Vibration Based Condition Monitoring, Fault Diagnosis and Root Cause Analysis for Bearing Components-A Review

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Abstract— Everything which rotates needs a friction less surface or can say a bearing in machinery equipment. All machines with moving parts produce a signification amount of vibration and has a specific vibration signature related to the design and environmental condition of the machine. In case of variation occurs in machine vibration the vibration signature will also change and that change can be used to detect the fault before it came into the action. The condition monitoring technique used to get the continuous monitoring of the machine is based on identification of fault present in the system, its diagnosis and to found the probable root cause of the fault and assessing the level of severity of the fault and after verification suggesting the correction necessary correction in the system. This article displays a short survey of recent developments in bearing failure, wellsprings of vibration and vibration estimation procedures have been completed for improving the exactness and capacity of condition monitoring and forecast frameworks for bearing.

Keywords: Condition Monitoring; Rolling Element Bearings; Vibration Signals; Fault Diagnosis; Failure Mode Analysis; Operation and Maintenance, Root Cause Analysis

I. INTRODUCTION

Bearing parts assumes a significant job in a large number of mechanical turning and transport apparatus applications. Bearing is a machine segment that obliges relative development to simply the perfect development and diminishes rubbing between moving parts. More than 90% of machines use rolling element bearings and their failure may lead to failure of the machine. Thus, they are considered as the most critical components in industrial applications [1]. The underlying fault diagnosis, of course, may avert pointless failures of a large portion of the rotating hardware framework and along these lines increment operational reliability and availability of machine [2][3]. Fault diagnosis techniques serve a vital role in order to prevent the fault conditions in bearing and other machinery equipments. The recent techniques available in the industries have a variety of limitations [4]. An effective method has to be developed for industrial machinery component health diagnostic activities. Condition-based upkeep generally depends with respect to discovery of the flaw before disappointments, such as an adjustment in vibration level and pattern, Increased temperature of the parts, wear in the surface detected via analysis of lubricant, change in system performance, motor current change, etc. The task is to look for out for such signs using condition monitoring technique so that the risk of failure and maintenance costs, both decreases [5]. A CBM program, if appropriately settled and adequately executed, can altogether reduce upkeep cost by diminishing the quantity of superfluous booked preventive support tasks [6]. Fault discovery is the way toward watching the deliberate framework information and framework status data and contrasting them and an ordinary scope of observed characteristics to determine whether some measurements fall outside the range representing the healthy condition of the system. Unfortunately, no one technique is able to detect all [7]. Root cause analysis of the bearing component is performed to identify the probable cause of bearing failure which may be at extreme operating condition of heavy load condition, very high RPM, and increased or decreased operating temperature. at the point when structure necessities not met that prompts over the top avoidance, vibration, high frictional torque and temperature [8][9].

II. BEARING SIGNIFICANCE AND BEARING FAILURES

This section review concentrates on continuous monitoring of rolling element bearings as they are the most critical part of any mechanical system and the fault in this part may result in poor output product and substantial economic loss and, sometimes, catastrophic failure [10]. The standard essential components of a ball bearing are: inner race, outer race, rolling elements, and cage or separator has shown in Fig. 1. The first three elements support the bearing load and reduce the friction and provide a relative motion, while the cage separates adjacent rolling elements so the load distributes over the rolling element must be uniform and avoid friction between them [11].

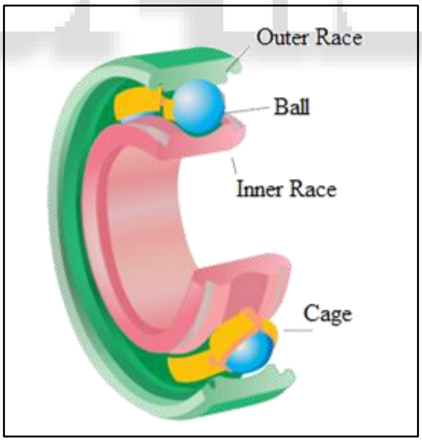

Fig. 1: Bearing Components

The qualities of the vibration reactions because of shortcomings can be related to the accompanying suspicions: (1) All rollers are equivalent in dimensions; (2) There is an unadulterated moving contact between rollers, inward race and external race; (3) There is no slipping between the spindle and the bearing; (4) Outer race is stationary and internal race pivots. The relative speed between rollers, internal race, and external race are zero since they are in unadulterated moving contact [12].

