Wear ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Wear

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

Rail wear on the curve of a heavy haul line—Numerical simulations and comparison with field measurements

Xia Li [a,*], Tao Yang [b], Jian Zhang [a], Yabo Cao [c], Zefeng Wen [c], Xuesong Jin [c]

[a] School of Traffic and Transportation, Dalian Jiaotong University, Dalian 116028, China
[b] Rock Failure and Instability Institute, Dalian University of Technology, Dalian 116024, China
[c] State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China

ARTICLE INFO

Article history:
Received 5 October 2015
Received in revised form
21 June 2016
Accepted 22 June 2016

Keywords:
Rail wear
Coupling dynamic model
Non-Hertzian theory
Heavy haul line

ABSTRACT

A numerical procedure for the simulation of rail profile wear is proposed and applied to a heavy-haul line in China. The procedure includes a coupling dynamics model of the freight vehicle and track, a Non-Hertzian contact model, and a material wear model. Freight vehicles equipped with different types of three-piece bogies are considered in the dynamics model. The track is considered as a 3-layer model with rails, sleepers and ballast masses. Each rail of the track is modeled with a Timoshenko beam on discrete sleepers. A moving sleeper support model is developed to simulate the effect of the periodical discrete sleepers on the vehicle/track interaction. Kalker's non-Hertzian contact model is modified as the post-calculation for the local contact analysis. The wear depth in the contact patch is based on Archard's model. Extensive field measurements of the wheel/rail profile have been carried out on the curves of the Shuohuang heavy-haul line. Comparisons between simulated and measured rail profiles have been conducted. The shapes of the worn rail profiles of the simulation broadly agree with the field measurements.

1. Introduction

Rail surface damage on the curves, such as rail side wear, corrugation, headcheck, shelling, spalling, etc., is a major cause of rail maintenance in Chinese heavy haul railways. Despite substantial improvements in rail material and vehicle design, rail maintenance continues to be an issue, as axle loads, train length and speed increase to improve throughput. The focus on track maintenance costs draws attention to the possibilities of rail wear control. Therefore, it is of great importance to predict rail wear by simulation and then provide some pertinent remedies for filed applications, which is the exact purpose of this paper.

Modeling wheel/rail (W/R) profile evolution due to wear is a complicated process, involving vehicle-track dynamics, contact mechanics, tribology, metal-material subject, etc. For a wheel/rail wear prediction model to be reliable, all these models must be included and validated with field measurements. A comprehensive wheel/rail wear prediction tool was developed by Szabo and Zobory [1]. The friction work wear approach and the stochastic model are used in the simulation. A generalized procedure for the wheel profile evolution was developed by Jendel and Berg [2]. The vehicle-track dynamics simulations were performed with the multi-body system (MBS) tool, GENSYS. And the local contact analysis was performed by applying the Hertz theory in combination with FASTSIM. Archard's wear model was employed locally. Validation was realized through comparisons with a worn wheel profile of a Swedish X10B commuter vehicle after running more than 200,000 km. Enblom et al. [3,4] continued Jendel's methodology. Their study considered the elastic strain in the sliding velocity assessment, the disc braking, the W/R contact environment, the non-elliptic contact models, etc. They also investigated the evolution of the rail profile due to uniform wear [5]. In general, W/R wear can be divided into the following two categories: uniform and non-uniform wear. Uniform wear is the wear of the profile in the cross section of the W/R. Non-uniform wear relates to the wear of the profile in the circumferential/longitudinal direction of the W/R, i.e., out-of-roundness and rail corrugation. Out-of-roundness is also known as wheel polygonalization. Rail corrugation is the counterpart of out-of-roundness. These two types of wear not only give rise to large dynamic forces but also affect the uniform wear to some extent. For example, when considering rail corrugation, the large W/R forces induced by the corrugation will cause serious wear and accelerate the evolution of the W/R profile. Non-uniform wear is an interesting area of research but is not the focus of this paper. The core of this paper is the uniform wear of W/R, particularly rail wear.

* Corresponding author.
E-mail address: xiali20034164@126.com (X. Li).

http://dx.doi.org/10.1016/j.wear.2016.06.024
0043-1648/© 2016 Elsevier B.V. All rights reserved.

