Run time to failure analysis of ball bearings under varying loads using vibration signature

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Abstract: **Bearings are the machine elements widely used in rotating machine parts and subjected to dynamic conditions, so are more prone to failure. Hence, their close monitoring is necessary to reduce the down time and catastrophic failure of machine. In this paper, run time to failure analysis for ball bearings has been done. An experimental setup with healthy 6205 (SKF) bearing is used and run at constant 3000 rpm and different loading conditions i.e. 300psi, 400psi & 500psi. Vibration signals are acquired using DAQ (Data acquisition Card) and accelerometer/transducer for analysis. FFT (frequency domain) and time response data of the acceleration & torque are analyzed to compare the vibration signature of the bearing under varying load conditions.**

Keywords: run time to failure, FFT, vibration signature

1. INTRODUCTION

Bearings are the critical components in rotating machines. The degradation of bearings over time is one of the most important reasons that cause a machine to breakdown. For example, bearing faults are the most frequent faults in electric motors (41%) according to an IEEE motor reliability study for large motors above 200 hp, followed by stator (37%) and rotor faults (10%) (Group, 1986). Hence their close monitoring is necessary by observing the degradation behavior with time under varying loading conditions. As a typical rolling-element bearing, ball bearing is the fundamental rotating part in mechanical system, and a lot of research has been conducted in bearing fault diagnosis(W.He, 2009) (Mohanty, 2007) (Antoni, 2011) (H.Qiu, 2006).Among various methods like visual inspection, performance monitoring, vibration monitoring, wear debris monitoring and temperature monitoring (Keith, 2002)for bearing health assessment, vibration-based techniques are the most widely used since it is easy to obtain vibration signals without interfering with machinery operation, and abundant information is contained in the vibration signals. Vibration data is acquired using an accelerometer and FTMS (friction torque measurement system) located near the component to be monitored. Common features extracted from the vibration signal for analysis of rolling element bearing are Peak value (Pv), RMS value (RMS), Crest factor (Crf) (Sreejith, 2008).In this paper, the run time to failure analysis of 6205 SKF ball bearing at constant rpm & varying load is done using vibration signals (time domain & frequency domain).

This paper is organised as follows. Section 2 presents the details of experimental setup. Section 3 gives the descriptions of results and finally conclusions from present work are drawn in section 4.

2. EXPERIMANTAL SETUP

The bearing run-to-failure tests were conducted using a custom built bearing prognostic test rig produced by Spectra Quest, Inc. The details of the test rig are displayed in Fig.1.This is connected to a computer where we can monitor the data online (vibration signals) and alsosave thedata for further processing. The speed of the stepper motor can be increased from the speed controller in range of 0-3500 rpm. For experiments the speed is kept constant at 3000 rpm. The Hydraulic system is capable of applying pressure in range of 0-2000 psi in radial direction. The piston diameter

is 2.5" hence 100psi corresponds to a force of 2.18KN. The test bearings used in the run to failure tests were deep groove ball bearings 6205-Z2C3 with the dimensions as mentioned in table 1.
When a bearing has localized fault, a transient force will be generated which in turn results in a short term impulse signal each time the rolling element contacts the defects. If the input speed is kept constant, the impacts will occur at regular intervals, the frequency of the occurrence of the impacts will be the fault characteristic frequency. These defect frequencies are related to bearing geometry and shaft speed. The following bearing defect frequencies in hertz were calculated for the test bearing (Table 2): Ball pass frequency outer race (BPFO); Ball pass frequency inner race (BPFI); Ball spin frequency (BSF); and Fundamental train frequency (FTF).

$$BPFI = \frac{N_b}{2} * \left\{1 + \frac{B_d}{P_d} * \cos\theta\right\} * \frac{RPM}{60}$$

$$BPFO = \frac{N_b}{2} * \left\{1 - \frac{B_d}{P_d} * \cos\theta\right\} * \frac{RPM}{60}$$

$$FTF = \frac{1}{2} * \left\{1 - \frac{B_d}{P_d} * \cos\theta\right\} * \frac{RPM}{60}$$

$$BSF = \frac{P_d}{2 * B_d} * \left\{1 - \left(\frac{B_d}{P_d}\right) * (\cos\theta)^2\right\} * \frac{RPM}{60}$$

