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Study on the Influence of the Marshalling Position of Vehicles Without Braking Function on the Safety of Empty Freight Trains Under Braking Condition

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Abstract. In order to study the influence of the position of without braking function on the safety of empty freight trains, a dynamic model of the locomotive and vehicle-track coupling system was established based on the theory of vehicle system dynamics and the theory of train-track coupling dynamics. And the safety indicators of the empty freight train's lateral wheelset force, derailment coefficient, and wheel unloading rate were analyzed and compared with the dynamic safety indicators of the empty freight trains with normal braking function, while the vehicles without braking function located in the front, middle and rear parts of the freight train. The results show that during the service brake conditions, whether there are vehicles without braking function or not, the safety performance of the empty freight train is not much different, and all meet the requirements of the GB5599-2019 standard, the safety performance of the vehicles without braking function is not significantly different from that of the normal vehicles, the lateral wheelset force and the derailment coefficient are slightly greater than those in other parts while the vehicles without braking function located at the front part of the train, and the dynamic performance is not much different when the vehicles without braking function located in the middle and rear of the train..

Keywords. Vehicles without braking function, marshalling position, empty freight train, safety

1. Introduction

Railway freight vehicles are important equipment for railway freight transportation and the basis for railway freight. In order to meet the needs of safe operation, the "Railway Technical Management Regulations" stipulates that the automatic brakes of the locomotives and vehicles in the train must all be connected to the braking system of the whole train. In freight trains, vehicles which need to stop braking due to the provisions of the loaded goods, and vehicles whose automatic brakes temporarily fail, are allowed to closed cut-off cock, thus to cut off the connection between the vehicle brake pipe and the train brake main pipe, and in this state the vehicle have no braking function [1].

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The vehicles without braking function is a temporary measure according to the special needs of goods transported loading or the temporary failure of the automatic brake of the vehicle at the non-main train station or intermediate station to prevent accidents. When braking, since the vehicles without braking function cannot brake, it will have a certain impact on the braking distance of the train, and during the braking process, there will be momentary impulse and squeeze between the vehicles.

More seriously, the impulse and squeeze will be more intense, which may cause derailment, broken hooks, decoupling and other accidents due to brake rushing ,when the marshalling position and number of vehicles without braking function is improper. However, in the process of railway transportation, the vehicles without braking function was existed objectively for a long time, which has brought a greater impact on railway freight transportation [2].

In view of the impact of vehicles without braking function on the safety of freight trains, relevant researches have carried out on vehicles without braking function. Yang Shiquan [3] analyzed the causes of brake failure of 60t-class open wagons, and proposed improvement measures, Lai Bingling [4] aimed at the image recognition of the TFDS system for freight train operation dynamic faults, proposed a solution based on Relief algorithm to identify vehicles without braking function of a train, Zhao Yubo [5] discussed the use of the dynamic image detection system for truck operation faults to find the vehicles without braking function of the C80 series gondola wagon on the Datong-Qinhuangdao Railway, Yu Bingchen [6] made statistics on the number of vehicles without braking function, and analyzed the reasons why these vehicles could not be repaired in time, Guan Wentao [7] proposed the suggestion to increase the emergency braking test while repairing the vehicles without braking function, Guo Cong [8] carried out the analysis of loss of the fastening bolts of the brake shoe lash adjuster, which caused the situation of the vehicles without braking function, Wang Jiangang [9] analyzed the causes of the brake failure of the vehicles without braking function and proposed corresponding countermeasures, Chen Jianli [10] analyzed the influence of the vehicles without braking function on the longitudinal impulse of the train on the straight line and on the ramp road. Li Yuliang [11] discussed the establishment of the whole process management mode for the maintenance of the closed car. Teng Zhenhai [12] calculated and studied the speed limit of the passenger trains of braking cock cut out. Guo qiang [13] and Liu Yunxiang [14] analysis brake failure of freight cars and proposed repair suggestions.

The above research mainly focused on the analysis of how to identify the vehicles without braking function, and the reasons for the brake failure and the measures to reduce the amount of vehicles without braking function. These studies have reduced the amount of vehicles without braking function in the train and strengthened the management and maintenance of the vehicles without braking function. And played a huge role in promoting the safety of freight train transportation, but there is little research on the difference in the dynamic performance of the vehicles without braking function marshalling at different positions in the train and the impact on the overall safety of the train.

