IOP Conf. Series: Materials Science and Engineering **376** (2018) 012137 doi:10.1088/1757-899X/376/1/012137

Vibration Analysis of Polytetrafluoroethylene (PTFE) Deep Groove Ball Bearing

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Abstract. Polymer matrix composites have shown the ability to balance traditional polymer properties such as low weight and ease of processability with the strength and stiffness of reinforcing agents. Ball bearings are broadly used in industry from home appliances to aerospace industry. In order to prevent catastrophic damages, the proper functioning of these machine elements is extremely important. Therefore, it is important to examine the condition of the bearings and to know the severity of the defects prior to they cause severe catastrophic damages. Hence, the study of vibrations produced by these defects plays a significant role in quality check as well as for condition monitoring of the ball bearing/machine element. In this paper, an attempt is made to study the performance of polymer ball bearings made with Polytetrafluoroethylene (PTFE) material using vibration analysis on different components of the bearing structure using the time and frequency domain parameters. This paper investigates the relationship between vibration frequency, RMS, amplitude and kurtosis for different speeds on new and defective ball bearing conditions.

1. Introduction

As a sliding material, thermoplastics have long shown their suitability. For decades, they have been successfully used in sliding applications in precision engineering, electrical industries and in small electrical appliances, to name a few. Compared with metal bearings, the polymer bearing itself does not have high load carrying capacity, but they offer other advantages such as operation in dry running conditions and mixed friction, electrical insulation, chemical resistance, maintenance free operation, low noise and also have processing advantages.

Ball bearings are one of the important basic components used in machinery for various engineering applications. These bearings are used in most of the engineering applications such as electric motors, pumps, roller skates and bicycles. In general ball bearings are made of four different components, the ball element, an outer ring, an inner ring and the cage.

The cage element helps to separate the rolling elements on a regular basis and keep them in the inner and outer raceways to allow them to freely rotate on the raceways [1]. As ball bearings are most generally used components in machinery, these have received a great attention in the field of condition monitoring. Even a geometrically new bearing may also generate vibrations due to components running at heavy dynamic loads, high speeds and also due to existence of contact forces between the bearing components. Bearing defects may be classified as localized and distributed. The localized defects include spalls, pits and cracks caused by fatigue on rolling surfaces [4]. The distributed defects comprise misaligned races, waviness, surface roughness and off size rolling elements. The sources of defects may be due to either abrasive wear or manufacturing error. Hence, study of vibrations produced by these defects plays a significant role in quality examination as well as for condition monitoring of the ball bearing/machinery [5].

There are several techniques used in order to prevent bearing failure. Such as, wear debris analysis, oil analysis, vibration analysis and acoustic emission analysis. Among them vibration and acoustic emission analysis [8,11] are the most universally accepted techniques due to their ease of application. The time domain and frequency domain analysis are generally accepted for detecting defects in bearings. The frequency domain analysis is more useful as it identifies the exact nature of fault in the bearings. These frequencies of the ball bearing depend on the bearing characteristics and are calculated from the relations shown below.

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

At times the fault frequencies are not noticeable by Fast Fourier Transform spectrum, since the signals produced by the faults are covered by noise. In order to overcome this problem, many researchers have implemented signal processing methods. There are numerous techniques developed to detect local defects in bearing based on vibration signal processing [10]. Hence it is an important tool for condition monitoring through non-destructive testing.

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 Carbon fiber reinforced Polytetrafluoroethylene (CFRPTFE) has a highly crystalline structure with transition into an amorfic one at a temperature of 330°C. By virtue of its molecular structure, it has so called “easy slippage planes”, what results with a very small coefficient of friction when sliding against steel (as low as 0.04) [2,6,9,12]. Carbon fiber reinforced Polytetrafluoroethylene 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 wear resistance, fatigue endurance, creep resistance and solvent resistance under demanding service conditions. Also, it is a lubricious, strong and has good dimensional stability. The details of the Carbon fiber reinforced Polytetrafluoroethylene (CFRPTEF) ball bearing used in the vibration analysis is shown in the Table 1 and Figure 1.

