A critical review of condition monitoring parameters for fault diagnosis of rolling element bearing

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Abstract: Rolling element bearing find predominant domestic and industrial applications, so genuine functioning of these appliances depends on proper functioning of bearing. Detection of defects are not found in time it leads to malfunctioning of the machines. A plenty of work on condition monitoring and detection of defects in bearing has done already. This paper presents a brief review of all this work to provide a good reference for the researchers to be utilised. This covers latest developments in research on detection of bearing faults, different origins of vibration and vibration analysis techniques in time domain, frequency domain, time and frequency domain and some new signal processing techniques.

Keywords: Rolling element bearing, defects, vibration analysis, time domain, frequency domain.

1. Introduction

Rolling element bearing is an absolutely necessary machine element which plays a crucial role in all types of rotating machinery is totally depend on the health condition of rolling element bearing which recital almost 45 % of these machine failure. Thus they are considered as the most censorious constituent of rotating machines. The durability of bearing is must require for good condition of machine. In working condition bearings are subjected to abounding loads initiated by machines and passed through the parts of rolling element bearing, so vibration monitoring of bearing is contemplate as a core part of rotary machineries to assure to constant decrease an element prize, unplanned downtimes and unpredicted malfunctions, therefore early detection of these bearing faults is very much important for condition monitoring and smooth operation of rotating machines. Various techniques are obtainable for identification and discovery of defects that are likely to be classified like vibration analysis, acoustic and temperature measurements and wear debris analysis. Vibration analysis is widely useful techniques between all of these techniques. The vibration signatures obtained are found to be unique for a particular type of bearing fault and these can be used for identification of bearing faults. When a rolling elements inflict a defect on races, an impulse is generated these impulses will be periodic with certain amount of frequency. Smith and McFadden suggested a vibration based model for identifying single point fault on inner race of bearing [1]. A review of vibration monitoring parameters in time and frequency domain analysis is represented by Mathew and alfresco in 1985 [2]. N Tandon, some condition monitoring techniques such as vibration, stator current, acoustic emission and shock pulse methods are compared [3]. Kim also reviews some specific signal process techniques for health of bearings[4, 5] .The Continuous wavelet transform (CWT) techniques is applied to determine these bearing faults [6].Therefore the focus of this study is to cover latest developments in research on the vibration analysis techniques for diagnosis of defects in rolling element bearing.

2. Bearing defects

Some of the researchers explain the phenomenon of vibrations in the rolling element bearing [7, 8, 9, 10]. Rotating element bearing regular service life under the load is identifying by the material fatigue and wears at the working condition. there are huge number of factors can cause a betimes failure in rolling element bearing these are corrosion ,fatigue, wear, brineling, plastic deformation ,low lubrication, wrong positioning and in corrected design ,so finding these defects early in time is important is for smooth working of rotating machinery. These are classified as follows

2.1 Distributed defects

These defects consist of surface roughness, waviness, misalignment in races & off-size rolling elements. If surface feature is having smaller wavelength then it is called as roughness. If wavelength of surface feature is longer one, then it is called as waviness. The manufacturing error, improper installation or abrasive wear causes distributed defects in races. The variation in contact force between rolling elements and raceways due to the distributed defects results into increase in vibration signatures due to changes in contact force between rolling elements and races. Therefore the analysis of vibration response caused by fault is essential for quality inspection and condition monitoring [11].

2.2 Localized defects

These defects involve cracks, pits and spalls on rolling surfaces. The most influential approach of failure of rolling element bearing is observed to be fragmenting of the raceways or the roller. In such type of failure, fatigue crack starts below the surface of metal and it generates towards the surface until a metal piece breaks in a small pit. Fatigue failure may be happened due to overloading or shock loading of the bearing during operating condition & installation. In the literature they also explained the excessive shock loading which generates electric pitting or cracks on rolling surfaces [12, 13, 14, 15, 16].

3. Origins of vibration

The parts of rolling element bearings are inner ring, outer ring, roller, and separator come in contact by a merging of sliding and rolling to provide intricate vibration signatures. Impact energy, vibration measured at point and construction of bearing on these parameters amount of vibration is dependant. The different origins of vibration like, variable compliance, geometrical imperfection, surface roughness, waviness, raceway defect, roller defect and separator defect [17].

4. Vibration measurement techniques

Some methods are used to calculate and analyses the vibration signatures of bearing with local defects. Vibration methods they don't have their own governing equation and these are corresponding to each other.

