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Fault Detection and Condition Monitoring of Rolling Contact Bearings using Vibration Signature

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Abstract - *An experimental setup was developed to examine the performance of rolling contact bearings using vibration measurement and signal analysis. The defects are induced into defect-free bearings using the Laser Engraving Technique. During the test, vibration signals are acquired and the kurtosis value is evaluated using LabVIEW software and supporting hardware components. In the time domain analysis of vibration signatures, the kurtosis value specifies defects in bearings. In the time-frequency domain, a vibration signature is obtained by analyzing the bearing signal using Continuous Wavelet Transforms. Vibration signatures seem to be unique for a particular type of bearing defect and are useful for the detection of bearing defects and monitoring the condition of them.*

***Key Words*: Rolling Contact Bearings, Laser Engraving Technique, LabVIEW, kurtosis, vibration signature, Continuous Wavelet Transforms.**

1. INTRODUCTION

Rolling Contact Bearings (RCB) are the most significant components of a machine, playing a key role in all the manufacturing industries. RCBs are widely used due to their relatively lower cost and operational ease. Approximately 40-50% of the sudden breakdown of any machinery occurs due to failure of bearings. The abrupt stoppage of a machine can be avoided by the regular maintenance of major components such as bearings and gears etc. Recognizing and diagnosing hidden or invisible bearing faults to avoid catastrophic failure of the machine is a major challenge faced by researchers even today.

Researchers have invented different approaches to resolving issues related to bearing fault detection and condition monitoring. Emphasis is given to condition monitoring of RCB by using different diagnostic techniques with enhanced accuracy levels. The existence of bearing faults like galling, spalling, peeling, and subsurface fatigue are some of the primary sources of early bearing failure put forward by the authors. Misalignment, surface roughness, a high amount of waviness, and inclusions can all cause bearings to fail. Based on customized requirements and the accuracy level desired, different bearing fault detection and condition monitoring practices are followed.

As bearings are one of the vital components of a machine, sudden failure may lead to a drift in production activity and even human casualties. Failure also results in production downtime, causing a huge financial loss to the organization. Therefore, demands for development and execution of an efficient maintenance strategy to lessen the impact of system failure due to defective RCB.

A variety of techniques have already been implemented to identify and diagnose bearing faults, such as vibration measurement, acoustic measurement, spectrographic oil analysis, and infrared thermography and ultrasound techniques. Among them, vibration and acoustic measurement techniques have emerged as two major practices, according to N. Tandon and A. Choudhury [1], mainly to discover faults in RCB. Vibration analysis of bearings has emerged with the innovation in digital sensors, computers, and enhanced signal processing algorithms, which has made the job easy. The data acquisition system plays a major role in bearing fault diagnosis.

Even a good bearing (defect-free) working under standard conditions induces vibration under the action of radial or axial load. There will be a significant change in the vibration, if it is a defective bearing. In the case of RCB, when the rolling element contacts a defect on the contact path, an impulse is generated. If the bearing element is running at constant speed, the impulses generated will be periodic in nature with a definite frequency. Therefore, measurement of bearing vibration is useful in bearing fault diagnosis.

While supervising the condition of rotating machinery, it may be required to follow different maintenance techniques to augment production competence. Three major strategies are used in any manufacturing sector. They are breakdown maintenance, preventive maintenance, and condition-based maintenance (CBM). A recent development in the field of digital sensors with a more precise level of accuracy and compatible with computers has added more value to CBM. It is emerging as a prominent technique in dealing with bearing faults.

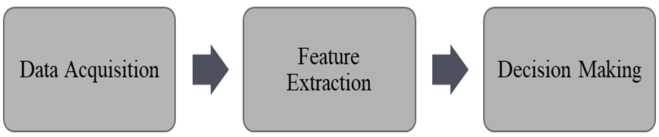
CBM is one of the best strategies implemented in most of the leading industries, as early detection can put off catastrophic failure. It is a decision-making strategy that strives to avoid unpredicted catastrophic failures. Thus, it enables the reestablishment of the condition of a machine by the early detection of faults and implementing the necessary maintenance actions for their isolation.

In the case of RCB fault investigation, vibration-based defect detection and condition monitoring have helped researchers discover a better strategy for further improvement. Recent developments in Time-Frequency Domain Technique (TFDT) could be able to detect the severity of a defect and help to find its approximate location. TFDT has a great advantage over other techniques since it can manage stationary as well as non-stationary vibration signals. In recent developments in the field of bearing condition monitoring, a new mathematical tool known as Wavelet Transform (WT) is widely used as one of the leading non-stationary signal processing techniques. Tremendous investigations have been conducted by many researchers in the WT domain with respect to bearing fault detection and monitoring its condition. The main reason for using WT is that it provides an easily interpretable visual representation of a signal induced by a bearing with or without fault. This is an essential requirement in the application of the vibration signature of a bearing [2].

1.1 Literature Review

Many researchers have contributed value-added efforts in the field of bearing fault diagnosis. Few people are constantly working on important research in the field of acoustics and vibration. Based on progress in digital technology and signal processing in extracting required information from the signal, vibration analysis of the bearing is the prior one. Tandon and Choudhury [1] analyzed both vibration and acoustic techniques in revealing flaws in RCB. It is well understood that there is more scope for vibration measurement techniques than acoustic measurement methods.

