Experimental Study of Single Row Deep Groove Ball Bearing with Influence of Defect Size, Defect Location, Speed and Load on Vibrations

R.R.Gidde
Department of Mechanical Engineering, SVERI's College of Engineering, Faculty Member
E-mail: ranjitsinhag1@rediffmail.com

Abstract:

Rolling element bearings are major components in rotating machinery. Rolling element bearing failure is a major factor in failure of rotating machinery and monitoring their condition is important to avoid catastrophic failures. Detection, location and analysis of faults in such machines play a vital role in the interest for high reliable operations as these are required to run at different conditions. The different techniques are available for condition monitoring of rolling element bearings as their vibration signature reveals important information about the defect development within them. Amongst them the vibration analysis has been used as a predictive maintenance procedure and as a support for machinery maintenance decisions. In the present work the effect of working under different speeds at different loading conditions for different defects on vibration amplitudes were studied. For this reason, artificial faults have been introduced to a bearing at inner race and outer race and the corresponding Fast Fourier Transform (FFT) spectrum has been recorded for both the cases. Results have shown that the vibration amplitudes are affected by both the parameters load as well as speed.

Keywords: Single Row Deep Groove Ball Bearing, Vibration Monitoring

1 Introduction

Bearings are one of the important components of any rotating machinery. They find widespread application in not only industrial applications but also in domestic applications. Failure of the bearings leads to the stoppage of the machinery resulting in loss of production, time and money. There are various reasons for the failure and one of them is due to the progressive growth of the defect induced in the bearing. The defect may be on the inner race, outer race or on the rolling element. As the bearings are subjected to fatigue loads, the defects grow at a faster rate. Hence, monitoring the health of the bearing is of prime importance to prevent the catastrophic failure of the bearings. Vibration monitoring is a popular technique used for condition monitoring of the bearings [1].

Fault that usually occur in the bearings, are caused by localized defects. Impact vibrations are generated whenever the rolling elements pass over the surface of this defect. These vibrations occur at the bearing characteristic frequency. It is possible to detect the presence of the defect by observing the change in the vibration amplitude in a FFT spectrum. About 40% of failures of electric motors are caused by bearings. Therefore, bearings play one of the most important roles in condition monitoring. Vibration signature monitoring and analysis in one of the main techniques used to predict and diagnose various defects in antifriction bearings [2].

Time waveform and frequency spectrum methods as the most widely used to analyze defects in antifriction bearings. Time waveform indicates severity of vibration in defective bearings. Frequency domain spectrum identifies amplitudes corresponding to defect frequencies and enables to predict presence of defects on inner race, outer race and rollers of antifriction bearings. The distinct and different behavior of vibration signals from bearings with inner race defect, outer race defect and roller defect helps in identifying the defects in roller bearings [3].

There are two approaches available namely the beating phenomenon and the bearing defect frequencies. The former has observed in the time domain due to two close frequencies. They seemed in the frequency spectrum and calculations pointed uniformity between the frequency domain and the time domain. The later one considered according to high spikes looked in the frequency spectrum. The bearing defect frequencies were evaluated and compared with the measured data, which indicates defects in both inner and outer races of the bearing [4].

A theoretical model developed to obtain the vibration response due to a localized defect in various bearing elements in a rotor bearing system under radial load conditions. The model predicts significant components at the harmonics of characteristic defect frequency for a defect on the particular bearing element. It has predicted some additional components at harmonics of shaft and cage frequencies due to a local defect on the inner race and a rolling element, respectively. It can be observed from the results that the spectral components predicted by the theoretical model find significant presence in the experimental spectra [5].

Vibration signature analysis provides early information about progressing malfunctions and forms the basic reference signature or base line signature for future monitoring purpose. Defective rolling elements in roller bearings generate vibration frequencies at rotational speed of each bearing component and rotational frequencies are related to the motion of rolling elements, cage and races. Initiation and progression of flaws on roller bearing generate specific and predictable characteristic of vibration. Components flaws (inner race, outer race and rolling elements) generate a specific defect frequencies calculated from equations, mentioned by Chaudhury and Tandon [6], namely;

Inner race defect frequency

$$F_{IRD} = \frac{n}{2} F_R \left[1 + \left(\frac{BD}{PD}\right) cos\beta\right] \quad (1)$$

Outer race defect frequency

$$F_{ORD} = \frac{n}{2} F_R \left[1 - \left(\frac{BD}{PD}\right) cos\beta\right] \quad (2)$$

Ball defect frequency

$$F_B = \frac{PD}{BD} F_R \left[1 - \left(\frac{BD}{PD}\right)^2 cos^2\beta\right] \quad (3)$$

Cage defect frequency

$$F_C = \frac{1}{2} F_R \left[1 - \left(\frac{BD}{PD}\right) cos\beta\right] \quad (4)$$

Where, F_R is the shaft rotational frequency in Hz, *N* is the speed in rpm, *n* is number of balls, *BD* is the ball diameter, *PD* is the pitch circle diameter & β is the contact angle of the ball (with the races).The frequency domain spectrum is more useful since it also identifies the exact nature of defect in the bearings.

