Defect Evaluation in Rolling Element Bearings Using Frequency Domain Analysis

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Abstract – Vibrations in a machine or rotating mechanicals components are mainly caused by the bearing defects and faults. By the virtue of its construction and its characteristics, bearings tend to produce vibration. As the condition of the bearing changes over time the vibration signal and its characteristics also changes. In this paper we shall discuss various vibration signal based techniques in condition monitoring. The inner race and outer race of the bearing can feature the defects of variable nature. The vibration dada is obtained from the bearing housing and its effect on the functionality and the seriousness of the defect is analyzed.. A total ranking of the parameters is tried with the aim of evaluating effective damage identification parameters from diagnosis of the rolling element bearings.

***Key Words*: Bearings, Vibrations, Defects, Damage, Defectiveness, Frequency**

1. Introduction

If there a considerable fault in the rolling bearings is not detected in advance, it can cause a major mechanical as well as economical loss. For the proper functioning of any mechanical part containing this type of rolling bearings, they need to operate smoothly and stably. Causes behind localized defects of rolling bearings can be one or more like inappropriate installation, material fatigue, faulty bearings etc. When a rolling bearing with a defect is rotated in an operation a certain amount of vibration and the vibration signal is generated. There are mainly two types of methods that are used to detect these types of defects in a rolling bearings vibration monitoring, acoustic monitoring, temperature measurements and wear debris analysis. Among these techniques the vibration measurement technique is most widely used in the defect evaluation. To measure the vibration signal and acoustic measurement, many types of techniques are employed, such as, time and frequency domain analysis, the shock pulse method, sound pressure and sound intensity techniques and the acoustic emission method. All round sound performance and stability of the rolling bearing is important for the functionality and failure avoidance in the machine.

Bearing health monitoring techniques is important step for evaluating the bearing health and its performance. For this purpose the condition monitoring is carried out by using the various condition monitoring techniques. Since it is very reliable and very sensitive, vibration analysis technique is most commonly used condition monitoring technique used nowadays. Bearings are a source of vibration and noise because of defects present or variable performance in parts of bearing. We can assess the bearing health by analysis the vibration signal coming out of the bearing when it is in the operating or the running condition.

1.1 Geometry of Rolling Element Bearing

Bearing geometry is an important component which is used to evaluate the defects because the geometry of ball bearings is the determining factor in the dynamics of components and their vibration characteristics. A schematic diagram of deep groove ball bearing is shown in figure 1.1. Ball bearings are generally characterized as having smaller size and lower load carrying capacity than most of their counterparts. Still with all these limitations they can support both axial and radial loads. Axial force is defined as the force applied parallel to the shaft. The radial force is applied perpendicular to the shaft. To maximize the life-span of the component, placement or location of the bearing, amount and the type of lubrication used, correct alignment plays an important role. The main components of a ball bearing is inner rotating race, outer rotating race, roller balls and the cage structure holding the races and balls together. The load zone and load distribution are also given with the direction of applied force in the figure. Most of the times the inner race and the roller balls rotate along with the shaft and the outer race is remaining stationary. Majority of the defects occur on the inner race and the roller balls as they are continuously rotating and most of the force such as static and dynamic load, torque and acceleration. Also the inner race and roller balls come under the load zone so they tend to be exposed to most amount of wear and tear happening in any rotating part or component in a machine. So the main focus of any condition monitoring schedule of maintenance is mostly on analysis of inner race and the roller balls of the bearing, the outer race is secondarily analyzed because of before mentioned reasons.

