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Bearing Fault Evaluation for Structural Health Monitoring, Fault Detection, Failure Prevention and Prognosis

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Abstract

In this work the two disciplines of condition based maintenance (CBM), structural health monitoring (SHM) and prognostics are described fault identification and estimation is an important and necessary step in condition based maintenance. In the present work, an experiment is carried out with a customized test setup where the seeded defects are introduced in the inner race and outer race of a radial ball bearing. The relationship between the acquired vibration data and their relation with the seeded defect is found in this paper. When experiment is performed on the test setup designed for Fault prediction, Analytical Wavelet Transform proved an effective tool for the analysis of vibration signal. In this work, AWT followed by the Power Spectral Density is implemented on vibration signals of a defective Radial Ball Bearing. After finding the fault, its location and its intensity Ball Bearing's remaining useful life is estimated.

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*Keywords:*Structural Health Monitoring; Vibration data Analysis; Analytical Wavelet Transform; Remaining Useful Life

1. Introduction

Structural health monitoring is a discipline that is closely related to condition monitoring, but has its origin in the inspection of structures. The methods are based on nondestructive testing (NDT) techniques. Due to the increased reliability and availability requirements of many assets, research has focused on developing continuous monitoring techniques, which evolved into the structural health monitoring discipline. A lot of scientific work is currently being

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done in this field, which also has its own scientific journals. The focus has been on the one hand on the development of new sensing techniques, and on the other hand on the development of advanced damage features and classifiers. Faults or damage can be detected by observing changes in the response of the system to the vibrations. Further, the first standard in this field was established only very recently (SAE, 2013), and in addition there is well-defined structure considering the five levels of SHM (Farrar & Worden, 2010). From levels 1 up to 5 more and more information on the damage in the structure is obtained:

- Level 1: damage detection,
- Level 2: damage localization,
- Level 3: damage characterization,
- Level 4: damage quantification,
- Level 5: prognostics.

Nomenclature

τ	Time Translation
s	Dilation(scale)
t	Time

1.1. Methodology

The major common faults of rolling bearings include corrosion in inner race, outer race and rolling elements, fatigue pitting and cage damage. In many cases indentation is also observed in inner and outer race due to high friction and lack of lubrication. Any faults of inner race, outer race and rolling elements will cause modulation phenomenon. When machine is in working condition and any fault is present in the rolling bearing it will generate a mechanical impulse and of higher amplitude as compared with the healthy bearing.

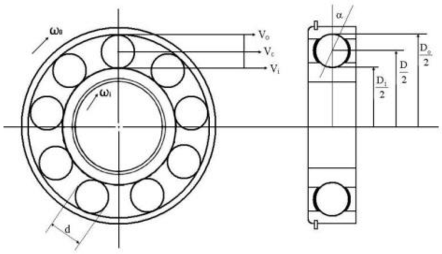

Figure 1 Radial Ball Bearing Geometry

For a particular bearing geometry, inner race, outer race and rolling element faults generate vibration spectra with unique frequency components. These frequencies, known as the defect frequencies, are functions of the running speed of the motor and the pitch diameter to ball diameter ratio of the bearing. Outer and inner race frequencies are also linear functions on the number of balls in the bearing. Given the geometry of the bearing in Fig. 1, for an angular contact ball bearing in which the inner race rotates and the outer race is stationary.

1.2. Damage Characterization

Four Stages in Bearing Failure Are Detected with Vibration Analysis

1. The first stage (normal operation) appears at ultrasonic frequencies from about 1,200K to 3,600K CPM (cycles per minute). At this point the frequencies are evaluated by Spike Energy and Shock pulse instruments which listen to these frequencies. Trending this information can tell a person if there is a change or not.
2. The second stage of bearing failure defects begin to ring bearing components natural frequencies, which are picked up with a spectrum analyzer in the middle of the spectrum, 3OK-12OK CPM.
3. In the third stage of failure, bearing defect frequencies and harmonics appear on the spectrum as bearing defect frequencies. At this time if you remove the bearing, you can see the defects in the rolling elements.
4. Stage four appears toward the end of bearing life.

