The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 7.10
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.7.10

Research on Wheel-rail Adhesion Characteristics of High-speed Railway on Long Ramp

HOU Bo-wen[1], QIN Jia-dong[1], J. Pombo[2] and MA Chao-zhi[1]

[1] School of Civil Engineering, Beijing Jiaotong University, China
[2]Institutc of Railway Research, University of Huddersfield, United Kingdom

Abstract

In this paper, based on multi-body dynamics, a vehicle-track coupled dynamic model considering long ramp is established, and the rail surface friction is set to 0.1 and 0.3 to simulate the low-adhesion rail surface and normal-adhesion rail surface respectively. The variation laws of train running acceleration, wheel-rail contact spot adhesion area and creep rate are studied when the high-speed train is running at the initial speed of 300km/h on different rail surfaces. The results show that the train running acceleration and the creep rate increase with the increase of the traction coefficient, and the adhesion area of the wheel-rail contact spot decreases with the increase of the traction coefficient; when the traction coefficient is 0.15, the traction force provided by the train during the uphill process can just offset the gravity component of the train, showing a constant speed running state; under the low adhesion rail surface, when the traction coefficient exceeds 0.25, the creep rate increases sharply during operation, the wheel-rail contact spot becomes full sliding, and the wheels will slip, which may cause the rail surface squat. The research results of this paper can provide a theoretical basis for the formation of rail squat in high-speed railway.

Keywords: high-speed railway, long slope, adhesion characteristics, traction.

1 Introduction

The high-speed wheel-rail adhesion mechanism is the basic theory to study the wheel-rail relationship and the formation of rail scratches. The adhesion between the wheel and rail directly impacts the traction and braking performance of high-speed trains. During the traction/braking of the train, due to insufficient adhesion between the wheel and rail, the wheel will spin or slide, resulting in wheel and rail damage[1], seriously affecting the quality of high-speed railway operation..

Scholars at home and abroad have studied the mechanism of wheel-rail adhesion and have achieved a series of research results. In terms of theoretical research, Chang Chongyi of China Academy of Railway Sciences [2] established a three-dimensional finite element model of wheel-rail rolling contact based on the ALE method. The accuracy of the calculation results was verified by the wheel-rail rolling test rig. An Boyang [3] established a three-dimensional wheel-rail high-speed rolling contact finite element model, and studied the effect of the functional friction coefficient on the wheel-rail rolling contact behavior, such as wheel-rail force, contact area stress, and stick-slip distribution. In terms of experimental research, LIU X [4] used a wheel-rail rolling test rig to analyze the influence of rolling speed on the lateral adhesion coefficient under dry and wet conditions. Shi [5] used a wheel-rail rolling test rig to study the effect of low temperature on the wheel-rail adhesion coefficient under dry and low-adhesion conditions. It can be seen that domestic and foreign researchers have little research on the wheel-rail adhesion characteristics with slopes. However, the traction/braking of trains on the slopes is more frequent in actual operation, and the influence of slopes on the wheel-rail adhesion characteristics cannot be ignored.

Based on the vehicle-track coupling analysis theory[6], considering the track irregularity and the effect of long slopes, this paper establishes a train-track coupled dynamic analysis model for long slopes. The influence of the traction coefficient on the running state and adhesion characteristics of the high-speed train during the climbing process were studied, and the relationship between the creep rate and the traction of the train and the state of the rail surface was analyzed. It can provide a basis for the prevention and control strategy of rail squat in high-speed railways, which is significant for improving the operation quality of high-speed railways.

2 Methods

Based on the multi-body dynamics theory, a train-track coupling dynamic analysis model is established considering the effect of track irregularities and long slopes. The models include a vehicle sub-model, a track sub-model, and a wheel-rail contact sub-model as shown in figure 1.

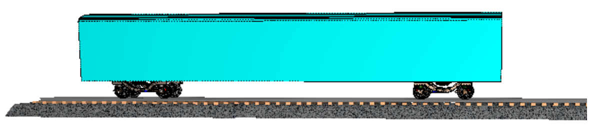


Figure 1: Train-track coupling dynamic analysis model.

