Journal of Sound and Vibration 401 (2017) 139–151

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Rolling bearing fault diagnosis based on time-delayed feedback monostable stochastic resonance and adaptive minimum entropy deconvolution

Jimeng Li [a,*], Ming Li [a], Jinfeng Zhang [b]

[a] College of Electrical Engineering, Yanshan University, Qinhuangdao 066004, PR China
[b] College of Liren, Yanshan University, Qinhuangdao 066004, PR China

ARTICLE INFO

Article history:
Received 19 December 2016
Received in revised form
17 April 2017
Accepted 25 April 2017
Handling Editor: K. Shin

Keywords:
Rolling bearing fault diagnosis
Stochastic resonance
Monostable
Time-delayed feedback
Minimum entropy deconvolution

ABSTRACT

Rolling bearings are the key components in the modern machinery, and tough operation environments often make them prone to failure. However, due to the influence of the transmission path and background noise, the useful feature information relevant to the bearing fault contained in the vibration signals is weak, which makes it difficult to identify the fault symptom of rolling bearings in time. Therefore, the paper proposes a novel weak signal detection method based on time-delayed feedback monostable stochastic resonance (TFMSR) system and adaptive minimum entropy deconvolution (MED) to realize the fault diagnosis of rolling bearings. The MED method is employed to preprocess the vibration signals, which can deconvolve the effect of transmission path and clarify the defect-induced impulses. And a modified power spectrum kurtosis (MPSK) index is constructed to realize the adaptive selection of filter length in the MED algorithm. By introducing the time-delayed feedback item in to an over-damped monostable system, the TFMSR method can effectively utilize the historical information of input signal to enhance the periodicity of SR output, which is beneficial to the detection of periodic signal. Furthermore, the influence of time delay and feedback intensity on the SR phenomenon is analyzed, and by selecting appropriate time delay, feedback intensity and re-scaling ratio with genetic algorithm, the SR can be produced to realize the resonance detection of weak signal. The combination of the adaptive MED (AMED) method and TFMSR method is conducive to extracting the feature information from strong background noise and realizing the fault diagnosis of rolling bearings. Finally, some experiments and engineering application are performed to evaluate the effectiveness of the proposed AMED-TFMSR method in comparison with a traditional bistable SR method.

1. Introduction

Rotating machinery has played a significant role in the production of modern industry, such as wind turbines and machine tools. Rolling bearings, as core components, have been widely used in almost every rotating machinery. However, due to the influence of harsh environments and complex working conditions, they are prone to failure. The failure may

* Corresponding author.
E-mail address: xjtuljm@163.com (J. Li).

http://dx.doi.org/10.1016/j.jsv.2017.04.036
0022-460X/

deteriorate mechanical performance and even lead to fatal breakdowns. Therefore, they have received a lot of attention in the field of vibration analysis as they represent a common source of faults. In order to obtain valuable feature information from the vibration signals acquired by the transducers, various signal processing techniques, such as spectral kurtosis (SK) [1], empirical mode decomposition (EMD) [2], sparse representation [3], and wavelet transform (WT) [4], etc., have been extensively studied and applied in rolling bearing fault diagnosis. In comparison to these signal processing techniques for extracting useful features by filtering or masking noise, stochastic resonance (SR) regards noise as a kind of signal energy that realizes the extraction and enhancement of weak signal features by utilizing noise instead of eliminating noise. Consequently, SR provides an effective approach for weak features extraction in the mechanical fault diagnosis [5–7].

