MAT JOURNALS
Journal of Advancement in Machines
Volume 4 Issue 1

Devising Methods to Avoid Formation of Defects in a Ball Bearing through FFT Analyzer

***Paresh P. Khairnar*[1*], *M. I. Ansari*[2]**
[1]*Assistant Professor, Dr. D. Y. Patil School of Engineering Department of Mechanical Engineering, Maharashtra, India,*
[2]*Assistant Professor, Dr. D. Y. Patil School of Engineering Department of Mechanical Engineering, Maharashtra, India,*
***Email:** paresh.khairnar@dypic.in*
***DOI:** http://doi.org/10.5281/zenodo.2561657*

Abstract
Most of the essentials part is rolling element bearings in rotating machinery. Between the two parts of linear and relative motion are permitted for the function of bearings. During the operation, the bearings are often subjected to high speed and severe conditions. Under these severe operating conditions, defects are often developed in the bearing components. If no corrective measures are taken, the machine could halt or be seriously damaged. A different effect of bearing failure yields its own distinctive damage like primary damage and secondary damage are peeling and flaws. Excessive internal clearance, vibration, noise, are primary da mage has been considered for the necessities. An unsuccessful bearing of times displays a mix of primary and secondary harm.

***Keywords**: Spall defect, Bearing, FFT analyzer, Vibration spectrum, BPFO, Rolling element*

INTRODUCTION
Rolling element bearings is obvious that more attention must be paid to the condition of a rolling element bearing if the human life is in question. Rolling element bearings are manufactured by assembling different components: The outer ring, the inner ring and the rolling elements which are in contact under heavy dynamic loads and relatively high speeds. When ball bearings are operated, they generate vibration. Even a geometrically perfect bearing may generate vibration due to varying compliance or time varying contact forces which exist between the various components of the bearing. The nature of vibration response changes with the presence of defect in bearing components. The function of bearings is to permit constrained relative rotation or linear motion between two parts. During the operation, the bearings are often subjected to high loading and severe conditions. Under this severe operating condition, defects are often developed on the bearing components. If no action is taken, the machine could be seriously damaged. Therefore, it is of prime importance to detect accurately the presence of faults, especially at their early stages, in bearings to prevent the subsequent damage and reduce the costly downtime. The vibration analysis is the most commonly used technique for monitoring of the bearings. This technique can provide early information about progressing malfunctions and forms base line for future monitoring purpose.

The radial clearance in rolling bearing systems, required to compensate for dimensional changes associated with thermal expansion of the various parts during operation, cause dimensional attrition and comprise bearing life, if unloaded operation occurs and balls skid. Also it can cause jumps in the response to unbalance excitation. These undesirable effects may be eliminated by introducing two or more loops into one of the bearing races so that at least two points of the ring circumference provide a positive zero clearance. The deviation of the outer ring with two loops, known as ovality, is one of bearing distributed defects. Although this class of imperfections has received much work, none of the available studies has simulated the effect of outer ring ovality on the dynamic behavior of rotating machinery under rotating unbalance. The speed of rotation, shaft elasticity and ball bearing nonlinearities has been considered in rotating machine. It is established that with best bearings (no ovality), the vibration spectrum is quantitatively and qualitatively the similar in both the vertical and horizontal directions.

TYPES OF DEFECTS IN BEARING

Rolling bearing defects may be categorized as localized or distributed:

A. A localized defect includes cracks, pits and spalls in the rolling surfaces, as well as particle contamination of the bearing lubricant. The crucial failure approach of a correctly operated and installed bearing generates defects of this sort. Imperfections of this sort evident themselves in the bearing's vibration signal as vibratory transients which result from gaps in the contact forces as the defect suffers rolling contact. A number of techniques have been developed to detect these transients in the vibration signal.
B. Distributed defects involve the entire structure of the bearing. Here are included such conditions as misaligned races, eccentric races, off-size rolling elements and out of-round components. The abrasive wear and manufacturing error are the defects may be results of these. Most of the factors are corrosion, foreign particle, insufficient lubrication, dirt, shifted bearing cap, overloading, misalignment are causes of the bearing. These defects of sorts are frequently rise to extreme contact forces which in turn the effect of premature ultimate failure and surface fatigue.

