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A sensor-dependent vibration data driven fault identification method via autonomous variational mode decomposition for transmission system of shipborne antenna

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ABSTRACT

With the increasing distance and time of voyage, condition monitoring and fault diagnosis of shipborne antenna play a crucial role in ship communication for navigation safety. However, it is still a challenging task to identify the hidden shipborne antenna fault from practical sensor-dependent vibration signals since the vibration features are always multi-modulated and submersed by heavy noise. Therefore, autonomous variational mode decomposition (AVMD) based on Independence-oriented Variational Mode Decomposition (IOVMD) and the Largest Lyapunov Exponent (LLE) criterion is proposed in this paper. First, the signal is decomposed into Intrinsic Mode Functions (IMFs) by IOVMD. Second, LLE of modes is calculated to measure fault information degree and then modes without fault features are eliminated. The combination rule is also defined and modes are combined orderly to enhance the fault feature expression. Then, an index structured by Kurtosis and LLE of combined signals is calculated and the combined signal is selected for demodulation. Finally, the combined signal is analyzed for fault identification by Hilbert Demodulation. A simulation and two cases show the effectiveness and superiority of the proposed method.

1. Introduction

Shipborne antennas play an important role in measuring, early warning and communicating of seafaring expedition. However, salt fog, sea wave and hot and humid environment on the ocean cause key transmission parts of shipborne antennas fatigue and damage after long-term operation. Without effective maintenance, faults of key transmission parts would shut down antennas, resulting in communication interruption and even serious accident. Therefore, self-organizing and accurate fault identification and location under operating conditions for shipborne antennas is desired [1–3].

Among all mechanical condition monitoring and fault diagnosis techniques, vibration analysis has been studied and used widely, for vibration signals contain working condition information and can be collected easily during operation [4]. Because the fault in shipborne antennas would cause periodic impulse responses, which is modulated in vibration signals, it is obvious that fault features can be extracted by demodulation techniques such as Hilbert Transform, energy operator demodulation and so on [5,6]. However, heavy noise and non-stationary caused by the complex condition make it hard to extract fault features by demodulation directly. Thus, various advanced signal processing method, such as Wavelet Transform (WT), Empirical Mode Decomposition (EMD) and Empirical Wavelet Transform (EWT) typically, are applied into the field of rotary machine diagnosis. Specifically, WT and its improved methods, such as Dual-tree Complex Wavelet Transform (DCWT) and Multiwavelet Transform (MT) can access the non-stationary signal and excavate fault features from different scales, but fixed base functions and binary band allocation may cause information loss and misclassification [7–10]. EMD and EWT overcome the influence caused by fixed basis functions and band allocation, but the heavy noise form hosts and hull vibration weakens their matching capability [11–15]. Therefore, a novel fault-diagnosing method, which can extract different fault features adaptively under heavy noise and complex condition, is expected.

Recently, Konstantin and Dominique proposed a novel decomposition method, Variational Mode Decomposition, to decopomose the signal into a discrete number of sub-signals with the certain sparsity properties [16]. Different from EMD and other adaptive decomposition methods, VMD can search the bands with modu-

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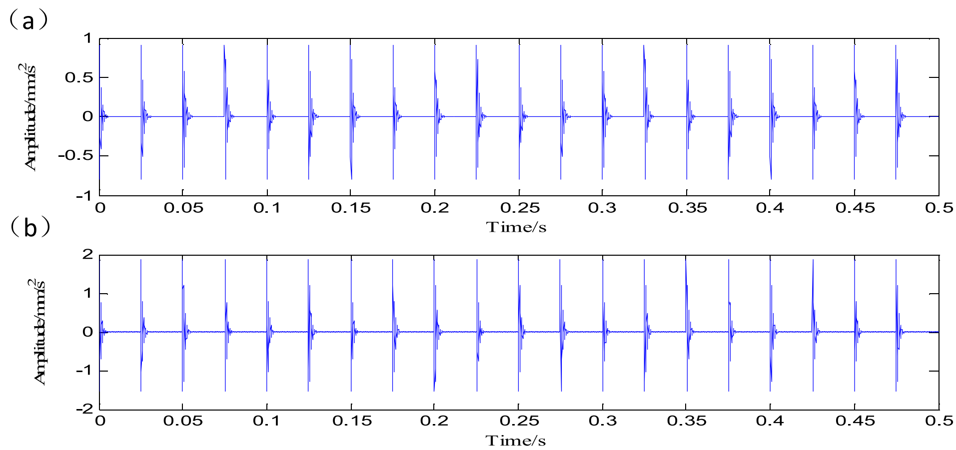

Fig. 1. Waveforms of the sub-signals.

