Fault Detection of Roller Bearing Using Vibration Analysis

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Abstract—The rolling element bearings are commonly used in rotating machinery, it mostly covers a broad range of rotating machinery and plays a significant role in industrial applications which is considered as a most critical element. If loads are moved in relative motion in between machine surfaces, then the action can simplify in an effective manner when rolling elements are interrupted between the sliding members. The bearing contains four mechanical components: an inner race, an outer race, rollers or balls, the groove that holds the balls. Ball bearings have limited load carrying capacity and smaller in sizes but it can support both axial and radial loads. The load distribution is given in the direction of applied force. When the ball rotates in the inner race or the outer race is held stationary. In the ball bearing most defects occur on the load zone which is directly under the applied force. The presence of tiny defects on the bearing may cause failure which leads to personal and economical losses. Main causes of bearing failure in the machinery are misassemble, insufficient lubrication, misalignment, overloading, dirt, corrosion, and manufacturing fault. The defects of the bearing are mainly considered in 'Distributed defect' and 'Localized defect. For detection and diagnosis of bearing defects condition monitoring used for inspecting the quality of bearings. Condition monitoring reduced the risk of serious accidents by avoiding failures. Vibration analysis is a fundamental tool of condition monitoring which has been developed widely. These vibration signal give the information about bearing health and detect incipient faults before they converted into critical defects. Vibration monitoring is very reliable and sensitive for fault severity. Most currently used fault detection methods are included in the following Categories: visual or localized experimental methods such as acoustic emission signals methods, Condition monitoring, wavelet packet transform (WPT) and vibration analysis methods.

Keywords — Rolling element bearing, Acoustic emission signals, Condition monitoring, Wavelet packet transform, vibration analysis.

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1 Introduction

A Rolling element bearing is one of the most widely used elements in rotating machinery. Due to the low friction, bearings are very crucial part in various engineering applications. The reliability and robustness of the bearings are vital qualities for the health of a machine. Bearing fault is also one of the primary cause of catastrophic failure in rotating machines. Due to failure of bearing there are several serious issues arise, which can decrease the production efficiency and huge economic loss. Where faults in bearings can also arise during the manufacturing process or throughout the time of use. Condition monitoring technique is important to detect and diagnosis the defects of bearings. It helps to reduce the destructive failures and maintenance cost through the detection and identification of early fault in the bearing. Diﬀ erent methods are used for the detection and diagnosis of bearing defects. Where, vibration measurements are the most widely used. Vibration analysis is that the most legendary technology applied for condition monitoring and are usually adopted for their easy acquisition and sensitivity to vary of faults of rotating machineries.

1.1 Fault detection

A bearing contains four main part, balls, cage, inner race, and outer race. Due to overload, unbalance, misalignment, improper lubrication and installation, corrosion etc. these parts might get damaged. Typical bearing faults are, axial, radial, bending moment, a shield defect and contamination. By evaluating the severity and nature of the defect and the lifespan of the bearing correctly then we can replaced the faulty bearings. In the initial stage of bearing wear, the frequency of the vibration is very high where the amplitude is very low. The design of rolling element bearings makes it much easier to detect fault conditions at an early stage because of the bearing geometry. Due to early stage of wear high frequencies generated which is easy to distinguish other fault conditions. But in this case it need to measure the vibration and analyse the data correctly. When an incipient fault is first initiated, the damage occur first in the subsurface of the bearing then it extend to the surface. Diagnosis identify the machine's condition or faults. If the presence of faults unseen for a prolonged period of time can cause the catastrophic failure of the system. The various techniques that are being employed for data collection are vibration monitoring, ultrasound thermal imaging, oil particle analysis, enveloping (demodulation), etc. The results of this analysis are used to find out the root cause failure to identify and remedy the main cause of the defect.

