Rub-Impact Fault Vibration Analysis of rotating machinery using Hilbert-Huang Transform

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Abstract— Vibration problems in rotors can be extremely frustrating and may lead to greatly reduced reliability. Rubbing is common faults in rotating machinery because of the clearance between the rotor and the stator. These problems cause malfunctions in rotating machinery and create strange vibrations coming from impact and friction. However, non-linear and non-stationary signals due to impact and friction are difficult to identify. Therefore, exact time and frequency information is needed for identifying these signals. For this purpose, a newly developed time—frequency analysis method, HHT (Hilbert-Huang Transform), is applied to the signals of partial Conventional signal processing methods such as FFT, and CWT were compared to verify the effectiveness of fault diagnosis using HHT.

Key words: Hilbert, CWT, CWT

I. INTRODUCTION

The performance of rotating machinery such as motors, compressors, pump and gas turbines can be raised when the clearance between the rotor and the stator is made as small as possible. However, the rotor can come in contact with the stator during whirling due to imbalance or misalignment of the rotor. A protrusion at the stator leads to a partial rub during the whirling motion. The partial rub characterizes intermittent contact which persists, becomes more severe, and leads to higher vibration levels. A partial rub can be one of the most damaging malfunctions in rotating machinery. However, it had been reported that the rotor once perturbed to interact with stator, might develop full rubbing from the partial rubbing. Continuous rubbing between rotor and stator accelerates wearing of these parts and increases the clearances between them, which in turn results in loss of efficiency and also economy. Rubbing might result in broken machine parts, for example, rubbing between a blade and stationary part could result in broken blade. Ignoring the occurrence of rubbing may lead catastrophic breakdown of the rotating machines. The rotor to stator rubbing is considered as a secondary phenomenon resulting from a primary cause, which perturbs the machine during normal operation. These primary causes could be rotor vibrations (due to unbalance or other sources) and/or displacements of rotor centreline, due to rotor misalignment, gravity force, fluid forces, etc. The conventional frequency analysis method, Fourier spectrum, does not contain time information about a signal. FFT offers a frequency-domain representation of a signal where the analyst can identify abnormal operation of the machinery through the peaks of the frequency spectra. FFT cannot detect transient signals that occur in non-stationary signals. As time-frequency analysis methods, STFT (short time Fourier-transform) and Wavelet are widely used. STFT is also called as short term Fourier transformer. It is Fourier related transformer used to determine sinusoidal frequency and phase content of local sections of a signal as it changes over time. The procedure for computing STFT is to divide a longer time signal into shorter segments of equal length. Then compute the Fourier transformer on each shorter segment. Unlike conventional Fourier transform wavelet transform based on small waves, called wavelets. It can give frequency and time information. These methods can detect mechanical phenomena that are transient in nature, such as a rotor rubbing the casing of a motor in the machine. This approach converts a time-domain signal into a time-frequency representation where frequency components and structured signals can be localized. However, these methods exactly determine the characteristics of the partial rub. A continuous wavelet transform (CWT) is used to divide a continuous time function into wavelets. Unlike Fourier transform, the continuous wavelet transform possesses the ability to construct a time frequency representation of a signal that offers very good time and frequency localization.

II. LITERATURE REVIEW

Seung-Mock Lee and Yeon-Sun Choi studied that Partial rub and looseness are common faults in rotating machinery because of the clearance between the rotor and the stator. These problems cause malfunctions in rotating machinery and create strange vibrations coming from impact and friction. However, non-linear and non-stationary signals due to impact and friction are difficult to identify. Therefore, exact time and frequency information is needed for identifying these signals. For this purpose, a newly developed time—frequency analysis method, HHT (Hilbert-Huang Transform), is applied to the signals of partial Conventional signal processing methods such as FFT, STFT and CWT were compared to verify the effectiveness of fault diagnosis using HHT. The time and frequency information was represented exactly by using HHT in both cases, which makes clear fault diagnosis between partial rub and looseness.

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Yen Lin mentioned Wavelet transforms have become one of the most important and powerful tool of signal representation. Nowadays, it has been used in image processing, data compression, and signal processing. This paper will introduce the basic concept for Wavelet Transforms, the fast algorithm of Wavelet Transform, and some applications of Wavelet Transform. The difference between conventional Fourier Transform and modern time-frequency analysis will also be discussed. Unlike conventional Fourier transform, wavelet transforms are based on small waves, called wavelets. It can be shown that we can both have frequency and temporal information by this kind of transform using wavelets. In this paper he introduced two of the most well-known transform of time-frequency analysis –
Windowed Fourier transform and Wavelet transform. Continous Wavelet transform can also be discretized. It is basically based on continuous wavelet transform. Then he studied the implementation and the efficient algorithm of discrete Wavelet transform. Nowadays, discrete wavelet transform has become the most useful tool for signal processing and it still has many potentialities.

