Vibration based fault Diagnosis of Rolling Element Bearing

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ABSTRACT
This paper is basically a fault detection of rolling element bearing by diagnosis of rolling element bearing for this we made a mechanical machine called machine fault simulator (MFS). As we know bearing failure is the main failure factor of Rotary machine. Generally for this failure machine will stop to avoid catastrophic damages. But, if the machine stop due to the failure of bearing this results economics losses and increase manufacturing time. Therefore it is more important to monitor the defect of bearings and take necessary action to avoid catastrophic damages. The various techniques are used to analyze the progressive defects in bearing and gives early information about it. In this paper we are using frequency domain analysis for detecting and diagnosis the type of defect in the bearing.

Keywords: GYE25KRRB bearing, Defects, Prediction, Vibration Signal, Signature Analysis.

Introduction:
Condition monitoring of bearings in rotating machinery using vibration analysis offers the advantages of reducing down time and improving efficiency. The machine and bearing need not be stopped for diagnosis. Also geometrically perfect bearings may create vibration because of contact forces. Classification of bearing defects may be as distributed and localized. The defects which are localized are cracks, pits and spalls due to fatigue on rolling surfaces[1]. And the distributed defects are surface roughness, waviness, and misalignment and off size rolling elements. This is due to manufacturing error and abrasive action result wearing. Hence, Vibration information generated by these above mention defects is vital for proper inspection and for condition monitoring[2]. These failures result in serious problems where the machines are running at high speeds. To avoid any

Catastrophic damage caused by a these failure, the following bearing condition monitoring techniques are used these are, temperature monitoring, wear debris analysis, oil analysis, vibration analysis and acoustic emission analysis.

Vibration signature analysis is the key technique, which gives the prediction as well as diagnose of different defects in bearings. Vibration signature analysis gives prior information about impending malfunctions and forms the basic reference signature or base line signature for future monitoring purpose. Defective rolling elements in bearings causes vibration frequencies at rotational speed of each bearing element and rotational frequencies are depend on the motion of rolling elements, cage and races. Initiation and progression of flaws on antifriction bearing generate specific and predictable characteristic of vibration. Components flaws (inner race, outer race and rolling elements) generate a specific defect frequencies calculated from equation.

The time domain and frequency domain analyses are widely accepted and internationally recognized for detecting defects and their effect in bearings. The frequency domain spectrum is generally more acceptable because it recognized the exact nature of defect in the bearings.

$$BPFI = \frac{N_b}{2} f_s \left[1 + \frac{d}{D}\cos(a)\right] \quad (1)$$

$$BPFO = \frac{N_b}{2} f_s \left[1 - \frac{d}{D}\cos(a)\right] \quad (2)$$

$$BSF = \frac{D}{2d} f_s \left[1 - \left(\frac{d}{D}\right)^2 \cos^2(a)\right] \quad (3)$$

$$CFF = \frac{1}{2} f_s \left[1 + \left(\frac{d}{D}\right)\cos(a)\right] \quad (4)$$

Notation

a	Ball contact angle
BPFI	Inner race fault frequency.
BPFO	Outer race fault frequency
BSF	Ball spin frequency
c	Ball center
CFF	Cage fault frequency
d	Rolling element diameter
D	Bearing pitch diameter to ball center
fs	Shaft frequency
Nb	Number of balls

Experimental Setup and Data Acquisition

3.1 – Machine Fault Simulator Unit (MFS)

An experimental test rig built to predict defects in GYE25KRRB bearing is shown in fig 3.1. The test rig consists of a three shaft with gear on first and second shaft and two overhang pulleys on second shaft and third shaft, which is supported on the bearings. The Experimental setup for Vibration Based Fault Diagnosis of Rolling Element Bearings can be broadly classified into two categories:

- Fault Generator.
- Vibration Analyzers.