Table 1. Details of Carbon fiber reinforced Polytetrafluoroethylene (CFRPTFE) ball bearing.

Bearing Type	CFRPTFE 6204
Outer diameter (D), mm	47
Inner diameter (d), mm	20
Width of the ring (W), mm	14
Pitch diameter (P_d), mm	31.5
Ball diameter (B_d), mm	7
Number of Balls (N_b)	7
Contact angle (β)	0

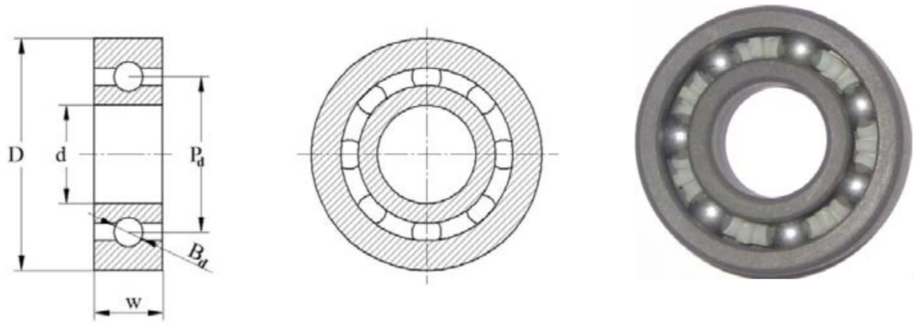

Figure 1. Details of Carbon fiber reinforced Polytetrafluoroethylene (CFRPTFE) ball bearing for Vibration Analysis

3. Bearing Test rig

The experimental bearing test rig is designed and fabricated to identify the presence of defects on a radially loaded Carbon fiber reinforced Polytetrafluoroethylene deep groove ball bearing by vibration and acoustic emission analysis technique is shown in Figure 2.

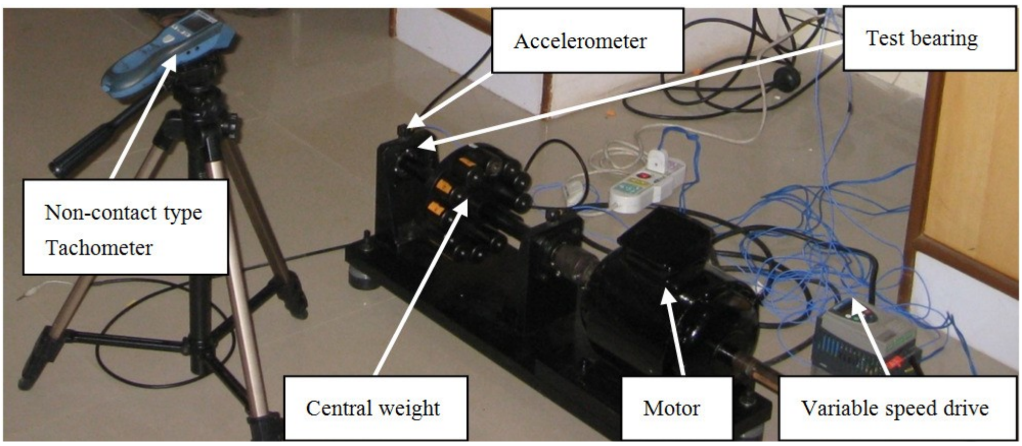

Figure 2. Experimental set up for capturing vibration signals

The bearing test setup consists of a circular shaft with a central rotor disc supported by two deep groove CFRPTFE 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 used for this study has a working speed of 10 to 2000 rpm, with central radial load of 200N capacity. The diameter of the shaft found to be 25mm considering the shaft subjected to both combined twisting and bending moment and a bushed pin type flexible coupling is used to connect two shafts. A provision is made to mount the accelerometer on top of the test bearing housing for capturing vibration signals from the test rig.

