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Lower Cross-Braced Truck and Swing Motion Truck Have Different Effect on Freight Car Dynamics Performance

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Abstract

There are two major types of trucks for freight car in Chinese railroad. One is the lower cross-braced truck; the other is the swing motion truck. To evaluate the different performance, diamond resistant rigidity of the lower cross-braced truck and the lateral stiffness of the swing motion truck are analyzed. To simulate the dynamics performance of the swing motion truck, an equivalent lateral stiffness is calculated. Then it is modeled as a lateral spring between side frames and bolstered to simulate the swing. After that, two typical freight cars' models which use the two types of trucks are built in SIMPACK. The L/V Ratio and Wheel Load Reduction Ratio are chosen for evaluating running safety of the freight car. The simulation results are compared and they prove that the impact force between wheel and rail when the car passing curve can be reduced effectively as the swing motion truck has a better lateral flexible. Therefore, it has a lower L/V ratio under the same running and loading condition. However, the swing leads a larger lateral displacement of the car-body, so the gravity center of loaded car has a larger lateral displacement than the car with lower cross-braced truck; which results to a larger Wheel Load Reduction Ratio.

Keywords: *truck; dynamics simulation; freight car; L/V Ratio; Wheel Load Reduction Ratio*

1. Introduction

The freight car of Chinese railroad has a fast development from 1980s [1]. Axle load is raised from 11t to 23t during the last sixty years. The 25t axle load truck has been used on the new types of freight car, so, freight car capacity can reach 70t and some heavy haul car's capacity is 76t or 80t. The designed speed of the new freight car is 120km/h. The speed increased trucks are all three-piece in China, and they have two types, one is lower cross-braced truck; the other is swing motion truck.

The running safety of railroad freight car can be evaluated by L/V Ratio and Wheel Load Reduction Ratio, the L/V Ratio is calculated from the forces of one wheel, and the Wheel Load Reduction Ratio is calculated from the forces of one wheel-set. So, under the same running condition and loading condition, the Ratios may be different as they are calculated by different forces. Reference [2-4] analysis the L/V Ratio and Wheel Load Reduction Ratio when the freight car with two kinds of trucks running through a curve. But there is rarely investigation about the relations between different types of trucks and safety ratios when car passing a curve.

This study investigates the dynamic response of the lower cross-braced truck and swing motion truck when the freight car running with the same running condition and loading condition. The cars are simulated by using multi-body dynamic software SIMPACK. The dynamic effect of different types of trucks is studied by the models when freight car passing a curve.

2. Topology Frameworks Analysis for Freight Cars with Different Trucks

The gondola car C70 and C70H are taken as analysis examples, C70 uses K6 which is lower cross-braced truck, and C70H uses K5 which is swing motion truck. The topology frameworks of the cars need to be analyzed before building virtual models in SIMPACK.

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2.1.Topology Frameworks Analysis of Freight Car System

The gondola car system is composed of car-body and two trucks. The car-body includes empty car-body and freight loaded on it, and the truck includes bolster, side frames, axle boxes and wheel sets, etc. The interaction of the components is caused by springs, friction, moment, joints, etc. Figure1 & Figure2 show the topology frameworks of C70 & C70H based on the structure of two types of trucks.

