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Influences of Suspended Equipment under Car Body on High-speed Train Ride Quality

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Abstract

A vertical dynamics model of rigid-flexible coupling railway vehicle including suspended device under chassis is built. Using this model, the influences of devices suspending methods on ride quality of high-speed train are analyzed with the covariance method. Results show that the reasonable parameters of the equipments, which are used to suspend devices under car body, can effectively suppress the vibration of the flexible car body. And the suspending equipment stiffness dominates in the anti-vibration effects. Devices with elastic suspending would better be close to the centre of car body and the bigger the device mass is, the better the ride quality of the car body centre will be achieved. The optimal static deflection point of elastic suspending equipment will change and fluctuate with the change of the vehicle running speed. With the static deflection of about 6mm, the high-speed train in this paper will achieve better ride quality and the vibration of suspended device will be acceptable.

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Keywords: High-speed Train, Suspended Equipment, Ride Qaulity

1. Introduction

With the lightweight design of car body and the improvement of velocity, the issue of high-speed train car body vibration has been concerned widespread[1-4]. High-speed trains whose traction convertor, auxiliary convertor and other devices are mounted directly under car body, use the distributed power technology. Some devices weight more than 3 tons and also have their own vibration excitation sources. In order to decrease the effects of device under car body on the ride quality of railway vehicles as well as

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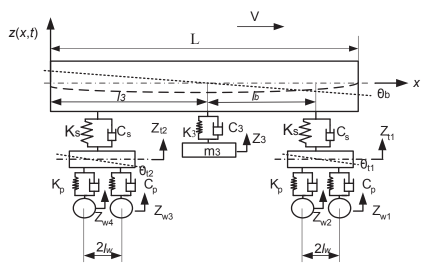
to avoid the device spreading and motivating the noise of passenger compartment vibration, elastic elements are mostly applied to suspend the devices under car body. At the same time, in order to provide the choice of suspending methods and the basis of parameters design, a vertical model of railway passenger vehicle is built in this paper which includes suspended devices under chassis and applied the covariance method[4,5]to analyze influences of mass, position and parameters of suspended device on vehicle ride quality and the effects of suspended device itself on its vibration.

2. Vertical model of railway passenger vehicle with flexible carbody

A vertical model of railway passenger vehicles which includes suspended device under chassis is shown in Fig .1. The model contains a car body, 2 bogies and 4 wheelsets. Each bogie has the same freedoms with the carbody rigid modes, i.e. bounce and pitch modes and it is supposed that the wheelsets are right close to rails. To research easily, this paper supposes the car body being simplified as a uniform Euler-Bernoulli beam and defines upward shift as positive and the direction of the car body movement as positive x-coordinate. The distance between suspended device position and car body end is assumed as l_3. The coordination definition and some dimensions in the whole model are shown in Fig.1. The displacement of flexible car body vibration is $z(x,t)$, in which x is the coordinate being apart away from the most left position in the carbody and t is time variable; θ_b is car body pitch displacement, z_{t1} , z_{t1} , θ_{t1} and θ_{t2} is the vertical and pitch displacement of bogie 1, 2 respectively; $z_{w1} \sim z_{w4}$ is the vertical track irregularity excitation of the 1st to 4th wheelsets respectively. The meanings of other symbols, whose original values can be found in the literature[6], show in the table 1.



Pitch Displacement Bounce Displacement Carbody flexible Deflection

Fig.1 Vertical Model of Railway Passenger Vehicle with Device Suspended under Chassis

Regarding the carbody as an elastic uniform Euler-Bernoulli beam, this paper supposes vertical carbody vibration displacement being $z(x,t)$ and applies variable separation method. When the rigid modes are included with the flexible modes in $z(x,t)$, the first mode of the carbody is chosen as bounce of rigid mode and its shape function is taken as $Y_1(x)=1$. The second mode is pitch and its shape function is $Y_2(x)=L/2-x$ accordingly under the coordinate definition as in Fig. 1. When n modes are considered, the vertical displacement [5, 6] of carbody can be written as:

$$z(x,t) = z_b(t) + (\frac{L}{2} - x)\theta_b(t) + \sum_{i=3}^{n} Y_i(x) q_i(t) \tag{1}$$

In above equation: $z_b(t)$ and $\theta_b(t)$ is modal the coordinate of bounce and pitch modal respectively; $Y_i(x)$ and $q_i(t)$ is the shape function of flexible carbody vibration and the modal coordinate separately. The establishment of the model function refers to the literature[5]. When suspended device is consolidated under the carbody, the functions based on the same principle can be deduced.

