Denoising of sensor signals for the flange thickness measurement based on wavelet analysis

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ABSTRACT

A railway wheelset is subject to normal wear due to large part to friction contact between the wheelset and the rail. Because the wear of wheelset will bring the hidden security troubles to the operation of the railway, it is very important to measure the wheelset's geometrical parameters, especially the flange thickness. The optoelectronic method is proposed and can dynamically measure the flange thickness on line. Fast Fourier transform and wavelet analysis methods are used to denoise the sensor's signals. It is found that the wavelet transform produces a much better way of denoising of the signals compared with the fast Fourier transform. Comparisons of the flange thickness measurement with the wheelset creeping and the optoelectronic system are presented. The root-mean-square errors of the flange thickness with the manual measurement with the wheelset creeping and the optoelectronic method measurement with the wavelet analysis are 0.22 and 0.18, respectively. The changing range of manual measurement is much larger than that of the optoelectronic method because of the difference between every operator's measuring standard. Measurement results of the optoelectronic method show that the system has better repeatability and reliability compared to the manual measurement.

1. Introduction

A railway wheelset is subject to normal wear due in large part to friction contact between the wheelset and the rail [1]. As a railway wheelset wears, the profile of the running surface and many critical dimensions of the wheelset change due to dynamic interaction of the wheelset with the rail. The flange thickness is a key parameter that influences the wheel–rail contact. The change of the flange thickness will certainly bring hidden security troubles to the operation of railway, so it is very important to measure the geometric parameters of the wheelset [2].

The measuring methods and systems have been researched in recent years [3–10]. However, safety check measurements of the wheelsets mostly still take place in train yards. All the wheelsets are visually inspected and only a wheelset with noticeable wear can be measured. Many technicians usually spend long times on the safety check of wheelsets and most of the measurements are still depend on the special mechanic tools by manual work, especially in China, so there is often big difference of the measurement results to the flange thickness between different operators. It is very important to realize dynamic and real-time measurements of the wheelset's geometric parameters [11–13].

One of the standard methods to remove the noise of the signal is the fast Fourier transform (FFT) which is the linear Fourier smoothing. Wavelet theory has been developed strongly in the past 10 years and been applied in various research fields: the quality improvement of signals or images [14], and data mining in a limited number of images [15], and real-time 3D cardiac ultrasound [16], and analysis of electrocardiograms [17], and neuroscience [18] and noise reduction in astronomical spectra [19,20], and texture synthesis and modeling [21]. The wavelet method can obtain better results in the analysis of non-stationary or non-periodical signals than FFT. In general, the measuring practical data of the optoelectronic sensors detecting are contaminated by the noise, so the noise removal is important to get the higher measurement accuracy. In this paper, FFT filter and wavelet analysis are used to denoise the practical data. The results obtained with two methods show that the wavelet method is prior to FFT in the noise removal of the practical data.

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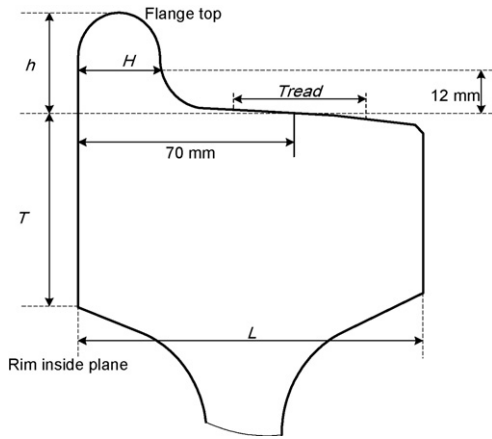E-mail address: zhifengzhang76@gmail.com (Z. Zhang).

Fig. 1. Profile of wheelset section.

2. Measuring principle

2.1. Definition of wheelset's parameters

Fig. 1 shows the profile of the part wheelset. Tread is the contacting zone with the rail when the wheelset moves. There is a base point on the tread and the distance is 70 mm to rim inside plane. Flange base line is the horizontal line 12 mm above the contacting point of the wheelset and rail. Flange height h is the height between flange base line and flange top. Flange thickness H is the horizontal thickness along flange base line. After the wheelset worked a long time, the flange height and thickness will change which is called the flange wear. Rim thickness T is the distance between the flange base line to the bottom of rim inside plane. Rim width L is the distance between rim inside base plane and the outside base plane. These parameters belong to geometric parameters of wheelset.