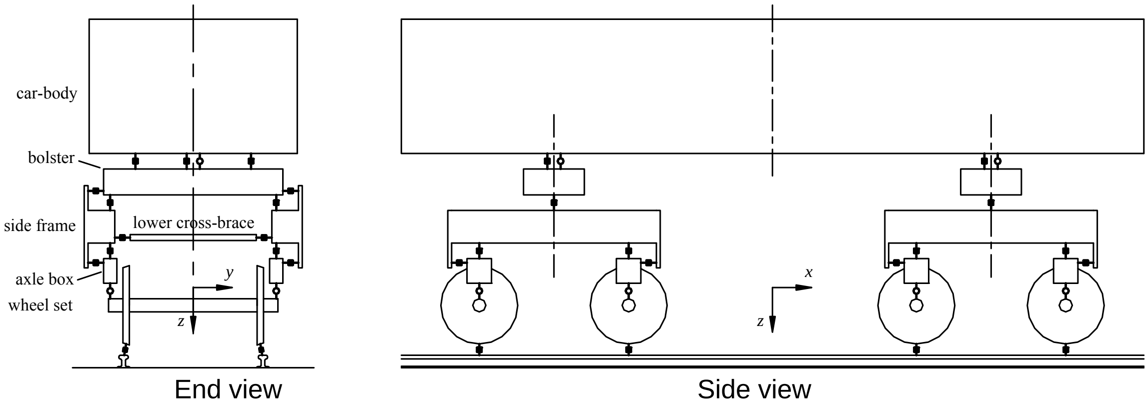

Figure 1. C70 gondola car system topology graph

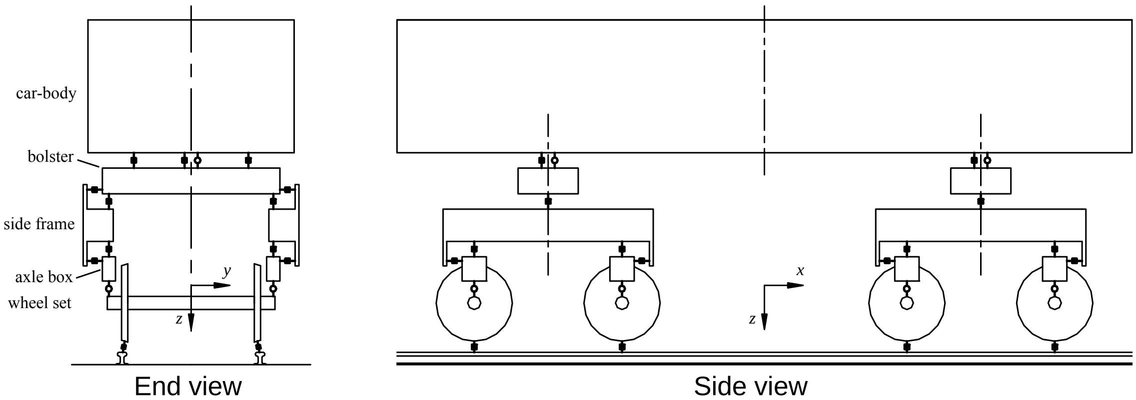

Figure 2. C70H gondola car system topology graph

In Figure1 & Figure2, “┿” represents the forces and moments between the components of vehicle system, “⚲” represents the joints between the components of vehicle system. Forces between side frame and wheel set are transmitted by axle boxes, and two axle boxes are set to the ends of axle with rotational joint.

2.2. Freight Cars Virtual Models Building

The cars virtual models are built in SIMPACK based on the topology graphs and the nonlinear forces between car components [5-7]. The virtual models are formed by managing the 3D shape, joints and forces.

2.2.1. 3D Shape

All the components are considered as rigid bodies in the model. The 3D shapes of car body, side frames, bolsters and axle boxes are simplified as key factors, which consist of gravity center, mass and moment of inertia in SIMPACK.

2.2.2. Joints

The topology framework has two types of joints. One is the z axis rotational joint between bolster and car-body. The other is the y axis rotational joint between axle box and wheel set.

2.2.3. Forces

The input of forces in SIMPACK includes choosing force element and nonlinear expression. For this study, the forces in Figure1 and Figure2 that have been used in SIMPACK are center plate friction moment; side bearing friction; vertical and lateral forces between bolster and side frame; vertical, lateral and longitudinal forces between side frame and axle box; forces between wheel and rail. Two methods are used to express the forces:

(1) There are vertical springs that have large stiffness between up and down center plates and side bearings. The friction can be calculated by friction coefficient and vertical spring force.

(2) Other nonlinear forces are expressed as value and relative displacement in SIMPACK. K5 truck is special; it needs to calculate the lateral force that is equal to a spring as the swing structural [8].

