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A review on Fault Diagnosis Methods for Bearings and Fan Faults Using Vibration Analysis

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***Abstract*- Roller bearings and Deep Groove Ball bearings play a very important role in industrial machines and machine components. However, the reliability of bearings can be compromised due to faults occurring in races, i.e. Inner and Outer and ball faults. Such faults, compromise machine life, performance as well as operator safety. So, condition monitoring of these becomes extremely necessary. Consequently, many studies have been published to establish techniques for fault diagnosis in bearings.**

Vibration Analysis method is widely used methodology for fault diagnosis in bearings. This Analysis is done in Time-domain, Frequency-domain and Time-Frequency domain. This review paper presents an overview on different methods of diagnosis in such domains like, Wavelet Transform, Fast Fourier Transform, Short Time Fourier Transform, and Hilbert-Huang Transform. Additionally, recent advancements in signal processing have been discussed in this paper.

***Keywords*— Roller Bearings, Fault diagnosis, Vibration Analysis, Signal processing.**

INTRODUCTION

Roller bearings serve as vital components in a myriad of mechanical systems, ranging from industrial machinery to automotive applications. Their function is to ensure smooth rotational movement while bearing substantial loads. However, like any mechanical component, roller bearings are prone to wear, degradation, and eventual failure over a period of time. Timely detection and diagnosis of faults within roller bearings help to prevent costly downtime, machine failures and increases reliability. Studies have shown that condition monitoring helps in reducing 50% costs over old traditional methods.[1]

Vibration analysis has emerged as one of the most effective and widely utilized techniques for diagnosing faults in roller bearings and fan faults. This method work on processing of vibrations generated by rotating machinery, providing data on the health condition of bearings. In this review paper, we review various fault diagnosis methods employing vibration analysis, with a particular focus on roller bearings.

Fundamentally, vibration analysis involves the examination of vibration signals generated by rotating machinery. This examination encompasses a range of signal processing techniques, each offering unique advantages in detecting and diagnosing faults. Among these techniques, the Fast Fourier Transform (FFT) analysis mostly used technique, facilitating the decomposition of complex vibration signals into frequency domains, thus identifying characteristic fault frequencies associated with bearing defects.

In addition to FFT analysis, time-domain analysis plays a significant role in fault diagnosis. By scrutinizing the time waveform of vibration signals, anomalies such as impacts, slips, and discontinuities indicative of bearing faults can be identified and analyzed. Calculating Kurtosis, Skewness, variation helps in differentiating between two signals or two bearings.

Moreover, techniques such as Short-Time Fourier Transform (STFT) and wavelet transform have gained importance for their ability to provide time-frequency representations of vibration signals, providing enhanced resolution and localization of fault features. STFT offers a trade-off between time and frequency resolutions, making it suitable for analyzing signals with non-stationary characteristics, while wavelet transform excels in detecting transient fault features and extracting valuable diagnostic information.

With this paper, we aim to provide a comprehensive overview of fault diagnosis methods in roller bearings using vibration analysis which have been previously studied, highlighting the significance of signal processing techniques such as FFT analysis, time-domain analysis, STFT, wavelet transform, and emerging methodologies.

LITERATURE SURVEY

Milind Natu (2013) [1] studied implementation of Haar wavelets upto two levels of approximation. By numerically calculating Characteristic frequencies, i.e. BPFO, BPFI and BPRF, and compared it with the frequency-acceleration plot after haar wavelet transform was implemented. Time domain analysis doesn't give in depth analysis of signal, which is why advance methods like wavelet analysis is required.

Ball Pass frequency outer race (BPFO)

$$\text{BPFO} = \frac{n}{2} f\left(1 - \frac{d}{D}\cos\beta\right)$$

Ball Pass frequency inner race (BPFI)

$$\text{BPFI} = \frac{n}{2} f\left(1 + \frac{d}{D}\cos\beta\right)$$

Ball Pass roller frequency (BPRF):

$$\text{BPRF} = \frac{D}{d} f\left(1 - \left(\frac{d}{D}\cos\beta\right)^2\right)$$

M. Deriche (2005) [2] studied the implementation of Discrete Wavelet Transform (DWT) and Discrete Wavelet Packet Transform (DWPT). He stated that Fourier analysis has only frequency resolution and no time resolution analysis. Due to this it is not possible to evaluate all frequency components present in a signal (including frequency components due to defects) which occur in time. Due to this, RMS extracted from the terminal node of a wavelet tree provide a robust solution.

T. Ooijevar et. al. [3] compared three method developed by the Linz Centre of Mechatronics (LCM), a physics based method by Flanders Make (FM) and an approach developed by the Centre for Intelligent Maintenance Systems (IMS). The LCM method is data oriented while other two methods rely on first feature extraction and then model training using data. He concluded that IMS and FM methods are more sensitive to detecting early faults the method developed by LCM. However, these two methods are limited to bearing health monitoring only, unlike the LCM method. The quality of training data is also important to get best output in these two methods.

Attoui Issam et. al. [4] implemented the DWT and FFT and used it into Adaptive Neural Fuzzy Inference System (ANFIS). He proposed that that de-noising vibration signal by DWT reduces the fluctuation of the curves, which helps in fault classification, mostly for the frequency features. The system proposed by him has an accuracy of 97% for fault classification. Hence, is useful in fault classification in variety of bearings and fault severities.