Where
Nb=Number of balls or rollers
Bd=Ball or Roller diameter
Pd =Bearing Pitch Diameter
Θ = Contact angle

FAULT FREQUENCY	VALUE (Hz)
Ball pass frequency inner race	270.75
Ball pass frequency outer race	179.25
Ball spin frequency	117.9
Fundamental train frequency	19.9

Table 2: Numerical values of Fault frequencies

Outer diameter (O.D.)	52 mm
Inner diameter (I.D.)	25 mm
Pitch circle diameter (P.C.D.)	39 mm
Ball diameter	7.93 mm
Width	15 mm
# of balls	9 nos

Table 1: Test bearing dimensions

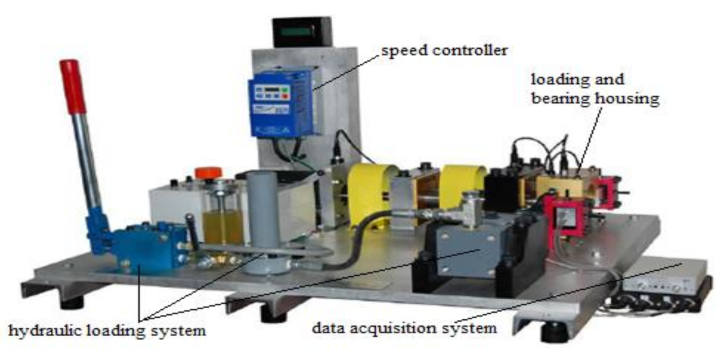


Fig 1 Bearing Prognostic Simulator (BPS)

3. RESULTS AND DISCUSSION

Figures 2(a, b, c), 3(a, b, c) & 4(a, b, c) are graphs of rms, peak & crest factor for bearing under different loads. These show a sudden increase in the amplitude at the end but no significant information regarding location of defect.

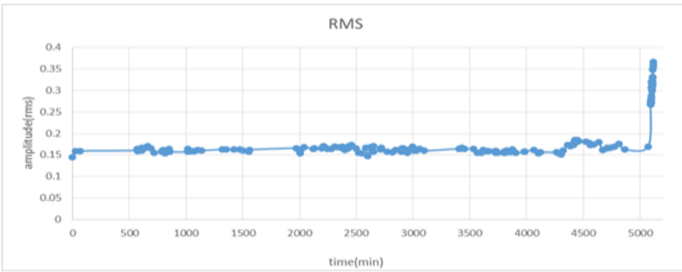


Fig 2(a) rms v/s time graph at 3000 rpm & 300 psi load

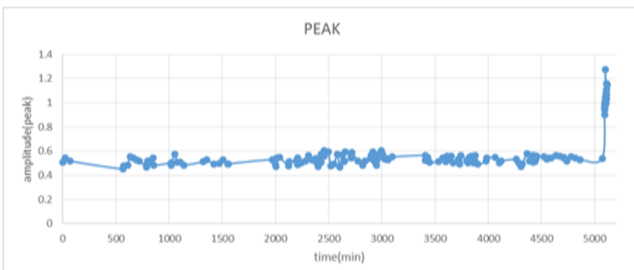
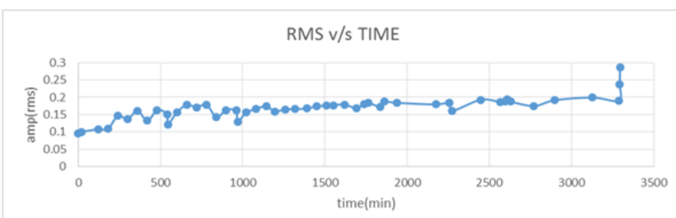


