DEFECT DETECTION IN DEEP GROOVE POLYMER BALL BEARING USING VIBRATION ANALYSIS

Attel Manjunath[1] and D V Girish[2]

[1]Department of Mechanical Engineering, Acharya Institute of Technology, Bangalore, Karnataka, India
manjuattel@gmail.com

[2]Department of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka, India
dv_girish@rediffmail.com

ABSTRACT

Over the past decades there have been many major advances in the development of high strength to lightweight polymeric composites in a variety of engineering applications. In this paper an effort is made to study the performance of polymer ball bearings made with Polyacetal (POM) material. Ball bearings are widely used in industry from home appliances to aerospace industry. Proper functioning of these machine elements is extremely important in order to prevent catastrophic damages. It is therefore, important to monitor the condition of the bearings and to know the severity of the defects before they cause serious catastrophic damages. Hence, the study of vibrations generated by these defects plays an important role in quality inspection as well as for condition monitoring of the ball bearing/machine element. This paper describes the vibration analysis technique to detect the defects in the ball bearing. The Fast Fourier Transform (FFT) detected the frequencies of damage present during the vibration analysis of a ball bearing.

KEYWORDS

Polyacetal (POM) ball bearing, Vibration signal, signal analysis, FFT.

1. INTRODUCTION

Ball bearing is the most basic component used in machinery for various engineering applications. Most of the engineering applications such as electric motors, bicycles and roller skates use these bearings, which enable rotary motion of shafts apart from complex mechanisms in engineering such as power transmissions, gyroscopes, rolling mills and aircraft gas turbines. In general ball bearings are made of four different components, an inner ring, an outer ring, the ball element and the cage. The cage element helps in separating the rolling elements at regular intervals and also it holds them in place within the inner and outer raceways to allow them to rotate freely [5].

Engineering thermoplastics have long demonstrated their suitability as sliding materials. For decades they have been used successfully in sliding applications in precision engineering, in small electrical appliances and in the electrical industry to mention only a few examples. Plastic/polymer bearings by their very nature do not have the high load-bearing capacity compared to metal bearings, but they offer other advantages such as operation in conditions of dry running and mixed friction, low noise, maintenance-free operation, chemical resistance, electrical insulation and also have processing advantages.

As ball bearing is most commonly used component in machinery, it has received a great attention in the field of condition monitoring. Even a newly manufactured bearing may also generate vibration due to components running at high speeds, heavy dynamic loads and also contact forces which exist between the bearing components. Bearing defects may be classified as localized and distributed. The localized defects include cracks, pits and spalls caused by fatigue on rolling surfaces [7]. The distributed defects include surface roughness, waviness, misaligned races and off size rolling elements. The sources of defects may be due to either manufacturing error or abrasive wear. Hence, study of vibrations generated by these defects plays an important role in quality inspection as well as for condition monitoring of the ball bearing/machinery [2].

In order to prevent bearing failure there are several techniques in use. such as, oil analysis, wear debris analysis, vibration analysis and acoustic emission analysis. Among them vibration and acoustic emission analysis [8] is most commonly accepted techniques due to their ease of application. The time domain and frequency domain analysis [3] are widely accepted for detecting malfunctions in bearings. The frequency domain analysis is more useful as it identifies the exact nature of defect in the bearings. These frequencies of the ball bearing depend on the bearing characteristics and are calculated from the relations shown below [4].

Inner race frequency, $$f_{ir} = f_s \frac{N_b}{2}\left(1 + \frac{B_d}{P_d}\cos\emptyset\right) \quad (1)$$

Outer race frequency, $$f_{or} = f_s \frac{N_b}{2}\left(1 - \frac{B_d}{P_d}\cos\emptyset\right) \quad (2)$$

Ball frequency, $$f_b = f_s \frac{P_d}{2B_d}\left(1 - \frac{B_d^2}{P_d^2}\cos^2\emptyset\right) \quad (3)$$

Fundamental train frequency, $$f_{ftf} = \frac{f_s}{2}\left(1 - \frac{B_d}{P_d}\cos\emptyset\right) \quad (4)$$

2. Literature Work

The effect of vibration on perfect bearing can be considerably reduced by selecting the correct preload and number of balls [9]. The vibration monitoring technique is used to analyse various defects in bearing and it also provides early information in case of progressive defects [8]. Triaxial vibration measurement was used to capture the signals and it was found that defect bearing has a strong effect on the vibration spectra [10].