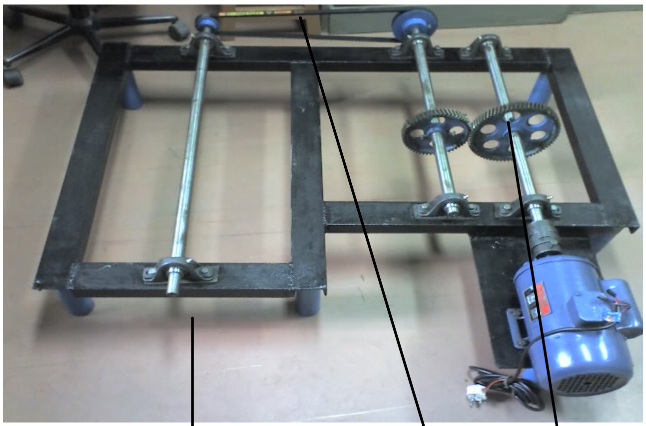
Fault Generator is the Machine Fault Simulator (MFS) unit. Machine Fault Simulator comprises of a shaft gear assembly driven by an AC Motor. Machine Fault Simulator comprises facilities to introduce various machine faults like misalignment, faulty bearings, damaged gear and faulty belt drive.

FIGURE: MACHINE FAULT SIMULATOR

TABLE 3.1: ROLLER BEARING DETAILS [GYE25KRRB]

S No	Parameter	Value
1	Number of roller	10
2	Outer diameter [mm]	52
3	Inner diameter [mm]	25
4	Pitch Diameter [mm]	39
5	Roller diameter [mm]	8

The details of the bearing used in the present are given in Table 3.1. FFT analyzer CSI 2400 Dynamic Vibration analyzer was used to monitor vibration signals from good and defective bearings.



Bearing

Gear

Belt Drive

FIGURE 3.1: VARIOUS POSSIBLE FAULT LOCATIONS IN MFS UNIT

3.2 - VIBRATION ANALYSERS:

The following hardware was used for vibration signal acquisition and processing. The signal acquired was further processed in signal analysis software. Experimental tests were carried out on these bearings. Initially new bearing (good bearing) was fixed in the test rig and signals were recorded using FFT analyzer. The good bearing was replaced by defective bearing and signals were recorded each one of the case separately under the same standard condition.

3.3 - HARDWARE:

- Portable Vibration Meter
- CSI 2400 Dynamic Vibration Analyzer.

Function Keys

Operation key

Alpha key

Numeric Key pad.

Figure: CSI 2400 DYNAMIC VIBRATION ANALYZER.

The model 2400 is a portable, battery operated, multi channel signal analyzer. The operational mode of the analyzer is controlled by application packages, which are downloaded into the analyzer and selected by the user. The model 2400 signal analyzer includes the standard application package “”FFT analysis” which allows the model 2400 to function as a digital oscilloscope and FFT spectrum analyzer.

With the additional of optional downloadable application packages, the model 2400 signal analyzer can also perform continuous machinery monitoring, transient data capture, balancing, acoustic analysis, structural analysis, and routine data collection.

3.5 - SOFTWARE:

- CSI Analysis Software.

The flexibility of the model 2400 to meet the needs of various applications is provided by the analyzer’s downloadable firmware capabilities. This ability to download application firmware that is written for specific tasks, coupled with the large memory and processing capacity of the analyzer provides the basis of the model 2400.

Rolling Bearing Element Component and Geometry

It can be used to detect bearing faults at a relatively early stage in the fault progression. Rolling element bearings generate characteristic vibration signatures in several ways. A typical ball bearing, shown in Figure, consists of an inner and outer race separated by the rolling elements, which are usually held in a cage. If a roller or a ball has a defect such as a pit, each revolution will result in a brief impact that is transmitted to the bearing housing. The fundamental frequency of these impacts is called the ball spin frequency (BSF). If the bearing inner race has a defect, then each ball will produce a shock as it passes giving rise to a fundamental vibration frequency called the ball-pass frequency, inner race (BPFI). Likewise a fault on the bearing outer race will produce a frequency at the ball-pass frequency, outer race (BPFO). The last frequency of interest is the frequency at which the bearing cage itself rotates. This frequency is called the cage fault frequency (CFF) or fundamental train frequency (FTF).

For the GYE25KRRB bearing, the outer race is fixed to the housing while the inner race rotates with rotating. This geometry has no effect on the ball spin, inner race and outer race fault frequencies but does change the calculations of the cage fault frequency.