Fig 3(a) peak v/s time graph at 3000 rpm & 300 psi load



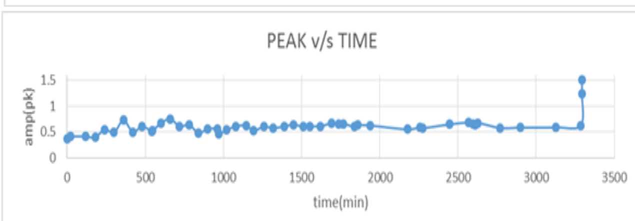
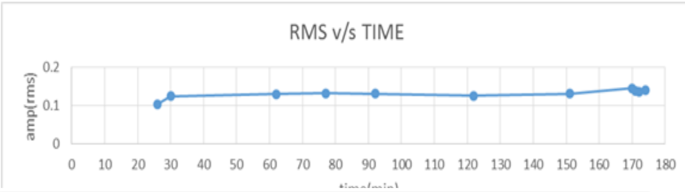


Fig 2(b) rms v/s time graph at 3000 rpm & 400 psi load

Fig 3(b) peak v/s time graph at 3000 rpm & 400 psi load



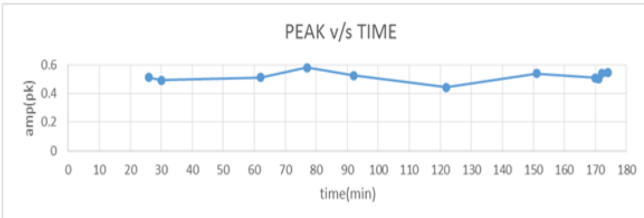
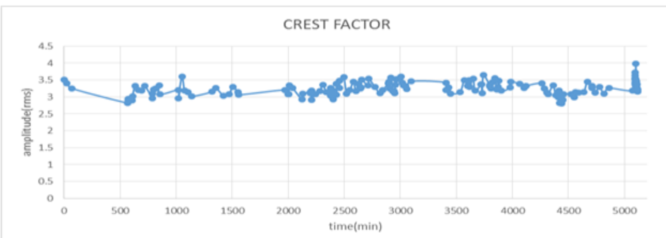


Fig 2(c) rms v/s time graph at 3000 rpm & 500 psi load

Fig 3(c) peak v/s time graph at 3000 rpm & 500 psi load



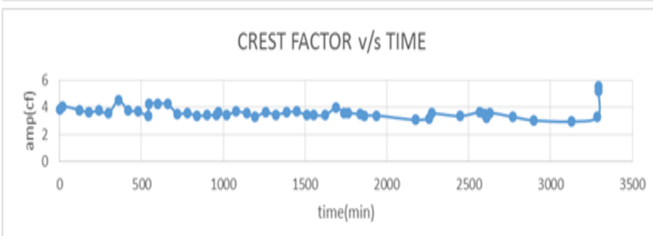


Fig 4(a) crest factor v/s time graph at 3000 rpm & 300 psi load

Fig 4(a) crest factor v/s time graph at 3000 rpm & 400 psi load

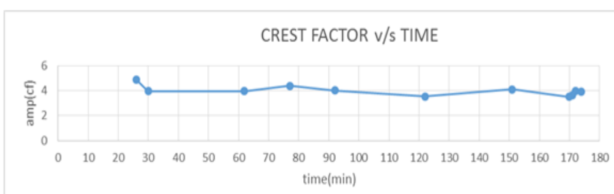


Fig 4(a) crest factor v/s time graph at 3000 rpm & 500 psi load

Figures 5, 6, 7are the vibration signals in frequency domain (FFT) picked up by Accelerometer

Fig 5 (a) frequency v/s time (FFT) graph at 3000rpm & 300 psi load (at start)