4. Experimentation

Experiments were carried on four sets of Carbon fiber reinforced Polytetrafluoroethylene (CFRPTEF) ball bearings, a new bearing and three defective bearings, i.e., ball defect, outer race defect and inner race defect shown in Figure 3. These defects were produced artificially by a drill tool, one on the rolling ball, one on the outer race and the other on the inner race. Initially vibration signals were captured for a new CFRPTEF ball bearing fixed on the bearing test rig by using PCB 356A16 tri-axial accelerometer mounted (magnetic type) on the bearing housing via eight-channel FFT analyzer (LMS

SCADAS Mobile SCM01). Subsequently the new bearing is replaced with the three faulty bearings for capturing the vibration signals. Recording of signals were observed for 30N radial load and five rotor speed running conditions at 200, 400, 600, 800 and 1000 rpm.

(a) **(b)** **(c)**

Figure 3. Photographic views of defects on CFRPTFE bearing (a) Inner race defect (b) Outer race defect (c) Ball defect

5. Results and Discussion

The vibration analysis is based on the principle that all systems produce vibration. When a bearing is running correctly, the vibrations produced are very small and usually constant. But, due to dynamic processes that act in the machine, faults develop causing the changes in the vibration spectrum. Firstly, Vibration signals recorded in the form of time signals are converted into frequency domain signals by processing Fast Fourier Transform (FFT) on four sets of bearings. The Kurtosis and RMS values computed from the frequency domain signals and amplitude of vibration at predominant frequencies are considered for the analysis.

Variation of frequency spectrum for new and defective bearings at 30N radial load and running at 200, 400, 600, 800 & 1000 rpm are shown in Figure 4 to Figure 8. From equation (1), the theoretically calculated frequencies are found to be 15.87Hz, 31.75Hz, 47.62Hz, 63.49Hz & 79.38Hz for CFRPTFE bearings with inner race defects running at 200, 400, 600, 800 & 1000 rpm respectively, the experimental frequency spectrum of the vibration signals for inner race defect show high peaks at 16Hz, 48Hz, 96Hz, 177Hz for bearing running at 200rpm, 32Hz, 64Hz, 95Hz, 127Hz, 159Hz for bearing running at 400rpm, 47Hz, 95Hz, 143Hz, 190Hz for bearing running at 600rpm, 64Hz, 127Hz, 191Hz for bearing running at 800rpm and 80Hz, 159Hz for bearing running at 1000rpm which are closely matches with the theoretical frequencies.

From equation (2), the theoretically calculated frequencies are found to be 10.79Hz, 21.59Hz, 32.38Hz, 43.17Hz & 53.97Hz for CFRPTFE bearings with outer race defects running at 200, 400, 600, 800 & 1000 rpm respectively, the experimental frequency spectrum of the vibration signals for outer race defect show high peaks at 11Hz, 55Hz, 76Hz, 117Hz for bearing running at 200rpm, 43Hz, 65Hz, 130Hz, 150Hz, 194Hz for bearing running at 400rpm, 65Hz, 98Hz, 128Hz, 194Hz for bearing running at 600rpm, 43Hz, 86Hz, 129Hz, 172Hz for bearing running at 800rpm and 54Hz, 108Hz, 161Hz for bearing running at 1000rpm which are correctly matches with the theoretical frequencies.

From equation (3), the theoretically calculated frequencies are found to be 8.43Hz, 16.87Hz, 25.30Hz, 33.73Hz & 42.16Hz for CFRPTFE bearings with ball defect running at 200, 400, 600, 800 & 1000 rpm respectively, the experimental frequency spectrum of the vibration signals for ball defect show high peaks at 34Hz, 77Hz, 145Hz for bearing running at 200rpm, 33Hz, 50Hz, 84Hz, 135Hz, 169Hz for bearing running at 400rpm, 25Hz, 50Hz, 76Hz, 101Hz, 151Hz for bearing running at 600rpm, 34Hz, 68Hz, 101Hz, 135Hz, 165Hz for bearing running at 800rpm and 42Hz, 84Hz, 127Hz, 168Hz for bearing running at 1000rpm which also closely matches with the theoretical frequencies.

