Effect of Transverse Irregularity of Maglev Track on Train Vibration

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Abstract: Aiming at the analysis of the influence of lateral irregularity of Maglev track, considering the force produced by electromagnetic contact medium, combined with the dynamic characteristics of track beam and maglev locomotive, the dynamic joint modeling is completed. Under three different deviation magnitudes, the analysis shows that the lateral acceleration and the mean deviation of clearance increase, which affects the comfort degree. In the later maintenance of track, efforts should be made to reduce the degree of lateral irregularity.

1. Introduction

As the world's largest population and the third largest country in land area, China has great potential in the long-distance passenger transport market. With the rapid development of China's economy and the continuous improvement of per capita income, the huge market has begun to emerge. Traffic congestion and exhaust pollution have become the problems facing big cities all over the world [1].

At present, the main modes of medium and long-distance traffic in China are high-speed rail and aircraft. The maximum speed of Fuxing is 350 km/h [2], and the speed of civil aviation is about 700 km/h-900 km/h. Obviously, due to the inherent wheel-to-rail constraints, there will be many problems to further improve the speed of high-speed rail operation, the most important of which is energy consumption and safety.

Maglev train is a new type of modern transportation. It combines the convenience of high-speed railway with the speed of civil aviation, and has great potential for development. Maglev train suspension is realized by electromagnetic force to avoid frictional resistance between body and track, and to avoid mechanical wear effectively. It provides traction power through linear motor, which is like high-speed railway. Each carriage can provide power, but also overcomes the limitation of traction force limited by wheel-rail adhesion in ordinary rail transit. In addition, maglev train has the advantages of low noise, small turning radius and comfortable ride. It is the only large-capacity land passenger transport system in the world that can be used for commercial operation at 400-500 kilometers per hour safely and economically. Many countries in the world have carried out or are preparing to carry out relevant engineering practices. It has been more than 10 years since China introduced high-speed magnetic levitation technology to build Shanghai Maglev Line in 2001. Millions of kilometers of unintentional operation have proved the safety and reliability of the maglev system.

Like traditional rail transit, track irregularity has many effects on the safety and comfort of maglev train in operation. Especially with the increasing operation time of Shanghai Railway, the lateral track irregularity is becoming more and more obvious, and the determination of maintenance methods and maintenance scales is becoming more and more important. The high-speed maglev train system is a multi-body dynamic system with a complex rigid flexible structure. The train runs at a speed of 430 km/h. The ride comfort and the stability of the train are two important issues in the operation of maglev train [3]. In this paper, the passenger comfort and the stability of suspension guidance system under the condition of track lateral irregularity are studied by multi-body dynamics simulation of train.

Based on the prototype of Shanghai Maglev Demonstration Line, the multi-body dynamic simulation model of the whole maglev train system is established in this paper. The dynamic simulation analysis of maglev train under the action of track irregularity is carried out to study the vibration of the vehicle body and the stability of the suspension guidance system. Through vehicle dynamics modeling, electromagnetic contact modeling and track beam modeling, and adding irregularity detection data, the model is analyzed jointly. Finally, the overall dynamic performance of the vehicle is summarized, including ride comfort and stability of the suspension system.

The results of dynamic simulation analysis in this paper can provide some reference for the study of the dynamic principle of maglev train and the control standard of track irregularity.

2. Modeling of HIGH-SPEED Maglev Train System

2.1 Vehicle Modeling

Vehicles mainly include carriages, suspension frames and electromagnets and suspension systems installed on them. Because aluminium alloy carriage is used in the design stage, the lightweight design is realized and the carriage has certain flexibility. Each vehicle is equipped with four suspension frames. Each suspension frame consists of four suspension frames and corresponding crossbeams and longitudinal beams. The suspension frame is composed of suspension arm and connecting parts. The secondary suspension system components include air spring support, air spring and Y-direction spring, etc. The pendulum structure ensures the matching between the carriage and the suspension frame and provides lateral restraint. Air spring improves vertical stiffness and damping. Y-direction positioning spring or auxiliary spring provides lateral damping, and metal rubber parts between bolsters achieve roll-proof stability [9].

The train model in this paper is composed of several different sections of vehicles. The rotational stiffness of the joints between the vehicles and their parts needs to be estimated in detail according to the experimental and simulation results. To simplify the analysis process, the following assumptions are made for vehicle vibration:

(1) Car body, suspension frame and electromagnet are all regarded as rigid bodies, without considering their elastic deformation, and all rigid bodies vibrate in small displacement near the equilibrium position [4].

(2) The body is symmetrical about the center of mass, left and right, front and back.

(3) The spring and damping of suspension are considered linearly.

(4) The vibration along the longitudinal axis of vehicle body, running mechanism and magnet is not considered.

Thus, a total of 129 degrees of freedom for a single vehicle is shown in Table 1.

Table 1. Vehicle Freedom.

	Yaw motion	**Pitch motion**	**Lateral motion**	**Roll motion**	**Vertical motion**	**Telescopic**
Car body	ψc	θc	yc	φc	zc	
Pillow		θb	yb		zb	
Suspension rack	ψt	θt	yt	φt	zt	
Electromag-nets	ψm		ym	φm	zm	

The above degrees of freedom are deduced by vector operation, and the final train dynamics equation can be expressed as follows:

$$M_v \ddot{X}_v + C_v \dot{X}_v + K_v X_v = F_v \quad (1)$$

In the formula, M_v, C_v and K_v are respectively the mass, damping and stiffness matrices of the train system; $\ddot{X}_v$, $\dot{X}_v$ and X_v are the acceleration, velocity and displacement vectors of the degree of freedom of the vehicle; F_v is the load vector acting on the degree of freedom of the train; the vibration load of the electromagnet can be divided into suspended electromagnet floating vibration load $F_{esl(r)i}(i=1,2,\cdots,7)$, suspended electromagnet nodding vibration load $M_{esl(r)i}(i=1,2,\cdots,7)$, guided electromagnet transverse vibration load $F_{egl(r)i}(i=1,2,\cdots,7)$ and guided electromagnet. There are four kinds of vibration loads $M_{egl(r)i}(i=1,2,\cdots,7)$ for magnet shaking head.