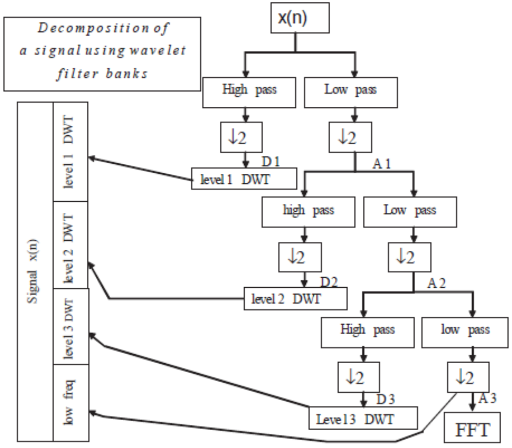

Figure 1: Three level wavelet decomposition tree integrating FFT as using in ANFIS [4]

Lin H-C et. al. [5] reviewed the enhanced-FFT method in this work. He stated that FFT outcomes are prone to incorrect solutions if the vibration frequency is non-integer due to spectrum leakage. It was verified that the e-FFT model is better than the usual FFT. However, the group bandwidth (t) should be appropriately selected in case of close harmonics. [5]

V. K. Rai et. al. [6] studied the Hilbert-Huang Transform technique for fault diagnosis. He stated that For the purpose of condition monitoring in rolling element bearings, the conventional Fast Fourier Transform (FFT) may be deemed adequate. However, for fault diagnosis, the application of advanced signal processing techniques such as the Hilbert-Huang Transform (HHT) combined with FFT analysis of Intrinsic Mode Functions (IMFs) becomes imperative. Also, FFT, if implemented solely, is not a very effective tool for determining the characteristic frequencies, that is BPFO, BPFI, BPRF in amplitude modulated, nonstationary vibration signal from a defective bearing.[6]

Prashant jain et. al. [7] studied six traditional time-domain statistical indicators, i.e. peak, root mean square, crest factor, kurtosis, impulse factor and shape factor and six new developed indicators by other researchers, namely TALAF, THIKAT, “kurtosis, crest factor and root mean square (KUCR)”, engineering condition indicator (ECI), SIANA, and INTHAR. He stated that for normal bearings, the indicators, RMS, SF, TALAF and ECI are flat at varying speeds. However, the values of indicators CF, IF, KUCR, THIKAT, SIANA and INTHAR show change in values as speed increases. He concluded that KUCR is the most sensitive indicator to faults while SF and TALAF are least sensitive.

Q. Zhang et. al. [8] proposed an intelligent fault diagnosis method of rolling bearings based on short-time Fourier transform and convolutional neural network. The results showed that the proposed method by authors were better than the other comparative methods and had the identification accuracy of 100% and 99.96% for CWRU and MFPT, respectively.

D. Liu et. al. [9] proposed a short time Fourier transform (STFT) and improved instantaneous frequency estimation algorithm. Through experimental work, he stated that the kurtograms are useful in determining the appropriate resonant frequency region that is sensitive to fault impulses. They also aid in the generation of a clear TFR containing the time-varying characteristic frequency components via the STFT and Hilbert transform.

L.H Wang et.al [10] in his experimental work collected vibration signal from different faulty motors. The experimental findings indicated minimal impact of preprocessing techniques, with batch size emerging as the predominant factor influencing both accuracy and training efficiency. Through exploration of feature visualization, it was demonstrated that within large datasets, Convolutional Neural Network (CNN) extracted features effectively depict intricate mapping correlations between signals and health conditions. Furthermore, CNN features are shown to surpass the reliance on prior knowledge and engineering expertise typically associated with traditional diagnostic methodologies for feature extraction.

CONCLUSION

The literature review studies various fault diagnosis of roller bearings using vibration analysis. Various signal processing techniques such as Haar wavelets, Discrete Wavelet Transform (DWT), Discrete Wavelet Packet Transform (DWPT), Fast Fourier Transform (FFT), Short-Time Fourier Transform (STFT), and Convolutional Neural Network (CNN) have been extensively investigated and compared for their efficacy in detecting bearing faults.

Research by Milind Natu and M. Deriche highlights the value of wavelet analysis by highlighting its capacity to offer thorough insights into both the frequency and temporal domains, hence enabling a more in-depth comprehension of intricate signal properties. Furthermore, developments like the Hilbert-Huang Transform (HHT) have been suggested as a supplement to FFT analysis, especially in cases where nonstationary vibration signals from faulty bearings are involved.

Comparative analyses conducted by researchers like T. Ooijevar et al. and Attoui Issam et al. have highlighted the strengths and limitations of different fault diagnosis methodologies, ranging from data-oriented approaches to physics-based methods. While approaches such as those proposed by Lin H-C et al. and V. K. Rai et al. have introduced innovative enhancements to conventional FFT analysis, emphasizing the importance of accurate frequency resolution in fault detection.

Additionally, investigations by Prashant Jain et al. underscore the significance of various time-domain statistical indicators in fault diagnosis, help in understanding their sensitivity to different fault types and operating conditions. Furthermore, the integration of advanced techniques like convolutional neural networks, as proposed by Q. Zhang et al., showcases promising results in achieving superior fault identification accuracy.

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