3. Lateral Force Between Bolster and Side-Frame of K5 Truck

There is a spring plank between two side frames in K5 truck, and the bolster spring forces are transmitted to side frames by it. The joints that between spring plank and side frames, between side frame pedestal and bearing adapter are all rotational joints. So, the two side frames can swing at the same time. The maximum angle is 3 degree [8]. Figure3 shows the swing structural of K5.

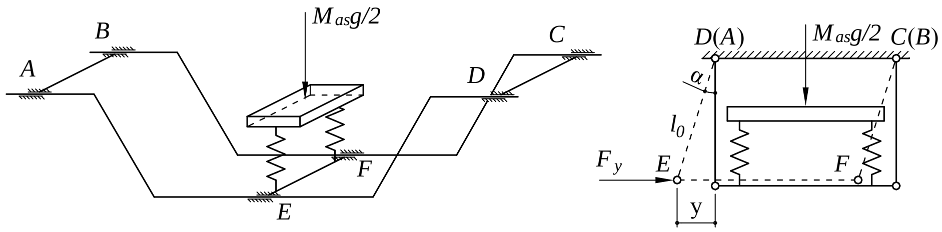

Figure 3. Diagram of side frames for swing motion truck

A~ D are the joints between side frame pedestal and bearing adapter; E, F are the joints between spring plank and side frames. The dot line in Figure3 (b) is the position when the side frames swing to left. Assume that it is the structural balance position, so the equation can be derived:

$$F_y = \frac{M_{as}g}{4} \cdot \tan\alpha \approx \frac{M_{as}g}{4} \cdot \sin\alpha = \frac{M_{as}g}{4} \cdot \frac{y}{l_0} = \frac{M_{as}g}{4l_0} \cdot y \qquad (1)$$

define $\frac{M_{as}g}{4l_0} = K_y^{'}$, then equation (1) is:

$$F_y = K_y^{'} \cdot y \qquad (2)$$

Where, M_{as} is the sprung mass of car / kg; α is the swing angle of side frame / degree; y is the lateral displacement of E, F / m; l_0 is the vertical distance of two swing points / m; $K_y^{'}$ is the calculated stiffness.

The swing motion of side frame is equal to a spring which has lateral stiffness. When the swing angle of side frame is less than 3 degree, the spring stiffness is the serial of bolster spring lateral stiffness and the calculated stiffness of side frame swing motion. It is the first step lateral stiffness,

$$K_S = \frac{K_y \cdot K_y^{'}}{K_y + K_y^{'}} \qquad (3)$$

Where, K_S is the serial lateral stiffness (one side) / N·m-1; K_y is the bolster spring lateral stiffness (one side) / N·m-1.

There will be only lateral stiffness of bolster spring when the swing angle of side-frame is 3 degree; it is the second step lateral stiffness which is K_y. After that, if the bolster keeps moving lateral, the bolster block will contact the spring plank eventually, which is rigid contact. It can be expressed as a high stiffness spring. A table is built includes the three steps of lateral displacement and force in the virtual model. Figure4 demonstrates lateral force characteristic curve for side frame and bolster of K5.

