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Vibrational Analysis of Self-Aligned Ball Bearing

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Abstract
Rolling element bearing is widely used in machineries used in sugar mills, paper mills, textile, railways and aerospace and much more. The failure of bearing may result in brake to production process. Therefore in this paper artificial fault is created on ball of self-aligned ball bearing in the form of square cut with depth varying 1mm,1.5mm,2mm and 2.5 mm with clearance of 0.06mm is kept between balls and outer race. Faulty bearing is subjected to various speed and single load. Results in terms of Amplitude of vibrations are measured with FFT analyser with accelerometer in vertical direction and is compared with healthy bearing. Harmonics at ball spin or defect frequency is observed.
***Keywords**-ball spinfrequency,clearance,depth of cut,FFT, Vibrationalanalysis*

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I. INTRODUCTION:

Antifriction bearings are essential parts of rotating machinery due to their load carrying capacity and low friction characteristics. Bearing ensures free rotation of the shaft or the axle with minimum friction. Bearing supports the shaft or the axle and holds it in correct position as well as guides rotating shaft. The bearing takes up the forces that act on the shaft or the axle and transmits them to the bearing block or bearing pedestal and finally transmitted to the foundation. Hence rolling element bearings are considered as critical components of rotating machines. Rolling element bearings have wide range of application in industries like power plants, chemical plants, sugar industry and automotive industries. Rolling element bearings include all types of bearings that make use of the rolling action of balls or rollers to permit minimum friction, from the constrained motion of one body relative to another. Any defect in the bearings lead to high vibration, noise level and temperature rise which ultimately cause deviation in theperformance of the machine. Due to such effects or faults system may fail before its predicted life and causes high production loss.

Many bearings fail prematurely in service because of contamination, poor lubrication, temperature extremes, poor fits, looseness and misalignment in the assembly. Machine condition monitoring technique provides information about the condition of rolling element bearings, which is vital information for the proper functioning of the machine. To avoid sudden failures, it is important to monitor the condition of the bearings. It is also essential to diagnose the fault in the bearing if vibration or noise level is abnormal.

II. LITERATURE REVIEW

Dougda et al.,[1] presented an experimental verificationof a simplified model of a nonlinear stiffnessball bearing in both static and dynamic modes and testingits capabilities to simulate accurately fault effects.Results of defects simulation and model behaviour in statics and dynamics are compared to experimentalresults. In conclusion, the proposed model gives globallycorrect representation of the behaviour of ball bearingin static and dynamic modes under several conditions.It also proves its capability to accurately simulatefaults, knowing the difficulties encountered to accomplishexperimentations.An interesting relationship is observed between theorder of the highest harmonics and the fault size.

An analytical model is proposed by Rafsanjania et al.,[2] to study the nonlinear dynamic behaviour of rolling element bearing systems including surface defects. Various surface defects due to local imperfections on raceways and rolling elements are introduced to the proposed model.It was investigated that the defect frequencies are slightly different from calculated values as a consequence of slipping and skidding in the rolling element bearings This analysis shows that in most range of shaft speeds, the system is not depended on initial conditions but strongly affected by the parameters of the system particularly radial internal clearance and surface defects. Rolling contact fatigue failure is an unavoidable consequence of normal bearing operation and itresults in the creation of spalling on the contact surfaces of the rolling elements and the raceways. Under alternative loading, small cracks initiate below the surface and propagate to the surface, finally causing spallingand reducing the performance of the bearing. Vibration and acoustic emission signal processing techniqueshave been successfully used as fault diagnosis tools, indicating the existence of such faults and abnormalbearing operation [3]

Tarle et al., [4] 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**.**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. Amplitude at ball pass frequency at outer race (BPFO) is higher than ball pass frequency at inner race (BPFI) and ball spin or defect frequency (BSF). Amplitude at BPFI is less than BPFO and BSF. Also amplitude for bearing with lack of lubrication is higher than bearing with good lubrication.

Kulkarni and Wadkar[5] analysed effect of surface roughness on the vibration response of outer race of the ball bearing. Vibration spectrum produced by thesingle roughness defect under pure radial load at various locations on outer race of bearing is studied. Effect of roughness size,speed and load on the vibration response has been investigated.It is concluded that, the outer ring defected bearings has higheramplitudes of vibration when speed increases.For the outer race roughness, the spectrum had components at outer race defect frequency and its harmonics. Other orders of roughness generate sidebands at multiples of cage frequency about these peaks. It also emphasis thatwith increase in the amplitude levels of the defect frequency with increase in the load at the test bearing.

Theoretical and experimental vibration studies of dynamically loaded deep groove ball bearings having local circular shape defectson either race are reported by Patel et al.,[6]Based on this study the following conclusions are drawn:

- When a ball approaches to the inner race defect, the additional displacement of the ball changes from zero tomaximum, while, it reaches to zero from its maximum value when ball reaches from the centre of the defect tothe other end of the defect.
- The additional displacement reaches to zero from its maximum value when ball reaches from the centre of theouter defect to the other end of the defect.
- The vibration peaks at characteristic defect frequencies (BPFO and BPFI) with their harmonics are recorded fordefective bearings.
- In case of defective inner race, characteristic defective frequency along with the side bands at shaftrotation frequency is noticed.

Vibration of angular contact ball bearings in presence of local defects have been investigated by Arslan and Aktürk [7]. The authors have developed a dynamic model of shaft-bearing system to study the components of defect frequency in vibration spectra of angular contact ball bearings. However, Ashtekar et al. [8] have studied the effect ofsurface defects/dents on the bearing motion. A paper of Patel et al. [9,10] presents vibration studies of shaft, balls, and housing inpresence of local defects on either races by applying steadily radial load (constant magnitude and direction) on the deep grooveball bearings. The authors have compared theoretical and experimental vibrations of bearing housings for the cases of healthy and locally defective bearings.

In this paper artificial depth of cut is created on ball with EDM and its effect at different speeds with the help of FFT analyser is studied.