Objectives of Study

- Study of vibration response characteristics of ball bearing with Healthy bearing.
- Study of vibration response characteristics of ball bearing with defected bearing.
- Effect of spall size on vibration response characteristics of ball bearing.
- Effect of running parameters on vibration response characteristics of ball bearing.
- The analysis is carried out with the help of using CATIA and ANSYS.
- CATIA is a solid modeling tool. Since "Finite Element Method" procedure
- Needs solid of the component to be analyzed. ANSYS is basically an
- Analyzing system, with which any physical working conditions can be simulated virtually.

Methodology

1. ***Introduction:*** It gives the outline of the project. It contains information of various defect of bearing, failure theories of bearing.
2. ***Literature Review:*** It contains the research work carried out by the various authors, recently on the detection of defect (spall) by using vibration analysis.
3. ***Bearing Types, Bearing Failures and Their Causes:*** It contains the types of bearing, bearing component and types of failure, their causes.
4. ***Design Consideration and Theoretical Calculations:*** It contains the experimental work carried out on experimental set-up, and the reading of the experiments and steps for the experiment.
5. ***Experimental work:*** It contains the experimental work carried out on setup and steps for the experimental procedure.
6. ***Numerical Analysis:*** It contains how the model is created in ProE design software then its ANSYS analysis. The

FEM Analysis of bearing for Structural Aspects gives defective frequencies and amplitude.

7. ***Results and Discussion:*** It contains the experimental results and graphs related to the readings.
8. ***Conclusion and Future Scope:*** It contains the conclusion and the future scope of the dissertation.
9. ***References:*** Required for the entire work are included at the end of the report compressive load.

LITERATURE REVIEW

L D. Meyer et .al [1] an analytic model for ball bearing vibrations to predict vibration response to distributed defects. When ball bearings are operated, they generate vibration. In many cases, these vibrations can be sensed using appropriate transducers (e.g., accelerometers) on the outside of the structure containing the bearing. The principal forces which drive these vibrations are the time-varying contact forces which exist between the various components of the bearing: balls, races and ball retainers. The presence of a number of defects or aberrant operating modes is reflected by changes in the character of these bearing vibrations. This family of bearing problems comprises those operating modes in which the magnitude of the ball-race contact force varies continuously and periodically as the bearing rotates.

Choudhury et. al [2] presented A theoretical model to predict vibration response of rolling bearings to distributed defects under radial load. An investigative model has been existing to foresee the tremor response of rolling contact bearings due to spread defects beneath radial load. For bearings without flaw and with race fault, the model foresees a distinct band with machineries at outer and inner race characteristic defect occurrences for the response of the respective races. The plenty level for race faultknowinglysurges at the individual occurrences in evaluation to the retort of a bearing without fault. For a bearing with off-size rolling element, the answer is at the relative frequency of cage with respect to the frequency of motion of the conforming race. In this paper it is described that rolling element bearing vibration is of considerable interest to scholars.

Bin Zhang et. al [3] mentioned that the sources of bearing vibration are the external time varying forces between the components and the transmission mechanism of the machine during the bearing operation. Even a perfect bearing produces vibration because of the time-varying contact force between bearing components which is caused by the shaft rotating and the change of position of the rolling elements. The bearing itself also acts as an excitation source that harvests time-changing forces to induce the machinery trembling. Since the accelerometers are regularly mounted on the basis, the collected vibration facts also comprise machinery vibration. For a strong bearing without a fault, the interaction force between bearing components is nonstop.

