Vibration based Fault Diagnosis Techniques for Rotating Mechanical Components: Review Paper

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Abstract: A rotating mechanical components in machineries like bearings, gears, pulleys, belt drives etc. are major components in any rotating machinery. The failure of these components leads to downtime of machines and reduction in production. Significant economic losses will be caused due to an unexpected failure of these components. Belt drives are widely employed in various industrial equipment. Finding the early fault symptoms in the belt drive is very important. This can be achieved by various methods. For detecting faults and monitoring the condition of a belt drive, the vibration signal can be used as one of the parameter. Thus, vibration signal can be used as a procedure for predictive maintenance and it is used for machinery maintenance decisions. The changes in vibration signals due to fault can be detected by employing signal processing methods. It can be used to evaluate the health status of the machinery. The nature and severity of the problem can be determined by analysing the vibration signal and hence the failure can be predicted. Signature of the fault in the machine is carried by the vibration signal. It is possible to have early fault detection by analysing these vibration signals. Different signal processing techniques are used for processing these signals. The various techniques used for fault diagnosis based on vibration analysis method are discussed in this paper. The application of the artificial intelligence techniques such as Artificial Neural Network (ANN), fuzzy sets and other emerging technologies are discussed.

Keywords: Fault Diagnosis, Vibration signature, Fast Fourier transform, Continuous wavelet transform, Vibration Measuring Techniques, Envelope power spectrum, Wavelet.

1. Introduction

The machines are made up of moving parts, which generates sound and vibration. According to the state and construction of the machine, each part will have a specific vibration signal. The vibration signal changes along with the change in state of the machine part. This change in the vibration signature indicates the incipient defect and hence it can be detected and corrected before failure. This is the main advantage of condition monitoring. The maintenance efficiency and risk of serious accidents can be reduced by using condition monitoring and hence it can save money. This vibration analysis is a fundamental tool for condition monitoring. The machine supervision has been completely automated by the use of electronic equipment, transducers, computers and software. A review of variety of diagnosis techniques for rotating mechanical components has been presented in this paper. The two main purpose of the vibration technique as follows. First is to separate the machine related signal from other components and minimize the noise in the early stage. Second is to identify the status of the machine and indicate the defective components. The various techniques are Spectral Analysis, Order Analysis, Time Synchronous Average, Time – Frequency analysis, Waveform analysis, Fast Fourier Transform(FFT) and Probability Density Moments. Due to their ease of measurement, these vibration based diagnosis techniques are widely used. Formally, the vibration analysis was being used for determining fault and critical operation conditions.
1.1 Condition Monitoring Techniques

Condition monitoring technique is used for identifying significant changes in the machinery, which is under observation. These changes indicate the development of fault. It is a predictive maintenance technique. There are many predictive maintenance techniques, including:

i. Vibration monitoring: This is the most effective technique, which can be used to detect mechanical defects in any rotating machinery.

ii. Oil analysis: In this technique, the lubrication oil is analyzed for finding certain microscopic particles, which can indicate the condition of bearings or gears.

iii. Acoustic emission: This technique is used for detecting, locating and continuously monitoring the cracks in many kind of structures, pipelines etc.

iv. Particle analysis: This method involves the collection and analysis of the debris, which are released by reciprocating machinery such as hydraulic systems or gearboxes. The debris provides vital information of the deterioration of components.

v. Corrosion monitoring: The corrosion wear in pipes is monitored by Ultrasonic thickness measurements for pipelines, offshore structures and process equipment.

vi. Thermography: The active mechanical and electrical equipment are analyzed by this method. It can detect thermal or mechanical defects. It can also be used for detecting the cell damage in carbon fiber structures.

1.2 Fault Detection and Diagnosis using Vibration

The vibration signal acquired from a machine in working condition contain effects of several individual components along with noise. One has to identify and choose the signal which is related to the component under observation. In most of the cases the vibration signals are collected from the casing. The presence and type of fault will be detected at start of development and its progress will be monitored and hence the residual life of the machine guessed. This helps in planning a suitable maintenance. The typical causes of vibration in belt drives are, side-cut-out, side-cut-in and loose belt conditions.

1.3 Signal Processing Techniques

The condition monitoring system involves the signal processing techniques. There are different types of faults and processing these signals is crucial. The selection of the appropriate technique depends on the nature of the captured signal. These techniques include,

i. Time domain analysis: Time domain analysis involves the analysis of physical signals or time series of data, with respect to time. A time-domain graph is used for visualizing the change in a signal with respect to time.

ii. Frequency domain analysis: Frequency domain analysis involves the analysis of physical signals or time series of data, with respect to frequency. It shows the number of signals lying within the given frequency band over a range of frequencies.

iii. Time Frequency domain analysis: It comprises the techniques used in both the time and frequency domains simultaneously. This analysis involves the study of two-dimensional signal.

2. Review

Many number of papers are presented on fault detection by using vibration techniques. There are three types of approaches, namely Time domain approach, Frequency domain approach, Time-Frequency domain approach.

