Vibration Measurement Methods for the Detection of Defects in Rolling Element Bearings- A Review

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Abstract: To detect the defects in rolling element bearings various vibration measurement methods are used widely which is discussed in this review paper. Many researchers have studied the vibrations generated by bearings through a theoretical model as well as experimentations. It is very difficult to extract the information from the vibration signal due to the presence of external noise. This paper enlightens about vibration measurement techniques used in fault detection of ball bearings in the presence of external noise. Additionally, fault detection techniques used, have also been summarized. The signal processing techniques like adaptive noise cancellation, self-adaptive noise cancellation, wavelet transform, envelope analysis have improved fault detection.

***Keywords*— bearing defects, Wavelet analysis, Adaptive noise cancellation, Envelope analysis, Fault detection**

I. INTRODUCTION

Bearing health is important as it plays a major role in the proper working of the rotating machinery. With the risk of machine breakdown, monitoring of bearings is very essential.

Vibration signals generating from rolling-element bearings have so much useful information, the proper analysis of these signals can lead to the identification of possible faults.

The vibration signals contain information about defective parts and a variety of vibration based techniques have been developed to monitor the condition of rolling-element bearings. Vibration signals are analysed using time domain analysis as well as frequency domain analysis. Due to the presence of external noise, it is so much difficult to extract useful information from the data of time domain analysis. Whereas, the frequency domain is used in the signal processing technique due to periodic signal gives peaks when the repetition takes place.

When rolling elements pass through the locations of defective outer race or inner race, a series of pulses are generated which can be seen by time domain analysis, but due to external noise pulses are buried under the noise or masked by the unwanted signal. Here the signal processing plays an essential role to separate the signal and noise.

II. SIGNAL PROCESSING TECHNIQUES

Signal processing techniques play an important role in the extraction of useful signal when it is combined with the noise. But these techniques are dependent and complementary to each other.

A. *Time-domain approach*

In time domain approach signal processing techniques like root mean square (RMS), crest factor, kurtosis, spectral kurtosis, probability density have been proposed by researchers [3]-[5] to detect the bearing faults.

1) *Spectral kurtosis:*

Spectral kurtosis (SK) is a statistical parameter which indicates how the impulsiveness of a signal varies with frequency. As the rolling elements strike on the races faults in rolling element bearings it gives rise to a series of short impulse responses, the Spectral Kurtosis is most probably useful for determining the frequency bands dominated by the bearing fault signals which usually containing resonance frequencies excited by the faults.

In order to choose the optimum frequency band, information is required to demodulate for the execution of envelope analysis on the bearing signals. The kurtosis value for the healthy bearing is nearer to 3 with Gaussian distribution. If the value goes above 3 then it said to be a defect in the bearing .but due to this reason it is applicable only if the damage is well advanced. Kurtosis has not become a very popular method in the industry for the condition monitoring of bearings.

Spectral kurtosis is an analysis technique for use in the diagnostics of rolling element bearing faults. Without requiring historical data it can be used to indicate the best band to demodulate for envelope analysis. It can also be used to determine the optimum bandwidth as well as a center frequency to maximize the kurtosis of the filter output.

It can also be used to generate filters to separate the most impulsive part of a signal from stationary masking components and aid diagnosis. It can be an advantage to use pre-whitening of the signal before analysis in order to extract the bearing fault signal from the background noise.

2) *shock pulse method:*

The shock pulse method has been widely used by industries and it has been reported to be promisingly detect the defects of rolling element bearing defects [6]. Semiskilled personnel can operate them due to the easy handling of shock pulse meters.

In shock pulse method piezoelectric transducer is used having a resonant frequency based at 32 kHz. The shock pulses caused by the impacts in the bearings initiates damped oscillations in the transducer at its resonant frequency.
The shock pulses are generated by the impacts in the rolling element bearing initiate damped oscillations in the transducer at its resonant frequency.

Due to surface roughness, the shock pulse value is generated by good bearings and it has been found experimentally to be dependent upon the bearing bore diameter and speed. This value, called the initial value, is subtracted from the shock value of the test bearing to get the normalized shock pulse value.

B. *Frequency-domain approach*

Frequency-domain analysis of the vibration signal is perhaps the most commonly and extensively used approach of bearing defect detection due to its simplicity. Whenever the defect strikes or is struck owing to the rotational motion, the system rolling element bearings produces pulses of very short duration. The pulses generated by it excites the natural frequencies of bearing elements and housing structures, resulting in an increase in the vibrational energy at high frequencies.