Table 1. Parameters meanings of railway vehicle model

Parameter meaning	Parameter symbol	Parameter meaning	Parameter symbol
Mass of car body	m_b	Primary spring stiffness(per axle)	k_p
Car body pitch inertia	I_b	Primary damping (per axle)	c_p
Mass of bogie	m_t	Half of two bogie centers distance	l_b
Bogie pitch inertia	I_t	Half of bogie wheel base	l_w
Secondary spring stiffness(per bogie)	k_s	Carbody length	L
Secondary damping(per bogie)	c_s	Mass of suspended equipment	m_3
Equipment suspended stiffness	k_3	Equipment suspended damping	c_3

3. Influences of elastic suspension on vehicle ride quality

Because rubber parts are compact and they can provide three degrees of stiffness and certain damping, rubber components are often selected for suspending devices under railway vehicle carbody. The damping ratio of rubber component should be between 0.075 and 0.02, which should not be too big. Otherwise rubber will easily become heated and thus age and creep quickly. Rubber static and dynamic stiffness ratio varies with temperature, vibration frequency and formula. The ratio is generally between 1.2 and 2.8. Because static deflection is the design basis of the stiffness and the number of rubber suspended connections, this paper applies suspended static deflection as parameters to analyze the influences of the elastic suspended method on the vibration of the vehicle and of devices.

The parameters of high-speed train in the literature[6] are used in this paper. The track irregularity utilizes high-speed spectral[7]. Only the top 2 flexible vibration order modals are considered in this model. The covariance method[4, 5] is used to calculate the vehicle ride quality and the vibration of suspended devices whose results show in Fig.2-4. In Fig.2 and Fig.3, the suspended material is rubber elastic; the static and dynamic stiffness ratio is 1.4; the damping ratio is 10% and 15% respectively and the mass of suspended equipments is 3000kg. According to Fig.2 and Fig.3, the main factor that influences the vertical vehicle ride quality is the stiffness of the suspended equipment. The damping ratio can slightly broaden the good stability range. When the vertical vehicle vibration frequency is 12.3 Hz, the device is under the carbody center and the damping ratio is 15% , the equipment static deflection optimization range is 4 - 10mm, 5-9mm considering the centre of car body and the top of bogie respectively. From Fig.4, it can be seen that when suspension is 8m away from the carbody end, the suspended equipment static deflection optimal range is 4-6mm for the carbody centre and is around 4mm for the top of bogie. From Fig.2-4, it also can be seen that when the elastic suspension is located under the carbody centre, the ride quality is better than that located on the distance of 8m from the car body end.

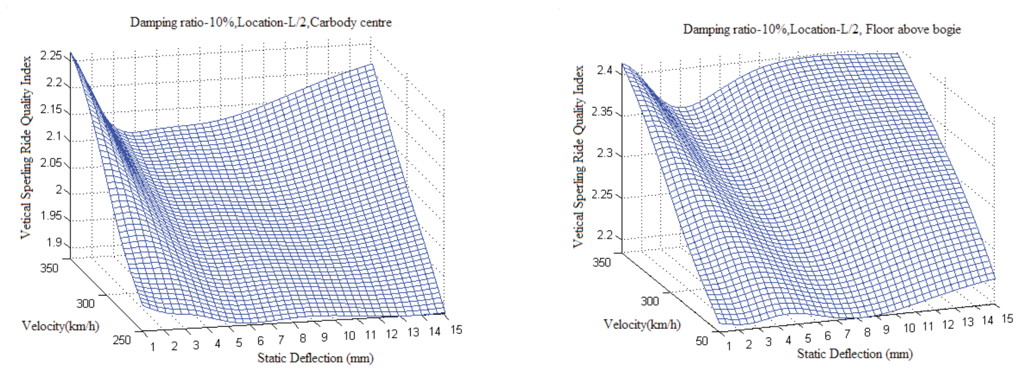


Fig.2 (a) Vertical ride quality of the car body centre (b) Vertical ride quality above the bogie

