Research on Fault Feature Extraction of Rubbing Rotor Based on Vector-Bispectrum Energy

Zhang Chao
Department of Mechanical Engineering, North China Electric Power University (071003), Baoding, China

(Received 11 December 2014; accepted 10 June 2016)

Signals collected from dual-channel sensors contain abundant fault characteristic information when the rub-impact fault occurs in a rotor system. As a combination of bispectrum and vector-spectrum analisys, vector-bispectrum analysis can achieve an effective elimination of Gaussian noise and accurate analysis on quadratic phase coupling in signals by combining dual-channel information. However, it has been found in the slight rubbing experiment that part of the fault information is lost by simply using the bispectrum or vector-bispectrum method. In order to resolve this problem, a new fault feature extraction approach for the rubbing rotor based on the energy index of vector-bispectrum is proposed and used in the experimental test to obtain typical characteristics of the full annular rub-impact fault. It is shown that this novel method of feature extraction inherits the advantages of vector-spectrum analysis. The features of the rub-impact fault based on the energy index of vector-bispectrum has been extracted successfully, and the result of classification through SVM illustrates that the extracted features are very noticeable, and the proposed method can comprehensively reflect nonlinear information of the rubbing rotor.

1. INTRODUCTION

In a theoretical sense, the rotor of rotating machinery is a complicated nonlinear system. The occurrence of the rub-impact faults in a rotor system may result in irregular and unstable shafting vibrations containing nonlinear phase coupling, which was harmful to the unit. Typically, conventional methods for fault detection use the power spectrum analysis based on Fourier transformation, which was built on the assumption of stable and Gaussian signals. Spectrum analysis could be used to characterize the Gaussian process, but it was not suitable for processing non-minimum phase systems or non-Gaussian signals due to its incapability of reflecting Gaussian skewness and nonlinear characteristics of signals.[1] Consequently, developing better ways to analyze the fault of the rubbing rotor has attracted much attention in the field of fault diagnosis of rotating machinery.

High order statistics analysis, in contrast with power spectrum analysis, could suppress Gauss noise completely in theory, and meanwhile effectively reveal the nonlinear information of the signal. As the simplest and lowest-order means in the high order statistics, bispectrum was the most commonly used high-order spectrum, and can be applied to deal with nonlinear phase coupling existing in nonlinear vibration signals. In the current study, bispectrum was generally used in the extraction of fault features in double frequency domain for rotating elements, such as gears and bearings.[2–6] Shen et al. applied bispectrum to extract the features of the rub-impact fault, and the results indicated the obvious existence of differences in bispectrum between the X-direction and the Y- direction signals.[7] However, why only the Y-direction signals were not selected for analysis was not explained. Yan et al. adopted the method of diagonal slice of bispectrum to analyze nonlinear coupling of harmonics occurred in steam turbines, but the results showed that the difference between the stable and the unstable vibrations was not notable in the figure of diagonal slice of bispectrum.[8] Generally, fault diagnostics based on bispectrum used the method of the statistical change detection, which was not ideal to distinguish the fault degree.[9] Therefore bispectrum coupled with other methods such as HHT or LMD, were suggested, but the complexity of the algorithm would increased.[10–13]

In general, the monitoring system of a rotor had a couple of sensors at each measuring point. The aforementioned studies mostly computed bispectrum of signal per channel respectively and selected the most obvious difference as the fault features by intercomparison. In fact, the signals of different directions were not identical due to the anisotropy of rotor systems. Hence, single channel based bispectrum analysis was not enough to comprehensively and exactly reflect the fault features because the insufficient signal combination would lead to the fault information missing. Based on the research of vector spectrum,[14] a new method of vector-spectrum integrating dual-channel signals was discussed and used to extract the feature of fault signals.[15] However, applications of this method carried out by the author of this paper for the fault signals of the rubbing rotor showed that the fault features reflected by vector-bispectrum were not obvious enough to identify the rubbing rotor.

In short, a new method of feature extraction based on the energy index of vector-spectrum was proposed for the rubbing rotor in this paper. The experiment results show that the energy index of vector-spectrum obtains bispectral characteristics of the full annular rub-impact fault, and a reasonable explanation is given. Finally, a SVM classifier is developed to validate the effectiveness of this method.

2. PRINCIPLE OF VECTOR-SPECTRUM

Assume that X- and Y- are the two orthogonal directions at a measuring point in a rotor system, and x_k, y_k are the discrete time series of X- and Y-direction respectively. X_k and Y_k are defined as the Fourier transforms of x_k and y_k. Let R_{xk}, I_{xk}, R_{yk}, I yk as the real and the imaginary parts of X_k and Y_k, respectively. The amplitude and phase of harmonics included in x_k and y_k are defined by:

$$\begin{cases} A_{xk} = \sqrt{R_{xk}^2 + I_{xk}^2} \\ \varphi_{xk} = \arctan\left(I_{xk}/R_{xk}\right) \\ A_{yk} = \sqrt{R_{yk}^2 + I_{yk}^2} \\ \varphi_{yk} = \arctan\left(I_{yk}/R_{yk}\right) \end{cases}; \qquad (1)$$