4.1 Time –domain Approach

Time domain signals have time as one axis (independent variable) and vibration amplitude as other (dependent variable). It shows nature of vibration signal whether it is sinusoidal, random, repetitive or transient in nature. The main advantage of collecting and storing data as a time domain signal is that detailed analysis is possible at later stage and no loss of data is there prior to analysis. There is often too much data being collected for simple and direct defect analysis. Most of the times, information characterizing the faults is hidden in the spectral content of the signal. These signals are useful for studying transient types of vibration signals. Some mechanical problems, in spite of having different dynamic behaviour, may result in identical frequencies. Many times it is found that spectra of impulse or transient and random signal are same even though their time Domain representations are very different in nature. Hence the spectrum may not provide all the information needed to make a complete diagnosis. Therefore it is better way to examine the time waveform. From the time record of vibration signal, some indices are useful in diagnostics. The most Commonly used indices are the statistical parameters which can be computed from raw vibration signal and which highlight differences between records, making them useful for defect identification in rolling element bearings. Unfortunately these parameters cannot identify the faulty component in the machine since they are affected by vibrations of all the components of the machine. Some of these indicators are peak, RMS, crest factor, kurtosis, K-factor, impulse factor, shape factor, probability density function etc. It is beneficial to take plot of these features at regular intervals of time. Significant variations of these features from their reference or base line values (measured in normal condition) will indicate that the system has faults.

4.1.1 Peak (maximum) value
The most common statistical parameter used to identify the defect is peak value without considering of time history of wave this indicates the maximum value. It is remarkable parameter for quantifying the level of short duration shocks, which is typically half sine in nature, as the growth of defect increases the peak value also increases [11].

4.1.2 Root mean square (RMS) value
The RMS value is calculated taking into consideration of the time history of the wave. The RMS value measures the energy content in vibration analysis and it is used for severity of the fault detection. RMS value
Is very useful for gross vibration level, but it does not indicate on which component fails. For finding the major out of balance RMS value is very effective. RMS value also increases as the defect size increases.

$$RMS = \sqrt{\frac{1}{M}(Y_i - \bar{Y})} \quad (1)$$

4.1.3 Crest Factor
It is the ratio of peak value to RMS value and it is a dimensionless quantity. A machine with a major imbalance have a usual vibration signal and the value of crest factor is about 1.5 but as the bearing starts to wear resulting in impacts ,the crest factor must be higher than this. The resulting of the keen peaks in signatures is that the peaks are very shortly lived and does not contain much energy. It is very helpful for identify the faults in bearings. Crest factor is easily measured and is relatively in sensitive to bearing speed and load. Though it increases under bearing faults, it may decrease in the final stage of the fault due to a considerable increase in the RMS value with progressive wear [11].

4.1.4 K and Impulse factor
It is the product of the peak value and the RMS value of the time signal. It increases as bearing defects increases.

Impulse factor
It is also a good indicator of identify the faults and is defined as the ratio of peak value to mean value of the time signal and computed as

$$\frac{peak}{\frac{1}{M}\sum|Y_i|} \quad (2)$$

4.1.5 Shape factor
It is the ratio of the RMS value to the mean value of the time signal. It presents changes under unbalance and misalignment. The value of shape factor computed as y =

$$\frac{RMS}{\frac{1}{M}\sum|Y_i|} \tag{3}$$

4.1.6 Kurtosis

Kurtosis is a fourth moment, return to the normal with respect to the fourth power of the standard deviation. The vibration signatures initiated in beginning stages of bearing defect kurtosis is the indicator always used and it is responsive to impulsiveness. [18] First proposed importance of kurtosis for bearing defect detection by Dyer and stewart. [19]

The kurtosis is computed by,

$$K = \frac{\frac{1}{n}\sum_{i=1}^{n}(y_i - \bar{y})^4}{\sigma^4} \tag{4}$$

Where y_i is the instantly amplitude $\bar{y}$ is the mean and σ is standard deviation of data n is the sample length. For a good bearing the value of kurtosis is 3 and value more than 3 shows the defect in bearing, and no previous history is required. limitation of the kurtosis is when the fault is more ahead its value comes down up to the level of undefective bearing. Some other papers also proposed the efficacious of kurtosis in fault identification [20, 21, 22,23]. But in some papers the method does not find the defect efficiently [2, 5, 24]. Morando proposed on-line condition monitoring techniques of bearings by shock pulse methods [25].

4.2 Frequency domain Analysis

Frequency domain analysis is also called as spectrum analysis. It is the universal techniques for processing the vibration signals. it is mostly used in diagnosis of rotating machinery faults and 75% to 85% mechanical problems identify with the frequency domain analysis.

The time domain signal is transformed into the frequency domain by implementing Fourier Transform using FFT algorithm. In frequency domain contains the energy in different frequency elements and amplitude vs. frequency graph of signal is plotted. This frequency domain is used for cyclical in the vibration signatures as they are surely observed the peaks in the spectrum at corresponding frequencies. The main indicator of defect is the observation of characteristic defect frequencies in the frequency domain analysis. It is mostly rely on the rotational speed and the location of the defect.

Every bearing element has characteristic rotational frequency, as the defect occurs in bearing there is increase in vibrations so at this moment rotational frequency occurs in element. These characteristic frequencies computed from kinematic considerations. i.e. geometry of bearing and its rotational speed [24,26,27,28,29,30] .