From equation (4), the theoretically calculated frequencies are found to be 1.35Hz, 2.7Hz, 4.05Hz, 5.4Hz & 6.75Hz for CFRPTFE bearings with no defect running at 200, 400, 600, 800 & 1000 rpm respectively, the experimental frequency spectrum of the vibration signals for new bearing show peaks at 43Hz, 89Hz, 144Hz for bearing running at 200rpm, 22Hz, 59Hz, 146Hz, 163Hz, for bearing running at 400rpm, 41Hz, 53Hz, 181Hz for bearing running at 600rpm, 26Hz, 51Hz, 191Hz, for bearings running at 800rpm and 36Hz, 106Hz, 148Hz, 176Hz for bearing running at 1000rpm which also closely matches with the theoretical frequencies.

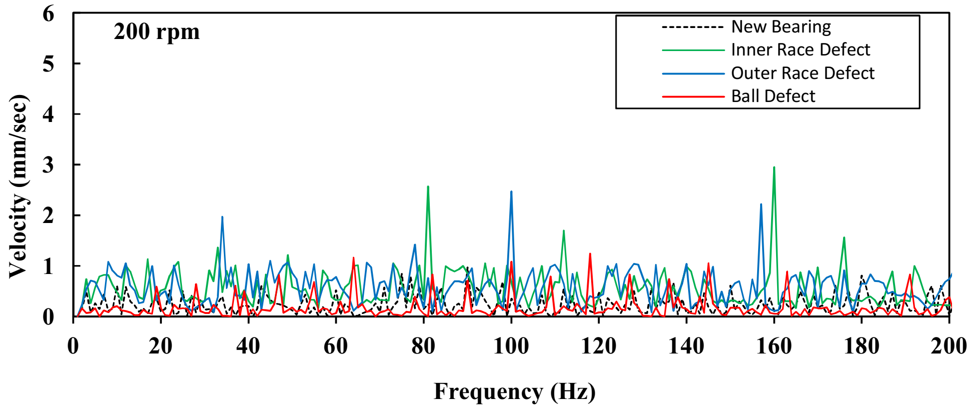

Figure 4. Variation of frequency spectra of CFRPTFE bearing running at 200 rpm under 30N radial load

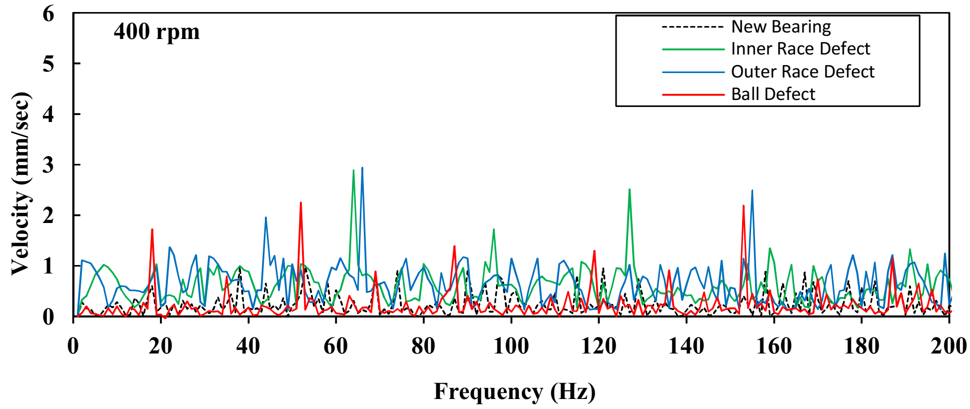

Figure 5. Variation of frequency spectra of CFRPTFE bearing running at 400 rpm under 30N radial load