III. SIGNAL PROCESSING TECHNIQUES

During the operation any machine can be subjected to the unfriendly environment and cause the failure in any part of the bearing which results in high amplitude of vibration. Because of the communication between neighborhood imperfection on the component and it's mating surface unexpected change in contact stresses produces pulses of short term. These pulses produce vibration which can be observed [13].The bearing having different frequencies for different bearing elements like, BSF, BPFO, BPFI and FTF are called characteristic frequencies. When we consider these characteristics frequencies for fault detection we called them as characteristic defect frequencies which can be determined by following equations [14][12][1].

Ball Pass Frequency, Outer race (BPFO)

$$\mathrm{BPFO} = \frac{\mathrm{nfr}}{2}\left(1 - \frac{\mathrm{d}}{\mathrm{D}}\cos\emptyset\right) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (1)$$

Ball Pass Frequency, Inner race (BPFI)

$$\mathrm{BPFI} = \frac{\mathrm{nfr}}{2}\left(1 + \frac{\mathrm{d}}{\mathrm{D}}\cos\emptyset\right) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (2)$$

Fundamental train frequency, (FTF)

$$\mathrm{FTF} = \frac{\mathrm{fr}}{2}\left(1 - \frac{\mathrm{d}}{\mathrm{D}}\cos\emptyset\right) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (3)$$

Ball (Roller) Spin Frequency

$$\mathrm{BSF} = \frac{\mathrm{D}}{2\mathrm{d}}\left(1 - \left(\frac{\mathrm{d}}{\mathrm{D}}\cos\emptyset\right)^2\right) \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (4)$$

Where, D is pitch circle diameter, d is roller diameter, ∅ is contact angle, n is number of roller and Fr is shaft rotational frequency in Hz [2]. Several researchers [14][15][4] have announced achievement in bearing deformity discovery by distinguishing these rotational frequencies. In some work It is additionally announced that significant peaks are hard to be distinguished when the sign is loud and the deformity is little. Bearing faults are best distinguished by wavelet transform and other time-frequency examination techniques [16].

IV. Vibration Analysis Techniques

The vibration signal generated by the faulty bearing can be analyzed in time domain or frequency domain or time and frequency domain.

Time domain technique is easiest and simplest technique to analyze the vibration signal waveform. The least difficult methodology in the time-space is to quantify the general root-mean-square (RMS) level and peak factor, i.e., the ratio of peak value to the RMS value of acceleration. The resultant RMS qualities are contrasted with suggested values with deciding the state of a heading

$$\mathrm{RMS}\ (\mathrm{X}) = \sqrt{\frac{\mathrm{XI}^2}{\mathrm{N}}} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} (5)$$

Where, N is the number of discrete points and represents the signal from each sampled point. The resultant RMS qualities are contrasted with prescribed qualities with decide the state of a course [10] [17] [12].

Frequency domain technique is the most broadly utilized methodology for the diagnosis of bearing fault. Frequency domain systems convert time-domain vibration signals into discrete frequency parts utilizing a Fast Fourier Transformation (FFT). Examination of raw vibration signal in the frequency domain should be possible through Discrete Fourier Transformation (DFT) and Fast Fourier Transformation (FFT) [13] [18]. DFT is a straight scientific methodology however is wasteful while Fast Fourier Transformation (FFT) analyzers are a simpler and proficient method for getting thin band spectra [13][1].

Time-Frequency technique: In pivoting machines, bearing vibration sign is a blend of intermittent parts, commanded by the machine revolution, with a sign of an irregular sort, ruled by a conceivable bearing flaw or defect. This marvel is periodic in nature, has time invariance and non-stationary. This has prompted the improvement of time-frequency investigation techniques [19]. The upside of time-frequency area procedures over FFT is that it has the capacity to deal with both, stationary and non-stationary vibration signals. Various time-frequency examination procedures, similar to the Short Time Fourier Transform (STFT), Wigner-Ville Distribution (WVD), and Wavelet Transform (WT) are the systems in a time-frequency area [1] [18] [14].

V. Methodology of Measurement

A. Measurement Location:

Vibration readings should be taken with the pickup perpendicular to the surface of interest like fixing bolts, vibro dampers, base frames, support columns etc [15]. For rotating machines Vibration readings are generally taken at each bearing housing in horizontal, vertical and axial directions; Further Vibration readings may be taken at any location that seems relevant to the particular problem at hand [5].