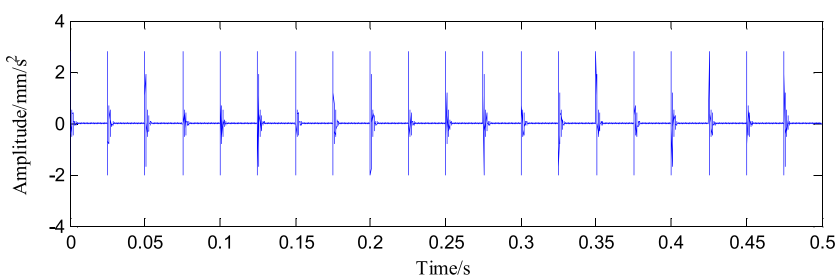

Fig. 2. Waveforms of the mixed signal.

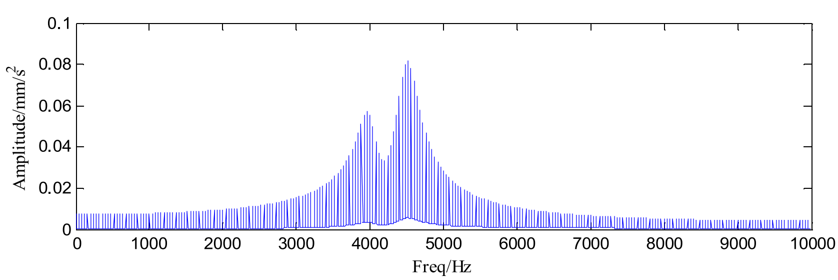

Fig. 3. Frequency spectrum of the mixed signal.

lation information adaptively and decompose the non-stationary signal into IMFs non-recursively [17]. Many successful applications in the area of mechanical fault diagnosis reflect VMD's advantages and effectiveness. Wang first introduces VMD into the area and verify its feasibility through the simulation and experiment [18]. Ming uses VMD for detection of bearing faults in the multistage centrifugal pump [19]. Li propose Independence-oriented VMD to solve the inherent problem of the traditional method and apply it to weak fault diagnosis of wheel set bearing for locomotive [20]. However, the decomposition result of vibration signals gained from VMD is incompetent, for meaningless modes are also retained after decomposing and weak fault features may be divided into different modes, which suggests a new effective mode-processing method.

To screen meaningless modes and enhance expression of the fault feature, many rules and methods are studied and applied for sub-signals postprocessing, such as Spectral Kurtosis, Energy Criterion, Similarity Criterion and so on [21–23]. However, those methods would either retain meaningless modes before combining or combine modes in an inappropriate way. The drawback would influence subsequent demodulation and feature expression. On the other hand, Largest Lyapunov Exponent algorithm, as an effective method to measure the degree of non-linearity of the vibration signal [24,25], can judge whether a mode contain fault features and choose the most suitable sub-signal for Hilbert demodulation. Therefore, it is suitable to process the modes gained by VMD, however, necessary improvement and relevant assistant algorithm should be studied to ensure its accuracy and effectiveness.

Aiming at timely and accurate fault identification for transmission system of shipborne antenna, a self-organizing fault diagnosis method named autonomous variational mode decomposition (AVMD) based on IOVMD and LLE algorithm is proposed. It can choose the most reasonable mode number of VMD, eliminate the meaningless modes after decomposition, combine the remaining modes and extract the fault feature without manual intervention. Firstly, IOVMD is applied to decompose the original vibration signal; Secondly, LLE parameter of each mode is calculated and the modes whose LLE parameter is negative would be eliminated; Thirdly, retained modes are combined according to positional relation orderly; Finally, the most suitable mode is chosen according to a new-structured index by LLE index and Kurtosis and demodulated for fault features extraction.

The rest of this paper is organized as follows: Section 2 discusses the initial VMD algorithm and the improved IOVMD structure; Section 3 introduces the proposed AVMD method through a simulation