In case of defect on the fixed ring the frequency spectrums generated will appears at its multiples. If the defect is located on the inner ring or the ball, frequency spectrum is amplitude modulated. The more is the wear, higher are the amplitudes of the components. Low speed fault simulation tests were conducted with various defects on the bearing. This study gives the best frequency bandwidth for early detection of bearing defects running at lower speeds [11].

3. Experimental Setup

3.1. Bearing Test Rig

The experimental bearing test rig is designed and fabricated to identify the presence of defects on a radially loaded Polyacetal deep groove ball bearing by vibration analysis technique is shown in Figure 1. The test rig consists of a circular shaft with central disc rotor, which is supported on two deep groove polymer ball bearings of 6204 series. An induction motor with variable speed drive is coupled to a flexible coupling which drives the shaft. The bearing test rig employed for this study has an operational speed of 10 to 2000 rpm, with central load of 200N capacity. Considering the shaft subjected to both combined twisting and bending moment the diameter of the shaft found to be 25mm and a bushed pin type flexible coupling is used to connect two shafts. For capturing vibration signals from the test rig a provision is made to mount the accelerometer on top of the test bearing housing.

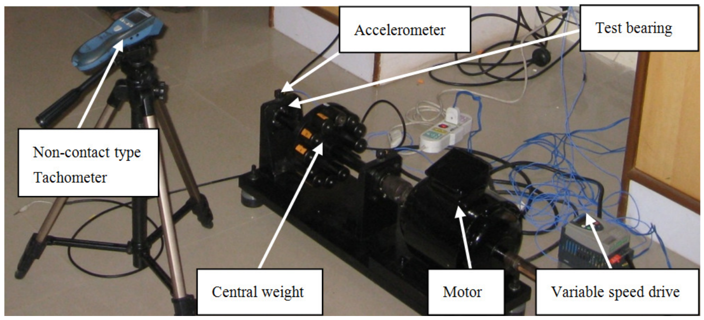

Figure 1. Experimental setup for ball bearing vibration analysis.

3.2. Bearing Type and Bearing Material

The bearing type used in this study is a single row deep groove ball bearing with bearing model 6204 series. The ball bearing is made with thermoplastic material called Polyacetal shown in Figure 2. The Polyacetal has melting temperature (Tm) 182-2180^{o}C, density 1.41 g/cc and carbon Polyacetal known as polyoxymethylene (POM), is a high strength, crystalline engineering thermoplastic material having a desirable balance of excellent properties and easy processing [6].

Polyacetal is one of the thermoplastic materials that can replace metals and thermosets because of its long-term performance over a wide range of temperature conditions and harsh environments. It retains properties such as creep resistance, fatigue endurance, wear resistance and solvent resistance under demanding service conditions. Also, it is a lubricious, strong, and has good dimensional stability. The details of the ball bearing used in the vibration analysis is shown in the Table 1.

Table 1. Details of Polyacetal ball bearing.

Bearing Type	**POM 6204**
Inner diameter (d), mm	20
Outer diameter (D), mm	47
Pitch diameter (P_d), mm	31.5
Number of Balls (N_b)	8
Ball diameter (B_d), mm	6
Width of the ring (W), mm	14
Contact angle (β)	0

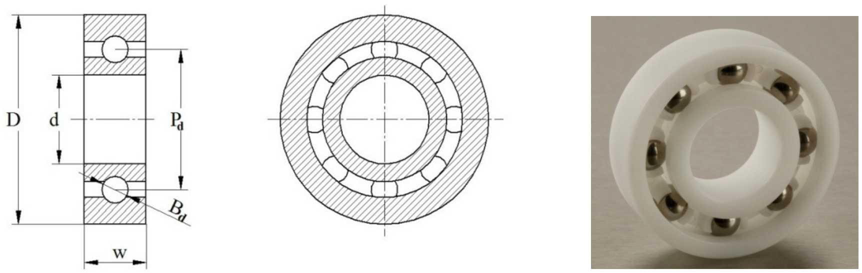

Figure 2. Details of Polyacetal ball bearing for Vibration Analysis.

