xEMD procedures as a data — assisted filtering method

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Abstract

The article presents the possibility of using Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD), Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) and Improved Complete Ensemble Empirical Mode Decomposition (ICEEMD) algorithms for mechanical system condition monitoring applications. There were presented the results of the xEMD procedures used for vibration signals of system in different states of wear.

Keywords: EMD, EEMD, CEEMDAN, ICEEMD, filtering, harmonic frequencies

1. Introduction

Vibration signals, acquired in rotating machines, are carriers of valuable information useful for the early detection of system damage. The input signal, obtained by the vibration measurement, could constitute a nonlinear and non- stationary data set. The majority of commonly used analysis methods for this type of signals are characterized by the occurrence of significant limitations. For instance, the results of spectral analysis using Fast Fourier Transform (FFT) algorithm, provide information about low physical sense. An alternative to Fourier Transform could be STFT (Short- Time Fourier Transform). However, this method of data analysis is associated with certain restrictions. Difficulties causes a priori determination of the sliding in time domain window length, required to ensure the piecewise stationary nature of the waveform. Another method frequently used in rotating machines condition monitoring is a Wavelet Transfrom (WT). The main problem arising from the application of WT is proper selection of wavelet base function or the levels number [6]. On the basis of research [4] it may be considered that the restrictions of the above methods can be overcome by using the Empirical Mode Decomposition.

2. xEMD algorithms overview

The xEMD methods group has taken its beginning from the adaptive time- frequency analysis method, presented by Huang [2]. The EMD algorithm involves the carrying out the process of dividing the signal to components, called Intrinsick Mode Functions (IMF). The input data sieving to achieve IMF is based on signal extremes inetrpolation by the cubic spline and the determining of the envelopes. The prototype modes are obtained by the subtraction the envelopes mean value from the input signal. Proto- IMF is deemed as an IMF if it fulfills two conditions: in the whole data set, the number of extremes and the number of zero crossings must be either equal or differ at most by one, at any point the mean value of the upper and lower envelopes is zero. Sifting process is repeated n times until the satisfaction of the assumed stoppage criterion.

One of the problems limiting the possibilities of EMD algorithm is the mode mixing phenomenon. In order to reduce mentioned effect there were implemented method modification-Ensemble Empirical Mode Decomposition (EEMD). Modified procedure involves performing decomposition on a intentionally noised input signal. The white Gaussian noise addition helps to reduce the mode mixing phenomenon. Despite some new possibilities, EEMD algorithm has also has drawbacks such as noise content embedded in modes or a different modes number.

Weaknesses of the EEMD method were the subject of new research, such as Complementary EEMD [7], Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) [5] and Improved Complete Ensemble EMD (ICEEMD) [1]. Particularly noteworthy are the CEEMDAN and ICEEMD algorithms. The first one allows to reduce the sifting number and enables the accurate reconstruction of the input signal by the modes sum. Due to the fact that CEEMDAN algorithm has not been deprived of drawbacks, such as the presence of residual noise in modes and some kind of 'information delay' in decomposition, there were taken subsequent attempts to improve the algorithm. Consequently, the ICEEMD method [1] has been formed.

3. Application to acquired data

The object of research was a mechanical system with double turbine runner. Registered data includes two waveforms acquired with identical system operating parameters- speeds and loads. The signals differ from one another according to the degree of driving turbine wear. The paper attempts to filter signals by algorithms EMD, EEMD, CEEMD and ICEEMD.

In terms of applicability of xEMD algorithms, signals obtained from the object are specific due to the difficulties of separation characteristic frequencies [3]. Despite the difficulties in the main frequencies separation, EMD- type algorithms could be a valuable diagnostic tool. These procedures allow for the isolation of harmonics, which may indicate the different types of damage.

