Applied Acoustics 105 (2016) 67–74

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Defect detection and location in switch rails by acoustic emission and Lamb wave analysis: A feasibility study

Jinrui Zhang [a], Hongyan Ma [a,*], Wangji Yan [a,b], Zongjin Li [a]

[a] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, China
[b] Department of Civil and Hydraulic Engineering, Hefei University of Technology, Hefei, Anhui 23009, PR China

A R T I C L E I N F O

Article history:
Received 16 July 2015
Received in revised form 30 September 2015
Accepted 26 November 2015
Available online 17 December 2015

Keywords:
Rail inspection
Acoustic emission
Frequency
Lamb wave
Continuous wavelet transform

A B S T R A C T

An acoustic emission (AE) based approach is proposed in this study to identify and locate newly initiated defects or the propagation of existing defects in railroad switch rails. Defect-induced AE signals are identified through frequency analysis, as frequencies of these signals are much higher than those induced by structural vibration. Continuous wavelet transform (CWT) is employed to analyze the Lamb wave dispersion of the detected signal, so that two characteristic points can be selected on the CWT contour map to locate the defect. Using this approach, defects in a damaged switch rail can be located using a single sensor.

1. Introduction

The structural integrity of railroad tracks degenerates with time due to the intense bending and shear stresses, the plastic deformation and wear, which may lead to serious accidents and economic losses [1]. The US federal railroad administration (FRA) reported that train accidents caused by railroad track failures during 2000–2010 resulted in US $1064 million economic losses [2]. The failure of in-service railroads is primarily attributed to the propagation of defects in the rail head, web and foot due to fatigue and excessive wear [3]. Defects caused by normal fatigue mechanisms are often initiated earlier than those predicted by the design lifetime of the railroad or exhibit accelerated growth due to improper operational utilization. Therefore, in-service railroads need to be systematically inspected for internal and surface defects. Researchers in industry and academia have made significant progress in developing various NDT techniques, including eddy current sensing, ultrasonic, magnetic induction and visual inspection, to maintain the reliability of railroads [4–7].

In the field of NDT for railroad tracks, two difficulties can be identified, i.e. the variable head cross-section profile of switch rails and the defect detection in the foot of rails. As an important component of railroad tracks, the railroad switch is a mechanical installation enabling railway trains to be guided from one track to another. For safety reasons, switches are generally designed for the traversing of trains at low speed. Nowadays, there is a growing pressure (higher travel speeds and axle loads) on modern railway switches due to the rapid development of high-speed trains, thus the health monitoring of in-service railway switches has attracted widespread attention. As shown in Fig. 1, the switch normally consists of a pair of linked tapering switch rails lying between the diverging stock rails. Different from the stock rail, the tapering switch rail has a variable cross-section profile of the rail head, which leads to the invalidation of the traditional NDT techniques designed for stock rails, e.g. the ultrasonic method and magnetic flux leakage inspection, especially in the vicinity of the bolt holes on the tapering switch rails [8,9]. In addition, the widely used ultrasonic testing method is applied using track inspection vehicles and the ultrasonic probes only cover defects in the head, web and a small part of the foot directly beneath the rail web, so most of the defects in the rail foot cannot be detected during inspection [10,11]. However, the defect detection in the rail foot is particularly important, because a high percentage of rail failures are caused by defects which initiate and propagate in the foot of the rail [11]. Based on the aforementioned discussion, one can conclude that the health monitoring of in-service railway switches is extremely urgent, especially for the foot of switch rails.

Defect detection and location are the key objectives of health monitoring of in-service railway switches. Traditional locating

* Corresponding author at: Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, Rolla, MO 65401, United States. Tel.: +1 573 341 6250.

E-mail addresses: mhy1103@gmail.com, cehy@ust.hk (H. Ma).

http://dx.doi.org/10.1016/j.apacoust.2015.11.018
0003-682X/

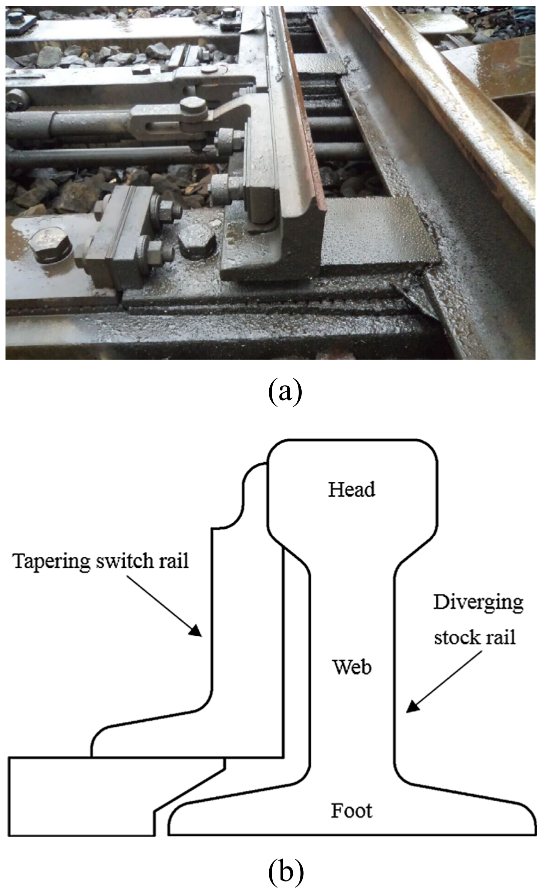

Fig. 1. An in-service rail switch: (a) on-site photograph; (b) schematic diagram.

