Wear 317 (2014) 120–128

Contents lists available at ScienceDirect

Wear

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

Study on the cause and treatment of rail corrugation for Beijing metro

Hougui Zhang*, Weining Liu, Weifeng Liu, Zongzhen Wu

School of Civil & Architecture Engineering, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Article history:
Received 18 February 2014
Received in revised form
28 May 2014
Accepted 31 May 2014
Available online 9 June 2014

Keywords:
Rail corrugation
Rail–wheel tribology
Contact mechanics
Wear testing

ABSTRACT

This paper presents the results of a study concerning a special type of rail corrugation occurring on Beijing metro. Field observations, investigations and measurement results show that the dynamic behavior of the train–track interaction is responsible for corrugations. When the train speed is more than 60 km/h, as is the case for Beijing metro, the train/track dynamic interactions at the dominant frequencies are recognized to be the cause for corrugation. The natural frequencies of the Egg system track structure were identified by the hammer test, which correlated well with the dynamic response frequency spectrum of the rail when the metro trains pass by. In order to verify the investigative results and provide a method to reduce rail corrugation, a test section was installed at a typical corrugated curve by avoiding the dominant frequencies of the track structure. When monitoring rail roughness, results show the method used is an effective way to control the development of the wavelength-fixed corrugation in the case of Beijing metro.

1. Introduction

There have been many studies on rail corrugation that span for more than a century [1], however, the mechanism of rail corrugation is still a common issue throughout the world. Several reports [2–5] have indicated that rail corrugation is due to various combinations of several mechanisms and consequently, there is not a single procedure for its treatment. Because of this, it has been said that the "…track is a dynamic system with sufficient variety that corrugation may persist, like influenza, forever being treated, perhaps never being cured, and always recurring in a new way and puzzling strain" [5,6].

Six different types of corrugation with significantly different characteristics have now been identified with the mechanism of each type of corrugation being discovered, and thus, recommendations for treatment were made in 1993 by Grassie and Kalousek [4]. According to the updated classification proposed by Grassie in 2009 [5], the trackform-specific corrugation was associated with a pronounced resonance (such as P2-resonance and pinned–pinned resonance). In order to reduce the possibility of having this type of corrugation form, recommended treatments include: (1) control friction, (2) improve steering and (3) avoid peak resonance. However, lubricating the track, using hard rail and grinding do not guarantee that such corrugation would be avoided, and removing the peak resonance has not been accomplished in practice.

The use of a softer direct fixation fastening system has shown reduction of corrugation in some reports. For example, the high resilience fastening system, entitled "Egg system", which is commonly used on Beijing metro for vibration isolation, was installed in the San Francisco Bay Area Rapid Transit (BART) as a solution for reducing the tendency for the formation of corrugations [7]. BART had a problem with a 25–50 mm wavelength rail corrugation in the area with its original fasteners. The original fasteners had a stiffness of about 52.5 kN/mm and the new Egg fasteners have a stiffness of about 10.5 kN/mm. However, the rail corrugation was not avoided after the track was retrofitted with the Egg system. On the contrary, it was shown as a vibration in the 400 Hz and 500 Hz one-third octave bands, which is consistent with a corrugation wavelength of 38–50 mm and a train speed of 72 km/h.

This paper introduces a study on a trackform-special type rail corrugation of Beijing metro. Field investigations and measurements were performed to determine the cause of corrugation and to develop a practical solution for corrugation mitigation.

2. Description of rail corrugation in Beijing metro

Rail corrugation becomes a serious problem in certain new lines of Beijing metro. The periodic wear on the running band of rail head generates noise disturbances which affect residents living near the metro lines and discomfort to the passengers. Measurements show that the pass-by noise was increased by

* Correspondence to: Room 2110, Tower 3, 18 Jiaodadonglu Road, Beijing 100044, China. Tel.: +86 1381110277.
E-mail address: 08115261@bjtu.edu.cn (H. Zhang).

