Engineering Failure Analysis 44 (2014) 382–399

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

The study of post-derailment dynamic behavior of railway vehicle based on running tests

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ARTICLE INFO

Article history:
Received 20 March 2014
Received in revised form 20 May 2014
Accepted 26 May 2014
Available online 11 June 2014

Keywords:
Railway vehicle
Derailment experiment
Half-car
Post-derailment dynamic model
Collision detection model
Contact force model

ABSTRACT

This paper is to investigate the post-derailment dynamic behavior of the half car and to verify the proposed post-derailment dynamic model. Firstly, a half-car derailment experiment is conducted in the laboratory. Then a comprehensive post-derailment dynamic model of half-car is put forward. The model is composed of three parts, namely, dynamic model of half-car, collision detection model and the contact force model, respectively. In addition, the kinematic analysis is carried out to investigate the possible path of motion after derailment. Through the comparison analysis of laboratory test and numerical simulation, the post-derailment dynamic model of half-car is validated, and can reflect the dynamic behavior after the derailment. Accordingly, the collision detection model and contact force model adopted in the post-derailment dynamic model of half-car can be used in the post-derailment simulation to detect the contact conditions and calculate the contact forces.

1. Introductions

Since the operation of the first railway in the world, railway vehicle scientists have focused their attention on the derailment problem [1]. Especially with the increasing of operation speed, the train derailment has become an issue of great concern in the railway industry. Fig. 1 indicates the derailment accident of Japan Shinkansen bullet train caused by the Niigata earthquake on 23 October 2004. This event was the first derailment accident of Shinkansen high speed train after it has been operated for 40 years. Fig. 2 shows the Jiao-Ji line derailment accident in China. The reason of this accident was that the speed of the train exceeded the limit speed of the curved track. Meantime, the train collided with another train after derailing from rails. Therefore, this derailment accident caused a large number of casualties and property losses.

It is well known that the derailment of railway vehicles will lead to considerable casualties and property losses. Therefore the avoidance and prevention of the derailment is extremely vital to the railway industry for both safety and economic reasons. Nevertheless, the essential feature of the wheel set running on rails without strong constraints in the horizontal plane creates a great challenge to prevent the derailment, particularly when the vehicle is subjected to the poor railway line conditions and large lateral wheel/rail interaction forces.

The earliest investigations of the derailment can be backdated to 1896. Based on the equilibrium principle of static forces on a single wheel, Nadal [2] put forward a single-wheel lateral force over vertical force limit criterion to calculate the critical derailment coefficient L/V. Nadal established the criterion for limiting the L/V ratio to minimize the risk of derailment.

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http://dx.doi.org/10.1016/j.engfailanal.2014.05.021
1350-6307/

Fig. 1. Derailment of Japan Shinkansen.

Fig. 2. Jiao-Ji line derailment accident in China.

Although this criterion has turned out to be conservative in tests and operation, it has been used throughout the railway community. Since then, many researchers contributed to the investigation of mechanics of pre-derailment and extend Nadal's formulation, such as Weinstock axle-sum L/V limit criterion [3,4], L/V time duration criterion [5,6] and wheel climb distance criterion [7]. The derailment almost occurs in the curve. Therefore, Suda's research team did a large number of innovation work to improve the curving performance of the railway vehicle, such as the self-steering tricks using unsymmetrical suspension with independently rotating wheels [8], self-steering ability of the independent rotating wheels using inverse tread conicity [9]. However, up to now, the mechanism of the derailment is still not understood thoroughly, and no effective way is found to prevent the derailment of railway vehicles. Due to this situation, understanding of the post-derailment dynamic behavior becomes particularly meaningful. As we know the post-derailment dynamic behavior is directly related to the outcomes of derailment accidents [10]. As long as the post-derailment dynamic behavior is understood, the countermeasures of reducing the losses of the derailment can be considered into the design stage of new railway vehicles.

However, the motions of railway vehicles after the derailment are affected by a variety of contacts, which bring tremendous difficulties to predict the post-derailment dynamic behavior of railway vehicles. Hence, most references simplified the dynamic contacts in the evaluation of post-derailment behavior, especially the contacts between the wheel and track [11–18]. Birk et al. [10,11] developed a prototype computer program to simulate some of the consequences of a train derailment accident. Toma [13] developed a planar derailment model of train. The planar model is based on coupled sets of 5 degrees of freedom sub-system models for each rail car. Paetsch et al. [14] established a planar rigid-body model to examine the gross motion of the railway vehicle in a train derailment. The influence of on- and off-track coefficients of friction on the gross motion was investigated. Brabie and Andersson [15,16] established a systematic multi-body system (MBS) module that detects impact conditions with concrete sleepers and applies impact force resultants based on the impact conditions. In order to obtain impact forces a simplified wheel–sleeper contact model was established by means of finite element method (FEM). Based on the MBS module mentioned above, the influences of low-reaching brake disc and bogie frame on the post-derailment dynamic behavior were investigated. Boronenko et al. [17] developed a dynamic model using MEDYNA to study the derailment process of freight wagon. They simplified the effects of interaction between the wheel set and sleeper as the vertical track irregularities introducing into the post-derailment simulation. Han and Koo [18] simulated a high-speed train crash in three dimensions using multi-body dynamic method. The contact element was used to simulate the collision