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Vibration Analysis of Ball Bearing

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Abstract: ***In today's scenario, maintenance of any machinery is very important in view of downtime of machinery. The bearing sector is one of the examples without which not single rotating machinery work. Products of bearing sector are of high value which leads to the aspects of bearing life & application in more demanding situations. This project addresses Design, Experimentation and Validation analysis of fault diagnosis of ball bearing related to rotor system. Detail analysis using FFT Methodology is done to find out the possible faults and finally validate with MATLAB software. Numbers of faults are identified and this will be validated for each fault. Faults are identified on single rotor system test rig. Experimental Evaluation & validation of faults are done to confirm results and finally effective solution is implemented to completely indicate faults of bearing which are being reported during validation process. In addition to this we have done lubrication analysis by using FFT analyzer for bearing with lack of lubrication and bearing with lubrication.***

Keywords: vibration, bearing fault, FFT, Hilbert-Huang Transform, Intrinsic Mode functions, empirical mode decomposition

1. Introduction

The importance of Vibration analysis is used to determine the operating and mechanical condition of equipment. A major advantage is that vibration analysis can identify developing problems before they become too serious and cause unscheduled downtime. This can be achieved by conducting regular monitoring of machine vibrations either on continuous basis or at scheduled intervals.

Regular vibration monitoring can detect defective bearings, mechanical looseness and worn or broken gears. Vibration analysis can also detect misalignment and unbalance before these conditions result in bearing or shaft deterioration. Trending vibration levels can identify poor maintenance practices, such as improper bearing installation and replacement, inaccurate shaft alignment or imprecise rotor balancing.

All rotating machines produce vibrations that are a function of the machine dynamics, such as the alignment and balance of the rotating parts. Measuring the amplitude of vibration at certain frequencies can provide valuable information about the accuracy of shaft alignment and balance, the condition of bearings or gears, and the effect on the machine due to resonance from the housings, piping and other structures. Vibration measurement is an effective, non-intrusive method to monitor machine condition during start-ups, shutdowns and normal operation. Vibration analysis is used primarily on rotating equipment such as steam and gas turbines, pumps, motors, compressors, paper machines, rolling mills, machine tools and gearboxes. Recent advances in technology allow a limited analysis of reciprocating equipment such as large diesel engines and reciprocating compressors. These machines also need other techniques to fully monitor their operation.

1.1 Vibration

When any elastic body such as spring, shaft or beam, is displaced from the equilibrium position by the application of external forces and then released, it commences cyclic motion. Such cyclic motion of a body or a system, due to elastic deformation under the action of external forces is known as vibration.

Causes of Vibration:
Unbalance forces and couples in the machine parts.
External excitation forces applied on the system.
Dry friction between two mating surfaces.
Winds may cause vibrations in certain systems such as telephone lines, electricity lines, etc.
Earthquakes also cause vibrations in civil structures like buildings, dams, etc.
Disadvantages of Vibrations:
It creates excessive stresses in machine parts.
It leads to loosening of assembled parts..
It may lead to partial or complete failure of machine parts.
It creates undesirable noise.

A vibration analysis system usually consists of four basic parts:
1. Signal pickup(s), also called a transducer
2. A signal analyzer
3. Analysis software
4. A computer for data analysis and storage.

These basic parts can be configured to form a continuous online system, a periodic analysis system using portable equipment, or a multiplexed system that samples a series of transducers at predetermined time intervals. Hard-wired and multiplexed systems are more expensive per measurement position. The determination of which configuration would be more practical and suitable depends on the critical nature of the equipment, and also on the importance of continuous or semi-continuous measurement data for that particular application

1.2 Bearing

The bearing sector is one of the example in which customer expectations in terms of Quality & Cost are boosted across world. This project addresses analysis of failures related to ball bearing. Detail analysis using rotor system with ball bearings Methodology is done to find out the possible causes and finally root cause. Bearing is a mechanical element which locates two machine parts relative to each other & permits relative motion between them, with minimum friction.

Figure 1.1: Self aligning ball bearing

The functions of the bearings are as follows:

Bearing ensures free rotation of the shaft or the axle with minimum friction. Bearing supports of the shaft or the axle and holds it in correct position. The bearing takes up the forces that act on the shaft or the axle and transmits them to the frame or the foundation.

2. Literature Review

2.1 Review of Papers

In 2002, N.G. Nikolaou et.al presented rolling element bearing fault using wavelet packets (WPT). A time-frequency decomposition of vibration signals is analyzed and those components of signal having important information are selected for processing. The method is evaluated using simulated and experimental signals. They have used a PCMCIA DAQ Card-1200 data acquisition card. He concluded that compared to other methods, using filters or continuous wavelet transform, it has the advantage of flexibility and efficient computational implementation.

In 2007, V.K. Rai, A.R. Mohanty [2007] have discussed bearing fault diagnosis using FFT of intrinsic mode functions in Hilbert–Huang transform. They have used the conventional data acquisition card for measurement of vibration data and calculated the CDFs analytically. They have taken readings for Healthy bearings, IR fault and OR faults. The HHT technique provides multi-resolution in various frequency scales and takes the signals frequency content their variation into consideration. In the present work, FFT of IMFs from HHT process has been incorporated to utilize efficiency of HT in frequency domain. The comparative analysis is presented in this paper indicates the effectiveness of using frequency domain approach in HHT and its efficiency as one of the best-suited techniques for bearing fault diagnosis (BFD). They have done comparative analysis and indicated the effectiveness of HT in frequency domain. They have shown presence of amplitude modulation as well as capturing the defect frequencies accurately.

In 2009, Tuncay Karacay et.al have discussed experimental diagnostics of ball bearings using statistical and spectral methods. They have conducted test on test rig with new bearings and data acquisition card is used to measure the vibrations. The bearings run throughout their lifespan under constant speed and loading conditions. The formation and development of localized defect in ball bearings are investigated running a bearing through failure. Vibration signatures produced are recorded and statistical measures are calculated during the test. In this study, the formation and development of localized defect in ball bearings are investigated running a new bearing through to failure. During the test, vibrations are acquired and traditional metric values such as peak-to-peak value, RMS, Crest factor and kurtosis are calculated. They have found that first an inner-race defect is formed in the ball bearing together with a slight ball defect. While at the end of test an inner-race and ball-localized defects developed at the end of the test, an outer race defect followed them.