Pankaj Gupta et al. [3] have worked hard to summarise current research on vibration analysis of RCB faults and techniques for fault recognition in time, frequency, and time-frequency domain. The time-frequency domain approach is an effective signal processing technique for both stationary and non-stationary vibration signals. The WT is an extensively used technique in the time-frequency domain because it is capable of extracting weak signals for which Fast Fourier Transforms (FFT) are ineffective.



According to R. J. Alfredson [4], the tests carried out proved to be very useful in examining a wide range of time and frequency domain parameters that are potentially useful in condition monitoring of bearings.

he early investigation reveals three major approaches followed in the identification of severe defects in bearings. They are Time Domain Technique (TDT), Frequency Domain Technique (FDT), and Time-Frequency Domain Technique (TFDT).

In the year 1978, a valuable parameter called kurtosis was proposed as a prior indication of damage which occurs in the lower frequency band (3 to 5 kHz). Even though it was clear by a value of 3, indicating that it was in the direction of failure.

Mathew and R. J. Alfredson [4] both carried out additional experiments to investigate a variety of time and frequency domain parameters that are very useful in monitoring the condition of bearings. All the parameters yield some values depending on the type of bearing failure encountered. If there is a presence of considerable impulsiveness in the vibration data, the statistical parameter like kurtosis gives a better indication of bearing damage. In the meantime, they have all reported that the crest factor appears to be a poor predictor of RCB fault detection.

Whenever a rolling element of a bearing interacts with a defect, it produces pulses of very short duration due to the rotation of the bearing. These pluses stimulate the natural frequencies of the bearing house and supporting structure. This in turn increases the vibration energy at high frequencies. There will be an increase in vibration energy level at the element rotational frequency if there is a defect in any of the bearing elements. The defect frequencies can be evaluated from kinematic considerations like bearing geometry and its rotating speed.

The dynamic behaviour and/or the external excitation, mainly under time-varying conditions in a rotating system, lead to non-stationary signals. There is a need for an efficient analysis method which can take care of both frequency information and time-invariant features from non-stationary signals simultaneously.

Non-stationary signals are well analyzed using time-frequency analysis in controlling the stable state of the machinery. Time-frequency analysis can identify frequency components present in the vibration signal and also reveal their time-dependent features. It has become an effective tool to extract the bearing faults hidden in non-stationary signals.

Many analytical methods that address the non-stationary nature of the signal by decomposing it over two dimensions, proposed by many experts. The typical method includes linear time-frequency representation like Short Time Fourier Transforms (STFT), WT, and bilinear time-frequency representation such as Winger villa distribution and Hilbert Hung transforms.

The major advantage over previous techniques is that its decomposition permits projections of the time history of vibration data onto a space that allows separation of components of the signal. It facilitates improvement, recognition, filtering, classification, and resynthesis of the signal.

The STFT implemented by researchers might only make provisions for slicing the signal with a fixed tiny window along the time axis. The segmented signal under the short window does not change too much, hence it can be assumed as stationary. The major disadvantage of STFT is that once the window function and its length are chosen, the time-frequency resolution is fixed.

In a specific application, it is desired to resolve time instant of a higher frequency component. A shorter time window should be employed. If we are interested only in lower frequency components, a longer time window is chosen. Therefore, it is not appropriate to use it in the analysis of signals having highly transient behavior. To overcome the problem of multi-resolution, researchers have switched to WT.

WT utilizes wavelets in place of sinusoidal functions, as in the case of STFT. In addition to the time variable, it also has a scale variable in the inner product transform. Thus, it is a successful method suitable for time-frequency localization and is more useful in transient signal analysis.

A detailed study on the application of WT in the fault diagnosis of RCB 's reveals that it plays a major role today as an effective TFDT in dealing with condition monitoring of bearing faults using vibration data. WT can be efficiently implemented for de-noising the raw bearing vibration data, which includes unwanted noise etc. Further, WT decomposes the non-stationary bearing vibration signal into components with simple frequency content.

Madhavendra Saxena [2], has stated that Continuous Wavelet Transform (CWT) analysis is an effective tool for analyzing bearing fault data because in this we may get all the three details, that is time detail, frequency detail, and amplitude detail, and also the CWT signature, which is the unique feature.

3. Problem Definition

Based on the above literature review, the problem for this work is defined as "Fault detection and condition monitoring of rolling contact bearings using vibration signature".

4. Objectives

The key objectives of the present work are as stated below.

- ❖ To develop an experimental setup for the purpose of measuring bearing vibrations.
- ❖ To establish a data acquisition system as part of an experimental setup using National Instruments (NI) hardware devices and Laboratory Virtual Instruments Engineering Workbench (LabVIEW) software.
- ❖ To make use of Matrix Laboratory (MAT lab) software and the available WT function to analyze bearing vibration signals.
- ❖ To generate a bearing vibration signature for assumed cases using CWT.

5. Methodology

To attain the objectives stated above, subsequent methodology is implemented.

1) Using the Laser Engraving Technique (LET), defects are artificially seeded on the inner-race, outer-race, ball, and cage of a geometrically perfect bearing.
2) Vibrations are measured in terms of acceleration for geometrically perfect and defected bearings using the experimental setup developed.
3) Vibration signals are recorded for all bearings using the data acquisition system.
4) The Mat lab environment and available algorithms are used to visualise and analyse bearing vibration signals.
5) Vibration signatures are generated using CWT analysis.