THEORETICAL CALCULATIONS

In this project work 6206 deep groove ball bearing is used. Geometry of bearing is shown in Figure 1. And geometrical specifications are given in Table 6. The bearings are designated by a number. In general, the number consists of at least three digits. Added digits or letters are used to specify special landscapes. The previous three digits give the succession and bearing bore. The previous two digits from 4 ahead, when reproduced by 5, give the diameter of bore in millimeters. The third last digit is shown as the series of the bearing. The most popular ball bearings are accessible in four series as trails;
1] Extra light (100), 2] Light (200), 3] Medium (300), 4] Heavy (400)
The bearing selected is 6206 (2RS), the number “06” indicates the inner bore

diameter 30mm, third digit from last i.e. “2” indicates Light Duty, and the first digit from start i.e. “6” indicates deep-groove ball bearing. The term “2RS” indicates the Rubber-Seal for the bearing on both sides

Facilities Available: All the required facilities for this dissertation work are available at Dr. D. Y. Patil School of Engineering. Pune; (a) well equipped vibration lab and (b) Library facilities

Frequency Equations Required:

Cage speed Wm and Cage frequency fm:

Consider inner race and outer race are rotating at Wi and Wo respectively.

Therefore, the velocity at a point on a rotating body is,

$$v = r \times w \tag{1}$$

Generally bearing vibration sensors such as accelerometers or proximity probes are pick up the radial component of vibrations. Therefore the equations are developed in terms of radial component of vibration.

The velocity at inner race contact point is,

$$vi = wi \times ri$$

$$vi = wi \times \frac{di}{2}$$

Therefore $vi = wi \times \frac{1}{2}(dm - dbcos\beta)$

Therefore

$$vi = \frac{1}{2} \times wi \times (dm - dbcos\beta)$$

Therefore

$$vi = \frac{1}{2} \times wi \times dm\left[1 - \left(\frac{db}{dm}\right)cos\beta\right] \tag{2}$$

Similarly,

Velocity at outer race contact point is,

$$vo = \frac{1}{2} \times w0 \times dm\left[1 + \left(\frac{db}{dm}\right)cos\beta\right] \tag{3}$$

Put, $\left(\frac{db}{dm}\right)cos\beta = \mu$ (4)

Therefore equation 2 and 3 becomes,

$$vi = \frac{1}{2} \times wi \times dm[1 - \mu] \tag{5}$$

$$v0 = \frac{1}{2} \times w0 \times dm[1 + \mu] \tag{6}$$

Now the velocity of rolling element or balls is taken as the mean of inner and outer race velocities

Therefore $vm = \left[\left(\frac{vi+v0}{2}\right)\right]$

$$vm = \frac{1}{2}\left[\frac{1}{2} \times wi \times dm(1-\mu) + \frac{1}{2} \times w0 \times dm(1+\mu)\right]$$

$$vm = \frac{1}{4} \times dm[wi \times (1-\mu) + w0 \times (1+\mu)] \tag{7}$$

But $vm = \frac{1}{2} \times (wm \times dm)$ (8)

Put equation 8 in equation 7 we get,

$$wm = \frac{1}{2} \times [wi \times (1-\mu) + w0 \times (1+\mu)] \tag{9}$$

Since rotational speed is directly proportional to frequency,

Therefore, w=f

Equation 9 becomes,

$$Fm = \frac{1}{2} \times [fi \times (1-\mu) + f0 \times (1+\mu)] \tag{10}$$

Fundamental train frequency (FTF) or Cage defect frequency (fcd):

If the bearing is too lose or the cage is worn out or cracked, vibration amplitudes at Vm (FTF) and its harmonics may appear. If the defect is severe enough the harmonics of running speed (i.e.) multiplies of fi) are modulated by FTF and side bands of FTF will appear in the spectrum.

Therefore,

$$FTF = fm = \frac{1}{2} \times fi(1-\mu) \tag{11}$$

Ball pass frequency of outer race (BPFO) of outer race defect frequency (fod):

If there is significant defect on the stationary outer race then each rolling element (ball) produces on impact vibration. The frequency which is generated by this phenomenon is called as outer race defect frequency.

Therefore BPFO=n*FTF

$$BPFO = n \times \frac{1}{2} \times fi \times (1-\mu) \tag{12}$$

This frequency is generated related to the cage motion relative to a fixed reference frame.

Ball pass frequency of inner race (BPFI) or inner race defect frequency (fid):

If there is a defect on the rotating inner raceway then a spike caused by the impacting of each rolling element as it contacts the defect. The frequency which is generated by this phenomenon is called inner race defect frequency.

