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Wavelet analysis to detect fault in Clutch release bearing

Gaurav Joshi [1], Akhilesh Lodwal [2]

[1] *ME Scholar, Institute of Engineering & Technology, DAVV, Indore, M. P., India*
[2] *Assistant Professor, Dept. Of Mechanical Engineering, Institute of Engineering & Technology, DAVV, Indore*

Abstract - *Automobile clutch release bearings are important automotive driveline components. An unexpected failure of the bearing may cause catastrophic failure leads to vehicle off road, increased down time and economic losses. For that reason, fault diagnosis in bearing has been the subject of intensive research. Vibration signal analysis has been widely used in the fault detection of bearings. The vibration signal of a bearing carries the signature of the fault in the outer race, inner race, cage and rolling element. Early fault detection of the bearing is possible by analyzing the vibration signal by using wavelet analysis. Wavelet analysis is able to characterize the local features of the signal in different scales. This project addresses fault diagnosis of ball bearing related to clutch release system. Detail analysis using wavelet methodology is done to find out the faults in MATLAB software. Numbers of faults are identified and validated for each fault. Faults are identified on clutch release bearing vibration test rig.*

Key Words: Vibration signal, Wavelet analysis, Fault detection, bearing.

1. INTRODUCTION

A wavelet is a waveform of effectively limited duration that has an average value of zero. Wavelet analysis is a time-frequency method and applied to non-stationary signals. It is breaking up of a signal into shifted and scaled versions of the original (or mother) wavelet. Wavelets are a recently developed signal processing tool enabling the analysis on several timescales of the local properties of complex signals that can present non-stationary zones. Wavelets have essentially been imposed as a fruitful mathematical theory and a tool for signal and image processing. By omitting the purely mathematical contributions and focusing on applications, we may identify three general problems for which wavelets have proven very powerful.

The objective of the project is to make a bearing fault identification system using Wavelet analysis. To investigate the type of bearing failures of a complex clutch release bearing system on a well-designed test rig suited for practical implementations. The advantages of wavelet analysis can be materialized by local detailing, meaning that it can be taken only a part of the signal. By wavelet analysis we can find mechanical failures like fatigue (surface or subsurface, cage wear, handling damage, corrosion pitting, crack etc.

2. LITERATURE SURVEY

In 2015 Guoliang Chen & Xiaoyang Chen Studies on Automobile Clutch Release Bearing Characteristics with Acoustic Emission Acoustic emission techniques in contact fatigue failure detection have unique advantages, which include highly sensitive non-destructive testing methods [1]. In 2014 Robert Bicker & Alaa Abdulhady Jaber presented a paper on Simulation of Non-stationary Signal Analysis Using Wavelet Transform Based on Lab VIEW and Matlab. Defines Basic concepts of signal, types of analysis technique and Wavelet analysis which represents an efficient method of time frequency analysis. In this paper, a real-time wavelet analysis system has been designed. Hybrid programming combining Lab VIEW graphical programming with Matlab textural programming has been shown to be an effective method to build an intelligent signal monitoring and feature extraction system [2]. In 2012 D.P. Jena & S.N. Panigrahi presented a paper on Bearing and gear fault diagnosis using adaptive wavelet transform of vibration signals. There work reveals that statistical parameters, even though suitable for defect identification, are sensitive towards detecting their severity. The proposed method of adaptive wavelet design and its implementation provide adequate time frequency information in order to analyze the non-stationary signals [3]. Springer science 2011, A handbook on “Wavelets – Theory and Applications for Manufacturing” by Robert X. Gao , Ruqiang Yan describes the selection criteria of mother wavelet based on Qualitative & Quantitative measure. By selecting a base wavelet that is best suited for analyzing non-stationary signals. These measures are examined from two difference aspects: their corresponding wavelet coefficient i.e. the energy / Shannon entropy and the relationship between the signal analyzed and the coefficients of the base wavelet. Based on this two comprehensive base wavelet selection criteria the maximum energy to Shannon entropy and the maximum information measure are identified as the quantitative measure for determining the best suited wavelet [4]. Matlab 2013, A handbook on “Wavelet Toolbox” by Michel Misiti, Yves Misiti, Georges Oppenheim and Jean-Michel Poggi describes an introduction to wavelet, Types of wavelet, Continuous wavelet transformation, scaling, shifting etc in detail [5]. In 2015 Josko Soda & Igor Vujovic presented a paper on Analysis of the vibration signal using Time frequency methods. This paper presents advantages of the wavelet transform for the acceleration vibration signal analysis due to its non-stationary nature [6].

