

Fault feature extraction of variable speed bearings based on order analysis

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Abstract: In the case of variable speed, the vibration signal of the measured bearing will contain the bearing itself information and the speed change information at the same time, and the signal is very non-periodic and non-stationary. In this paper, the order analysis method is adopted, the bearing vibration signal and the speed pulse signal are analyzed, and the signal is reconstructed by angle resampling, which reduces the non-stationarity of the signal, enhances the usability of the subsequent time-frequency analysis method, and can better extract the bearing fault characteristics in the variable speed environment.

Keywords: Variable speed; Bearing; Order analysis.

1. Introduction

Bearing is an important component of rotating machinery equipment, through the sensor to collect the vibration signal of the bearing, and then analyze and process, you can judge whether the bearing is faulty, and the bearing is in the variable speed condition most of the time. The signal collected by the sensor includes the vibration signal of the bearing itself and the changing speed signal, and at the same time, because of the change of speed, the vibration signal of the bearing loses its periodicity, so that the signal collected by the sensor has strong non-stationarity. Under the condition of constant speed, the fault signal occurs periodically, and the fault signal can be effectively extracted by resonance demodulation, wavelet analysis, EMD (Empirical Mode Decomposition) and other methods, which has a good analysis effect on the situation of constant speed. However, under the condition of variable speed, the fault information cannot be extracted by the original method.

Potter et al. [1] proposed the Order Tracking (OT) method, in which the vibration signal was resampled at equal angles and then spectrally analyzed, but it was highly dependent on auxiliary equipment. Fyfe et al. [2-3] proposed Computing Order Tracking (CT), which effectively improved the application effect of order analysis. The core of the computational order-based analysis method is to sample the vibration signal and the rotational speed rate simultaneously at a fixed sampling frequency, and the analysis method of stationary signal can be used in the future. This method is less dependent on hardware devices and is mainly implemented by software, which is the most widely used order analysis method in the industrial field. Tang Guiji et al. [4] proposed a method for extracting weak fault features from bearings based on time-time transformation combined with computational order analysis. Gao Guanqi et al. [5] proposed a frequency estimation method based on time-frequency extrusion, which realizes frequency estimation and feature extraction through time-frequency extrusion and resampling order ratio analysis; Feng Gang et al. [6] proposed an improved order analysis method, which resampled sequentially according to the angular velocity of each point of the sample, which improved the accuracy of order analysis. Wang Yatao [7] of Beijing University of Chemical Technology studied a composite fault diagnosis method based on multi-time frequency curve

classification. It can be seen that order analysis is widely used in variable speed bearing inspection.

In this paper, the calculation order analysis method is adopted, the bearing vibration signal and the speed pulse signal are analyzed, and the signal is reconstructed by angle resampling, so as to reduce the non-stationarity of the signal and enhance the processing ability of the time-frequency analysis method. The bearing data set of Xi'an Jiao tong University is used to verify the method, and the test results show that the method can effectively extract the fault characteristic order ratio information of the bearing, and the results obtained can prove the effectiveness and superiority of the method.

2. Analytical methods

2.1. Calculate the basic content of order analysis

By analyzing the pulse signal of the bearing, the rotation speed of the bearing is obtained, and the corresponding rotation angle equation coefficient is solved through the equation and the known pulse signal, and the angle resolution is introduced at the same time to obtain the time required to rotate an angle resolution, on this basis. The interpolation calculation is carried out, that is, an angular resolution corresponds to a moment, and a moment corresponds to a vibration amplitude, so as to realize the connection between the angle and the vibration amplitude, and obtain a complete resampling signal. The diagram is a flowchart of the resampling process as shown in Fig.1.

