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Robust bearing performance degradation assessment method based on improved wavelet packet– support vector data description

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ABSTRACT

Bearing performance degradation assessment is one of the most important techniques in proactive maintenance aiming to realize equipment's near-zero downtime and maximum productivity. In this paper, we propose a new robust method for it based on improved wavelet packet decomposition (IWPD) and support vector data description (SVDD). A health index is designed based on general distance. Node energies of IWPD are used to compose feature vectors. Based on feature vectors extracted from normal signals, a SVDD model fitting a tight hypersphere around them is trained, the general distance of test data to this hypersphere is used as the health index. Research results of its application in a bearing accelerated life test show that this health index can reflect effectively bearing performance degradation comparing with many other parameters.

1. Introduction

Bearing is one of the most important element in rotary machine; to a great degree, its performance influences the whole machine's. To prevent unexpected bearing failure that might cause costly downtime, even casualties, condition monitoring and diagnosis for it have received considerable attention for many years; thereinto, the vibration signal analysis-based method, which is the most suitable and effective for bearing, has been applied extensively [1,2].

Many studies have been carried out in this field, and they have furthered the development of fault diagnosis for bearing. These studies mainly focus on two aspects: signal analysis and pattern recognition. As a whole, on the former aspect, the basis of fault diagnosis, there are three main categories of data analysis: time domain analysis, frequency domain analysis and time–frequency analysis [3]. Time domain analysis is directly based on the time waveform itself, including amplitude domain analysis using statistics method to obtain some characteristic features such as mean, peak, peak–peak, root mean square, shape factor, crest factor, impulse factor, factor and kurtosis, correlation analysis and time-series analysis. Most of frequency domain analysis methods are based on fast Fourier transform (FFT). Its advantage over time domain analysis is its excellent ability to identify and isolate certain frequency components we are interested in. Envelop analysis is one of the most commonly used methods based on frequency domain because of the strong amplitude modulation phenomenon that occurs with occurrence of fault in bearing. But this method is not suitable for non-modulation signal. Time–frequency analysis is aiming to resolve the frequency domain analysis inability to non-stationary signals, such as short-time Fourier transform (STFT) and Wigner-Ville distribution (WVD). Recently, wavelet-based methods have become a new study focus in signal analysis field, wavelet decomposition (WD), wavelet packet decomposition (WPD) and improved wavelet decomposition (IWD) have been proposed and applied. Another time–frequency analysis method named Hilbert–Huang

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transform (HHT) [4] has become more and more popular. Though HHT has good computation efficiency and does not involve the concept of the frequency resolution and the time resolution, it also has one unresolved and maybe unavoidable deficiency–ripple phenomenon in its estimated frequency, which would mislead our analysis [5]. Fault diagnosis can be seen as a problem of pattern recognition and various intelligent methods such as artificial neural network (ANN) [6,7], hidden Markov model (HMM) [8,9] and support vector machine [10–12] have been applied.

Recently, in order to realize near-zero downtime and maximum productivity, proactive maintenance, which needs advanced tools of prognostics, has received more and more attention. Prognostic is much more efficient than diagnostics to achieve zero-downtime performance [3]. The research emphasis of this field has been focused on performance degradation assessment, so failure can be predicted and prevented. There are some new challenges to realize this [13]. One challenge is selecting some proper features that can reflect comprehensive performance degradation degree. This is very different from previous traditional fault diagnosis that basically just needs to be able to identify different faults. Previous researches show that different features are sensitive to different faults and degradation severity, for example, Kurtosis value, crest factor and impulse factor are sensitive to impulse faults, especially in the incipient stage, but after some degree, they will decrease to normal-like levels as the damage grows. So these feature's stability is not good. Lybeck et al. [14] studied some statistic features' correlation with spall length. These features' behavior is disappointing. Another challenge is how one can obtain an effective index comprehensive assessing performance degradation after extracting features. Through continuous study, now, some research results have been achieved on the aspect of performance degradation assessment. Lei et al. [15] and Lee [16] adopted cerebellar model articulation controller (CMAC) neural network to assess machine performance degradation; Pengju and Birtwhistle [17] realized condition assessment of power transformer onload tap changers using wavelet analysis and self-organizing map (SOM); Qiu et al. [13] developed a robust performance degradation assessment method for rolling element bearing based on optimal wavelet filter and SOM. On this basis, Huang et al. [18] further predicted its residual life using back propagation neural network and experiment results demonstrated that the proposed method is greatly superior to those, based on L10 bearing life prediction that is currently being used. Yan and Lee [19] and Yan et al. [20] utilized logistic regression to realize machine performance assessment. Gao et al. [21] studied bearing health assessment under varying operating condition using neural network. Ocak et al. [22] developed a new robust scheme based on WD and HMM for tracking the severity of bearing faults, and got the result that the probabilities of the normal bearing HMM kept decreasing as the bearing damage progressed toward bearing failure. Lingjun et al. [23] applied support vector data description (SVDD) to assess an equipment running state and helped successfully detect bolt crack.

The WPD is a generalization of the wavelet transform, it supplies a finer analysis method, but it is also faced with the problem of selecting proper wavelet when applied in engineering. Improved wavelet packet decomposition (IWPD), based on second generation wavelet transform (SGWT) realized by lifting scheme [24] in time domain, can overcome this shortcoming partly. SVDD is an excellent method of one-class classification, with the advantages of robustness and high computation. So, in this paper, we combine these two methods to develop a new robust method for bearing performance degradation. We use node energies of IWPD to compose feature vectors, use feature vectors extracted from normal data to train a SVDD model fitting a tight hypersphere around them. Then the general distance of test data to this hypersphere is used as health index. At last, we performed a bearing accelerated life test to collect vibration data over whole life time. Experiment results validate this designed index's advantages over many other parameters, showing the proposed method's feasibility and validity.

The following contents of this paper include: in Sections 2 and 3, we introduce, respectively, the two key techniques of proposed method: IWPD and SVDD, including performance assessment method based on it. Section 4 is about the bearing accelerated life test and experiment validation. Our conclusions from this research are presented in Section 5.

2. Improved wavelet packet decomposition

IWPD, based on second generation wavelet transform (SGWT) realized by lifting scheme in time domain, not only supplies a finer analysis method, but also can overcome the problem of selecting wavelet.

The second generation wavelet transform based on lifting scheme no longer relies on Fourier transform. All computation is performed in time domain. The process mainly includes three steps: split, predict and update [25].

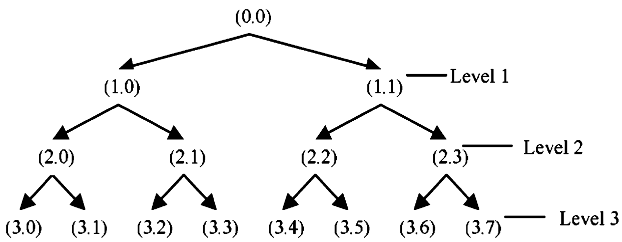

Fig. 1. An example of three-level wavelet packet decomposition.