3. Basic Concepts of Signals

A signal can be defined as a function that describes a physical variable as it evolves over time. Analogue signals, such as sound, noise, light and heat, represent the majority of signals in nature. Variations in these signals are continuous over time and the processing of analogue signals is called analogue signal processing (ASP). By sampling such continuous signals at repeated time intervals using data acquisition equipment, they can be converted into discrete format, and the processing of the digital (discrete) signal is named digital signal processing (DSP). A discrete signal, on the other hand, has values only at specific time periods. The benefits of converting signals from analogue to discrete (digital) form are that it can avoid the degradation and corruption of the signals. Knowing the type of signal to be analysed has a significant influence on the type of analytic technique chosen. Subsequently, it is necessary to carefully inspect the various types of signal that are encountered in practice. Thus, signals can be classified as shown in Figure 1.

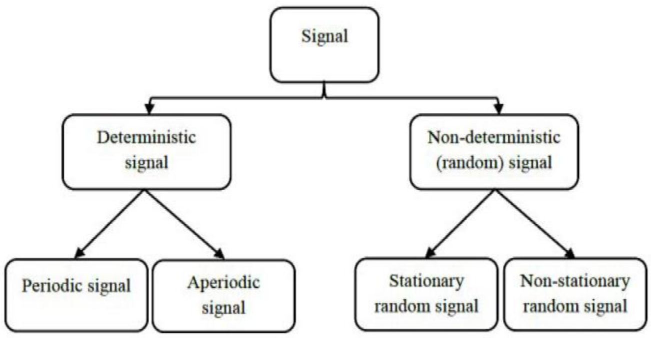


Figure 1. Schematic diagram of signal classification.

3.1 Deterministic signal

If, after a suitable number of measurements, the signal can be described by an analytical expression and its values can be predicted at any time in the past and future, then it is called a deterministic signal, such as a sinusoid signal. A deterministic signal may be classified as a periodic signal if the change in the magnitude of the signal repeated at regular time intervals, and if not it is termed an aperiodic signal.

3.2 Non-deterministic

Conversely, non-deterministic or random signals cannot be described by a deterministic mathematical expression and they are more complex than deterministic signals. By determining their statistical properties, random signals can be broken down into stationary and non-stationary parts. Therefore, the statistical properties of the random signal which do not change with time can be called stationary, otherwise, they are named non-stationary. However, a majority of the signals emitted from industrial machines are non-deterministic. And when a fault starts to appear in a machine the signals monitored tend to non-stationary in nature.

4. Signal analysis technique

After a signal is being captured, a large number of signal processing techniques can be utilized to extract the most sensitive and interesting features concerning defects. Signal processing techniques are classified as using time domain, frequency domain, and time-frequency domain methods. These methods are not totally independent, and in many situations they complement each other. As a matter of fact, choosing the most suitable method for each specific task represents a major challenge in condition monitoring.

4.1 Time domain analysis

The technique used in processing the signal can be classified as a time domain method if it processes a raw signal directly in the time domain without being transformed into another domain, such as the frequency domain. The purpose of time domain analysis is to determine the statistical features of the original signal by manipulating the series of discrete numbers. In this technique statistical parameters such as standard deviation and root mean square can be used to give useful information about the hidden defects represented in the time domain signal.

