



Acoustic emission detection of rail defect based on wavelet transform and Shannon entropy



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ABSTRACT

In order to detect cracks in railroad tracks, various experiments have been examined by Acoustic Emission (AE) method. However, little work has been done on studying rail defect detection at high speed. This paper presents a study on AE detection of rail defect at high speed based on rail-wheel test rig. Meanwhile, Wavelet Transform and Shannon entropy are employed to detect defects. Signals with and without defects are acquired, and characteristic frequencies from them at different speeds are analyzed. Based on appropriate decomposition level and Energy-to-Shannon entropy ratio, the optimal wavelet is selected. In order to suppress noise effects and ensure appropriate time resolution, the length of time window is investigated. Further, the characteristic frequency of time window is employed to detect defect. The results clearly illustrate that the proposed method can detect rail defect at high speed effectively.

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1. Introduction

With the increase of traffic speed, density and loads on modern railways, it is necessary to focus on the safety problems caused by track degradation [1]. Growing defect is one of the most important reasons for track degradation, and various methods are employed for defect detection (e.g. acoustic emission, ultrasonic, magnetic testing and so on). Be different from other detection methods, Acoustic Emission (AE) method is suited to investigate dynamic behavior of materials and structures [2]. It can estimate dynamic characteristics of defects and it is ideal for on-line continuous monitoring [3,4]. This is very important to solve the safety problems caused by rail defects.

Various experimental studies have been examined to detect defects in railroad tracks by AE method [5]. In field experiment, Konstantinos Bolas's recent work verified the great potential of AE method in detecting geometric defects (such as flat surfaces on wheel circumference) by mounting AE sensors on rail. However, the maximum speed is only 40 km/h [6]. These signals have high signal to noise ratio and traditional AE analysis is effective to detect defects. At laboratory level, acoustic emission has already been applied for the detection of rail track faults. Kristoffer Bruzelius and Mba demonstrated the potential of applying AE to rail defect detection based on the test rig with a rail track wheel and a rail wheel, and the maximum speed is 25 km/h [7]. Thakkar investigated the normal rolling signals with natural rail defects by acoustic emission. The test rig includes a circular mild steel track and a scale model wheel with maximum speed 14 km/h [8]. The contribution of these studies is that they demonstrated the potential of applying AE to rail defect detection. These studies are at low speed, AE signals have high signal to noise ratio, and traditional AE analysis is effective to detect these

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defects. However, little work has been done on studying the AE detection of rail defects with noises at high speed in which most defect signals are submerged in noise and AE parameter analysis is invalid. Many details need to be worked out. It is necessary to set up a test rig which can run at high speed and find a method in detecting defects effectively. In this paper, a new test rig is set up with the maximum speed 124 km/h. This speed is three times more than that of previous studies and it can simulate the cases in which most defect signals are submerged in noise at high speed.

With the increasing power of data acquisition systems and the increased sensitivity of new sensors, recording the entire waveform with high fidelity becomes feasible. Based on waveform analysis, the features of defects can be extracted effectively. Since AE is not a stationary process, Wavelet Transform (WT) is a powerful tool for detecting local variations of non-stationary signals accurately. And the effectiveness of WT for the analysis of AE signals is also proved in [9,10]. The energy distribution of wavelet coefficients is quantitatively described by Shannon entropy [11], the combination of wavelet and Shannon entropy is very effective to select the optimal wavelet and extract the signal features [12,13], and it is very important to detect defects in rail at high speed.

Based on the rail–wheel test rig, this paper presents a study on AE detection of rail defect with noise at high speed by WT and corresponding Shannon entropy. The rest of this paper is organized as follows. Section 2 presents the theoretical background. Section 3 introduces the rail–wheel test rig and test procedure. In Section 4, the characteristic frequencies from noise signals and defect signals at different speeds are analyzed, the appropriate decomposition level is determined by characteristic frequency, and the optimal wavelet is selected by Energy-to-Shannon entropy ratio. In order to detect rail defects, the Shannon entropy with time is utilized. Section 5 gives the concluding remarks.

2. Theoretical background

2.1. Discrete wavelet transform

In order to detect rail defects in real time, an effective computation is necessary to analyze the large data. Discrete wavelet transform (DWT) has smaller amount of computations and faster analysis speed than that of continuous wavelet transform (CWT). Therefore, DWT is selected to analyze signals. The CWT of a given signal $f(t)$ in time t is defined as [14,15]:

$$wt(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) \psi^* \left(\frac{t-b}{a} \right) dt \quad (1)$$

where $\psi_{a,b}(t) = \psi((t-b)/a)/\sqrt{a}$, with $a, b \in \mathbb{R}$, and $\psi^*(t)$ is complex conjugate of the mother function $\psi(t)$. a is scale parameter and b is translation parameter. For the discrete set of parameters, $a = 2^{-j}$ and $b = 2^{-j}k$, with $j, k \in \mathbb{Z}$ (the set of integers), and the corresponding family of base wavelet is then expressed as:

$$\psi_{j,k}(t) = 2^{j/2} \psi(2^j t - k) \quad (2)$$

As a result, the DWT of a given signal $f(t)$ is obtained as:

$$wt(j, k) = \langle f(t), \psi_{j,k}(t) \rangle = 2^{j/2} \int_{-\infty}^{+\infty} f(t) \psi^*(2^j t - k) dt \quad (3)$$

where the symbol $\langle \cdot \rangle$ denotes inner product operation.

2.2. Appropriate decomposition level

Before wavelet transform, it is necessary to select the appropriate decomposition level L , in which subfrequency band contains the characteristic frequency of interest. The formula of decomposition level L is expressed in the following equation:

$$\frac{f_s}{2^{L+1}} \leq f_{char} \leq \frac{f_s}{2^L} \quad (4)$$

where L is decomposition level, f_s is sampling rate, f_{char} is characteristic frequency of interest. According to this formula, the appropriate decomposition level L is obtained.

2.3. Optimal wavelet selection

Different wavelets may have significant influences on analysis results [16]. It is important to select a suitable wavelet for detecting rail defects by AE signals. Several factors should be considered in selecting a wavelet (e.g. orthogonality, symmetry, support size and vanishing moments) [17]. An orthogonal wavelet will result in efficient signal decomposition into nonoverlapping subfrequency bands. High computational efficiency can be achieved when orthogonal wavelets are selected. Meanwhile, linear phase and symmetry feature are also important in AE detection. Considering these requirements, discrete wavelets considered in this paper include Haar, Meyer and biorthogonals family. In order to select an optimal wavelet from the candidate wavelets, a selection criteria is necessary. Researchers have developed various methods

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