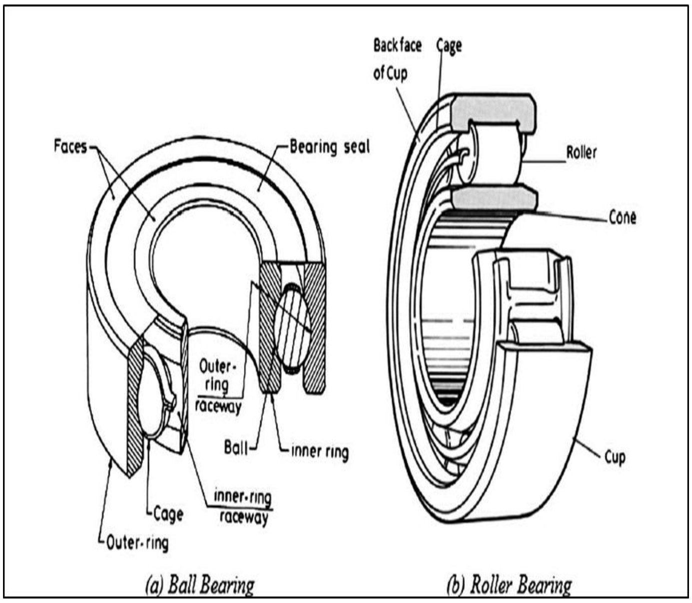


Fig 1 Rolling Element Bearing

1.2 Bearing Faults Characteristics Frequencies

To find out the characteristics of the vibration signal output due to inherent faults, it is assumed that the bearings are continuous and isolated systems. It is also assumed that: (1) All rollers of the bearing are equal in diameter; (2) There is only pure rolling contact between rollers, inner race and outer race; (3) No slippage between the rotating shaft and the bearing; (4) Outer race is stationary and inner race rotating. Since there is pure rolling contact between the inner race, outer race and the roller balls, the relative velocity between all of them is also zero. The theoretical characteristic fault frequencies for a fixed outer race bearing can be calculated using following equations-

1. Outer race defect frequency:

$$f_o = \left(\frac{Nr}{2}\right)\left(\frac{N}{60}\right)(1 - \frac{Dr}{Dp}.cos\alpha) \quad \text{... Eq.2}$$

2. Inner race defect frequency

$$f_i = \left(\frac{Nr}{2}\right)\left(\frac{N}{60}\right)(1 + \frac{Dr}{Dp}.cos\alpha) \quad \text{... Eq.3}$$

3. Roller defect frequency:

$$f_r = \left(\frac{Dp}{Dr}\right)\left(\frac{N}{60}\right)(1 - \frac{Dr^2}{Dp^2}.Cos^2\alpha) \quad \text{... Eq.4}$$

2. Condition Monitoring

2.1 Basic Condition Monitoring Techniques

Basic condition monitoring is mainly done through elementary observations. There are ample numbers of tools that can magnify, amplify the results to make them more recordable.

2.2 Visual monitoring (Looking):

Visual monitoring of the bearings typically includes observation of deformation of condition of bearing, corrosion if present and the lubricant quantity and quality. If a mounted bearing is lubricated properly then it will purge the grease from its sealing. The analysis of this purged graze can be used to determine the quality and amount of the lubrication. Milky, dark and caked grease found can imply that lubrication schedule and procedures may need to be improved.

2.3 Audible monitoring (Listening):

Audible monitoring or simple listening is most common and traditional way of the condition monitoring. Odd noises are an indication of faulty operation of the bearing. This can be sensed even by any untrained worker. This task can be a part of workers daily routine.

2.4 Temperature monitoring:

Monitoring the operating temperature of any bearing is the mist simple technique that does not require any tool. Monitoring operating temperature is important as operating temperature has direct effect on failure. If the operating temperature is high then it implies that bearing has a fault and vice versa. Logging the daily operating temperature will help in detecting fault in early stages to avoid catastrophic failure. Thermocouples and resistance temperature detectors (RTDs) are the tools that can be permanently mounted on the bearing housing for continuous real-time monitoring.

2.5 Vibration Measurement Techniques and Analysis

When a defect is present, it produces vibration which can be sensed using vibration transducer or accelerometers. There are some analysis techniques that are used to process raw data for the condition monitoring of bearings. They can be classified as following: time-domain, frequency domain and time frequency or time-scale analysis methods.