4.2 Frequency domain analysis

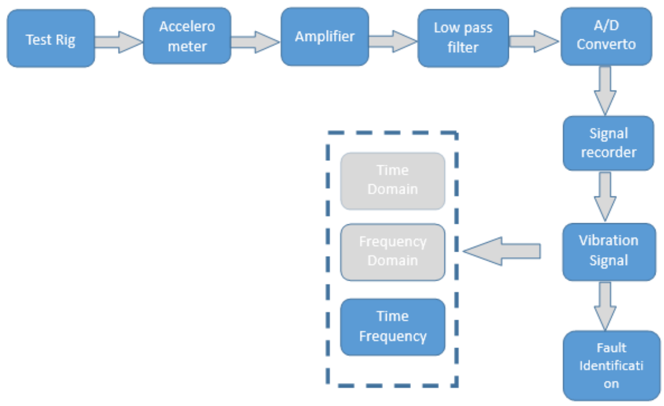
In most applications, signal representation in the time domain is not the best method, since much of the relevant information is hidden in the frequency content of the signal. Frequency or spectral analysis provides additional information about time series data, and can be used to explain the spectra of frequencies which exist in the signal. The parameters of frequency domain analysis are more reliable in damage detection than time domain parameters. However, time-amplitude signals can be represented by a family of complex exponents with infinite time duration using Fourier transforms (FTs). Additionally, any given time-domain signal can be written as a function of all of the frequencies present in it using Fourier transforms.

4.3 Time –frequency analysis

The signals from faulty parts have a non-stationary nature. However, if the frequency component of non-stationary signals is calculated using the Fourier transform, the results will represent the frequency composition averaged over the duration of the signal. Consequently, the characteristics of the transient signal cannot be described adequately using the Fourier transform. Therefore, time frequency analysis has been investigated and applied for the fault diagnosis of machinery because of its capability of signal representation in both the frequency and time domains. This unique feature of time-frequency analysis techniques means that it is suitable for non-stationary signals. Moreover, time-frequency methods can give interesting information in regards to energy distribution over frequency bands. A number of techniques of time-frequency analysis, such as the short time Fourier transform and wavelet transforms, have been used for fault detection and diagnosis. [2]

5. Experimental Methodology

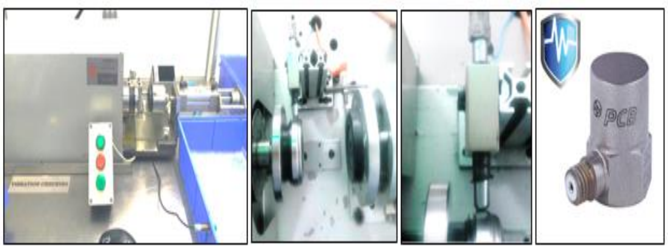
In an experimental procedure bearing will allowed to run at 1000 RPM and by applying 60N load. For vibration measurements spring loaded accelerometer will place on the radial direction of the bearing. By making all above arrangements, readings will be taken for healthy bearing and faulty bearing condition. Vibration spectrums are taken for bearing having various faults & the data is stored in computer for further analysis. For different condition of faulty conditions data is collected. Vibration signals captured from this setup will further analyzed in MATLAB for Wavelet analysis



Overview of fault diagnosis based on vibration signal analysis

6. Test set up configuration

The experimental set-up comprises a test-rig, an AC motor with variable speed drive for a shaft-rotor assembly. The bearing is supported on rotor shaft and axial load of 60 N is applied through transducer. Accelerometer have been used to measure and digitally acquire free vibration data. Accelerometer probe is placed radially on bearing outer race. The motor is run at a constant speed of 1000 RPM which rotates inner race of bearing.



Bearing Specification	
Parameter	**Specification**
Application	Clutch Release Bearing
Type	Ball Bearing (Self Centering)
Inner Diameter	30 mm
Outer Diameter	62 mm
Number of balls	28
Ball Diameter	5 mm
Bearing Width	18.20 mm

Accelerometer Model: 352C33	
PERFORMANCE	**Specification**
Sensitivity (±10 %)	10.2 mV/(m/s^2)
Measurement Range	±490 m/s^2 pk
Frequency Range (±5 %)	0.5 to 10,000 Hz
Frequency Range (±10 %)	0.3 to 15,000 Hz
Resonant Frequency	≥50 kHz
Broadband Resolution (1 to 10000 Hz)	0.0015 m/s^2 rms
Non-Linearity	≤1 %
Transverse Sensitivity	≤5 %
Sensing element	Ceramic

7. Conditions considered for fault diagnosis are:-

- Healthy Bearing
- Horizontal scratch on inner race
- Horizontal scratch on outer race
- Vertical scratch on inner race
- Vertical scratch on outer race
- One ball missing

8. Experimental Approach:

1) Take the readings for different bearing faults & collect data.

