Vibration Feature Extraction and Analysis for Fault Diagnosis of Rotating Machinery-A Literature Survey

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Abstract – *Safety, reliability, efficiency and performance of rotating machinery in all industrial applications are the main concerns. Rotating machines are widely used in various industrial applications. Condition monitoring and fault diagnosis of rotating machinery faults are very important and often complex and labor-intensive. Feature extraction techniques play a vital role for a reliable, effective and efficient feature extraction for the diagnosis of rotating machinery. Therefore, developing effective bearing fault diagnostic method using different fault features at different steps becomes more attractive. Bearings are widely used in medical applications, food processing industries, semi-conductor industries, paper making industries and aircraft components. This paper review has demonstrated that the latest reviews applied to rotating machinery on the available a variety of vibration feature extraction. Generally literature is classified into two main groups: frequency domain, time frequency analysis. However, fault detection and diagnosis of rotating machine vibration signal processing methods to present their own limitations. In practice, most healthy ingredients faulty vibration signal from background noise and mechanical vibration signals are buried. This paper also reviews that how the advanced signal processing methods, empirical mode decomposition and interference cancellation algorithm has been investigated and developed. The condition for rotating machines based rehabilitation, prevent failures increase the availability and reduce the cost of maintenance is becoming necessary too. Rotating machine fault detection and diagnostics in developing algorithms signal processing based on a key problem is the fault feature extraction or quantification. Currently, vibration signal, fault detection and diagnosis of rotating machinery based techniques most widely used techniques. Furthermore, the researchers are widely interested to make automatic procedures for fault extraction techniques. Such expert systems, neural networks, artificial intelligence and system devices and most powerful methods described above in conjunction with some of the techniques being used fuzzy inference system.*

Keywords – *Condition monitoring, rotating machinery faults, fault diagnostic method, fault features extraction, advanced signal processing methods, frequency domain, time frequency analysis.*

INTRODUCTION

Machinery rotating mass often with very demanding performance standards, some of which are complex used in the industry today. Machine failure, a failure of a reliable lead-time is not able to predict, without effective evaluation. Thus resulting in costly downtime can be devastating. Therefore, effective and efficient condition monitoring and fault diagnosis is essential for the industry. However, the diagnosis of faults in rotating machinery is often a labor-intensive and time-consuming. Effective and efficient fault diagnosis is always a challenging task for the technicians and plant diagnostics. Fault diagnosis is usually done in the following steps: data acquisition, feature extraction, and fault detection and identification structure. Vibration signals collected and processed by the sensor are often contaminated by noise and thus unusable for direct machine faults diagnose. Properties (signatures and characteristics) can go undetected without the help of special techniques. Feature extraction techniques can increase the signal to noise ratio to detect machine faults signal for help or find some ingredients. Several vibration of rotating machinery fault diagnosis techniques have

been applied to. Usually vibration techniques based techniques to model data, and includes various signal processing algorithms measured vibration signal to extract useful diagnostic information. In the last twenty years, some research from different points of view, the company's technical review has been conducted in the1980, Matthew and Alfredson time and frequency of vibration monitoring techniques review for rolling element bearings domains [2]. McFadden, Smith [3] and low [4] classical non-parametric spectral analysis, principal component analysis, joint time-frequency analysis, discrete wavelet transform, and the generation of residual includes a change detection algorithm. Lebold and McClintic [5] gear when the vibration characteristics evaluation methods to extract the data reviewed [6]. To [7] provides a brief overview Tandon and Choudhury defects in rolling element bearings for detecting vibration and acoustic measurement techniques reviewed models based approach and signal processing approach to motor error. Each category structure, as shown in Figure 1.This paper, rotating machines for a variety of different vibration techniques in the detection and diagnosis presents an updated review and is divided into three types, methods of general principles, some of which contain a diverse range of techniques in the existing literature. Tips are also provided for future work that are presented in the form of a unified. The following figure 1 shows the step by step process.

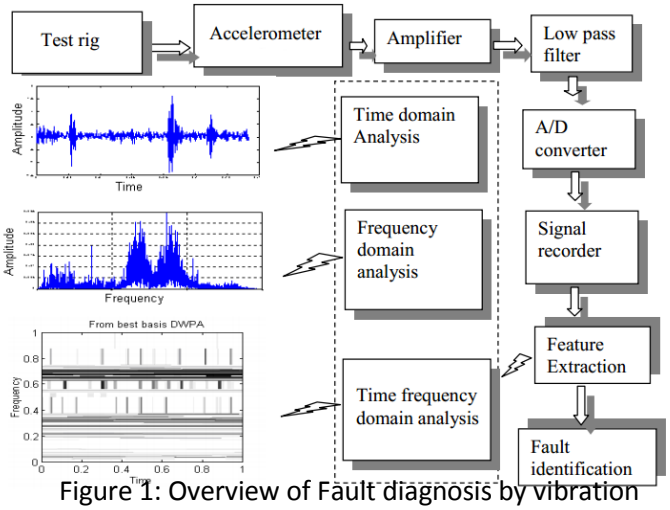

Figure 1: Overview of Fault diagnosis by vibration signals

TIME DOMAIN

The proximity of vibration signals, velocity represented as a series of digital values and acceleration are in time domain. This section reviews recent research on the vibration technique rotating machinery and techniques classified in the following groups for different types of domain (as shown in Figure 2).