III. EXPERIMENTATION:

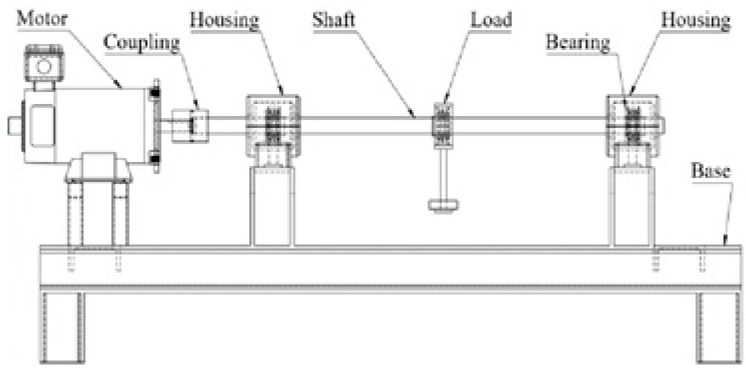

Figure 1: Experimental set up

The experimental setup shown in Fig.1, is designed and fabricated to investigate the vibration characteristics of ball bearings.Experimental setup has electricalmotorwhich vary speedfrom 0 rpm to 2000rpm.Motor is connected to shaft through coupling. Test specimen of healthy bearing and faulty bearing is fitted on the non-driving end of shaft. The fault on the ball i.e. rolling element of self-aligned bearing is created by electric discharge machining (EDM).Square hole of different depth i.e.1mm, 1.5mm, 2mm and 2.5mm is produced. When bearing is mounted in sleeve a clearance of 0.06mm is maintained by feeler gauge between balls and outer race. Whole setup is placed on rubber cushion to reduce vibrations. Experiments on healthy and faulty bearing is carried out under four speeds i.e.500rpm,700rpm,900rpm and 1100rpm and single load of 20N. Load is acted on shaft at the middle. Vibration analysis is investigated through FFT analyser and accelerometer mounted in vertical position. Specification of used Self aligned 1206K bearing is given in Table 1.

Table 1 PropertiesofSelfaligningballbearing1206K.

Bearingnumber	1206k
Sizeinmm	30x62x16
BoreDiameterinmm	30
OuterDiameterinmm	62
Widthinmm	16
Numberofballs	28
BallDiameterinmm	7.94

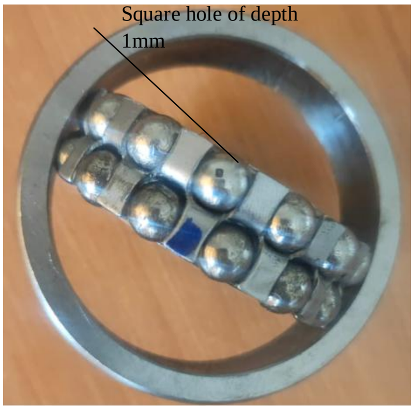

Figure 2: 1206K Self aligned Ball Bearing

IV. RESULT AND DISCUSSIONS:

4.1 Frequency response of healthy bearing

FFT frequency spectrum of healthy bearing for 500rpm and 1100rpm are shown inFig.3 and Fig.4. In these figures peak amplitude of vibrations are 0.368mm/s and 1.51mm/s at 500rpm and 1100rpm respectively. In Fig.3 harmonics of vibrations are observed and are present at shaft frequency (8.34Hz) of 5*N to 13*N .Similarly in Fig.4 it is at 3.7*N, 5.5*N and 6.4*N at 18.34Hz. Their magnitudes are small and is due to presence of unbalances in the system.

