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A Review on Rolling Element Bearing Of Acoustic Based Fault Detection Methods

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Abstract— *A rolling element bearing is a major component in revolving equipment and used in various industrial applications. A sudden failure of the bearing may cause substantial economic losses. Therefore, it is very important to find early fault symptoms in various methods, where the vibration analysis is most widely used. Vibration analysis has been used such as a prognostic maintenance procedure and as a support for machinery maintenance decisions. By using appropriate signal processing methods, changes in vibration signals which are produced by fault can be identified for evaluating the health status of the roller bearing. Vibration techniques are difficult to detect the fault in early stage so acoustic emission (AEs) were used. Transient elastic waves are the acoustic emissions which produced strain energy which impairment the material surface. Here the analysis for using the algorithm for maximizes the ratio of Shannon entropy and kurtosis for wavelet packet transform (WPT) and the optimal bandpass filter utilizing envelope. This paper provides a verify review of various technique i.e nature, the severity of the defect and predicts the machine's failure.*

Keywords- *Acoustic emission signals, Condition monitoring, Wavelet packet transform, vibration analysis*

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I. Introduction

The rolling elements bearings are commonly used in rotating machinery, it mostly covers a wide range of rotating machinery and plays an important role in industrial applications which is considered as a most critical element. If loads are moved in relative motion in between the 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 outer race, an inner race, balls or rollers, 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 economic losses. Main causes of bearing failure in the machinery are misassemble, insufficient lubrication, misalignment, overloading, dirt, corrosion, and manufacturing fault. The faulty bearings were mainly categories in localized and intensified defect. For revealing and analysis of bearing faults in mechanical condition monitoring are used for checking the quality and quantity 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. Frequently used the damage detection approaches were included in the following classification which included the wavelet packet transform (WPT), vibration analysis techniques and acoustic emission signals methods.

II. Bearing Failure

The bearing failures can occurs in various modes. In below details of failure are given.

2.1 Excessive loads: Excessive loads lead to premature fatigue due to which spalling occurs on the ball path.

2.2 Overheating: Introduce It occurs due to improper lubrication and extreme operating temperatures cause oxidation leaving a dry, brittle that can cause the bearing failure. Its symptoms are discoloration of the balls, cages. cause the bearing failure. Its symptoms are discoloration of the balls, cages, and rings that are from gold to blue. There is a loss of capacity and hardness of bearing.

2.3 True Brinelling: Brinelling occurs due to exceeding of loads to the elastic limit of the ring material or rapid movement of the balls in the raceway whereas the equipment is idle. Brinell marks in the raceways defined as concavity which increases the bearing vibration (noise). Extreme Brinell impression can arises the premature fatigue failure.

2.4 Contaminations. It is caused by external substances which are getting into the bearing lubricants. Contamination includes dust, dirt, abrasive sand, steel chips from unclean areas etc.

2.5 Normal Fatigue Failure. Fatigue failure occurred due to spalling fracture on the running surfaces and successive elimination of discontinuous, small particles of material. Spalling can arise on the outer ring, inner ring, or balls. This type of failure is continuous and when initiated it will increase as a consequence of more operation. It will always be conveyed by an obvious rise in indicating an abnormality and vibration.

2.6 Fitting: It causes due to improper clearance during installation. Loose fits can cause Outer race slippage. Tight fits Indicate substantial ball wear path in the bottom race.

Condition Monitoring Techniques

Condition monitoring can improve the efficiency of machine operation, improve the reliability of rolling bearing, reduce replacement cost & increase the useful lifespan of the machine. It shows that under certain loading form when the bearing is operated at a definite rotating speed, the defective frequency components in a signal are formed due to flaws present in a bearing. This generated information are diagnosed by proper signal analysis techniques to evaluate the health condition of the machine. Signal analysis techniques of condition monitoring include frequency-domain techniques, time-domain techniques, or time-frequency techniques.

Vibration Measurement Techniques

It is a time- domain statistical technique. It is based on the variation of observed data or information which can extend to provide a future data indication and established a prognostic model on the observed data.

2.1 Rms & Burst Duration. These are used as the most significant statistical parameter for estimating the defect size. It accurately measures the defect size and locations of bearings.

2.2 Crest Factor. It is the ratio of peak acceleration and RMS. At advanced stages of material wear, RMS increases, bearing damage propagates and crest factor decreases.

2.3 Kurtosis. It is a statistical measurement technique used in industries to detect the incipient faults and health of bearing by describing whether it is relative to a normal distribution and skewness of the observed data.

Kurtosis= $\sum_{n=1}^{N}\left(\frac{[x(n)-\mu]^4}{N(\sigma^2)^2}\right)$ ……………………..(i) Here, x(n)= time series,

μ= mean value
σ= variance of data
N= total number of data point

2.4 Skewness. It is more delicate to loading conditions and easily tracks the bearing conditions. There are no substantial changes by increasing the defect size of bearings. It describes the shape of the distribution curves.

2.5 Peak To Peak Value. It only shows the damage at bearing but does not give the information about the defect locations (inner race, outer race, cage or the roller).

III. Review

2.6 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.

2.7 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.

2.8 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.

2.9 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.

2.10 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.

2.11 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 (Δf) and optimal central frequency(f) for maximum value of kurtosis.

2.12 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 envelope analysis the optimal band-pass filters can be determined.

2.13 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.

2.14 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.

2.15 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.

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

2.17 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.

2.18 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.

2.19 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.

IV. Mathematical Analysis

The characteristic fault frequencies can be calculated by the following equations.

- Ball pass frequency outer race(BPFO):

$$\text{BPFO}=\frac{n}{2}f\left(1-\frac{d}{D}CosB\right)\quad\text{……………(ii)}$$

- Ball pass frequency inner race(BPFI):

$$BPFI=\frac{n}{2}f\left(1+\frac{d}{D}CosB\right)$$ …………….(iii)

- Ball spin frequency (BSF):

$$BSF=\frac{D}{d}f\left(1-\left(\frac{d}{D}CosB\right)^{2}\right)$$ …………(iv)

- Fundamental train frequency(FTF) :

$$FTF=\frac{1}{2}f\left(1-\frac{d}{D}CosB\right)$$ ……………...(v)

Where,
f=shaft frequency,
n=number of ball,
B=contact angle between inner race and outer race,
d=ball diameter,
D=bearing pitch diameter

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Time-frequency domain technique (TSA) used to remove the noise from the signal successfully. Wavelet Transform shows a precise result for localizing and detecting the fracture with different damages in bearing. The rolling bearing faults are used under stationary and non-stationary operating under different load condition. The rolling bearing techniques with time-frequency for vibration signals such as RMS value, crest factor, peak level value and complete vibration level. The ball bearings to be the presence of several defects on their races have been studied in time-frequency domains. The key points of vibration measurement such as time domain and frequency domain. The frequency spectra are to be identifying the single defect and two defects, the time delay between two defects is no additional frequencies are due to impulses generated.

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