In 2009, P.K. Kankar, et.al have discussed fault diagnosis of a rotor bearing system using response surface method. They have considered the distributed defects such as internal radial clearance and surface waviness of the bearing components. They have studied ball waviness, inner race waviness and outer race waviness individually and also taken readings of combined waviness. They investigate an accurate performance prediction, which is essential to the design of high performance rotor bearing system. They used mathematical formulation the contacts between the rolling elements and the races are considered as nonlinear springs, whose stiff nesses are obtained by using Hertzian elastic contact deformation theory. From the obtained responses following conclusions are drawn:

1) Nonlinear dynamic responses are found to be associated with large internal radial clearance and distributed defects.
2) It is shown that the system exhibit dynamic behaviors that are extremely sensitive to small variations of the system parameters, such as internal radial clearance and ball waviness.
3) The system shows periodic nature, when ball waviness is at its maximum level.

In 2010, P.K. Kankar et.al have focused on fault diagnosis of ball bearings using machine learning methods. They have used supervised machine learning methods like artificial neural network (ANN) and support vector machine (SVM) to extract the features. A test rig of high speed rotor supported on rolling bearings is used. The vibration response are obtained and analyzed for the various defects of ball bearings. The specific defects are considered as crack in outer race, inner race with rough surface and corrosion pitting in balls. A comparative experimental study of the effectiveness of ANN and SVM is carried out. This study presents a procedure for detection of bearing fault by classifying them using two machine learning methods, namely, ANNs and SVMs. Features are extracted from time-domain vibration signals using statistical techniques. it is observed that bearing shows severe vibrations occur under bearing with rough inner race surface and ball with corrosion pitting. It is also observed that the classification accuracy for

SVM is better than of ANN.

In 2011, Matej Tadina, et.al have developed the numerical bearing model to investigate the vibrations of the ball bearing during run-up. The numerical bearing model was developed with the assumptions that the inner race has only 2 DOF and that the outer race is deformable in the radial direction, and is modelled with finite elements. They have considered centrifugal load effect and the radial clearance effect. The contact force for the balls is described by a nonlinear Hertzian contact deformation. They have considered outer vrace, inner race and ball defects into account. They used the continuous wavelet transform (CWT) and envelope analysis to identify simulated bearing faults. The continuous wavelet transform (CWT) found better for vibration analysis of a bearing with ball fault.

In 2011, P.K. Kankar, Satish C. Sharma, S.P. Harsha have discussed bearing fault diagnosis using continuous wavelet transform (CWT). They have used three machine learning techniques for fault classifications out of which two are supervised machine learning techniques i.e. support vector machine (SVM), artificial neural network (ANN) and other one is an unsupervised machine learning technique i.e. self-organizing maps (SOM). The result showed that the SVM identifies the fault categories of rolling element bearings more accurately compared to ANN and SOM. The fault diagnosis method consists of three steps, firstly the six different base wavelets are considered in which three are from real valued and other three from complex valued. Out of these six wavelets, the base wavelet is selected based on wavelet selection criterion to extract statistical features from wavelet coefficients of raw vibration signals. Two wavelet selection criteria Maximum Energy to Shannon Entropy ratio and Maximum Relative Wavelet Energy are used and compared to select an appropriate wavelet for feature extraction. Finally, the bearing faults are classified using these statistical features as input to machine learning techniques. This study presents, a methodology for detection of bearing faults by classifying them using three machine learning methods, like SVM, ANN, and SOM. This methodology incorporates most appropriate features, which are extracted from wavelet coefficients of raw vibration signals.

In 2012, Mohit Lal, Rajiv Tiwari, have developed an identification algorithm to estimate parameters of multiple faults in a turbine-generator system model based on the forced response information. A simple discrete model of the system has been developed with the assumption of the rigid rotor, flexible-bearings and the flexible-coupling. The advantage of the present method in respect to existing methods is that it does not assume equivalent forces and moments of faults, which often suffers from erroneous estimation of fault parameters due to severe ill-conditioning of regression equations. The effect of change in assumed unbalance parameters and disc masses on estimates of residual unbalance is discussed and it is observed that the estimates are showing good agreement with change in these parameters.

In 2012, Tiago Cousseau et.al, have studied influence of grease rheology on thrust ball bearing friction torque. They were measured friction torque amd operating temperature for seven different types of greases.they concluded that grease rheology is stronglty dependent on the thickner type also the bearing rolling torque and bearing sliding torque mainly dependes upon viscosity and specific film thickness of the oil.

In 2013, Bubathi muruganatham et.al has used singular spectrum analysis for extraction of features from rolling bearing. An artificial neural network (ANN) is used for fault diagnosis. They have considered four bearing conditions for study; healthy bearings, bearing with a point defect on inner race, bearing with a point defect on outer race and bearing with a point defect on ball.

2.2 Comment

From the literature review, it is observed that each paper has study based on single or multiple bearing faults with single signal processing technique. There is no comparative study of signal processing technique. We will do the comparative study of all techniques.

3. Problem Definition

3.1 Brief Problem Definition

Problem definition is very important step in any problem resolution it is said that well defined problem is half way towards problem solving hence systematic approach of problem definition i.e. 4W 1H (4 why and 1 how) is adopted.

SKF produces different types of bearings with different sizes. Rolling contact bearing has wide variety of bearings which are well known brands in Indian Market. All these bearings having either of the two types of bearings like ball bearing and roller bearing. Same platform has the Major Field issue of ball bearing. This is highest rate of field failures causing customer dissatisfaction. Hence it is decided to investigate bearing failure to avoid major failure to any rotating machinery the by Root Cause analysis & Advanced Validation Methods.

Problems of this system are defined in 4W 1H as below;
What : Bearing failure
When : During running condition of machinery
Where : In the Field at end user.
Which : This failure is in rotating machinery.
How : Lack of lubrication, uneven loading, higher load than capacity etc.
Since, there are different failure modes of bearing which is resulting in different failures.