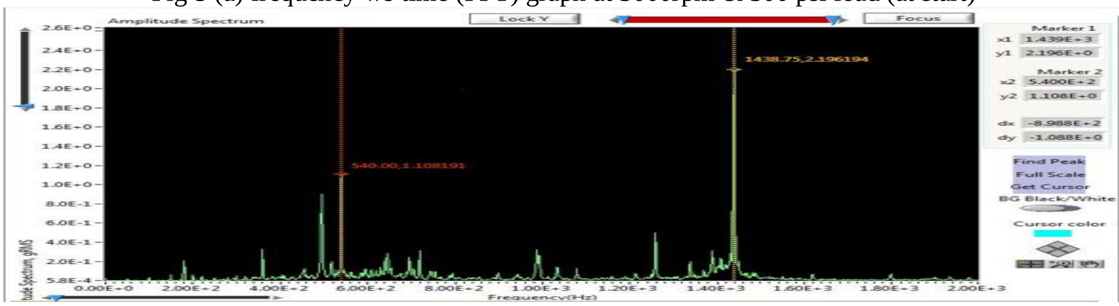


Fig 5 (b)frequency v/s time (FFT) graph at 3000rpm & 300 psi load (before failure)

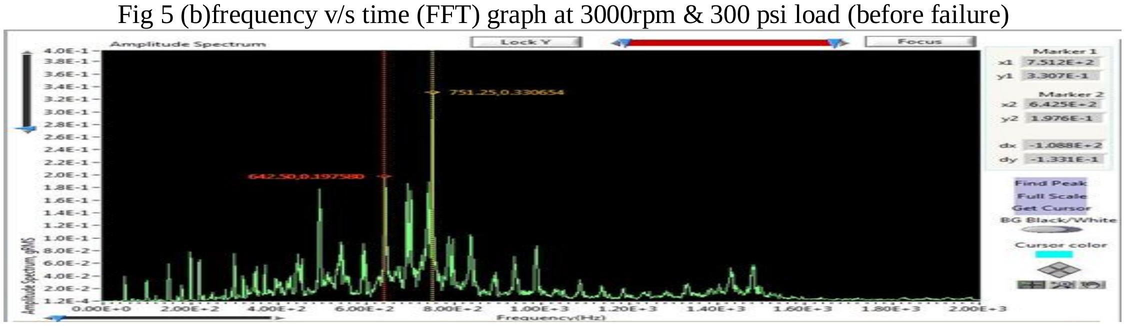


Fig 6(a) frequency v/s time (FFT) graph at 3000rpm & 400 psi load (at start)

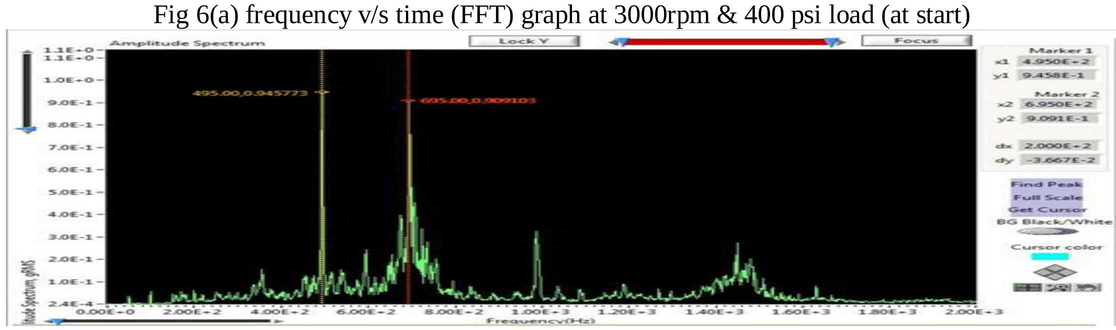


Fig 6(b) frequency v/s time (FFT) graph at 3000rpm & 400 psi load (before failure)