1.3. Damage Quantification

Although the fundamental frequencies generated by rolling bearings are expressed by relatively simple formulas they cover a wide frequency range and can interact to give very complex signals. This is often further complicated by the presence on the equipment of other sources of mechanical, structural or electro-mechanical vibration. For a stationary outer ring and rotating inner ring, the fundamental frequencies are derived from the bearing geometry as follows:

$$f_{c/o} = \frac{f_r}{2} 2[1 - d / D \cos \alpha]$$

$$f_{c/i} = \frac{f_r}{2} 2[1 + d / D \cos \alpha]$$

$$f_{c/o} = \frac{f_r}{2} 2[1 - d / D \cos \alpha]$$

$$f_{b/o} = Z f_{c/o}$$

$$f_{b/i} = Z f_{c/i}$$

$$f_b = \frac{D}{2d} f_r [1 - (d / D \cos \alpha) * 2]$$

where

f_r : inner ring rotational frequency

$f_{c/o}$: fundamental train (cage) frequency relative to inner ring

$f_{c/i}$: fundamental train frequency relative to inner ring

$f_{b/o}$: ball pass frequency of outer ring

$f_{b/i}$: ball pass frequency of inner ring

f_b : rolling element spin frequency

D : pitch circle diameter

d : diameter of rolling element

Z : number of rolling element

α : contact angle

2. Experimental Setup

The experimental setup used in this experiment consists of 0.25horse power induction motor, having fixed 1440 RPM, an extended shaft is mounted on the main shaft of the motor so that the seeded fault bearings can be mounted on the shaft for taking vibration data. In this experimental setup ADXL 335 accelerometer is used to capture the vibration data from bearing housing, the faulty bearings are mounted on the shaft and they are covered by the bearing housing and accelerometer is mounted on the top of the housing. In order to collect data from the accelerometer it is coupled with ARDUINO UNO board (microcontroller) which is compatible to MATLAB 2013R where the data can be captured. The Figure 1 shows schematic diagram of the experimental setup and Figure 2 shows actual experimental setup.

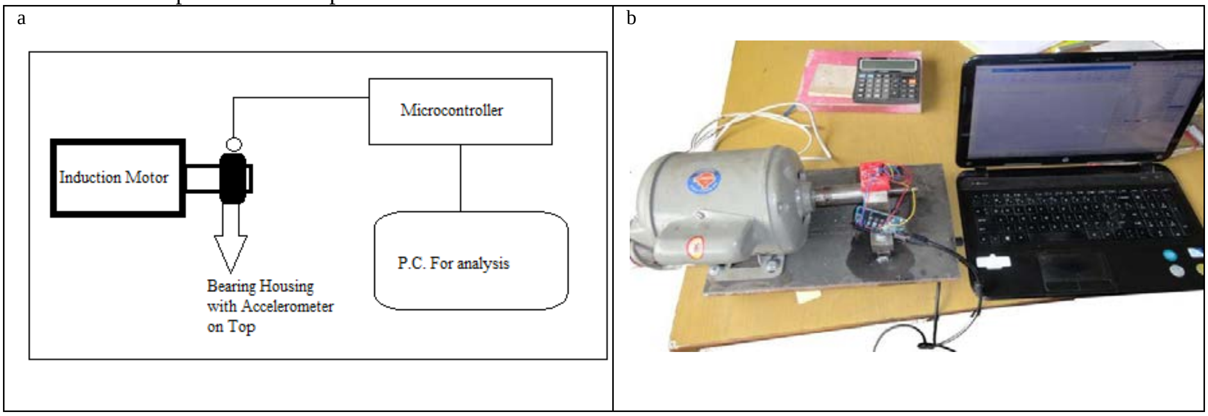

Figure 2 (a) Schematic Diagram for Experimental setup; (b) Actual Experimental Setup

2.1. Accelerometer

An accelerometer is a device that measures proper acceleration ("g-force"). Proper acceleration is not the same as coordinate acceleration (rate of change of velocity). Accelerometers have multiple applications in industry and science. Highly sensitive accelerometers are components of inertial navigation systems for aircraft and missiles.. Figure 3 shows ADXL 335 accelerometer which is used in the experiment.