3.3. Experimentation

Experiments were carried on four sets of Polyacetal ball bearings, a new bearing and three defective bearings, i.e., inner race defect, outer race defect and ball defect. The defects were artificially produced by a drill tool, one on the inner race, one on the outer race and the other on the rolling ball. Initially a new Polyacetal ball bearing was fixed in the bearing test rig and vibration signals were captured using eight-channel FFT analyzer (LMS SCADAS Mobile SCM01). Then the new bearing is replaced with the three defective bearings for capturing the vibration signals. Recording of signals were observed for two running conditions for each bearing. The central radial load on the ball bearing was set to 30N and 60N and motor was made to run at a constant speed of 1000 rpm.

4. RESULTS AND DISCUSSIONS

The vibration analysis or condition monitoring is based on the principle that all systems produce vibration. When a bearing is running properly, the vibrations generated are very small and generally constant. But, due to some of the dynamic processes that act in the machine, defects develop causing the changes in the vibration spectrum.

Firstly, Vibration signals collected in the form of time domain are converted into frequency domain by processing Fast Fourier Transform (FFT) on each of the four bearings. The RMS values and Kurtosis values computed from the frequency domain signals and amplitude of vibration at predominant frequencies are considered for the analysis.

Vibration signals of a new bearing and defective bearings for a radial load of 30N and 60N at 1000 rpm are shown in Figure 3 and 4. The fundamental frequency theoretically calculated for the inner race defect bearing from equation (1) is found to be 79.38 Hz. The experimental frequency spectrum of the vibration signals for the inner race defective bearing (f_{ir}) shows higher peaks at 80Hz and 160Hz compared to new bearing frequency spectrum peaks. The frequency spectrum of the vibration signals for the outer race defective bearing (f_{or}) shows peaks at 52Hz, 104Hz and 164Hz which are closely matches with the fault frequency of outer race defect from equation (2) is 53.97Hz. The frequency spectrum of the vibration signals for the bearing with ball defect (f_b) shows peaks at 44Hz, 86Hz, 126Hz and 170Hz which also closely matches with the fault frequency of ball defect bearing calculated theoretically as 42.17Hz.