2. Experimental Test Rig

The experimental test rig is designed to investigate failure and a vibration characteristic of ball bearings is shown in Fig. 1. It consists of a 3HP/2880 rpm three-phase induction motor driving the V-belt drive. Vibration isolation rubber sheets are also provided under the motor and it's supporting legs to reduce the vibration transmission from ground to the test bearing. The test bearing is mounted on output shaft. The loading arrangement along with load cell is placed between these two support bearings.

A piezo-electric accelerometer is mounted on the housing of the test bearing by using magnetic mount. The accelerometer is connected to the charge amplifier, the output of which is connected to a computer. The computer contains the relevant hardware and the software to acquire the data, store it and display the time domain signal.

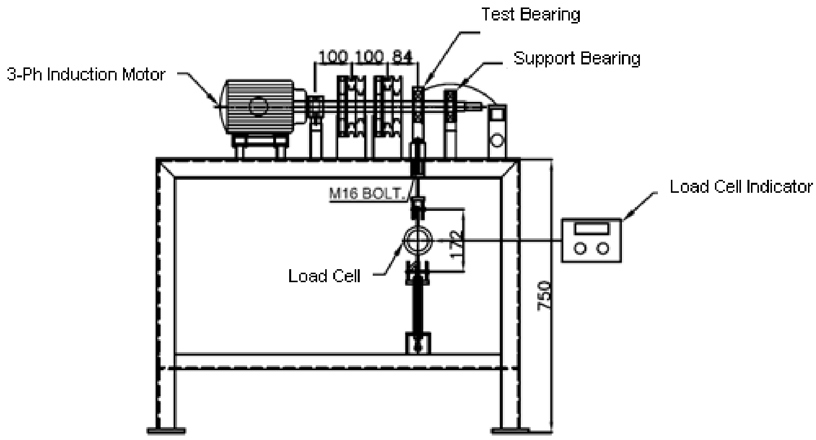

Fig. 1 Experimental test rig

3. Experimental Procedure

The approach used to study the effect of localized defect such as crack, pits, dents is to introduce the defect in the bearing by techniques such as spark erosion, scratches and indentation and measure the vibration response and compare the response with healthy bearing. Three DFM-85 single row deep groove ball bearings are used in the present study. One is a healthy bearing (assumed to be free from defects).Defects (through cracks) were created on the inner race of second bearing & outer race of third bearing respectively. The defect (crack) is 1mm in width & 5mm in length. Defect depth was kept constant as 100 μm. The tests were conducted for constant load 20 kg and speeds being 2880 rpm and 4866 rpm. Also the tests were conducted for constant speed 4866 rpm and loads being 5 kg, 10 kg, 15 kg and 20 kg.

The characteristic defect frequencies for inner race & outer race at speeds 2880 and 4866 rpm are calculated by using equations 1 & 2 respectively. The values for different frequencies are as shown in following Table 1.

Table 1 Bearing characteristic defect frequencies

Sr.No.	Shaft Speed (N)	Shaft rotational frequency (F_R)	Inner race defect frequency (F_{IRD})	Outer race defect frequency (F_{IRD})
1	2880 rpm	48.00 Hz	216.09 Hz	119.90 Hz
2	4866 rpm	81.10 Hz	365.13 Hz	202.59 Hz