Based on this, a dynamic model of the long freight train was established ,and the safety of the empty freight train while marshalling vehicles without braking function in different positions was analyzed, the research can provides theoretical support for the marshalling and safe operation of freight trains.

2. Train Dynamics Model

Based on the theory of multi-body system dynamics, the locomotive and vehicle dynamics model were established. A dynamics model includes 1 car body, 2 frames, 4 wheelsets, 8 axle boxes. The car body, frame, and wheelset are each have 6 degrees of freedom, and axle box have one degree of freedom around the wheelset, namely nodding freedom, and the entire vehicle system have 50 degrees of freedom, including 42 independent freedom. The locomotive also considers the degree of freedom of the motor's nodding freedom, and the vertical and lateral motions are coupled together.

In the model, the wheel-rail contact geometry is considered as a non-linear single-point contact, and the creep force between the wheel and rail is calculated by simplified creep theory (FASTSIM), and the non-linear factors of suspension components were taken into account. Considering all the above factors comprehensively, the nonlinear dynamic model of locomotives and vehicles is established. On this basis, considering the coupling effect between rolling stock, and using the vehicle-track coupling dynamics theory [15], considering the coupling effect between the track and the vehicle, the train-track coupling dynamics model is established, as shown in Figure 1.

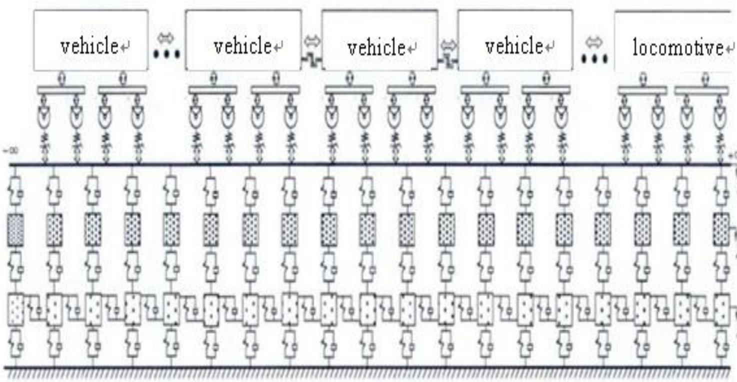


Figure 1. Train-track coupling dynamics model

For the train system,, the equation of motion of the train system is:

$$[M]\ddot{Y}+[C]\dot{Y}+[K]Y=\{P\}+\{F\} \tag{1}$$

Where: $[M]$, $[C]$ and $[K]$ is the mass matrix, damping matrix and stiffness matrix of the train system, Y is the train freedom variable, $\{P\}$ is the external environment force acting on the train system, $\{F\}$ is the interaction force between vehicles, the Circular-Variable solution method [16, 17] is used to solve this problem. The train motion Eq. (1) can be decomposed into n sub-equations:

$$[m_i]\{\ddot{Y}_i\}+[c_i]\{\dot{Y}_i\}+[k_i]\{y_i\}=\{p_i\}+\{f_i\} \quad (i=1, \ \ldots, \ n) \tag{2}$$

According to Eq. (2), a single vehicle can be regarded as a basic integral unit, and the large computational problems of the train system can be divided into n basic integration elements to calculation. When the calculations of a vehicle are completed, the calculation results are deposited in the transit variables, and then release the degree of freedom variables and for the calculation of the next vehicle until the calculation of all vehicles in the train are completed, and then go to the next integration step, until the completion of all the calculation. This integration method is called Circular-Variable method, and use to solve the train dynamic calculation.

3. Calculation Conditions

In the dynamic calculation, the American Fifth-Level line spectrum is used for excitation, and the operating speed is 80km/h, 85km/h, and 90km/h respectively. The safety performance of straight line and curves was calculated respectively, the radius of the curve is 600m, and the length of the transition curve is 110m. The pressure reduction is 70kpa during service braking. In the analysis results, the dynamic indicators such as the lateral wheel axle force, the derailment coefficient, and the wheel unloading rate are taken as the maximum value during operation in the straight line, and taken the maximum value through the transition curve and the circular curve in the curve railway condition.

