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An insight concept to select appropriate IMFs for envelope analysis of bearing fault diagnosis

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ABSTRACT

Traditional envelope analysis must examine all the resonant frequency bands during the process of bearing fault detection. To eliminate the above deficiency, this paper presents an insight concept based on the empirical mode decomposition to choose an appropriate resonant frequency band for characterizing feature frequencies of bearing faults by using the envelope analysis subsequently. By the band-pass filtering nature of the empirical mode decomposition, the resonant frequency bands are allocated in a specific intrinsic mode function. The inner or outer ring of bearings scratched intentionally is used to validate the feasibility of the proposed idea, and comparisons with the traditional envelope analysis are addressed. The experimental results show that the proposed insight concept can efficiently and correctly diagnose the bearing fault types.

1. Introduction

Rolling bearings are important components in rotating machines. They are used in many fields, such as machine tools, motors, and turbo-pumps. However, bearing faults are a common cause of the breakdown of machines. For reducing machinery downtime, the fault diagnosis of rolling bearings is crucial. Fault detection techniques of roller bearings, such as vibration, acoustic, and temperature measurements, have been investigated recently. Among these, the vibration measurement and analysis are extensively employed. When bearing faults occur, vibration signals exhibit an amplitude modulation phenomenon that combines the characteristic frequency of the bearing defect with the structural resonance of systems. Therefore, many detecting methods are devoted to the research of the demodulation resonance analysis, especially in the envelope analysis technique. It was presented in the early 1970s by Mechanical Technology Inc. [1] and originally called the high frequency resonance technique [2], and was widely applied in the fault diagnosis of rolling bearings. Donelson III and Dicus [3] employed the envelope analysis to detect bearing faults of the large-sized vehicle; the vibration and acoustic signals were measured for analyzing different types of the bearing defects. Hochmann and Bechhoefer [4] applied the envelope analysis in the diagnosis of helicopter bearings. To detect bearing faults of a two-sided rotor platform and a high-speed cutting machine, Chu [5] applied the traditional envelope analysis in the band-pass filtered signals, where appropriate filter bands were chosen by the excitation of speeding up machines. Additionally, McInerny and Dai [6] developed a module on the bearing diagnostics by the graphical user interface of MATLAB which relied on the traditional spectral analysis and the envelope analysis.

The literature described above shows that the envelope analysis is an effective method for the fault diagnosis of rolling bearings. With the traditional envelope analysis, a bearing fault can be inspected by the peak value of an envelope

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spectrum. For obtaining an envelope signal, a band-pass filter with an appropriate central frequency and the frequency interval needs to be decided from experimental testing which yields subjective influences on the diagnosis results [7]. In the recent years, a new time–frequency analysis method called the Hilbert–Huang transform (HHT) was brought out by Huang et al. [8]. The HHT includes two procedures, namely, the empirical mode decomposition (EMD) and the Hilbert spectrum analysis (HSA). The EMD is a self-adaptive signal analysis method which is based on the local time scale of the signal and decomposes a multi-component signal into a number of intrinsic mode functions (IMFs). Each IMF represents a mono-component function versus time. The spectral band for each IMF ranges from high to low frequency and changes with the original signal itself. Therefore, the EMD is a powerful signal analysis method for treating non-linear and non-stationary signals. In applications, the EMD has been successfully applied to numerous investigation fields, such as acoustic, biological, ocean, earthquake, climate, and fault diagnosis [9]. Moreover, the EMD associated with other techniques like the wavelet packet transform, the energy operator demodulation, the support vector machine and the Teager Kaiser energy operator has also been applied to assist in bearing fault diagnosis [10–13]. It is found some studies [14–17] combined the EMD with the envelope analysis as a detection tool for the bearing fault diagnosis.

However, how to select an appropriate IMF for subsequent envelope analysis to characterize bearing faults has not been explored and addressed in the above literatures. It is noted that the component of IMF 1 was always used in the envelope analysis subsequently without any explanation. Moreover, when the conventional envelope analysis was used along to detect bearing faults, all the resonant frequency bands need to be examined. Therefore, the above approaches are not suited for practical applications. This paper demonstrates the procedure with an insight concept that combines the EMD with a swept-sine excitation to select a resonance frequency band (or more) for the subsequent envelope analysis of rolling-bearing fault detection. As examples, both the outer-race and the inner-race faults are considered and used to justify the proposed idea. Further, this detection procedure superior to the conventional envelope analysis in the bearing fault diagnosis is compared and discussed.

2. Experimental setup

An experiment test bench, including a servo-motor, a coupling, and a shaft with two rotor-disks and two ball bearings (ASAHI UCP-204), is shown in Fig. 1. Various fault types, such as unbalance, misalignment and bearing faults, can be created using this platform. In this paper, the platform was employed to investigate bearing-fault detection techniques. The geometric parameters of the bearing are the number of rolling balls, $n = 8$, the contact angle, $\alpha = 0^\circ$, the ball diameter, $d = 7.8$ mm and the pitch diameter, $D = 33.5$ mm. Two accelerometers were mounted on the bearing seats to measure vibration signals translating to the bearings. The digital tachometer was used to measure the shaft speed. In the experimentation the left-hand-side bearing remained normal, and the other one varied with different conditions (normal, inner-race and outer-race faults). Fig. 2 illustrates a normal bearing, an outer-race-defect bearing with 1-mm diameter hole, and an inner-race-defect bearing with a slot of 0.2-mm width and 1-mm depth. During the data acquisition to detect bearing faults, the motor speed kept stationary around 1500 rpm, or the rotation frequency, f_r, 25 Hz. Additionally, the data acquisition system, including a low-pass filter and DAQ Card (NI-6024E) was used to acquire measurement data. The sampling frequency and the data-acquisition period were 20 kHz and 1 s, respectively.

3. Proposed procedure to detect bearing faults

This study proposes a detection procedure for rolling-bearing fault diagnosis. An insight concept is exploited as the decomposed IMFs through the EMD computation possess a band-pass filtering nature. Combining the EMD with a swept-sine excitation is able to select an appropriate IMF that contains a resonance frequency band modulating the defect characteristic frequency. This frequency exhibiting a specific faulty condition can be eventually characterized by the envelope analysis.

3.1. Empirical mode decomposition method: a sifting process

The empirical mode decomposition is an adaptive signal decomposition method, which is able to decompose

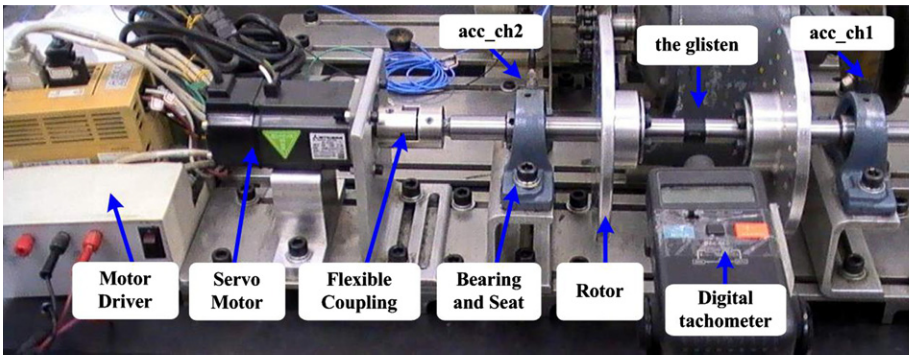

Fig. 1. Experimental setup with a set of two-sided rotor.