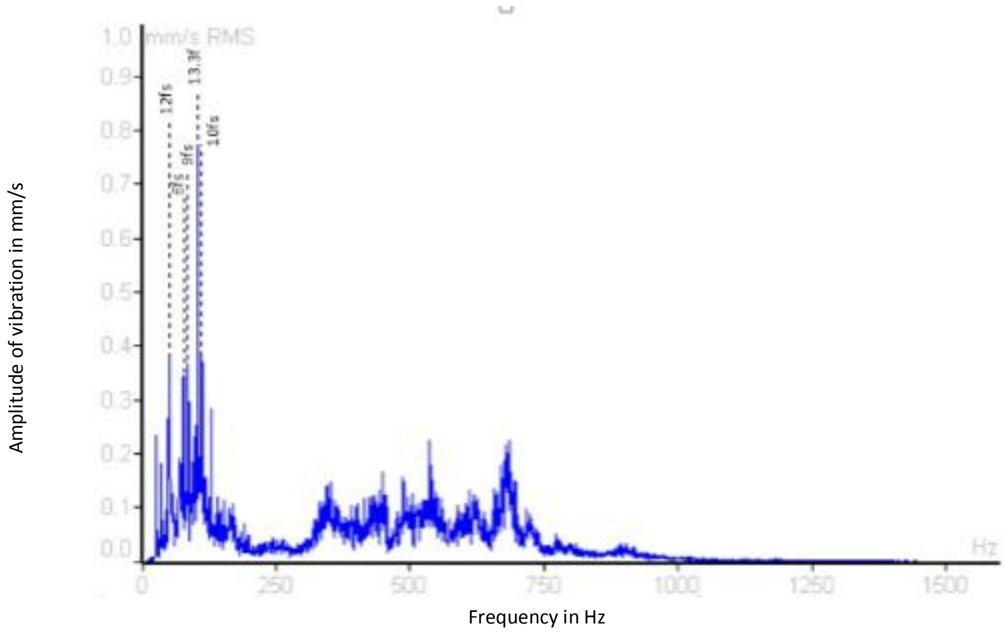

Figure 3: Frequency spectrum for healthy bearing at 500rpm

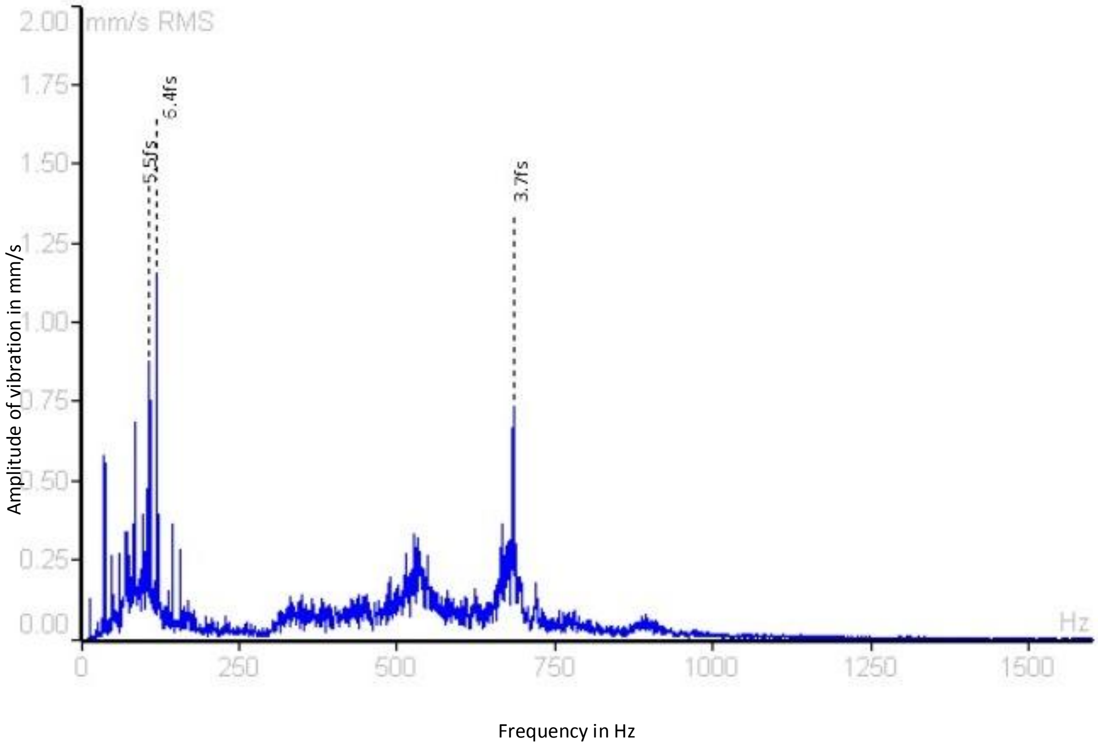

Figure 4: Frequency spectrum for healthy bearing at 1100rpm

4.2 Frequency response of faulty bearing with 1mm depth and 0.06mm clearance

InFig.4 and Fig.5 frequency spectra for speedof 500rpm and 1100rpm isshown. .Atshaftspeed(fs)at500rpm(8.34Hz)andballdefectfrequency(fbd)23.43Hz,amplitudeofvibrationis0.025mm/s.Frequencyspectraassociatedwithharmonicpeaksisasfbd,2fbd,2.2fbd,3fbd and fs+3fbd at shaft speed of 500rpm. Likewise harmonics areassociatedwithothershaft speed is shown in Fig.5.

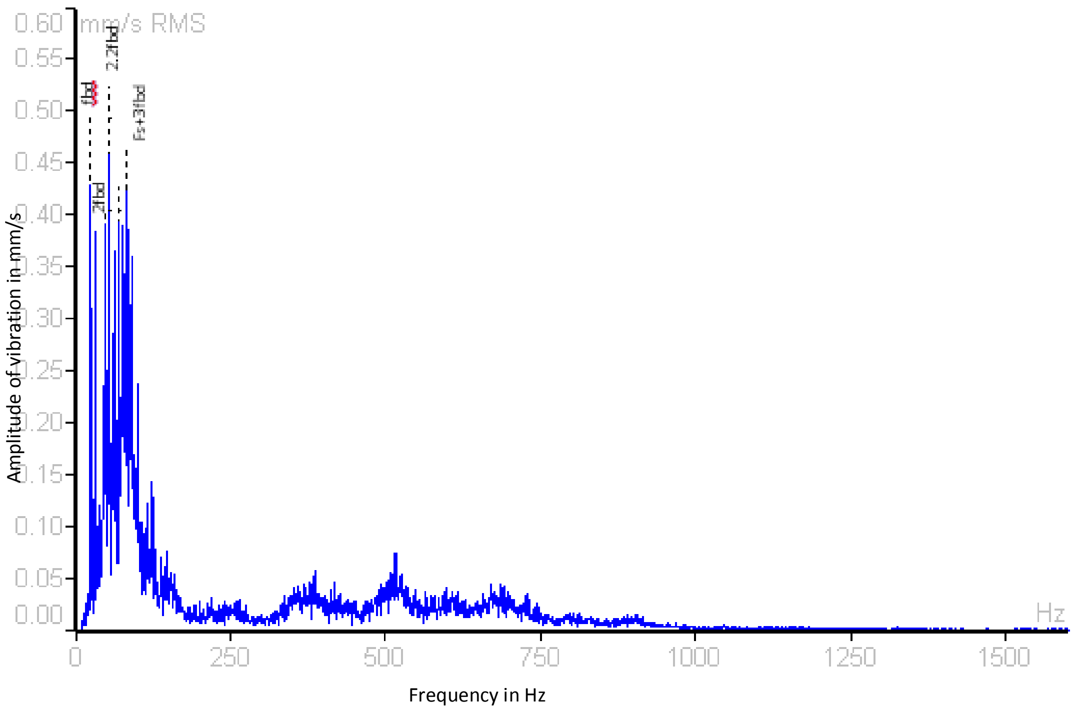

Figure 5: Frequency spectrum for faulty bearing 1mm and 0.06mm clearance at 500rpm