3.2 Criticality of the Problem

This Causes Loss of Money/Time/Energy. This is top concern in the field of process industry also it increases the machine downtime hence this problem is selected for resolution.

This small bearing problem causes failure of total system. Due to bearing failure the system is going to under maintenance.

Faults considered for diagnosis:-
We have artificially created faults on different elements of bearing elements all inner race, outer race; ball etc by Electrical discharge machine (EDM). We have selected the bearing 1205 ETN9 which is easy to dismantle. We have created artificial faults and diagnose the same by using FFT analyzer and validate the same by MATLAB software.

Conditions considered for fault diagnosis are:-
- Healthy bearing
- Bearing with crack on inner race
- Bearing with crack on outer race
- Bearing with spall on ball
- Bearing lubrication

In Fig 3.1 we have shown that inner race with crack created by artificially (By using EDM).

Figure 3.1: Inner race crack

In Fig 3.2 we have shown that outer race with crack created by artificially (By using EDM).

Figure 3.2: Outer race crack

In Fig 3.3 We have shown that spall on ball created artificially.

Figure 3.3: Spall on ball

4. Methodology for Analysis

4.1 Project overview

4.1.1 Objectives

The work has been carried out in the following stages:
- To construct a single rotor test rig supported in conventional ball bearings. That could be used to simulate and determine vibration analysis of bearing with different faults.
- Specifically vibration analysis of healthy ball bearing, bearing with inner race crack, bearing with outer race crack, ball bearing with ball having spall and bearing without lubrication are the targeted faults.
- Under investigation both supports acceleration has been carried out for the vibration signatures due to different faults mention with the help of FFT analyzer.
- Compare experimental parameters with results by MATLAB software.

4.1.2 Future Scope

The subject of vibration monitoring and fault diagnosis in rotating machinery is vast, including the diagnosis of items such as rotating shafts, bearings, gears and pumps. The different types of faults that are observed in these areas and the methods of their diagnosis are accordingly great, including vibration analysis, model-based techniques.

The literature on the subject of fault diagnosis is vast and wide-ranging, encompassing such areas as general surveys, general system modeling and also methods applied to the fault detection and isolation (FDI) of specific items of machinery, such that found in land and marine-based power plant and in aero-engines. Many kinds of FDI techniques can be applied in different situations, including both static and dynamic processes, where the same method can often be employed using different input and output parameters, depending on the system type.

One of the major areas of interest in the modern-day condition monitoring of rotating machinery is that of vibration. If a fault develops and goes undetected, then, at best, the problem will not be too serious and can be remedied quickly and cheaply; at worst, it may result in expensive damage and down-time, injury, or even loss of life. By measurement and analysis of the vibration of rotating machinery, it is possible to find an effective signal processing technique for predictive maintenance.

4.2 Methodology

Bearing is essential for rotating machinery to reduce friction. In rotating machinery bearing plays an important role. It reduces friction as well as carry load of the system. When bearing gets damaged it reduces life of a machine as the vibrations are increased due to damage. So that solution for this problem is to use FFT analyzer to find vibration intensity. But to study the effectiveness of these bearing problems, design of condition monitoring kit and manufacture it. Further to study vibration due to bearing faults such as, inner race crack, outer race crack, and spall on ball, etc. Different methodological approaches are,

4.2.1 Analytical Approach

Different parameters are considered in analytical approach.

4.2.1.2 Parameter Selection

There are various parameters which decide capacity & size of bearing. These parameters we have to vary with requirement. Following are some important parameter for experimental set up design.

a) diameter of shaft
b) torque required
c) bearing capacity
d) Other dimensional specification

4.2.1.3 Design Calculation

Design of components of experimental set up for suitable loading capacity is done.

4.2.2 Experimental Approach

1) Take the readings for different bearing faults & collect data accordingly by using using FFT analyzer.
2) Compare these results with different signal processing techniques & find the most effective technique for any rotary system with ball bearing for predictive maintenance.

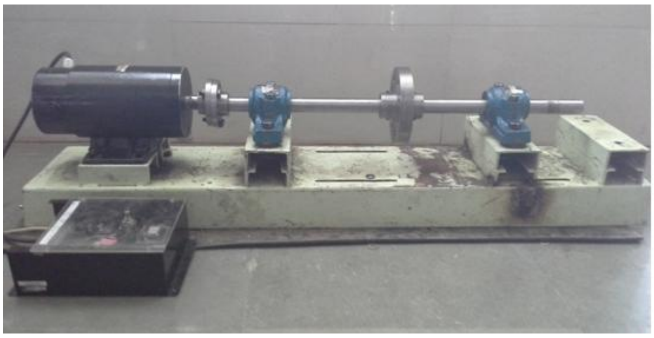

Figure.4.1 Experimental set up

4.2.3 Simulation Approach

1) By using MATLAB software with Hilbert- Huang Transform (HHT) and Fast Fourier Transform (FFT) as a signal processing technique for simulation.
2) First by using HHT we decompose the signal by empirical mode decomposition (EMD) and then take separate Intrinsic mode function (IMF) from EMD to find out fault frequency, time and amplitude.

FFT is the instrument giving the detail information of rotating machinery related to vibration, like bearing lubrication, etc. like bearing fault, misalignment, looseness, unbalance, crack on blower etc.

5. Statement of Requirement and Experimentation Plan

5.1 Aim

FFT is the instrument giving the detail information of rotating machinery related to vibration, like bearing fault. Commodity assumption:-

Purpose:-
To detect the bearing fault type.
To improve the operator safety.
To reduce the field failure of machinery.

5.2 Experimentation Plan

5.2.1 Design Validation Plan

FFT analyzer is the important instrument in Experimental analysis of any component in rotating machinery for vibration analysis

Objective:-To design the single rotor test rig & to detect the fault on bearing.

Scope: - This analyzer gives the amplitude of vibration by which we can analyze the severity of the faultest Equipment: - four channel FFT analyzer.