Braghin et al. [6] presented a wheel wear procedure based on the interfacing of a multi-body dynamics simulation code for vehicle-track dynamics, a local contact model based on elastic half-space and influence functions, and a material wear model in which wear was assumed to be proportional to friction work. The numerical simulation results were compared with the experimentally measured wear using a full-scale wear test. A good agreement was reached on the wheel tread, but there was an overestimation of the flange wear. Kovalev et al. [7] created a tribodynamic model of vehicle-track interaction, and the results of the computation of the wheel and rail profile wear were discussed. Recently, Li et al. [8] presented a wheel profile wear prediction tool, in which the three-dimensional contact geometry analysis of the wheel/rail, Kalker's non-Hertzian rolling contact theory, and Archard's wear model were collected. Based on the semi-Hertzian method, Ding et al. [9] predicted wheel wear in a heavy haul freight car. Casanueva et al. [10] investigated the influence of switches and crossings on wheel profile evolution in freight vehicles. Zhai et al. [11] proposed an optimization strategy for the rail-grinding profiles to be used on heavy-haul railway curves to reduce the rail side wear. Saidova et al. [12] refined the parameters of Archard's wear model for wheel wear calculations for 25 t per axle freight wagons on Russian railways. Sun et al. [13] proposed a numerical method using VAMPIRE modeling to predict the turnout of curve wheel–rail wear. Pombo et al. [14] proposed a computational tool to predict the evolution of wheel profiles for a given railway system. Ignesti et al. [15] developed a model for the simultaneous analysis of wheel and rail wear.

The purpose of this paper is to investigate the rail wear on the curves of a heavy-haul line through field measurements and numerical simulations. The following three heavy haul lines are dedicated to coal transportation from west to east in China: the Datong-Qinhuangdao Railway, the Shuohuang Railway and the Jiaozuo-Yanzhou-Rizhao Railway. As the second main line for coal transportation, the Shuohuang line's annual traffic volume is over 200 million gross tons (MGT) since 2013. Freight wagons with three-piece running gear are in operation on this line. The average speed is approximately 70–80 km/h for the loaded trains. Severe rail wear occurs on the curves of this line. Rails on some tight curves are replaced due to excessive wear when the total traffic load is only 300 MGT in the loaded line, which means that the rail lifetime is less than 2 years with radius smaller than 600 m, resulting in high maintenance costs. Therefore, a theoretical study was conducted, parallel to field observations, with the goal of proposing a model that can qualitatively predict rail wear and provide some useful approaches to slow the wear rate.

2. Field observations and measurements

Extensive measurements of the wheel/rail profile of the Shuohuang heavy-haul line were performed in 2014. The MINIPROF portable instrument was applied at the test sites, as shown in Fig. 1. This instrument is widely used in studies related to the wear of wheel/rail profiles, such as Magel et al. [16], Eadie et al. [17] and Telliskivi et al. [18]. Three vehicle types, C64, C70 and C80, were investigated. The main difference in these wagons is the running gear. The C64 is equipped with Z8A bogie while the C70 and C80 are equipped with K6 bogie. The wheel profiles of these wagons were measured for all wheels. The standard wheel profile is LM, which is widely used in the Chinese freight wagon. The hardness of the wheel tread is between 270 and 341 HB. Various typical measured worn wheel profiles are illustrated in Fig. 2. It can be observed that wheel tread wear and flange wear are very serious.

Fig. 1. Measurements of wheel/rail profile at test sites. (a) Wheel profile measurement (b) rail profile measurement.

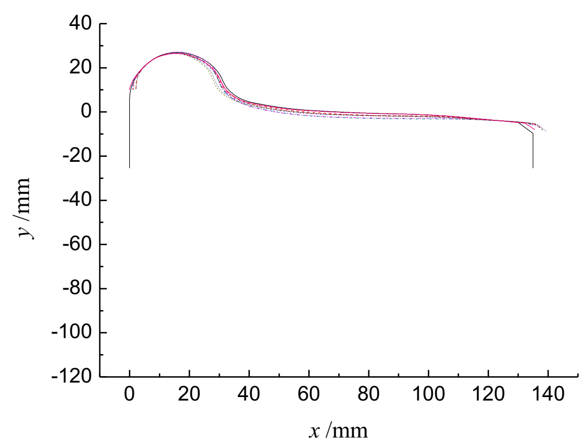

Fig. 2. Typical measured wheel profile of freight car.

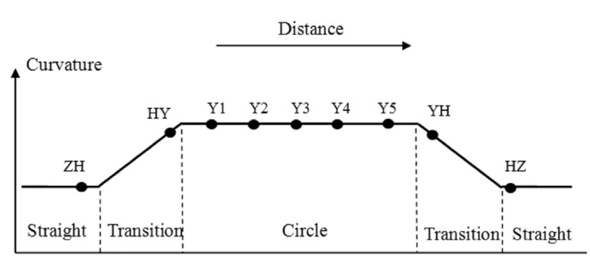

Fig. 3. Definition of the curve.

The rails on the track have 75 Kg/m profile with an inclination of 1:40. The steel grade is U75V. The hardness is 360 HB or more. The rail profiles of curves with four different radii, 500 m, 800 m, 1000 m and 2000 m, were measured. At each curve, 9 measuring spots were selected. Their locations on the curves are illustrated in Fig. 3. Two points (ZH, ZH) locate on the straight line, two points (HY, YH) locate on the transition curve, and the remaining five

Please cite this article as: X. Li, et al., Rail wear on the curve of a heavy haul line—Numerical simulations and comparison with field measurements, Wear (2016), http://dx.doi.org/10.1016/j.wear.2016.06.024