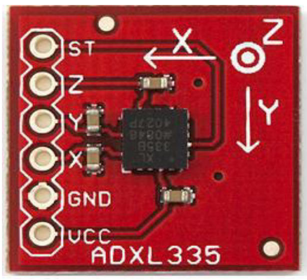

Figure 3 ADXL 335 Accelerometer

2.2. *Arduino Board*

Arduino is an open-source computer hardware and software company, project and user community that designs and manufactures kits for building digital devices and interactive objects that can sense and control the physical world.An Arduino board consists of an Atmel 8-bit AVR microcontroller with complementary components. Figure 4 shows ARDUINO UNO board used in the experiment.

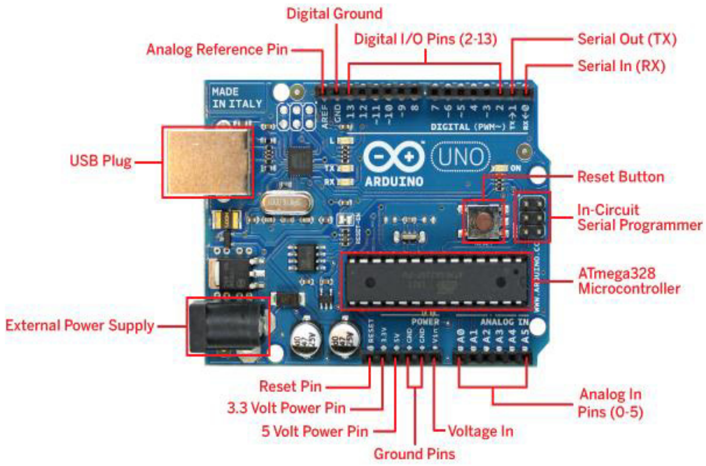

Figure 4 Arduino Board

2.3. *Bearings*

Thirty seven unassembled bearings of bearing no. 6204 are arranged and on those bearings various types of faults are seeded by the EDM machine and some are dipped in the acid solution for creating the rusting effect on the races, ball and cage. Indentation is made in inner and outer race of the bearing for simulating the bearing inner and outer race defect due to overloading. In ball and cage corrosion, pitting is main cause for their failure so similar type of faults is seeded in cage and ball Generation of Bearing fault Signature

3. Results and Discussion

"The 1947 Lundberg and Palmgren report on 'Dynamic Capacity of Rolling Bearings' is still the basis for all the bearing life calculations that are done today," says McKenzie. "They are the fathers of modern bearing life calculations. The 1947 Lundberg-Palmgren equation includes the probability of survival, the internal stress created by the external load, the number of stress repetitions, the stressed volume, the contact area and the length of the raceway. In 1952, the two men expanded their vision to produce the formula that remains at the heart of all of today's standards:

$L_{10} = (C/F)^p$

L_{10} = bearing life, the point at which 10% of the bearings will fail

C = basic dynamic capacity of the bearing based on the number of rolling elements, the roller length and diameter, and the contact angle

F = applied load

p = a power: 3 for ball bearings, 4 for pure line contact bearings, or 10/3 for typical roller bearings.

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Many factors besides slag inclusions and voids could affect bearing life, Here the L10 from Lundberg- Palmgren was multiplied by five separate and independent factors for material, processing, lubrication, speed and misalignment.

Results:

After performing the various test on the different specimen of seeded faults of rolling ball bearing (SKF 6204) the following results are obtained. The first figure will illustrate the raw vibration data acquired by the accelerometer and then final power spectral density figures are shown for healthy and the faulty bearing having various kinds of faults:

