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Research of weak fault feature information extraction of planetary gear based on ensemble empirical mode decomposition and adaptive stochastic resonance

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ABSTRACT

Characterized by small size, light weight and large transmission ratio, planetary gear transmission is widely used in large scale complex mechanical system with low speed and heavy duty. However, due to the influences of operating condition, manufacturing error, assembly error and multi-tooth meshing, the vibration signal of planetary gear exhibits the characteristics of nonlinear and non-stationary. Especially when early gear fault occurs, the weak fault feature information is submerged in interfering signal. A weak fault feature information extraction method of planetary gear based on Ensemble Empirical Mode Decomposition (EEMD) and Adaptive Stochastic Resonance (ASR) is proposed. The original signal is decomposed to the Intrinsic Mode Functions (IMFs) with small modal aliasing by EEMD. The Signal to Noise Ratio (SNR) of fault feature frequency information of each IMF is calculated, and the IMFs with first four higher SNR are reconstructed and selected as the effective IMFs containing main fault feature information. ASR system is built by combining Particle Swarm Optimization (PSO) and Stochastic Resonance (SR). PSO algorithm is used to optimize the critical parameters of SR, and SNR of ASR output signal is defined as an optimization objective. When the signal reconstructed by effective IMFs is inputted into ASR system, the weak fault feature information can be extracted from the output signal of ASR system. The experimental results show that the proposed method can extract the weak fault feature information of normal gear and fault gears successfully. The amplitudes of fault feature frequency and its sidebands generated by planetary gear fault have a significantly increase, and the effects on sideband amplitudes of faults become even greater than that on the amplitude of fault feature frequency. For different gear faults, the amplitude of fault feature frequency has different changes, meanwhile different sidebands are produced. Planetary gear fault diagnosis can be achieved accurately by comparing the extracted weak fault feature information, so it is an effective method of weak fault feature information extraction of planetary gear.

1. Introduction

Planetary gear transmission has many advantages, such as small size, light weight and large transmission ratio, so it is widely used in large scale complex mechanical system with low speed and heavy duty. Planetary gear transmission is a strong nonlinear system comparing to gear transmission with fixed axis, and there is more Amplitude Modulation (AM) and Frequency Modulation (FM) phenomenon in planetary gear transmission. Due to the influences of working conditions, different internal parameters, manufacturing error, assembly error, multi-tooth meshing

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and transmission paths, the planetary gear transmission can be characterized by more intense nonlinear and non-stationary [1]. At the same time, planetary gear often works in poor working conditions and suffers from noise interferences, so the feature information extraction becomes more difficult. Especially when the early gear fault occurs, the fault feature information submerged in ambient noise is very weak [2]. Therefore, how to effectively extract the fault feature information generated by planetary gear fault is the key in current study.

Empirical Mode Decomposition (EMD) is proposed in 1998 by Huang. It is a time–frequency analysis method to process the vibration signal with nonlinear and non-stationary, and the complex vibration signal is decomposed to many IMFs with strict definitions [3]. Compared with the proposed time–frequency analysis method, such as short-time Fourier transform, wavelet analysis, this method does not need to select the basis function in advance, so it is an adaptive decomposition process. At present, EMD has been widely used in machinery equipment fault diagnosis, but EMD has two disadvantages. One is endpoint leak, and the other is modal aliasing. Model aliasing is that a single IMF contains multiple scales or multiple bands signal, or the same scale signal is decomposed into a plurality of IMFs. That causes false mode components. Research shows that the main factors causing mode aliasing include intermittent signal, pulse interference and noise signal. Mode aliasing results in the physical characteristics of IMFs cannot be reflected, which affects the accuracy of fault feature information. To solve this problem, EEMD is proposed based on the research of statistical properties of Gaussian white noise signal [4,5]. The extreme point distribution of original signal is changed by adding Gaussian white noise, and EMD is used to decompose original signal. According to the frequency homogeneity characteristic of Gaussian white noise, the added white noise is eliminated by calculating the average of multiple decomposed IMFs, so the effective IMFs can be obtained.

In the actual process of planetary gear transmission, multi-tooth meshing can generate a lot of interference signal, so the early weak fault feature information will be submerged by interference signal [6]. Generally main fault feature information generated by gear fault is decomposed into several IMFs, so those IMFs containing main fault feature information should be extracted. However, due to the complex transmission of planetary gear, even though the IMFs contain main fault feature information, the fault feature information is still very weak. So the method that is effective to extract weak fault feature information should be used. Now the method of weak fault feature information extraction is divided into two categories. One category is the noise reduction of original signal. But noise reduction will eliminate some fault features, which makes weak fault feature information be weaker. The other category is that noise is used to improve the SNR of weak signal, and SR theory is a typical method [7]. At the synergy of input signal, noise and nonlinear system, SR method can achieve the purpose of enhancing weak signal. But SR method is limited by adiabatic approximation theory and linear response theory, so it only applies to deal with small parameter signal. In order to solve this problem, many scholars have continued some appropriate research. Lei [8] proposed a weak fault feature information extraction method of planetary gear that combines SR theory and ant colony algorithm. Tan [9] proposed a SR method based on shifting frequency and changing scale, and the large parameter signal is converted to a small parameter signal defined as the input signal of SR system. In SR system building process, SR system needs to determine two important parameters, and they are related to the effectiveness of SR system directly. So the optimization algorithm should be introduced to optimize those parameters. Lei [8] and Zou [10], respectively, proposed ant colony algorithm and genetic algorithm to optimize the parameters of SR system, but those two methods have obvious shortcomings. PSO with fast speed of approaching optimal solution is a global and multi-variable optimization method, and it can effectively optimize the system parameters. The nature of PSO is that the particle positions of next iteration are guided according to current location, individual extreme and group extreme, and the adjustment of particle status depends on their own experience and group experience is the key to reflect the excellent characteristics of PSO. Compared with genetic algorithm, PSO has not crossover and mutation, and few parameters need to be set. So PSO with the advantages of high efficiency and fast speed has strong engineering value. Ant colony algorithm is a typical probabilistic algorithm, and its parameter setting is usually determined by experimental methods. The optimized performance of ant colony algorithm is closely related to the analysis experience, so it is difficult to optimize the system performance. Meanwhile, the existing methods ignore the interaction between various parameters, and the advantages of SR in weak feature extraction could not be fully realized.

In order to overcome those above problems, a method of weak fault feature information extraction of planetary gear based on EEMD and ASR is proposed. Firstly, the original vibration signal of planetary gear is decomposed to some IMFs with small mode aliasing by EEMD. Then for each IMF, SNR of fault feature frequency information is defined as a reference, and several IMFs containing main fault feature information can be extracted. The reconstructed signal of effective IMFs is defined as an analysis target. Next ASR system is constructed based on PSO and SR, and that is used to extract weak fault feature information. The reconstructed signal matches the requirements of small parameter by changing scale processing. The maximum SNR of ASR output signal is defined as an optimization objective. At last, the weak fault feature information of planetary gear can be extracted by the output signal of ASR system accurately.

The rest of this paper is composed as follows: In Section 2, the mathematical model of weak fault feature information extraction of planetary gear based on EEMD and ASR is established. In Section 3, the experiment is completed in DDS mechanical fault comprehensive simulation bench. The vibration signal of two-stage planetary gear is measured by using acceleration sensors. In Section 4, the vibration signal is decomposed to some IMFs, and SNR of fault feature frequency information of each IMF is defined