A Review on Fault Diagnosis of Gear-Box by Using Vibration Analysis Method

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ABSTRACT

Gearboxes are important part of mechanical transmission systems, and they are used to transmit power, torque etc. between shafts of machineries. Generally gearbox work 24 hours a day in the production system so that any failures in the gearboxes may introduce unwanted downtime, expensive repair cost, and even danger of human casualties. So that it is very important to detect and diagnose faults in gearbox working at initial stage for its effective working. There are various methods to detect faults in gearbox. Among them vibration measurement is an effective way to detect any abnormality/fault produced in a gearbox as every machine has its own specific vibration signature as faults occurs in any part of gearbox/machinery its vibration signature changes accordingly. By measuring and analysing the machine’s vibration, it is possible to govern both the nature and severity of the defect, and hence predict the machine’s failure. The vibration signal of a gearbox conveys the signature of the fault in the gears, and early fault detection of the gearbox is possible by examining the vibration signal using different signal processing techniques. This paper gives a brief review on various techniques used for analysing the faults of gearbox based on vibration analysis method with small insight on new approach used for diagnosis of gearbox such as Artificial Neural Network, fuzzy sets and some emerging technology in gear fault analysis.

Keywords: Vibration, Gearbox, Fault diagnosis, Vibration signature, Vibration measurement techniques

1. INTRODUCTION

All machines with moving element give rise to sound and vibration. Each machine has a specific vibration signature related to the structure and the condition of the machine. The vibration signature will also change with change of state of machine. A change in the vibration can be used to detect incipient defects. This is the basics of condition monitoring methods. Condition monitoring can help to increase profit of an organization through increased maintenance efficiency and by reducing the risk of accidents by preventing interruptions.

The basic of condition monitoring has been used in practice since a long time. An experienced operator can monitor the condition of a machine by listening to the vibrations. However, it will require years for an operator to develop the necessary skills. Number of techniques for automated condition monitoring has been developed during the last decades. These techniques generally include three basic steps; measurement of a physical quantity, determination of suitable condition monitoring parameter with advanced signal processing techniques and comparison of that parameter to standard values.

Approx. 65\% of gearbox failure is due to failure of gear such as pitting, spalling, cracking, wear. This fault mainly occurs due to excessive vibration. Hence vibration analysis for their monitoring and diagnosis was implemented and found as most powerful analysis technique. The vibration analysis mainly divided into three approaches as Time domain, Frequency domain and Time-Frequency domain.

The time domain methods comprise time synchronous average and statistical analysis. The frequency domain methods consist of spectral analysis such as power spectral density and Cepstrum analysis. The time-frequency domain methods consist of the short-time Fourier transform, Wigner-Ville and wavelet analysis.

2. VIBRATION ANALYSIS FOR FAULT DETECTION AND DIAGNOSIS

A measurement signal acquired from a machine in working environment will often contain effects from several different components with noise. One major challenge of condition monitoring is to identify and choose the part of the signal that can be related to the condition of the monitored component.

Most modern techniques for gear diagnostics are recognized on the analysis of vibration signals collected from the gearbox casing. The main target is to detect the presence and the type of fault at start of development and to monitor its progress, in order to guess the machine’s residual life and choose a suitable plan of maintenance. It is well known that
the most important components in gear vibration are the gear meshing frequency and harmonics, accomplished with sidebands due to modulation. The increment in the number and amplitude of sidebands can indicate a fault in gearbox. In Gears, vibration analysis can detect tooth meshing faults, misalignment, cracked and/or worn teeth, eccentric gear etc. faults. Vibration analysis can detect Unbalance, bent shaft, misalignment, eccentric journals, loose parts, rubs, crucial speed, cracked shaft etc. faults of a rotor and shaft. Pitting of race and ball/roller, spalling etc. faults of rolling element bearing can be detected by using vibration analysis techniques effectively.

3. REVIEW

Numbers of papers are presented on fault detection of gearbox by using various vibration analysis methods. Here we are going to review some of techniques used to model faults of gearbox using vibration analysis method. These techniques are mainly divided into three areas as Time domain approach, Frequency domain approach and Time-Frequency domain approach.