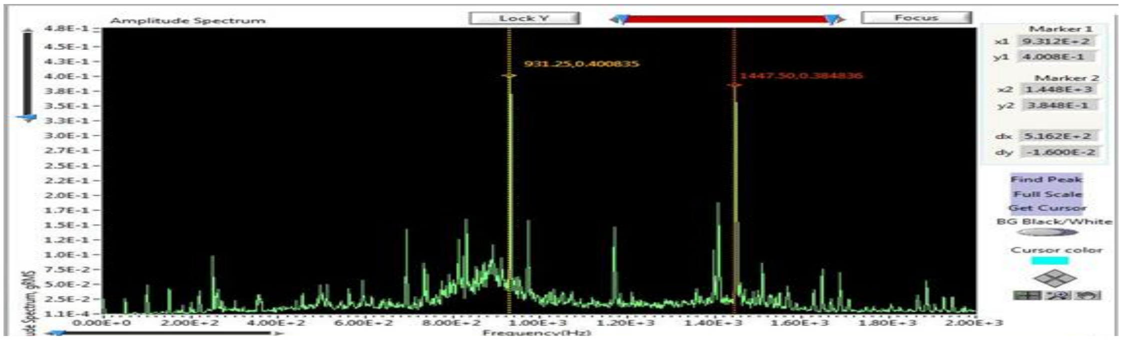


Fig 7(a) frequency v/s time (FFT) graph at 3000rpm & 500 psi load (at start)

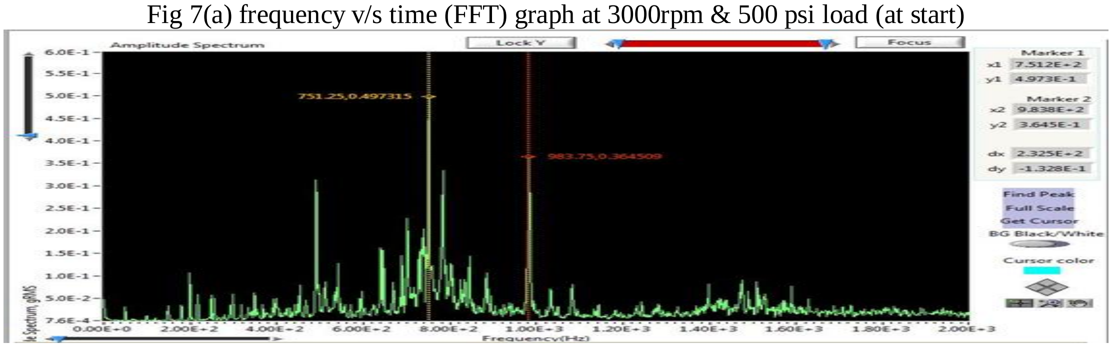


Fig 7(b) frequency v/s time (FFT) graph at 3000rpm & 500 psi load (before failure)

Figures 8, 9, 10are the signals in frequency domain (FFT) picked by Friction Torque measurement system (FTMS)

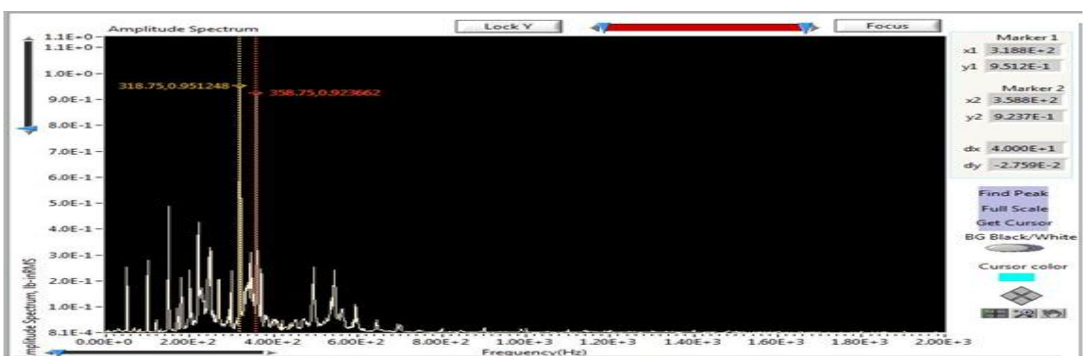


Fig 8 (a) frequency v/s time (FFT) graph at 3000rpm & 300 psi load (at start)