Table 1: Specification of FFT analyzer

Number of lines	1600
Number of samples	4096
Frequency range	0-1600Hz
Window type	Hanning
Spectral average mode	normal
Accelerometer sensor sensitivity	100 mV/g

5.3. Experimental set-up

The experimental set-up comprises a test-rig, an AC motor with variable speed drive for a shaft-rotor assembly. The shaft is supported on self aligning ball bearings 1205 ETN9 series. There are number of conditions we considered by creating artificially induced defects. The defects have been introduced using electrical discharge machining (EDM) process. The bearing specifications have been listed in Table 5.2 Table 5.3 gives the theoretically calculated values of CDFs. The contact angle for the bearing under no load can be assumed to be zero. Accelerometer and data acquisition card have been used to measure and digitally acquire free vibration data. The motor is run at a constant speed of 17 Hz shaft revolutions (fs).

5.4 Characteristic Defect Frequency calculations

A rolling element bearing consist of inner and outré races, a cage and rolling element (ball). Defect can occur in any part of the bearing and causes high amplitude of vibration. The bearing having different frequencies for different bearing elements like, BSF, BPFO, BPFI and FTF are called characteristic frequencies. When we consider these characristic frequencies for fault detection we called them as characteristic defect frequencies (CDF). The CDFs are determined by following equations. Various symbols used in the equations can be related to tables 5.2and 5.3.

$$BSF = f_s \frac{P_d}{2B_d}\left(1 - \frac{B_d^{\,2}}{P_d^{\,2}}\cos^2\phi\right)$$; Ball spin frequency

$$BPFO = f_s \frac{N_b}{2}\left(1 - \frac{B_d}{P_d}\cos\phi\right)$$; OR frequency

$$BPFI = f_s \frac{N_b}{2}\left(1+\frac{B_d}{P_d}\cos\phi\right)$$; IR frequency

$$FTF = \frac{f_s}{2_d}\left(1-\frac{B_d}{P_d}\cos\phi\right)$$; Fundamental train frequency

Pd= Bearing pitch diameter, mm
Bd= Ball diameter, mm
Nb= number of balls
Ø= contact angle
Fs= shaft speed or inner race speed, rpm

Table 5.2: Bearing Specifications

Ball diameter(B_{d})	7.87 mm
Pitch dia(P_{d})	38.5 mm
Number of balls (N_b)	13
Contact angle (Ø)	0

Characteristic defect frequencies of rolling element bearing used in this study are given in table.

Table 5.3: Different Characteristic Defect Frequencies

Bearing type	Shaft speed(Hz)	N_b	BPFI (Hz)	BPFO (Hz)	FTF (Hz)	BSF (Hz)
SKF 1205 ETN9	17	13	134	91	7	43
	18	13	141	96	7	45

6. Results and Discussion

We have done experimental analysis and simulation for four different cases. These cases are as follows:-
1) Healthy bearing
2) Bearing with crack on inner race
3) Bearing with crack on outer race
4) Bearing with spall on ball

6.1 Healthy bearing

6.1.1 Experimental Observation for rotating machinery by using FFT analyzer

We got spectrum from FFT analyzer for healthy bearings against amplitude. From above figure we got amplitude of vibration (in g RMS – Acceleration) at 1095rpm (18Hz). In fig. we can see that vibrations are present in system, but they are not from bearing fault, these vibrations are due to some misalignment or system vibrations. At CDF the vibrations are very small or there are no peaks at CDFs. This shows that bearing is healthy one that means there is no defect in bearing.

Above spectrum we can simulate by using MATLAB software with FFT of Intrinsic Mode Functions in Hilbert-Huang Transform.

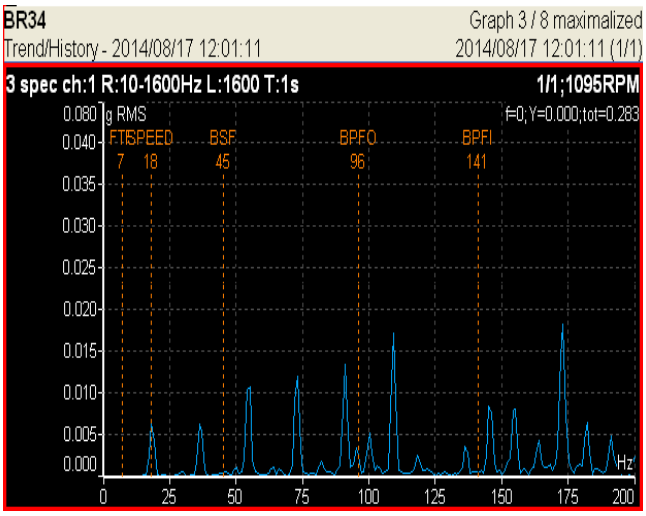

Figure.6.1: FFT of a Healthy bearing

6.1.2 Observations from simulation by using software:-

In software we have used signal processing technique as a HHT. In HHT technique we have decomposed the signal by Empirical Mode Decomposition (EMD). In EMD we got different IMFs. IMFs are plotted amplitude against time for healthy bearing we got 11 IMFs as maximum number of IMFs in this case.

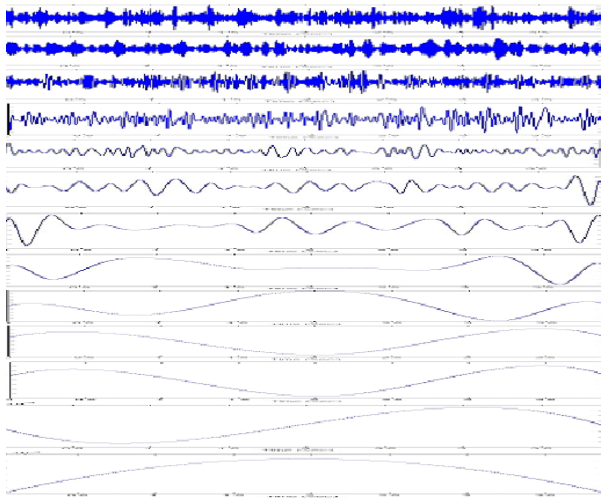

Figure 6.2: EMD of healthy bearing signal, IMFs, residue

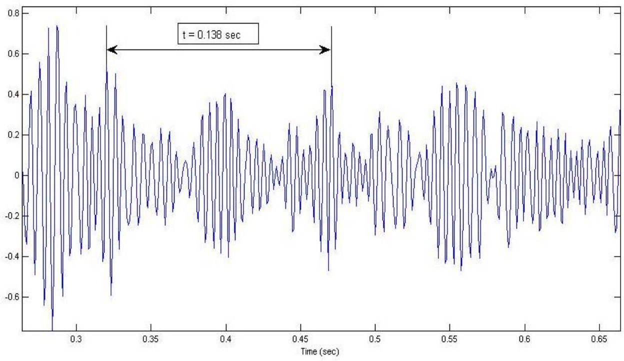

Figure 6.3: Details of IMF 1 for healthy bearing

Use of time domain approach in HHT for detection of defects in rolling element bearing introduces scope for subjective error in calculation of CDF. It can be seen from fig, bearing with no defect case (healthy bearing), that time period of

.138s (t= 0.138s) corresponds to 6.2 Hz, which is close to the fundamental train frequency of 7 Hz.