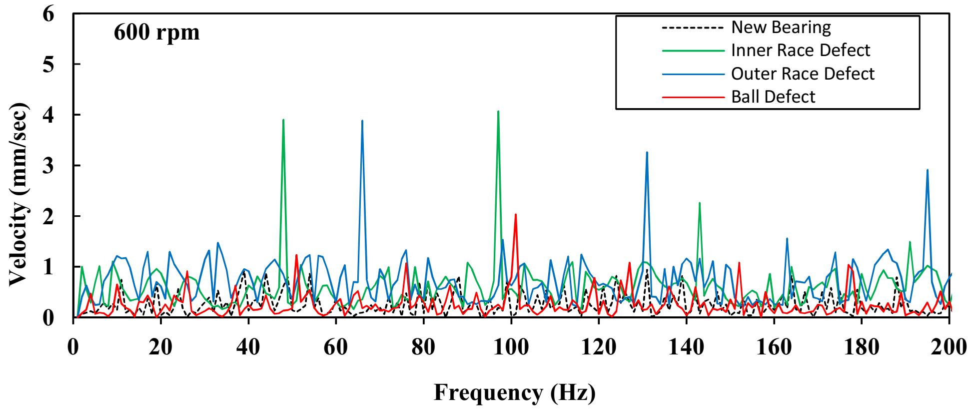

Figure 6. Variation of frequency spectra of CFRPTFE bearing running at 600 rpm under 30N radial load

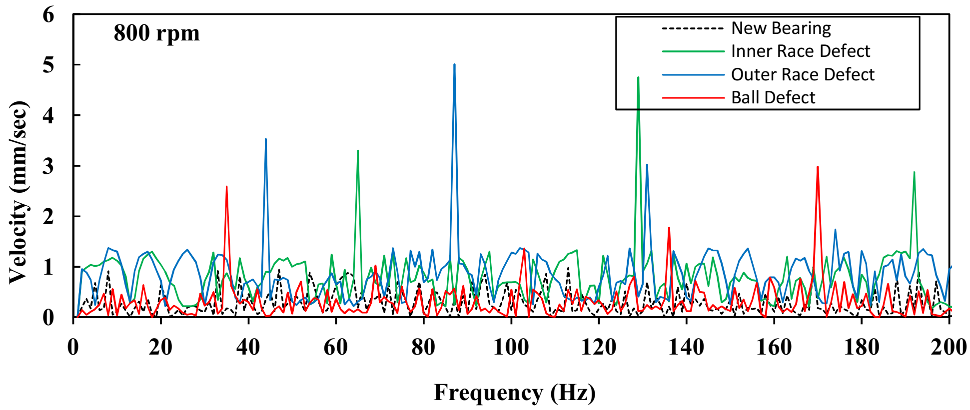

Figure 7. Variation of frequency spectra of CFRPTFE bearing running at 800 rpm under 30N radial load

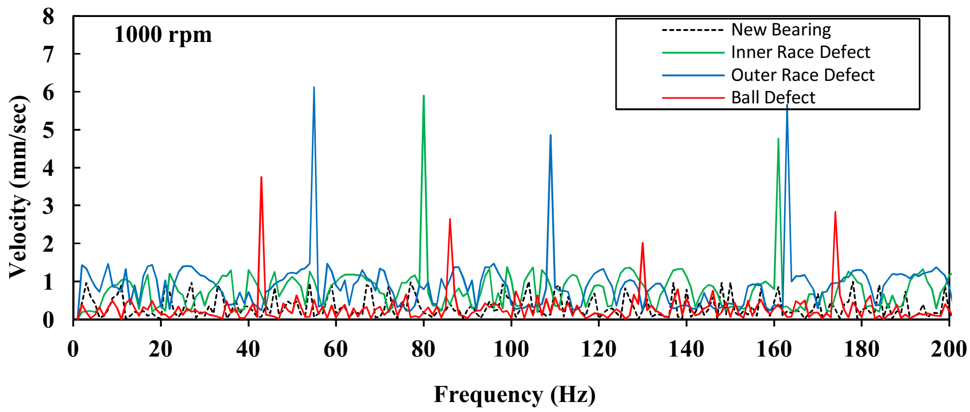

Figure 8. Variation of frequency spectra of CFRPTFE bearing running at 1000 rpm under 30N radial load

