Application of Local Mean Decomposition to Acoustic Emission Data for Natural Fatigue Cracks Feature Extraction in Rotating Shafts

Yue Zhou, Lin Li and Zhou Yong

ABSTRACT

This paper presents the results of applying recently developed local mean decomposition (LMD), a new iterative approach to acoustic emission (AE) feature extraction of natural fatigue cracks in rotating shafts providing an energy-frequency-time distribution with more adaptable precision. The method decomposes AE signals into a set of functions, each of which is the product of an envelope signal and a frequency modulated signal from which a time-varying instantaneous frequency can be derived. It has been found that LMD appears to be a better tool providing an energy-frequency-time distribution compared to Hilbert–Huang transform (HHT) for natural fatigue crack characterization in a rotating rotor in the experiment cases. It was concluded that LMD-based AE technology could more successfully extract the features of natural fatigue cracks induced on rotating shafts.1

KEYWORDS

Index Terms—Local Mean Decomposition, Acoustic Emission, Fatigue Crack, Feature Extraction.

INTRODUCTION

The extraction of meaning from AE signal data of cracks is fundamental in the AE detection[1-3]. Currently there are many techniques of AE signal characteristic extraction available such as the classical AE parameters, fourier spectrum analysis,

1Yue Zhou, The Ohio State University at Columbus
Lin Li, Dalian Jiao Tong University, Dalian 100240
Zhou Yong, Dalian University of Technology, Dalian 110023
wavelet analysis[4], Hilbert–Huang transform signal processing technique[5, 6] and so on[7-15][16].

Since 2005, Local mean decomposition proposed LMD[17] analysis has been studied extensively as a powerful tool in many areas dealing with the analysis of transient signals for the past years. However, the application of LMD to AE feature extraction of natural fatigue cracks in rotating shafts is still few.

This paper is built further on the work of the author[16] who showed significant changes of fatigue crack AE signals frequency by Hilbert–Huang transform signal processing technique. This paper introduces LMD into AE signals analysis and the analysis results demonstrate the advantages of LMD compared to fast Fourier transform, continuous wavelet transform and Hilbert–Huang transform for the natural fatigue crack characterization in a rotating rotor.

LOCAL MEAN DECOMPOSITION

The local mean decomposition was developed by Jonathan S. Smith in 2005 to decompose signals into a small set of product functions, each of which is the product of an envelope signal and a frequency modulated signal from which a time-varying instantaneous frequency can be derived. Then we can plot the instantaneous frequency and envelope energy values together in the form of a demodulated signal time–frequency-energy representation, which we can obtain the steps in detail from the article[17].

APPLICATION TO NATURAL ROTATING FATIGUE CRACK AE SIGNALS

The special purpose built test rig which can simulate the bending stress of train axle for generating natural rotating fatigue crack has been clearly addressed[16]. This test rig and the experimental procedure had been given[16]. In this paper we give the photo of the test rig in actual operation in Fig.1.(a). And Fig.1.(b) shows the photo of the test rig after the axle fracture.

![Figure 1](image.png)

Figure 1.(a) Test rig in actual operation(b) Test rig after the axle fracture (c) The shaft crack AE waveform.
One of the AE signals collected from the test rig of Fig.1.(a) is shown in Fig. 1.(c) after employing the radial load of 100N when fatigue crack occurred. The instantaneous frequency, time and energy values can be displayed together in the form of the demodulated signal LMD time-frequency-energy representation as shown in Fig. 2.(a). The colour scale represents frequency changes and energy variation with time. As a comparison, the time-frequency-energy representation of the same data is shown in Fig. 2.(b) and Fig.2.(c). The HHT time-frequency-energy representation giving the energy–frequency–time distribution in the color map format for the same shaft crack AE signal is given in Fig. 2.(b). Fig.2.(c) gives the wavelet time-frequency-energy representation.

The article[16] has found that HHT appears to be a better tool compared to continuous wavelet transform for natural fatigue crack characterization. From the Fig.2, we had also seen like the article[16] that the wavelet result gives a smeared frequency range over which the main wave energy resides comparing with the HHT and LMD results because wavelet analysis is essentially an adjustable window Fourier spectral analysis and, although wavelet is well suited for analyzing data with gradual frequency changes, its non-locally adaptive approach causes leakage to bring spread frequency energy over a wider range at the energy concentration around 100 kHz and 200 kHz. We can see the similar result by using LMD and HHT on the same shaft crack AE signal, but the HHT time-frequency-energy representation shown in Fig.2.(b) has caused a certain degradation of the amplitude and frequency information in the data, compared with the LMD time-frequency-energy representation shown in Fig.2.(a) from which, we can see more clearly that the frequency fluctuation around 100 kHz and 200 kHz from 0.2 ms to 0.5 ms because the repeated iterations using cubic splines in the HHT of the AE data causes a loss of energy and frequency information and gives too much components.

The time-frequency-energy representation shown in Fig.2 suggests that the LMD result gives more refined definition of energy consisting primarily in the frequency axis and retains more of the amplitude and frequency information than the EMD result since the instantaneous frequency is calculated from a frequency modulated signal, it should be well-behaved and appears to be a gentler way of decomposing the AE data than the cubic spline approach used in EMD.

![Figure 2](image.png)

Figure 2. (a) The LMD time-frequency-energy representation. (b) The HHT time-frequency-energy representation. (c) The wavelet time-frequency-energy representation.
CONCLUSIONS

This paper attempts to bring the LMD into the AE signal time–frequency–energy feature extraction of nature fatigue cracks on the rotating shaft analysis. The study has demonstrated that the LMD analysis can more effectively and more clearly show the time-varying frequency and energy features of the rotating shaft fatigue cracks than the HHT analysis causes a loss of energy and frequency information and gives too more components due to the repeated iterations using cubic splines in the EMD of the AE data. And the LMD is found to be more well-behaved and appears to be a gentler way for extracting the nature fatigue crack features than the HHT because the instantaneous frequency is calculated from a frequency modulated signal rather than from an IMF with a time-varying envelope which may be distorted. To sum up, the LMD method appears to be a better tool for further fatigue crack research of the rotating train axle because it can offers the possibility of extracting genuinely more new information from the real damaged AE signal data.

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