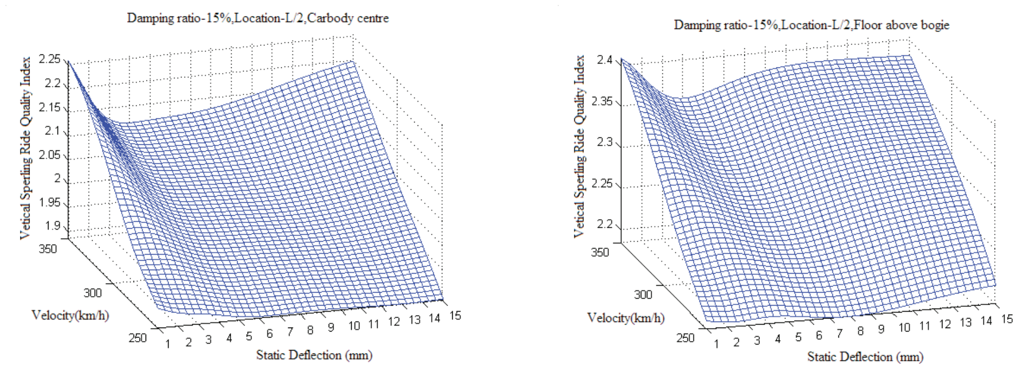


Fig.3 (a) Vertical ride quality of the car body centre (b) Vertical ride quality above the bogie

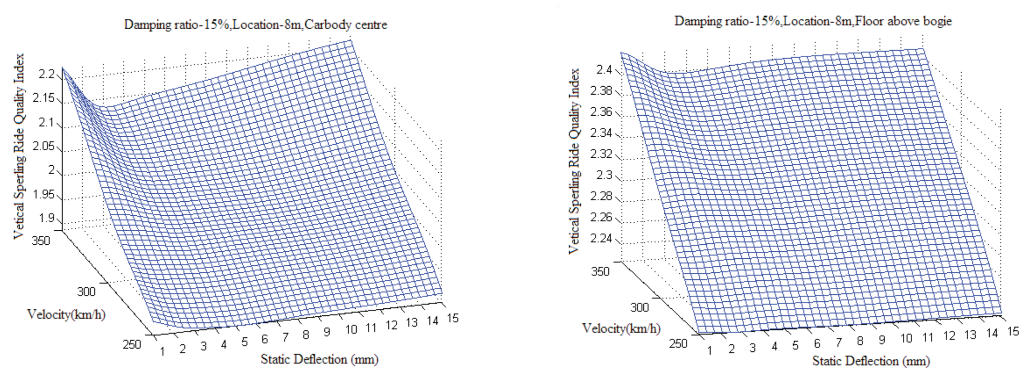


Fig.4 (a) Vertical ride quality of the carbody centre (b) Vertical ride quality above the bogie

Fig.5 and Fig.6 show the vibration acceleration RMS value calculation results of the car body and of the suspended device on condition of a elastic suspended equipment, the dynamic and static stiffness ratio of 1.4, and the damping ratio of 15%,. In Fig. 5 and Fig.6, suspended equipment is put under the car body centre and under the place which is 8m away from the car body end respectively. When the static deflection of suspended equipment is low, the vibration of the car body is very strong. The static deflection of the lowest vibrating spot is displaced from 10mm to 6mm when the speed changes from 250km/h to 350km/h. Therefore, the static deflection should be controlled in the range from 4mm to 6mm considering the lowest vibrating spot above the car body. Although the vibrating RMS peak value is lower when the damping ratio is 15% compared with 10%, the overall trend is consistent.