5.1 Experimental Setup

A suitable experimental setup is required to examine the performance of RCB. An experimental test setup was developed to acquire vibration response for geometrically perfect bearings and bearings with faults. Faults are artificially induced into bearings using LET. A data acquisition system is established by employing NI hardware devices, computer, and LabVIEW software. It is connected to the test setup to acquire vibration signals as per requirements. The vibration data is stored in the system with the help of the Virtual Instrument (VI) program developed in LabVIEV software. The line diagram of the test setup necessary to conduct experiments is illustrated in Figure1.

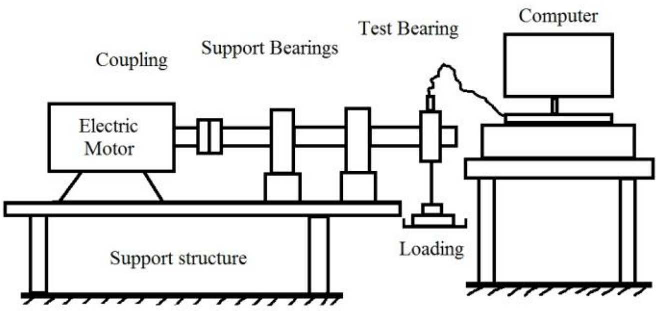


Fig -1: Schematic line diagram of experimental setup

It comprises a 0.37kW induction motor, a shaft of 490mm in length and a diameter of 20mm. The shaft is coupled to the electric motor with flexible coupling in order to reduce the effect of high frequency vibration induced by the motor.

The test setup accommodates one test bearing at the free end of the shaft and two support bearings mounted at an equal distance from the test bearings on a common shaft. The support bearings are mounted in housings. They are ball bearings of the same bore size as the test bearing. The test bearing is examined with the loading arm kept on the outer-race so as to restrict the rotation of the outer-race of the bearing. The loading arm is hinged to the base structure so that it will have line contact with the test bearing. The radial load is applied to the test bearing through the loading arm.

In order to measure the test bearing vibrations, a tri-axial piezoelectric accelerometer is mounted onto the loading arm exactly above the test bearing. In order to record vibration data, it is coupled to the CompactDAQ chassis, which works as an interface between the accelerometer and LabVIEW software. Vibration data is stored on a computer with the help of the LabVIEW program. Loading is used in order to enhance the spectrum amplitude of the system.

Fig -2: Developed experimental setup

Figure 2 shows the various components connected to develop the test setup for the bearing condition monitoring. It consists of the below-mentioned components.

1) 0.5Hp 3 Phase induction motor
2) Tri-axial Piezoelectric Accelerometer
3) C-DAQ Hardware
4) Flexible coupling
5) Test bearing
6) Support bearings (Plummer block)
7) Solid shaft of 250mm length
8) Loading arm of 2.5mm thick and 300mm length
9) Wooden Table
10) Computer

5.2 356A15 accelerometer

It has fixed voltage sensitivity, irrespective of the cable type or length. It possesses a low impedance output signal, which can be transmitted over lengthy cables in harsh environments with virtually no loss in signal quality. It also includes features like low noise, voltage output signal compatible with standard readout, signal analysis, recording and data acquisition equipment.

Table -1: 356A15 accelerometer details

Make	PCB Piezotronics
Type	ICP
Mounting Methods	Adhesive or Stud
Sensitivity	102.8mV/g or10.48 mV/ m/s2
Measurement range	±50g or ±490 m/s2
Frequency range	2 to 5000Hz
Operating temperature range	-54° to +121°C

Fig -3: Tri-axial piezoelectric accelerometer

5.3. Test Bearing Specifications

The test bearings utilised in the experiments are SKF 6304 deep groove ball bearings with a 20mm bore. Three bearings with zero defects were also tested to establish the vibration levels of geometrically perfect bearings. The detailed specification and dimensions of the test bearing are listed in Table2.

Table -2: SKF 6304 bearing specifications

Bearing number	6304
Make	SKF
Limiting speed	19000rpm
Ball bearing type	Deep Groove
Inside Diameter	20mm
Race width	15mm
Outside Diameter	52mm
Static load Rating	7.8kN
Bore Type	parallel
Number of rows	1
Dynamic load Rating	16.8kN
Max speed grease	11000rpm
Max speed oil	14000rpm
Race Type	plain
Cage material	steel
End type	open

5.4. Artificial Defect Seeding

Techniques such as spark erosion, acid etching, scratching, mechanical indentation, and laser engraving are used to introduce defects onto normal bearings. Hence, it is essential to create faults artificially on bearing elements without disturbing their basic geometry. LET is used to seed defects in the work, as it is a simple method.

A CO2 laser is used to create a defect in the bearing. A bearing is oriented in a direction so as to create a defect in the form of a line or pocket. It is a tedious task to create faults exactly on the contact path of the rolling element with the inner-race and outer-race. Care should be taken while the orientation of the bearing is under the laser probe.

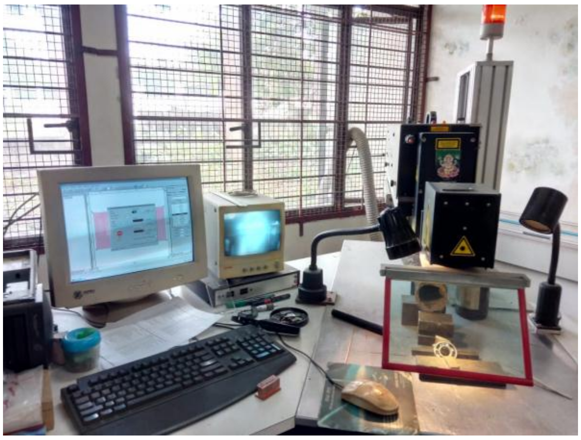


Fig -4: Defect seeding using laser engraving technique

Table -3: Fault details in ball bearings

SI No.	Bearing Type	Location of defect	Nature of defect
1	Geometrically perfect	Defect-free	No defect
2	Geometrically Imperfect	Inner-race (on the contact surface)	Rectangular pocket
3		Outer-race (on the contact surface)	Line crack
4		Ball and cage (Combined)	Material degradation

5.5. Data Acquisition System

For the purpose of measuring bearing vibration, signals induced at the test bearing need to be acquired and recorded by integrating NI hardware and the LabVIEW software environment. NI hardware devices are compatible with the LabVIEW environment, it is required to use this combination as a data acquisition system. Hence, the data acquisition system includes certain hardware devices and computer installed with the required software.