SR was originally presented by Benzi et al. to describe the periodicity associated with the Earth's ice ages in climatology in the 1980s [8]. And yet, in view of the good performance of SR using noise to enhance periodic signal features, SR-based fault diagnosis methods have been investigated in the last decade. Lei et al. proposed an adaptive SR method by using ant colony algorithm, and realized the fault diagnosis of planetary gearbox [9]. By introducing the wavelet packet transform into the multiscale noise tuning SR, Wang et al. presented an improved SR method particularly suited for the identification of multiple transient faults in rolling bearings [10]. In order to increase the calculation speed and noise utilization, Qin et al. [11] proposed an adaptive and fast SR method based on dyadic wavelet transform and least square parameters solving algorithm to extract the fault feature of a rotor system. Chen et al. studied a weak fault feature extraction method of planetary gear based on ensemble empirical mode decomposition (EEMD) and adaptive SR [12]. The effective intrinsic mode functions obtained by EEMD are selected and reconstructed, and then the reconstructed signal is processed by the adaptive SR method based on particle swarm optimization, thus realizing the weak feature extraction and fault diagnosis. Aiming at the shortcomings of multiscale noise tuning SR method based on discrete wavelet transform, Hu et al. [13] introduced the dual-tree complex wavelet transform into the multiscale noise tuning SR method, and realized the fault diagnosis of wind turbine drivetrain. Lai et al. [14] studied a SR method based on bistable Duffing oscillator, and solved the problem of large parameters signals detection to realize the incipient fault diagnosis of rotor system. These modified and optimized SR techniques have effectively promoted the development of SR theory and popularized the application of SR method in mechanical fault diagnosis.

However, it is worth noting that these engineering signal processing methods are almost all implemented in the framework of the bistable SR model. And in actual system there are a lot of monostable systems [15]. Therefore, some researches on the SR phenomenon in a monostable system have been conducted [16–18]. For example, Guo [19] studied the SR in a bias monostable system subject to frequency mixing force and multiplicative and additive noise based on adiabatic elimination theory, and obtained the analytic expression of the signal-to-noise ratio (SNR). Agudov et al. investigated the SR in an over-damped monostable system based on linear-response theory, and found that SNR was a nonmonotonic function of the noise intensity [20]. But the engineering application research is few about the SR method based on a monostable model in mechanical fault diagnosis. Furthermore, in consideration of the periodicity of weak signal to be detected, if the historical information can be used effectively in the SR system with a proper way, the periodic component in the SR output may be enhanced, i.e., weak signal detection performance is improved. Such an effect can be realized via a time-delayed feedback SR (TFSR) system [21]. The TFSR in a bistable system has been investigated in physical system and signal processing. However, the research on the TFSR in a monostable system is few, especially in the mechanical fault diagnosis. Therefore, this study combines the merits of the TFSR system and a monostable model, and presents a novel time-delayed feedback monostable SR (TFMSR) method to realize the engineering signal processing in rolling bearing fault diagnosis. The SR phenomenon of TFMSR system is demonstrated in theory, and analyzes the influence of time delay and feedback intensity on the SNR of system output. By selecting proper time delay, feedback intensity and re-scaling ratio with genetic algorithm, the SR output periodicity can be enhanced to realize the detection of weak periodic signal. On that basis, combined with the characteristics of rolling bearing vibration signals that the vibration signal collected by the transducer is the convolution between the defect-induced impulse response and the system transfer function, the minimum entropy deconvolution (MED) method [22,23] is adopted as the pretreatment way to effectively deconvolve the effect of the transmission path and clarify the impulses. And a modified power spectrum kurtosis (MPSK) index is constructed to evaluate the filtering effect of MED method, so that the filter length can be adaptively selected. By combining the adaptive MED (AMED) method and the TFMSR method, it is beneficial to extract the useful feature information from vibration signals in the fault diagnosis of rolling bearing. Finally, experiments and engineering application demonstrate that proposed AMED-TFMSR method in the paper is effective in the fault diagnosis of rolling bearings.

The rest of the paper is organized as followed: Section 2 mainly introduces the TFMSR method and AMED method in detail; and the algorithm flow of the proposed AMED-TFMSR method is described in Section 3. Then, Section 4 verifies the practicability of the proposed method by the experiments and engineering application, and provides further discussions. Finally, conclusions are drawn in Section 5.

2. Theoretical foundation

2.1. The model of TFMSR

SR describes a physical phenomenon that in a nonlinear system, the output SNR of the system increases to the maximum