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Extraction of fault component from abnormal sound in diesel engines using acoustic signals

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ABSTRACT

In this paper a method for extracting fault components from abnormal acoustic signals and automatically diagnosing diesel engine faults is presented. The method named dislocation superimposed method (DSM) is based on the improved random decrement technique (IRDT), differential function (DF) and correlation analysis (CA). The aim of DSM is to linearly superpose multiple segments of abnormal acoustic signals because of the waveform similarity of faulty components. The method uses sample points at the beginning of time when abnormal sound appears as the starting position for each segment. In this study, the abnormal sound belonged to shocking faulty type; thus, the starting position searching method based on gradient variance was adopted. The coefficient of similar degree between two same sized signals is presented. By comparing with a similar degree, the extracted fault component could be judged automatically. The results show that this method is capable of accurately extracting the fault component from abnormal acoustic signals induced by faulty shocking type and the extracted component can be used to identify the fault type.

1. Introduction

Acoustic and vibration signals of engines often provide significant dynamic information on mechanical system conditions; these mixtures of signals contain fault acoustic signal, other normal acoustic signal, and background noise [1]. The fault feature, which is useful for ensuring safe running of engines, can be extracted either from the mixture signal to diagnose the engine condition or detect the fault source. Many useful signal analysis methods for fault diagnosis have been set up such as Fourier transform, wavelet analysis, empirical mode decomposition, blind source separation and acoustic emission [2–6].

The Fourier transform method transfers the signal from time domain to frequency domain, which is a simple method to deal with the signal. Yadav used Fast Fourier transform (FFT) method to calculate the engine amplitude–frequency values subdivided into bands and to determine the correlation coefficient matrix for diagnosing the faults of engines by matching with a prototype engine matrix [7]. However, FFT cannot handle non-stationary signals well. The wavelet analysis is used for multi-scale analysis of a signal and can effectively extract its frequency features [8]. Shirazi used discrete wavelet transform (DWT) method to deal with the vibration signals taken experimentally from a typical 4-cylinder IC engine to transfer the

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signal from time domain to the time–frequency domain for fault detection and diagnosis [9]. Many different types of wavelet function exist, so choosing the appropriate one to extract fault features from the sound signal of an engine is difficult [10,11].

The empirical mode decomposition (EMD) method can handle the nonlinear and non-stationary signals effectively [12]. Wang used improved empirical mode decomposition to decompose vibration signals into a number of intrinsic mode functions and to extract fault characteristics out of vibration signals for faulty engine diagnosis [1]. However, the enveloping line sometimes deviates from the true one because of the end effect restraint (EER) [13]. Blind source separation (BSS) is the separation of a set of source signals from a set of mixed signals without the aid of information on the former. Many algorithms for this method are used in signal separation. Zhang used improved BSS technique to recover the corrupted signals and obtain the accurate piston slap signals [14]. However, the algorithms of this technique are immature to handle the practical problem [15]. Acoustic emission (AE) is the phenomenon of radiation of acoustic waves in solids that occurs when a material undergoes irreversible changes in its internal structure. The parts of the engine produce an acoustic wave of high frequency, which has the feature to confirm the fault source. Munoze used acoustic emission based on various statistical feature isolation and pattern recognition techniques to extract faulty features and identify machine fault conditions [16]. However, the AE signal can be easily affected by background noise and has low positioning accuracy [17].

The overall context is that many methods are employed to deal with engine faults by using vibration and acoustic signals, but no common approach or algorithm is used to handle more than one fault in various conditions. Most of the aforementioned methods need to transfer the signal from time domain to frequency domain for processing signal and filtering, where the processing changes not only the background signal but also the concerned signal component. In this paper, a new approach is presented, which is used to extract the faulty component of the noise signal of the engine in the time-domain to diagnose the engine fault. This method would not change the concerned component of the signal.

2. Signal processing method

In this paper, a new approach that is integrated with dislocation superimposed method, gradient method used in searching for starting points of interception signals, and correlation analysis is presented. The main difference between the proposed method and other signal processing methods (such as EMD) is that the first one is based on the time-domain and the others are based on frequency-domain. This condition means that the original signal does not need time and frequency conversion during the entire signal processing procedure by the proposed method.

3. Random decrement technique review

The random decrement technique (RDT), which was original proposed by Cole to study the application of correlation functions in measuring damping and assessing damage in aircraft structures, has been studied extensively for signature analysis of vibrating systems. This method has developed rapidly and **is** mainly used to obtain free response estimates of linear structures to process the vibration and modal problem [18,19]. The RDT technique is a time domain approach, that was initially developed to form a characteristic signature based on the ensemble average of selected signal segments from random response signals. When the signal is accordance with Gaussian white noise assumption and has certain initial conditions, it can represent the free vibration response of the dynamic system [20]. The definition of random decrement technique (RDT) for linear system is defined as

$$x_{rdt}(\tau) = \frac{1}{M}\sum_{i=1}^{M} x(t_i+\tau) \quad (1)$$

where $x_{rdt}(\tau)$ is the approximate signal of random excitation; $x(t)$ is the system response signal under random excitation; M

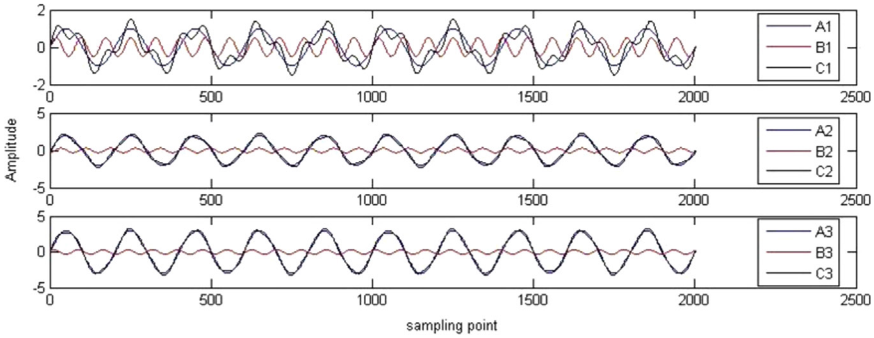

Fig. 1. Graphical representation of dislocation superimposed method.