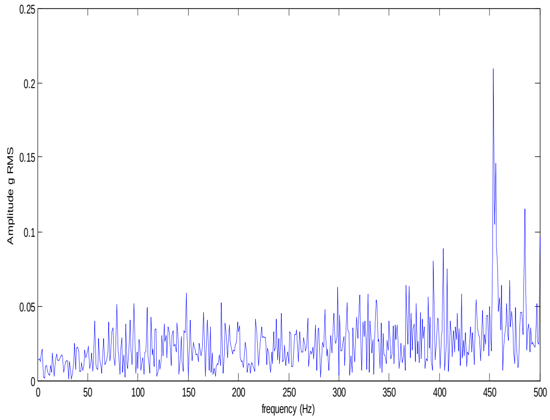

Figure 6.4: Vibration spectrum of healthy bearing after FFT

6.2 Bearing with Crack on Inner Race

6.2.1 Experimental Observation for rotating machinery by using FFT analyzer.

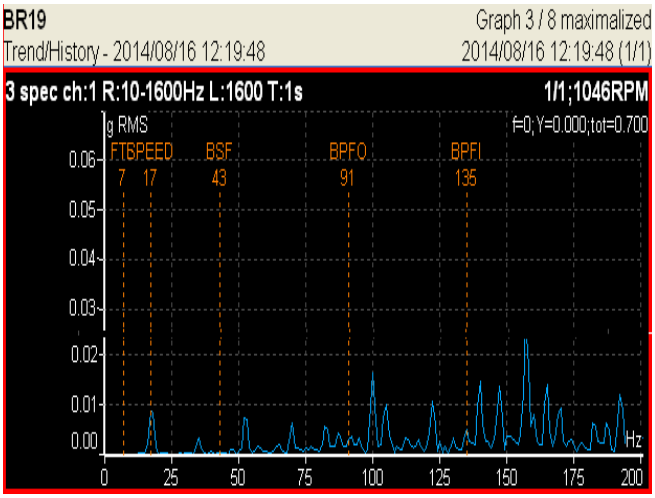

Figure 6.5: FFT of a crack on inner race

We got spectrum from FFT analyzer for bearing with inner race crack. From above figure we got amplitude of vibration (in g RMS – Acceleration) at 1046rpm (17Hz). In fig.6.5 we can see that vibrations are present in system and at the BPFI we got peak amplitude 0.0045 g RMS. At CDF the vibrations are present and it clearly shows that there is defect in inner race of bearing.

6.2.2 Observations from simulation by using software

In HHT technique we have decomposed the signal by Empirical Mode Decomposition (EMD). In EMD we got different IMFs. For bearing with inner race crack we got 9 IMFs in this case.

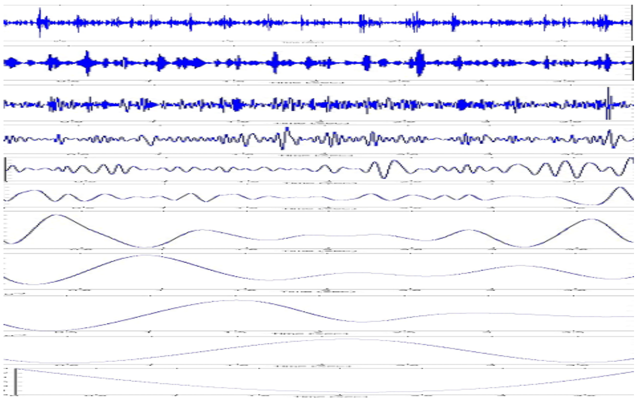

Figure.6.6: EMD of healthy bearing signal, IMFs, residue

Use of time domain approach in HHT for detection of defects in rolling element bearing introduces calculation of CDF. It can be seen from fig.6.6, bearing with inner race crack (defective bearing), that time period of .0074s (t= 0.0074s) corresponds to 135.13 Hz, which is close to the Ball Pass Frequency of Inner Race (BPFI) of 135.13 Hz.