Corresponding frequencies with defective bearings are,

$$BPFO(Hz) = \frac{b}{2} f_s \left(1 - \frac{RD}{PD}\mathrm{Cos}\,\gamma\right) \tag{5}$$

$$BPFI(Hz) = \frac{b}{2} f_s \left(1 + \frac{RD}{PD}\mathrm{Cos}\,\gamma\right) \tag{6}$$

$$BDF(Hz) = \frac{RD}{PD} f_s \left[1 - \left(\frac{RD}{PD}\mathrm{Cos}\,\gamma\right)^2\right] \tag{7}$$

$$FTF(Hz) = \frac{1}{2} f_s \left(1 - \frac{RD}{PD}\text{Cos}\,\gamma\right) \tag{8}$$

Where, b is the number of balls, RD is rolling element diameter, PD is the pitch diameter, γ is the contact angle, f_s is the Rotational frequency.

Several researchers have been studied successfully detection of defects in bearing by identify these characteristic rotational frequency. [28, 31, 32, 33, 34, 35]. In some papers they said that it is tough to get a significant at these frequencies in the direct spectrum obtained from a defective bearing[36, 37] .Tondon proposed that cestrum unable to identify defects at inner race but he founds outer race defects capably [38].To better the signal to noise ratio in bearing defect identification Adaptive noise cancelling (ANC) technique is used [39].FFT is better when signal to noise ratio is low and signals are non-stationary Envelop detector or high frequency resonance technique also used for the defects faults identification, In this faults are determined by the extracting the characteristic bearing frequency. The vibration signal is bandpass filtered about one of the resonant frequencies excited by the defect striking within the bearing which exclude most of undesirable vibration signal. Using the envelope detector band pass filtered signal gets rectified and smoothed by low pass filter which is turn eliminate the carrier. Several researchers have been used this techniques efficiently. [40, 41, 42, 43]. Randoll and ho proposed that in cooperation of envelope technique self-adaptive noise cancellation (SANC) techniques gives better result.

4.3 Improvement of Frequency Domain

Now time frequency domain vibration analysis techniques used for diagnosis of machine the vibration generated by a wear are more complex than the fatigue failure. Common rotating machines required simple condition parameters techniques like time domain and frequency domain and complicated rotating machinery requires highly developed signal processing techniques[44] .the importance of time –frequency analysis is that they represent the vibration signal in both time and frequency domain. This feature is helpful in analyse the non-steady vibration signal. The researchers finding the type, size, and location of faults in rolling element bearing by using various signals processing techniques such as time frequency analysis, high frequency resonance techniques (HFRT), and wavelet transform. Morphological signal processing techniques [44, 45].empirical mode composition [46]. Harr Transform, cesptrum analysis, higher order spectral analysis, Adaptive noise cancellation (ANC), Artificial neural network (ANN) and cyclic autocorrelation.

A wavelet Transform technique is mostly used time frequency domain techniques for bearing fault identification. Taking STFT as reference the CWT Technique is developed for better results of time frequency resolution, [48] the discrete wavelet transform technique was used to identify the spalling in bearing. [49]. Discrete wavelet packet analysis (DWPA) [50] and discrete wavelet analysis [51] these techniques also useful for identify the fault. The scalar features of Cyclostationary processes, which are non-steady vary periodically with time. The scalar features of defective bearing signal vary periodically with time in the association of slink or changes in forces. The intensity of signals in case of cyclostationary analysis gives more clear results as compare to stationary analysis. The cyclostationary analysis gives the clear results of fulfilled of a signal and its cyclic variation. The degree of cyclostationarity (DCS) gives total indication of presence of the modulating frequencies. The researchers have been studied [52, 53, 54, 55] the cyclostationary analysis of Defective bearing signal. They identify the cyclic autocorrelation more useful than other methods in bearing detection.

5. Conclusion

In present paper, an endeavour taken to collect the latest developments in vibration measurement methods for finding the defect in bearing using time, frequency and time and frequency domain. The discovery of defect calculating the remaining life of bearing has been challenging work for the researchers to reduce the manufacturing and financial losses happening in the industry caused by malfunction of rotating machines. In time domain analysis the stastal parameter like RMS, Kurtosis, and crest factor identify the defect but does not find the location of defect by using frequency domain we can find the defect location. In time-frequency the latest trends for signal processing techniques has been used for feature extraction. The high-frequency resonance technique is mostly used technique in the frequency domain analysis. Sometimes FFT cannot detect the poor signals at that time Wavelet transform technique is very effective in time frequency domain. In steady and unsteady vibration signals the time-frequency analysis is very useful. This paper is very useful to researchers for a critical review in the latest trends in the area of vibration measurement methods for identify the defects in bearings.

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6. References

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