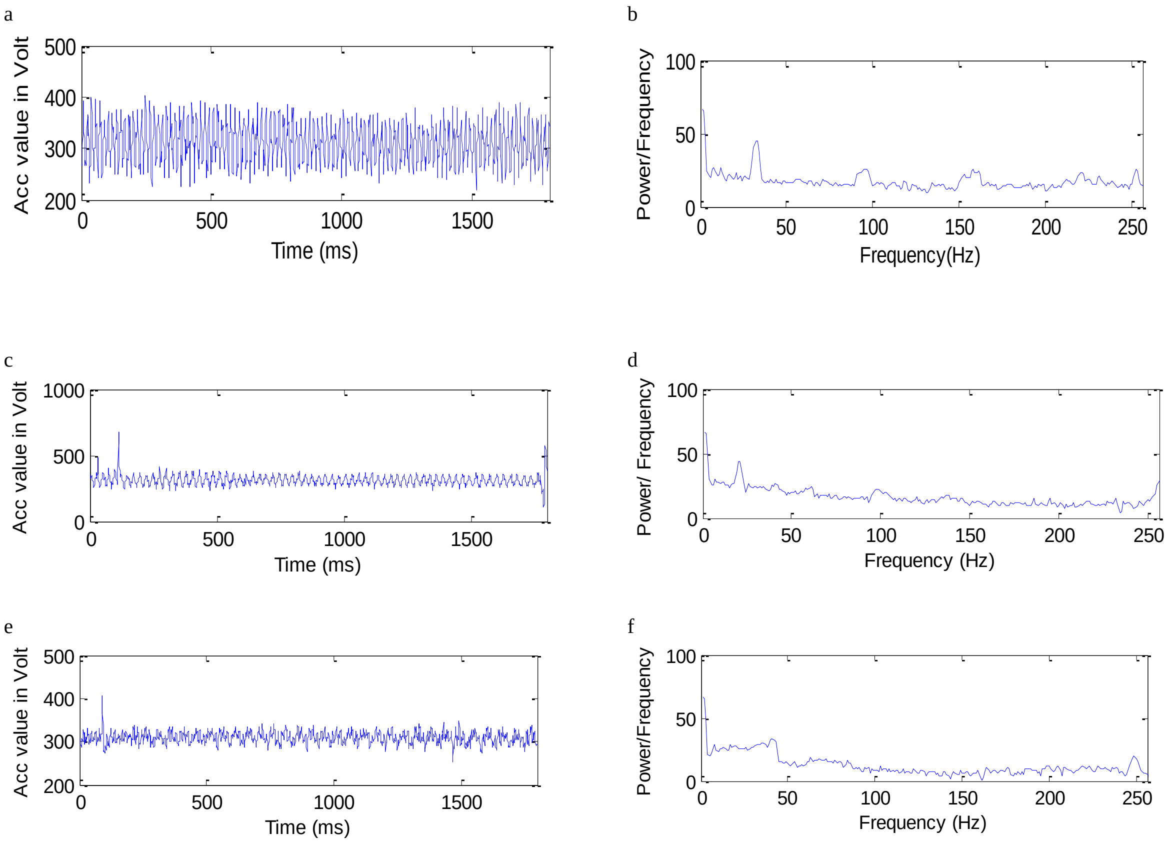

Figure 5 (a) Healthy Bearing Vibration signal (b)Power Spectral density of healthy bearing (c) Bearing vibration Signal of fault in inner race (d) Power spectral density of Bearing having fault in inner race (e) Bearing vibration signal for fault in outer race

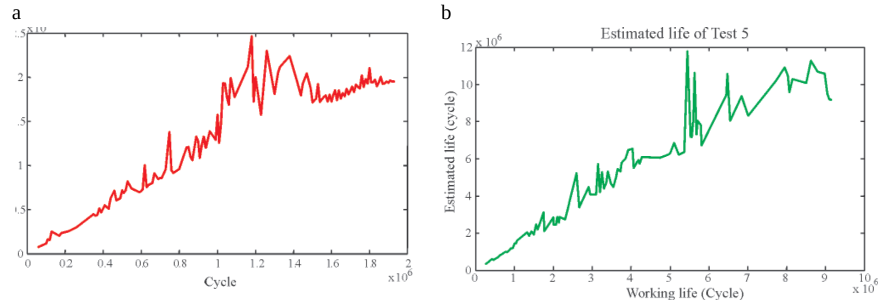

Figure 6 Estimation of useful life before failure of Radial Ball Bearing

As seen in the above experimental results we can clearly classify the faulty bearing vibration data as compared with the healthy bearing. awt and power spectral density (psd) proved to be an effective tool for brief classification of fault and after studying the psd results one can also classify the category of fault by further analysis and can predict the mean time before failure of the bearing .

4. Conclusion

The bearing fault detection and its prognostics plays vital role in saving money as well as production losses in very critical applications like wind turbine; oil refineries etc. From this paper we have seen three methods of bearing fault analysis and its prognostics. We have also seen the use of Power Spectral density Estimation tool to categorize the sub fault of a ball bearing but psd did not prove to be an effective tool for identifying the kind of fault and also the location of fault.

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