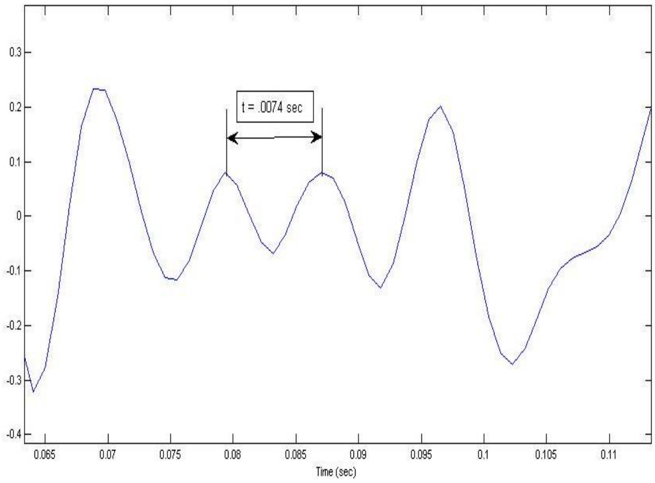

Figure 6.7: Details of IMF 1 for bearing with inner race crack

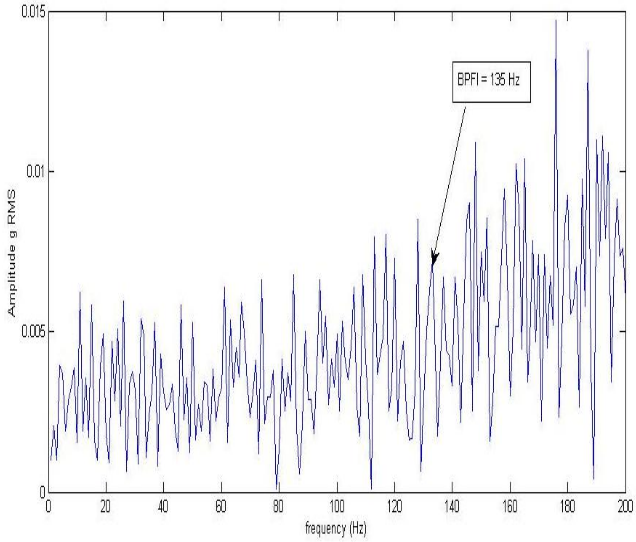

Figure 6.8: Vibration spectrum of bearing with inner race crack after FFT

6.3 Bearing with crack on outer race

6.3.1 Experimental Observation for rotating machinery by using FFT analyzer

We got spectrum from FFT analyzer for bearing with inner race crack. From fig.8.9 we got amplitude of vibration (in g RMS – Acceleration) at 1039rpm (17Hz). In fig.6.9 we can see that vibrations are present in system and at the BPFO we got peak amplitude 0.0065 g RMS. At CDF the vibrations are present and it clearly shows the peak at CDF of outer race. This shows that bearing has defect in outer race. From above spectrum we can simulate by using MATLAB software with FFT of Intrinsic Mode Functions in Hilbert-Huang Transform. In HHT we take EMD of signal and take different IMFs for analysis.

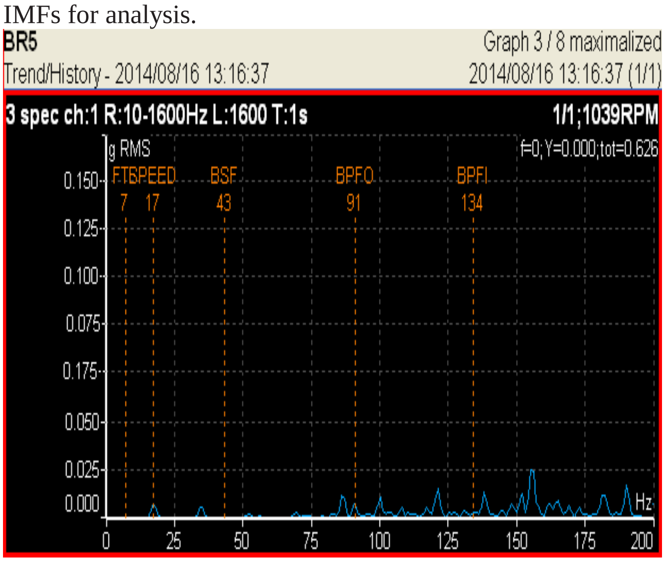

Figure 6.9 - FFT of a crack on outer race

6.3.2 Observations from simulation by using software

For bearing with inner race crack we got 9 IMFs in this case. Use of time domain approach in HHT for detection of defects in rolling element bearing introduces calculation of CDF. It can be seen from fig.6.11, bearing with inner race crack (defective bearing), that time period of .0109s (t= 0.0109s) corresponds to 91.74 Hz, which is close to the Ball Pass Frequency of outer Race (BPFO) of 91.74 Hz.

