Available online at www.sciencedirect.com
ScienceDirect
Mechanical Systems and Signal Processing 21 (2007) 668–677
Mechanical Systems and Signal Processing
www.elsevier.com/locate/jnlabr/ymssp

The application of energy operator demodulation approach based on EMD in machinery fault diagnosis

Cheng Junsheng*, Yu Dejie, Yang Yu

College of Mechanical and Automotive Engineering, Hunan University, Changsha 410082, People's Republic of China

Received 16 April 2005; received in revised form 20 October 2005; accepted 20 October 2005
Available online 1 December 2005

Abstract

An energy operator demodulation approach based on EMD (Empirical Mode Decomposition) is proposed to extract the instantaneous frequencies and amplitudes of the multi-component amplitude-modulated and frequency-modulated (AM-FM) signals. Furthermore the proposed approach is applied to machinery fault diagnosis. Firstly, EMD method is used to decompose a multi-component AM-FM signal into a number of intrinsic mode functions (IFMs). Secondly, the energy operator demodulation method is applied to each IMF and the instantaneous amplitudes and frequencies of a multi-component AM-FM signal are extracted. Finally, the spectrum analysis is applied to each instantaneous amplitude in order to obtain envelope spectra from which the mechanical fault can be diagnosed. The analysis results show that the energy operator demodulation approach based on EMD can extract the characteristic of machinery fault vibration signals efficiently.

Keywords: AM-FM signals; EMD Energy operator demodulation; Machinery fault diagnosis

0. Introductions

When the faults occur in the mechanical system, the machinery fault vibration signal always present the feature of modulation [1,2]. Therefore demodulation analysis method has been established as the widespread method for machinery fault diagnosis, especially for diagnosis of fault location [3–5]. At present, the Hilbert transform has been widely used in machinery fault diagnosis as one of the most common demodulation analysis methods because the characteristic information can be obtained by Hilbert transform, which has quick algorithm and could extract envelope of the machinery fault vibration signal effectively [6]. However, owing to the inevitable window effect of Hilbert transform, the demodulation results present non-instantaneous response characteristic, that is, at the two ends of the modulated signal which has been demodulated as well as the middle part with break would produce modulation again, which makes the amplitude get fluctuation in an exponential attenuation way, and then the demodulation error would increase. On the other hand, the central frequency of the filter is determined with experience while forming an envelope

*Corresponding author.
E-mail address: signalp@tom.com (C. Junsheng).

0888-3270/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ymssp.2005.10.005

signal, which will make great subjective influence on the results. Aiming at these problems, the energy operator demodulation approach based on empirical mode decomposition (EMD) is proposed and applied to machinery fault diagnosis.

It is also accessible to extract the instantaneous amplitudes and frequencies of a modulated signal by energy operator demodulation approach and the demodulation effect is superior to Hilbert demodulation method, meanwhile the computation time is also decreased greatly [7–10]. However, the energy operator demodulation approach put forward by Teager [11] can be applicable for amplitude-modulated signal and frequency-modulated signal that just has single component (AM-FM signal), $s(t) = a(t)\cos[\phi(t)]$, while in practice most machinery fault vibration signals are all multi-component AM-FM signals, $s(t) = \sum_{m=1}^{M} a_m(t)\cos[\phi_m(t)]$. For these signals, they are usually decomposed into single component AM-FM signals by band-pass filter and then demodulated to extract the instantaneous frequencies and amplitudes in conventional demodulation methods. However, both the number of the carrier frequency components and the magnitude of the carrier frequency are hard to be determined in practice, so the selection of central frequency and bandwidth of band-pass filter carries great subjectivity that would bring demodulation error and make it ineffective to extract the characteristic of machinery fault vibration signal. To target this problem, the EMD method is used to decompose the multi-component signal into the single component signals. It is Huang who put forward the a new signal analysis method, EMD method [12], which can decompose a complex signal into a number of intrinsic mode functions (IMFs), and each IMF component can be amplitude-modulated or frequency-modulated, that is, a single component AM-FM signal, $s(t) = a(t)\cos[\phi(t)]$ [12]. In this way, the amplitudes and frequencies information of the original complex signal can be obtained after each IMF component is demodulated by the energy operator demodulation method. In paper [13], an approach called Teager-Huang analysis which is the conjunction of the energy tracking operator and EMD method was proposed for sonar target recognition. In this paper, the energy operator demodulation method and EMD method are combined for mechanical fault diagnosis. The analysis results from simulation and actual signals confirm that the energy operator demodulation approach based on EMD can extract the fault feature of machinery vibration signal efficiently.

1. Energy operator demodulation approach based on EMD

Both the amplitude $a(t)$ and the phases $\phi(t)$of an AM-FM signal are various, and the general expression of this kind of signals is as follows

$$s(t) = a(t)\cos[\phi(t)] \tag{1}$$

and its instantaneous frequency is

$$\omega(t) = \dot{\phi}(t) = \frac{\mathrm{d}\phi(t)}{\mathrm{d}t} \tag{2}$$

Define the non-linear signal operator ψ for formula (1)

$$\psi(s) = (\dot{s})^2 - s\ddot{s} \tag{3}$$

by using the energy operator demodulation method the instantaneous amplitude and frequency of an AM-FM signal can be obtained [11]

$$|a(t)| \approx \frac{\psi(s)}{\sqrt{\psi(\dot{s})}} \tag{4}$$

$$\omega(t) \approx \sqrt{\frac{\psi(\dot{s})}{\psi(s)}} \tag{5}$$

The above method is applicable only for single component AM-FM signals, and for multi-component AM-FM signals, $s(t) = \sum_{m=1}^{M} a_m(t)\cos[\phi_m(t)]$, it is necessary to preprocess original signals, namely, decompose them into single component AM-FM signals before the amplitudes and frequencies information are extracted, which can exactly be fulfilled by EMD method.