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Review on Vibration Based Condition Monitoring of Rolling Element Bearing by numerical method and Its Validation by Experimental Approach

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Abstract— Bearing is very important part in whole machinery as failure in bearing leads to failure in machinery. Vibration analysis is effective method to detect fault in bearing. Vibration analysis is done by condition monitoring effectively by which location of fault & cause of vibration can be easily detected. It makes use of vibration signatures to calculate characteristic fault frequency. Recent trend in vibration analysis is use of numerical method with the help of finite element method. This paper sums up some of the recent research and developments in rolling bearing vibration analysis techniques by numerical approach and its validation by experimental approach.

Index Terms— Bearing, Vibration Analysis, Numerical Method, Bearing Defects, FEA, time domain, frequency domain

1 INTRODUCTION

Rolling element bearings are mostly used in rotating machineries and it is the most critical component. Proper functioning of bearings is most important in nuclear power stations, chemical plants, aviation industries and also process industries. Good performance and reliability of rolling element bearings is essential for proper functioning of machines and to prevent sudden failure of the machinery. Bearing health and performance can be easily identified by using health monitoring techniques. Many condition monitoring techniques is available to monitor the health of bearing; which are wear debris analysis, motor current analysis, noise monitoring, temperature monitoring, vibration monitoring etc. But the vibration monitoring is the most useful technique because it is reliable and very sensitive to fault severity. Bearings act as a source of vibration and noise because of either varying compliance or the defects presence in parts of bearing. These vibration signals will give information about the health of bearing. Vibration monitoring is the general technique to diagnosis of rolling element bearing faults. Presence of surface irregularity like pits, cracks, dislocations are the most obvious parameters in failure analysis the defect vibration signatures tend to vary for different types of defects. **Following Table 1 collects all possible types to detect source vibration & from table it is clear that vibrational analysis is versatile technique. [7]**

Many researchers have been worked on vibration signal analysis techniques and numbers of research papers have been published by them. Vibration signature analysis of defective deep groove ball bearings by numerical & experimental approach by Abhay Utpat [2] modeled whole bearing using ANSYS & their results are compared &concluded that experimental & numerical approach give good match for defected outer & inner ring bearing. In finite element modeling of vibrations caused by a defect in the outer ring of a ball bearing by Arnaz Malhi [1] modeled only outer race with cylindrical defect in ANSYS & energy values of two different types of defect sizes are observed and compared.

TABLE 1
Comparison of Different Methods of Fault Detection

Sr no	Problem	temperature measurement	acoustical analysis	Oil analysis	SPM meter	vibration analysis
1	misalignment					Yes
2	Bent shafts					Yes
3	Bearing damage		yes	yes	yes	yes
4	Mech. Rubbing	yes		yes		Yes
5	Gear damage			yes		Yes
6	Mech. looseness					Yes
7	Noise		yes			Yes
8	cracking					yes

Simulation & analysis of vibration signals generated by rolling element bearing with defects by Zeki Kiral & Hira Karagulle [4] meshed whole bearing structure & dynamic analysis is carried out as well as time domain analysis results were studied. In time domain analysis root mean square (RMS) & crest factor (Cf) are assessed from time domain graph. Their behavior is plotted in graphs with respect to shaft speed conclusion is drawn on the basis of these graphs. Radial ball bearing inner race defect width measurement using analytical wavelet transform of acoustic and vibration signal by Dibya prakash Jena, Manpreet Singh, Rajesh Kumar focused [8] on acoustical analysis to find out source of vibration. Paper reported other techniques like envelope method & self-adaptive Noise Cancellation (SANC) technique gives better result with in conjunction to an envelope detection method. Vibration analysis of rolling

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element bearings with various defects under the action of an unbalanced force by Zeki Kıral, Hira Karagu¨ lle [5] focused on time domain analysis of vibration signals and vibration in machine is introduced by unbalanced forces. For time domain analysis statistical parameters liks kurtosis, crest factor and RMS is calculated and their behavior is observed against different shaft speeds. Vibrational analysis of self align ball bearing having a local defect through FEA and its Validation through experiment by

Prof U.A.Patel, Shukla Rajkamal [3] done modal analysis in numerical metod of defected and healthy bearing and matched that result with experimental reading.

2 DIFFERENT DEFECTS IN BEARING

Bearing defects arises due to faulty design of bearing, manufacturing error, overloading, and lack of lubrication, high temperature application, fatigue, shock or impact loading conditions. Bearing defects can be classified into 2 types distributed defects and localized defects. Distributed defects include surface waviness, manufacturing or assembly error like improper assembly of inner race, outer race and balls, misalignments while localized defects include spalls, cracks due to fatigue, impact or shock loading condition, over speeding. More focus of Vibration analysis technique is on localized defect as local defect produces successive impulses in signals.

