Vibration Studies of Defective & Non Defective Deep Groove Ball Bearing Using FFT Analyzer

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Abstract*-Rolling element bearing is one of the most important and common components in rotary machines, whose failures can cause both personal damage and economic loss. In condition monitoring and fault diagnosis of rolling element bearing focuses on in order to detect the failure ahead of time and estimate the fault location accurately when failure occurs. Several methods/techniques are available to monitor the condition of bearing. Such as Bond graph modeling, singular values of EEMD, spatial condition matrix, Gath-Geva clustering, CWT Based Vibration Signature Wavelet De-noising etc. In this paper, a novel diagnosis scheme based on the FFT Analyzer and deep grove ball bearing 6205(SKF) used.*

Keywords:condition monitoring, deep groove ball bearing, fault diagnosis, FFT Analyzer,

I. INTRODUCTION

A rolling-element bearing, also known as a rolling bearing, is a bearing which carries a load by placing rolling elements (such as balls or rollers) between two bearing rings called races. The relative motion of the races causes the rolling elements to roll with very little rolling resistance and with little sliding.

One of the earliest and best-known rolling-element bearings are sets of logs laid on the ground with a large stone block on top. As the stone is pulled, the logs roll along the ground with little sliding friction. As each log comes out the back, it is moved to the front where the block then rolls on to it. It is possible to imitate such a bearing by placing several pens or pencils on a table and placing an item on top of them.

A rolling element rotary bearing uses a shaft in a much larger hole, and cylinders called "rollers" tightly fill the space between the shaft and hole. As the shaft turns, each roller acts as the logs in the above example. However, since the bearing is round, the rollers never fall out from under the load.

Rolling bearings are widely used component in the mechanical equipments; they may directly affect the dynamic performance, running accuracy, reliability and service life of the equipment. Hence, it is necessary to diagnose and detect the faults in rolling bearing. This is a dynamic process and the fault degree gradually increases from a low level. The early damage detection is in demand not only for high precision machines but also for general engineering equipments because minor faults often can lead to major faults. However, the rolling bearing should be replaced when the fault reaches a certain degree. Therefore, the service life of mechanical equipment can be extended and production costs can be reduced through the quantitative diagnosis of fault in rolling bearing.

In the present research work vibration analyses have been focused to detect bearing fault at early stage. To accomplish the above task an experimental setup consisting flexible jaw coupling, variable frequency drive, induction motor, a vibration analyzer apparatus are developed for vibration analysis of non-defective bearing. Afterwards, a bearing with a propagating crack is also examined for the vibration analysis.

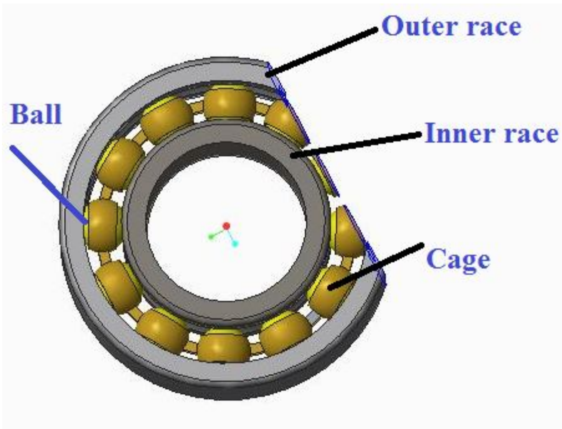


Fig1.Rolling element bearing

II. LITERATURE REVIEW

The rolling elements bearings are widely used in industrial and domestic machines. The existence of even tiny defects on the mating surfaces of the bearing components can lead to failure through passage of time. Their failure leads to economical and personal losses. The vibration monitoring technique is mostly used in the industries for health monitoring of bearings. Significant studies are available in open literature for vibration analysis of healthy and defective rolling elements bearings. Various researchers have studied the vibrations generated by bearings through theoretical model and experimentations. The researchers have developed the dynamic model of shaft bearing systems for the theoretical studies.

C.Mishra et. al. (2016), proposed a scheme which initially represents the vibration signal of rotor shaft bearing resampled by using interpolate instantaneous angular position measurement method and then intrinsic mode function (IMFs) was generated through empirical mode decomposition (EMD) of resampled vibration signal. This data is compared with bond graph model [1].