3.1. Results of xEMD algorithms

As the result of analyzed algorithms for each of the waveforms it has been found distribution of 13 modes, except ICEEMD (healthy driving turbine case), where it has been obtained 12 modes. Previously sifted IMFs were analyzed by FFT, whereby there were extracted significant signal harmonics. No algorithm has provided a complete reduction mode mixing phenomenon, while the majority of the tested procedures has allowed for the stable partial separation. Unstable and therefore unsuitable in this application algorithm was the CEEMDAN procedure. It has been generated a false modes, what caused irregular harmonics distribution. The algorithms containing additive noise have allowed for better harmonics separation in contrast to the EMD procedure, where the harmonic frequencies have been grouped together. The ICEEMD procedure appeared as the best one, allowing the clearest identification of the harmonics.

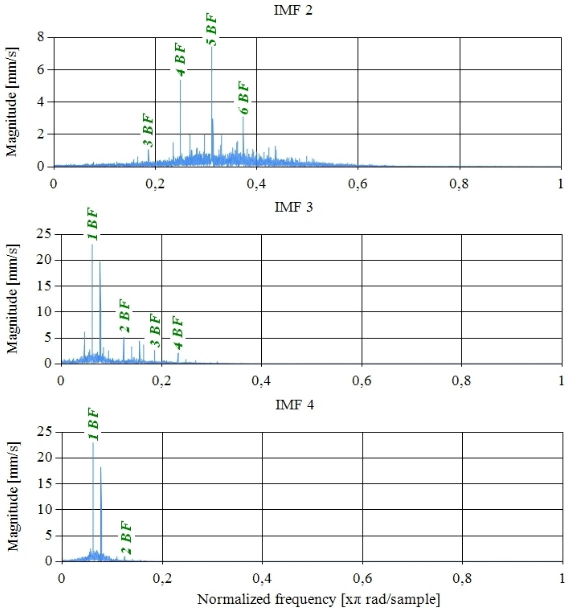

Figure 1: Significant modes of the healthy turbine ICEEMD decomposition

3.2. xEMD algorithms in condition monitoring applications

It is known that the harmonic analysis is a poweful tool for rotating machines condition monitoring. The specific apperances of vibration spectra may indicate components faults. In reference to the faulty driving turbine data, distribution and amplitude values of harmonics indicate the possibility of the mechanical looseness occurrence (visible all of the harmonics, the presence of 1/2 *BF* component in IMF3 and the high amplitude of the second harmonic- IMF3, IMF4). Figure 1 shows the ICEEMD decomposition of healthy turbine signal and the faulted turbine ICEEMD decomposition with marked harmonics is illustrated on Fig. 2.

4. Conclusions

The carried out analyzes indicate the possibility of a partial signal separation using algorithms from the xEMD group. As it has been already mentioned, there were no universal method allowing for the complete separation of frequencies. xEMD limitations in hardly separable signals are now a challenge for further research. However, despite some drawbacks, xEMD procedures appear to be a valuable preprocessing tool in dynamic characteristic frequencies filtration.

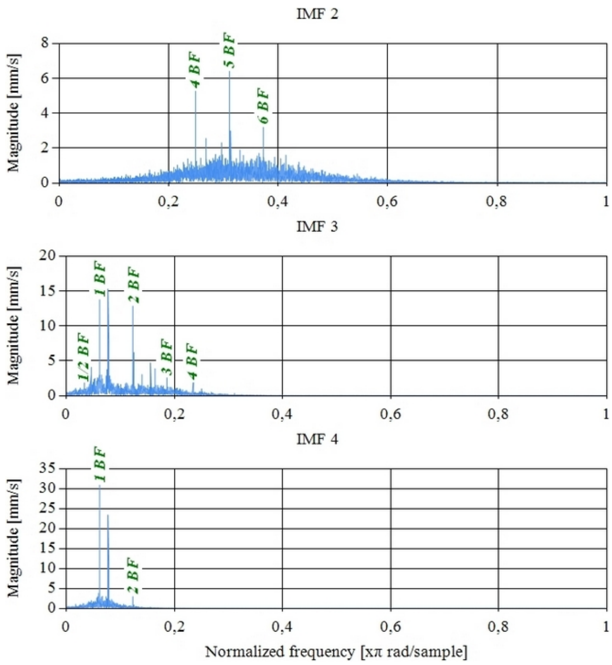

Figure 2: Significant modes of the faulted turbine ICEEMD decomposition

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