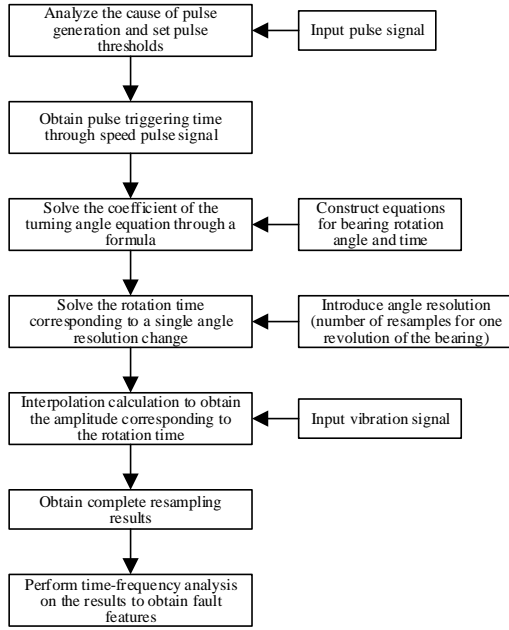


Fig.1 Flow diagram of angular resampling

2.2. Principles of computational order analysis methods

For rotating machinery, there is generally a rotation frequency, and the ratio of vibration frequency to rotation frequency is the order ratio, and the relationship between the order ratio and the rotation speed can be expressed as:

$$f = l * R * 60 \quad (1)$$

In the formula, the frequency (f Hz) is described, the order ratio is R denoted and the rotational speed (rpm) is described, and a reference is required to be selected to calculate the order analysis. The axis is used as the basis for the calculation, and its main idea is to pass the hardware collects the speed signal of the reference axis at equal intervals between time and passes through it. Angular domain resampling, cubic spline interpolation, and Fourier variation were obtained. Order spectrum. First, assuming that the rotating machinery accelerates uniformly over a period of time, its angle of rotation θ can be expressed by equation (2).

$$\theta(t) = b_1 + b_2 t + b_3 t^2 \quad (2)$$

The determination of the coefficients b_1 , b_2 and b_3 requires three consecutive sampling times t_1 , t_2 and t_3 , and the interval between each sampling is equal angle $\Delta\theta$, i.e., the phase difference between two adjacent points is $\Delta\theta$, then the polynomial coefficient b can be found by equation (3):

$$\begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix} = \begin{bmatrix} 1 & t_1 & t_1^2 \\ 1 & t_2 & t_2^2 \\ 1 & t_3 & t_3^2 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} \quad (3)$$

where θ_1 , θ_2 , and θ_3 are the rotation angles corresponding to the equal angle sampling, and the corresponding polynomial coefficient b can be calculated by sequentially inter spacing $\Delta\theta$, through the corresponding corner time, the corresponding sampling time t can be obtained by the following formula:

$$t_n = \frac{1}{2b_2} \left[\sqrt{4b_2(\theta_n - b_1) + b_2^2} - b_2 \right] \quad (4)$$

wherein, is the rotation angle, is the sampling time corresponding to the θ_n rotation angle, and t_n the time of equal angle sampling can be obtained through equation (4), and then the corresponding bearing vibration amplitude is calculated through the interpolation sampling method, and the vibration signal in the angle domain is obtained. The Fourier transform is performed on the angle resampled signal to obtain the corresponding order ratio spectrum.

3. Data validation

3.1. Data Description

In this paper, the S QV dataset dataset of Xi'an Jiaotong University is used for method validation and fault feature extraction. The data package contains two fault types, inner ring fault (IF) and outer ring fault (OF), the bearing type is NSK6023, and the specific dimensions of the bearing are shown in Table 1.

Table 1. Structural parameters of rolling bearings

Number of scrolling elements	Outer diameter (mm)	Inner Diameter(mm)	Thickness (mm)	Rolling element diameter (mm)
8	40	17	12	6.7462

From the bearing size, the characteristic value of the rolling bearing failure order can be calculated, as shown in Table 2.

Table 2. Rolling bearing failure order (multiple of rotation frequency Hz).

