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A Review on Engine Fault Diagnosis through Vibration Analysis

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Abstract

Vehicles engine failure is disapproved problem for drivers, and repair of that needs experience to identify fault and troubleshooting. The fault diagnosis in a machine is significant for fending off dangerous damage. The vibration signals of a machine always carry the dynamic information of the machine. These vibration signals of internal combustion engines are extremely helpful for the feature extraction and detect the fault diagnosis. The former sensing of defects by supervising can keep farther harm to the internal combustion engine and deflect further causalities. The faults lead to reducing the engine performance and increasing the harmful pollution. In this paper, present techniques of a denoising method for vibration signal analysis that had been proposed such as fast Fourier transform (STFT), higher-order statistics (HOS), Wigner–Ville distribution (WVD), and wavelet transform (WT) and adaptive order-tracking.

Keywords: Vibration; Denoising; Fast Fourier transform (STFT); Internal combustion engines.

Nomenclature

IC	Internal combustion
ICE	Internal combustion engine
ANN	Artificial Neural Networks
FL	Fuzzy Logic
STFT	Short time Fourier transform
WVD	Wigner–Ville distribution
WT	Wavelet transform
NLAR	Non Linear Auto Regressive

1. Introduction

Internal combustion engines (ICEs) are widely employed as a power source in the vehicle, ship, and power equipment industries. However, unforeseen flaws are common due to the complicated structure and tough and unpredictable working circumstances. A catastrophic ICE failure could result in lost productivity or even human casualties. Condition monitoring and fault diagnosis approaches are gaining in popularity and have shown to be quite useful. Furthermore, [1][2] summarises and reviews current achievements of these approaches for industrial applications. Misfire, knock, piston slap, injection faults, valve faults, bearing cap wear, and connecting rod with incorrect screw preload are among the most commonly reported issues [1]. Furthermore, the techniques for ICE fault detection mainly include vibration [3], acoustic emission [4], in-cylinder pressure [5] and the crank angular velocity [6] as well as oil [7], etc. The condition observing and fault diagnosis in a mechanical system is significant for avoiding serious damage. The internal combustion engine is classical rotating machinery that must be work under deferent conditions for various performance

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requires. The engine can be monitored using various sensors. The engine monitoring can supply a large amount of data containing dynamic, combustion, fluid flow processes, and main incidents of the engine conditions. There is no doubt that detection of faults can prevent further damage of the engine and prevent further causalities. In addition to decreasing the engine performance and increasing the pollution emissions [8][9]. Sound emission and vibration signal of engine oftentimes give much dynamic information of mechanical system condition. The signal analysis has been layout as one of the useful methods for fault diagnosis [10]. In modern internal combustion engines (IC engines), the diagnosis systems have been used to locate subsystem or engine element cannot work clearly or do its task due to damage. Condition surveillance of the engine during it works can decrease costs of repair and maintenance by increasing durability and reliability of them. Fault detection techniques are developing continually such dynamical model based, Fuzzy Logic (FL), Artificial Neural Networks (ANN), Statistical models, etc. The ANN models stimulated to human brain learning ability. comparable, to human training, the ANN method is can learn with examples [11].

Many valuable techniques for signal analysis have been suggested such as fast Fourier transform (FFT) [12], higher-order statistics (HOS) [13], and adaptive order-tracking [14][15]. Nonetheless, the time-frequency domain information is emphasised in the problem diagnosis system of sound emission or vibration signals analysis. There are many other techniques that have been developed such as the short time Fourier transform (STFT) [16], Wigner–Ville distribution (WVD) [17][18] and wavelet transform (WT) [19][20][21][22][23]. All the techniques were developed successfully, but WT is the best of these tools because STFT only provides a constant time-frequency resolution and WVD produces interference terms on the time-frequency domain in a critical condition [20]. Vibration signals are always utilized for mechanical fault diagnosis, due to they carry the dynamic information of the machines. Also, these vibration signals sampled on the spot often include a great deal of noise If the noise is excessively loud, the useful information will be distorted, making it impossible to determine the working status or even drawing incorrect conclusions.