Therefore BPFI=$n \times Fixed$

$=n \times (fi - fm)$

$= n \times (fi - FTF)$

$= n \times \left[fi - \frac{1}{2} \times fi(1-\mu)\right]$

Therefore,

$$BPFI = \frac{n}{2} \times fi(1 + \mu) \quad (13)$$

This frequency is generalized related to the rotational speed of inner race and the cage assembly.

Ball spin frequency (BSF) or ball defect frequency (fbd):

A single defect on a rolling element generates measurable vibrations at the relative spin frequency of the ball relative to the cage.

$$Fb = \frac{1}{2} \times \frac{dm}{db} \times (1 - \mu)(1 + \mu) \times fi$$

Table 1: *Frequency Equations Required.*

Characteristic frequency(Hz)	symbol	Equations
Shaft Rotational Frequency	Fs	N/60
Inner race defect frequency	Fid	n/2×fr[1+(bd/pd)×cosβ]
Outer race defect frequency	Fod	n/2×fr[1-(bd/pd)×cosβ]
Ball defect frequency	Fbd	Pd/2bd×Fr[1-(bd/pd)2×(cosβ)2

$$FB = \frac{1}{2} \times \frac{dm}{db} \times fi \times (1 - \mu^2) \quad (14)$$

Table 2: *Geometrical Properties of Ball Bearing (6206) Inner Race Defect Frequency.*

Parameter	Dimensions(mm)
Bearing outside diameter, (D)	62
Bearing bore diameter, (d)	30
Ball diameter(Bd)	9.52
Bearing width, (B)	16
Pitch diameter (Pd)	46
Contact angle, (β)	0
Number of balls, (n)	9

In this Table 3 inner race defective frequency at various RPM with the help of defective frequency equation.

Table 3: *Inner Race Defective Frequency.*

Inner Race Defective Frequency		
Sr. No.	**Speed in RPM**	**Defective frequency in Hz**
1	1490	135.05
2	1200	108.3
3	1000	90.32
4	800	72.26

In this Table 4 outer race defective frequency at various RPM with the help of defective frequency equation.

Table 4: *Outer Race Defective Frequency.*

Outer Race Defective Frequency		
Sr. No.	**Speed in RPM**	**Defect FREQ in Hz**
1	1490	89.12
2	1200	71.56
3	1000	59.6
4	800	47.7

DESIGN

CAD model of set-up of project with actual dimensions of mechanical elements used in set-up. In this segment modelling of bearing is done with the help of CATIA software, modelling is a complex task for designing a bearing because in the modelling of bearing various types of joints should be applied at the design stage which is very complex.