2.5.1 Time - Domain Analysis

Series of digital values representing proximity, velocity, or acceleration in the time domain are known as the vibration signals. The display and analysis of the vibration data as a function of time is called as the “time – domain analysis” of the obtained vibration signal. The main advantage of this type of analysis is that negligible dada is lost before the inspection.

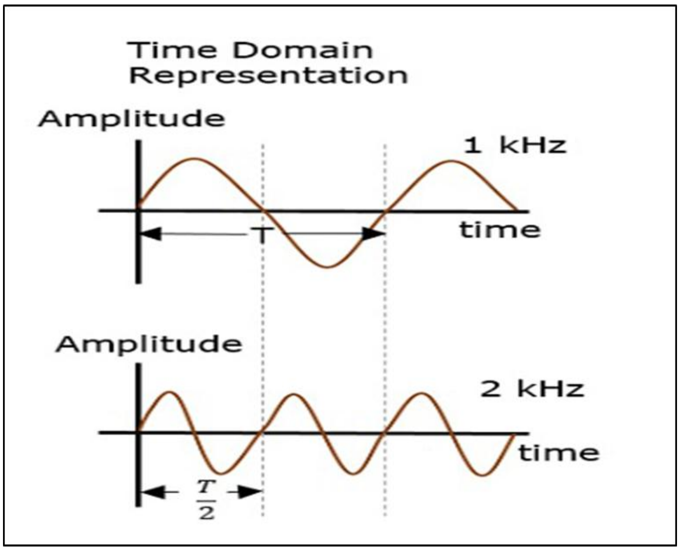


Fig 2 Time Domain Analysis

This technique can play a very important role in condition monitoring of the simpler machines but they are not very viable for a complex machine. It is useful in detecting a simple defect prior to failure. Since it detects the fault after forming it, the bearing needs to be replaced but the economic implications of changing a bearing is much lesser than having to face a catastrophic failure of a component.. Dyer and Stewart (1978) stated that the probability density. Generally used time-domain metrics consist of waveform analysis and vibration features.

2.5.2. Frequency- Domain analysis

Extracting the frequency content of the time domain signal spectrum analysis is known as the "frequency – domain analysis" of the vibration signal. It is the most common technique used for health inspection in rolling bearings. It can be considered as an important way to find out fault and perform its diagnosis in simple rotating machinery. Frequency analysis is a measure of the vibrations over a large number of discrete neighboring narrow frequency bands. At constant speed and specific geometry, the frequencies of the vibrations which are produced by the many components in the bearing can be established. Generally, the defect diagnosis with the help of vibration level along with wave shape features can be improved by dividing the vibration signal in to number of frequency bands prior to analysis. A fault or defect present may not cause a significant variation in the signal and it can also be masked or hidden under other high energy signals detected which is not rooted in defect. But, the defect or a fault can generate a considerable variation in a band of frequencies in which vibrations which are not associated with the fault is generally smaller.