Each bearing element has a characteristic rotational frequency and it can be calculated from kinematic considerations. Whenever a defect is present on the rolling element an increase in vibrational energy at this element's rotational frequency may occur.

In some research paper, it is mentioned that it is problematic to obtain a significant peak of defective frequencies in the direct spectrum obtained from a defective bearing. This is due to the noise or vibration from other sources that masks the vibration signals from the bearing unless the defect is adequately large.

Some researchers [7], [8] have found that the frequency domain approach detects the outer race defect reasonably well but failed to detect the inner race defect. So in order to improve the signal to noise ratio different signal processing techniques have been used by researchers. So to overcome this problem some researchers have come with the signal processing technique is envelop detector or High-Frequency Resonance Technique (HFRT).In this technique, defects are identified by extracting characteristic bearing frequency.

To eliminates, most of the unwanted vibration signal bandpass filter is used while the resonant frequencies excited by defect striking in the rolling elements of the bearing. The bandpass filtered signal is then demodulated by an envelope detector where the signal gets rectified and smoothed by low pass filter which eliminates the bandpass filtered resonant frequency. The spectrum of the envelope signal in the low-frequency range obtains the characteristic frequencies associated with the faulty bearing.

As time domain and frequency domain approach doesn't give solutions directly some of the advanced signals processing techniques are required. Some researchers have done work in this field as well, which is briefly discussed here.

1) Envelope analysis

Envelope analysis is an amplitude-demodulation process. It used to obtain the bearing defect harmonics from the spectrum for fault diagnostic purposes. But the process also demodulates noise components which may be in the same frequency region as the bearing fault and therefore cover the necessary information. Signal processing techniques like ANC and SANC are used to remove the periodic noise signal before using envelope analysis.

A Question may arise in the mind that if signal processing techniques can be used to fault detection then what is the use of envelope analysis. The very clear and simple answer to this question is when machinery is in running condition it also generates the vibration related to vibration generated by the defective bearing. Envelope analysis plays an important role in this type of situation.

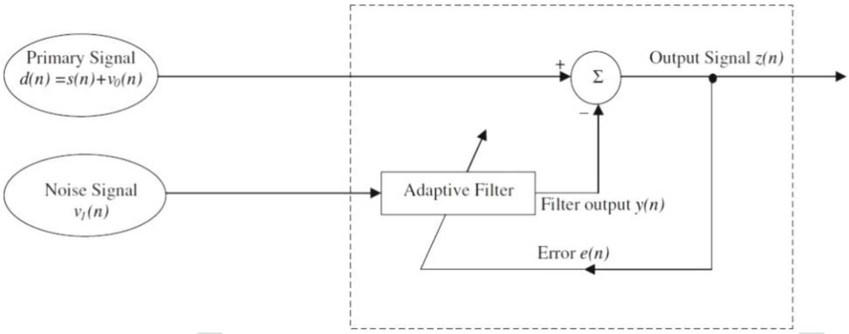
Researchers [9]-[12] have found that demodulation or envelope analysis allows for the earliest possible detection of a bearing failure since the bearing failing frequencies that appear in the demodulation spectrum are the first indicator of the beginning of a bearing issue. Demodulation is very useful to detect such failing frequencies before they become strong enough to appear in the standard spectrum.

Unfortunately, demodulation spectrum cannot be used alone as the diagnostic tool as it does not correlate to the amplitude of the fault frequencies with the damage condition. The main reason behind it is that as the bearing deterioration progresses, the number of defects in the bearing increases, causing the demodulated signal to become more and more random. So that whenever the bearing damage progresses, the harmonics in the demodulation spectrum will lose amplitude, and may even disappear.

2) Adaptive noise cancellation

Research works [13]-[18], has been done on this particular signal processing technique. The long-established method of estimating a signal corrupted by an additive noise is to pass it through different types of filter to remove the unwanted noise while leaving the signal adequately unchanged. The signal-to-noise ratio (SNR) has been increased as the signal remains unchanged and minimizing the total energy of the system output.

The principle of ANC is shown in Figure1 [14]. The primary input consists of a signal *S* which is corrupted by a noise *n*1. The reference input consists of a noise *n* uncorrelated with the signal *S* but correlated with noise *n*1.



