A New Intelligent Weak Fault Recognition Framework for Rotating Machinery

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The presence of strong background noises makes it a challenging task to detect weak fault characteristics in vibration signals collected from rotating machinery. Thus, a two-stage intelligent weak fault recognition framework, which includes signal enhancement and intelligent recognition, is proposed in this work. The signal enhancement is accomplished via an optimized relevant variational mode decomposition (ORVMD) algorithm. Specifically, the optimal parameters is derived by combining a particle swarm optimization (PSO) algorithm and the novel defined relevant energy (Re) index. This optimized VMD algorithm can extract the principal components from the raw signals. Then, the enhanced vibration signals via the proposed ORVMD are converted into spectral signals and fed into an improved stacked auto-encoder (ISAE) algorithm for fault recognition. Experimental results demonstrate the effectiveness of the proposed algorithms and fault diagnosis framework in rotating machinery fault recognition and detection.

1. INTRODUCTION

Large-scale rotating machinery, such as steam turbines and wind turbines, are widely used in current industrial fields.1–3 They play a vital role in economic production and industrial manufacturing. However, rotating machinery is prone to failure, which could damage property and human life.4, 5 Early detection or diagnosis of the potential weak fault in these systems is desirable to cut down the economic loss of industrial production and increase the benefits.6, 7

The vibration signals captured from rotating machinery are mostly non-stationary and consist of multiple-component aliased vibration signals. These signals are usually affected by the attenuation of the vibration in the transmission path and background noise. These signal characteristics seriously impede the fault information extraction from the raw industrial vibration signals.8 Compared with the severe or late-in-life faults of rotating machinery, it is a more challenging topic to extract and recognize weak fault feature information in advance.8–10

Moreover, the multiple-component vibration signals are separated into many single component signals from each vibration source. If the fault features can be effectively extracted from the noises, fault diagnosis techniques become more effective.

The weak fault diagnosis method based on time-frequency analysis is widely used in the field of fault diagnosis and detection of rotating machinery. It is mainly divided into two modes: one is recursive signal decomposition, and the other is non-recursive signal decomposition.8–11 For the recursive signal decomposition, Huang et al. proposed an adaptive signal processing method called empirical mode decomposition (EMD).11 In the EMD, a given multiple-component signal is decomposed into a series of components under different frequency bands.11, 12 However, there still exist some problems, such as mode mixing, which will result in obstacles on signal decomposition and reconstruction.12, 13 Inspired from EMD, Smith et al. proposed a new time-frequency signal decomposition method, namely local mean decomposition (LMD), which can adaptively decompose a given nonstationary signal into a linear combination of multiple product function (PF) components.14 Su et al. developed an early fault diagnosis method based on EMD and spectral kurtosis.15 Bin et al. constructed a feature extraction approach built on the combination of wavelet packet decomposition (WPD) and EMD.16 Li et al. proposed an LMD algorithm based on differential rational splines (DRS-LMD) for early fault diagnosis in rotating machinery.17 At the same time, Kullback-Leibler (K-L) divergence was applied to select the sensitive product function (PF) component signals. Due to the interference of background noise and amplitude modulation effects, the weak faults in planetary gear systems are difficult to detect. To detect these weak faults in planetary gearboxes, a comprehensive diagnostic method called improved maximum correlation kurtosis deconvolution (IMCKD) was proposed by Zhang.5 The weak root crack in the single-stage planetary sun gear was used to prove its effectiveness. Cheng et al. proposed an improved symplectic ge-