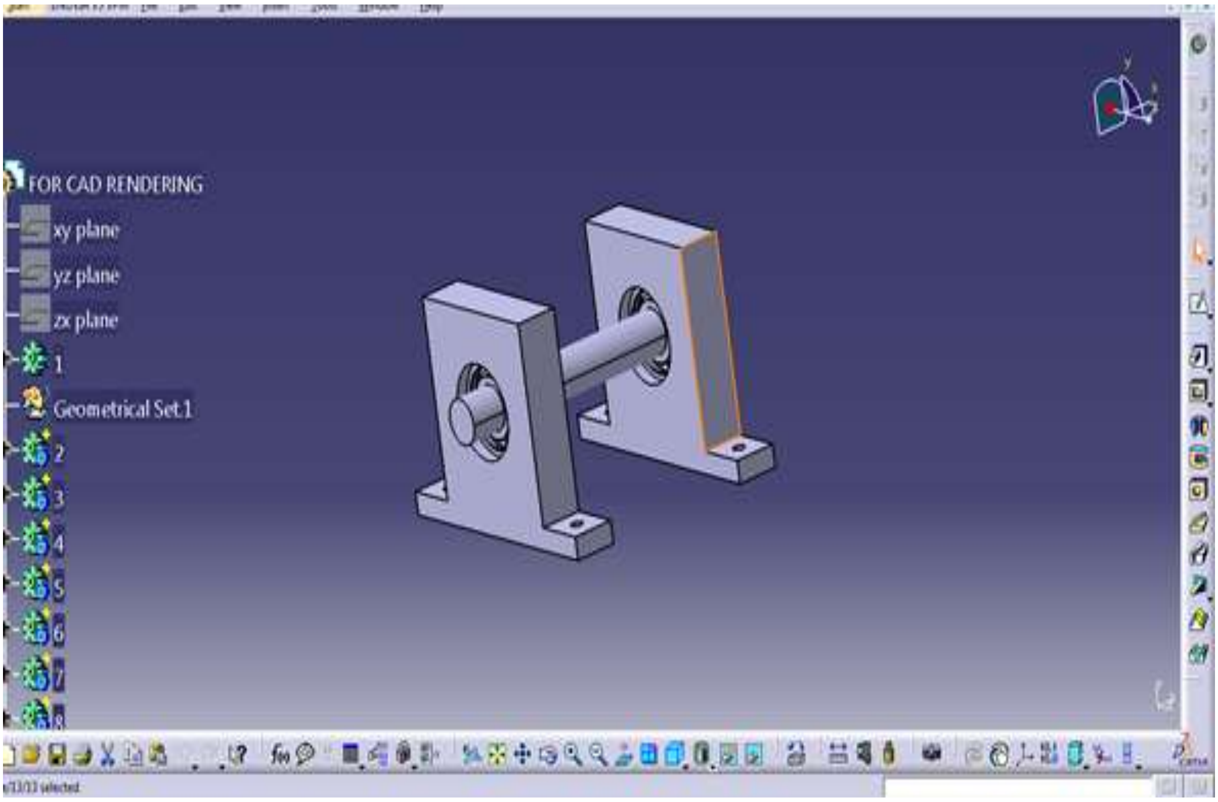

Figure 1: *Cad Model for Set Up.*

The created solid model was brought in to ANSYS analysis environment using ANSYS-CATIA interface. The small features like round, chamfer, have not been modelled .Since the analysis to be made on the different geometry were created. In ANSYS, solid model is divided into small elements. This process is called creating sub-assemblies. The following are the two CATIA model of inner race defected and outer race defected model of bearing.