The adaptive filter which has the possibility of adjusting its own parameters and it can automatically act to minimize the average power of the residual interference present in the signal at the system output, the error signal. This error *e* is again introduced in the filter to readjust it through a "Least Mean Square" adaptive algorithm.

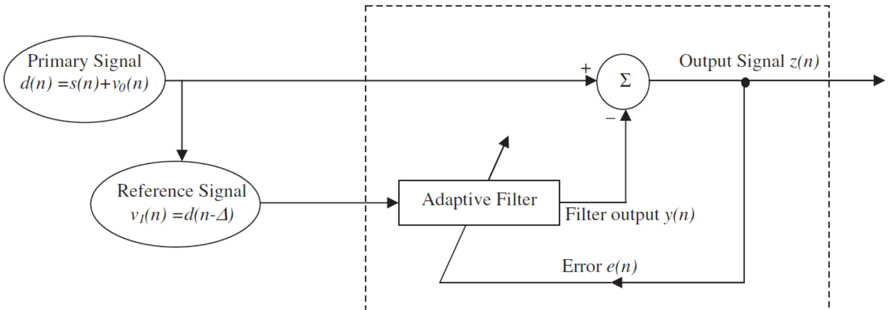


Fig. 2 Basic Concept of self-adaptive noise cancellation [13]

The self-Adaptive noise cancellation filter has the ability to increase the signal to noise ratio of a periodic defect signal corrupted with noise. Self-Adaptive noise cancellation filter requires a single signal which is used as a primary input.

For the reference input, a delayed version of the primary input is used. Self-adaptive noise cancellation is also known as adaptive self-tuning.

The performance of the adaptive filter and self-adaptive filter is affected by the number of taps, step size, and the length of the signal. The selection of these parameters requires trial and error approaches. The only difference between Adaptive noise cancellation and Self-adaptive noise cancellation is the reference signal. In Self adaptive noise cancellation the delay signal is the primary signal itself.

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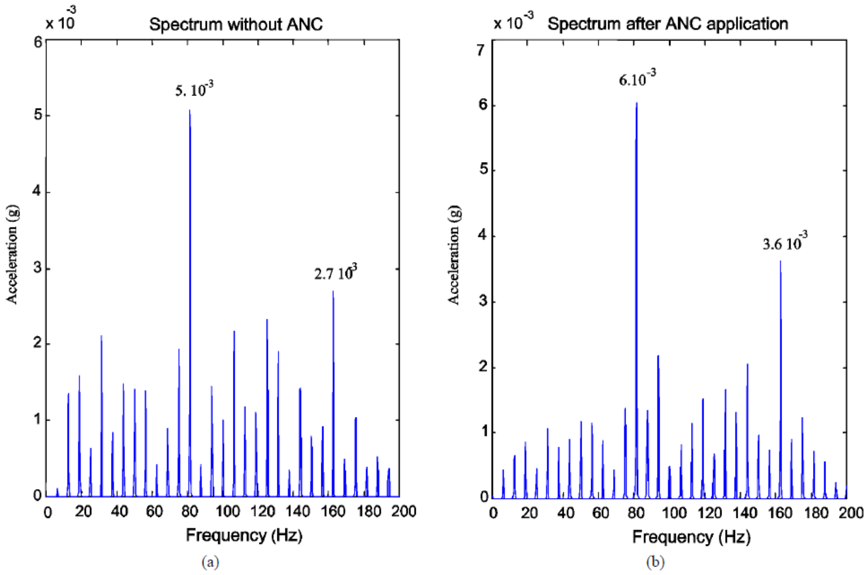

Fig. 3 Frequency analysis of a bearing having a defect on the inner ring of width 0.05 mm,(a) before ANC application and (b) after ANC application[14]