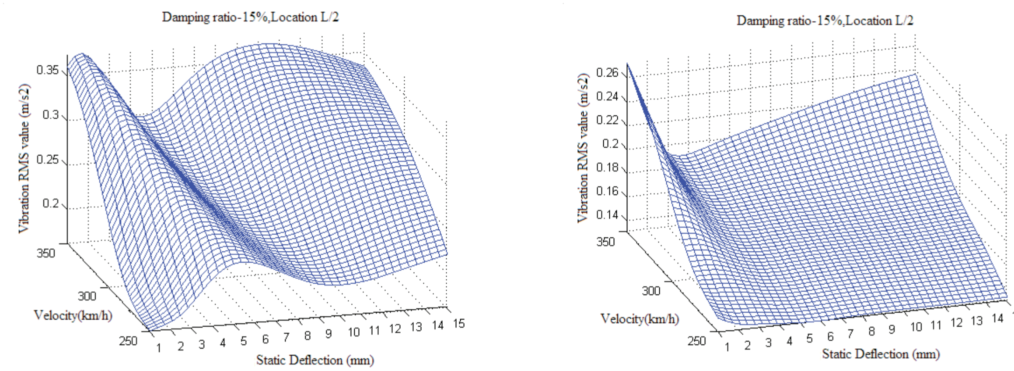


Fig.5 (a) Vibration RMS value of device (b) Vibration RMS value above the carbody

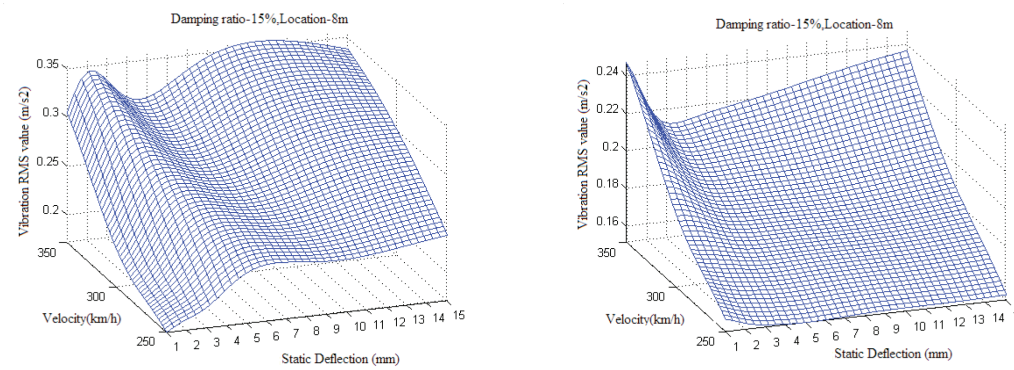


Fig.6 (a) Vibration RMS value of device (b) Vibration RMS value above the car body

According to the comparison above, if the dynamic and static stiffness ratio is 1.4 and the elastic suspended equipment static deflection is about 6mm, the high-speed train analyzed in this paper will get satisfactory results. Fig.7 shows the influences of suspended position on the car body vibration when the static deflection of the elastic suspended equipment is 6mm. It is obvious that when the mass of suspended device is 3000kg and the location is closer to the car body centre, the ride qualities of the car body centre and of the bogie top are both better.

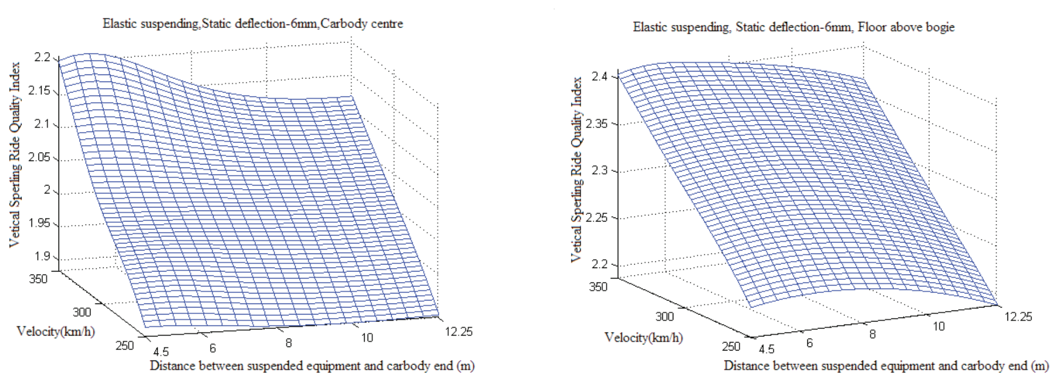


Fig.7 (a) Relations between the vertical ride quality of carbody center and the suspended position (b) Relations between the vetical ride quality above bogie and the suspended position

Fig.8 shows the relations between the ride quality and the suspended device mass. It is obvious that when elastic suspension is located under the car body centre, the Sperling index of the car body centre decreases with the increase of the mass of the device and the Sperling index of the bogie top changes slightly. At the speed of 300km/h and above, the increase of the device mass can result in decreasing the Sperling index of the bogie top little.