methods are based on the time difference of arrival (TDOA) technique of P-wave. However, in practice, the switch rails withstand high impact loads as train wheels pass though. The damage-induced high-frequency AE signal will inevitably be masked by the impact-induced low-frequency structural vibration of the rail in the time domain, thus it is difficult to identify the arrival time of the defect-induced AE signal from the detected vibration waveform. Besides, if the rail was treated as 1-D case, at least two sensors were needed to locate the defect. In order to identify the arrival time of effective characteristic signal as well as to reduce the number of sensors needed, in this study, a novel method on the basis of acoustic emission (AE) and continuous wavelet transform is proposed to identify and locate the initiation or propagation of defects in switch rails, and the feasibility of this method is discussed. Rails are excellent waveguides, which allow the AE signals to travel a long distance with little loss of energy [12–14]. Although this method can be generally used in defect detection in railroad tracks, discussion in this study is limited to the defect locating in the foot of switch tracks, which is a difficult case as discussed previously. In experiments, notched and un-notched switch rails are stimulated by the tap hammer method to simulate the actual impact action by the train wheels. The accompanying AE signals induced by different mechanisms propagate along the switch rails as guided Lamb waves. Therefore, the dispersive properties of Lamb wave can be utilized to locate the defect with only one sensor. PMN $[Pb(Mg_{1/3}Nb_{2/3})O_3{\cdot}PbTiO_3{\cdot}PbZrO_3]$-based piezoelectric sensors are mounted on the foot of the switch rails to detect the AE signals. A novel defect identification and location method using only a single sensor is proposed by analyzing the time–frequency characteristics as well as the dispersion properties of the defect-induced AE signals guided in the switch rail.

2. Methodology

2.1. Principle of defect identification

AE-based techniques have been widely used for nondestructive testing in various mechanical and civil engineering applications [15–18]. However, in practice, the on-site noise is so huge that the valuable AE information is submerged in certain situations. Differentiating useful signal information from the background melange is thus essential in the application of AE-based techniques.

Fig. 2 shows the waveform and frequency spectrum of a detected on-site vibration signal of the switch rail subjected to the impact loads by the train wheels. It can be seen that the signal has a high voltage magnitude in the time domain, and the energy is concentrated mainly at around 340 Hz in the frequency domain. In the higher frequency range from 60 kHz to 400 kHz, the energy is

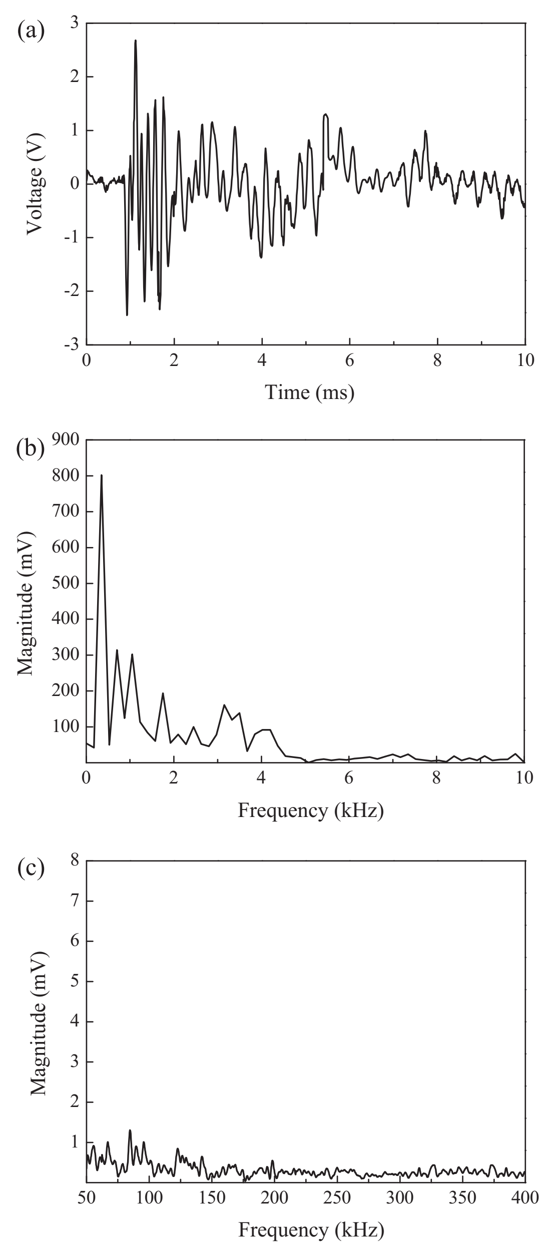

Fig. 2. A typical on-site signal due to the impact of train wheels on the switch rail: (a) waveform; (b) frequency spectrum in low-frequency range; (c) frequency spectrum in high-frequency range.