5.6. Hardware Components

The CompactDAQ 9178 chassis incorporates a data acquisition card 9234, which is extensively used for acquiring sound and vibration signals. The hardware system is interfaced with LabVIEW software installed on the computer with the minimum configuration desired. The drive software corresponding to C-DAQ 9178 is installed. The data acquisition card has four simultaneous channels to acquire vibration data, namely ai0, ai1, ai2, ai3. The vibration signal can be measured at a default rate of 25.6 kHz with 25.6k samples per second.

Table -4: C-DAQ Hardware specification

Number of Channels	4
Voltage range	±5V
Acceleration range	±5m/s^2
Temperature range	-40º to +70ºC

5.7. Virtual Instrument (VI) to Acquire Vibration Signal

A VI program is created to acquire signals from bearings.

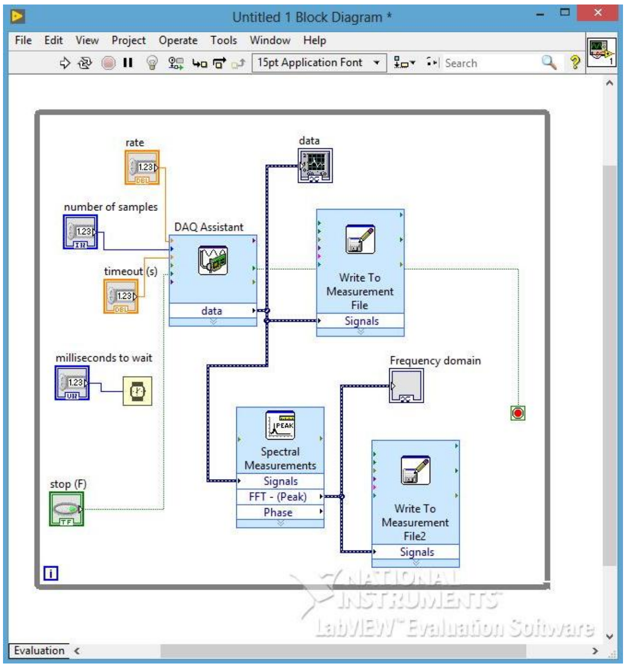


Fig -5A: Vibration Signal Acquisition VI

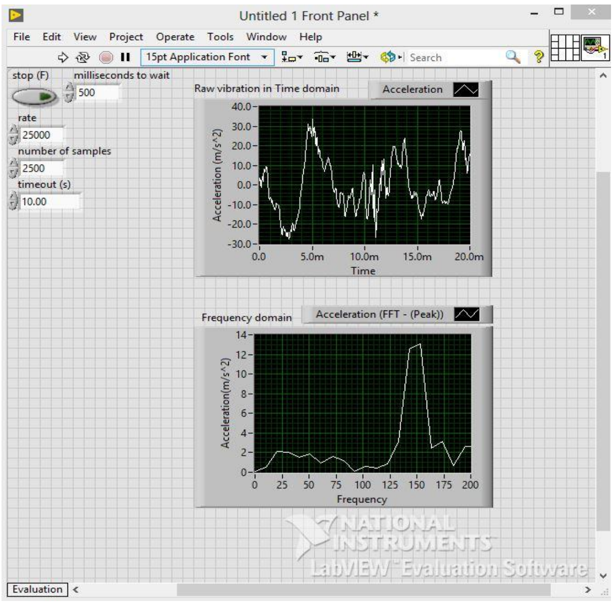


Fig -5B: Vibration Signal Acquisition VI

We can make use of the final VI generated in LabVIEW to conduct all experimental trails.

5.8. Bearing Test Cases

Normally, for all tests, the new bearings are taken first, based on the nature of the faults to be induced using the laser engrave technique. The test conditions are as follows:

Case 1: A geometrically perfect (defect-free) bearing is examined to obtain base line data.

Case 2: Fault was induced by creating a small rectangular pocket in the inner race. The inner-race was finally damaged, particularly over the loaded section of the race. The outer-race and the rolling elements were not obviously damaged but were clearly polished.

Case 3: Fault was produced by creating a small line crack on the outer-race. Severe damage subsequently occurred on that outer race on the loaded side. The inner-race and the rolling elements appeared not to be damaged.

Case 4: In this bearing, some small flats were ground on the rolling elements and cage. The rolling elements were also clearly spalled and the original flats were barely identifiable. The inner-race and outer-race appeared not to be damaged.

5.9. Experimental condition

Vibration data at the test bearing was acquired at a constant speed of 1490 rpm. The load on the test bearing was varied in three steps for a geometrically perfect bearing. It is observed that with the variation of load on the bearing, the amplitude of vibration has changed.