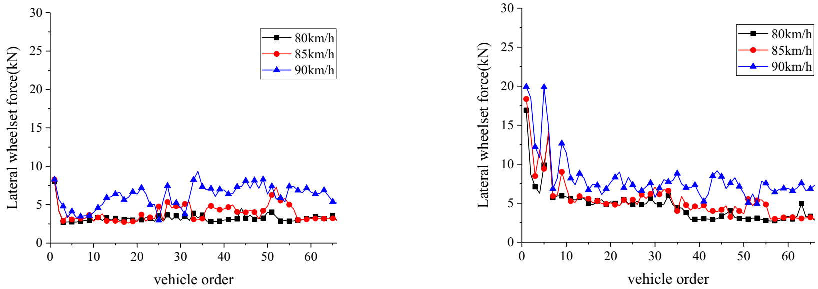
In order to analyze the impact of the vehicles position without braking function on empty freight train safety, the position of the vehicles without braking function was located in number 2,33,34 and 66, where the number represents the position of the vehicle without braking function in the train, the number starting from the locomotive, that is, the locomotive number is 1, and the vehicles without braking function are marshalling in three different positions at the front, middle and rear of the train.

4. Impact of the Marshalling Position of Vehicles without Braking Function

4.1. Safety Performance when Marshalling Vehicles without Braking Function

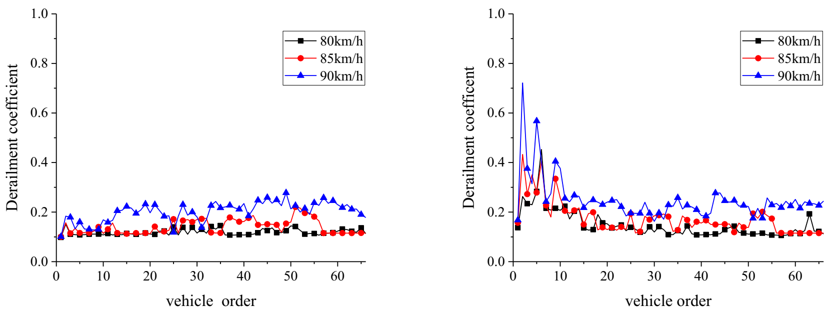
The train-track coupling dynamics model is used to analyze the dynamic performance of the vehicles without braking function while marshalling at different positions, and the GB5599-2019 standard [18] is used to evaluate the safety indicators of lateral wheelset force, derailment coefficient and wheel unloading rate of the vehicle.

Under service braking, the safety calculation results of the vehicles without braking function marshalling at positions 2, 33, 34, and 66 are shown in Figure 2-Figure 4. From the results, it can be seen that under the condition of straight and curved lines, with the initial brake speed of 80km/h, 85km/h, and 90km/h under service braking, the lateral wheelset force of the empty train does not exceed the limit value required by the GB/T5599-2019 standard, and the derailment coefficient is not exceeds the limit value 1.0 specified in GB/T5599-2019, and the wheel unloading rate does not exceed the limit value 0.65 specified in GB/T5599-2019, which all meet the standard requirements.



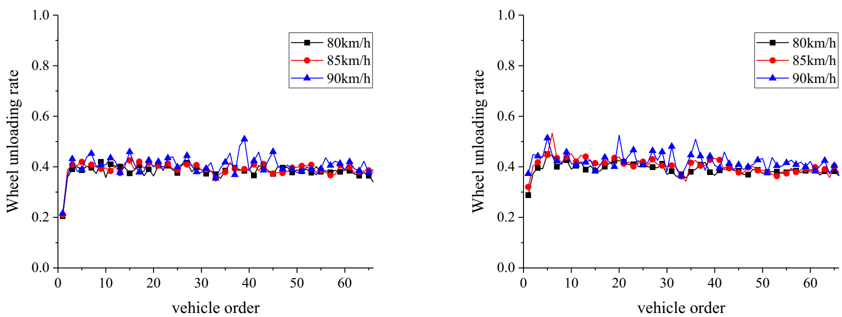
(a) Straight railway (b) Curved railway

Figure 2. The maximum lateral wheelset force while marshalling vehicles without braking function



(a) Straight railway (b) Curved railway

Figure 3. The maximum derailment coefficient while marshalling vehicles without braking function