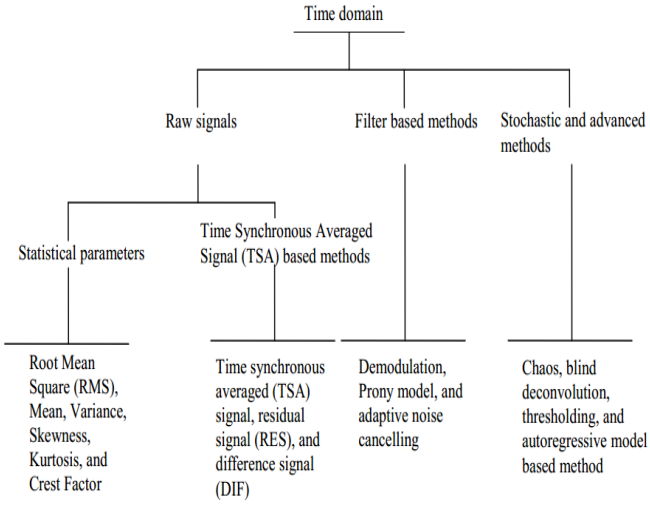

Figure 2: Vibration features extraction method in time domain

Root Mean Square (RMS), Mean, Variance, Skewness, Kurtosis, and Crest Factor are the statistical parameters for feature extraction technique.

The root mean square (RMS) value and crest factor methods have been applied in diagnosing bearings and gears fault [6]. The RMS of a vibration signal is a time analysis feature that measures the power content in the vibration signature. This feature is very effective when detecting an imbalance in rotating machinery. The most basic approach to measuring defects in the time domain is to use the root mean square approach which is often not sensitive enough to detecting incipient faults in particular. A move described as "crest factor", is to use RMS level, the ratio of the peak level of the input signal. Therefore, the series will result in signal peaks Statistical parameters filter based on probabilistic methods , advanced methods raw signal , average time synchronous Signal (TSA) based methods , Root Mean Square (RMS), Mean, variance and skewness.

Kurtosis, and Crest Factor Time Synchronization Average (TSA) Signal, outstanding Signal (RES), and Difference signal (DIF) For demodulation, Prony model, and Adaptive Noise Cancel Chaos, blind deconvolution, thresholding and The Autoregressive Model based method Time Domain crest factor value. This feature is used to detect changes in the signal pattern due to impulsive

vibration sources such as tooth breakage on a gear or a defect on the outer race of a bearing.

Statistical analysis of vibration signals has proved useful in the detection of machinery faults. According to Tandon [6] probability density is correlated with bearing defects. Prospects density in good condition, while the results of an impact quickly affect a Gaussian distribution, it cause the relative increase in the number of high-level dominant non-Gaussian distribution with tails acceleration. Matthew and a close Alfredson also damaged some of Gaussian distribution report bearings. Andrade [8] target distribution density function of the comparison (CDF) proposed a reference distribution CDF (cumulative density function) and the gear teeth are used for fatigue crack detection possibilities.

More moments of their distribution data simplify the analysis of the mean, variance, skewness and is the first moment, the moment, and the probability distribution respectively. The third bridge is the kurtosis distribution as the fourth minute and a distribution as relative measures peakedness or sadness compared to a normal distribution. Kurtosis provides a measure of the size of the tail of the distribution is used rotating Machinery fault presents itself as a set of data as an indicator of the peaks. Kurtosis should be bearing vibration diagnosis has been applied due to the increased level of kurtosis indicates an error, and the gearbox faults [9].

Route mean square (RMS), peak, crest factor, kurtosis and detect high-frequency resonance techniques in conjunction with an adaptive line enhancer methods used to detect the localize damage in rolling bearings [10].

Time synchronous averaging based methods which include Time Synchronous Averaged (TSA) Signal, residual signal (RES), and difference signal (DIFS)

TSA synchronous signal timing and redundant average initial data obtained by reducing the noise level. TSA after repeated signal which needs to be diagnosed faults, data showed. Comblet including FM0 and TSA [5] Such rolling bearings, gears, or shaft defect frequency as the frequency of the desired signal is repeatedly not need to know. Rolling bearings and gears synchronous signal success [11-13] were used for the diagnosis of faults in the average.