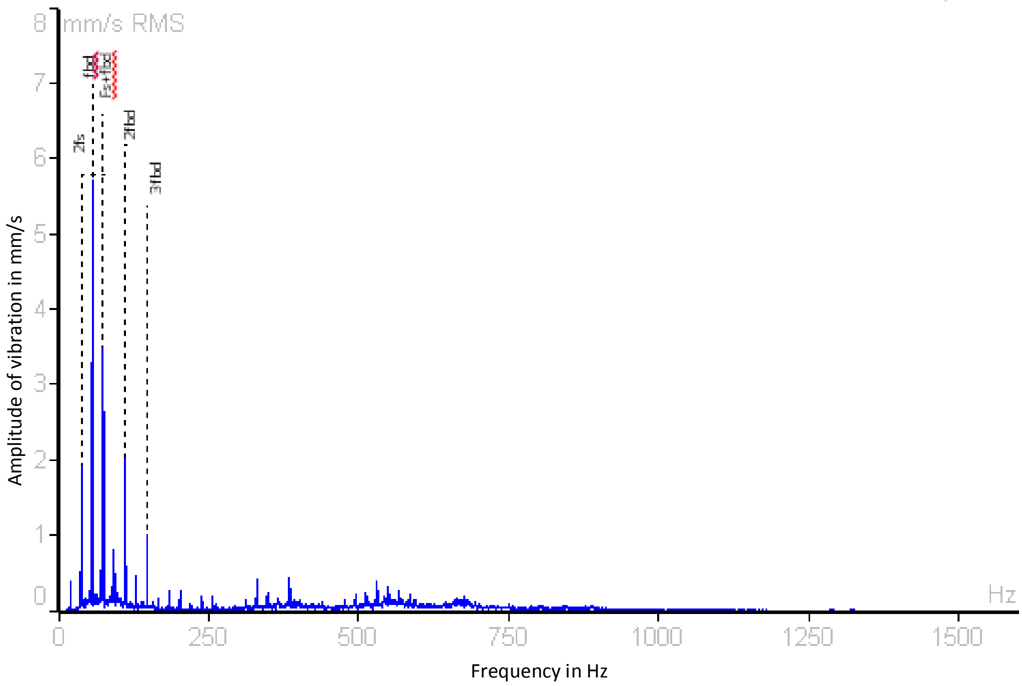

Figure 6: Frequency spectrum for faulty bearing 1mm and 0.06mm clearance at 1100rpm

4.3 Frequency response of faulty bearing with 1.5mm depth and 0.06mm clearance

FFT spectraforfaulty bearing withdepth 1.5mm and0.06mm clearance are shown in Fig.7 to Fig.8.Here also vibration harmonicswith sidebands areobserved.At 1100rpm i.e.18.34Hz,ball defectfrequency is51.53Hzatwhich amplitudeofvibrationis0.14mm/s. Harmonics obtained arefbd,2fbd,fs+fbd,fs+1.5fbdandfs+2fbdat1100rpm.Magnitude of vibration level is higher than healthy and faulty with 1mm depth. Amplitude of vibration level are higher than 1mm depth bearing.

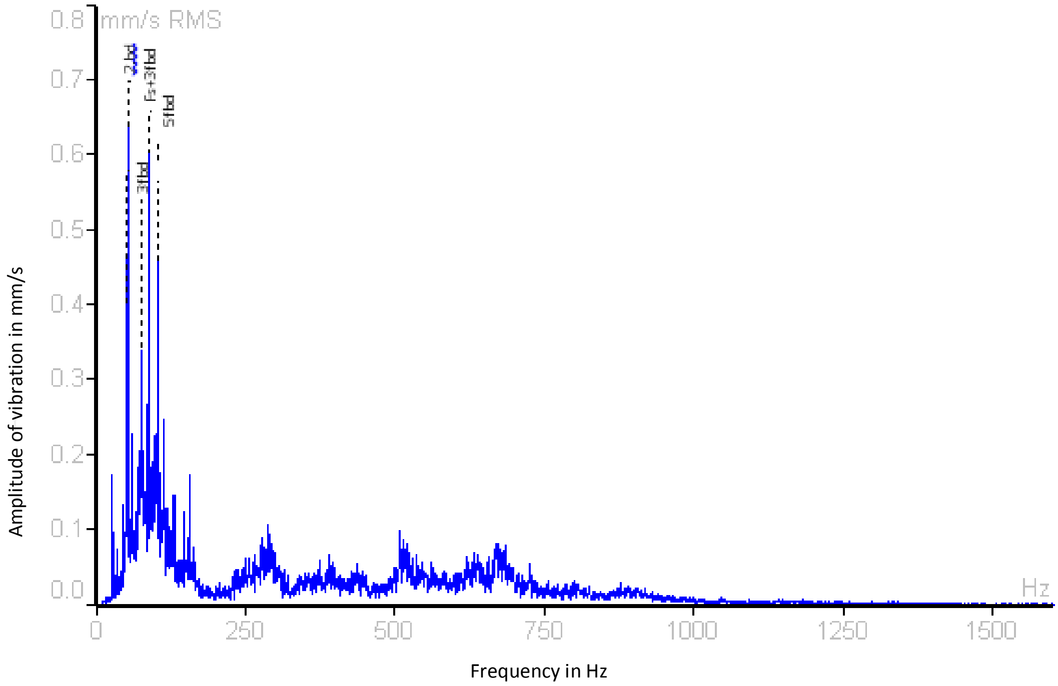

Figure 7: Frequency spectrum for faulty bearing 1.5mm and 0.06mm clearance at 500rpm