This “Y” series extra wide inner ring setscrew bearing has increased shaft supported of HVAG and other industrial application. The bearings features super finished raceway, 10 balls and anti-blackout, nylon patch setscrew. They are factory pre-lubricated and are re-lubricatable, setscrew mounting feature is ideal for reversed loading condition.

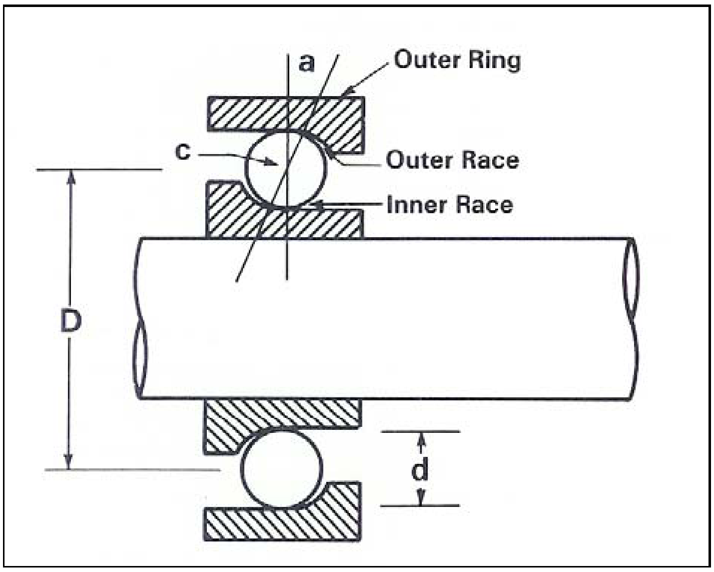


Fig: Wide Inner Ring Bearing With Setscrew Locking Gye25krrb

4.2 - NOMENCLATURE OF THE BEARING USED

Numbers:

Last three numbers indicate bore size —
First in inches, last two in sixteenths
015 15/16”
103 1-3/16”
203 2-3/16”
25 25mm (metric)
40 40mm (metric)

Prefixes:

Basic Series and Additional Features
C concentric collar
E metric bore
G relubricatable
1 standard series (200 series bearings)

L light Series
N heavy series (300 series bearings)
RA extended inner ring, one side only
SM standard series (open type bearings)
SMN heavy series (open type bearings)
GY, ER, YA setscrew locking device series
M medium duty setscrew locks series

RESULT AND DISCUSSION

The vibration signal of a good bearing and effective bearing as shown in the figure 1 and figure 2 respectively. In order to assess the clarity and effects in bearing the spectrum analysis is shown in the figure for bearing with Cage defect the details of the cage defect as shown in figure.

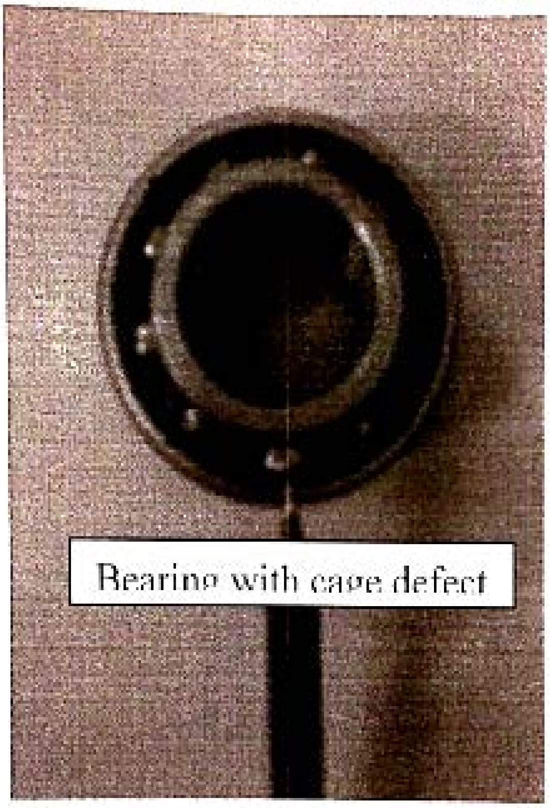


Figure 5.1: Bearing with Cage Defects

The magnitude spectrum at various harmonic frequencies for defective bearing is found to be quiet distinct in comparison to good bearing. The
frequency spectrum of the vibration signal from the keys defect bearing shows the peaks at fourth and eleventh multiple of fundamental frequency. The Fundamental frequency estimated for the cage from the equation (4) is found to be 31.89 Hz.

