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ORIGINAL ARTICLE

Minimization of the vestigial noise problem of empirical wavelet transform to detect bearing faults under time-varying speeds

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Abstract

This work proposes a systematic approach to detect and classify bearing faults using vibration signals under varying speeds. The proposed approach consists of several steps, such as segmentation of signal consisting of maximum fault relevant information and extraction of features less influenced by varying speeds, and develop a machine learning model for online classification of bearing faults. Bearing when operating under time-varying speeds, the most critical and challenging step, is the demodulation of non-stationary and nonlinear vibration signals exhibiting severe modulations. The empirical wavelet transformation (EWT) algorithm has been used to decompose the raw signal into multiple mode functions (MFs), thereby detecting faults. However, these MFs contaminated by vestigial noise, when processed, mislead the detection of incipient bearing faults, thereby reducing EWT performance. Hence, this study addresses this by proposing the selection of the most impulsive MF for varying speed by estimating instantaneous frequency, which lies near bearing characteristic defect frequencies, thereby eliminating the possibility of vestigial noise being processed. Further, ten entropies, root-mean-square, and kurtosis are computed from the selected MF for statistical analysis. The results of the proposed approach are compared with the ensemble empirical mode decomposition to highlight the capabilities. Statistically significant fault discriminating features are identified using the Kruskal–Wallis test. These identified features are subsequently utilized by the Random Forest classifier. Thus, it has resulted in higher accuracy in detecting and classifying the different faults trapped by severe modulations.

Keywords Bearing · Vibrations · Signal decomposition · Fault classification · Varying speed

1 Introduction

Bearings are one of the most crucial elements of rotating as well as manufacturing machinery [1, 2]. Therefore, timely diagnosis of bearing faults is important, as ignorance or missed alarm may cause severe consequences, sometimes catastrophe [3]. Bearing vibration signals are multi-component, nonlinear, and nonstationary and their analysis for a time as well as frequency could yield the health state of bearing [4], e.g., bearing when operating at a constant speed, the information related to the bearing defect appears as amplitude modulation (AM) and frequency modulation (FM), masked by noise [2, 5]. Envelope analysis–based approaches are successful in demonstrating periodic collisions reflected as transients [6].

In real time, when the operating speed of a machine varies, the modulations may be more severe with non-periodic transients; for such cases, envelope analysis will not be effective [2]. Hence, detecting bearing faults under varying speed becomes extensively challenging. Therefore, adaptive signal-processing techniques are required to detect the presence of a fault. Any inaccurate method may lead to an erroneous or delayed diagnosis. A review of the fault diagnosis methods for bearing [7] includes but is not limited to Hilbert transform [8], empirical mode decomposition [9, 10], and wavelet transform [2, 11–14].

One of the advanced signal processing techniques is the empirical wavelet transform (EWT) which decomposes a signal into finite mode functions (MFs) for extracting features [15]. Fundamentally, EWT is structured as a pair of bandpass filters of wavelet transform with flexible frequency segmentation, thus inheriting the mathematics of wavelet

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