Kun Yu et. al. (2017), suggested that we can extract useful data from rolling element bearing by using ensemble empirical mode decomposition (EEMD) and singular value decomposition (SVD) techniques. The fault related signals was classified by a fuzzy clustering method and Gath-Geva (GG) clustering for cluster center and membership matrix for pattern recognition [2].

MadhavendraSaxena et. al. (2015), found faulty bearing by using continuous wavelet transform (CWT) technique [3].

C. Mishra et. al. (2017), found fault related symptoms in slow speed bearing by using envelop analysis and wavelet de-noising with sigmoid function based thresholding. Wavelet de-noising was done by modulation (by filtering using a suitable band pass filter), demodulation (by enveloping Hilbert transform) and FFT [4].

Lingli Cui et. al. (2016) developed a nonlinear vibration model for fault diagnosis of rolling element bearing and bearing with outer race defect was analyzed. Vibration signal was analyzed for different fault sizes. The signals were analyzed quantitatively to find out relationship between vibration responses for different fault sizes [5].

V. N. Patela et. al. (2014) carried theoretical and experimental vibration studies on deep groove ball bearing having defects on either race. To accomplish above task, shaft housing raceway and ball masses were formed in mathematical model. Governing equation of motion has been achieved by using Ruge-kutta method. The mathematical model provides vibration signal in time and frequency domain. The test bearing were loaded by using electro-mechanical shaker [6].

V. N. Patela et. al (2014), studied the vibration generated by deep groove ball bearings having multiple defects on races, in time and frequency domains. The equation of time delay between two or more successive impulses are derived and compared with experimentally results. Frequency spectra for single and two defects on either race are compared [7].

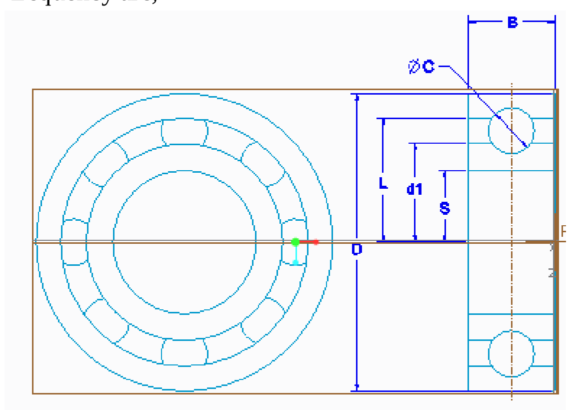
PurwoKadarno et. al.(2008), studied the vibration analysis of defective rolling element bearing. To accomplish above task, the vibration data was captured from different defect states of the rolling element bearing (outer race, inner race, combination of outer, inner race and ball), for four different speed of shaft [8].

III. OUTCOME OF LITERATURE REVIVE

Vibration analysis/study is most appropriate technique/method for fault diagnosis of rolling element bearing.

IV. BALL BEARING FREQUENCIES

Ball bearing frequencies is based on some basic assumptions. While deriving the BCFs, it is assumed that inner race and outer race are moving at constant angular speed, all the elements in the bearing are rigid, there is no slip between elements of bearing and the pressure angle remains constant throughout the operation. Contact angleø, ball diameter d, pitch circle diameter fi, inner race angularfrequencyfi, outer race angular frequency fo and number of balls Nb ,the expression of inner race ball pass frequency of inner race (BPFI), ball pass frequency of outer race(BPFO), ball pin frequency (BSP)and fundamental train frequency (FTF) or cage frequency are,



$BPFI = Nb\ (fi - fo)\ (1 + d/D\ cos ø)/2$,

$BPFO = Nb\ (fi - fo)\ (1 - d/D\ cos ø)/2$,

$BSF = D\ (fi - fo)/\ 2d * (1 - (d/D\ cos ø)\text{^}2)$,

$FTF = (fi - fo)\ (1 - d/D\ cos ø)/2$

These altogether are called bearing characteristics frequencies. In this article, we consider a ball bearing (6205 SKF) for which the contact angle ø=0 and the outer race is fixed, i.e.$fo = 0$.

V. FAST FOURIER TRANSFORM APPROACH IN VIBRATION ANALYSIS

An FFT spectrum analyzer works in an entirely different way. The input signal is digitized at a high sampling rate, similar to a digitizing oscilloscope.