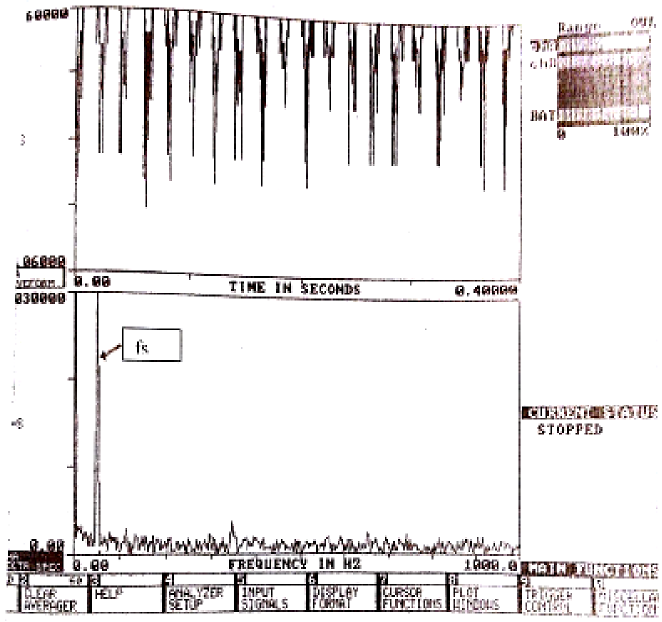


Fig 5.2: Vibration Signal of Good Bearing

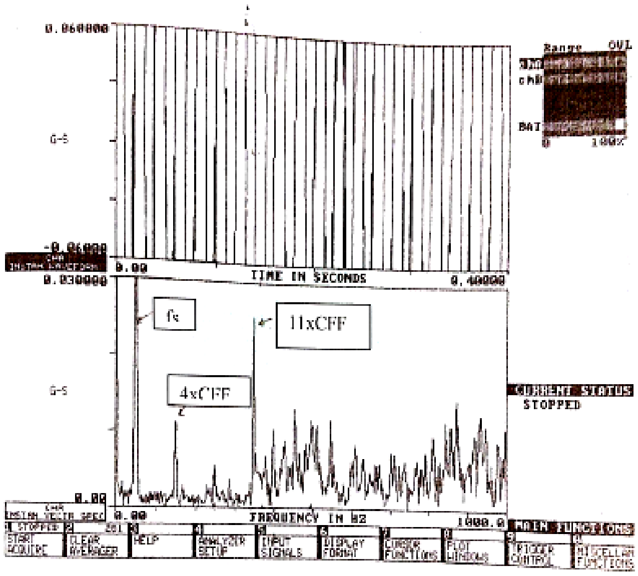


Fig 5.3: Vibration Signals for cage defect bearing

Table 5.1: Shaft Rotating Frequency and its Multiple Frequency

Multiple 1	Multiple 2	Multiple 3	Multiple 4	Multiple 5	Multiple 6	Multiple 7	Multiple 8	Multiple 9	Multiple 10
52.93 Hz	105.86 Hz	158.79 Hz	211.72 Hz	264.65 Hz	317.58 Hz	370.58 Hz	423.44 Hz	476.37 Hz	529.3 Hz
Multiple 11	Multiple 12	Multiple 13	Multiple 14	Multiple 15	Multiple 16	Multiple 17	Multiple 18	Multiple 19	Multiple 20
582.23 Hz	635.16 Hz	688.09 Hz	741.02 Hz	793.95 Hz	846.88 Hz	899.81 Hz	952.74 Hz	1005.67 Hz	1058.6 Hz