The vehicle sub-model consists of seven structural components, including one body, two bogies, and four wheelsets. Each component ignores the vibration and deformation of its flexible body and only considers rigid body motion. It has 6 degrees of freedom of longitudinal, vertical, lateral, side rolling, nodding and shaking its head. [7] The primary suspension connects the wheelset and the bogie, and the secondary suspension connects the vehicle body and the frame. According to the traction characteristic of the train, the traction force is applied to the mass center of each wheelset in the form of torque [8]. The relationship between the traction coefficient and the traction torque is determined by the formula (1):.

$$u = \frac{M}{Rmg} \qquad (1)$$

In the formula: M is the traction torque, R is the wheel radius, m is the axle load of the train, and g is the gravitational acceleration.

The track sub-model adopts the moving mass track model. The rail considers the lateral, vertical and torsional degrees of freedom. The track alignment is set to a 30‰ inclination, and the measured track irregularity is used as excitation. The measured irregularity is shown in figure 2.

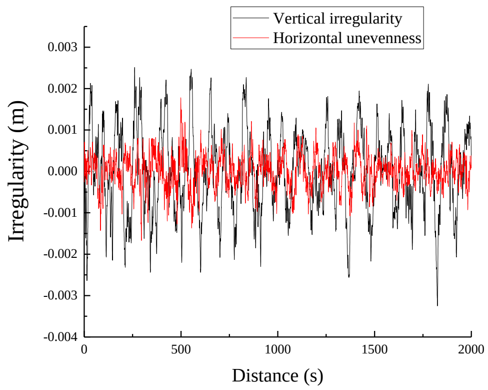


Figure 2: Measured track irregularity.

The wheel-rail space contact relationship includes calculating the geometric relationship between the wheel and the rail and calculating the wheel-rail contact force. The wheel-rail contact force is divided into the normal and tangential contact forces. Firstly, the normal contact force is obtained according to the Hertz contact theory. Then the creep force is calculated according to Kalker's theory and modified according to Shen's method. Thus the normal force and tangential force at the wheel-rail contact point are finally obtained.

3 Results

The high-speed train runs uphill at a speed of 300km/h. The friction coefficient of the rail surface is taken as 0.1 (low adhesion) and 0.3 (normal adhesion), and the changing laws of the running acceleration, the adhesion area and the creep rate are analyzed when the train traction coefficient is 0, 0.05, 0.1, 0.15, 0.25, and 0.35, respectively.

3.1 driving acceleration

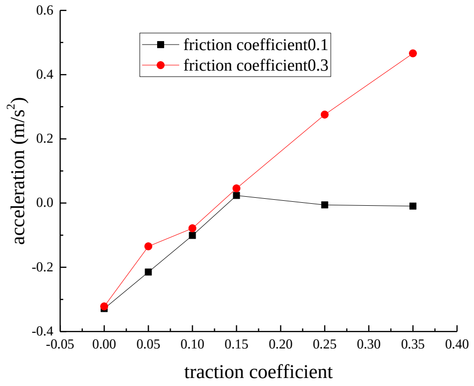


Figure 3: Variation characteristics of train acceleration with traction coefficient.

Figure 3 shows the variation laws of the train acceleration with the traction coefficient. It can be seen that the train presents a state of deceleration when the traction coefficient is 0 due to the influence of the gravitational force along the slope. When the friction coefficient is 0.1 and the traction coefficient exceeds 0.15, the train's acceleration cannot continue to increase due to insufficient wheel-rail adhesion, which may cause the wheels to spin. When the friction coefficient is 0.3, the traction coefficient exceeds 0.15, and the train acceleration increases with the increase of the traction coefficient.