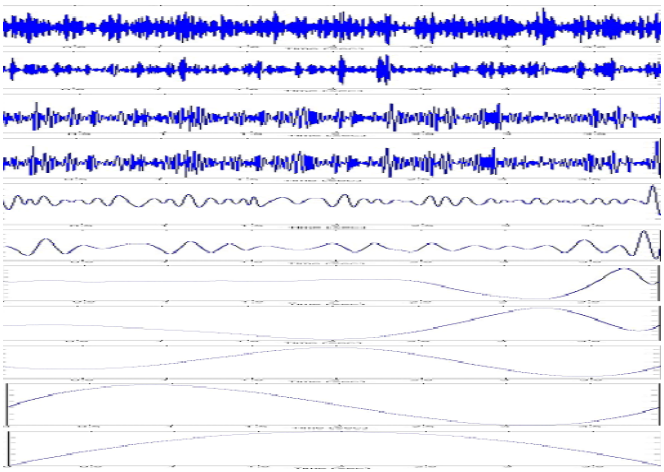

Figure 6.10: EMD of healthy bearing signal, IMFs, residue

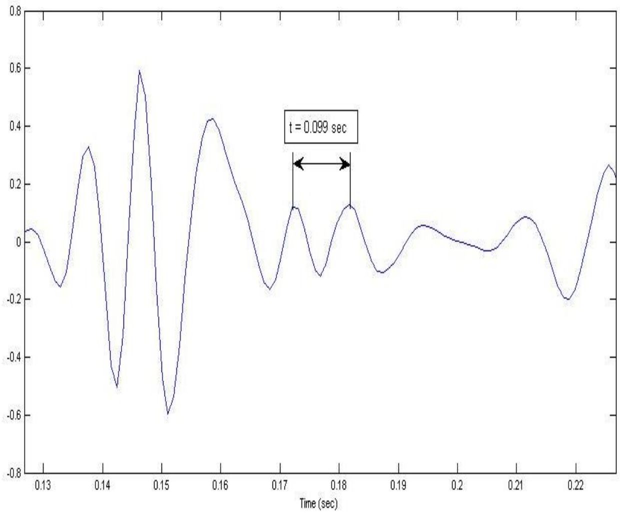

Figure 6.11: Details of IMF 1 for bearing with crack on outer race

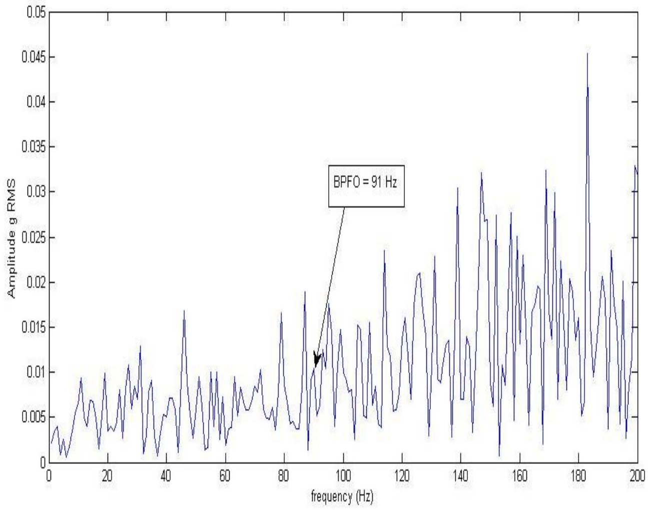

Figure 6.12 Vibration spectrum of bearing with inner race crack after FFT

6.4 Bearing with spall on ball

6.4.1 Experimental Observation for rotating machinery by using FFT analyzer

We got spectrum from FFT analyzer for bearing with spall on outer race. From fig.8.13 we got amplitude of vibration (in g RMS – Acceleration) at 1027rpm (17Hz). In fig. 8.13 we can see that vibrations are present in system and at the BSF we got peak amplitude 0.0044 g RMS. At CDF the vibrations are present and it clearly shows the peak at CDF of ball. This shows that bearing has defect on ball.

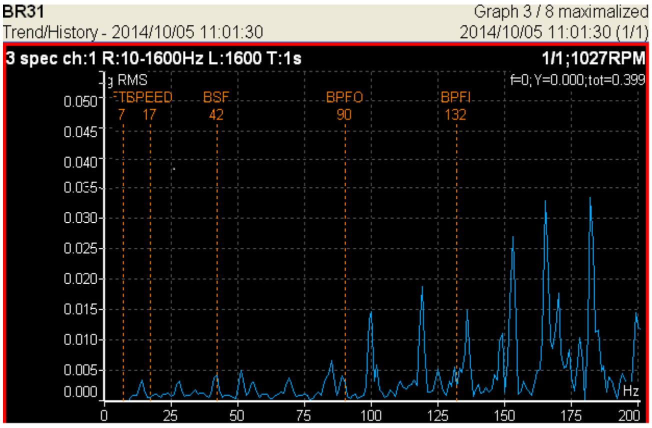

Figure 6.13: FFT of a spall on ball

6.4.2 Observations from simulation by using software

Use of time domain approach in HHT for detection of defects in rolling element bearing introduces calculation of CDF. It can be seen from fig.6.14, bearing with spall on ball (defective bearing), that time period of .024s (t= 0.024s) corresponds to 41.66 Hz, which is close to the Ball Pass Frequency of Inner Race (BPFI) of 41.66 Hz

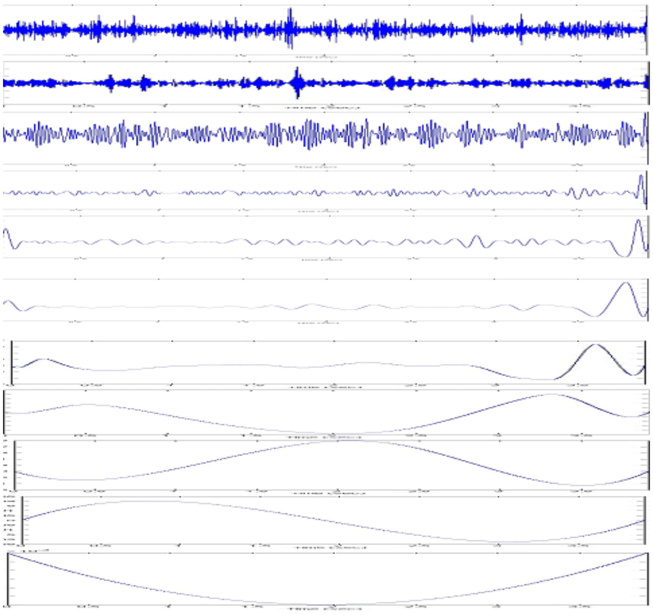

Figure 6.14: Details of IMF 1 for bearing with spall on ball

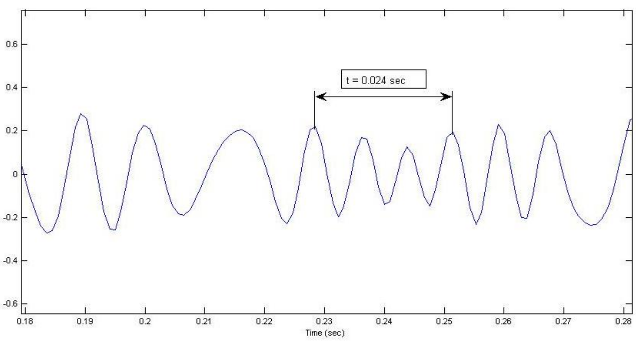

Figure 6.15: Details of IMF 1 for bearing with spall on ball

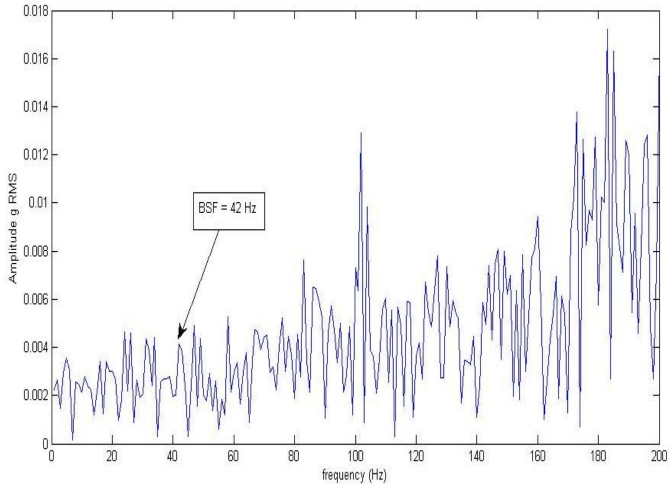

Figure 6.16: Vibration spectrum of bearing with spall on ball after FFT

The values of CDFs thus determined from the time period impulses are close to the actual value but not accurate. Additionally, the time resolution significantly affects the calculation of corresponding frequency content of signal. Therefore, FFT of IMFs from HHT process has been introduced in order to utilize the efficiency of HT in frequency domain and accurately determine the frequencies present in the vibration signature of rolling element bearing.