3 Bearing Pass Frequency

Each bearing element generates characteristic rotational frequency. Damage on any part of rolling element bearing generates corresponding impulses in machinery called as bearing pass frequency assuming no skidding of rolling elements bearing pass frequency can be given by following equation [9]

1) The frequency of rolling elements making contact with a certain point on the in inner race in equation (1)

$$f_i = \frac{z}{2} f_r (1 + \frac{d}{D} \cos \beta) \quad (1)$$

2) Frequency of rolling elements making contact with a certain point on the outer race in equation (2)

$$f_o = \frac{z}{2} f_r (1 - \frac{d}{D} \cos \beta) \quad (2)$$

Where fi – inner race pass frequency

fo – inner race pass frequency

z– Number of balls

d- Diameter of ball

D-pitch diameter

β-contact angle

fr- rotational speed of inner ring

4 Vibration analysis by condition monitoring

4.1 Experimental approach

a) Time Domain Method

In time domain analysis signals acquired are plotted in time domain that is graph of amplitude of vibration is plotted against time axis. But it is difficult to extract information from time domain signal. Hence to extract information different statistical parameters are used like RMS in equation (3), kurtosis which is given in equation (4)

$$\text{RMS(x)} = \frac{x^2}{N} \quad (3)$$

$$k = \sum_{n=1}^{N} \frac{[x(n) - \mu]^4}{N \cdot (\sigma^2)^2} \quad (4)$$

Where N is number of samples

Vibration analysis of rolling element bearings with various defects under the action of an unbalanced force by Zeki Kıral, Hira Karagulle [5] reported time domain analysis by using three different sensor positions and signals are acquired. In this case vibration is produced due to unbalanced forces. To extract information from them statistical parameters are calculated and plotted against different shaft speeds depending upon the graph pattern conclusions were drawn. Kurtosis value, Crest factor, Impulse factor and Clearance factor are non-dimensional statistical parameters. Impulse and Clearance factors have similar effects like Crest factor and Kurtosis value [5]. It is observed that the acceleration kurtosis ratios can be a good defect indicator at low speeds. Li and Pickering proved that the Impulse factor, Kurtosis value, Crest factor and Clearance factor are all sensitive to fatigue spalling. Conclusion drawn crest factor and the kurtosis ratios can be used for defect detection at relatively low shaft speeds and the defects located at the upper part of the bearing structure are easy to monitor.

Simulation and analysis of vibration signals generated by rolling element bearing with defects [4] by Zeki Kiral, Hira Karagu¨lle included time domain analysis on healthy and defected bearing. To extract information from time domain data statistical parameters are calculated for defect on outer race, inner race and healthy bearing also effect of loading and plotted against different shaft speeds depending upon the graph pattern conclusions were drawn. Similar conclusion observed as above and they found that the kurtosis ratio is not a suitable indicator for defect detection for the second structure. It can be concluded that time domain analyses generally fail while detecting a defect.

b) Frequency domain method

Frequency analysis includes vibration signature against frequency. Frequency-domain techniques convert time-domain vibration signals into discrete frequency components using a fast Fourier transform (FFT). Simply stated, FFT mathematically converts time-domain vibration signals trace into a series of discrete frequency components. Power spectrum is used to identify the location of rolling element defects by relating the

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characteristic defect frequencies to the major frequency components which can be found in the spectrum. The characteristic defect frequencies depend on the rotational speed and the location of the defect in a bearing. It works on principle that when rolling element passes over defect generating peak frequency which is detected by FFT analyzer. The consecutive impacts between the defect and rolling elements and excites the resonances of the structure and hence defect frequency can be detected. Simulation and analysis of vibration signals generated by rolling element bearing with defects by Zeki Kiral, Hira Karagu¨lle converted time domain signals acquired and converted that signals with the help of FFT by filtering velocity signal and by envelope method of filtered velocity axis. They concluded that effect of rotational speed, defect size and loading condition can be illustrated by vibration signal analysis. Each bearing element has a characteristics defect frequency and it can be calculated theoretically as discussed before. Envelope analysis is a well-defined technique for bearing defect diagnosis. Spyridon and Ioannis [10] studied vibration signals of the radial ball bearings which was loaded in radial direction and compared the results taken from FFT and envelope analysis and conclude that bearing fault can be easily found by using FFT where as envelope analysis is tool for detection of the bearing failure. Simulation and analysis of vibration signals generated by rolling element bearing with defects by Zeki Kiral , Hira Karagu¨lle concluded frequency domain technique is sensitive to changes in rotational speeds, structure geometry and loading type. Vibration analysis of rolling element bearings with various defects under the action of an unbalanced force by Zeki Kıral_, Hira Karagu¨ lle found the envelope method can be used efficiently in order to detect the outer and inner ring defects, but rolling element defects are difficult to detect.