1.2 Machine Condition Monitoring

Condition-monitoring (CM) techniques are essential to get the operation condition data of a rotating machine which can provide incipient faults of machines to take an appropriate action before that fault causes breakdown or a harmful failure. It simplify to avoid irregular event development, minimize loss, also as develop the stability of rotating members. CM shows that under certain loading condition when the bearing is operated at a certain rotating speed, then the defective frequency components in a signal are formed due to faults present in a bearing. These data can then be analysed by using relevant signal analysis techniques to get the most appropriate characteristic constraints before being used in diagnosis to evaluate the health condition of the machine. Condition monitoring can

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improve the reliability of rolling bearing, increase the efficiency of machine operation, reduce replacement cost & rise the useful lifespan of the machine. Continuous CM permits a machine repair and maintenance to improve the economical operation and reduce the potential harmful discharges. The data employed in a condition-monitoring program can be noise, vibration, electric current, oil and grease, temperature or a combination of these data. It is used to evaluate the health condition of the machines the generated information are analysed by proper signal analysis techniques such as, time-domain techniques, frequency-domain techniques, or time-frequency techniques. This section reviews some of the most commonly employed techniques in condition-monitoring applications of rolling element bearings

2 Procedure

2.1 Review Stage

In this segment, signal processing technique is used to monitor the condition of rolling element bearing system which is based on vibration signals and acoustic measurements, wear debris analysis and temperature measurements. Vibration signal measurements techniques are most widely used. Relevant techniques have been applied to evaluate the vibration and acoustic responses from the defective bearings are briefly discussed here to understanding the result which are obtained from the following chapters of this thesis. The principle causes for bearing failure are given by an error of design, includes improper bearing geometry which is caused by using wrong materials, lubrication, quality etc. And application error like a manufacturing error which caused by vibration. Error can be formed due to machining fault and also due to heat treatment during mounting or installation, maintenance of bearing.

Farzad et. Al [1] (2016) have studied the robustness and reliability necessarily need qualities of the bearing for the machine health. For enhancing the ratio of Shannon entropy and Kurtosis the algorithm is established in the optimal bandpass filter by applying envelope detection and wavelet packet transform (WPT). Acoustic emission technique is measured the size of defect on rolling element bearing by its accuracy and with the help of a wide range of squared Hilbert transform implemented under different loading conditions, rotating speeds and defect sizes to calculate the time difference between the double AE impulses.

Lei Y et. Al [2] (2011) in machinery fault diagnosis a very powerful tool is used known as Kurtogram. Kurtogram detects and characterizes transients in a signal. It is established on the short time Fourier transforms (STFT), for identifying the machinery fault and noisy signals more precise filters are needed. Where the filters are founded on the wavelet packet transform (WPT). Here two varieties of rolling element bearings are used for collecting the vibration signals and improve the performance of the recommended method which is related with the original kurtogram.

Wu JD and Liu CH [3] (2009) wavelet packet transform (WPT) improved the continuous wavelet transform (CWT) used over a huge operand and lengthier computing time. The frequency-band variance can also solve by discrete wavelet transform (DWT). In this investigational work, the mother wavelets are used to perform and build the recommended WPT technique. WPT technique takes several advantages on CWT and DWT.

Sawalhi et. Al [4] (2007) have been studied that Spectral kurtosis (SK) remove transients submerged which present in the noise. Signals are analyzed with minimum entropy deconvolution (MED) technique from a high-speed test rig containing a bearing through a spalled inner race. Minimum entropy deconvolution improves the effects of envelope analysis.

Zarei J, Poshtan J [5] (2007)Describe that in the Meyer wavelet the detection of bearing defect is discovered by using the stator current study as the fault indicator in the wavelet packet structure. In this technique, WPT can provide better analysis which covers the range of frequency band and its detection are easier due to the actual bearing-defect and produced the vibration frequency.