http://dx.doi.org/10.1016/j.wear.2014.05.011
0043-1648/

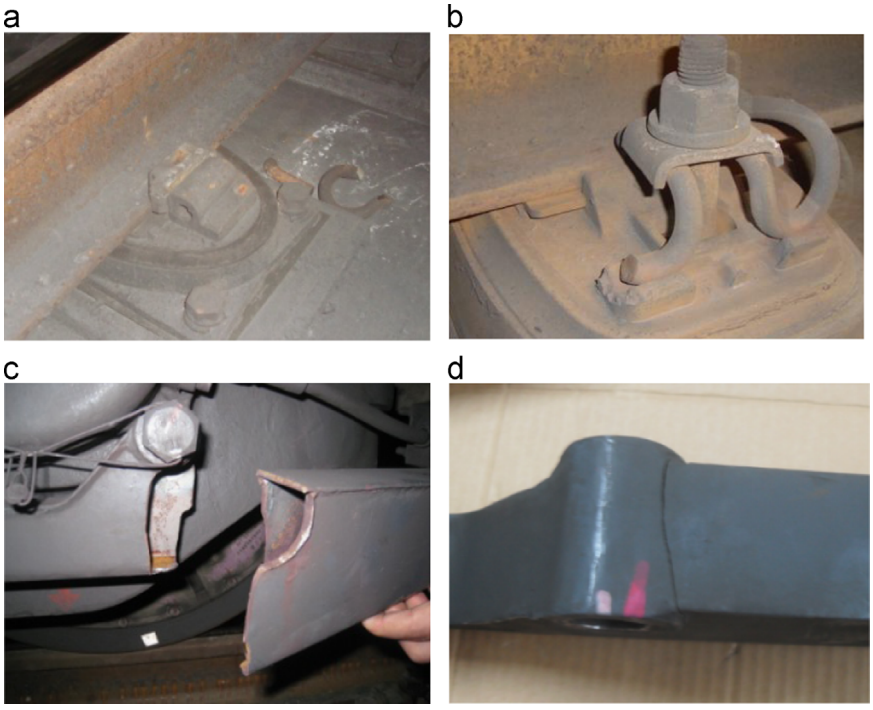

Fig. 1. Damaged parts of track and rolling stock caused by corrugation. (a) The clips drop off (track), (b) the clips broken (track), (c) parts of bogie frame cracked (train) and (d) parts of bogie frame cracked (train).

Table 1
Corrugated rail on Beijing metro line 5.

Track form	Radii of curve	Total length(Lt)		Corrugated length (Lc)		Percentage Lc/Lt (%)
		$v > 60$ km/h	$V < 60$ km/h	$v > 60$ km/h	$V < 60$ km/h	
Egg system	Tangent line	7.42	6.96	2.25	0.09	16.27
	$R > 800$ m	2.79	0.73	1.36	0.06	40.34
	$400 < R \leq 800$	1.47	0.54	0.92	0	45.77
	$R \leq 400$ m	0.6	0.04	0.48	0	75.00
DTVI2	Tangent line	9.06	6.54	0.05	0.13	1.15
	$R > 800$ m	0.9	0.91	0.01	0	0.55
	$400 < R \leq 800$	2.11	0.69	0.07	0.07	5.00
	$R \leq 400$ m	1.18	1.09	0.18	0	7.93
Other	Tangent line	3.51	3.72	0.06	0	0.83
	$R > 800$ m	0.75	0.72	0.21	0	14.29
	$400 < R \leq 800$	0.43	0.26	0.30	0	43.48
	$R \leq 400$ m	1.15	0.12	0.17	0	13.39

15–20 dB (A) in the sections where rail corrugation was found. Operation safety is becoming a concern due to an increase in drop off and broken clips within the fastening system which are found every day in severely corrugated sections. Cracks in bogie frames and wheelset components have also been observed, see Fig. 1.

Rail corrugation posed a serious problem for track maintenance personnel of Beijing metro. Currently, the primary method for controlling corrugation is to grind the rail at regular intervals. However, as corrugation develops so fast in some sections that the rail had to be renewed because of the frequent grinding procedure.

In order to find out the main factors of corrugation growth for the Beijing metro, field observations were conducted to collect the relative data. Take Beijing metro line 5 for example, the data in detail are listed in Table 1.

According to statistical analysis, characters of rail corrugations were found in Beijing metro and are summarized as follows.

2.1. Closely related to track structure

A variety of track structures are in use on Beijing metro, including direct fixation fastening system DTVI2, the Egg fastening system, and other structures such as the ladder track.

The commonly used track structure in Beijing metro is the concrete slab track, in which necessary elastic is provided by a direct fixation fastening system, known as DTVI2 (static stiffness is 20–40 kN/mm) (see Fig. 2-a). The elastic of DTVI2 was provided by rubber rail pad and baseplate pad. The sandwiched steel baseplate and baseplate pad was fixed directly on the concrete slab by spikes. On the sections of DTVI2, rail corrugation was found only in some of the tight curves ($R < 400$ m), which develops at a slow rate, which leads to an acceptable use of grinding (the grinding interval is over 2 years). In comparison, the vibration isolation track structure is the slab track with a very low stiffness fastening