Inner ring failure	Outer ring failure	Cage failure	Rolling element failure
4.9469	3.0530	0.3817	3.9874

3.2. Data analysis

Fig. 2 shows the change of bearing speed, and it can be seen that the bearing first increases speed to 3000r/min, then rotates at a relatively uniform speed, and finally gradually decelerates. Fig. 3 is the original vibration signal waveform under the variable speed in Fig. 2, and it can be seen that the vibration amplitude is affected by the rotational speed, and the time-domain waveform of the vibration signal is irregular. Figure 4 shows the spectrum of the original vibration signal, and there is a lot of signal interference information, and it is impossible to obtain any effective information by relying on the Fourier transform alone, so it can be inferred that the traditional time-frequency analysis method will have great limitations.

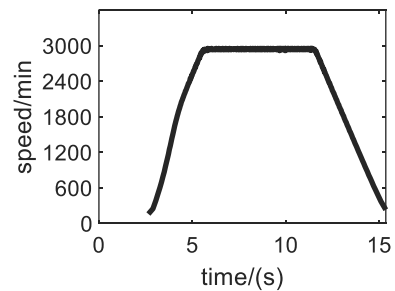


Fig.2 Rotational speed change

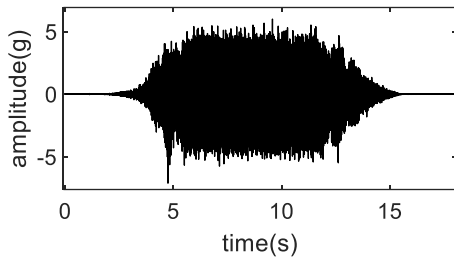


Fig. 2 Raw signal waveform

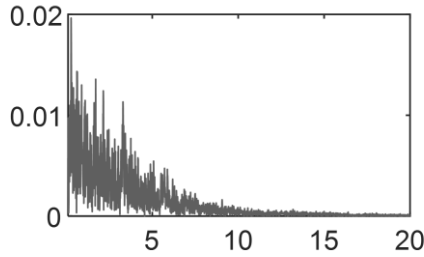


Fig. 3 Raw signal spectrum

The angle domain signal of the bearing is obtained by angle resampling of the original signal, as shown in Figure 5, the angle domain signal at this time can be analogous to the time domain signal under the condition of constant speed, and the resampling signal can be further analyzed and processed. The Fourier transform is performed from the angle domain signal to obtain the order spectrum of the signal, as shown in Figure 6.

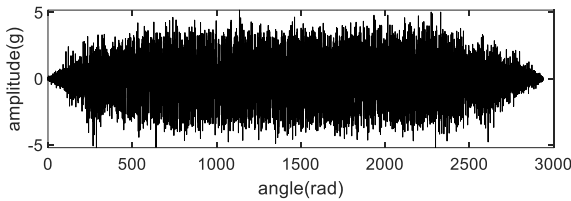


Fig. 4 Angular domain signal

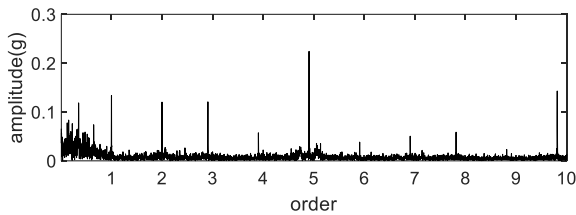


Fig. 6 Order spectrum of angular domain

As can be seen from the order spectrum, the characteristic fault value of 4.9 is present, which matches the eigenvalue calculated in Table 2, and it can be judged that the fault type of the analyzed signal is an inner ring fault.

4. Conclusion

Bearing fault detection in the case of variable speed is a popular research point, but because the rotation speed of the bearing is changing, the measured signal is very non-periodic, which brings great interference to the analysis. The order analysis used in this paper reconstructs the signal through angle resampling, which can reduce the influence of velocity change on the vibration signal and obtain the fault characteristics of the signal easily and quickly.

Acknowledgments

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