4.2 Numerical approach

The present commercial trend to use various computer aided packages for vibration signal analysis and verify it with experimentally. Most of the studies focus numerical approach of vibration signal analysis by using ANSYS. Arnaz S. malhi half outer race with defect and detailed transient analysis were carried out. The radial load is transferred to the bearing structure through more than one ball and therefore a loading zone is formed on the bearing structure considering the total force and moment relationship. The distribution of the load around the circumference of a rolling element bearing under radial load is defined by the Stribeck equation [4]. Principle behind numerical approach was that when ball passes over defect generates force in equation (5)

$$q(\phi) = q_0 \left(1 - \frac{1}{2\varepsilon}(1 - \cos\phi)\right)^n \quad (5)$$

Where q0 –maximum load intensity

ε – load distribution factor

Ø – Angular co-ordinates in load zone with respect to

$$q_0 = \frac{5F_r}{Z\cos\alpha}$$

type of bearing considered

The maximum load can be approximated in equation (6)

$$q_0 = \frac{5F_r}{Z\cos\alpha} \quad (6)$$

Where z- number of balls

Fr- radial load

α- contact angle

By using above formulae Arnaz Malhi [1] calculated load on four different nodes. Two nodes were taken on defect and two nodes were taken just outside defect. Load is considered to be stepped load in this study. After carrying out transient analysis on four nodes with calculated load energy values of 2 different defect sizes were compared. Study found that energy dissipated for smaller defect was seen higher than energy dissipated for large defect. Hence by comparing energy dissipated values difference in defect size can be detected by signal analysis. Abhay Utpat [2] modeled bearing by assuming spring mass system races as masses and balls as spring. Finite element analysis is carried out on whole bearing model for different speeds, loads, and defect sizes. Signals acquired in time domain analysis and frequency is calculated by measuring distance between different two crests. Then results obtained were verified by experimental approach and conclusion drawn. Study found that outer race defected bearing shows higher amplitude than inner race defected bearing. Also defect on outer race defect is more severe than defect on inner race. Simulation and analysis of vibration signals generated by rolling element bearing with defects by Zeki Kiral, Hira Karagu¨lle [4] focused on finding optimum sensor location by High Frequency Resonance Technique (HFRT). Rolling element bearing structure along with outer race with defect is modeled and meshed. Dynamic load model for radial load is formed for different nodes in load zone. More focus of study is on time domain analysis. To extract information from time domain analysis statistical parameters such as RMS, kurtosis is calculated [4],[5]. These parameters are plotted against different shaft speeds. After observing their behavior and frequency domain analysis conclusion were drawn. They found that both time domain and frequency domain techniques are sensitive to change in speed, structure geometry and loading type. Also numerical method can be used to find out optimum sensor position and signal processing technique. Vibrational Analysis of Self Align Ball Bearing Having a Local defect through FEA and its Validation through Experiment by Prof U.A.Patel, Shukla Rajkamal done modeling of bearing shaft assembly in PRO-E and then it is exported in ANSYS [3]. Modal analysis was carried out and results obtained were verified by experimental approach using frequency domain analysis. Study found that numerical result almost matching with the maximum amplitude values of experiment result. In addition this study also recorded in finite element software different damping coefficient and damping ratio was changed and correspond to that various amplitude in terms of displacement were recorded and for these values graphs were plotted by

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seeing these graphs. It is found that damping ratio and damping coefficient serves inversely proportional relationship and it is helpful to increase bearing life.

5 Conclusion

This paper is an attempt to summarize vibration analysis technique by numerical approach and its validation by experimental method. In experimental approach it is found that the time domain techniques only can indicate the faults present in the bearing but it fail to identify the location up to some extent. Frequency domain techniques have ability to identify the location of faults in bearing. When ball passes over defect generates peak frequency which can be matched with characteristic frequency. Numerical approach in most of the studies is carried out by finite element analysis. Numerical approach is complicated but it can detect change in defect size, load type, defect position. Also numerical result can validate by experimental approach.

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