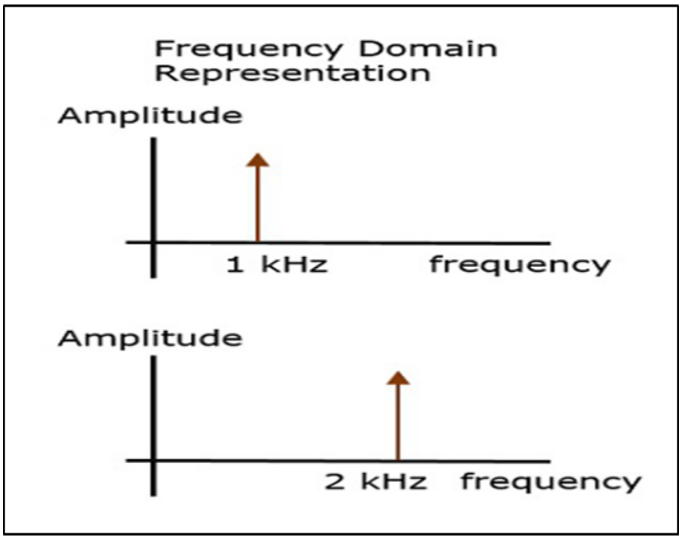


Fig 3 Frequency Domain Analysis

2.5.3 Time-frequency domain techniques

To handle stationary and non-stationary vibration signals, we may have to use a combination of time frequency domain analysis. This proves to be the considerable advantage for the same. This analysis can show the signal frequency components and it can also illustrate their time variant features. Methods such as the Wavelet Transform (WT Wigner-Ville Distribution (WVD),.

3. Failure Modes in Bearings

The bearing defects can be widely categorized as the localized defects and generalized defects. They are briefly described below-

3.1 Bearing Wear

When the amount and type of lubrication is inadequate or incorrect or if a foreign particle infiltrates the rollers, the bearing wear may occur. If there is vibration in a component when the bearing is not rotating then the wear may happen in that case also.

3.2 Bearing Smearing

Smearing is a concept when two poorly lubricated surfaces slide against one another and some amount of material gets transferred from one surface to another. This is known as smearing. The surfaces undergoing smearing appear to be swollen, and they appear to be torn, the material is heated to a temperature that re-hardening of that same surface takes place. This results in production of localized stress concentrations which in result causes flaking and cracking on the surface. When the rollers are subjected to high amount of acceleration when they are in the load zone, then smearing may occur.

3.3 Bearing Corrosion

Corrosion may take place in any bearing when a dust or other corroding materials intrude then bearing surface beyond a level at which lubricant can resist the corrosion from taking place. Once the corrosion starts taking place on any surface, it leads to the formation of deep seated extensive rust on the surface. Deep seated rust causes a great harm to bearings because it can lead to flaking and cracks. While it is important to note that acidic liquid corrodes the bearing surface quickly than the basic liquid.

3.4 Bearing Brinelling

Brinelling can be described as the regularly spaced indentations which are distributed over the entire raceway circumference and which are corresponding approximately in shape to the Hertzian contact area. The main causes of brinelling are, (1) Static overloading which can cause the plastic deformation of the bearing races, (2) When a shock load and vibrations are applied to a stationary bearing and (3) when and electric current is caused by a loop of passage.

3.5 Improper Bearing Lubrication

When a bearing is inadequately lubricated or the type of lubricant is improper, it may lead to problems like sticking, skidding, excessive heat generation. Region of Hertzian contact when the lubrication is not proper, the surfaces in contact will weld together due to heating, then they are torn apart as the bearing starts rolling more.

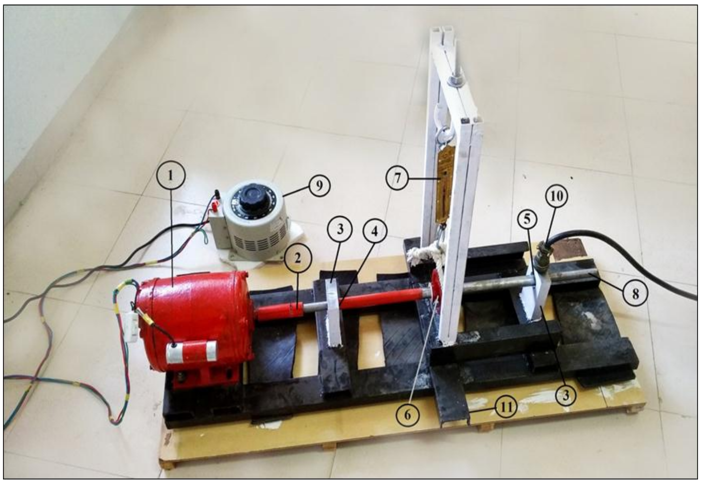
3.6 Faulty Installation of the Bearing

Faulty installation of the bearing at the beginning and other mishaps such as misalignment, loose fits, excessive axial or radial preloading can lead to faulty behavior and ultimately failure.