RES time of synchronous faults where the gear was used to assess the residual signal (RES) drove their basic meshing with harmonics and signal average with shaft components [5]. RES system may depend. Regular time synchronous meshing components were calculated by taking the difference signal (DIF) signal averaging. Duff effectively the gearbox was used to diagnose faults [14].

Demodulation, Prony model, and adaptive noise cancelling (ANC) used for the Filtering method.

Massive Noise filter to remove and isolate the signal feature extraction techniques used. Here we usually filter-based methods as their calling methods. Based modes of demodulation, prony model, and adaptive noise cancellation (ANC) filter added.

Including demodulation of the phase and amplitude demodulation is an important signal processing technology. The turnover or the resonance demodulation are known as high-frequency resonance of amplitude demodulation, demodulation technique [15] to activate them, the low level of background noise, low-frequency signal separated gear easily detect faults in the application. To be measured, the amplitude demodulation focus on Fault-induced dominant gear around the high-order harmonic modulation sidebands meshing [16]. It is also the effect of fault [17]. The evaluation was applied on stage, the band called demodulation error induced effects [15] induced by the structural resonance associated with.

Usually demodulation method using conventional Infinite Impulse Response starts with (IIR) .In such a band or stopband BUTTERWORTH, Chebyshev, Bessel, and ellipse as filters. The model was Prony with a time domain impulse response IIR filter algorithm to search a model based Prony Method [18] evaluated the effect of fault was implemented. A modern developed filter, adaptive filter was embedded an adaptive noise cancellation (ANC) system and the fault [19] showed promise in evaluation. Asynchronous adaptive noise canceling technology, self-aligning roller bearing was employed to detect faults success [20].

Stochastic methods (including chaos) and others (blind deconvolution, thresholding, and autoregressive model based method)

Stochastic parameters such as vibration analysis in advanced time domain methods have been used to. Chaos, and in particular the correlation dimension, encouraging several different sin was used to characterize rolling element bearing [21] in intensity. Correlation dimension can provide some inside information a basic dynamical system, and various crime rate can be used to intelligently [22]. Nirbito [23] by suggesting signals affect the possibilities to

improve the experience of blind deconvolution noise. Some pseudo-phase portrait rotating machinery faults [24] was sensitive to. Threshold denoising (Hard and soft limits, including limits) are often used for vibration analysis denoise. Limit when denoising methods usually diagnosed with a turnover or some other methods were combined with machinery faults. A soft thresholding method and hard thresholding method has been used in the evaluation machine fault [25]. Autoregressive model based on a method has been successfully applied in fault diagnosis [26].

VIBRATION FEATURE EXTRACTION TECHNIQUES IN BOTH TIME AND FREQUENCY DOMAIN

Frequency and time frequency domain characteristics such as the characteristics of frequency information features Extensive currently being investigated. These features can usually identify better machinery faults compared to the time domain vibration characteristics such as resonance frequency characteristic frequency components defect components or frequency components relatively easily detected and can be dialed from fault.

This new fast Fourier transform (FFT) starts arrival, emphasizes the different time frequency representation and time frequency analysis including scale. As shown in Table 1, the frequency and time-frequency analysis techniques effectively in order to increase the extraction coefficients are being researched change frequency or time frequency parameters. By calculation techniques were applied as a relationship or logarithmic value changes of parameters. For example, power spectrum both linear and logarithmic spectrum was used widely since the spectrum was implemented successfully.

Suitable vibration diagnostic techniques to get the most need to be selected according to the application performance. Frequency domain or spectral analysis are widely used in the bearing fault detection. FFT [27] most conventional diagnostic technology and has been widely used. Frequency characteristics of the signal to identify the raw signal or the signal can be processed signal. For example, to obtain a spectrum envelope signal a procedure was well established [28] which separated other machine elements by vibration generated by the vibration generated by a defective component.

The amplitude spectrum is the square of the amplitude of the power spectrum. Spectrum is also called higher order bispectrum and motor bearings assessment [30] error can be applied [29] is an effective method for the diagnosis of machinery faults. Bicoherence used to measure the spectrum is a third-order spectrum due to non-linear wave coupling between the spectral components of stage lighting. Bicoherence the state [31] have been used for surveillance. Logarithm of the power spectrum of the power was applied to machinery fault diagnosis [6]. Frequency and time-frequency techniques to prepare an overview of the techniques is given in the table some detailed definitions and applications of these techniques is the process as follows.

