Study Of Detection Of Defects In Rolling Element Bearings Using Accoustic Measurement Methods- A Review

M. Jasmin Nerella[*1], Ch.Ratnam[2], and V.Vital Rao[3]

[1*]*Research Scholar, Mechanical Engineering, A.U College of Engineering (A), Visakhapatnam, India*

[2] *Professor& H.O.D, Mechanical Engineering, A.U College of Engineering (A), Visakhapatnam, India*

[3]*Assist., General Manager, Engg. Shops& Foundry Dept., Visakhapatnam Steel Plant, Visakhapatnam, India*

Abstract: *In this paper a review of defect detection in rolling element bearings using Acoustic Measurement (AM) methods is focused. Different types of defect detection have been reviewed. It is vital to monitor the condition of the bearings and to know the severity of the defects before they cause serious damages. Therefore, the study of Acoustic emission as an emerging technique for condition monitoring of rolling element bearings as well as potentially offers advantages for detection of incipient damage at an early stage of failure. Along with Acoustic emission measurements, some other techniques like sound pressure and acoustic emission of acoustic measurement have been investigated in this paper.*

Keywords:Acoustic Emission, Rolling element bearings, Defect detection, Condition monitoring, Bearing defects.

I. INTRODUCTION

Most of the machinery used in the modern world operates by means of motors and other rotating parts that may develop faults. Rolling element bearings are the most common machine elements plays vital role in all kinds of rotating machines. These faults may cause the machine to break and decrease its level of performance. Generally, when a machine develops a fault it gives a signal in various forms such as changes in acceleration, pressure, strain characteristics, etc. Therefore, detection of these defects is very important from point of condition monitoring as well as quality inspection of bearings. Different techniques have been developed for monitoring and diagnosis of rolling element bearings [1].Rolling Element bearings are manufactured by assembling different components: The rolling elements, the outer ring and inner ring, which are in contact under heavy dynamic loads and relatively high speeds [2].

Condition monitoring can be divided up into three main areas, detection, diagnosis, and prognosis. Detection can often be determining any serious changes occurred in the mechanical condition of the machine. Diagnosis, in effect, determines the location and type of the fault, while prognosis involves estimation of the remaining life of the damaged bearing. In order to keep the machines performing at its best, different techniques used for detection and diagnosis of bearing defects; they may be broadly classified as vibration, acoustic measurement, temperature measurements and wear debris analysis. Among these vibration and acoustic measurement are the most widelyused. Several techniques have been applied to measure the vibration and acoustic responses from defective bearings i.e., vibration measurement in time and frequency domains, the shock pulse method, sound pressure and sound intensity techniques and the acoustic emission method.

A lot of work has been published in the last two decades on the detection and diagnosis of bearing defects by vibration and acoustic methods. Tandon and Nakra presented a detailed review of the different acoustic methods for condition monitoring of rolling bearings [3]. Mcfadden and Smith and Kim have also presented reviews on specific techniques for condition monitoring of rolling element bearings[4,5] . White describes a method for simulating the machinery fault signals which are impulsive in nature and analyzed them [6]. The load distribution around the circumference of the rolling element bearing and impulse response of the bearing structure are proposed in Mc fadden and Smith [7]. The mode summation method is employed to find the vibratory response of the bearing subjected to radial or axial load for the case of different defect locations. The bearing vibration signals are modeled as a combination of different sources as fault, modulation with nonuniform loading, flexural bearing modes, machinery induced vibrations and noise in Wang and Kootsookos[8].

II. BEARING FAULTS

Rolling bearings are the common elements used in heavy rotating machinery and equipment which carries loads and eliminates the sliding friction by having balls or rollers as rolling elements between two bearing rings known as outer and inner raceway. Broadly, rolling bearings are classified as radial bearings, which carry radial loads and thrust bearings which carry axial loads. The presence of bearing faults such as peeling, spilling, galling, subcase fatigue or failure of the bearings due to misalignment, surface roughness, high extent of waviness, shaft slope and inclusions, etc., causes a catastrophic collapse of the system and thereby reducing the availability and reliability of the industry or plant. Due to the reasons, such as improper manufacturing or mounting, improper design of the bearing, misalignment of bearing races, unequal diameter of rolling elements, improper lubrication, overloading, fatigue, uneven wear etc., there may be rise of the defects in the rolling element bearings. Rolling defects/faults categorized in two kinds: Distributed defects and localized defects.