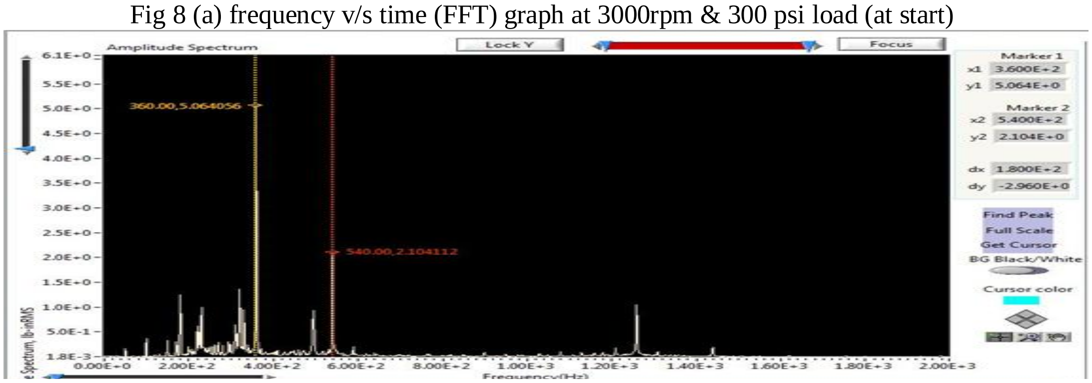


Fig 8 (b) frequency v/s time (FFT) graph at 3000rpm & 300 psi load (before failure)

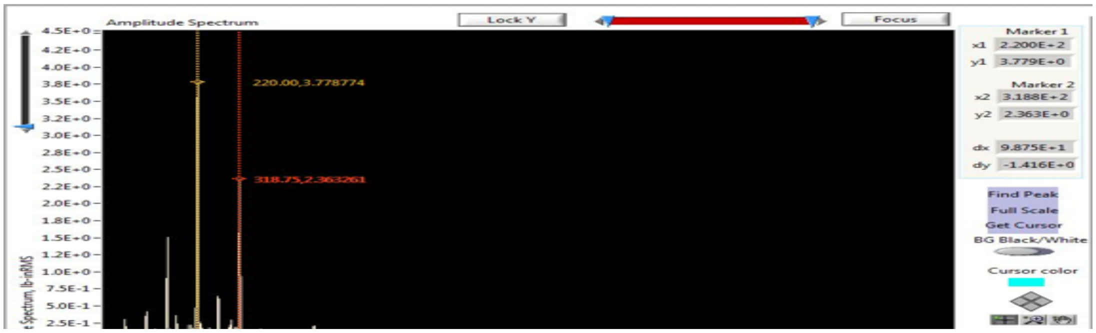


Fig 9 (a) frequency v/s time (FFT) graph at 3000rpm & 400 psi load (at start)

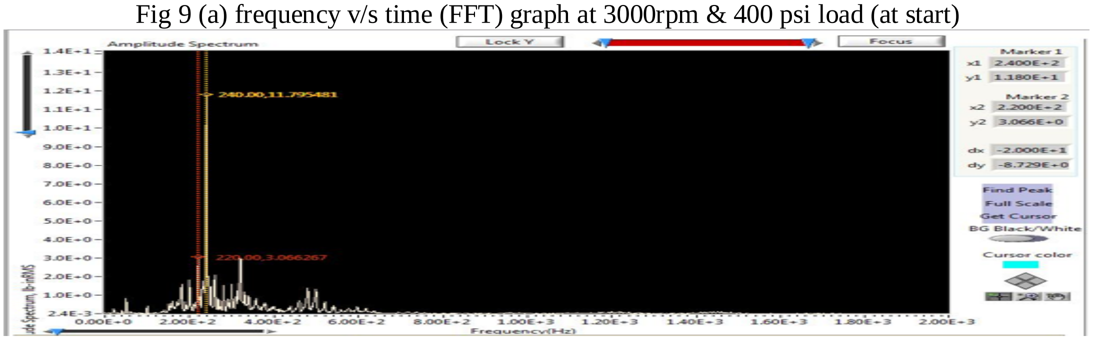


Fig 9 (b) frequency v/s time (FFT) graph at 3000rpm & 400 psi load (before failure)