Table 5.2: Cage Defect Frequency and Its Multiple Frequencies

Multiple 1	Multiple 2	Multiple 3	Multiple 4	Multiple 5	Multiple 6	Multiple 7	Multiple 8	Multiple 9	Multiple 10
31.89 Hz	63.78 Hz	95.67 Hz	127.56 Hz	159.45 Hz	191.34 Hz	223.23 Hz	255.12 Hz	289.01 Hz	318.9 Hz
Multiple 11	Multiple 12	Multiple 13	Multiple 14	Multiple 15	Multiple 16	Multiple 17	Multiple 18	Multiple 19	Multiple 20
350.79 Hz	382.68 Hz	414.57 Hz	446.46 Hz	478.35 Hz	510.24 Hz	542.13 Hz	574.02 Hz	605.91 Hz	637.78 Hz

CONCLUSION AND FUTURE SCOPE

In the past, some methods have been developed by the authors for analyzing the accuracy of the results obtained with model based techniques aimed to identify faults in rotating machinery. The capabilities of these methods had been already shown with previous studies carried out using only machine responses simulated with mathematical models. This thesis has shown that the developed methods also can be successfully used for the analysis of experimental vibrations of real machines. These proposed diagnostic techniques have shown to be able to give useful information for identifying the most probable fault also when different sets of equivalent excitations which can induce fault symptoms very similar to the real one are considered.

Therefore, these methods are helpful to discriminate the actual fault from other wrong but probable faults. In addition to this, these methods have shown to be very useful in detecting lacks of accuracy in the model of the fully assembled machine as well as errors in the experimental vibration data.Time waveform and frequency spectrum provide useful information to analyze defects in antifriction bearings. Time waveform indicates severity of vibration in defective bearings. Frequency domain spectrum identifies amplitudes corresponding to defect frequencies and enables to predict presence of defects on inner race, outer race and rollers of antifriction bearings. The distinct and different behavior of vibration signals from bearings with inner race defect, outer race defect and roller defect helps in identifying the defects in roller bearings.

REFERENCES:

[1]. Y Li and C Zhang. 'Dynamic Prognostic Prediction of Defect Propagation on Rolling Element Bearing'. Journal of Vibration and Acoustics, Trans of ASME, vol 120, no 1, pp 214-220.

[2]. S Braun and B Danter. 'Analysis of Roller/Ball Bearing Vibration'. ASME Journal of Mechanical Design, vol 101, 1979, pp 118-125.]

[3]. Teruo Igarishi and Hiroyoshi. 'Studies on Vibration and Sound of Defective Rolling Bearings'. Bulletin JSME, vol 25, no 204, 1980, pp 994-1001.

[4]. A Chaudhary and N Tandon. 'A Theoretical Model to Predict Vibration Response of Rolling Bearings to Distributed Defects Under Radial Load'. Journal of Vibration and Acoustics, Transactions of ASME, vol 120, no 1, 1998, pp 214-220.

[5]. I J Taylor. 'Identification of Bearing Defects by Spectral Analysis'. Journal of Mechanical Design, Transaction of ASME, vol 120, 1980,

[6]. M Amaranth and Rshrinidhi. 'Prediction of Defects in Antifriction Bearing using Vibration Signal Analysis' IE(I) journal-MC.

[7]. M.P. NORTON, 1989, Fundamentals of Noise and Vibration Analysis for Engineers. London: Cambridge University Press. Chapter 8: Noise and Vibration as a Diagnostic Tool.

[8]. J. COURRECH, 1991, in Handbook of Acoustical Measurements and Noise Control (C.M. HARRIS, editor). New York: McGraw-Hill, Inc.. Chapter 39: Condition Monitoring of Machinery.

[9]. P.D. MCFADDEN, and J.D. SMITH, 1984, Journal of Sound and Vibration, 96(l), 69-82. Model for the Vibration Produced by a Single Point Defect in a Rolling Element Bearing.

[10]. P.D. MCFADDEN, and J.D. SMITH, 1985, Journal of sound and Vibration, 98(2), 263-273. The Vibration Produced by Multiple Point Defects in a Rolling Element Bearing.

[11]. Y.H. KIM, B.D. LIM, and W.S. CHEOUNG, 1991, Mechanical Systems and Signal Pz-ocessing, 5(6), 461-473. Fault Detection in a Ball Bearing System Using a Moving Window.

[12]. Varga, G., G. Lipovszky and Sólyomvári, K., Vibration Testing of Machines and Their Maintenance, Elsevier Publisher, Amsterdam, 1990.