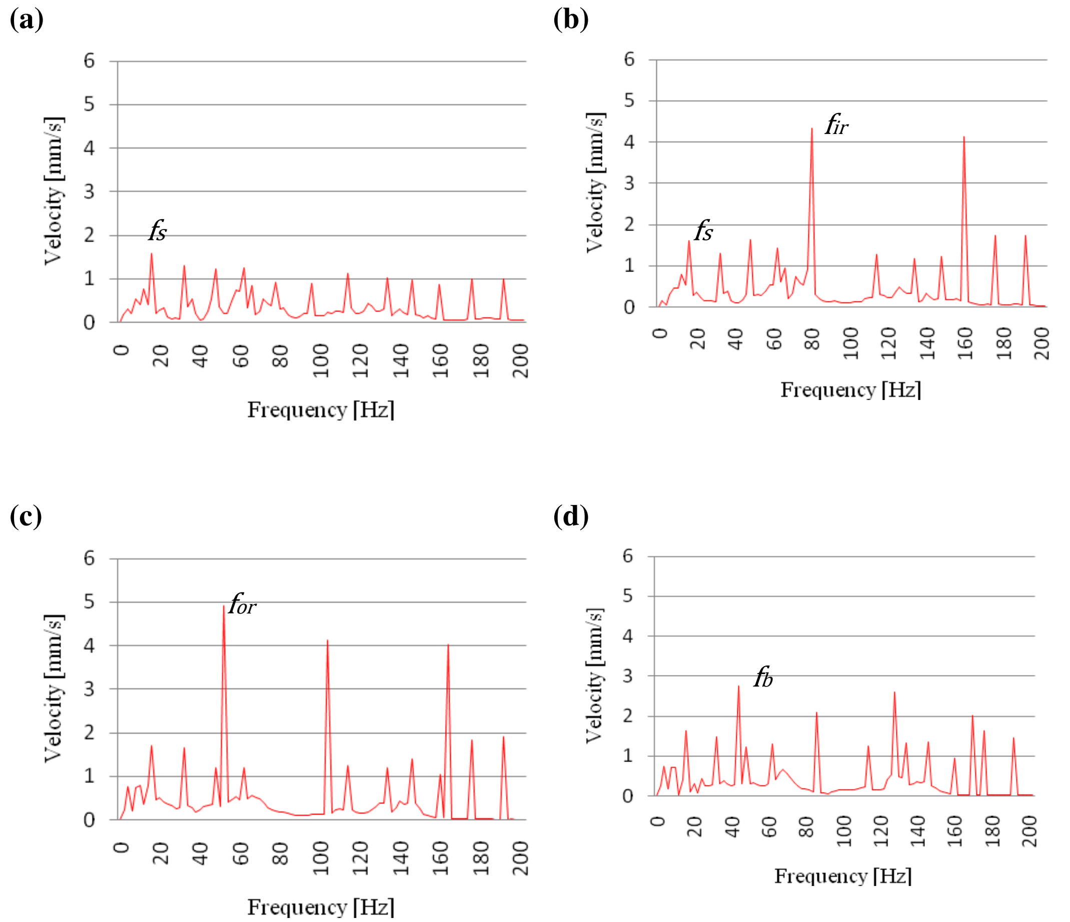

Figure 3. Vibration spectra of the Polyacetal ball bearing running at 1000 rpm with central radial load of 30N for: (a) New bearing (b) Inner race defect (c) Outer race defect and (d) Ball defect.

The RMS value for velocity response for new and defective bearings shows higher for higher radial loads. Also it is found RMS value is higher for outer race and inner race defect bearing compared to ball defect and new bearing as shown in Table 2.

Table 2. RMS values of Polyacetal ball bearing for different defects.

Condition of Bearing	**RMS Value [mm/s] at**	
	Load 30N	**Load 60N**
New Bearing	0.47	0.55
Inner race defect	0.79	0.85
Outer race defect	0.93	1.03
Ball defect	0.69	0.72