HE Yongyong, CHU Fulei & WANG Qingyu studied that Rubbing is the frequent and dangerous fault in the rotating machine, and efficient identification of the rubbing is a hot research subject in the field of fault diagnosis. In this paper, a new rubbing identification method is proposed, which is based on the acoustic emission technique. In this method, the acoustic emission signal of the rubbing in the multi-support rotor-bearing system is acquired by the acoustic emission sensor, and then the continuous wavelet transform is utilized to analyze this signal. Based on the rubbing mechanism, the frequency feature of the multiple frequency relation in the instantaneous frequency wave is extracted as the rubbing identification feature. The continuous wavelet transform (CWT) is utilized to analyze the AE signal and extract the frequency feature of the rubbing in the instantaneous frequency wave of CWT to identify the rubbing, which is based on the rubbing mechanism.

Gang Zhao studied that many vibration signals of fault turbine rotor are non-stationary and have highly complex time-frequency characteristics. A good way to analyze the non-stationary mechanical signals is the wavelet transform. Unfortunately, the direct result of wavelet transform in fault diagnosis of steam turbine is not easy to understand because it lack of physical meaning compared with FFT. Consequently, time-frequency contour map is introduced into fault diagnosis of steam turbine. The time-frequency contour map can easily show the power distribution of signal in time and frequency domain.

Ruqiang Yan studied that a signal analysis technique for machine health monitoring based on the Hilbert-Huang Transform (HHT). The HHT represents a time-dependent series in a two-dimensional (2-D) time-frequency domain by extracting instantaneous frequency components within the signal through an Empirical Mode Decomposition (EMD) process. The analytical background of the HHT is introduced, based on a synthetic analytic signal, and its effectiveness is experimentally evaluated using vibration signals measured on a test bearing. The results demonstrate that HHT is suited for capturing transient events in dynamic systems such as the propagation of structural defects in a rolling bearing, thus providing a viable signal processing tool for machine health monitoring. The goal of health monitoring is to identify potential failure causes at the early stage such that timely adjustment and maintenance actions can be taken to reduce severe machine damage and costly machine downtime.

S. Braut studied that Rotor–stator rubbing is occasional problem faced by rotating machines especially during start-ups and shut downs when passing through their critical speeds. The rubbing often occurs in rotating machinery at position with small clearances and can sometimes cause catastrophic breakdown of machine. So it is important to develop reliable tools for rub diagnosis. This paper investigates partial rub occurrence during constant and slightly variable speed operation and try to define vibration diagnosis patterns for its detection with Variational Mode Decomposition (VMD). The VMD is relatively new method with promising results potentially interesting for machinery failures diagnosis.

Fengli Wang studied that Local rub-impact is the common fault in rotating machinery and results in impact and friction between rotor and stator. The vibration signal due to impact and friction is always non-stationary which includes three components, namely, the rub-impact signal, the background signal and the noise signal. EMD (Empirical mode decomposition) is based upon the local characteristic time scale of signal and could decompose the complicated signal into a number of IMFs (intrinsic mode functions).

M. Sifuzzaman mentioned that Wavelet analysis is an exciting new method for solving difficult problems in mathematics, physics, and engineering, with modern applications as diverse as wave propagation, data compression, signal processing, image processing, pattern recognition, computer graphics, the detection of aircraft and submarines and other medical image technology. Wavelets allow complex information such as music, speech, images and patterns to be decomposed into elementary forms at different positions and scales and subsequently reconstructed with high precision.

Galal A. Hassaan mentioned that, this paper is a research effort to provide a stone in the building of machinery fault detection and diagnostics. It relies on using the spectrum analysis of the vibration signal using FFT. Depending on the expected faults of a specific machine, the technique of bandpass filtering is applied on the frequency spectrum of the vibration signal generating bandpass spectra helping in easier fault diagnostics. Central frequencies and proper bandwidth are assigned to generate the new spectra of the defected machine. Machinery condition, life, reliability and accuracy are key factors in any industrial process supporting successful economical plans and outcome. Because of this the area of machinery faults diagnostics is very attractive to researchers around the world for decades.

P Shakya mentioned that a comparative study of various vibration signal-based damage identification parameters for rolling element bearings is undertaken. Defects of varying severity are seeded on the outer and inner races of a double-roller angular contact bearing. The influence of a defect and its severity on the observed identification parameters is investigated using vibration data acquired from the bearing housing.