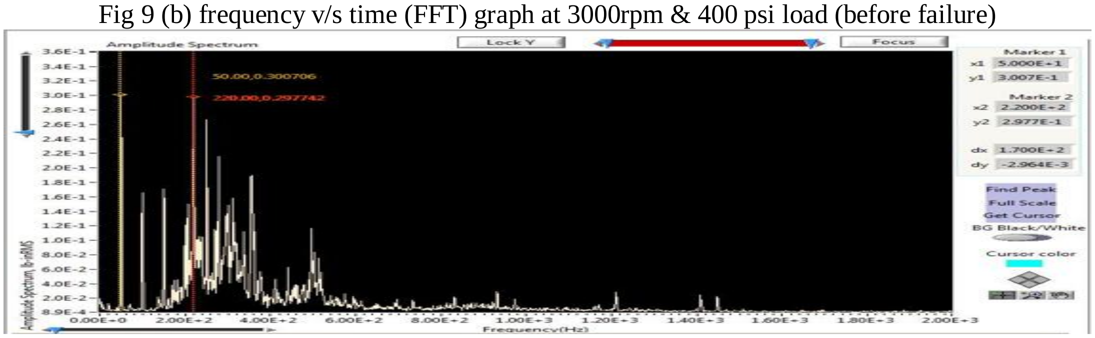


Fig 10 (a) frequency v/s time (FFT) graph at 3000rpm & 500 psi load (at start)

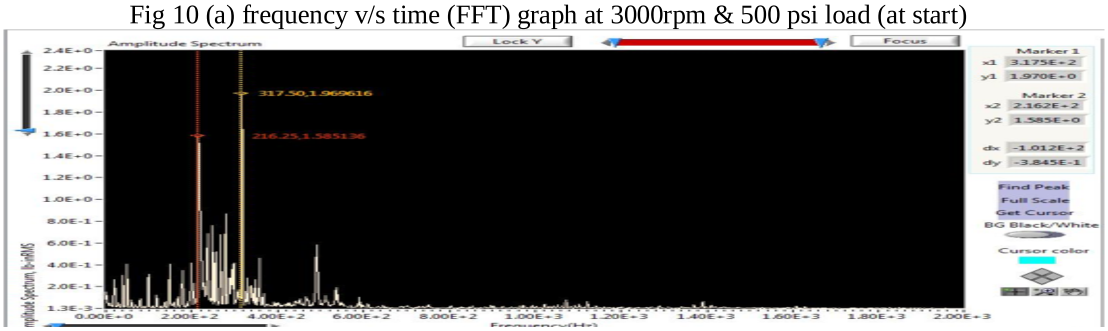


Fig 10 (b) frequency v/s time (FFT) graph at 3000rpm & 500 psi load (before failure)

Test bearing	**300 psi load**	**400 psi load**	**500 psi load**
Peak frequency before failure (accelerometer data)	1438.75 Hz	495 Hz	751.25 Hz
	8xBPFO	4xBSF	
Peak frequency before failure (FTMS data)	360 Hz	240 Hz	317.5 Hz
	2xBPFO	2xBSF	
Result	outer race fault	ball fault	burning

Table 3: Peak frequencies before failure

The peak frequencies before failure are multiples of bearing fault frequencies as in Table 3 which is consistent with the defects observed in the test bearing after run time to failure as shown in fig 11 (a, b, c)

Figures 11a, b and c show the defects observed after run time to failure of the test bearing under different loads.



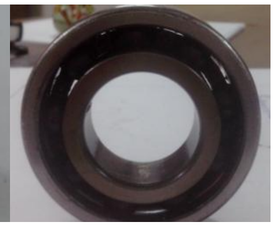


Fig 11(a) Defect at 300 psi (O R fault) Fig 11(b) Defect at 400 psi (ball fault) Fig 11(c) Defect at 500 psi (burning)

4. CONCLUSIONS

The features extracted from time domain data like rms, peak & crest factor don't give us the location of the defect. They only show the degradation behavior of bearing and anomalies, also these features take time for evaluation. The FFT signals on the other hand provide us information of the location of fault in the bearing through data acquired online.

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