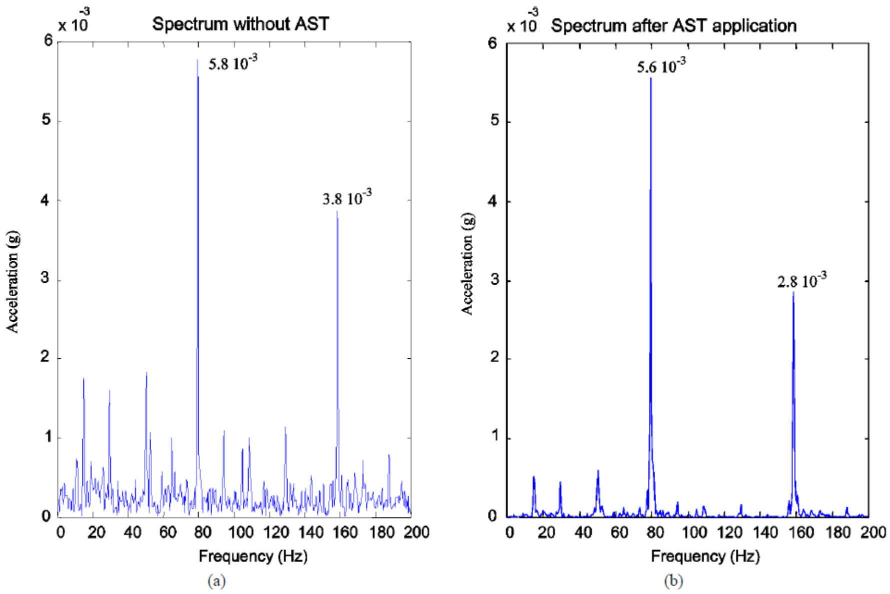

Fig. 4 Frequency analysis of a bearing having a defect on the inner ring of width 0.05 mm, (a)before AST application and (b) after AST application. [14]

The experimental studies presented in the research paper [14] shows that adaptive filtering is a very effective tool for noise reduction and amplification of the signal to noise ratio. Two adaptive algorithms have been tested here which are the adaptive noise cancellation algorithm (ANC) and the adaptive self-tuning algorithm (AST) also called as self-adaptive noise cancellation (SANC).

The experimental results show that the self-Adaptive noise cancellation filter effect is much more remarkable than that of the Adaptive noise cancellation filter since a higher increase of the Signal to noise ratio has been observed for the self-Adaptive noise cancellation filter than for the Adaptive noise cancellation filter.

3) *Wavelet analysis*

A wavelet is a waveform of limited duration that has an average value of zero and Breaking up of a signal into shifted and scaled versions of the original wavelet is the method of wavelet analysis. Fault diagnosis which includes time–frequency analysis of signals, fault feature extraction, singularity detection for signals, denoising and extraction of the weak signals, compression of vibration signals and the system identification.

Researchers [19]-[26] have successfully done work on Fault investigation which includes time–frequency analysis of signals, fault feature extraction, denoising and extraction of the weak signals, compression of vibration signals and the system identification is the main aspects of the wavelet analysis.

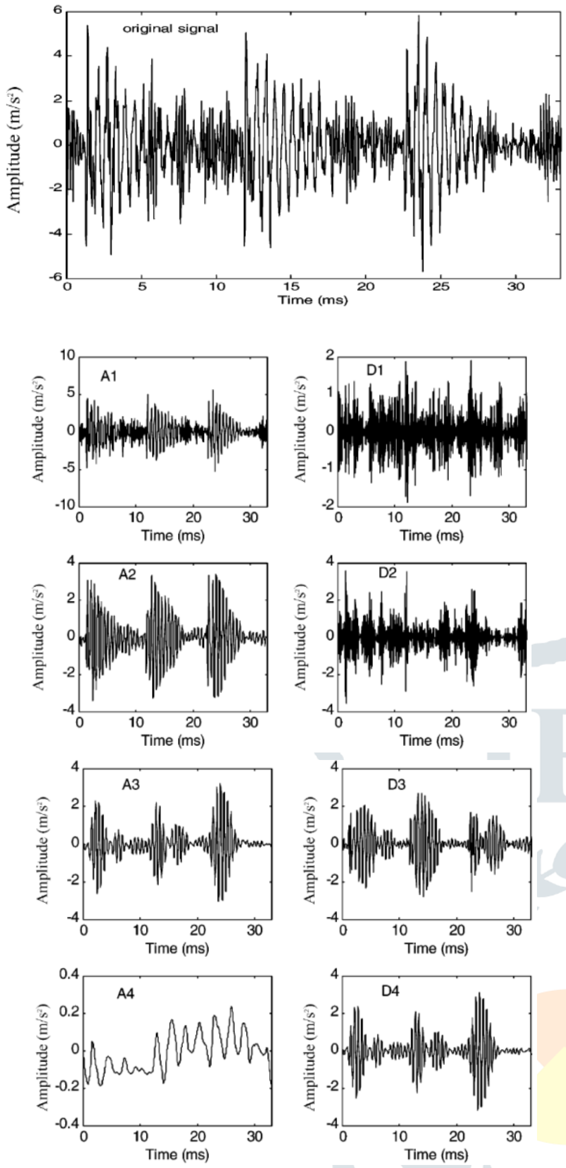

Fig.5 Original time signal and the wavelet decompositions for one revolution of the outer race defect bearing. [19]