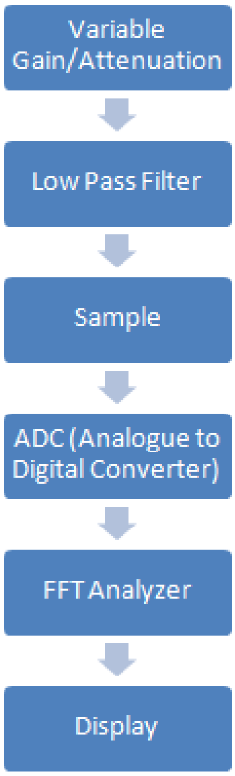


Fig2.FFT Analyzer Component

Nyquist's theorem says that as long as the sampling rate is greater than twice the highest frequency component of the signal, the sampled data will accurately represent the input signal; the input signal passes through an analog filter which attenuates all frequency components above 156 kHz by 90 dB This is the anti-aliasing filter. The resulting digital time record is then mathematically transformed into a frequency spectrum using an algorithm known as the Fast Fourier Transform, or FFT. The FFT is simply a clever set of operations which implements Fourier's theorem. The resulting spectrum shows the frequency components of the input signal. Now here's the interesting part. The original digital time record comes from discrete samples taken at the sampling rate. The corresponding FFT yields a spectrum with discrete frequency samples. In fact, the spectrum has half as many frequency points as there are time points.

VI. EXPERRIMENTAL SETUP

All the experiments have been performed in SKF India Limited on rotor kit setup. To generate test signal, attachments are provided in the fault simulator system to introduce fault in ball bearing under high speed operations. The important parts of machine fault simulator system (Fig. 4) are four ball bearings (6205 SKF), a loader, a flexible jaw coupling, a variable frequency drive, and an induction motor (3-phase, 1/2 HP lhp). The entire setup is mounted on an anti-vibration table.

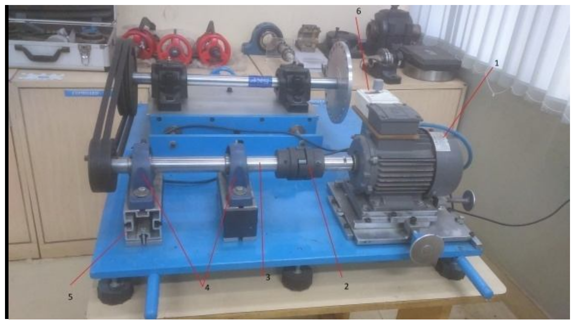


Fig3. Experimental setup

Part Name-

1) Motor
2) Flexible Jaw Coupling
3) Shaft
4) Bearing
5) Aluminum pedestal
6) Controller

Power is transmitted from the induction motor by connecting the output shaft of it through a flexible jaw coupling. Aluminum pedestals are used to mount deep groove ball bearings where the drive and driven shaft connected through belt by providing appropriate tension. The ball bearing located near the induction motor is said to be located at the drive shaft while other two is said to be located at the driven shaft. Experiments were conducted by installing non-defective bearingson the drive shaft and faulty bearings on the driven shaft.Reading is not exactly equal to the set frequency given to VFD due to various factors such as electrical and mechanical losses.To impart radial load, a loader of 6 kg is attached to the driven shaft. The variable frequency drive (VFD) is used to regulate the speed of driver shaft within 0.16 Hz to 40 kHz range. Since, the speed is set by manually; repetition of the speed profile is difficult. Due to experimental limitations, speed of the control knob is adjusted above 5

Hz.For the experiments, bearings with no fault, fault in the inner race& outer race and ball only are used. The vibration of the bearing's inner race, outer race, and ball is measured by a SKF Microlog Analyzer GX (Fig5).

Fig 4. SKF Microlog Analyzer GX

The SKF Microlog Analyzer GX is widely used for contact type measurement of surface vibration. The operating frequency range of the used vibrometer is 0.16 Hz to 40 kHz and the amplitude (vibration level) range is 0.05 mm/sec to 0.5 m/s. The measurement is done by knob of SKF Microlog Analyzer GX touch on the test surface.

VII. RESULTS AND DISCUSSION

All the experiments were conducted using 6205 SKF ball bearing with speed of the shaft adjusted 17 Hz through the knob of the speed controller. The results of FFT analyzer are in the form of spectrum.This spectrum is a graph of amplitude drawn verses cycle per minute (CPM), in which amplitude (in mm/s.) is plotted along Y-axis and no of cycle along X-axis. Same results are obtained for non-defective as well as defective bearing.