2) Compare these results with different signal processing techniques & find the most effective technique for any rotary system with ball bearing for fault identification.

9. Methodology

Following are the steps for Bearing fault identification performed in MATLAB (Version – R2013A)

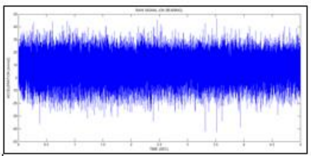
1) Load healthy and faulty bearing signals in MATLAB
2) Compare loaded time domain signal for both healthy and faulty bearing signals
3) Compare frequency domain signal for both healthy and faulty bearing signals
4) Short time Fourier transform used to produce time frequency visualisation (Spectrogram)
5) Compare time frequency domain signal for both healthy and faulty bearing signals
6) Localise by reducing the window size used in the spectrogram
7) CWT (Continuous wavelet transformation) function used to obtain joint time frequency analysis of bearing signals data
8) Selection of complex Morlet wavelet for analysis
9) Produce a plot of coefficients
10) Produce a plot of coefficients at a given scales
11) Produce a plot of local maxima of coefficients across scales
12) Select the displayed plots
13) Switch from scale to pseudo-frequency information
14) Zoom in on detail

10. Vibration signal analysis

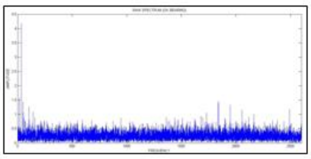
Signal sampled at 8000 Hz and duration 5 seconds (Time domain representation of signal)

➤ **Analysis of Healthy bearing**

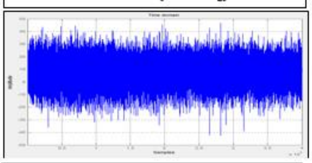
Raw Signal (Ok Bearing)



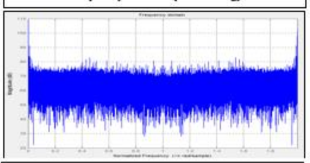
Raw Spectrum (Ok Bearing)



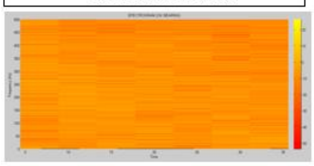
Time Domain (Ok Bearing)



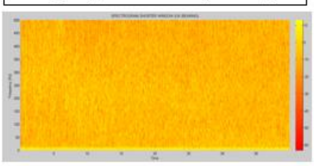
Frequency Domain (Ok Bearing)



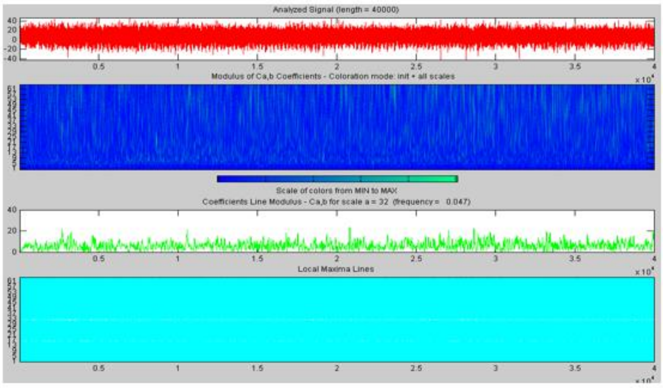
Spectrogram (Ok Bearing)



Spectrogram Short Window (Ok Bearing)



Continuous wavelet transform (Ok Bearing)



Looking at the time domain representation of the signal, we see distribution of acceleration over a period of time. It is difficult to separate the healthy and faulty signals from the signals just by looking at the time-domain representation. Many naturally occurring signals have similar characteristics. These are composed of varying components interspersed with abrupt changes. Similarly, the characteristics of the transient signal cannot be described adequately in frequency domain analysis. Therefore, time frequency analysis has been applied for the fault diagnosis of bearing because of its capability of signal representation in both the frequency and time domains.