III. PROBLEM DEFINITION

A. Gaps identified from literature survey:

They have not focused on faults other than rubbing such as vibration response for misalignment, improper braking system. The Fourier spectrum gave the exact frequency information but it showed limitations for non-linear and non-stationary signals. STFT was difficult to apply to non-linear and non-stationary signals because of the constant window function. Furthermore, it was not suitable for the data within a very short time. In CWT the peaks were spread widely at both the time and the frequency region, and the scales, which were in the relatively lower frequency region, were not clear enough for recognition of the exact information. EMD as a data driven alternative approach to the analysis of non-stationary signals appears some drawbacks. Because the rub-
impact signal is weak, it is very difficult to separate the rub-impact signal from the vibration signal including noise and background signal by using the straightforward EMD method.

B. Problem definition:

Rotor once perturbed to interact with stator, might develop full rubbing from the partial rubbing. Continuous rubbing between rotor and stator accelerates wearing of these parts and increases the clearances between them, which in turn results in loss of efficiency and also economy. Rubbing might result in broken machine parts, for example, rubbing between a blade and stationary part could result in broken blade. Experimental set up is shown in Fig. 5.1. Problem can be defined as “analysis of vibration response for rub detection using HHT, FFT, and CWT.”

C. Objective of project:

1) To diagnose the faults using HHT, FFT, and CWT.
2) To study and analyze vibration response for rub detection and misalignment using HHT (Hilbert Huang Transform).
3) To compare vibration response of HHT with other conventional methods such as FFT and CWT.

IV. EXPERIMENTAL METHODOLOGY (THEORETICAL)

A. Experimental set up:

![Fig. 1: Experimental set up](image)

B. Components in experimental set up:

1) Motor:

Motor Specification- AC induction motor -380 Watt 1440RPM. It is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate excitation or self excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor’s rotor can be either wound type or squirrel cage type.

2) Couplings:

Coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shaft during operation. The primary purpose of coupling is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both. By careful selection, installation and maintenance substantial saving can be made in reduced maintenance costs and downtime. A hose coupling is used in experimental set up. Hose coupling is a connector on the end of a hose to connect (or couple) it with another hose or with a tap or a hose appliance. It is usually made up of steel, brass cast iron, stainless steel, aluminium or plastic. There are many types of hose couplings such as Air King, Barcelona, Cam and groove, Expansion ring, Express coupling, Garden hose thread, Gost, Ground joint, Guillemin symmetrical clutch, Holedall, Hozelock, Machino, Nakajima, Storz, etc.

3) Bearing and bearing housing:

A bearing is machine part, which support a moving element and confines its motion. The supporting member is usually designated as bearing and the supporting member may be journal. Since there is a relative motion between the bearing and the moving element, a certain amount of power must be absorbed in overcoming friction, and if the surface actually touches, there will be a rapid wear. Shafts are generally supported by two bearings in the radial and axial directions. Pillow Block type bearing which have good load carrying capacity and it can accommodate misalignment bearings of 20mm bore diameter were selected for the design; it was ensured that bearings would allowed for the mounting of all components onto the shaft physically and that the mass of all components including bearings was minimized. These bearings provide coefficient of friction in between 0.001 to 0.002. These bearings offer advantages like rapid replacement, less space requirement and warning of failure with increasing noisiness. The bearing housing is cylindrically hollow shaped possessing good strength and toughness. The housing design was implemented by selecting dimensions that will result in smaller bending moment.

4) Pedestal bearing:

A cylindrical hole formed in a cast iron machine member to receive the shaft which makes a running fit is the simplest type of solid journal bearing. Its rectangular base plate has two holes drilled in it for bolting down the bearing in its position as shown in the figure. An oil hole is provided at the top to lubricate the bearing. There is no means of adjustment for wear and the shaft must be introduced into the bearing endwise. It is therefore used for shafts, which carry light loads and rotate at moderate speeds.

5) Shaft:

Shaft is a rotating machine element used to transmit power. Since the loads on most shafts in connected machinery are not constant, it is necessary to make proper allowance for harmful effects of load fluctuation.
6) Data Acquisition Card:

![Data Acquisition Card Image]

Fig. 3: Data acquisition card

V. CONCLUSIONS

In this paper, an attempt to summarize the recent research and developments in the vibration analysis. The present study includes opinion of different authors on vibration response for rub detection using Fast Fourier Transforms, Continuous Wavelet Transform, and Hilbert Huang Transform. In this paper we also studied theoretical part of vibration analysis of rotor system. we will use time domain and frequency domain for feature extraction and fault diagnosis in our work.

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