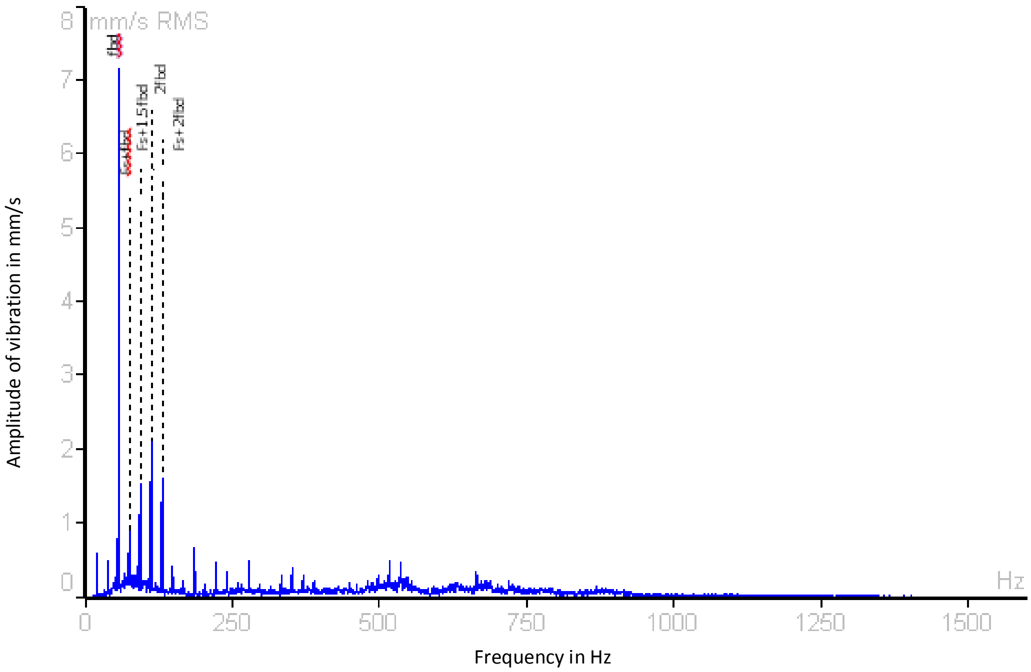

Figure 8: Frequency spectrum for faulty bearing 1.5mm and 0.06mm clearance at 1100rpm

4.4 Frequency response of faulty bearing with 2mm depth and 0.06mm clearance

Ball defect frequency for shaft speed 500rpm(8.34Hz) is 23.43Hz.Atthis frequency amplitude of vibration noted is 0.023mm/s.In Fig.9 vibration harmonicsobserved arefbd, 2fbd, 3fbd, fs+fbd and 1.8fbd at500rpm.Similarlyvibrationmodulation isshown inFig.9.

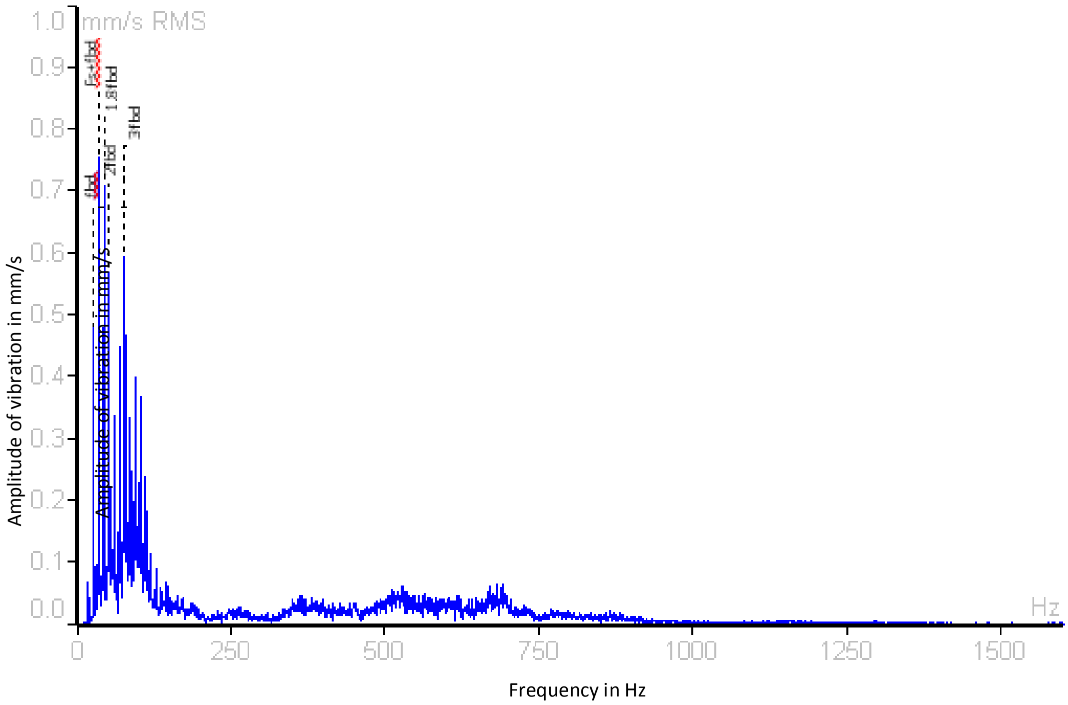

Figure 9: Frequency spectrum for faulty bearing 2mm and 0.06mm clearance at 500rpm