2. Vibration different techniques

There are three types of vibration signals: torsional, longitudinal, and mixed vibrations. The torsional vibrations are mainly caused by the exertion of cyclic combustion forces within the cylinder in addition to the inertial forces of the rotating parts such as the crankshaft, camshaft and connecting rod. The pressure on the piston generates the tangential force that does useful work and rises the rotational speed of the crankshaft during the combustion stroke, whereas the compression stroke reduces the engine's angular velocity. The crankshaft's speed fluctuates as the rotational speed changes, resulting in torsional vibrations at the crankshaft. The primary source of longitudinal vibration is the unbalanced forces acting on reciprocating and rotating components of the engine which propagate in three orthogonal directions [24]. Unbalanced forces at the engine block are produced by variations in combustion pressure during downward motion, and the unbalanced forces at the block are recorded as longitudinal vibrations in three orthogonal directions. [25].

The frequency resolution limitations introduced by a digital FFT (Fast Fourier Transform) analysis [12], however, have led to consider the possibility to implement time-domain vibration analysis techniques [26]. All machines with moving parts generate vibrations and consequently noise. The analysis of the produced vibration can offer information about the condition of the machine. The machine fault offers rise to a variation in the shape of the vibration's frequency spectrum. The presence of such a fault can thus be detected by comparing two frequency spectra recorded at various times. The cause of the fault can then be diagnosed by

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evaluating which frequency components increased and matching them with machine parts. In split of the presence of faults can be successfully recognized by classical FFT approach and many studies often propose frequency domain analysis for fault diagnosis, the major limitation of the method in the detection of incipient faults in real time remains the poor frequency resolution associated to short lengths of the signal, which may not be sufficiently long to produce proper narrowband spectra for identifying the frequencies of interest [27].

Lin & Qu. [20] utilized vibration signals for the feature extraction and fault diagnosis based on the Morlet wavelet as the fundamental waveform and limits the time accuracy and frequency resolution by controlling the b value to adapt to different signals. After testing it with two simulated signals, it can be noted that this denoising method is more active Donoho's and soft-thresholding denoising" method.

Ghazaly et al.[28] presented the model that proposed the misfire fault of the engine is mapped or clustered into groups based on the cylinder which inherited the misfire fault by transferring the combustion process history via a triaxial vibration sensor, The purpose is to map the misfire location on self-organizing neural network with the best quality comparing 1D, 2D and 2D vibration signals. Four fault locations of the 4-cylinder engine are clustered and applied at normal and misfire conditions. The results showed that is found the 3D vibration signal is improved the clustering with minimum errors 0.0025, 0.0011, 0.00043 for three different operation conditions. In additions, the maximum accuracy in detecting the misfire is 93.55% for 3D vibration signal at 3000 rpm.

Siano and Panaza [27] analyzed the capability the vibration based techniques to detect, monitor and prevent pump cavitation. Experimental tests were performed on a gear pump used in the lubrication circuit of internal combustion engines as shown in Fig.1. A preliminary spectral analysis, based on the Fast Fourier Transform (FFT) of the vibrational signal, was performed in order to easily identify cavitation detection. A time-domain analysis technique was then implemented, aiming to realize an on line pump cavitation fundamental frequencies, domain analysis technique was then implemented, aiming to realize an on line pump cavitation detection, Specifically, a Non Linear Auto Regressive (NLAR) approach based on the use of Artificial Neural Networks (ANN) Neural Networks (ANN), was applied for modeling system behavior. The results of the vibration-based method are discussed in depth, highlighting the pros and cons of the methodology. The presented outcomes demonstrate the ability of the proposed algorithm in accurately detect the presence of cavitation phenomena and to determine its intensity in pump real time operation. Hence, it may turn out to be powerful tool for early detection of pump incipient faults.

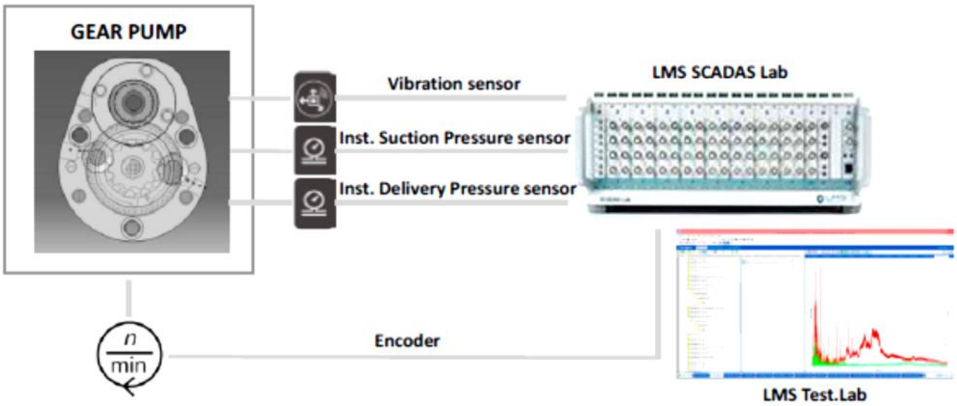

Fig. 1. Experimental layout [27].