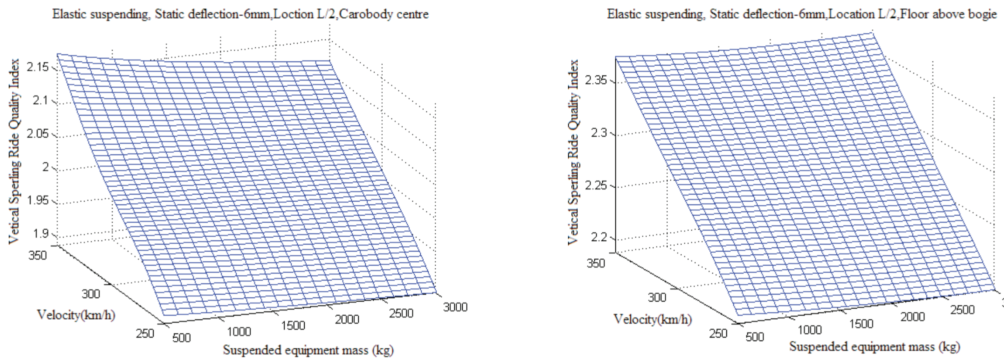


Fig.8 (a) Relations between the vertical ride quality of carbody center and the suspended device mass (b) Relations between the vetical ride quality above bogie and the suspended device mass

4. Conclusions

This paper analyzes the influences of device suspended methods on ride quality of high-speed train and suspended device vibration. The results show that the vibration of flexible carbody and of suspended device can be suppressed with reasonable parameters of suspended equipment, and its stiffness dominates the anti-vibration effects of device. The suspended device with elastic connection should be put close to the car body centre and the bigger the device mass is, the better the ride quality of car body centre is. Results also show that the optimal static deflection of elastic suspended equipment will change with the running speed. For the model studied in this paper, if the static deflection of suspended equipment is about 6mm, the ride quality will be achieved better and the vibration of equipment is also acceptable.

References

[1] Jing Zeng, Ren Luo. Vibration analysis of Railway Passenger Car Systems by Considering Flexible Carbody Effect[J]. Journal of the China Railway Society, 2007, 29(6):19-25. (In Chinese)

[2] Foo E, Goodall R M. Active Suspension Control of Flexible-bodied Railway Vehicle Using Electro-hydraulic and Electromagnetic Actuators[J]. Control Engineering Practice, 2000, 8: 507-518

[3] Schandl G, Lungner P, Benatzky C, Kozek M, et al. Comfort enhancement by an active vibration reduction system for a flexible railway car body[J]. Vehicle System Dynamics, 2007, 45(9):835-847.

[4] J Zhou, R Goodall, L Ren, et al. Influences of car body vertical flexibility on ride quality of passenger railway vehicles[J]. Proceeding of the institution of mechanical engineers, Part F: Journal of Rail and Rapid Transit, 2009, 223(5)：461-471.

[5] J Zhou, G Shen， H Zhang， et al. Application of modal parameters on ride quality improvement of railway vehicles[J]. Vehicle System Dynamics， 2008， 46(1)： 629–641.

[6] Jinsong Zhou, Wei Zhang, Wenjing Sun, Lihui Ren. Vibration Reduction Analysis of the Dynamic Vibration Absorber on the Flexible Car Body of Railway Vehicles[J]. China Railway Science, 2009, 30(3), pp86-90. (In Chinese)

[7] Futian Wang, Jin-song, Zhou Lihui Ren. Analysis on track spectrum density for dynamic simulations of high speed vehicles[J], Journal of the China Railway Society. 2002, 24(5):21-27. (In Chinese)