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Planetary gearbox fault diagnosis using an adaptive stochastic resonance method

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ABSTRACT

Planetary gearboxes are widely used in aerospace, automotive and heavy industry applications due to their large transmission ratio, strong load-bearing capacity and high transmission efficiency. The tough operation conditions of heavy duty and intensive impact load may cause gear tooth damage such as fatigue crack and teeth missed etc. The challenging issues in fault diagnosis of planetary gearboxes include selection of sensitive measurement locations, investigation of vibration transmission paths and weak feature extraction. One of them is how to effectively discover the weak characteristics from noisy signals of faulty components in planetary gearboxes. To address the issue in fault diagnosis of planetary gearboxes, an adaptive stochastic resonance (ASR) method is proposed in this paper. The ASR method utilizes the optimization ability of ant colony algorithms and adaptively realizes the optimal stochastic resonance system matching input signals. Using the ASR method, the noise may be weakened and weak characteristics highlighted, and therefore the faults can be diagnosed accurately. A planetary gearbox test rig is established and experiments with sun gear faults including a chipped tooth and a missing tooth are conducted. And the vibration signals are collected under the loaded condition and various motor speeds. The proposed method is used to process the collected signals and the results of feature extraction and fault diagnosis demonstrate its effectiveness.

1. Introduction

Planetary gearboxes are commonly used in aerospace, automotive and heavy industry applications to derive benefits from their large transmission ratio, strong load-bearing capacity and high transmission efficiency [1]. Despite these advantages, the tough operation conditions of heavy duty and intensive impact load may cause gear tooth damage such as fatigue crack and teeth missed etc., occurrence in the planetary gearboxes frequently [2]. The tooth damage may lead to undesirable dynamic behaviors resulting in large vibration, heavy noise and unacceptable performance of planetary gearboxes.

The term planetary gearbox is actually a gearbox including a planetary gear set, which refers to the compound gear systems with several planet gears between a center sun gear and an outer ring gear. Fig. 1 shows an elementary planetary

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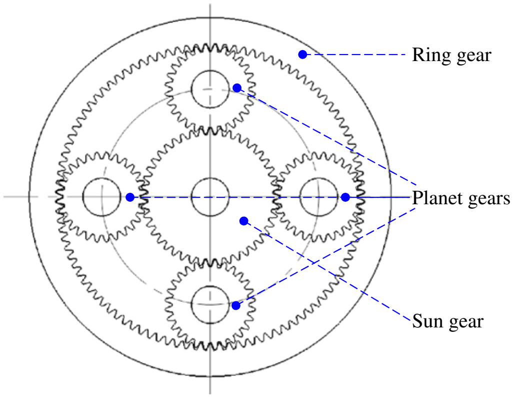

Fig. 1. A schematic showing the components of a 4-planet planetary gear set.

gear set with four planets. It is evident that an elementary planetary gear set has a stationary (non-rotating) ring gear, a sun gear that rotates around its own center, and several planet gears that not only rotate around their own centers but also revolve around the center of the sun gear. The planet gears mesh simultaneously with the sun gear and the ring gear.

A planetary gearbox is more complicated than a fixed-axis gearbox in gear transmission structures. In a planetary gearbox, there are several planet gears that not only rotate around their own centers but also revolve around the center of the sun gear. However, in a fixed-axis gearbox, all gears rotate around their own fixed centers only. Thus, a planetary gearbox generally exhibits different behaviors from a fixed-axis gearbox. (1) In a planetary gearbox transmission system, there are multiple and time-varying vibration transmission paths from gear meshing points to transducers, which are typically mounted on the housing of a planetary gearbox. These vibration transmission paths may deteriorate or attenuate vibration response of faulty gears through dissipation and interference effects [3]. In addition, torques or loads applied to the gearbox may also lead to non-linear transmission path effects [4]. These effects would weaken the fault characteristics hidden in vibration signals. (2) Planetary and fixed-axis gearboxes have different distributions in the frequency spectrum of vibration signals. For a pair of meshing gears in a fixed-axis gearbox with gear faults, the fault characteristic frequencies, sidebands, symmetrically locate around the meshing frequency and its harmonics in the frequency spectrum. For a planetary gearbox, the sidebands are not symmetric about gear meshing frequency and its harmonics because multiple planet gears produce similar vibrations but with different meshing phases, which cause some of the excitations of multiple gear meshes to be canceled or neutralized [5–7]. (3) Some components in a planetary gearbox generally operate under low rotating speeds because of the large transmission ratio. It is true that low-frequency characteristics are easily buried by heavy noise. Thus, it is particularly difficult to discover the fault characteristics of low-speed components in the planetary gearbox. The above three behaviors integrate to largely increase the difficulty of feature extraction and fault diagnosis of the planetary gearbox.

A few interesting studies regarding condition monitoring and fault diagnosis of planetary gearboxes have been reported recently in the literature. Blunt and Keller [4] developed two methods based on a planet and the carrier for detecting a crack in the planetary carrier of a helicopter planetary gearbox. Bartelmus and Zimroz [8,9] investigated the influence of the varying load on condition monitoring of planetary gearboxes and proposed a feature for monitoring planetary gearboxes under time-variable operating conditions. Lei et al. [10,11] introduced methods based on new diagnostic parameters and multi-sensor information fusion to classify different damage modes in a planetary gearbox. Barszcz and Randall [12] applied the spectral kurtosis technique to crack detection of the ring gear in the planetary gearbox of a wind turbine. Zhang et al. [13,14] integrated a blind deconvolution algorithm and vibration modeling for detecting a seeded fault in the helicopter planetary gearbox. Samuel and Pines [15,16] proposed a technique based on the constrained adaptive lifting algorithm for detecting gear fault with all teeth spalled in the planetary gearbox of a helicopter transmission. Zimroz and Bartelmus [17] investigated the cyclo-stationary properties of vibration signals for multi fault detection in multi-stage gearboxes: fixed axis and planetary. Bartkowiak and Zimroz [18] found outliers in a large data of two excavator planetary gearboxes under good and bad condition respectively, and used them for condition monitoring of planetary gearboxes. Bartkowiak and Zimroz [19] utilized data projection techniques to reduce observation space of real vibration signals from a mine excavator planetary gearbox and explored the data distribution and dimensionality. In addition, Inalpolat and Kahraman, and Mark [20–23] predicted the vibration and spectra of planetary gear transmission by establishing dynamic models. The above studies have provided critical insight on fault diagnosis of planetary gearboxes. Investigations on fault diagnosis of planetary gearboxes, however, are much limited in comparison with those of fixed-axis ones. There are still lots of issues to be addressed in fault diagnosis of planetary gearboxes. The issues in fault diagnosis of planetary gearboxes include selection of sensitive measurement locations, investigation of vibration transmission paths and weak feature extraction. One of them is how to effectively discover the weak characteristics from noisy signals of faulty components in planetary gearboxes. Weak characteristics mean small amplitudes of the spectral components in this paper.