Bearing specifications

Table1. The ball bearing parameters detail.

Sr.No.	Parameter	Dimension
1	Ball diameter (C)	25 mm
2	Pitch circle diameter (D)	52mm
3	Pitch diameter (dm)	39 mm
4	Raceway width (B)	15 mm
5	Outer ring raceway (L)	23.1mm
6	Inner ring raceway (d1)	17.175 mm
7	Inner raceway (S)	12.5 mm
8	Number of balls (Nb)	9
9	Contact/ pressure angle (ø)	0

The outer race frequency fo=0. Substituting these parameters, the corresponding fault frequencies are determined as BPFI=33.317fs, BPFO= 11.6828fs, BSF=3.9980fs and FTF=1.2980fs, where fs is the shaft speed.

The algorithm (flow chart) of diagnosis scheme is given in Fig2.

A short segment of the vibration signal from a Non defective and defective bearing is considered. The original signal (not normalized) is in the time-span of 0.5s.

The rolling element bearing represents a complex vibration system. The vibrations are recorded from the bearing housing in vertical, horizontal and axial direction. The vibration signal measured vertically is put to use for analysis. Whereas the signal measured from horizontal and axial direction is used for the verification. Each test trial consists of 18.3 second duration. The instrument measurement range was 80 kHz and Fmax up to 25,600 FFT lines of resolution.

Each bearing is tested under shaft running speed 17Hz. The data was collected, when load (6 kg) attached to the driven shaft for the 17 Hz running speed.

The non-defective and defective frequencies showed in Fig 5, 6, 7 and 8, 9, 10 respectively. Fig 8, 9, 10 shows variation of additional displacement during interaction of bearing surfaces (outer races, inner races and ball) with local defect.

It can be seen that when a ball surface approaches defect, how the displacement of the vibration changes from zero to maximum.

Non Defective bearing

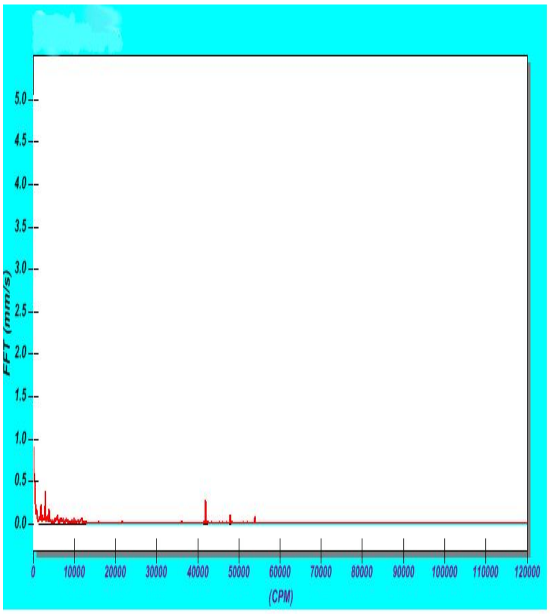


Fig5. Signal processing result for diagnosis of no faults in bearing in axial direction

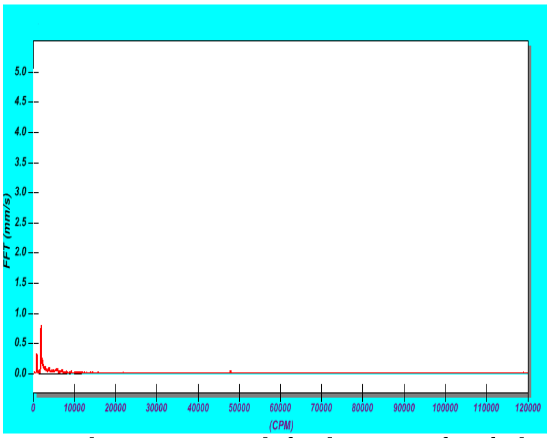


Fig6.Signal processing result for diagnosis of no faults in bearing in Horizontal direction