B. Liu et al (2006) present a paper in which they apply empirical mode decomposition (EMD) and Hilbert spectrum method to vibration signal analysis for localized gearbox fault diagnosis. They use B-spline EMD as a filter bank to understand mechanisms behind EMD. After that they investigate the effectiveness of the original and the B-spline EMD with their corresponding Hilbert spectrum in the fault detection. Vibration signals collected from an automobile gear box with an initial tooth crack are used in the examination. The results show that the EMD processes and the Hilbert spectrum perform superbly to found defect and is more effective than the frequently used continuous wavelet transform to detect fault with help of the vibration signatures of gearbox. [1]

David G. Lewicki et al (2011) gives insight to Planetary Gearbox Fault Detection Using Vibration Separation Techniques supported by NASA. In this paper total nine condition indicators are used to determine fault present in planetary gearbox of helicopter. They are as RMS, crest factor, energy ratio, FM0, kurtosis, energy operator, FM4, M6A and M8A. They found that condition indicator M8A performed the best during their study. The fault in sun and planet gear is detectable by using vibration analysis techniques. Enveloping of signal is an effective method for detection of planet bearing inner and outer-race spalling fault. They found that greater change in vibration was noticed when crack is being closed rather than it open up during meshing. [2]

Dejje Tu et al (2005) proposed a method for the fault diagnosis of roller bearing based on Empirical mode decomposition and Hilbert transform. The orthogonal wavelet sources are used to transform vibration signals of a roller bearing into time-scale illustration. Then, an envelope signal can be obtained by envelope spectrum analysis of wavelet coefficients of high scales. By applying EMD method and Hilbert transform to the envelope signal, we can get the local Hilbert marginal spectrum from which the faults in a roller bearing can be detected and fault patterns can be identified. Practical vibration signals measured from roller bearings with out-race faults or inner-race faults are analyzed by them. The results show that the method given by in this paper is superior to the old envelope spectrum method in detecting the fault characteristics of roller bearings.[3]

Enayet B. Halim et al (2008) proposes a new technique as time domain averaging across all scale, which combines the time synchronous average and wavelet transformation with each other to extract the periodic waveforms at different scales from noisy vibration signals. The technique effectively cleans up noise and detects both local and distributed faults at the same time. The presence of a fault in any gear of the gearbox gives rise to a peak in the plot of the TDAS. A missing tooth creates a large peak and a chipped tooth creates a peak with a parallel side peak at the meshing frequency. Instantaneous multiple faults in the gearbox can be detected by looking at the peaks of the plot of TDAS. A pilot plant case study is presented to validate the efficacy of the proposed technique. [4]

Farag K.Omaret al (2011) proposed dynamic wavelet-based tool for gearbox diagnosis in noisy environment. It utilizes a windowing process at time of analysis of gearbox vibration signals in the wavelet domain. The gear vibration signal is processed by using dynamic Kaiser’s window of varying parameters. The window size, shape, and sliding rate are revised due to increasing the similarity between the non-stationary vibration signal and the designated mother wavelet. The window parameters are uninterruptedly revised until they offer maximum wavelet coefficients restricted to the detected tooth. They applied this technique on laboratory data corrupted with high noise level. This technique has shown accurate results in detecting and pinpointing gear tooth fracture with altered damage severity. [5]

G Diwakar et al (2012) analyze gear faults by using FFT Analyzer. The vibration signals of gearbox are detected and processed using FFT analyzer. They detect the fault in Gearbox by the interpretation of vibration data and spectrums. The vibration signature shows the fault in Gearbox when Gearbox is operated at different Gears on full load condition. They found that vibration analysis provides a highly sensitive, selective, and effective technique for online monitoring of a wide variety of heavy industrial machinery. The peaks are present at sub-harmonics and multiples of frequencies. The cause of presenting the sub harmonics & multiples of frequencies is due to the presence of fault in the Gearbox.[6]

Ming Yang et al (2010) present an ARX model-based gearbox fault detection and localization under varying load conditions. Firstly they calculate residual signal using an autoregressive model with variables (ARX) fitted to the time-synchronously averaged (TSA) vibration data and filtered TSA envelopes at healthy condition of gearbox operated under several load conditions. The gear of interest is separated into several sections so that each section includes the
same number of adjacent teeth. Then, the fault detection and localization indicator is calculated by applying F-test to the residual signal of the ARX model. The proposed fault detection scheme indicates gear fault occurrences as well as location of faults i.e. section of the gear. Hence it is very suitable to use this technique for online condition monitoring.

J. Antoni, R. B. Randall (2002) deals with the vibration-based diagnosis of rolling element bearings with existence of strong intrusive gear signals, such as is typical of helicopter gearboxes. The key idea to detect gear frequency is that gear signals are purely periodic, whereas bearing signals occurs with some randomness and is close to cyclo stationary, i.e. with a periodic bivariate autocorrelation function. They found that for localized faults pseudo cyclostationary vibration signal are produced which can considered as cyclostationary in first approximation. And for Distributed faults they propose simple spectral analysis. They check the effectiveness of this method on experimental and actual vibration signal.