Table 1. Frequency and time frequency technique overview

First order	Second order	Third order	Fourth order
Spectrum (FFT)	Power spectrum	Bicoherence	
	Power cepstrum (logarithm of Power spectrum)	spectrum	
Correlation of spectrum, signal averaging	Cyclostationarity	bilinearity	
Short time Fourier transform (STFT)	Spectrogram		
	Wigner distribution	Wigner bi spectra	Wigner tri spectra
Continuous wavelet transform(CWT)	Scalogram		
Discrete wavelet transform(DWT)			
Discrete wavelet packet analysis (DWPA)			
time-averaged wavelet spectrum (TAWS)			
time-frequency-scale domain (TFS)			

Cyclostationarity synchronizing a frequency domain average method is second order. Cyclostationarity issued another order spectral correlation function parameter is effective for early diagnosis gear faults in the system. Early diagnosis of gear tooth spalling cyclostationarity application research and helicopter gearboxes early diagnosis [33 was a new parameter in the application [32]. Cyclostationarity and demonstrated the power of a comparison between bilinearity [33].

In the past decade, time frequency analysis technique has been studied and applied to machinery fault diagnosis.This feature of time-frequency analysis techniques to the analysis of the vibration signal stationery needs. The time frequency analysis techniques to monitor the condition of machinery was applied [35], Fourier [34] windowed and short-time Fourier transform (STFT) change.

Wigner distribution [36] and spectrogram [37] was applied to the diagnosis of gear faults belonging to the class of Cohen's most famous square, the frequency are represented. Cross the basic gestures such conditions, the main causes interference not allow a direct interpretation energy distribution. Choi Williams directional distribution (dCWD), the planar motion of a quickly rotating machinery, which represented various complex valued signals, was proposed to account for [38]. Directional Wigner distribution (DWDs) forward and backward to define analytic signal [39] grinding machines have been implemented in order to analyze. Third and fourth-order moment spectra using Wigner, respectively, was used to analyze the signal and the spectra called Wigner bi-Rotating Machinery [40].

The sliced Wigner fourth-order moment spectra for multiple signals had problems with its application which was due to the existence of non-oscillating cross-terms not smoothed by conventional methods. This technique have been applied to the diagnosis of engine valve system [41].

Improved continuous wavelet time frequency resolution is based on STFT and machinery fault diagnosis [12] scalogram has been applied to the rotating (CWT) change – square CWT [26] was applied in the evaluation of the modulus gears. Vibration signature of a rotorcraft planetary gear train system to diagnose and mean square algorithm wavelet map [42] The change was approved in a harmonic wavelet.

Discrete ball bearings spalling [43] was used for the evaluation of (DWT) wavelet transform. Discrete wavelet packet analysis (DWPA) [44], and discrete wavelet analysis (DWA) [45] was also used to diagnose the fault. Matching Pursuit [46] and the acquisition [47] adaptive frequency which was applied to the diagnosis of machinery faults approximation are two recent techniques. A time scale frequency domain (the TFs) techniques machinery fault [48-54] has been developed for the diagnosis.

CONCLUSION

Vibration feature extraction techniques such data, signal processing, and advances in computing science as the subjects are getting better all the time. Domain techniques raw signal, filter the signal, and models based on probabilistic methods include time. Such means, as covariance data moments, and kurtosis rotating equipment to detect faults in a range can be calculated. Statistical parameters machinery faults detection sensitivity for the fault of the research are to improve. Demodulation such as filter-based methods effectively separated from other unrelated signal "error" is used to vibrate the noise as such.

Usually the time domain frequency domain characteristics parameters are more consistent than the loss detection. Frequency conversion techniques and parameters in order to increase the frequency techniques are being investigated by. Moreover, the frequency techniques such as inter-term issues are being investigated components between neighboring frequency bands. Moreover, the frequency techniques, for example, dyadic discrete wavelet transform. Specific programs need to be studied to analyze specific ingredient information is rather low frequency band is focused on high-frequency bands. Discrete wavelet packet analysis sets fault diagnosis for rotating machinery to make it powerful low-frequency and high-frequency coefficients of the packet.

Researchers have worked on various projects to improve the detection and diagnosis of faults in time frequency domain [47].The chosen method results fine resolution and signal sparsity. By implementing this new method, the vibration frequency components can be clearly displayed on a map. This led to the relatively which is often include noise signals, the direct interpretation.

Moreover, researchers using feature extraction techniques of evaluation are increasingly interested in automating procedures. Used in conjunction with some of the most powerful being, tools and such expert systems, neural networks, and fuzzy inference systems as well as techniques in artificial intelligent systems the technique described above.

The authors also automatic fault diagnosis of rotating machinery has started research. Time frequency analysis technology and is based on neural network techniques. The further results of this work will be reported in due course.

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