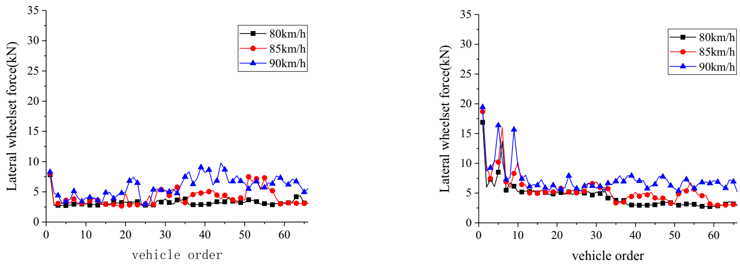
(a) Straight railway (b) Curved railway

Figure 4. The maximum wheel unloading rates while marshalling vehicles without braking function

It also can be seen, as the initial braking speed increases, the dynamic index values increase, when braking on a curve, the lateral wheelset force, derailment coefficient, wheel unloading rate and other indicators are greater than which braking on a straight line. And the lateral wheelset force and derailment coefficient are greater than other positions when the vehicles without braking function is located at the head of the train.

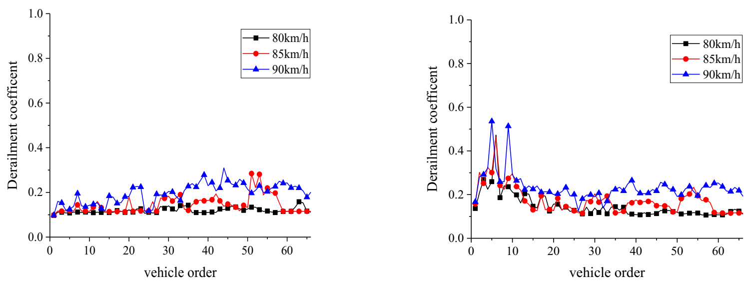
4.2. Safety Performance of Vehicles with Braking Function

The safety calculation results of the vehicles with braking function are shown in Figure 5-Figure 7. From the results, it can be seen that under the condition of straight and curved lines, with the initial brake speed of 80 km/h, 85 km/h, and 90 km/h under service braking, the lateral wheelset force, the derailment coefficient and the wheel unloading rate all meet the standard requirements, and as the initial braking speed increases, the dynamic index values increase, when braking on a curve, the lateral wheelset force, derailment coefficient, wheel unloading rate and other indicators are greater than which braking on a straight line. And compared with the situation when the vehicles without braking function are formed at positions 2, 33, 34, and 66 in the train, there is no significant difference in the safety of the vehicles without braking function and the entire empty freight train.



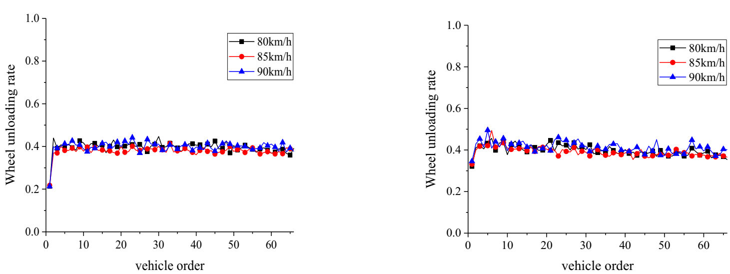
(a) Straight railway (b) Curved railway

Figure 5. The maximum lateral wheelset force of normal vehicle



(a) Straight railway (b) Curved railway

Figure 6. The maximum derailment coefficient of normal vehicle



(a) Straight railway (b) Curved railway

Figure 7. The maximum wheel unloading rates of normal vehicle

5. Conclusions

By analyzing the dynamic safety of the vehicles without braking function under the service braking state, when it is marshalling in different positions of the train, and compared with the condition of train of normal vehicles, it shows that:

(1) As the initial braking speed increases, safety indicators such as lateral wheelset force, derailment coefficient, and wheel unloading rate also increase, but the increase is small.

(2) When braking on a curve railway, safety indicators such as lateral wheelset force, derailment coefficient, and wheel unloading rate are greater than on straight line;

(3) Whether there are vehicles without braking function in the train or not, the safety performance is not much different, and all meet the requirements of GB5599-2019. The safety performance of the vehicles without braking function is not significantly different from that of the normal vehicles. when the vehicles without braking function is located at the head of the train, the lateral force and derailment coefficient are slightly larger than those in other parts, when the vehicles without braking function is located in the middle and rear of the train, the dynamic performance is not much different.

Acknowledgement

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