S. J. Loutridis, 2004, has presented a method for detecting the faults in gear by using the empirical mode decomposition scheme. The theoretical model of a pair of gear with a tooth crack was prepared. The vibration signal obtained from the experiment was decomposed intrinsic mode functions (IMF). The energy content of the intrinsic modes and the crack size was related by an empirical law. The system failure was estimated by using the model energy associated with the deterioration in gear condition. The
presence of the damage in the gear pair is determined by the instantaneous frequency of the vibration signal.

Vijay Kumar Karma, 2016, has used frequency domain technique to study the improper chamfering and pitting defects of spur gear. The vibration signals are obtained from spur gear in a two-stage spur gear box setup. He has used the Fast Fourier Transformation technique to determine the frequency contents of the signal for predicting the faults. The tooth faults present in the gear produces peaks and sidebands. The FFT analysis can predict the fault. But it cannot be used for determining the severity of the fault.

Abdulrahman Abdulshakoor Al Bulushi et al, 2015, has analyzed the belt drive using Vibration monitoring method. The experiment was conducted to study the system for healthy and faulty running condition. Three kinds of faults where induced in the system. The faults used are, side-cut-in, side-cut-out and loose & side-cut-out. They have used a minimum speed of 540RPM and a maximum speed of 1000RPM. The relation between severity of fault, vibration amplitude and speed are explained. The running speed of the belt has an effect on the frequency of the belt drive. The intensity of the vibration increases with the increase in the RPM. The loose & side-cut-out condition recorded the maximum level of vibration.

Hui Li, Yuping Zhang and Haiqi Zheng, 2009, have applied the order cepstrum and Radical Basis Function (RBF) Artificial Neural Network (ANN) for the detection of gear fault during the speedup process. The fault diagnosis in non-stationary machine vibration found in varying speed machines are difficult by using the conventional signal processing methods. Because they are carried out in constant time interval. In the present work, computed order tracking and cepstrum analysis are combined with ANN. During the first stage, at constant time increments, the vibration signal is sampled. It is then re-sampled at constant angle increments. The re-sampled signals are processed by cepstrum analysis during the second stage. The feature extraction is done by processing the order cepstrum with normal, we.ar and cra.ck faults. Finally the extracted features are used as input RBF for the recognition. For the known machine conditions, the RBF is trained with a subset of the experimental data. The remaining set of data is used for testing the ANN. The gear condition can be effectively detected and diagnosed by the use of RBF and order cepstrum.

Amar Pawar, 2016, has presented the technique for detecting fault in two stage helical gear box. The aim of the work is to process the waveforms using advanced signal processing technique. This is achieved by Acoustic Emission (AE) and vibration measurement. He has presented the instrumentation of each monitoring methodology along with experimental setup. The conventional and novel parameters features of potential diagnostic value are extracted from the waveforms. The discrete wavelet transform is used for proposing innovative wavelet features. The Acoustic Emission was found to be superior to the vibration recordings of the early diagnosis of natural wear in gear systems.

J Antoni, R B Randall, 2002, have differentiated bearing faults from gear faults through the analysis of vibration signals. The bearing faults are recognized as cyclostationary, whereas the gear faults are recognized as periodic. The distinction between the localized and distributed faults were also made. For localized faults pseudo cyclostationary vibration signal are produced. They can be considered as cyclostationary in first approximation. For distributed faults a specific diagnostic procedure based on advanced spectral analysis. The effectiveness of this method was checked based on experimental and actual vibration signal.

Bing Liu, V. Makis, 2006, have used dynamic principal component analysis (PCA) and condition monitoring technique for the gear failure diagnosis based on vector autoregressive modeling of high – frequency vibration data and dimensionality reduction. They have used the multivariate Q control chart
for the detection of localized fault on the gear. The vibration data is obtained using dynamic PCA and all useful information are extracted. Then a real gearbox vibration data is used for the implementation of a failure diagnosis scheme. When there is any damage in the gear, the gear teeth failure pattern can be indicated by the failure diagnosis scheme. Then the PCA is applied to the same data set for the purpose of comparison. The dynamic PCA indicates the occurrence of incipient fault more accurately. It also indicates actual gear condition with lower false alarm rate. The study can point out to what degree the results of the analysis can be trusted and it also recognize the severity of failure, location of the failure on the gear.

Nader Sawalhi, Robert B. Randall, 2004, have introduced the Spectral Kurtosis (SK) as a new analysis technique for the diagnosis of rolling elements. The SK indicates the best band for the demodulation, without the use of historical data. The optimum bandwidth and the centre frequency can be determined for maximizing the filter output kurtosis. The most impulsive part of a signal can be separated from stationary masking component by using the filters generated by SK. The SK can be used for bearing fault signal extraction from the background noise.

DejjeTu et al (2005) have used Empirical mode decomposition and Hilbert transform for the fault diagnosis of roller bearing. The vibration signals are transformed into time scale illustration by using orthogonal wavelet sources. The local Hilbert marginal spectrum gives the faults and its pattern. The EMD method and Hilbert transform are applied to the envelope signal. This method is better than the old envelope spectrum method.