3.7 Bearing Incorrect Design

If the size of the bearing required for a specific set of operation is not proper and it is calculated incorrectly then design malfunction may occur. This incorrect design can lead to serious effects on low lad and low speed operations too.

4. Experimental Setup



(1) 1H.P. single ϕ Motor (2) Coupling (3) Bearing Housing (4) Standard (Healthy) Bearing (5) Test (Fault) Bearing (6) Pulley (7) Spring Balance (8) Shaft (9) Dimmerstat (10)

Accelerometer (11) Frame

The adjacent figure shows the model of the proposed experimental set up. The main shaft is supported by using the two support bearings. The induction motor is connected with shaft end with the help of a coupling. The dimmerstat is used for changing the speed of the induction motor. It also consists of the arrangement of a spring-balance in order to vary the load on the shaft with the help of pulley mounted on the shaft. The coupling connecting the main shaft to the motor also acts the vibration isolating setup. The samples taken are described below.

Bearing Sample No.	Defect Type
B0	No Defect (Healthy)
B1	Inner Race
B2	Outer Race
B3	Ball

Table 1 Bearing Sample

Bearing Sample No.	Contaminant Size (micron)	Weight Percentage (%)
B4	53	5
B5	53	15

Table 2 Contaminants Sample

5. Design of Experimental Setup

Shaft Design

$$d = \sqrt[3]{\frac{16 \times Te}{\pi \times \tau}} = \sqrt[3]{\frac{16 \times 43595}{\pi \times 47.5}} = 16.72 \text{ mm}$$

Bearing Selection

For shaft diameter (d) = 20 mm and C_o = 2.432 kN bearing selected is *HCH 6004-2RS*.

d	20 mm
D	42 mm
B	12 mm
d_1	24.65 mm
D_2	37.19 mm
$r_{1,2}$(min.)	0.6 mm

Table 3 Bearing Dimensions

6. Results of FFT analysis

Sr. No.	Speed, N (RPM)	Shaft Frequency, Fs (Hz)		Inner-race Frequency, Fi (Hz)	
		A	E	A	E
1	1080	18	18.125	97.90	99.375
2	1820	30.33	30	164.96	165

Table 4 Fault frequencies at various speeds. (Analytical & Experimental)

Sr. No.	Speed, N (RPM)	Outer-Race Frequency, Fo (Hz)		Roller (ball) Rotational Frequency, Fr (Hz)	
		A	E	A	E
1	1080	64.09	65.125	82.49	81.625
2	1820	108	107.5	136.8	135.875

Table 4 Fault frequencies at various speeds. (Analytical & Experimental)

7. Conclusion

In this paper, we studied about the rolling bearing geometry, types of failure in rolling bearing, condition monitoring techniques and the vibration analysis. Experimental setup for carrying out the study was designed and manufactured. The method used for the study was the frequency domain analysis along with the modal analysis of the bearing. During the experimentation various bearing defects like inner race defect, roller (ball) defects and outer race were taken into consideration. The metal Burr was used as solid contaminant. Finally the results obtained from vibration spectra illustrate firmly, that, as the speed of defective bearing increases the frequency and acceleration values also start increasing. Substantial variation in the vibration signals were observed when the contamination was added in the vibration lubricant. The acceleration values also change according to the variation in speed and load. The particle size also has a major impact on the outcome of the study. When the size is increased the corresponding acceleration values go on increasing up to point, and then start decreasing. The reason is that the contaminants start bto occupy the corners present in the bearing. The same outcome was observed when contamination concentration and size was increased. At the speed of 1080 RPM, with small particle size and varying concentration of the contamination, we found the desired results. At other instance, there is a mismatch observed in experimental and actual results. This may be happening because the particles may not come in direct contact with rotating elements.

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