3.2 Adhesion area

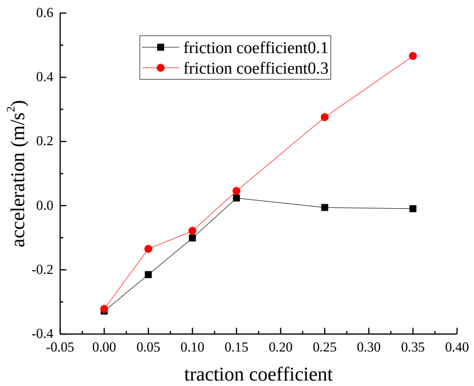
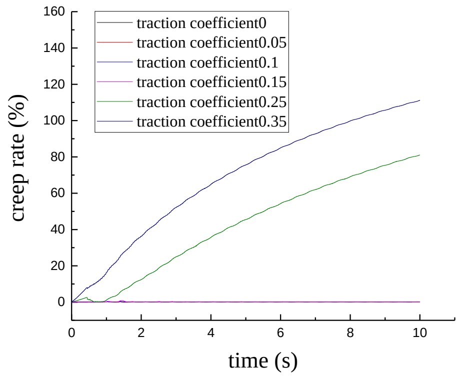


Figure 4: The variation characteristics of the adhesion area with the traction coefficient.

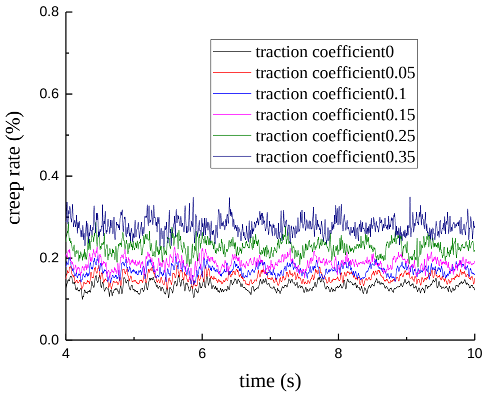
Figure 4 is the characteristic curve of the adhesion area with the traction coefficient. It can be seen that the adhesion area decreases with the increase of the traction coefficient. When the friction coefficient is 0.1, the traction coefficient increases from

0 to 0.25. The contact patch adhesion area is reduced from 79.83 mm^2 to 0 mm^2; When the friction coefficient is 0.3, the traction coefficient increases from 0 to 0.35, and the contact patch adhesion area decreases from 85.06 mm^2 to 39.84 mm^2.

3.3 Creep rate



(a) friction coefficient0.1



(b) friction coefficient0.3

Figure 5: The variation characteristics of the adhesion area with the traction coefficient.

Figure 5 is a curve showing the change of creep rate with time. It can be seen from figure 5 (a) that when the traction coefficient increases from 0 to 0.15, the creep rate increases from 0.09% to 0.17%, and when the traction coefficient is 0.25 and 0.35, it increases sharply with the increase of time. When the train runs for the 10th s, the traction coefficients are 0.25 and 0.35, respectively, and the creep rate is 81 and 111.2%. It can be seen from figure 5 (b) that the creep rate increases from 0.13% to 0.27% when the traction coefficient increases from 0 to 0.35.

4 Conclusions and Contributions

In this paper, by establishing a train-track coupling dynamics analysis model considering the effect of long slopes and analyzing the change characteristics of train running acceleration, adhesion area and creep rate under different traction coefficients, the following conclusions are drawn:

(1) When the train runs uphill on a 30‰ slope, the traction coefficient is less than 0.15, and the running state decelerates. When the traction coefficient equals 0.15, it runs at a constant speed. When the traction coefficient is greater than 0.15, it accelerates. On the low-adhesion rail surface (friction coefficient 0.1), the traction coefficient exceeds 0.15, the train running acceleration cannot be further increased, and the maximum adhesion force has been reached. On the normal track surface (friction coefficient 0.3), the traction coefficient increases from 0.15 to 0.35, and the train running acceleration increases from 0.04 m/s^2 to 0.47m/s^2.