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Ben-Ari et al.[29] presented an experiments performed with a four-stroke, four-cylinder in-line, carbureted SI engine as shown in Fig.2. The vibrations were measured at two different points around the rear crankshaft bearings in addition to two opposing points on the sides of the engine-block. Vibrations were measured in the axial, radial, and tangential directions relative to the crankshaft axis at each location. Different malfunctions were monitored and the resulting vibrations waveforms were transformed to the frequency domain by application of a fast Fourier transform. The results obtained in the course of the study demonstrate that different malfunctions can be detected with the proposed method and that few distinguish symptoms can provide conclusive criteria regarding the general health condition of the engine. The results indicated that, The location and the direction of the acceleration transducer is impact on the vibrations signature and the sensitivity of the results to the engine condition and the measurements in the transverse and the axial directions provided useful information whereas the contribution of the measurements in the vertical direction were negligible. Also found that in most cases the measurements on the engine-block side (point 1) were the most sensitive to the malfunctions to which we exposed the engine. Finally, noted that in general criteria concerning the engine health can be set. Thus, the presence of noticeable peaks at the revolution frequency, at half the revolution frequency, and at six or eight times the revolution frequency can provide a warning that the engine is running under abnormal conditions.

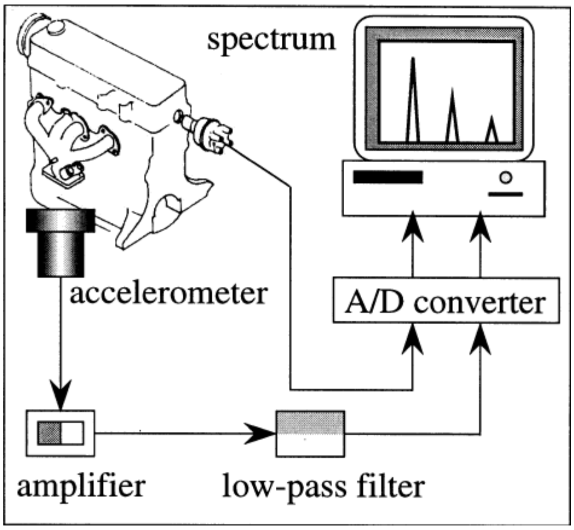

Fig. 2. Experimental set-up [29].

Wu and Chuang [29] presented an investigation of the fault diagnosis technique in internal combustion engines based on the visual dot pattern of acoustic and vibration signals. Most of the conventional methods for fault diagnosis using acoustic and vibration signals are primarily related observing the amplitude variation in the time or frequency domain. visual dot pattern technique is suggested to identify the acoustic emission and vibration signals for fault diagnosis in an internal combustion engine and drive axle shaft. The experiments are carried out to evaluate the proposed system for fault diagnosis under various fault conditions. The results shown that the proposed technique is effective in the fault diagnosis of an internal combustion engine and drive axle shaft.

Kumar et al [30] vibration analysis using signal processing and ML techniques for identification of gearbox faults in the four-stroke single cylinder IC engine. To simulate the real-time operating conditions, experiments were conducted with actual combustion of the engine with various loading conditions. Gear tooth with healthy and defect conditions (50% tooth defect, 100% tooth defect) was selected for the analysis. The vibration signals were analyzed using spectrum, cepstrum, STFT and CWT. The experimental results showed that spectrum, cepstrum, STFT, CWT and J48 decision tree techniques clearly identify gear fault in IC engine gearbox. Spectrum, cepstrum, CWT and decision tree are more effective in extracting the information of the gearbox using vibration signals. Hence, spectrum, cepstrum, CWT and J48 decision tree can be suggested for identification of faults in the gearbox of automobile and expected to be useful in fault diagnosis of other machine elements such as bearing, piston and crankshaft during actual running condition.

3. Conclusion

The vibrations are mainly caused by the exertion of cyclic combustion forces within engine moving parts, vibration signals are categorized as torsional, longitudinal and mixed vibrations subjected to vibration due to unbalanced reciprocating and rotating parts, this paper presented the importance of internal combustion engine fault detection early that depending on using vibration signals, as (FFT), (HOS), (ANN), (STFT), (WVD) and WT , the WT technique is the best according to Lin & Qu [20] study.

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