Prashant Bagde et al (2013) studied various faults arise in gearbox and the corresponding change of vibration signature. They found that the condition of the tested gearbox is very well represented by the RMS value of the vibration signal. Behavior of the RMS, peak and crest factor value is described in this paper. The energy ratio has a steady trend except at the start of the test. The peak value has a similar trend as the RMS value. The trend of the crest factor depends on the trends of the RMS and peak values. FM0 follows the trend of the crest factor. The trends of FM4, NA4 and NB4 are similar, and reflect the very fine wear of the teeth. At about 60% of the test FM4, NA4 and NB4 rapidly increase in value, but the gearing does not show abnormal wear.

Shashikant Shukla et al (2014) deals with fault detection of two stage spur gearbox having tooth breakage and improper chamfering fault in the gear, using time domain techniques with the use of MATLAB. Acquired data is analyzed to find out various statistical parameters like peak value, crest factor, RMS, kurtosis. Healthy and breakage gears are compared using statistical parameters. All parameters have greater values in Tooth breakage gear than healthy gear. Faulty gear has large kurtosis value as compared to healthy gear. All parameters increases with increase in speed in faulty gear but in healthy gear the values are almost constant. In improper chamfering gear all the time domain values lie between Healthy gear and faulty gear.

S.J. Loutridis (2004) present a method for monitoring the detection of gear faults based on the empirical mode decomposition scheme. A gear pair with a tooth root crack was modeled theoretically. Experimental vibration signals from an instrument were decomposed intrinsic mode functions (IMF). An empirical law relating the energy content of the intrinsic modes to the crack size was developed. The modal energy associated with the deterioration in gear condition can be utilized for system failure estimate. In addition, it is shown that the instantaneous frequency of the vibration signal is a sensitive sign for to detect the presence of damage in the gear pair.

T P Raveenkumar et al (2014) addresses the use of vibration signal for automatic fault detection of gearbox. The Performance of the fault detection system using vibration signals is discussed. In their studies, they examine good gears and face wear gears to collect vibration signals for good and faulty conditions of the gearbox. Two different speeds and loading conditions are used to test each gear. The statistical parameters such as Mean, Median, Mode, RMS, Kurtosis, Skewness, variance and standard deviation are calculated from the measured vibration signals. These parameters are used as an input to the support vector machine (SVM) for fault detection. Support Vector Machine shows superior classification capability to identify various faults in the gearbox and it can be used to automate fault diagnosis system.

Xianfeng Fan et al (2005) combines Hilbert transform and wavelet packet transform. Both virtual signals and real vibration signals collected from a gearbox dynamics simulator are used to verify the proposed method. Investigated outcomes show that the proposed method is effective to select particular modulating signal and help to detect the early gear fault. In addition, it has the capability to analyze non-stationary signals. Compared with wavelet packet transform only, it has more benefits such as accuracy, efficiency, and easy faults detection by visual inspection of vibration spectra.

Xiyang Wang et al (2010) discussed a wavelet approach to fault diagnosis of a gearbox under varying load conditions. As varying load can make changes in a measured gearbox vibration signal it is necessary to develop a technique which provide accurate condition monitoring of gearbox under fluctuating load conditions. They presents a method to detect gear fault based on complex Morlet continuous wavelet transform under varying load condition. Gear motion residual signal usually represents the withdrawal of time synchronously averaged signal from the average tooth-meshing vibration. This is analyzed as source data due to its inferior sensitiveness to the varying load condition. A fault growth factor based on the amplitude of wavelet transform is suggested to evaluate gear fault progression. They found that this parameter is insensitive to varying load and can correctly indicate early gear fault. The efficiency of the proposed fault indicator is validated using a full lifetime vibration data history obtained under sinusoidal varying load.

Yimin Zhan et al (2006) gives a robust model-based technique for the detection and diagnosis of gear faults under varying load conditions using the gear motion residual signal. The gear motion residual signal usually shows evidence of faults earlier and more clearly than the TSA signal. They proposed a method in which the load is continuously
4. SUMMARY

Empirical mode Decomposition system (EMD) use the modal energy associated with deterioration in gear can be used to detect faults. An instantaneous Frequency of vibration signal is sensitive indicator of existence of damage in gear pair. Time-frequency domain average technique (TSA) successfully removes the noise from the signal and captures the dynamics of one period of the signals. Wavelet Transform shows accurate result in detecting and localizing gear tooth fracture with different damage severity. Time domain techniques for vibration signal analysis such as waveform generation, indices (RMS value, peak level value and crest factor) and complete vibration level do not provide any diagnostic evidence under varying load condition. In frequency domain, FFT was able to show the whirls at fault characteristics frequencies and its multiple frequencies but other peaks are also presents due to signal modulation effect. By this technique identification of fault categories is difficult. Support Vector Machine shows better classification ability to detect various faults in the gearbox and it can be used for automatic fault diagnosis. Convolution Neural Network could lower cost of maintenance and guarantying a continuous production system, and also it can be used to online diagnosis of process.

References


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