6.5 Bearing Lubrication

In FFT analyzer there are number of modules, we used Lubrication module for checking of lubrication. We have checked bearing with good lubrication and bearing with lack of lubrication.

6.5.1Bearing with good lubrication:-

We have used one bearing for analysis that is well lubricated and we got results as shown in fig.6.17 by FFT analyzer. The green portion in fig.6.17 clearly indicates that bearing is well lubricated as well as there is one comment that “Greased”. That clearly indicates that there is no need of lubrication or bearing is well lubricated. In the upper portion of the fig.6.17, the value 0.177g RMS indicates acceleration.

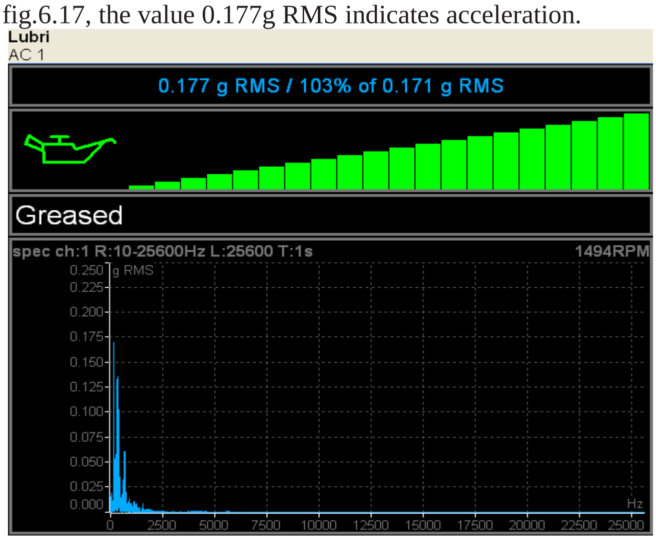

Figure 6.17: Lubrication indicator diagram for bearing with good lubrication

6.5.2Bearing with lack of lubrication

We have used one bearing for analysis that has improper lubrication and we got results as shown in fig.6.18 by FFT analyzer. The green portion in fig.6.18 indicates that bearing having lubrication, yellow portion indicates bearing with small amount of lubrication and red portion indicates no lubrication as well as there is one comment that "Grease". That clearly indicates that we have to lubricate this bearing or bearing having lack of lubrication. In the upper portion of the fig6.18, the value 11.9g RMS indicates acceleration.

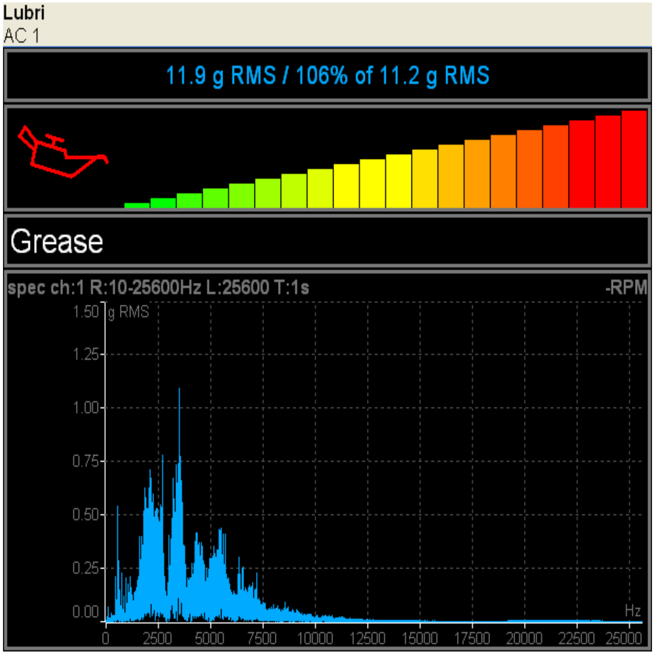

Figure 6.18: Lubrication indicator diagram for bearing with lack of lubrication

Observations from fig.6.17 and 6.18 clearly indicates bearing lubrication, also the bearing with good lubrication indicates small value of acceleration .i.e. amplitude as compare to bearing with lack of lubrication indicates large value of acceleration.

6.6 Benefits of Project

Project has given benefits in terms of detection bearing fault which occur in any rotating machinery.
Benefits like

- Detection of type of bearing fault (whether fault on inner race, outer race, ball or combined)
- Severity of Bearing fault
- Check for lubrication of bearing within few seconds.
- We can get idea of replacement of bearing or not.

7. Conclusion and Future Scope

7.1 Conclusion

A study completed in this project by data collection shows that FFT of intrinsic mode functions in Hilbert-Huang transform is useful tool in finding out all possible root causes and predict root causes based on systematic study. Also bearing failure is the High Severity Field Concern causing failure of whole machine & affects the production rate as well as the Safety of the operator.

At present the major failures in bearings like inner race crack, outer race crack, and spall on ball are analyzed by using FFT analyzer. Input signals of FFT are given to MATLAB and simulate the data. We got nearly same results from MATLAB as FFT analyzer signals. From results and discussion following conclusions can be drawn.

Amplitude at BPFO is higher than BPFI and BSF. Amplitude at BPFI is less than BPFO and BSF. Those IMFs with a concurrent frequency band which also occurs in the response of run up excitation selected for subsequent analysis. If a selected IMFs with intense noise arising from the excitation of test bench, the noise may introduce unwanted signals, such IMF can be ignored. Experiments in this study have demonstrated that the proposed procedure using an appropriate IMF or several IMFs is superior to the approach using the HHT and FFT of IMF analysis which needs to examine all resonant frequency bands. One can easily judge the bearing with good lubrication and bearing with lack of lubrication. Also amplitude for bearing with lack of lubrication is higher than bearing with good lubrication.

7.2 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. Smart techniques like FEA analysis can be developed for vibration analysis which can be easily simulate from FFT analyzer to reduce Energy, Effort & Time.

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