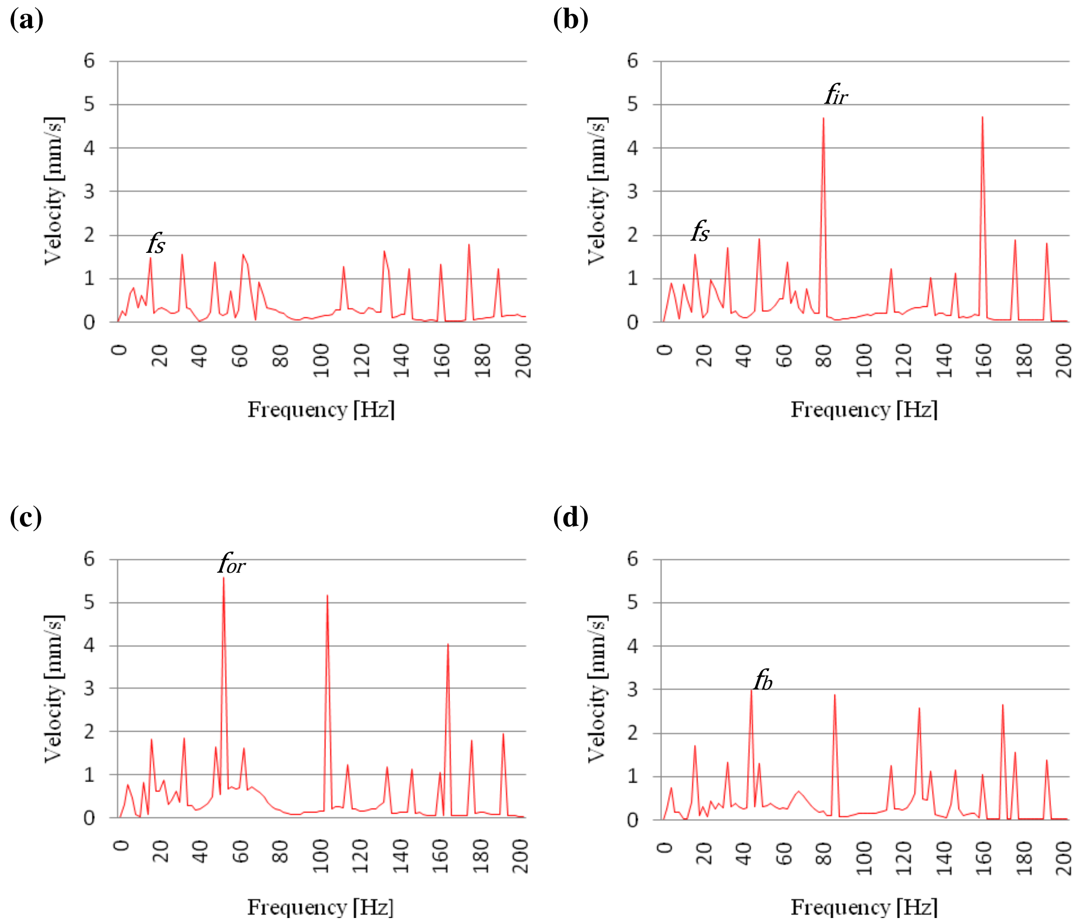

Figure 4. Vibration spectra of the Polyacetal ball bearing running at 1000 rpm with central radial load of 60N for: (a) New bearing (b) Inner race defect (c) Outer race defect and (d) Ball defect.

From Figure 5 the value of kurtosis for new bearing falls below 3 which indicate the fault free state of the bearing. For defects on the inner race, outer race and ball lies between 5 and 20. This is the clear indication of the defects in the bearing.

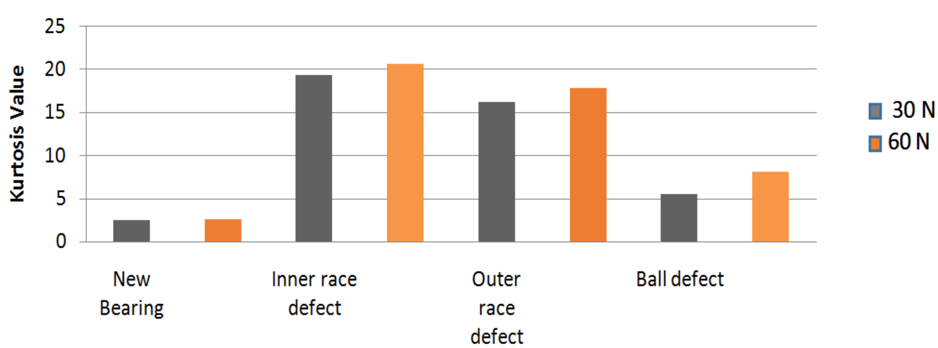

Figure 5. Kurtosis values for different bearings running at central load of 30N and 60N.

5. CONCLUSIONS

The vibration response of new and defect Polyacetal deep groove ball bearing is compared. The Fast Fourier Transform, RMS and Kurtosis are performed on each of the four bearings. From the vibration data, the amplitude of vibration spectra is relatively small for new bearing and defect ball bearing cases, where as vibration spectra is comparatively larger in both the cases of load i.e., 30N and 60N for defects on inner ring and outer ring. Also from Figure 3 and 4, the values computed from the frequency domain signals and amplitude of vibrations for new and defect bearings shows the location of the fault and severity of the defect.