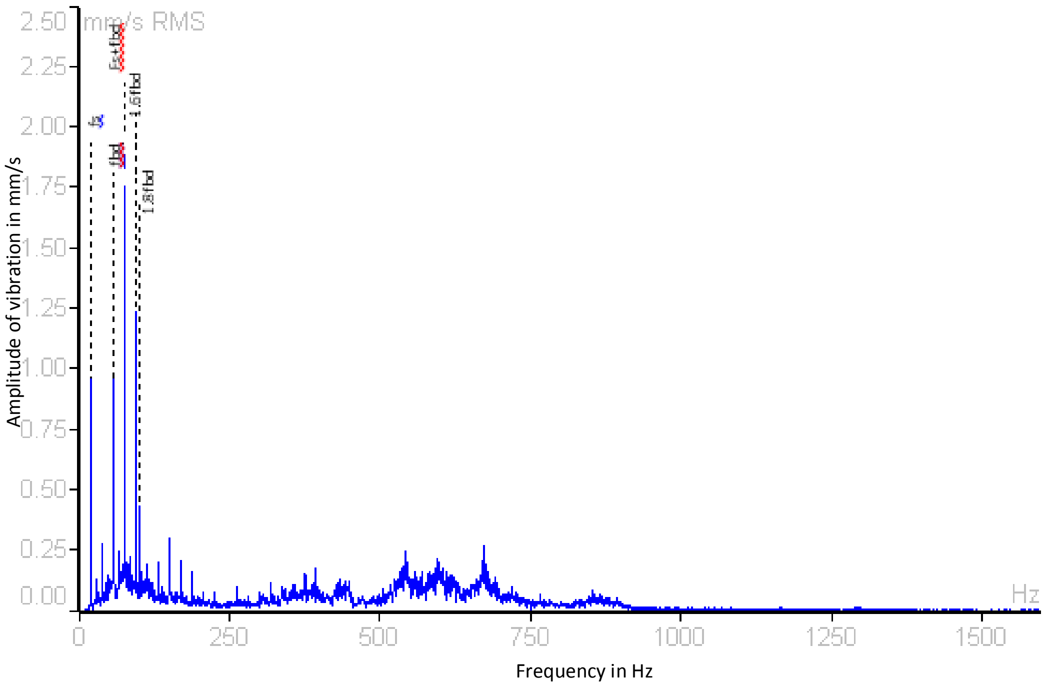

Figure 10: Frequency spectrum for faulty bearing 2mm and 0.06mm clearance at 1100rpm

4.5 Frequency response of faulty bearing with 2.5mm depth and 0.06mm clearance

FFT spectra is shown in Fig.11 and Fig.12.Consider for speed of1100rpmor18.34Hzshaftfrequencyatwhichballdefectfrequencyis51.53Hz.At this fbd ,amplitude of vibration is 0.11mm/s. Frequency harmonicsatthisspeedisfbd,2fbd,2fs,fs+fbd andfs+2fbd.. Magnitude of vibration levels are higher than 2mm depth at same clearance. Similar can be observed at speed of 500rpm.

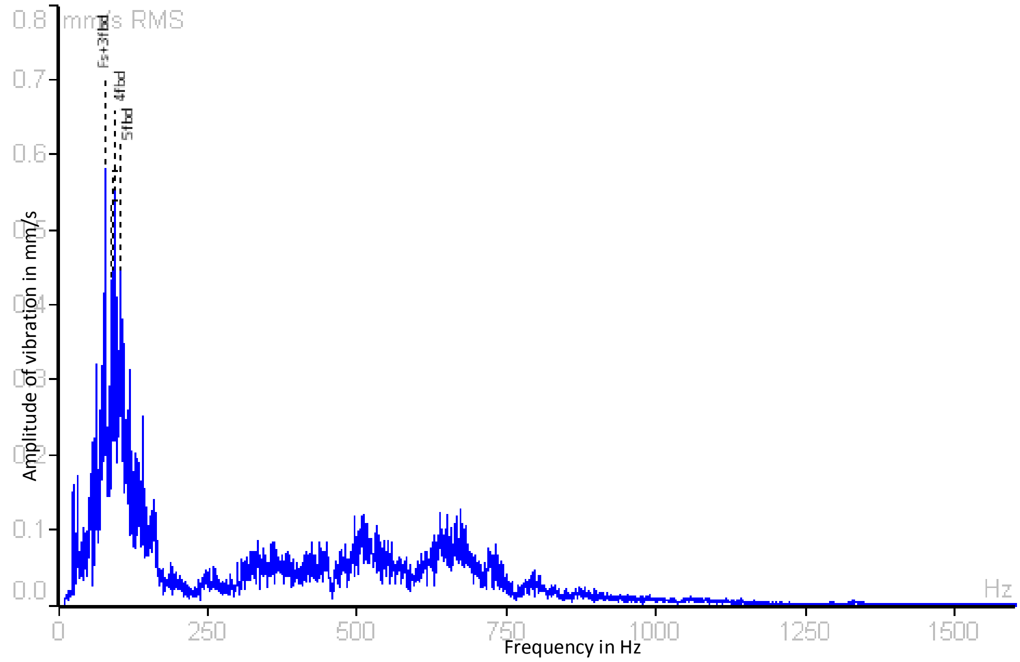

Figure 11: Frequency spectrum for faulty bearing 2.5mm and 0.06mm clearance at 500rpm

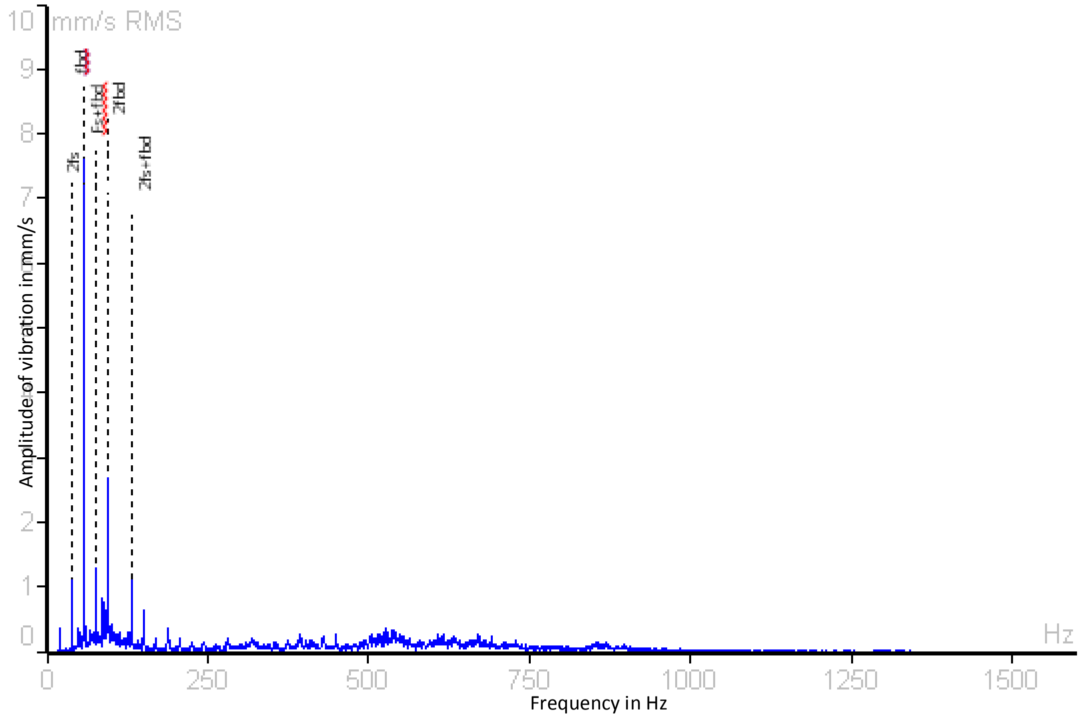

Figure 12: Frequency spectrum for faulty bearing 2.5mm and 0.06mm clearance at 1100rpm