[13].Y.T. Su, and S,J. LIN, 1992, Journal of sound and Vibration, 155(1), 75-84. On Initial Fault Detection on a Tapered Roller Bearing: Frequency Domain Analysis.

14. Y.L. YAN, and T. SHIMOGO, 1992, Mechanical Systems and Signal Processing, 6(2), 167-176. Application of the Impulse Index in Rolling-Element Bearing Fault Diagnosis.

15. C.K. MECHEFSKE, and J. MATHEW, 1992, Mechanical Systems and Signal Processing, 6(4), 297-307. Fault

Detection and Diagnosis in Low Speed Rolling Element Bearings Part I: The Use of Parametric Spectra.
[16]. W.Y. WANG, and M.J. HARRAP, 1996, Machine Vibration, 5, 34-44, Condition Monitoring of Ball Bearings Using Envelope Autocorrelation Technique.
[17]. B.G. QUINN, and J.M. FERNANDES,"A Fast Technique for the Estimation of Frequency," Biometrika, 78(3), 489-497, 1991.
[18]. S.M. KAY, Modern Spectral Estimation – Application and Theory, Prentice-Hall, 1988.
[19]. P.J. KOOTSOOKOSC, RC for Robust and Adaptive Systems Internal Report, A Review of the Frequency Estimation and Tracking Problem, July 1993.
[20]. Y.F. WANG and P.J. KOOTSOOKOSsu, bmitted to Mechanical Systems and Signal Processing, Modeling of Low Shaft Speed Bearing Faults for Condition Monitoring.

[21]. C.Q. LI, and C.J.D. PICKERING, 1992, Condition Monitoring and Diagnosis Technology, 2(3), 81-84. Robustness and Sensitivity of Non-Dimensional Amplitude Parameters for Diagnosis of Fatigue Spalling.

[22] Janko Slavic, Aleksandar Brkovic, Miha Boltezar, "Typical Bearing-Fault Rating Using Force Measurements-Application to Real Data", Journal of Vibration and Control, December 2011 vol. 17 no. 14 2164-2174.

[23] Mao Kunli, Wu Yunxin, "Fault Diagnosis of Rolling Element Bearing Based on Vibration Frequency Analysis", IEEE Third International Conference on Measuring Technology and Mechatronics Automation (ICMTMA) 2011, 337.

[24] Tandon, N., Choudhury A., "A Review of Vibration and Acoustic Measurement Methods for the Detection of Defects in Rolling Element Bearings", Tribology International, Vol. 32, 1999, pp.469–480.

[25] Jayaswal Pratesh, Wadhwani A. K., Mulchandani K.B. "Rolling Element Bearing Fault Detection via Vibration Signal Analysis". The Icfai University of Journal of Science & Technology, Vol. 4, No.2, 2008, pp. 7-20.

[26] M Amarnath, R Shrinidhi, A Ramachandra, S B Kandagal, "Prediction of Defects in Antifriction Bearings using vibration signal analysis.", IE(I) Journal-MC 2002.pp88-92.

[27] Aziz Kubilay Ovacikli," Condition Monitoring of Ball Bearings Using Vibration Analysis", Master's Thesis, Department of Computer Science, Electrical and Space Engineering, Lulea University of Technology 2010.

[28] Sorav Sharma, "Fault Identification in Roller Bearing using Vibration Signature Analysis", Master's Thesis, Department of Mechanical Engineering, Thapar University, Patiala, 2011.

[29] Shahab H. Ghafari, "A Fault Diagnosis System for Rotary Machinery Supported by Rolling Element Bearings", PhD Thesis, Department of Mechanical Engineering, University of Waterloo, Canada, 2007.

[30] M. Barakat, M. El Badaoui, F. Guillet, "Hard competitive growing neural network for the diagnosis of small bearing faults", Mechanical Systems and Signal Processing 37 (2013) 276–292.

[31] Abhinay V. Dube, L.S.Dhamande, P.G.Kulkarni, "Vibration Based Condition Assessment of Rolling element Bearings With Localized Defects", International Journal of Scientific & Technology Research Volume 2, Issue 4, April 2013.