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A novel intelligent detection method for rolling bearing based on IVMD and instantaneous energy distribution-permutation entropy

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Abstract

Due to the strong non-stationary properties of the vibration signal, fault diagnosis of rolling bearing under different working conditions has become a difficulty. To address this issue, a new scheme based on improved variational mode decomposition (IVMD) and instantaneous energy distribution-permutation entropy (IED-PE) is developed for recognizing fault category of the rolling bearing. In this approach, IVMD with cross-correlation criterion is provided to decompose the collected data samples into several sub-signals and determine adaptively the mode number. Next, a novel feature extraction technique named IED-PE is proposed to obtain the three-dimensional (3D) eigenvector, which can improve the recognition degree of fault category. Finally, 3D eigenvector is imported into k-nearest neighbor (KNN) classifier for achieving the multi-fault recognition. Experimental studies show that the presented scheme is not only capable of extracting accurately fault features, but can distinguish availably multi-class fault patterns. The research offers a new perspective for intelligent fault detection of rolling bearing.

Keywords: Improved variational mode decomposition; Instantaneous energy distribution-permutation entropy; k-nearest neighbor; Rolling bearing; Fault diagnosis

1. Introduction

Rolling bearing is the key units of rotating machinery and has been widely used in all kinds of engineering situations. Due to the complex structure and inferior running environments of rotating machinery, rolling bearings emerge easily defects which bring about fatal accidents and generate major disruptions. Therefore, timely detect faults resided in rolling bearing are valuable for ensuring the safe and stable operation of mechanical equipment [1].

The content of bearing fault detection mainly includes feature extraction and pattern recognition. Feature extraction is the most critical step of fault detection, because the extracted features are directly related to the effect of pattern recognition. Owing to the impact of various nonlinear factors (e.g. friction, clearance, and stiffness), the vibration signals derived from rolling bearings are usually characterized by nonlinear and non-stationary, it is very hard to identify efficiently the defect categories of bearing solely using the time domain (e.g. statistical analysis of time series, including mean, variance, skewness and kurtosis etc. [2]) or frequency domain (e.g. fast Fourier transform (FFT) and its variants [3]). Hence, time-frequency analysis technique is introduced to extract bearing fault features [4, 5]. Nowadays, successful results have been achieved by use of Wigner-Ville distribution (WVD), wavelet transforms (WT), empirical mode decomposition (EMD), local mean decomposition (LMD), and intrinsic time-scale decomposition (ITD) for fault detection. However, these methods have some inherent weaknesses for non-stationary signal processing. For instance, for the mixed signal, WVD has the unavoidable cross-term interference which limits its applications [6]. WT can separate a vibration signal into a set of wavelet details, but it not possesses self-adapted ability due to the predefined wavelet basis and levels [7]. In the application example of EMD, some drawbacks such as the end effect, mode mixing, envelope overshoot and undershoot will emerge [8]. As a perfection of EMD, property of LMD greatly relies on the step length choice of moving average, because the unfitted moving step length will cause the inferior decomposition results [9]. Moreover, LMD also involves the end

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