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Application of an impulse response wavelet to fault diagnosis of rolling bearings

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Abstract

To target the characteristic of roller bearing fault vibration signals, the impulse response wavelet is constructed by using continuous wavelet transform to extract the feature of fault vibration signals, based on which two methods namely scale-wavelet power spectrum comparison and auto-correlation analysis of time-wavelet power spectrum are proposed. The analysis results from roller bearing vibration signals with out-race or inner-race fault show that the two proposed methods can detect the faults of roller bearing and identify fault patterns successfully.

Keywords: Impulse response wavelet; Continuous wavelet transforms; Roller bearing; Scale-wavelet power spectrum; Time-wavelet power spectrum

0. Introductions

Wavelet transform is a time-frequency signal analysis method which is put forward in the recent years and has been widely used and developed. It has the local characteristic of time-domain as well as frequency-domain and its time-frequency window is changeable. In the processing of non-stationary signals it presents better performance than the traditional Fourier analysis. Hence, wavelet transform has many applications in rolling bearing fault diagnosis [1–4], in which the binary discrete wavelet transform and wavelet package transform are used mostly [5,6]. Although the applications of binary discrete wavelet transform and wavelet package transform lead to quick computing speed, both of them have to employ the orthogonal wavelet-base function which would make the scale partition presenting the jumping characteristic owing to the binary partition and the discrete interval too big which make the partition too coarse, which finally affects the extraction of fault feature. Compared with binary wavelet the continuous wavelet has finer time-scale partition and the selection of wavelet base only need to satisfy the admission condition. Besides, it has the time-invariable characteristic. So continuous wavelet transform could put the fine partition ability of wavelet transform to good use and is quite suitable for the rolling bearing fault diagnosis. The magnitude of the wavelet transform coefficient actually reflects the extent to which there is a similarity between the signal local

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and the corresponding wavelet-base function. The bigger the coefficient, the similar the two parts are [7]. Therefore different wavelet-base functions would lead to quite different results of signal analysis. In order to extract the fault feature of signals more effectively appropriate wavelet-base function should be selected. Presently in mechanical fault diagnosis, it is the Morlet wavelet that is mostly applied to extract the fault feature [2,8,9] and relatively satisfying results are obtained in all the applications. In this paper, to target the characteristic of roller bearing fault vibration signals, a kind of anti-symmetric continuous wavelet, that is, the impulse response wavelet is constructed to extract the fault feature. And on this foundation two rolling bearing fault diagnosis methods based on continuous wavelet transform are proposed, that is, the scale-wavelet power spectrum comparison and the time-wavelet power spectrum autocorrelation analysis method, which provide a new way to identify the rolling bearing fault. The analysis results from roller bearing vibration signals with out-race or inner-race faults showing that the feature of rolling bearing fault vibration signal can be extracted by continuous wavelet transform effectively.

1. Continuous wavelet transform

Suppose function $\psi(t) \in L^2(R) \cap L(R)$ and $\hat{\psi}(0) = 0$, and then according to the following formula construct the function group $\{\psi_{a,b}(t)\}$

$$\psi_{a,b}(t) = |a|^{-1/2}\psi\left(\frac{t-b}{a}\right) \quad a, b \in R, \quad a \neq 0 \tag{1}$$

which is called the analyzing wavelet or continuous wavelet, here ψ is named basic wavelet or mother wavelet and its Fourier transform is $\hat{\psi}(\omega)$. Besides a represents the scale parameter and b represents the orientation parameter.

The continuous wavelet transform of the function with finite energy $f(t) \in L^2(R)$ about $\psi(t)$ is defined as [10]

$$W_f(a,b) = \langle f(t), \psi_{a,b}(t) \rangle = |a|^{-1/2} \int_R f(t)\psi\left(\frac{t-b}{a}\right) \mathrm{d}t. \tag{2}$$

Wavelet transform has the isometric characteristic, that is, the wavelet transform of $f(t)$ is of energy conversation, which leads to the following formula:

$$\int_R |f(t)|^2 \,\mathrm{d}t = \frac{1}{C_\psi} \int_R \int_R |W_f(a,b)|^2 \frac{\mathrm{d}a\,\mathrm{d}b}{a^2}, \tag{3}$$

where $C_\psi = \int_R (|\hat{\psi}(\omega)|^2/|\omega|)\,\mathrm{d}\omega < \infty$ is called the admission condition of the wavelet.

2. The selection of wavelet-base function

When operating a roller bearing with local faults, the impulse impact response is generated. Because the impulse is a sort of transient excitation, the resonance of the bearing system natural frequency would arise. Suppose the delivery channel between the fault impact position and the fixed location of the sensor is changeless and take the rolling bearing as a system and its unit-impulse response function is $h(t)$, then the vibration signal picked up by the sensor is as follows [11]:

$$x(t) = \sum_{k=0}^{\infty} d_k h(t - kT_r) + n(t) = x_T(t) + n(t), \tag{4}$$

where d_k is the intensity coefficient of the fault impulse impact; $x_T(t)$ the vibration response signal aroused under the fault impact; $n(t)$ the vibration response signal aroused by other reasons but fault impact, that is, the noise signal; T_r the fault impact period, and its reciprocal is namely the fault feature frequency f_r.

Since for different faults the impact periods are different, it is accessible to identify the fault pattern by T_r. Fig. 1 is a typical vibration signal of rolling bearing with fault. When fault occurs in the rolling bearing, although owing to the broad band characteristic of the impulse force, multi-natural frequency vibrations of the bearing system will arise, the natural frequency vibrations periods are all equal to the fault impact period. Consequently, we can first think about the vibration situation that only one natural frequency is involved.