for defective outer race of taper roller bearing. This raw signal was processed with three different types of signal processing techniques time domain, frequency domain and time-frequency domain. These three used techniques are capable in detecting the outer defect correctly on the basis of frequency matching. This paper will be very helpful for those who wants to apply signal processing techniques in the condition monitoring of bearing.