To facilitate the bearing and increase the spectrum amplitude of vibration, a static load is applied by placing standard weights in the loading arm. The vibration of the test bearing in the vertical direction (along the z axis of the accelerometer) is measured by a tri-axial accelerometer with a sensitivity of 100mv/g.

The first set of experiments are conducted on defect-free bearings so as to establish the base line vibration data. Then the data is collected for different fault cases.

Sampling rate =25.6 kHz

Number of samples / data points = 25600

The tests are carried out for different cases with the same parameters. The recorded vibration data is stored on the computer in an LVM file extension. The stored data can be retrieved either into LabVIEW software or into the MAT lab environment.

5.10. Wavelet Transforms

The wavelet transforms (WT) is a rapid emergent mathematical and signal processing tool, which converts raw vibration data into a sequence of wavelet coefficients in a time-scale grid using the wavelet basic function. The wavelet transform provides the time-frequency representation.

In various situations, a particular spectral component occurring at any instant of time is of more interest. In such a situation, it is important to know the time intervals where particular spectral components occur. WT is able to provide the time and frequency information simultaneously.

Investigation with wavelets proceeds with breaking up a signal into shifted and scaled versions of its mother (or original) wavelet, that is, obtaining one high frequency term from each level and one low frequency residual from the last level of decomposition.

In other words, decomposition of signals is a process of breaking signals into lower resolution components with respect to levels. In particular, the Continuous Wavelet Transform (CWT) provides a multi-resolution in time-frequency analysis for characterization of the transitory features of non-stationary signals. The effect was an accumulation of higher frequency sine waves spread throughout the frequency axis. CWT is widely used to divide a continuous-time function into wavelets.

The frequency and time information of a signal at some certain point in the time versus frequency plane cannot be known. In other words, we cannot know what spectral component exists at any given instant. The best we can do is to investigate what spectral components exist at any given interval of time. This is a problem of resolution, and it is the main reason why researchers have switched to WT from STFT. STFT gives a fixed resolution at all times, whereas WT gives a variable resolution.

5.11. Continuous Wavelet transforms

The CWT was developed as an alternative approach to the STFT to overcome the resolution problem. This is used to analyze the signal in the time-frequency domain. This enables time-frequency selectivity, as it is possible to localize events both in time and frequency.

The CWT can be mathematically represented as

$$CWT(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} X(t)\, \psi^{*}\left(\frac{t-b}{a}\right) dt \quad \text{------------------4.3}$$

The transformed signal is a function of two variables a, b

where a-represents scale parameter

b-represents translation parameter

ψ-represents mother wavelet

ψ^{*}-complex conjugate of ψ

The results of the CWT are many wavelets' coefficients C, which are functions of scale and position. When multiplied by a sinusoid of appropriate frequency, it yields the constituent sinusoidal components of the original signal.

5.12. Steps followed in CWT analysis

1) Take a wavelet and compare it to a section at the start of the original signal.

2) Calculate the wavelet coefficient (C), which represents how closely correlated the wavelet is with this section of the signal. The higher the value of C, which indicates the more similarity. The results depend much on the shape of the wavelet we choose for a particular application.

3) Shift the wavelet to the right and repeat steps 1 and 2 until we've covered the whole length of the signal.

4) Scale (stretch) the wavelet and repeat steps 1 through 3.

5) Repeat steps 1 through 4 for all scales.

6.Vibration Signal Analysis

The bearing vibration signals recorded during the experiments contain unwanted noise and other disturbances in addition to the required information. In order to extract the desired feature from it, an appropriate signal processing technique with suitable software should be employed to represent the signal in an easily recognisable format.

The vibration data recorded in the time domain can be retrieved in the LabVIEW environment for further processing and evaluation of a few key parameters required for bearing fault diagnosis.

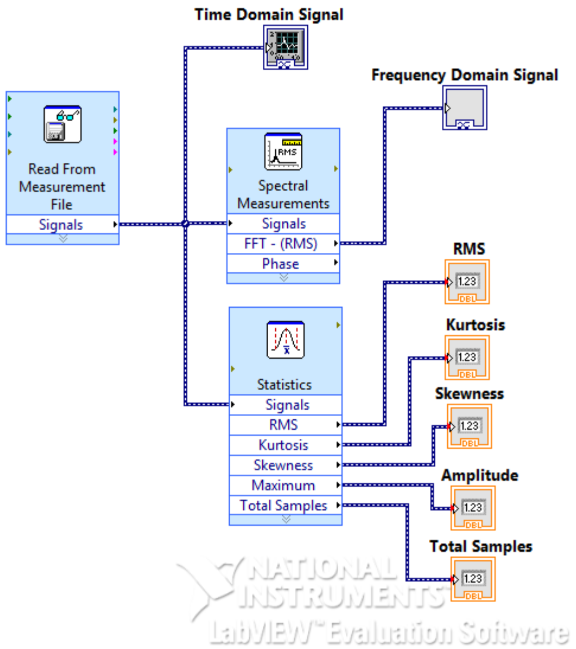


Figure.6 Virtual Instrument program to evaluate statistical parameters

A VI program is to be generated in LabVIEW as illustrated in Figure 6 so as to read the vibration signals stored during the experiments. The statistics pallet can also be incorporated into the same VI to evaluate some statistical features like Kurtosis, RMS value, skewness etc. In addition, it is also possible to calculate the amplitude of vibration and sample size of vibration data acquired.