4.6 Comparison of amplitude of vibration with speed for healthy and faulty bearings

In Fig.13 and Fig.14 peak amplitude of vibration of healthy bearing and various faulty bearings at clearance of 0.06mm are compared at different speeds. It can be observed that vibration level for healthy bearing is least and whatever magnitude seen is due to unbalances in the system. In all cases amplitude of vibrations increases with speed. Also with increase in depth of cut in ball causes rise in vibrations.

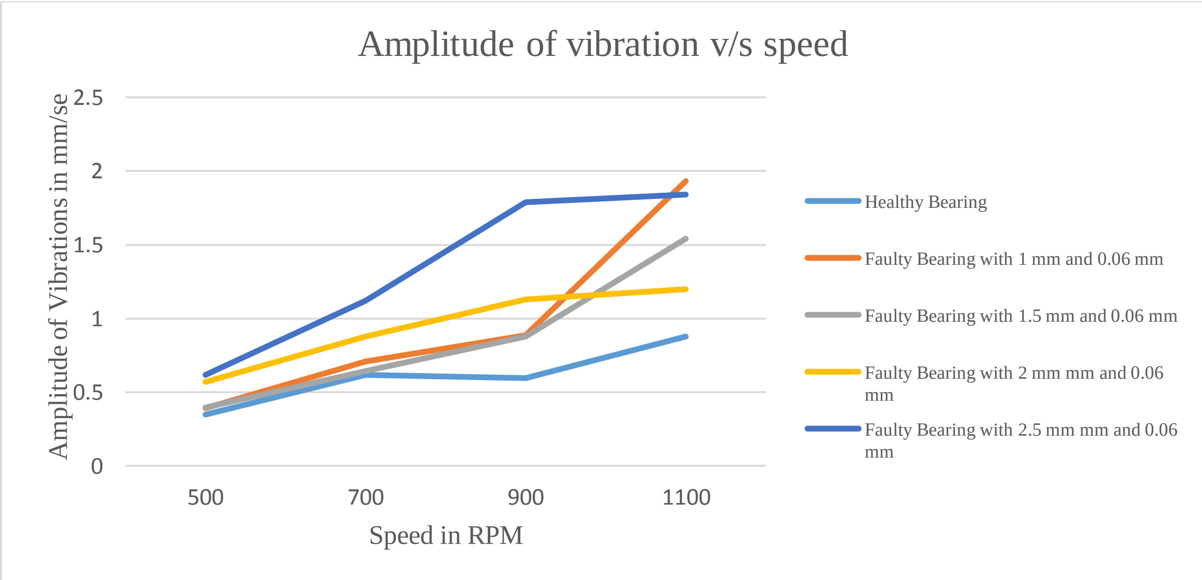

Figure 13: Amplitude of vibration Vs Speed

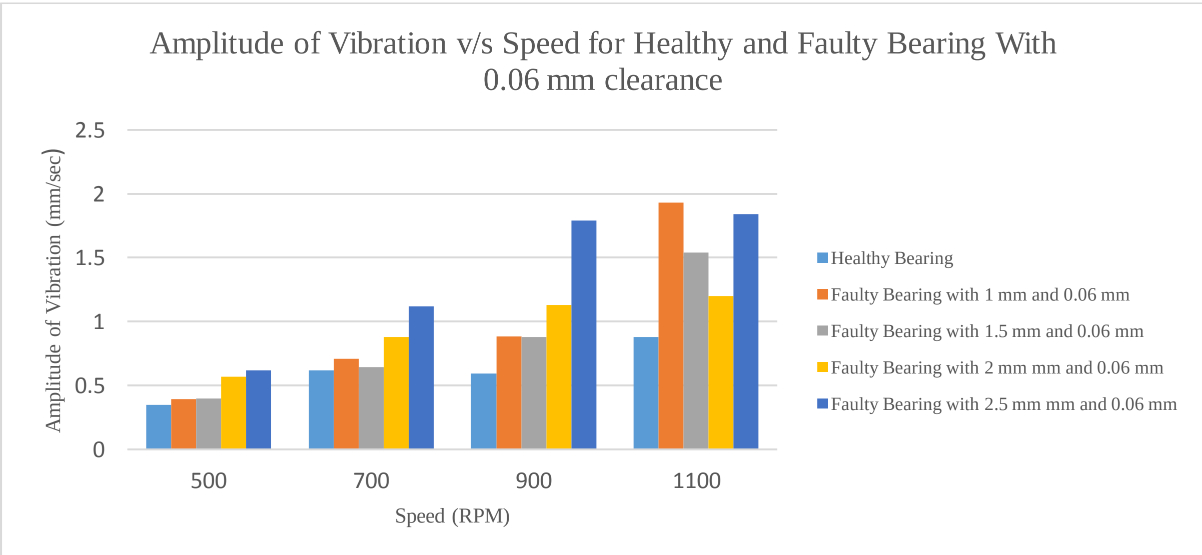

Figure 14: Amplitude of vibration Vs Speed

4.7 Comparison of amplitude of vibration with speed for healthy and faulty bearings for 0.04mm and 0.06mm clearance

Faulty bearing with depth of cut 1mm,1.5mm,2mm and 2.5mm having clearance of 0.04mm and 0.06mm between balls and outer race is compared in Fig.15 and Fig.16.Ampiltude of vibrations are compared at different speeds with healthy bearing. Healthy bearing is having least values. Difference between amplitude of vibrations for these selected two clearance is small.