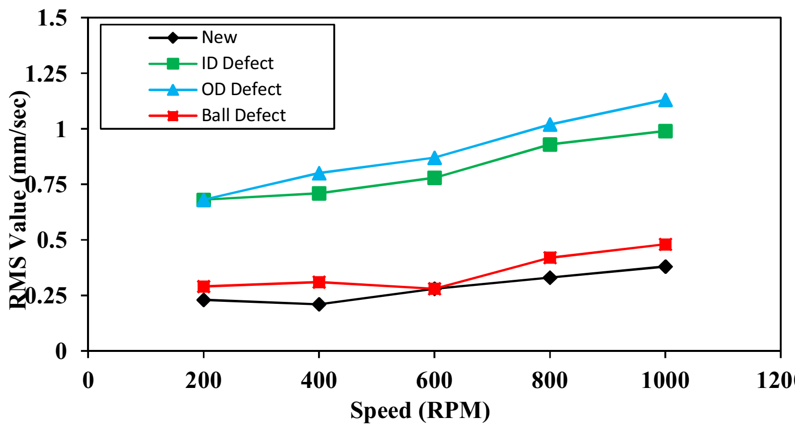

Figure 9. The RMS of vibration response for varying speeds under 30N radial load.

The RMS of vibration response for varying speeds under 30N radial load is shown in Figure 9. For new and defect bearings the RMS value of velocity response increases with increase in speed under 30N radial load. The RMS value is very high for inner and outer race defects when compared to the new bearing and ball defect bearings at 30N radial load.

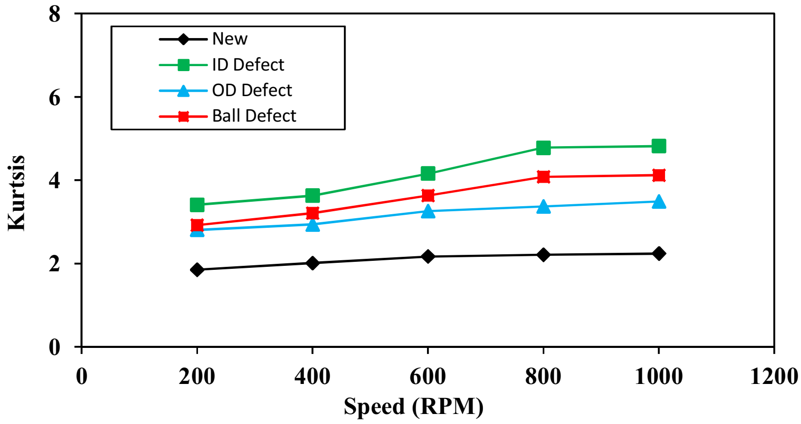

Figure 10. The kurtosis value of vibration response for varying speeds under 30N radial load.

Kurtosis value lies below 3 for new bearing, which indicates the defect free state of the bearing shown in Figure 10. However, this value clearly indicates state of defect for other cases with inner race, outer race and ball defects which falls between 3 and 5.

6. Conclusions

The vibration response of new and defect Carbon fiber reinforced Polytetrafluoroethylene (CFRPTEF) ball bearing is compared. The Fast Fourier Transform, Kurtosis and RMS are performed on each of the four bearings. From the vibration data, the amplitude of vibration spectrum is comparatively small for new bearing and ball defect bearing cases, while vibration spectrum is moderately larger for defects on outer race and inner race at 30N. Also from Figure 4 and 8, 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 reveals that as the speed increases, the vibration response magnitude also increased. In addition, the Kurtosis value for new bearing falls below 3 which is a clear indication that no defects in the bearing, for inner race, outer race and ball defects the value falls between 3 and 5, which indicates the moderate defect on the bearings. Hence kurtosis value shows the state of the bearing.

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