(2) When the train runs uphill on a 30‰ slope, the area of the wheel-rail contact patch adhesion area decreases with the increase of the traction coefficient. On the low-adhesion rail surface (friction coefficient of 0.1), when the traction coefficient is 0.25, there is no more adhesion area, wheel-rail contact patch becomes full sliding, on normal rail surface (friction coefficient 0.3), traction coefficient increases from 0 to 0.35, wheel-rail contact patch always has an adhesion area.

(3) When the train runs uphill on a 30‰ slope, in general, the creep rate increases with the increase of the traction coefficient. On a low-adhesion rail surface (friction coefficient of 0.1), when the traction coefficient exceeds 0.15, there is no adhesion area between the rails, and the creep rate increases sharply with the increase of time. If it is not controlled, the continuous idling of the wheels will easily cause rail squat.

Acknowledgements

The paper is supported by open project of the national key laboratory of the China Academy of Railway Sciences Co., Ltd. (2021YJ051) and Project of Science and Technology Research and Development of China State Railway Group Co. Ltd (P2021G053).

References

[1] Chang Chongyi, Cai Yuanwu, Li Lan, Chen Bo. Research Progress and Application of the Mechanism of high-speed wheel-rail adhesion [J]. China Railway,2017(11):24-32.DOI:10.19549/j.issn.1001-683x.2017.11.024.

[2] Wang Ping, Liu Yibin, Gao Yuan, Xu Jingmang, AN Boyang, Guo Jun. A Study on Influence of Surface Strengthening on Wheel-rail Rolling Contact Behavior at Rail Corrugation [J]. Journal of the China Railway Society,2020,42(05):105-112.

[3] Zhang Peng, Zhao Xin ,Wen Zefeng. Analysis on the Transient Wheel-rail Rolling Contactin Short Low Adhesion Zone when Braking [J]. Machinery,2019,46(09):1-6+45.

[4] Wu Bing, Chen Ming, Wu Tao, Wen Zefeng, Jin Xuesong. Numerical Analysis of Wheel-rail Adhesion Considering Thermal Effect and Micro Roughness at High-speed [J]. Journal of the China Railway Society,2020,42(12):42-49.

[5] Chang C , Chen B , Cai Y , et al. An experimental study of high speed wheel-rail adhesion characteristics in wet condition on full scale roller rig[J]. Wear, 2019, 440-441:203092-.
[6] Chen H , Tanimoto H . Experimental observation of temperature and surface roughness effects on wheel/rail adhesion in wet conditions[J]. International Journal of Rail Transportation, 2018:1-12.
[7] Cai Yuanwu ,Chang Chongyi , Chen Bo,Li Lan. Simulation and Experimental Validation of High Speed Wheel-rail Adhesion Characteristics Based on ALE Method [J]. China Railway Science,2018,39(05):33-41.
[8] An Boyang, Ma Daolin, Wang Ping, Xu Jingmang, Du Yanliang. Study on Influence of Slip-Dependent Friction on Wheel/Rail Rolling Contact [J]. Journal of the China Railway Society,2017,39(07):98-104.
[9]LIU X, XIAO C, MEEHAN P A. The effect of rolling speed on lateral adhesion at wheel/rail interface under dry and wet condition [J]. Wear, 2019, 438-439(2): 203073.
[10] SHI L B, MA L, GUO J, et al. Influence of low temperature environment on the adhesion characteristics of wheel-rail contact [J]. Tribology International, 2018, 127: 59-68.
[11] Ma Chaozhi, Gao Liang, Zeng Qin'e, Cui Rixin. Study on Modal Characteristics and Influencing Factors of Wheel-rail Coupling Vibration of High-speed Railway [J]. Journal of the China Railway Society,2021,43(12):85-93.
[12] BOWEN, HOU, LIANG, et al. Prediction of structural vibrations using a coupled vehicle-track–building model [J]. Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail & Rapid Transit, 2016.
[13] Hu Yanlin , Ling Liang , Wang Kaiyun. A 3D Analytical Method for Train Behavior on Long Steep Grades of High-speed railway [J/OL]. Journal of Southwest Jiaotong University:1-8[2022-03-19].http://kns.cnki.net/kcms/detail/51.1277.U.20210709.0939.004.html.