A. Distributed Defects

Defects that are mainly caused by manufacturing error, inadequate installation or mounting and abrasive wear [9]. A distributed defect includes surface roughness, waviness, misaligned races, and unequal diameter of rolling elements [10]. Distributed defects caused an increased in the vibration level due to the change in contact force between rolling elements and raceways. For quality inspection of bearings and condition monitoring, the study of vibrations generated by distributed defects is essential. [11]

B. Localized Defect

Localized Defects include cracks, pits and spalls on rolling surfaces caused by fatigue [12]. The common failure mechanism is the crack of the races or rolling elements, mainly caused when a crack due to fatigue originated below the metal surface and propagated towards the surface until a metal piece is detached causing a small defect or spall [1]. This defect accelerates when the bearing is overloaded or subjected to shock (impact) loads during their functioning and increase with the rotational speed. Spilling can occur on the inner ring, outer ring, or rolling elements.

The vibration response of the bearings in case of distributed defects studied mostly in the frequency domain as many of the frequencies resulting from distributed defects coincide with those due to localized defects and it becomes difficult to identify from frequency information alone whether a peak at a particular frequency is due to localized or a distributed defect.

Two approaches have been adopted by researchers for creating localized defects on bearing to study their vibration response. One is to run the bearing until failure and monitor the changes in their vibration response [5, 13]. The other is seeding the defects in the bearings by techniques such as acid etching, spark erosion, scratching or mechanical indentation. Later, measure the vibration response of the bearings and compare with that of healthy bearings [14].

III. BEARING KINEMATICS

A machine running with a faulty bearing, the rolling element comes across the defect and hits the edge of the defect, thereby, produce impulse in the races. The periodic impulses produce certain frequencies called Characteristic defect frequencies, and these frequencies depends on the bearing kinematics, its geometry and speed. And each bearing element has a Bearing Characteristic Frequency(BCF). The peaks will occur in the spectrum at these frequencies, due to increase in vibrational energy. A model presented by Rao and Ratnam [15,16] predicted frequency spectrum having peaks at these frequencies. Defects in components of rolling element bearing such as inner race, outer race, rolling elements and cage generate a specific defect frequencies calculated theoretically [17].

The computation formulas for the BCFs are as follows:

$$FTP = \frac{1}{2}(f_i)\left(1 - \frac{d\cos\theta}{D_p}\right)$$

$$BPFO = \frac{N}{2}(f_i)\left(1 - \frac{d\cos\theta}{D_p}\right)$$

$$BPFI = \frac{N}{2}(f_i)\left(1 + \frac{d\cos\theta}{D_p}\right)$$

$$BSF = \frac{D_p}{2d}(f_i)\left(1 - \left(\frac{d\cos\theta}{D_p}\right)^2\right)$$

Where,

FTF = Fundamental Train Frequency

BPFO = Ball Pass Frequency of the Outer race

BPFI = Ball Pass Frequency of the Inner Race

BSF = Ball Spin Frequency

N = Number of rolling elements

fi = Rotation frequency of inner race

d = diameter of rolling element.