A number of techniques of time-frequency analysis, such as the short time Fourier transform and wavelet transforms, have been used for fault detection and diagnosis.

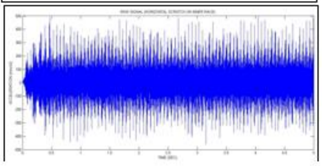
First, Use Short time Fourier transform to produce time frequency visualization. Pass the signal and sampling frequency (Fs = 1000) as input to the functional spectrogram. At the output, we can see that the energy spread of vibration signals. To see what happens when we try to localize the events by reducing the window size used in the spectrogram. By reducing the size of the window, we observed uniform spread of energy along frequency and time scale.

Now use wavelet analysis, we will use the Continuous Wavelet Transform function in MATLAB to compute the Continuous Wavelet Transform. This will help obtain a joint time frequency analysis of the bearing data. Started analysis using the Complex Morlet (cmor) wavelet at scales 1 to 64 in steps of one by using command line function. After computation, the tool displays the coefficients, the coefficient line plot corresponding to the scale a=32 and a local maxima plot, which displays the chaining across the scales (from a= 64 down to a= 1) of the coefficient local maxima.

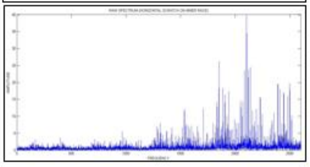
By visually analyzing the modulus of coefficient plot it is clearly evident that there is no abnormality in healthy bearing signals. Similarly faulty bearing analysis is as follows

- **Analysis of Horizontal scratch on inner race**

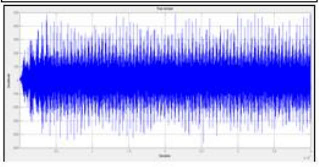
Raw Signal (Horizontal scratch on inner race)



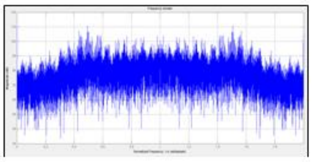
Raw Spectrum (Horizontal scratch on inner race)



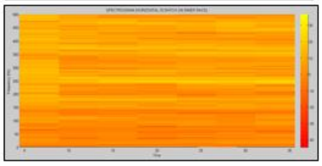
Time Domain (Horizontal scratch on IR)



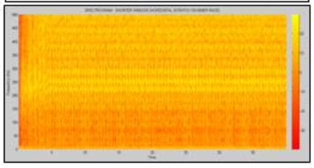
Frequency Domain (Horizontal scratch on IR)



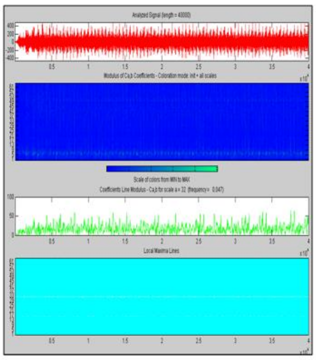
Spectrogram (Horizontal scratch on IR)



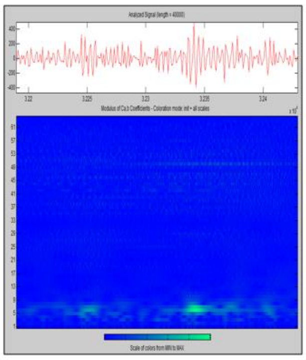
Short Window (Horizontal scratch IR)



CWT (Horizontal scratch IR)



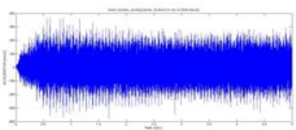
CWT Zoom (Horizontal scratch IR)