Z.K. Peng et al, 2005, has presented improved Hilbert Huang Transform (HHT). The vibration signal is decomposed into a set of narrow band signal by using the wavelet packet transform. The IMFs are generated by applying EMD on the narrow band signals. The useful IMFs are selected by effective selection method and unnecessary IMFs are eliminated. The resolution of the new HHT was found to be better in time and frequency domain. It also has better efficiency in calculation. The ripple phenomenon present in the HHT spectrum in the expected frequency may lead to wrong analysis.

B Liu et al, 2006, has applied empirical mode decomposition (EMD) and Hilbert spectrum method for the analysis of vibration signal from localized gear box. The mechanics of EMD is studied by using B-Spline EMD as a filter bank. The effectiveness of original and B-spline EMD is investigated with the corresponding Hilbert spectrum. The experiment is conducted by collecting the vibration signal from an automobile gearbox with an initial tooth crack. The EMD processes and Hilbert spectrum are more effective in finding the defect as compared to the continuous wavelet transform.

Enayet B. Halim et al, 2008, presented a technique by taking the average of time domain. The periodic waveforms at different scales are extracted from noisy vibration signals by combining the time synchronous average and wavelet transformation. The local and distributed faults are eliminated effectively at the same time. A peak in the plot of TDAS can be found due to the fault in any gear. A large peak is produced due to missing tooth and a peak with a parallel side peak at the meshing frequency results due to chipped tooth. By observing the peaks of the fault of TDAS, instantaneous multiple faults can be detected. The efficiency of the proposed technique is validated by presenting a pilot plant case study.

Yimin Zhan et al, 2006, has used the gear motion residual signal for the detection and diagnosis of gear faults. He has used the gear faults under varying load. As compared to the TSA signal, the gear motion residual signal helps to detect the fault more clearly. In this method, the load is continuously varied. In this method we can get a stable and reliable measure of state of gear as compared to any other techniques.
Xianfeng Fan et al, 2005, has combined Hilbert transform and wavelet packet transform. The proposed method is verified by the virtual signals and real vibration signals collected from a simulator. The proposed method was found to be effective in selecting the particular modulating signal and detect the early gear fault. The non-stationary signals also can be analyzed by this method. Hilbert Transform has more benefits of good accuracy, efficiency and easy fault detection as compared to wavelet packet transform.

M. Lokesha et al, 2011, have presented Fault diagnosis in gear using wavelet envelope power spectrum. The faults in vibration signals with no stationary, transient characteristics/components can be efficiently detected using wavelet analysis. The diagnostic capability of FFT power spectrum and the wavelet envelope power spectrum are compared by using experimental data. They are computed using Laplace and Morlet wavelet functions respectively. A healthy and a faulty gear are used for obtaining vibration signal. The results are compared for various stages of induced gear fault. The Morlet wavelet and Laplace wavelet based enveloped power spectrum shows better results as compared to the FFT power spectrum.

N. Saravanan, K.I. Ramachandran, 2008, has used the Wavelet Transform (WT) as a tool for the condition monitoring and fault diagnosis in a gear box. Feature extraction is achieved for various types of wavelets by collecting the vibration signal from a spur bevel gear box under different conditions. The relative effectiveness of the WT in feature extraction is compared by using Daubechies wavelets (db1 – db15). The classification and feature selection is obtained by the use of J48 Decision Tree algorithm. The linear and non-linear processing of vibration signal is decomposed by the WT as an illustration. The efficiency of the maximum average classification of a Daubechies wavelets was found to be 98.57%. Among the 15 levels of, db1 and db5 Daubechies wavelet has the maximum classification efficiency of 98.667%.

Lixin Gao et al, 2010, have proposed various methods for the diagnosis of fault in the gearbox which includes wavelet lifting, Support Vector Machine (SVM) and Rule-Based Reasoning (RBR). SVM is used for the initial diagnosis since the machines may not have the same type of fault. In the first stage, the wavelet packet decomposition was used for processing the gearbox vibration signals. Then the signal energy coefficients of each frequency band is extracted and used as input feature vectors in SVM for normal and faulty pattern recognition. In the second stage, the noisy signals are filtered using wavelet lifting and the impulse characteristics of the fault are maintained. Hence, the fault frequency of the machine is extracted. Finally the detailed fault type is identified by using the knowledge of the field rules summarized by experts. When the sample size is small, SVM can be used to recognize the gearbox fault pattern. The fault features can be effectively extracted by using wavelet lifting scheme. The detailed fault type can be identified by Rule – Based Reasoning. The RBR was achieved through the fuzzy matrix. Hence effective gearbox fault diagnosis can be achieved by using a method which combines SVM, wavelet lifting and RBR.

3. Conclusion

The vibration monitoring technique helps to remove the noise from the signal. The wavelet transform gives an accurate result in the detection and localization of the defects. The time domain techniques does not give any diagnostic evidence under varying load condition. By FFT method, it is very difficult to identify the categories of fault. Automatic fault diagnosis can be achieved by the use of ANN & Support Vector Machine. It also gives better classification of various faults. The maintenance cost can be reduced by the use of Convolution Neural Network. It is also used for online diagnosis of the fault, hence providing a guaranteed continuous production.
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