Antoni J. [6] (2006, 2007) spectral kurtosis (SK) identifies the occurrence of non-Gaussian constituents caused by the bearing faults to specify the range of frequency in which it can occur. It can also find the position in the frequency domain and presence of the transients in a signal. Kurtogram is a two-dimensional chart that grants the bandwidth (f) and optimal central frequency (f) for maximum value of kurtosis

Randall R and Antoni J [7] (2006) derive that the high prospective detection of the spectral kurtosis (SK) and illustrate the non-stationary signals. The transient elastic waves known as acoustic emissions (AEs) are produced a rapid release of strain energy can damage the surface of a material. Spectral kurtosis identifies and characterizes the non-stationary signals. It delivers a powerful way in the presence of strong masking noise for recognizing the incipient faults. For presenting en

Qiu H et. Al [8] (2006) describe the staging of traditional wavelet decomposition-grounded on de-noising methods is significantly affected on the signal coefficient by the relative energy levels. Morlet wavelet filter-based on the de-noising method for identifying the weak signature after a faulty bearing signal. Optimal time-frequency with optimal wavelet shape factor can be achieved by the implementation of minimal Shannon entropy criterion.

Singh BN, Arvind K. Tiwari [9] (2006) proposed that when the signal peaks near to the full amplitude, then the mother wavelet base functions are useful for denoising of the ECG signal in the wavelet domain. The wavelet-based denoised ECG signals are obtained to keep the essential diagnostics information confined in the original ECG signal.

Tandon N and Choudhury A [10] (1999) proposed that condition monitoring of rolling element bearings are used in different vibration and acoustic methods. Vibration calculations are done by the acoustic emission technique, frequency and time domains, and the sound measurement. In time domain the vibration can be measured by RMS level, probability density, crest factor, and kurtosis. The defect location can be identified through the frequency domain and also by the acoustic emission measurement

Abry P. Ondelettes [11] (1997) state that the maximum kurtosis to Shannon entropy is obtain by the mother wavelet which

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is preferred to be the all majority appropriate wavelet for fault withdrawal of bearings. Several orthogonal wavelets are used to evaluate the test signal, the corresponding frequency of scale has the maximum amplitude from the spectral study is designated to execute the wavelet transform.

Martin H and F. Honarvar [12] (1995) state the differences of the statistical moment analysis technique indicates the possible damage detection in the earlier stage. The data for the study is comparatively easy to accumulate by using an accelerometer which is mounted close to the bearing and then processed through a microcomputer by using appropriate software. Here data of the damaged and undamaged bearings are evaluating by both of the rectified and unrectified signals.

McFadden P, Smith J. [13] (1984) has been stated that under constant radial load, the vibration is formed on the inner race of a rolling element bearing by single point defect. The inner race defect and radial load of bearings have been presenting that the model suitably evaluates the relative amplitudes and frequencies of the spectrum.

Cizek V. [14] (1970) FFT study of the signals does not afford more data, hence high-frequency and noisy constituents are originate by the motion of rolling elements in opposition to each other frequencies of bearing faults. The fault frequencies are easily measured in the signal envelope.

2.2 Artificial intelligence method in fault detection

To develop the recent methodologies several diagnostics techniques have been recommended for different types of fault detection in rotating machinery. In the modern times the systems have depended on artificial neural network techniques to robustness and strengthen the of diagnostics structures. Artificial intelligence techniques of artificial neural network have been employed to reveal the analytical survey for fault diagnosis of bearings. AI techniques are easy to extend and modify when it is applied to rotating machinery so, it gives improved performance. For pattern classification, artificial intelligent (AI) methods are sometime employed to detect and to identify the faults. It also improve the accuracy and efficiency of fault diagnosis of rotating machineries. The main steps of an AI based diagnostic procedure are 'fault identification', 'fault severity evaluation' and 'signature extraction'. It recorded the natures of several damage states of bearings such as; mode shapes values of the bearings and natural frequencies by applying input data to diagnosis the condition of the faulted bearing. The artificial intelligence technique primarily based on the technique for on-line fault diagnosis to avoid catastrophic failure of mechanical system. By Using MATLAB'S neural network toolbox an ANN model was developed which are inspired from biological neural networks and composed from simple elements operating in parallel manner. The important neural networks have the ability which is employed to find out the appropriate solution for linear issues in order to solve non-linear issues. Applications of artificial neural network techniques includes, artificial neural network, fuzzy logic and genetic algorithm for fault detection of bearings.