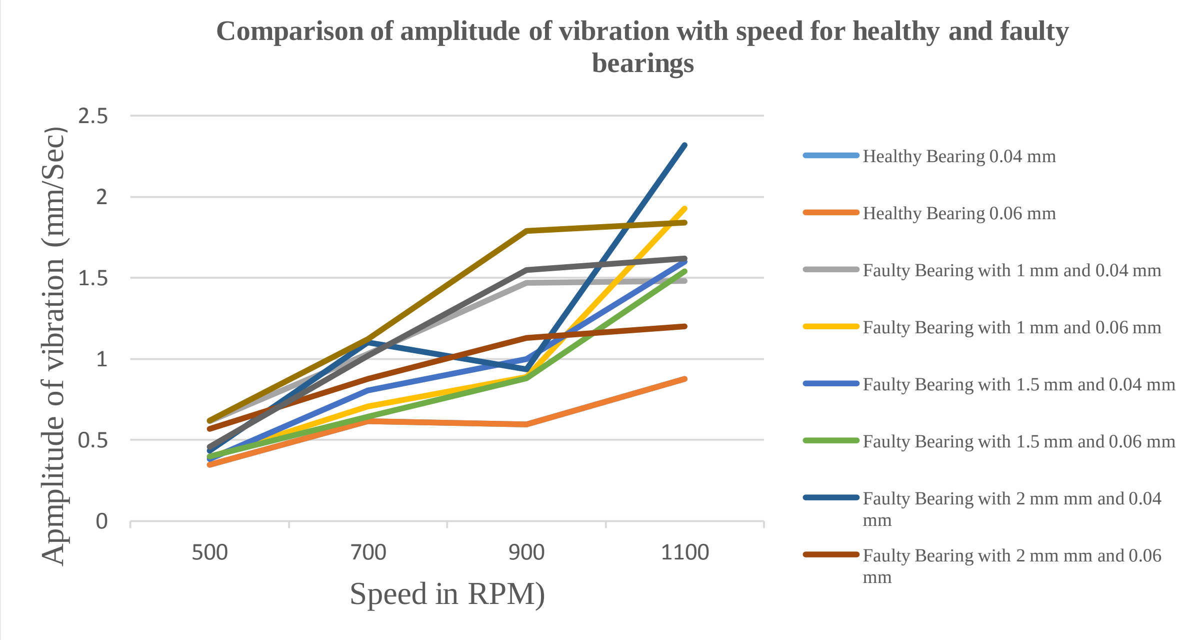

Figure.15: Amplitude of vibration Vs Speed

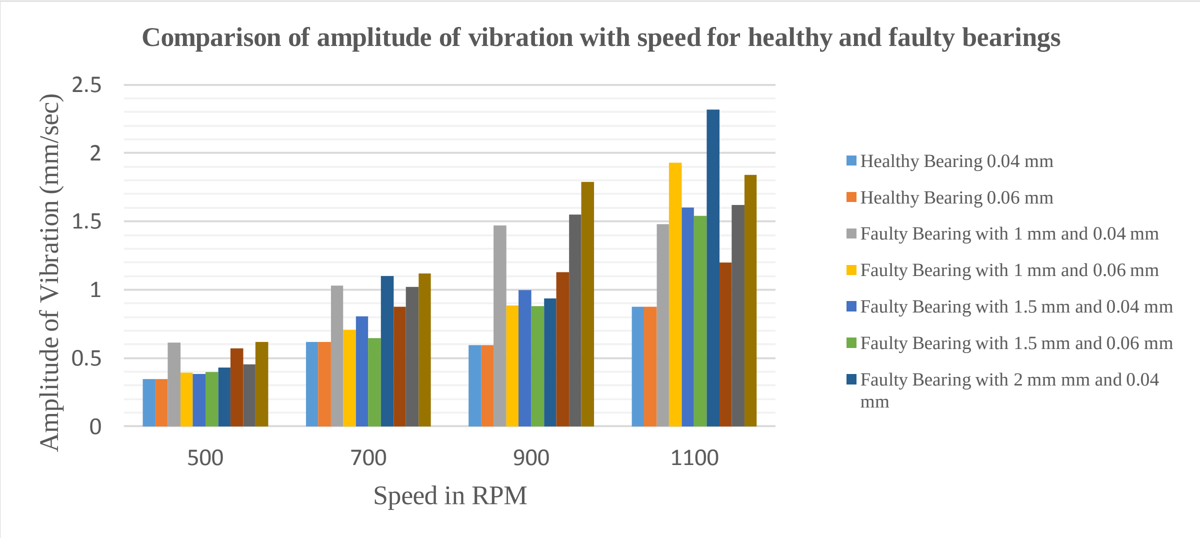

Figure.16: Variation of Amplitude of vibration with Speed

V. CONCLUSIONS

In this paper experimental vibrational analysis is done for healthy and faulty self-aligned ball bearing with clearance of 0.06mm between balls and outer race and its comparison is made with faulty bearing with 0.04mm clearance.. Following conclusions are drawn-

- Peak values of amplitude of vibrations noted by FFT analyser are small in magnitude in healthy bearing. It also accompanied by harmonics in terms of shaft frequency.
- Experiment on Self-aligned faulty bearing with 1mm and 0.06 clearance is at different speed is done. There is rise in magnitude of peak vibrations as compared to healthy bearing. Also harmonics of vibration noted at ball spin or ball defect frequency.
- For depth of cut of 1mm 1.5mm,2mm and 2.5mm on ball, induced more vibration level with rise in depth of cut.
- Ball bearing with depth of cut 2.5mm has highest amplitude of vibration at all speeds. Healthy bearing has least vibration.
- Amplitude levels for different clearance at various speed is compared then it is observed that although there is rise in vibrations but its magnitude difference is small.

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