B. Measurement Direction:

1) Horizontal plane readings are taken with pickup axis perpendicular to the machine shaft centreline and parallel to the ground.
2) Vertical plane readings are taken with pickup axis perpendicular to the machine shaft centreline and perpendicular to the ground.
3) Horizontal and vertical measurements are generally called radial vibration measurements.
4) Axial plane readings are taken with pickup axis parallel to the machine shaft centerline [5].

VI. Bearing Life

Bearing life for simplified figuring's and to acquire an approximate estimation of the bearing life the purported "handbook strategy" is utilized to ascertain the essential rating. The basic rating life of a bearing according to ISO 281 is:

$$\mathrm{L}_{10} = \left(\frac{\mathrm{C}}{\mathrm{P}}\right)^{\mathrm{p}} \text{ in millions of revolution}$$

Where

L10 = basic rating life (at 90% reliability), millions of revolutions

C = basic dynamic load rating, kN

P = equivalent dynamic bearing load, kN

p = exponent for the life equation = 3 for ball bearings = 10/3 for roller bearings, as typically utilized in axle-box applications [20][21].

$$\mathrm{L}_{10\mathrm{h}} = \frac{10^6}{60\mathrm{n}}\mathrm{L}_{10} \text{ in Hrs}$$

Where, n = RPM of spindle [21]

VII. BEARING FAILURE MODES CLASSIFICATION

The service life of bearings is expressed either as a time period in operating hrs or as the number of cycles before the occurrence of failures in the bearing components because of various modes. Appraised life of bearing communicated as the period at which hardware or machine component flops under the predefined state of utilization given by its maker. The administration life of bearing varies from appraised life, where bearing disappointment may cause by poor grease, misalignment, and mounting harm before its real life [8]. Primary physical root causes of failure mainly fall into one of the four fundamental categories like design defects, material defects, defects related to the method of assembly and operational anomalies. [9]

Root cause analysis is carried out with the reference of ISO 15243 and the possible root causes discussed in this section. This standard perceives six essential damage/failure modes and their sub-modes identified with post-fabricating supported harm. These depend basically upon the features visible on moving component contact surfaces and other useful surfaces and which distinguish the systems engaged with each sort of harm/disappointment. Most bearing damage can be connected back to the six principle modes just as their different sub-modes as appeared in fig. 2. [22] [18]

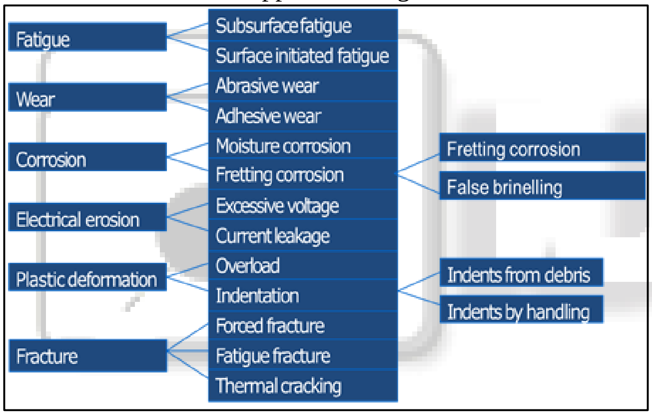

Fig. 2: Classification of Bearing Failure modes

A. Characteristics

Service performance result compared, by Visual appearance [22]

B. Damage

Any visible corrosion of the bearing operating surfaces or structures [22]

C. Event Sequences

Sequence of faults identified leading to bearing failure starting with initial damage to the bearing [22].

D. Failure

Any condition where bearing can no longer deliver its designed function [22].

VIII. CONCLUSION

In this paper for Vibration-Based Condition Monitoring, Fault Diagnosis and Root Cause Analysis for Bearing Components, Vibration estimation in time domain and frequency domain are key focuses for doing work. In this way, we will utilize the above technique to highlight extraction and shortcoming conclusion in our work. This examination found that the time domain procedures just can show the fault(s) present in the bearing yet it can't recognize the fault location. Frequency domain systems have capacity to distinguish the area of fault(s) in bearing. Vibration peaks produces in range at the bearing attributes frequencies, from that we can without much of a stretch comprehend which bearing component is defected. Envelope investigation is helpful technique to recognize nascent disappointment of moving component bearing.

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