2.3 Tables and Figures

Table -1

SI No.	Depth of defect on ball (in mm)	Relative natural Frequency (in Hz)
1	0	0
2	0.03313	-0.21136
3	0.5575	-0.19985
4	0.2969	-0.12096
5	0.04605	-0.06548
6	0.3919	0.075875

Table -2

SI No.	Depth of defect on ball (in mm)	Relative natural Frequency (in Hz)
1	0	0
2	0.022	-9.431285593
3	0.04525	-0.095576646
4	0.101	-0.029087877
5	0.2282	0.5131746
6	0.5151	0.89733064

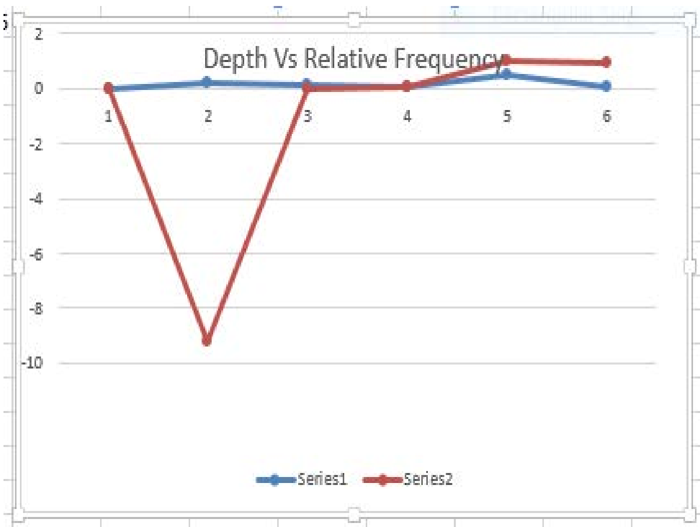

Fig-1; Graph between Depth & Relative frequency (table-1)

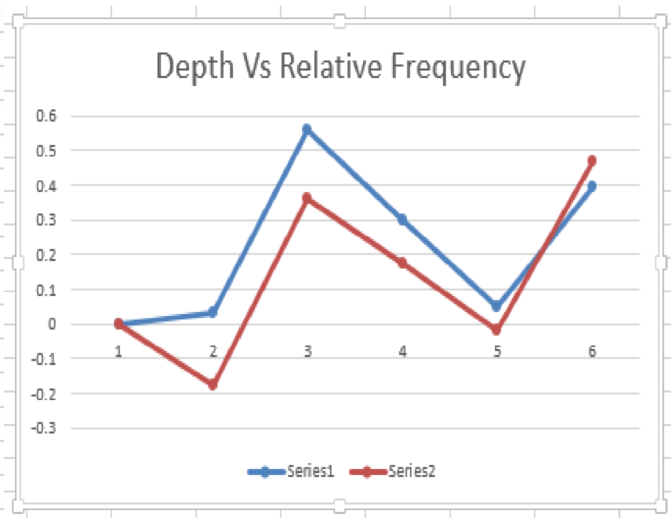

Fig-2; Graph between Depth & Relative frequency (table-2)