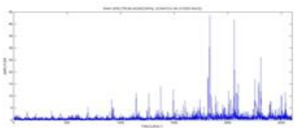
- **Analysis of Horizontal scratch on outer race**

- Analysis of Horizontal scratch on outer race

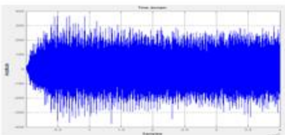
Raw Signal (Horizontal scratch on outer race)



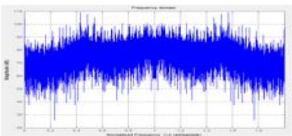
Raw Spectrum (Horizontal scratch on OR



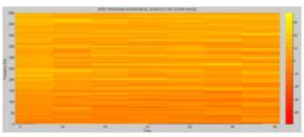
Time Domain (Horizontal scratch on OR)



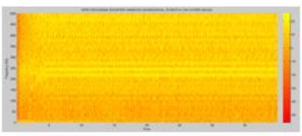
Frequency Domain (Horizontal scratch on OR



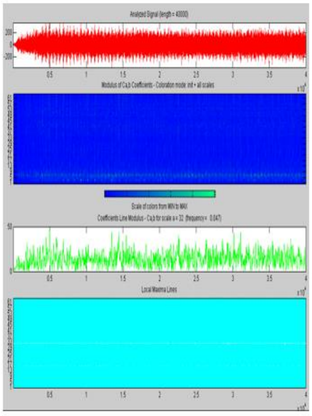
Spectrogram (Horizontal scratch on OR)



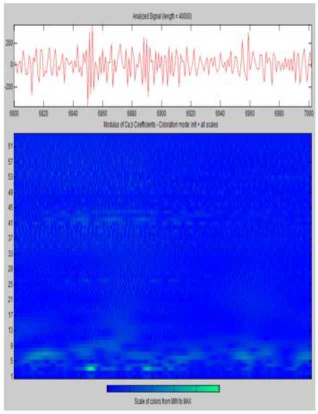
Short Window (Horizontal scratch on OR)



CWT (Horizontal scratch OR)

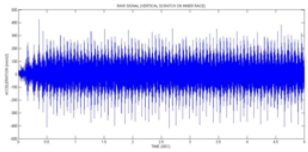


CWT Zoom (Horizontal scratch OR)

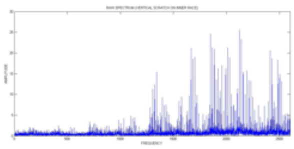


- **Analysis of Vertical scratch on inner race**

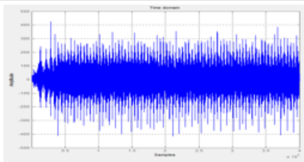
Raw Signal (Vertical scratch on IR)



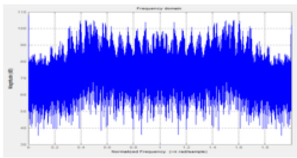
Raw Spectrum (Vertical scratch on IR)



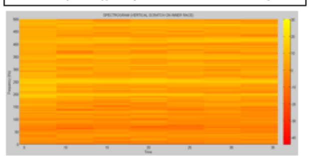
Time Domain (Vertical scratch on IR)



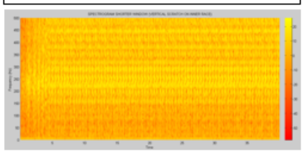
Frequency Domain (Vertical scratch on IR)



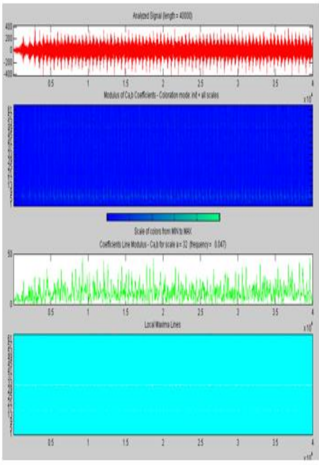
Spectrogram (Vertical scratch on IR)



