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A fault diagnosis approach for roller bearing based on VPMCD under variable speed condition

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ABSTRACT

Essentially the fault diagnosis of roller bearing is a process of pattern recognition. However, existing pattern recognition method failed to capitalize on the nature of multivariate associations between the extracted fault features. Targeting such limitation, a new pattern recognition method – variable predictive model based class discriminate (VPMCD) is introduced into roller bearing fault identification. The VPMCD consider that all or part of the feature values will exhibit interactions in nature and these associations will have different performances between different classes, which is always true in practice when faults occur in roller bearings. Target to the characteristics of non-stationary and amplitude-modulated and frequency-modulated (AM–FM) of vibration signal picked up under variable speed condition, a fault diagnosis method based upon the VPMCD, order tracking technique and local mean decomposition (LMD) is put forward and applied to the roller bearing fault identification. Firstly, LMD and order tracking analysis method are combined to extract the fault features of roller bearing vibration signals under variable speed condition; Secondly, the feature values are regard as the input of VPMCD classifier; finally, the working condition and fault patterns of the roller bearings are identified automatically by the output of VPMCD classifier. The analysis results from experimental signals with normal and defective roller bearings indicate that the proposed fault diagnosis approach can distinguish the roller bearing status-with or without fault and fault patterns under variable speed condition accurately and effectively.

0. Introduction

Roller bearing is one of the most widely used elements in rotary machines and it directly influences the operation of the whole machinery; the unexpected failures would cause fatal breakdown of machines that may lead to significant economic losses. Therefore, the fault diagnosis of roller bearing has been extensively studied in the past years.

The typical faults of roller bearings are localized defects in the inner-race, out-race and the rollers. These defects generate complicated vibrations which appear with complex frequencies. In fact, Fault diagnosis of roller bearing can be conceived as a pattern recognition issue [1]. Thus, finding out appropriate fault features and pattern recognition method to identify the different work conditions and fault patters have become the focus of the relevant research [2,3].

Various signal analysis techniques have been developed to extract the fault characteristics of the roller bearings. In fact, while the roller bearing with faults is operating, its vibration signals would present non-stationary characteristics, therefore it seems that extracting fault feature in time–frequency domain is the most suitable analysis method. Wavelet analysis can provide the local features of the signal in both time and frequency domain, so it

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has been widely used in the roller bearing fault diagnosis [4,5]. However, the wavelet analysis is essentially an adjustable windowed Fourier transform. Due to the limitation of the length of the wavelet bases, energy leakage will occur in wavelet transformation. Furthermore, once the wavelet bases and the decomposition scales are determined, the results of wavelet transform would be the signal under a certain scale, whose frequency components relate only to the sample frequency but the signal itself. Therefore, wavelet analysis is not a self-adaptive signal processing method in nature [6,7]. In 1998, a self-adaptive signal processing approach called empirical mode decomposition (EMD) was put forward by Huang et al. [8]. EMD is based on the local characteristic time scale of signal and could decompose the complicated signal into a set of intrinsic mode functions (IMFs). As an advanced signal process technique, EMD receives many applications to machine fault diagnosis [9]. However, there are many problems to be resolved in EMD such as the mode mixing [10], end effects [11], IMF criterion [12] and so on [13]. Meantime, when roller bearing fault occurs, it is generally the case that the roller bearing vibration signals picked up by sensor would present multi-component amplitude-modulated and frequency-modulated (AM–FM) feature [14]. At present, the Hilbert transform has been widely used in roller bearing fault diagnosis as one of the most common demodulation analysis methods. However, owing to the inevitable window effect of Hilbert transform, the demodulation results present non-instantaneous response characteristic, which makes the amplitude get fluctuation in an exponential attenuation way, and then the demodulation error would accordingly increase [15]. In addition, when Hilbert transform is used to demodulate, the multi-component AM–FM signals are always decomposed into single component AM–FM signals by band-pass filter. While the selection of central frequency and band width of band-pass filter would inevitably carries great subjectivity.

Nevertheless, local mean decomposition (LMD) is a novel self-adaptive time–frequency analysis method developed by Smith in recent years [16]. It is developed to decompose a modulated signal into a number of product functions (PFs), each of which is the product of an envelope signal from which instantaneous amplitude of the PF can be obtained and a purely frequency modulated signal from which a well-defined instantaneous frequency could be calculated. On the one hand, comparing with EMD method, LMD have more advantages such as less iterative times, unobvious end effect and less phoniness components of the instantaneous frequency [17]. On the other hand, after vibration signals are decomposed by using LMD, the envelope signal of each PF can be obtained directly because in essence the procedure of LMD could be regarded as the process of demodulation. Therefore the modulation feature could be extracted more effectively and accurately by directly applying spectrum analysis to the envelope signal of each PF.

Meantime, it should be noted that the vibration signals of roller bearing with variable speed usually have more comprehensive status information and thus the signals are able to represent fault features better than those under fixed speed. Therefore, fault diagnosis of the roller bearings under variable speed condition has been the subject extensive research. Unfortunately, if time–frequency analysis is directly applied to the vibration signal, frequency mixing would occur inevitably because of the influence of speed change. Therefore, an appropriate method that can remove speed change effects should be applied before extracting the fault features. In recent years, order tracking technique has been an effective method for fault diagnosis under variable speed condition in rotating machinery, which can turn one non-stationary time domain signal into the stationary angular domain signal by constant angle increment re-sampling [18]. Due to the superiority that the technique can highlight the feature information related to rotation speed and restrain the unrelated information, order tracking is a desirable method to extract fault feature under the condition of variable rotation speed.

Apart from advanced signal processing techniques, pattern recognition is another significant part of roller bearing fault diagnosis [19]. Among the various pattern recognition methods for condition monitoring and fault diagnosis of machinery, artificial neural network (ANN) has been a commonly used technique which can classify conditions base on training pattern from the samples. However, the approach has limitations on generalization of results in models that can over-fit the data [20]. Recently, support vector machine (SVM) as an effective tool for pattern recognition based on statistical learning theory is used in many applications of fault diagnosis because of its good generalization abilities. It is especially powerful for a smaller sample number and guarantee the local and global optimal solution are exactly the same [21]. However, SVM requires rigorous tuning of kernel parameters and the process of optimizing generates large amount of calculation. Moreover, in nature decision boundary searching algorithms in SVM are binary, namely, separating only two classes at a time. It should be noted that, all these methods such as ANN and SVM lose sight of the inter-relations between feature values extracted from the original signals, which is not always true in practice when roller bearing with faults is operating.

Targeting these limitations, Raghuraj and Lakshminarayanan put forward a new pattern recognition method – variable predictive model based class discriminate (VPMCD) and it has been applied in the pattern recognition field of biology [22]. The VPMCD consider that all or part of the feature values will exhibit interactions essentially and these associations will have different performances between different classes, which is always true in practice when faults occur in roller bearing. In VPMCD, the different mathematical models, namely, variable predictive models (VPMs) are established firstly by using the relationship within feature values from different faults and then the work conditions are distinguished by VPMs. VPMCD effectively capitalize on the nature of multivariate associations between the features which can bring out distinct dissimilarities between the classes. On the one hand, this pattern recognition method can avoid the disadvantages of ANN and SVM. On the other hand, the calculation quantity of VPMCD also decreases since in VPMCD method there is neither the iteration process of ANN nor the optimizing process of SVM.

In summary, a fault diagnosis approach for roller bearing under variable speed condition based on VPMCD is put for-