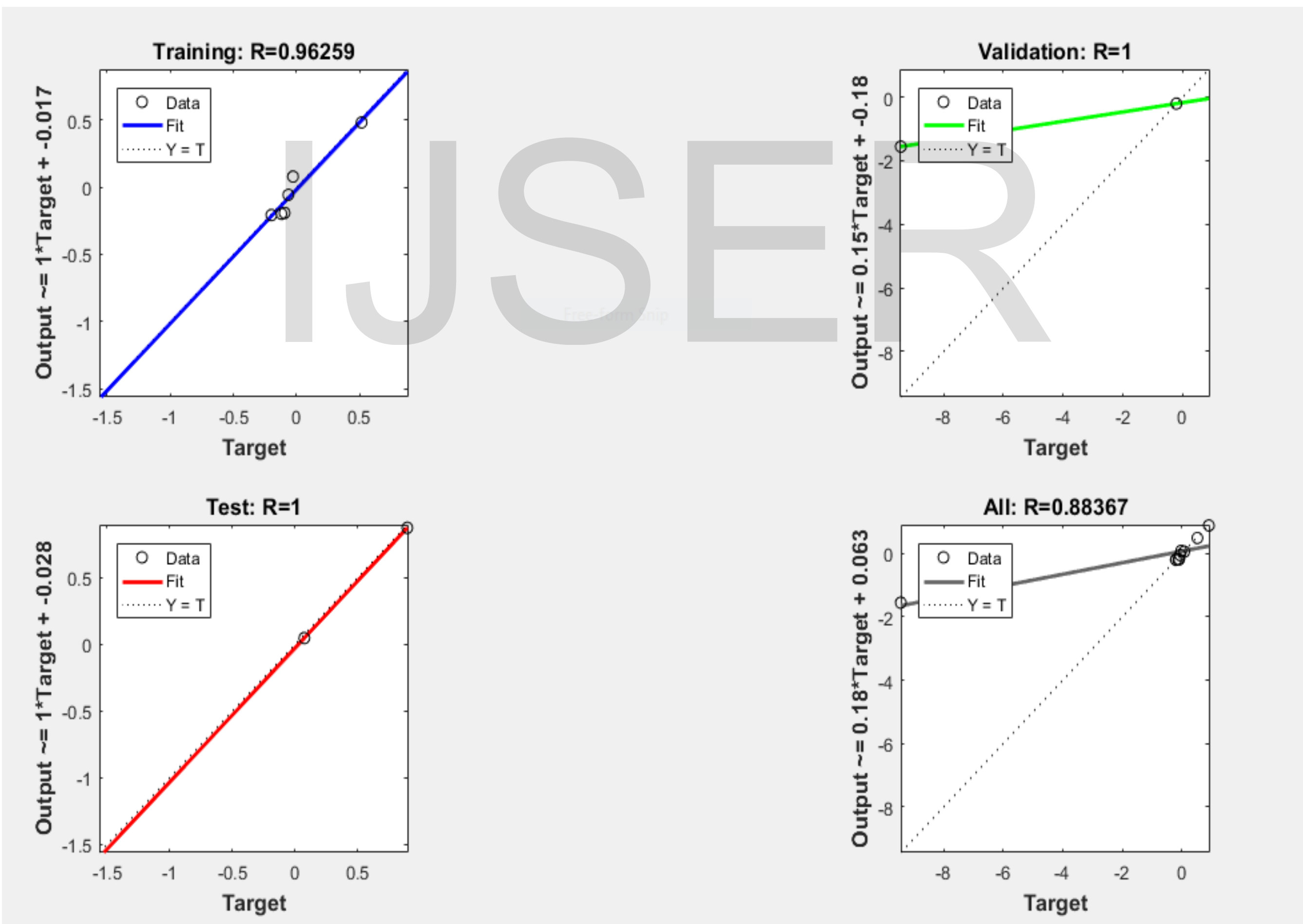

Fig-3: Plot progression of NeuralNetwork

3 Equations

The relative natural frequencies of the faulted ball bearing are calculated as:

$$rel.f = (\Omega n_{(healthy)} - \omega_{n\ (defective)}) / \Omega n_{(healthy)}$$

Where, rel.f = Relative frequency

$\Omega n_{(healthy)}$ = Natural Frequency of healthy bearing

$\Omega n_{(defective)}$ = Natural Frequency of defective bearing

4 Conclusion

This paper improved the prognostic technique to forecast the bearing defect. By using vibration analysis there is a change on the mode shapes and natural frequencies of the ball bearing in the decrease of ball radius. The ball radius of a ball bearing can be evaluated by using the values of relative natural frequencies by obtained from analysis.It can be observed that several damages can be found out by using artificial intelligence technique of ANN models which are trained with only relative natural frequencies with a reasonable accuracy. It also observed that whene there is a decrease in ball radius, then the relative natural frequency of vibration increases. This methodology takes very short time to give the overall performance of the adaptive prognostic system.

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