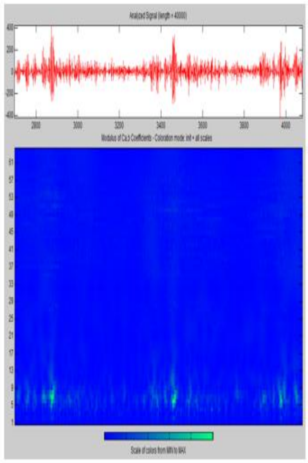
Short Window (Vertical scratch on IR)



CWT (Vertical scratch on IR)

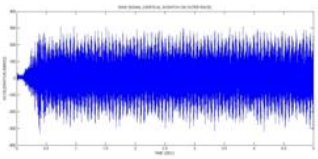


CWT Zoom (Vertical scratch on IR)

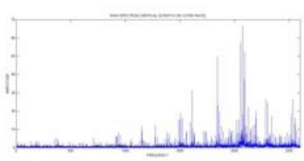


- **Vertical scratch on outer race**

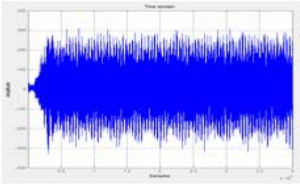
Raw Signal (Vertical scratch on OR)



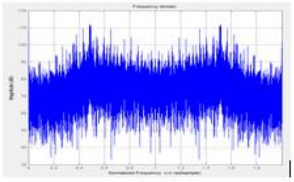
Raw Spectrum (Vertical scratch on OR)



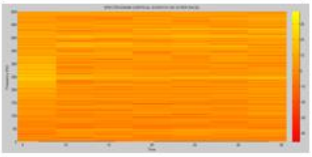
Time Domain (Vertical scratch on OR)



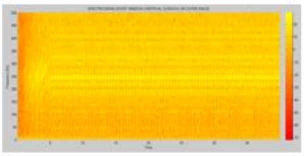
Frequency Domain (Vertical scratch on OR)



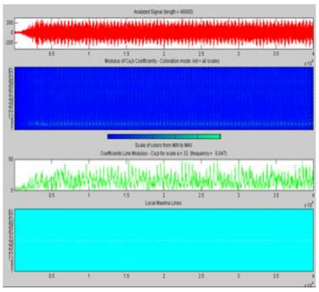
Spectrogram (Vertical scratch on OR)



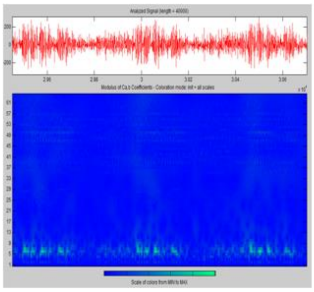
Short Window (Vertical scratch on OR)



CWT (Vertical scratch on OR)

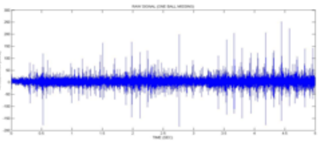


CWT Zoom (Vertical scratch on IR)

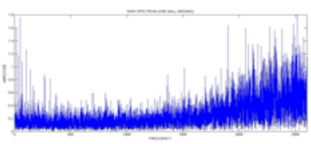


- **Analysis of one ball missing**

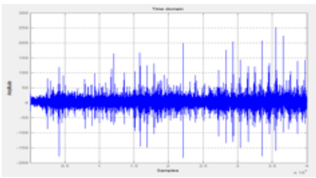
Raw Signal (Ball missing)



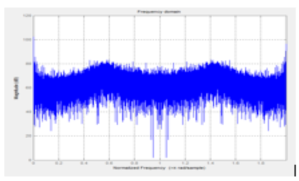
Raw Spectrum (Ball missing)



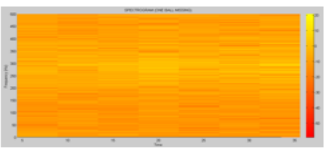
Time Domain (Ball missing)



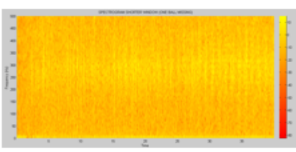
Frequency Domain (Ball missing)