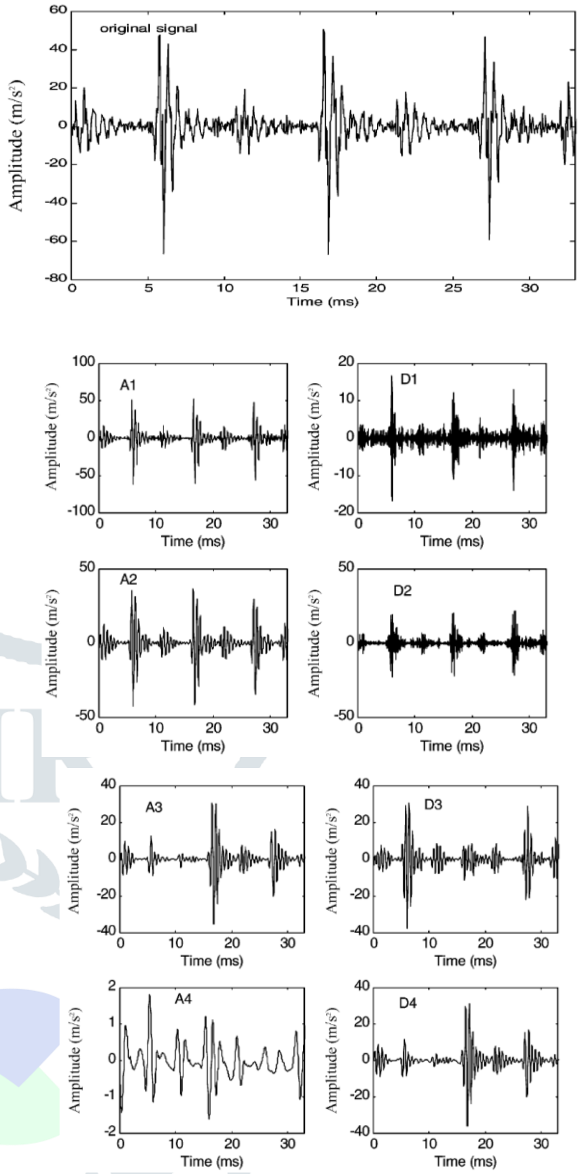

Fig. 6 Original time signal and wavelet decompositions for one revolution of the bearing with two defects on outer race. [19]

The example presented here by the researcher [19] has used discrete wavelet transform to detect single and multiple faults and combination of faults on the races of ball bearings. Daubechies 4 mother wavelet up to level 4is used to decompose the vibration signal.

The discrete wavelet transform uses filter banks for the synthesis as well as analysis and of a signal. In wavelet decompositions of the defective bearings faults are clearly visible. For detecting single and multiple faults in the ball bearing discrete wavelet transformation can be used as an effective tool.

III. CONCLUSIONS

From a review of studies on Vibrations generated in rolling element ball bearings due to the presence of defects on their races are difficult to detect in time domain analysis as well as frequency domain analysis in the presence of external noise.

Envelope analysis is used to obtain the bearing defect harmonics from the spectrum for fault diagnostic purposes as it demodulates noise components which may be in the same frequency region as the bearing fault and therefore cover the necessary information. The only drawback of the envelope is that it cannot be used to detect the defect by its own. Further signal processing is required to detect the defect in roller element bearing.

To increase the signal to noise ratio of the signals adaptive filters are widely used. From a review, It is suggested to use the self-adaptive noise cancellation filter rather than adaptive noise cancellation due to its high signal to noise ratio. SANC filter gives more system output than ANC.

In recent years, attention has also been focused on not only defect detection but also on defect size estimation of the defective ball bearing. To fulfill this criteria researchers have successfully applied wavelet analysis to have the best results.

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