6.1. Effect of radial load on bearing vibration response

The geometrically perfect (defect-free) bearing is tested at three different levels of loading in the radial direction. At each load step, three trials were conducted. Using LabVIEW for all trials, the interesting features are recorded from the bearing vibration signals. It is clearly understood from Table 4 that as the load is increased, the vibration level also increases in the present experimental setup.

Table -4: Effect of load on amplitude of vibration

SI No	Load (kg)	Amplitude (m/s^2)	Avg Value
1	5	45.97	49.58
2		55.26	
3		47.52	
4	7.5	70.36	79.58
5		82.99	
6		85.39	
7	10	94.45	106.24
8		107	
9		117.28	

6.2. Evaluation of Kurtosis value for bearing test cases

The kurtosis values for all four test cases are evaluated using the LabVIEW VI shown in Figure 6, with kurtosis values of 3.2, 5.58, 3.96, and 9.58 for the defect-free bearing and bearings with defects at the inner-race, outer-race defect, ball, and cage, respectively. The values are tabulated for the respective cases in Table 5. and even a bar chart gives more clarity of kurtosis values for different cases.

Table 5 Kurtosis value evaluated for four test cases

SI No.	Bearing Condition	Kurtosis
1	Defect-free	3.2
2	Inner-race (on the contact surface)	5.58
3	Outer-race (on the contact surface)	3.96
4	Ball and cage (Combined)	9.58

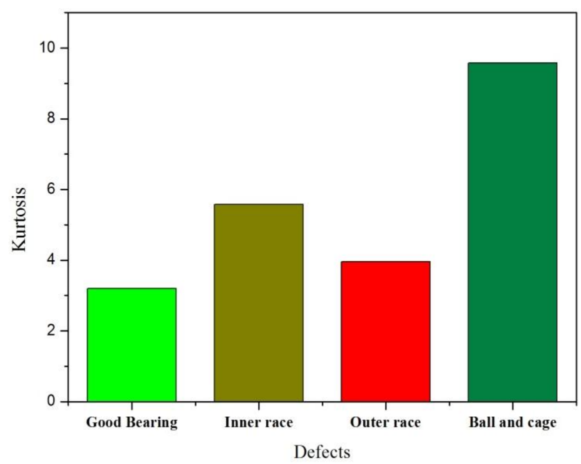


Chart -1: Variation of kurtosis value with bearing defect

6.2. Vibration Signature in Time Domain

To generate vibration signatures in the time domain, vibration signals acquired from defect-free and bearings with defects at the inner-race, outer-race defect, and ball and cage are plotted in a time amplitude grid using the MAT lab program. The vibration signature generated for all four cases is shown in Figures 7 to 9 in terms of time and acceleration.

Case 1: **-** Perfect bearing

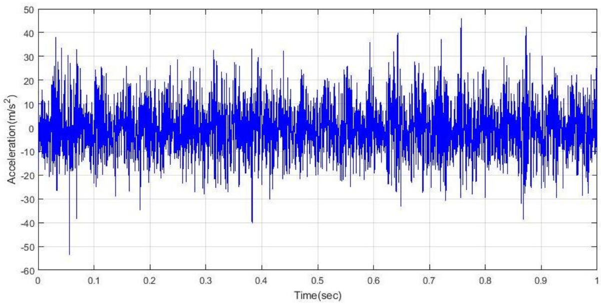


Figure.7 Time history of defect-free bearing

Case 2: - a bearing with an inner-race flaw

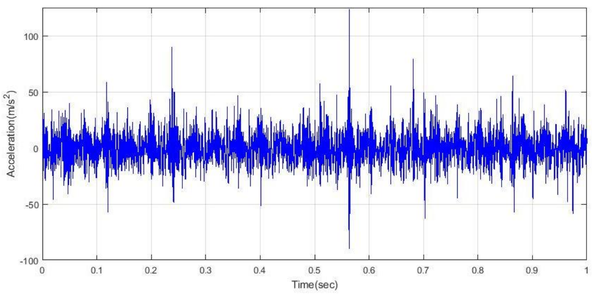


Figure.8 Time history of bearing with inner-race defect

Case 3: - a bearing with an outer-race fault

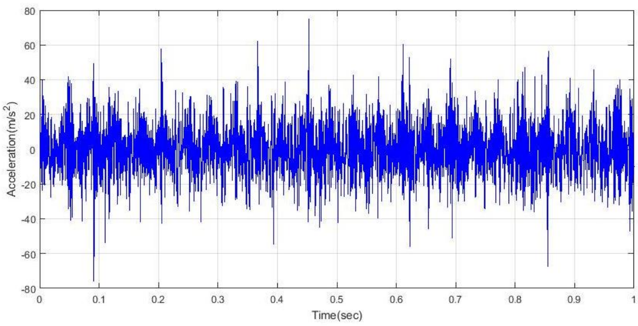


Figure.8 Time history of bearing with outer-race defect

Case 4: - bearing with a problem on the ball and cage

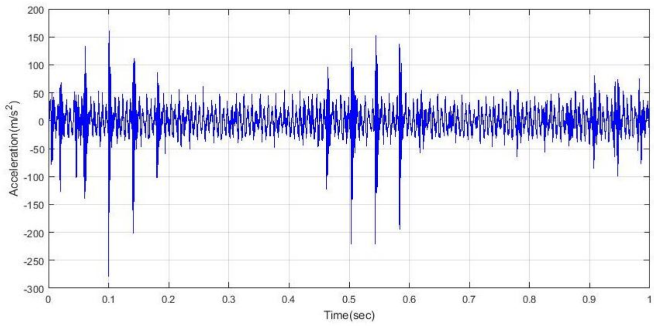


Figure.9 Time history of bearing with ball and cage defect

It is evident from all four test cases that each represents a unique vibration pattern. We can also observe periodic impulses present in bearings with different types of defects. Time domain information is insufficient to recognise the bearing defects effectively. Therefore, the vibration signals need to be analysed in the time-frequency domain to get more clarity.