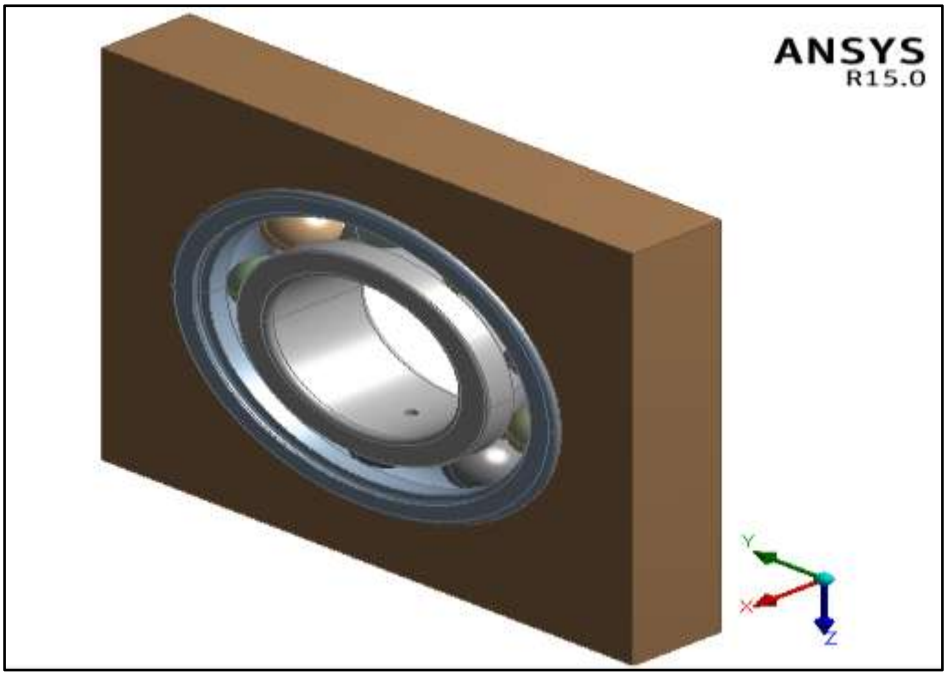

Figure 2: *3D Model of Inner Race Defective Bearing.*

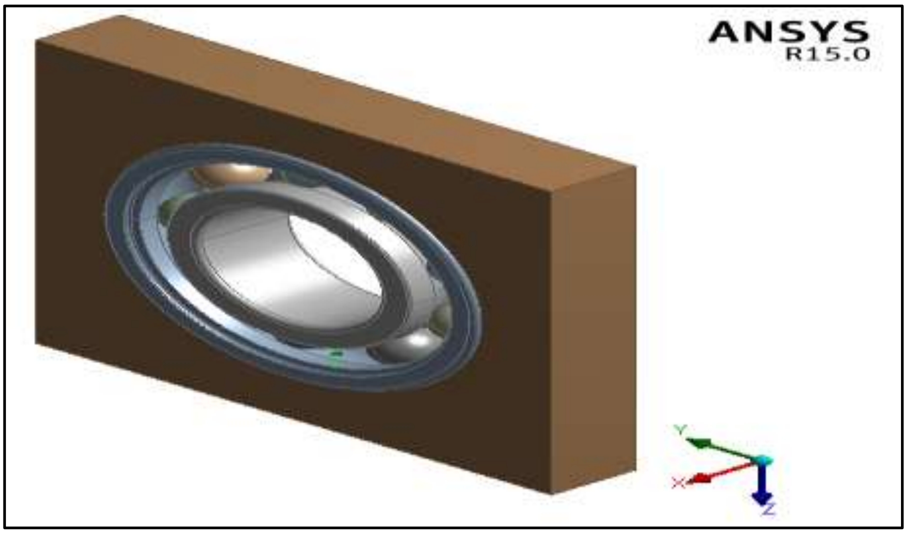

Figure 3: *3D Model of Outer Race Defective Bearing.*

RESULTS AND DISCUSSION

Vibration characteristics are most vital role in the revision of analytical for the system. In the experimental setup two bearings are well-thought-out one bearing was no any defect and additional bearing was with defect, both the bearings were attached to the system one after another for convey the result. The bearing dimensions are specified in the Table after taking the consequence it was observed that the amplitude values were added for the bearing with defect associate to bearing which has without defect. First arrangement is outing for few minutes to slow down all the inconsequential vibration. After this Accelerometer accompanied by the vibration analyzer is utilized to obtain the signals of vibration. Vibration signals are dignified at dissimilar speeds of the system for both non-defective and defective bearing. Subsequent are the rare results which are occupied through the help of FFT analyzer. Throughout performing the experiment speed of shaft are differ from 1490 rpm to 800 rpm, throughout these shaft speed amplitude values in positions of frequency (Hz) and amplitude (mm/s^2) were considered for better understanding. For with defect and without defect bearing results were reserved in time domain, consistently frequency domain results were also occupied for imperfect bearing for excellent accepting of vibration amplitude values.