4. Experimental Results

I) Vibration Analysis at Constant Load with Different Speeds

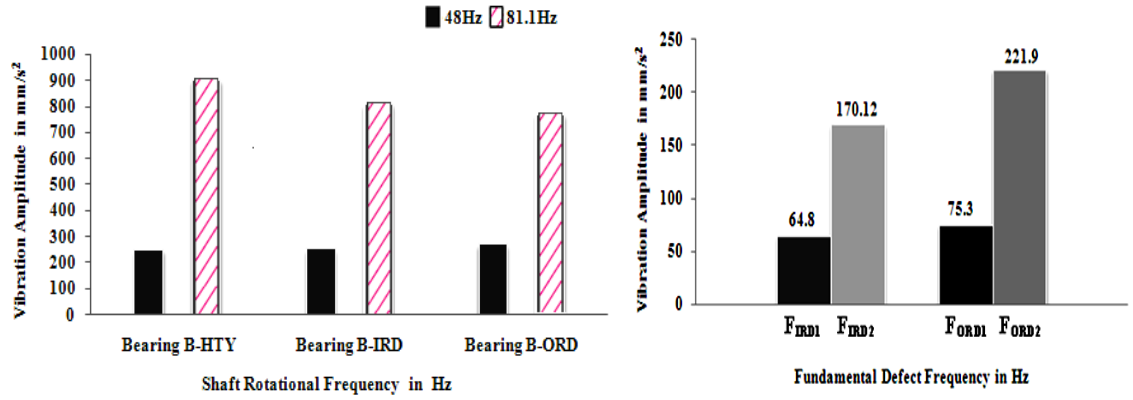

Fig. 2 (a) Speed effect on vibration amplitude at shaft rotational frequency for the healthy bearing, bearing with inner race defect & bearing with outer race defect & (b) Speed effect on vibration amplitude at fundamental defect frequency for the bearing with inner race defect & bearing with outer race defect

Comparing values of vibration amplitude at shaft rotational frequency (F_R) of the healthy bearing (B-HTY), bearing with inner race defect (B-IRD) and bearing with outer race defect (B-ORD), the effect of speed appears on the vibration amplitude with the 48 Hz and 81.10 Hz shaft rotational frequency. The vibration amplitude increases for shaft rotational frequency (F_R) with the increase of the shaft speed as illustrated in Fig. 2 (a). The vibration amplitude has been nearly thrice with the 48 and 81.10 Hz shaft speed. Similarly this effect is observed on the vibration amplitude at inner race defect frequency and outer race defect frequency. Additionally the vibration amplitude of inner race defect frequency and outer race defect frequency also increases with the increase of the shaft speed as illustrated in Fig. 2 (b).

II) Vibration Analysis at Constant Speed with Different Loads

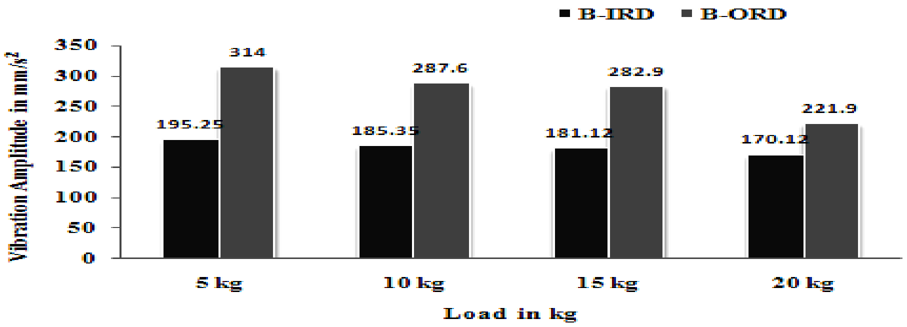

Fig. 3 Load effect on vibration amplitude for the bearing with inner race defect & bearing with outer race defect

The agreement between the calculated frequencies and those obtained from the FFT analyzer is quiet excellent. It is seen that there is decrease in the vibration amplitude when the load on bearing is increased under constant speed as shown in Fig.3. The variation in amplitude has the same trend in both cases (i.e. bearing with inner race defect and bearing with outer race defect). The vibration amplitude decreases to 170.12 mm/s^2 for maximum load 20 kg for bearing with inner race defect. However the vibration amplitude decreases to 221.9 mm/s^2 for bearing with outer race defect at maximum load 20 kg.

5. Conclusion

In the present work, vibration signal analysis of single row deep groove ball bearing was carried out for the healthy as well as defected bearings. Vibration signals induced by impact actions between rolling elements and the outer race as well as between rolling elements and the inner race at the fault location were collected. The frequency spectrum provides useful information to analyze defects in rolling element bearings. In this bearing defect frequencies considered according to high spikes appeared in the frequency spectrum. Also the bearing defect frequencies were evaluated and compared with the measured data.

Following conclusions can be drawn from the experimental results.

1. Defective bearings generate a train of impulses at a specific frequency (characteristic defect frequency), which depends upon the location of defect, geometric specification of the bearing and shaft rotation speed.
2. The vibration amplitude at shaft rotational frequency is increases with increase in shaft speed for each bearing.
3. It is observed that there is decrease in the vibration amplitude when the load on bearing is increased by keeping speed constant at inner race defect frequency and outer race defect frequency for defective bearings.
4. The study predicts the amplitude of vibration due to outer race defect to be much higher as compared to those due to inner race defect.
5. In particular, the bearing defect frequencies exhibited the largest spectral difference between healthy and defected bearings.
6. Also the vibration signal measurements performed on the bearing is successful in detecting simulated defects in the inner race & the outer race of the bearing.
7. The analysis has shown a consistent between the calculated and experimental values of fundamental defect frequencies.

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