Dp = Pitch diameter

θ = Contact angle

IV. ACOUSTIC EMISSION

Acoustic emissions(AEs)aredefined as transient elastic waves generated from a rapid release of strain energy caused by a deformation or damage with in or on the surface of a material [18]. There have been numerous investigations reported on applying AE to bearing defect diagnosis. When the material is subjected to stress at a certain level, a rapid release of strain energy takes place in the form of elastic waves which can be detected by transducers placed on the surface. Acoustic emission, inmetals,is mainly because of two reasons such as plastic deformation and growth of cracks. AE technique is, therefore, widely used in nondestructive testing for the detection of crack propagation and failure detection in rotating machinery. To date, most research hasstudied crack propagation resulting from artificial or seeded damage. This damage hasbeen induced in bearings by: scratching the surface, introducing debris into the lubricant ormachined with an electrical discharge.The acoustic signal is generated and measured in the frequency range is greater than 100 kHz.In recent years, acoustic emission (AE) sensors and AE-based techniques have been developed and tested for gearbox fault diagnosis[19]. Yoshioka and Fujiwara [20,21] have shown that selected AE parameters identified bearing defects before they appeared in the vibration acceleration range. David Mba *at el.* investigates the application of signal separation techniques in detection of bearing faults within the epicyclic module of a large helicopter (CS-29) main gearbox using Acoustic Emissions[22].Applications of AE to bearing diagnosis for extremely slow rotational speeds have been discussed [23]. The modulation of AE signatures at bearing defect frequencies has also been observed by other researchers [24–26]. Identification of variations of standard AE count parameters can also be helpful in diagnosis of different defects in ball bearings.Another study used vibration and AE for monitoring normal wind turbine gearbox [27]. The demodulated AE signals in detecting defects in rolling element bearings has been demonstrated by some researchers[28,29-31]. There are many analytical techniques such as resonance demodulation, instantaneous power spectrum distribution and conditional moment analysis etc. which have been developed for processing vibration signals to obtain useful diagnostic information [32,33].In highly transient signals such as AE, time and frequency components are very much dependent on each other. This prompted many researchers to work on automatic defect identification using wavelet algorithm [34,35]. Abdullah *et al.* reported relationship between AE r.m.s. amplitude and kurtosis for a range of defect conditions and relationship between the defect size and AE burst duration. Application of the AE technique for identifying the presence and size of a defect on a radially loaded bearing in[36].Centered on the application of the acoustic emission technique for identifying the size of a defect on a radially loaded bearing [37]. The contribution of this work is a methodology for detecting faults in induction motors in steady-state operation based on the analysis of acoustic sound and vibration signals. The faults diagnosed in this work are two broken rotor bars, mechanical unbalance and bearing defects[38]. The application of AE for low speed reversible slew bearings. The study focused on investigation of AE features as condition monitoring parameters for naturally occurring slew bearing defects[39]. Employing vibration and AE toidentify the presence of a bearing defect in a planetary typearrangement has been undertaken [40]. Energy Index (EI) technique, used in detecting masked AE signatures associated with the loss of mechanical integrity in bearings[41].The application of Acoustic Emission (AE) technique to condition monitoring of gears and bearings isgaining significance as it can detect early symptoms of defects such as pitting, wear and flaking of surfaces[42]. The speed and load applied to a bearing were investigatedseparately to determine their individual influenceupon the recorded AE signal when operatingunder a full fluid film lubrication regimedemonstrate the sensitivityof the AE technique to both bearing operatingconditions, and to bearing failure[43].It is concluded thatnot only does AE offer earlier fault detection and identification capabilities than vibrationanalysis but can also provide an indication of the defect size, thus allowing the user to monitorthe rate of degradation on the bearing [44].New approach of optimizing wavelet functions based on minimizing the Shannonentropy of reconstructed signal, and selecting the optimal band pass filter signal using KER calculation ofWPT band-pass signals to detect bearing faults [45]. The values of kurtosis and skewness estimated for theAE signals can be used to identify the crack size [46].Remarkable amount of work has been undertaken over the last 20-years in developing the application of AE technology for bearing health monitoring. Salah *et al.* [47] have been reviewing in various literatures on the significant research on the use of AE in rolling elements for condition monitoring and faults diagnosis. However, the studies carried out by Al-Dossary *et al.* [48-49] on the capability of AE technology for describing the defect sizes on a radially loaded bearing showed a direct relationship between the AE burst period and the defect length for bearing faults, thus creating a way for the user to observe the rate of degradation on the bearing was created; which is not visibly obtainable with vibration analysis [50].

V. CONCLUSION

According to previous studies, acoustic emission (AE) signals contain valuable information that can be used for gear and bearing condition monitoring and fault detection. Sound pressure and sound intensity are used for acoustic measurement purpose. The sound intensity technique seems to be better than sound pressure measurements for bearing diagnostics. Few studies indicate that acoustic measurements are better than vibration measurements and can detect a defect even before it appears on the surface. Some suggested that demodulation of AE signals for bearing defect detection. Thus, the result is enough to encourage and motivate the AE technique to be the new Condition Monitoring tool. Moreover, to make sure that this method is efficient, the fault detection ability on the other modes of gear breakdown, surface damage and fatigue need to be further investigated.

On the other hand, the development of Artificial Intelligent (AI) technique shows a promising potential in machine condition monitoring and diagnosis, although only few articles were found in this area. However Artificial Neural Network(ANN) based on AE has been successfully applied to many relevant problems. It can be considered that ANN is the newest popular method in condition monitoring with AE signal. The use of Fuzzy, Genetic Algorithms and Support Vector Machine in condition monitoring and fault diagnosis based on AE signal analysis still need additional attention because of the absence of existed paper. Lastly, the future works will be to find a new novel idea for machine condition monitoring and diagnosis using AE signal analysis and AI.

VI. REFERENCE

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