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Research on feature extraction algorithm of rolling bearing fatigue evolution stage based on acoustic emission

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ABSTRACT

This paper focuses on extracting effective evolution stage features of rolling bearing from the monitoring signal. Each feature has a different damage sensibility to different fatigue evolution stages. Fatigue evolution information is dispersed in different features, which increases the difficulty to recognize the fatigue stages. This paper presents a new feature extraction method for acoustic emission (AE) signal of rolling bearing to solve the problem, and a specially designed test rig is used for the experimental verification. The new method combines wavelet packet de-noising (WPD) with an improved kernel entropy component analysis (KECA). First, de-noising original signal by WPD method. Second, applying KECA method with Gaussian kernel function on the feature matrix extracted from the de-noised signal. A new particle swarm optimization method based on the best kernel entropy component number theory with inertia weight and dynamic accelerating constant (BWCPSO) is proposed to optimize the kernel parameter. BWCPSO method puts the minimized kernel entropy components number with the maximum stage information of rolling bearing as its objective. The optimal kernel parameter can make KECA method extract and converge the original signal information greatly. Finally, each fatigue evolution stage can be identified adaptively by the main kernel entropy score (KES) graphs. The experiment results show that the proposed method extracts the fatigue evolution stages information of rolling bearing effectively and much easier and more accuracy than the traditional feature trend analysis and other two traditional feature extraction methods.

1. Introduction

Rolling bearing is widely used in industry circle. Its fault occupies approximately 30% of rotating machinery faults [1]. Rolling bearing fault is mainly due to the fatigue damage caused by the alternating stress of rolling contact. These damages are mostly generated in a certain depth beneath the rolling contact surface and then extend to the surface. Eventually, failure forms of pitting or spalling can be observed. If each fatigue evolution stage can be identified clearly during this period, the fatigue evolution law of rolling bearing will be known further and the degradation information will be mastered better. It is very helpful to strengthen the awareness of the damage mechanism of rolling bearing in different evolution stages and help us to avoid major accident.

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Researches show that acoustic emission technique can get material damage condition earlier than vibration technique. It can detect the dynamic tiny damage beneath the material surface. Thus, it is possible to acquire the fatigue process information of rolling bearing effectively by AE technique, especially to obtain the early damage information which can't be seen from the material surface.

Youshioka and Fujiwara [2] carried out the acceleration fatigue test of thrust bearing with three rolling balls which was made of bearing steel. The research pointed out that the fault could be predicted much earlier than the vibration signal by AE event rate. The life-cycle of rolling bearing was divided into normal stage, crack initiation stage and the crack propagation stage. Al-Ghamd and Mba [3] researched rolling bearing fatigue with AE signal. The fatigue evolution stages of rolling bearing were divided into three stages by the trend analysis of RMS, max amplitude, kurtosis and duration features, these three stages are commissioning stage, stable elastic response stage and unstable elastic response stage, respectively. Elforjani and Mba [4–6] continued the research in [2], and carried out the acceleration fatigue test with a flat race. Event count, RMS, absolute energy and information entropy were the effective features for mornitering. Hort et al. [7] applied AE technique on recognizing evolution stages of thrust ball bearings by the trend of duration, rise time, etc. The whole life of rolling bearing was divided into running state stage, the first damage stage and raceway particles spalling stage (damage stage II), respectively. The author refined the unstable stage in literature [3], but it's still not clear enough for each stage.

From the literature above, scholars have described rolling bearing fatigue evolution process by AE technique with just a few features, usually by 3–5 features. Different features may give the fatigue information from different aspects. Thus, a few features can't represent the complete fatigue evolution information of rolling bearing and multi-features are needed. But the whole fatigue evolution information is dispersed in these features because of the different sensitivity in each feature. Thus, a comprehensive assessment should be made from these feature trend analysis results to acquire the complete fatigue information. But it will increase the time cost.

Kernel entropy component analysis (KECA) [8] is a feature extraction algorithm based on information entropy theory. The method can greatly reserve the raw data information by several main kernel entropy scores with clear physical meanings. It is an effective tool to extract the fatigue evolution information of rolling bearing. KECA method was often used in multi-fault classification and has obtained good results [9–11]. It could also distinguish different stages if there are feature differences between stages. Feature differences of the evolution stages can be embodied in each feature trend, and the evolution stages can be distinguished according to the comprehensive difference information from these features.

The accuracy of KECA method will be damaged when signal to noise ratio is low [8]. But noise is difficult to be avoided in AE signal. It interferes the analysis result and increase the ambiguity on the boundary of each evolution stage. So, a de-noising preprocessing is needed. Moreover, KECA method usually doesn't consider how to converge the information from raw data greatly in an appropriate way. In that case, a satisfying result may not be obtained.

Thus, a more convenient method which can identify the fatigue evolution stage information of rolling bearing is desiderated to solve the problems above. This method should weaken the need of professional knowledge or experiences to reduce the subjective interference. It should also have the ability to extract the key information from the whole feature set effectively and synthetically. This paper presents a method combines WPD and improved KECA technique to converge and extract the fatigue evolution stage information of rolling bearing.

The rest of the paper is organized as follows: In Section 2, wavelet packet noise reduction theory is introduced, and the process of WPD method with maximum decomposition layer theory is given. In Section 3, kernel entropy component analysis and traditional particle swarm optimization is introduced, and an improved KECA method based on the best kernel entropy component number theory is proposed. Then, the process of the improved KECA with WPD method is given. In Section 4, a specially designed test rig by self-made for acquiring the fatigue acoustic emission signal of rolling bearing is introduced, and the proposed method is applied on the testing AE signals. Then the results of it are analyzed and discussed. Finally, Section 5 concludes the paper.

2. De-noising signal preprocessing

It is necessary to de-noise the original signal firstly to make sure the interference is suppressed as much as possible before analysis. Wavelet packet algorithm is a multi-resolution time–frequency analysis method wildly used in de-noising. It has special advantages in processing the signal with non-stationary or nonlinearity like AE signal. So wavelet packet algorithm has the potential to de-noising AE signal effectively.

2.1. Wavelet packet noise reduction

From 1989 to 1991, R. R. Coifman, Y. Meyer, S. Quake and M. V. Wickerhauser proposed wavelet packet theory together [12,13].

Wavelet coefficients modulus of the effective signal is much bigger than the modulus of the noise according to wavelet transform local maxima theory [14–16]. Noise will be removed after the threshold quantization and reconstruction based on this principle, if appropriate thresholds are applied on each decomposition coefficients. The selection of the threshold, decomposition level, threshold function and wavelet basis is very important for the wavelet packet analysis result.