The RMS value shows that as the load increases, the magnitude of vibration response also increases. Additionally, the Kurtosis value for new bearing is lies below 3 which is a clear indication that no defects in the bearing, for ball defect the value lies between 5 and 7, it shows the moderate defect in the bearing, where as for inner and outer race defects the kurtosis value exceeds 10, which shows larger indication of damage on inner and outer race ways. Hence kurtosis value shows the state of the bearing.

REFERENCES

[1] Purwo Kadarno & Zahari Taha, Tatacipta Dirgantara, Kimiyuki Mitsui, (2008) “Vibration Analysis of Defected Ball Bearing using Finite Element Model Simulation”, Proceedings of the 9th Asia Pasific Industrial Engineering & Management Systems Conference, Indonesia, Vol. 1, pp2832-2840.

[2] Andy C.C. Tan, Katie L, McNickle and Danieal L. Timms, (2003) “A practical approach to learning vibration condition monitoring”. Journal of World Transactions on Engineering and Technology education, Vol.2, No.2, pp 217-220.

[3] Zeki Kiral, Hira Karagulle, (2003) “Simulation and analysis of vibration signals generated by rolling element bearing with defects”. Journal of Tribology International, 36, pp. 667-678.

[4] P. N. Botsaris, D. E. Koulouritis, (2007) “A preliminary estimation of analysis methods of vibration signals at fault diagnosis in ball bearing”. Proceedings of the 4th International Conference on NDT, Chania, Crete-Greece, Vol.1, pp 1-6.

[5] N. Tandon and A. Choudhury, (1999) “A review of vibration and acoustic measurement methods for the detection of defects in rolling element bearings”, Tribology International, Vol. 32, pp469–80.

[6] Attel Manjunath, D.V.Girish, (2010) “Characterization of short carbon fiber reinforced Polyacetal”, Proc. of International conference on Advanced Materials, Manufacturing, Management and Thermal Sciences. Tumkur, Karnataka, India, Vol.1, pp79-85.

[7] Sadettin Orahan, Nizami Akturk, Veli celik, (2006) “Vibration monitoring for defect dignosis of rolling element bearings as a predictive maintenance tool: Comprehensive case studies”, Journal of Non Destructive Testing & Engineering International. Vol.39, pp 293-298.

[8] M. Amarnath, R Shrinidhi, A. Ramachnadra and S.B. Kandagal, (2004) “Prediction of defects in antifriction bearings using vibration signal analysis”, Journal of IEI, Vol. 85, pp 88-92.

[9] R. K. Purohit and K. Purohit, (2006) “Dynamic analysis of ball bearings with effect of preload and number of balls”, International Journal of Applied Mechanics and Engineering, Vol. 11, No. 1, pp 77-91.

[10] H. Mohamadi Monavar, H. Ahmadi and S.S. Mohtasebi, (2008) “Prediction of defects in roller bearings using vibration signal analysis”, World Applied Science Journal. Vol.4(1). pp 150-154.

[11] Eric Y.Kim, Andy C.C.Tan, Bo-suk Yang and Vladis Kosse, (2007) “Experimental study on condition monitoring of low speed bearings: Time domain analysis”, 5th Australasian Congress on Applied Mechanics,Brisbane, Australia. pp 1-7.

Authors

Mr. Attel Manjunath received B.E degree in Mechanical Engineering from Gulbarga University, Karnataka, India in 2000. M.Tech in Maintenance Engineering from Visvesvaraya Technological University, Belgaum, India in 2004. Currently working with Acharya Institute of Technology, Bangalore as Assistant Professor in Mechanical Engineering Department. His interests are focused on Polymer Composites, Vibration and Acoustic Emission analysis

Dr. D V Girish received M.Tech degree in Design and Vibrations from IIT, Kanpur. Ph.D from IIT, Madras, India. He worked as HOD and Vice Principal in Malnad College of Engineering, Hassan, India. He worked as BOE, BOS in Visvesvaraya Technological University, Belgaum, India, His interests are focused on Composite Materials, Vibration and Acoustic Emission analysis.