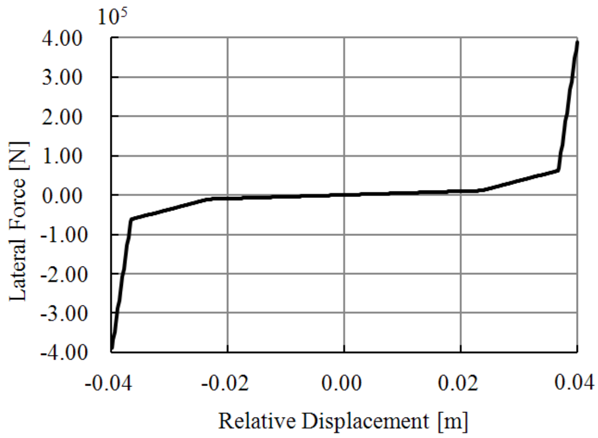

Figure 4. Lateral force characteristic curve for K5

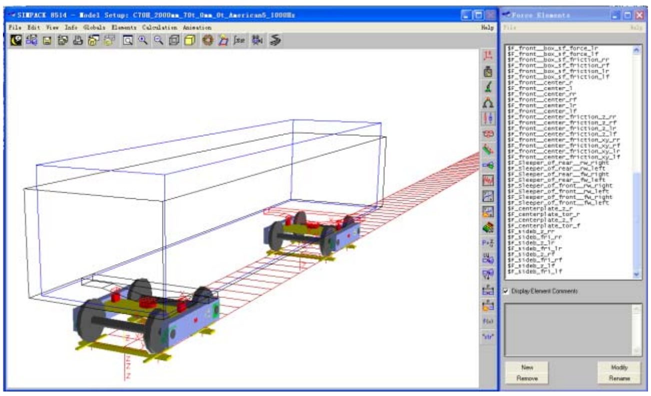

Figure 5. Virtual gondola car system model interface

The virtual gondola car system model is built by the combination of components, joints and force elements (see Figure 5). The virtual model includes twenty rigid bodies, one car body, freight, two bolsters, four side frames, eight axle boxes and four wheel sets. There are sixty-nine force elements based on the nonlinear relations.

4. Running Condition and Loading Condition

Four running conditions are set for simulation according to the Code for Design of Railway Line [9]. The four lines are the First Grade track of Chinese railroad and use AAR5 track irregularity, as there is not track irregularity power spectrum density for the First Grade track in China, and the permit running velocity of the First Grade track is almost the same as AAR5 [10] [11]. Table 1 shows the running conditions. The car passes the curves with balance speed.

Table 1. Running conditions

Curve Radius/m	Super elevation/mm	Spiral Curve/m	Balance Speed/km·h^{-1}
1600	90	190	110
1200	100	190	100
800	90	180	80
600	110	120	75

All the virtual models use the same load condition: Full load 70t, the center of gravity of the freight is on the center of car body, and the height of center of gravity of loaded car is 2000 mm.

5. Simulation Results

The sampling rate is 100Hz during simulation to ensure the precision and efficiency. Figure 6 and Figure7 show the simulation results of the L/V Ratio and Wheel Load Reduction Ratio when the models pass different curves. C70 gondola car which uses the lower cross-braced truck has higher L/V Ratio, but C70H gondola car which uses the swing motion truck has the higher Wheel Load Reduction Ratio. The lower cross-braced truck has higher diamond resistant rigidity to reduce hunting, but the attack angle and lateral force to rail are greater when the truck passing a curve. It leads to higher L/V Ratio. The swing motion truck has smaller lateral stiffness which leads to a larger lateral displacement of car body, so the center of gravity of loaded car has a larger lateral displacement and result in a larger wheel load reduction.