Fig. 2 shows the sketch diagram flange wearing. After wheel working a long time, the flange will turn thin, or sharp, or orthogonal. The flange thickness will change which is very dangerous. The optoelectronic system proposed can measure the change of this parameter on line. When the wheelsets pass through the measurement system, the measurement results of flange thickness are obtained. When the results of some wheelsets are beyond the limitation, the system will alarm and the technicians can repair or replace these wheelsets correctly and duly. This measurement system also can be combined with other measurement instruments to assess the wheelsets qualities.

2.2. Measuring principle and system

The optoelectronic system based on the laser displacement sensor can measure the flange thickness. The laser displacement sensor is composed of two sub-systems: one is the optical emitting system which uses a semiconductor laser with the wavelength 635 nm and light power 5 mW (THORLABS HL6312G) and the other is the optical receiving system which uses the linear CCD detector (NEC UPD3753). Fig. 3 shows the calibration result of the laser displacement sensor with a grating ruler (LG-50). The measurement range of the laser displacement sensor is 110 ± 15 mm. The response frequency of the laser displacement is 400 Hz. The laser sensor

Fig. 2. Sketch diagram of different flange wearing. (a) Thin after wearing, (b) sharp after wearing and (c) orthogonal after wearing.
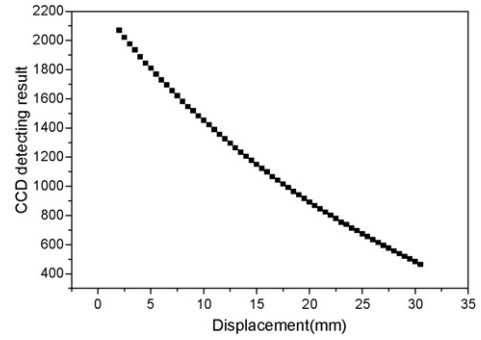

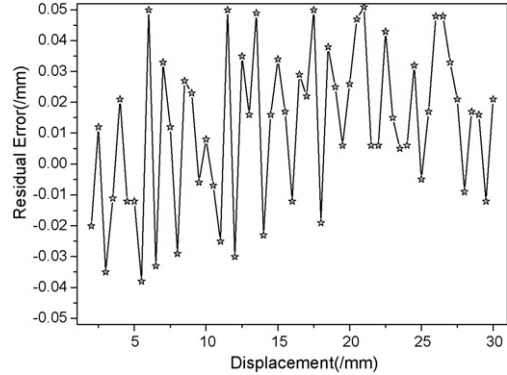**Fig. 3.** The laser sensor calibration curve.

Fig. 4. The residual errors vs displacement curve.

resolution is 0.02 mm. Fig. 4 shows the relation of the residual error and the displacement. The maximum residual error is 0.05 mm.

Fig. 5 shows the measuring principle and the measuring system. Fig. 5(a) shows the cross-section diagram of the system and Fig. 5(b) shows the top-view diagram. Measurement system fixed on the connection place of two rails is composed of two laser displacement sensors, laser sensor 1 and laser sensor 2. There is about ten centimeters gap between two rails in China, so the light emitted by laser sensor 1 can be projected on the wheel's point under the rail 12 mm according to the definition of flange thickness when the wheel passes through. Light emitted by laser sensor 2 is projected on the rim inner plane. Fig. 6 shows the schematic diagram of the measuring system on the scene. The flange thickness of the wheel can be obtained from Eq. (1):

$$H = L_0 - (L_1 + L_2) \tag{1}$$

where H is the flange thickness of wheel; L_0 is the distance between laser sensor 1 and laser sensor 2; L_1, and L_2 are the measuring results of laser sensor 1 and laser sensor 2, respectively.

3. Denoising algorithms

3.1. Fast Fourier transform denoising algorithm

For the signal $f(t)$, the Fourier transform $\hat{f}(\omega)$ can be obtained by the inner product of $f(t)$ with a sinusoidal wave $e^{i\omega t}$ according to Eq. (2):

$$\hat{f}(\omega) = \langle f(t), e^{i\omega t} \rangle = \int_{-\infty}^{\infty} f(t)e^{i\omega t}dt \tag{2}$$

It transforms the signal $f(t)$ from the time domain to the frequency domain ω and is viewed as the basis of modern signal processing. FFT [22] is the standard method for observing signals in the frequency domain. By suppressing the high-frequency com-