6.3. Time-frequency Domain Technique

As described earlier, CWT can be effectively used to monitor bearing faults. CWT-based analysis is used to identify bearing faults. This technique does not involve lengthy signal processing like other methods. It is a simple visual inspection method and does not require the analyst to have a lot of experience in signal processing or bearing fault diagnosis.

6.4. CWT Based Signal analysis

The processing of the vibration signal in the MAT lab can be divided into the following steps.

1) Load or import and visualize the vibration signal.

2) Processing vibration signals using the CWT algorithm.

3) plotting the signal's time-scale representation

1) Importing and visualizing the vibration signal

The following program can be used to load and visualizing the vibration signal.

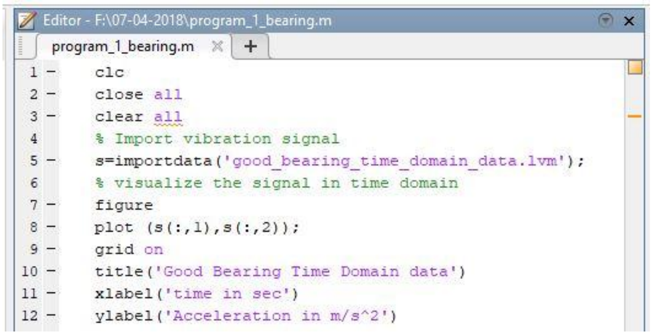


Figure 10-MAT lab Program for importing and visualizing signal

The above program enables us to import the vibration signals recorded in lvm file format. We can also visualize the signal in the raw format. The same program can be further continued to process bearing vibration signals using the CWT algorithm as described in the subsequent step.

2) Processing vibration signal using CWT analysis

The MAT lab is extensively used to process vibration signals using the CWT algorithm readily available in the software. We can make use of the CWT concept in analyzing the bearing vibration signals obtained from four test cases for a bearing rotating at 1490 rpm (24.83Hz). The CWT analysis plots results in terms of time and scale. The MAT lab code developed to obtain the CWT analysis of vibration signals is shown below. The same program is employed for all four test cases by importing the respective files recorded during the experiments.

```
clc
clear all
close all
% importing raw vibration data
Time_domain_signal =importdata ('test_1.lvm');
% continuous wavelet transforms
c = cwt (Time_domain_signal, 1:128,'db4','plot');
```

The last statement in the above program indicates parameters such as the signal to be analysed using CWT analysis, scales selected, and wavelet type employed. In this case, we have selected 128 as the scale and db4 represents the Daubechies wavelet having level 4.

3) Plotting time-scale representation of proceed signal

The function cwt produces a plot of the absolute values of the CWT coefficients. In this case, the coefficient matrix produced by the program will have a matrix size of 18 by 25600, with each individual row corresponding to a single scale. Figures 11 to 14 show the time-scale plots obtained from CWT analysis for defect-free bearings and bearings with outer-race defect, inner-race defect, and combined defect of ball and cage.

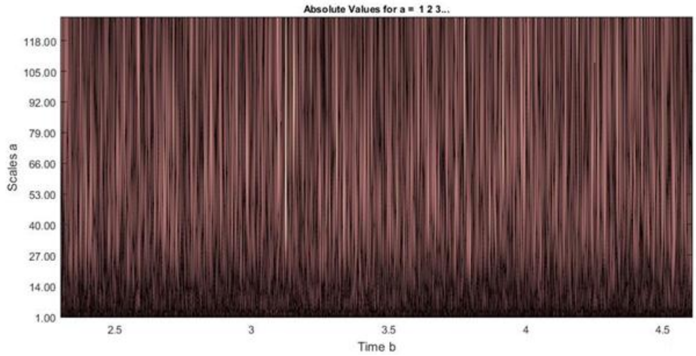


Figure 11- CWT plot for defect-free bearing

The plots shown in Figure 11 to 14 are the CWT coefficient plots on a time versus scale. The brightness of colour in the plot indicates the amplitude at the corresponding point on the time scale grid. The parameter scale, as explained earlier, may be considered the inverse of frequency. The low scales represent high frequency regions, and the high scales correspond to low frequencies.

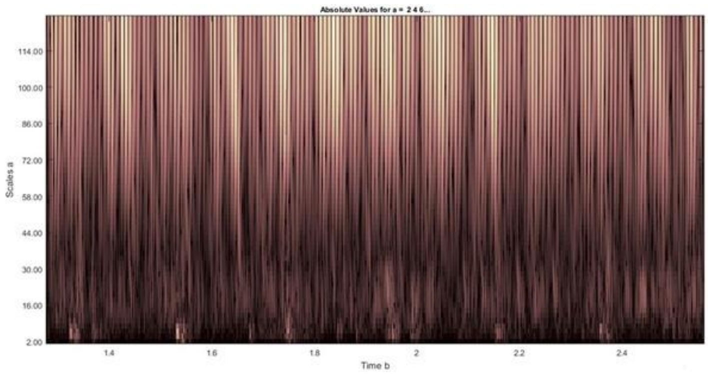


Figure 12- CWT plot for bearing having defect at outer-race

When the defect-free bearing is operating, the energy is accumulated in the low frequency range, where most of the macro structural vibrations are located, should be low. It can be observed from Figure 11 where dark color in the low frequency range (scales 92 to 118) indicates low energy content and specifies that bearing is in normal condition.