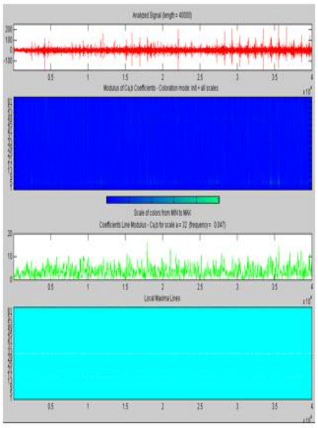
Spectrogram (Ball missing)



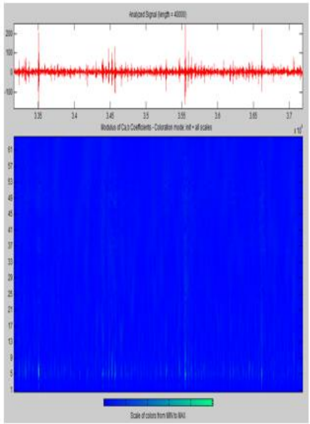
Short Window (Ball missing)



CWT (Ball missing)



CWT Zoom (Ball missing)



11. Results & Conclusion:

A comparison was made between the conventional time domain, frequency domain , time frequency domain Short Time Fourie Transform and wavelet transform based on Continous Wavelet Transform analysis. A study completed in this project by data collection shows that Continous wavelet transform is useful tool in finding out even a scratch in inner & outer race of the bearing based on systematic study. During study we considered manufacturing defects in bearings like scratch on inner race, scratch on outer race, and ball missing for analysis. Input signals of Continous Wavelet Transform are given to MATLAB and simulate the data. We got nearly same results from MATLAB as a fault location and scale in Time frequency domain. By this method one can easily identify the even a minor fault and distinguish the signals very effectively. By zooming in detail for specified signal length we are able to identify fault present in bearing in Time frequency domain. The analysed results showed that the bearing faults had been effectively identified by the proposed method. However, those faults could not be detected by either of the techniques with which it was compared

Fault Location & Corresponding values				
Defect	Acceleration (mm/s2)	Location	Scale	Frequency (Hz)
Horizontal scratch on inner race	490.98	X = 32335	Y = 8	0.187
		X = 32350	Y = 5	0.3
Horizontal scratch on outer race	358.51	X = 6848	Y = 3	0.375
		X = 6854	Y = 2	0.5
Vertical scratch on inner race	414.95	X = 2867	Y = 8	0.166
		X = 2886	Y = 4	0.375
Vertical scratch on outer race	307.95	X = 30490	Y = 8	0.214
		X = 30516	Y = 4	0.3
One Ball Missing	250.64	X = 35546	Y = 7	0.136
		X = 35560	Y = 2	0.5

12. Future scope:

There is always some future scope for any research work. For this particular work on "Vibration Analysis of Ball Bearing" following are the future scopes. Other types of faults can be study using same methodology. Above research data can be utilized for design consideration of vibration analysis of different types of bearing**.**

13. References:

[1] Guoliang Chen & Xiaoyang Chen Studies on Automobile Clutch Release Bearing Characteristics with Acoustic Emission. - Proceedings of the World Conference on Acoustic Emission–2013

[2] Alaa Abdulhady Jaber, Robert Bicker "A Simulation of Non-stationary Signal Analysis Using Wavelet Transform Based on LabVIEW and Matlab" - 2014 UKSim-AMSS 8th European Modelling Symposium

[3] D.P. Jena, S.N. Panigrahi "Bearing and gear fault diagnosis using adaptive wavelet transform of vibration signals" ELSEVIER ICASCE 2012

[4] Robert X. Gao , Ruqiang Yan " Wavelets – Theory and Applications for Manufacturing"

[5] Michel Misiti, Yves Misiti, Georges Oppenheim, Jean-Michel Poggi "Hand book by Wavelet and their application" – ISTE

[6] Josko Soda & Igor Vujovic "Analysis of the vibration signal using time frequency methods"