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Extraction of the largest amplitude impact transients for diagnosing rolling element defects in bearings

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ABSTRACT

This paper presents a method based on the extraction of the largest amplitude impact transients (ELAIT) for diagnosing the rolling element defect in bearings. As a defected rolling element causes two largest amplitude impact transients (LAITs) during a spin period when the element passes the load zone centre, LAITs are separated for each rolling element according to the kinematics of the bearing operation. By applying band-pass filtering, demodulation, low-pass filtering, and ensemble averaging to these LAITs, an enhanced signature named envelope ensemble average (EEA) is obtained for each rolling element, which allows a reliable indication of the defected elements. The robustness of the method is evaluated by investigating the localised fault model of rolling bearings with the inclusion of phase errors caused by rotational speed oscillation and rolling element slippage along with additive white noises. Evaluation results show that EEA signatures are very sensitive to element defects and give an accurate indication of the most probably defected element, and the ELAIT method is robust to rotational speed oscillation and slippage. The same performance is also achieved when the method was validated with experimental signals from a test rig of machinery fault simulation, showing effectiveness and robustness in detecting rolling element defects in an operated bearing. Besides, the proposed method can be easily implemented online as it does not need a tachometer and is implemented at low computation cost.

1. Introduction

Rolling bearing faults can cause the failure of rotating machinery if maintenance action is not taken in time. Fault diagnosis of rolling bearings supports the maintenance decision and then helps to prevent the rotating machinery from unexpected failures. Vibration based fault diagnosis approaches are based on the assumption that impacts of rolling elements cause vibration transients (or transient responses) when passing through the localised defect. In general, these successive transients exhibit largely periodical or repetitive responses. The periodicity is usually expressed as characteristic fault frequencies [1,2]. For no slippage between the rolling elements and races, fault frequencies can be calculated according to [3,4]:

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$$\text{Ball pass frequency of outer race}: f_{\mathrm{BPO}} = \frac{1}{2}Z\left(1 - \frac{d}{D}\cos\alpha\right)f_{\mathrm{r}} \tag{1}$$

$$\text{Ball pass frequency of inner race}: f_{\mathrm{BPI}} = \frac{1}{2}Z\left(1 + \frac{d}{D}\cos\alpha\right)f_{\mathrm{r}} \tag{2}$$

$$\text{Ball spin frequency}: f_{\mathrm{BS}} = \frac{D}{2d}\left(1 - \left(\frac{d}{D}\right)^2\cos^2\alpha\right)f_{\mathrm{r}} \tag{3}$$

where Z is the number of rolling elements, d is the element diameter, D is the pitch diameter, α is the contact angle, and f_{r} is the shaft rotational speed. A localised defect of a rolling element impacts the outer race and the inner race once a spin and two transients are generated. Thus $2f_{\mathrm{BS}}$ is normally used as the fault frequency to indicate element defects.

The rolling element defect and the inner race defect are more difficult to detect than the outer race defect, especially in cases when the defects are incipient and the components of fault frequencies are submerged in noise. Fig. 1 shows the load zone in a bearing for the case of a vertical external loading. As the outer ring is fixed, the outer race defect normally appears in the load zone and the transients caused by the contacts between defect and elements are not modulated. On the contrary, the inner ring and the elements are moving parts and their position to the load zone is always changing during rotation. Thus amplitude modulation is caused by the defect moving in and out of the load zone. The inner ring rotates at shaft speed and the modulation frequency is f_{r} for inner race defect case. The rolling elements rotate at cage speed and the modulation frequency is $f_{\mathrm{c}} = f_{\mathrm{BPO}}/Z$ for element defect case. Transients of different kinds of bearing defects are shown in Fig. 1. For equal sized defects, the transient intensity of the outer race defect would be larger than those of the inner race defect and the rolling element defect [5].

Many vibration signal processing methods have been introduced to characterize the bearing vibration signals for fault diagnosis. These methods, such as fast Fourier transform (FFT), short time Fourier transform (STFT), empirical mode decomposition (EMD) [6,7], Kurtogram method [8–10], modulation signal bispectrum (MSB) [11,12], etc., are used to extract effective diagnostic features from vibration signals, and then the extracted features can be used as inputs of a pattern recognition model for intelligent fault diagnosis. In order to improve the separation capability of the extracted features, preprocessing methods are used to improve the signal noise ratio (SNR) of vibration signals.

Time synchronous averaging (TSA) is a well-known signal preprocessing method for fixed-axis gears [13]. TSA divides a long gear vibration signals into successive short segments, the length of which is the interesting period T that corresponds to the shaft rotational frequency, $f_{\mathrm{r}} = 1/T$. Then a synchronous signal is yielded by averaging these segments,

$$x_{\mathrm{TSA}}(t) = \frac{1}{N}\sum_{n=1}^{N} x(t + nT). \tag{4}$$

The amplitude frequency characteristic of Eq. (4) is presented as a comb filter, which consists of a series of uniformly distributed band-pass filters and their sidebands. The central frequencies of these band-pass filters are the shaft rotational frequency and its harmonics $kf_{\mathrm{r}},\ k = 1, 2, \ldots$, thus noise as well as components whose frequencies are not integer multiples of the shaft rotational frequency are suppressed significantly.

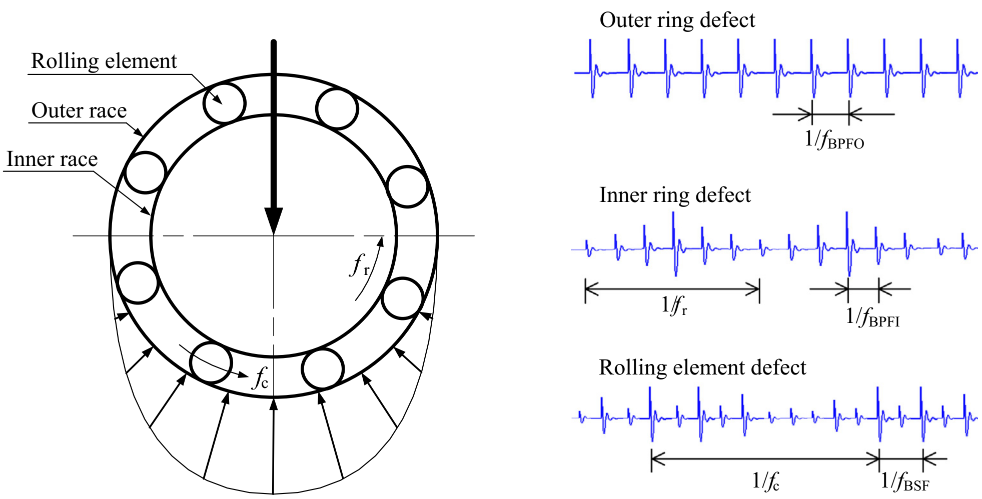

Fig. 1. The load distribution in a bearing and time domain response of bearing defects.