On the other hand, the energy level is high if high energy content is recognized in low frequency range where the bearing characteristic frequency lies, it indicates towards defective bearing. In Figure 12, where an outer-race fault exists in the bearing, the energy levels of vibrations in the low frequency range are high as highlighted by bright colored contours in the low frequency range.

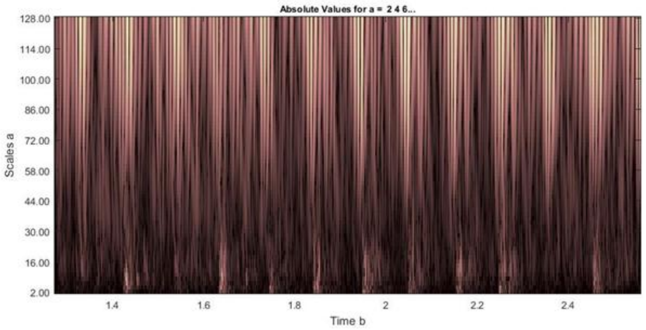


Figure 13- CWT plot for bearing having defect at inner-race

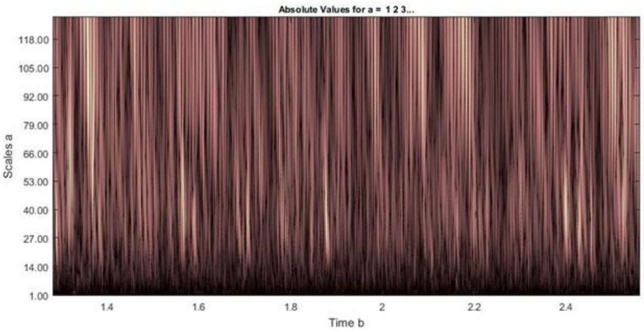


Figure 14- CWT plot for bearing having both ball cage faults

Another method of fault existence could be achieved by inspecting the energy level at the high frequency range, where the bearing excitation range is located i.e. scales 16 to2. The impacts caused by passage of rolling element over the defect causes an impact which excites the bearing resonant frequency.

The high energy impacts generated by the defects in the inner-race and the balls and cage can be noticed in Figure 13 and 14. The Impacts are indicated by appearance of strips of bright color (high energy) occurring at regular interval. Therefore, CWT analysis yields clear indication of different defects in terms of color variation.

7.Results and Discussions

The following section gives results obtained from the experiments and theoretical.

Effect of radial load on vibration response

The amplitude of vibration for different loading condition for a defect-free is as listed in Table 4. Amplitude of vibration increases as the radial load on the bearing increases.

Kurtosis value

The kurtosis values are evaluated for the four test cases and are listed in the Table 5. For a defect-free bearing kurtosis value is 3 and the values increases above 3. The bar chart clearly indicates the variation of kurtosis values for different cases.

CWT Analysis

The CWT analysis carried out for defect-free indicates accumulation of its energy in lower frequency bands as shown in Figure 11. For a bearing with defect at outer-race as illustrated in Figure 12 signifies the existence of high energy content at lower frequency band, because bearing characteristic frequency lies in this region. Similarly bearing having defect at its inner-race and defect on ball and cage also exhibit same behavior at its lower frequency band. In addition to this it also indicates the presence of energy level at high frequency band, where the bearing excitation range is located.

8. CONCLUSIONS

The below mentioned conclusion are draw from the present investigation.

1) The amplitude of vibration increases with increase in radial load. It indicates that load enhance the vibration level in the present experimental setup.

2) Kurtosis values used because it is a powerful tool for quantitative evaluation of the bearing condition. The main advantages of kurtosis are insensitive to changes in speed and loading bearing and an ability to indicate damage extent.

3) Wavelet transform based time-frequency analysis has great advantages for handling non-stationary vibration signals generated in condition monitoring of RCB.

4) Vibration signatures generated using CWT analysis are unique and clearly differentiate the defect-free, bearings with inner-race defect, outer-race defect and combined ball and cage defect. Therefore, CWT is an effective time-frequency technique for RCB fault diagnosis.

9. Scope for future work

- To fine tune the experimental setup to improve defect delectability.
- To improve feature extraction and to shorten processing time of signal analysis using Discrete Wavelet Transform.
- The same experiment can be conducted at different speeds by including a variable frequency drive to carry out same work at different speeds.

REFERENCES

[1] N. Tandon, A Choudhury: "A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings", Tribology International, 32.8, 1999, 469-480.

[2] Madhavendra Saxena, Olvin Oliver Bannet, Manoj Gupta and R.P. Rajoria: "Bearing Fault Monitoring Using CWT Based Vibration Signature", Procedia Engineering, 144, 2016, 234-241.

[3] Pankaj Gupta, M. K. Pradhan: "Fault detection analysis in rolling element bearing: A review", Materials Today, proceedings 4, 2017, 2085-2094.

[4] J. Mathew, R. J. Alfredson: "The Condition Monitoring of Rolling Element Bearings Using Vibration Analysis", Journal vibration acoustics, Stress and Reliability in Design, 106/447, 1984.

[5] N. Tandon: "A comparison of some vibration parameters for the condition monitoring of rolling element bearings", Measurement, 12, 1994, 285-289.

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