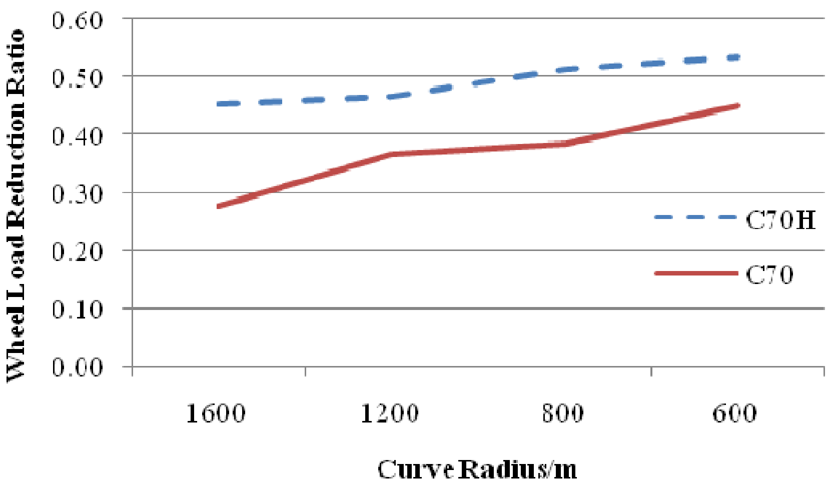

Figure 6. L/V Ratio of different curves

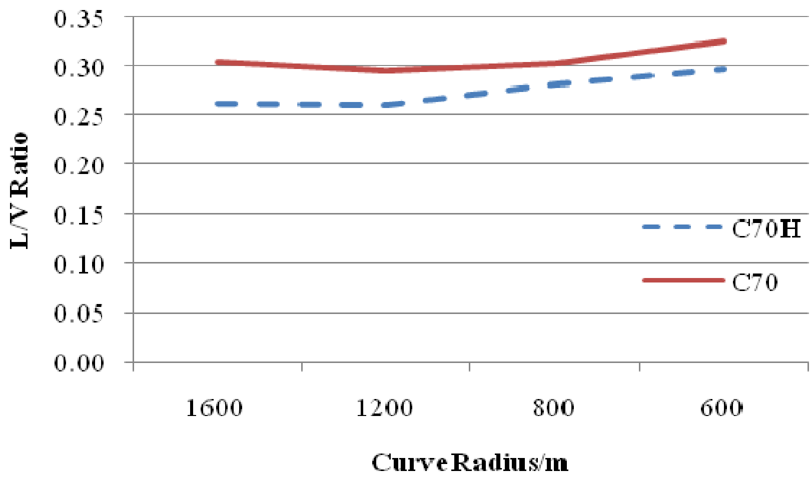

Figure 7. Wheel Load Reduction Ratio of different curves

6. Conclusion

In this work, the gondola cars C70 and C70H's topology frameworks are studied and virtual models are built in SIMPACK. The K5 swing motion truck's lateral force is calculated equivalent to a spring which has three steps of stiffness.

The simulation is conducted under the same loading condition but four different running conditions. The simulation results indicate that C70 gondola car which uses the lower cross-braced truck has higher L/V Ratio, but C70H gondola car which uses the swing motion truck has higher Wheel Load Reduction Ratio under same condition.

References

[1] Yu Shiming, Yang Danhu, Wang Wujian. *Survey on development of railway freight cars in our country*. Rolling Stock. 2006; 44: 9-13.
[2] Ham YS. *Measuring and analysis of derailment coefficients of swing motion bogie for railway freight car*. Proceedings of the KSPE Autumn Conference. 2003; 130-133.
[3] Beom-Gyu Eom, Hi Sung Lee. Assessment of running safety of railway vehicles using multibody dynamics. *International Journal of Precision Engineering and Manufacturing*. 2010; 11(2): 315-320.
[4] ChenLei, WangXinrui. Analysis on the dynamics performance of the freight car negotiating the small radius curve at low speed. *China Railway Science*. 2009; 30(6): 84-90.
[5] Miao Bingrong, Fang Xianghua, Fu Xiutong. *SIMPACK dynamics analysis tutorial*. Press of Southwest Jiaotong University, Chengdu, 2008.
[6] Miao Bingrong, Luo Ren, Yang Guangwu, et al. *SIMPACK dynamics analysis advanced tutorial*. Press of Southwest Jiaotong University, Chengdu, 2010.
[7] Chen Chao, Han Mei, Zhang Liyuan, et al. Study of reasonable height of turning rack for goods transported by five wagons based on SIMPACK. *Journal of System Simulation*. 2010; 22: 3016-3019.
[8] Yan Junmao, Fu Maohai. *Vehicle engineering*. China Railway Publishing House, Beijing. 2008.
[9] China's Ministry of Railway. *Code for Design of Railway Line*. GB50090-99. 1999.
[10] Han Mei. *Study on theory and application of railway out-of-gauge goods transport*. Beijing Jiaotong University, Beijing. 2006.
[11] Luo Zhen, Zhai Wanming, et al. Dynamics Model of Slab Track Subjected to Moving Vehicle and Its Verification. *Journal of the China Railway Society*. 2010; 32(4): 70-73.