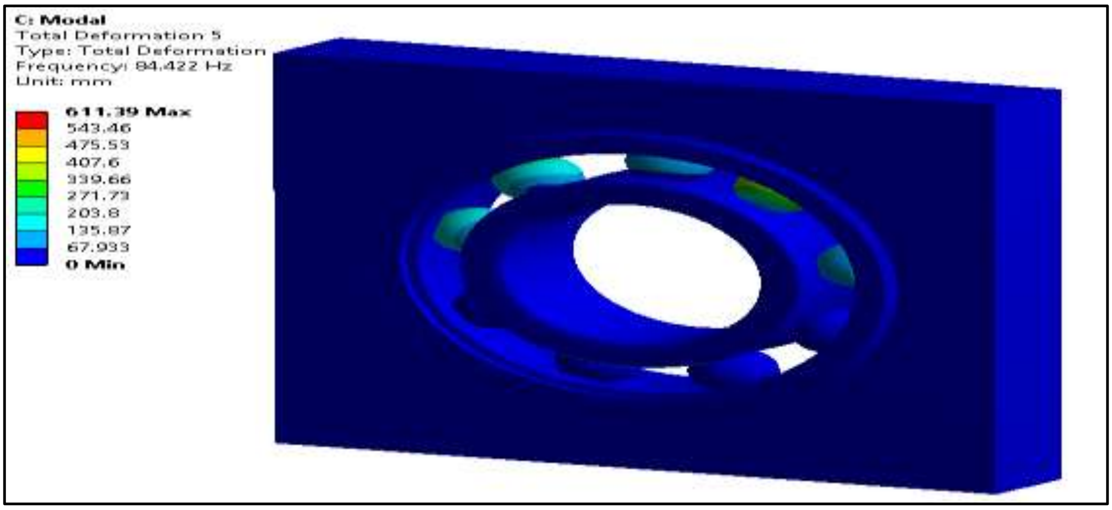

Figure 4: *Outer Race Defect 1490 RPM.*

Table 5: *Results Obtained from FEA (ANSYS) and Experimental Due to Outer Race Defect.*

Outer Race Defect							
Sr. No.	**Speed in RPM**	**Defect Frequency**	**FFT Amplitude (Healthy) Bearing**	**FFT Amplitude (Defective) Bearing**	**ANSYS Defective Frequency**	**ANSYS Healthy Bearing Amplitude**	**ANSYS Defective Amplitude**
1	1490	89.12	0.000212	0.0211	84	0.00019	0.0209
2	1200	71.56	0.002	0.0161	76	0.0018	0.0163
3	1000	59.6	0.0000698	0.0251	55	0.000067	0.0248
4	800	47.7	0.0028	0.031	44	0.003	0.034

Table 6: *Results Obtained from FEA (ANSYS) and Experimental Due to Inner Race Defect.*

Inner race defect							
Sr. No.	**Speed in RPM**	**Defect Frequency**	**FFT Amplitude (Healthy) Bearing**	**FFT Amplitude (Defective) Bearing**	**ANSYS Defective Frequency**	**ANSYS Healthy Bearing Amplitude**	**ANSYS Defective Amplitude**
1	1490	135.05	0.000212	0.0233	130	0.00019	0.0236
2	1200	108.3	0.002	0.0129	105	0.0018	0.013
3	1000	90.32	0.0000698	0.0295	86	0.000067	0.0276
4	800	72.26	0.0028	0.0125	67	0.003	0.0127

CONCLUSION

In most of the studies, the fault diagnosis of rolling element bearings has been focused mainly on vibration measurement methods and utilization of these methods for detecting faults on individual components. However, very few studies have been carried out and reported in literature, which address the effect of severity of localized defects of bearing components on the nature of the vibration response. In the present study, localized defect has been considered on the ball bearing. The dynamic behavior of healthy/faulty ball bearing elements is investigated. The vibration response due to localized defects on the inner race, outer race and balls have been demonstrated, also combination of these defects and rotational speed.

REFERENCES

1. Meyer L. D., Ahlgren F. F. & Weichbrodt B. An Analytic Model for Ball Bearing Vibrations to Predict Vibration Response to Distributed Defects. *Trans of ASME J. Mechanical Design*. 1980; 102: pp. 205-210.
2. Chaudhary A. & Tondon N. A Theoretical Model to Predict Vibration Response of Rolling Bearings to Distributed Defects under Radial Load. *Transactions of ASME*. January 1998; 214(120): pp. 214-220.
3. Zhang Bin, Georgoulas Georgios, Orchard Marcos, Saxena Abhinav, Brown Douglas, Vachtsevanos George & Liang Steven. Rolling Element Bearing Feature Extraction and Anomaly Detection Based on Vibration Monitoring. *16th Mediterranean Conference on Control and Automation Congress Centre, Ajaccio, France*. June 2008: pp. 25-27.

Cite this article as:
Paresh P. Khairnar, & M. I. Ansari. (2019). Devising Methods to Avoid Formation of Defects in a Ball Bearing through FFT Analyzer. Journal of Advancement in Mechanics, 4(1), 9–16. http://doi.org/10.5281/zenodo.2561657