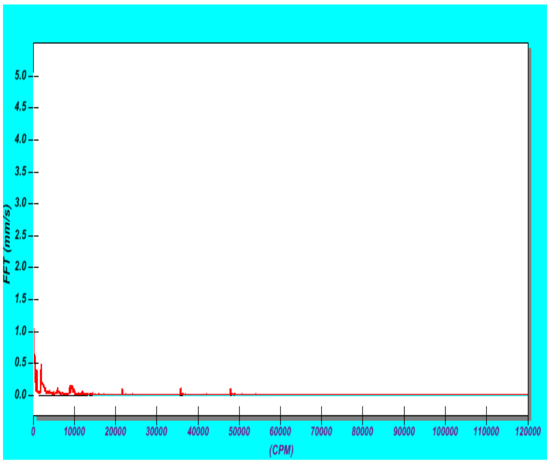


Fig7.Signal processing result for diagnosis of no faults in bearing in Vertical direction

Defective bearing

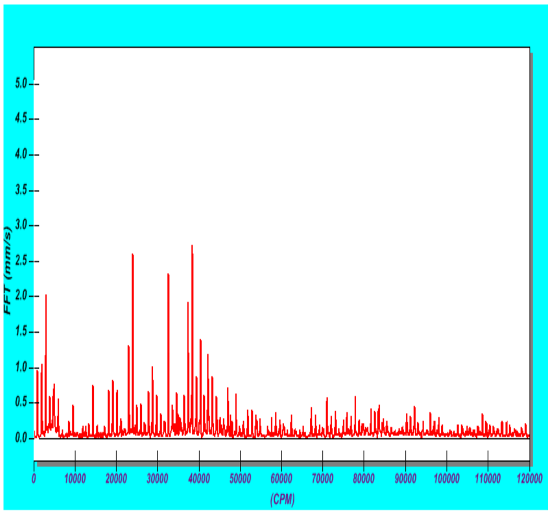


Fig8.Signal processing result for diagnosis of faults in bearing in axial direction

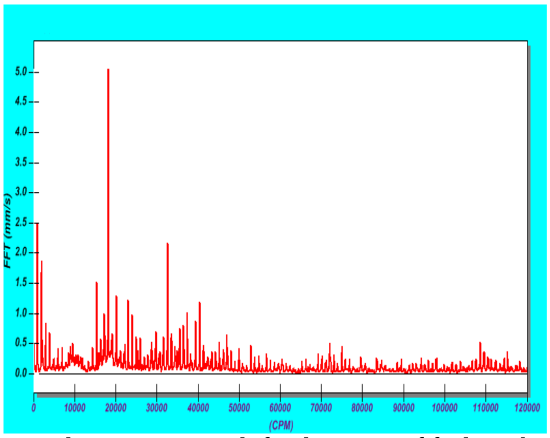


Fig9.Signal processing result for diagnosis of faults in bearing in horizontal direction

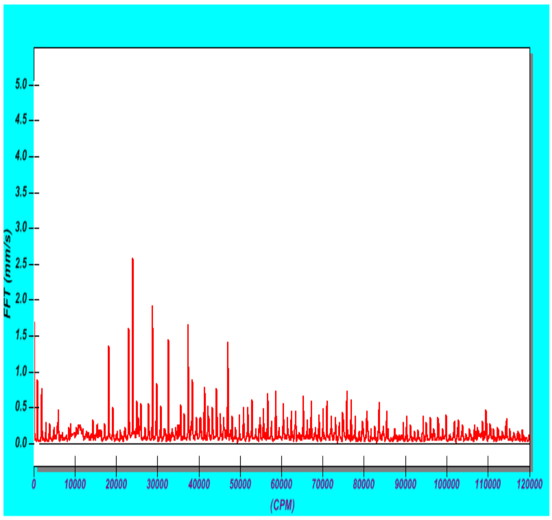


Fig10.Signal processing result for diagnosis of faults in bearing in vertical direction

VIII. CONCLUSION

Most important part of any machines or mechanical systems is the rolling element bearing due to its inherent effect on performance of rotating machinery. Rotating machineries are complex and have number of components that could potentially fail. A large majority of these components depends on the rolling bearing for continued successful operation. One way to increase operational reliability is to monitor defects in the rolling bearings. One of the most effective techniques to use for condition monitoring of the rolling bearing is vibration spectrum analysis by using FFT analyzer. Vibration analysis is a critical for condition monitoring to find the location, cause, and severity of defects. In this study, Non defective and defective bearings were tested under shaft running speeds (17 Hz) with load 6 kg. The data collected during running tests were observed, analyzed, and presented.

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