3. Electromagnetic Contact Model

Magneto-rail relationship is the link between train and track beam, and the reasonable simulation of electromagnetic force is the key to the dynamic analysis of train-line. The relationship between the magnetic track and the active control system is closely related. A reasonable model of the relationship between the magnetic track and the active control system can be derived from the mechanism of the electromagnetic force produced by the control system.

Because of the inherent open-loop instability of the electromagnetic levitation system, the air gap must be changed in a certain error range by the closed-loop feedback control method. According to the literature, the control strategies of air gap, gap change speed and acceleration feedback can be selected.

By deriving and solving the differential equation, the electromagnetic force of the levitation and guidance control points can be expressed by the following formula:

$$F(i,c)=\frac{\mu_0 N^2 A}{4}\left(\frac{i_0+k_p\Delta c(t)+k_v\Delta\dot{\hat{z}}(t)+k_a\Delta\ddot{z}(t)}{c_0+\Delta c(t)}\right)^2 \quad (2)$$

In the formula, i_0 is the current at the equilibrium point, c_0 is the gap at the equilibrium point, $u(t)$ is the electromagnet voltage, N is the turn number of the electromagnetic coil, μ_0 is the permeability, A is the pole area, $L(x,i)$ is the electromagnet inductance, $i(t)$ is the electromagnet current, R is the coil resistance, $c(t)$ is the suspension gap, m is the suspension mass, $f_d(t)$ is the external interference force, $z(t)$ is the displacement of the electromagnet to the absolute reference plane, k_p, k_v, k_a are the position, speed and acceleration, respectively. Feedback coefficient.

4. Track beam model

As the research object, the track beam structure is generally composed of piers, beams and other structures. Spatial model is used to analyze the lateral and vertical vibration of beam-pier system and train. To ensure the accuracy of deformation analysis, the degree of freedom should be more than five [5]. In view of the analysis methods used in the construction of Shanghai Line, ten degrees of freedom should be chosen [6] and the following assumptions should be made:

There is no relative motion between the functional parts and the track beam;

Vibration mode analysis is carried out for the whole pier-beam system. It is assumed that the vibration mode of the pier top joint is identical with that of the joint on the corresponding track beam, and the vibration mode values between the nodes are determined by Lagrange interpolation;

Ignoring the deformation of cross section of beam and pier in the course of vibration;

Neglecting the influence of temperature stress caused by sunshine and heat transfer [7].

Based on the above assumptions, the beam-pier system is discretized into a three-dimensional finite element model, and the motion equation of the beam-pier system joint can be expressed as:

$$M\ddot{X}_b + C\dot{X}_b + KX_b = F_b \quad (3)$$

In the formula, Mb, Cb and Kb are respectively the mass, damping and stiffness matrices of the track beam pier system. $\ddot{X}_b$, $\dot{X}_b$ and X_b are the acceleration, velocity and displacement vectors of the beam-pier system node respectively. F_b is the force transmitted from the maglev train running on the track beam Vibration of any point on any section of beam-pier system can be determined by transverse displacement Y_b, vertical displacement Z_b and torsion θ_b corresponding to the shear center of the section.

5. Dynamics simulation

5.1 Calculation condition

Combining with the actual beam end deviation, the lateral irregularity condition shown in Fig. 1 shows that the bearing offset occurred around 180 meters, and the deviation ranges are 3 mm, 5 mm and 7 mm, respectively. To simulate the most disadvantageous working conditions, the calculation speed is 431 km/h.

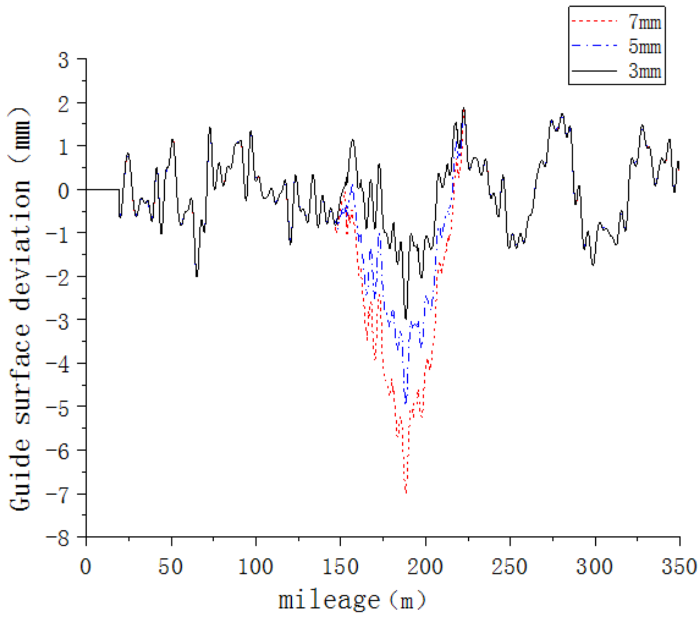


Figure 1. Changes in lateral irregularities.

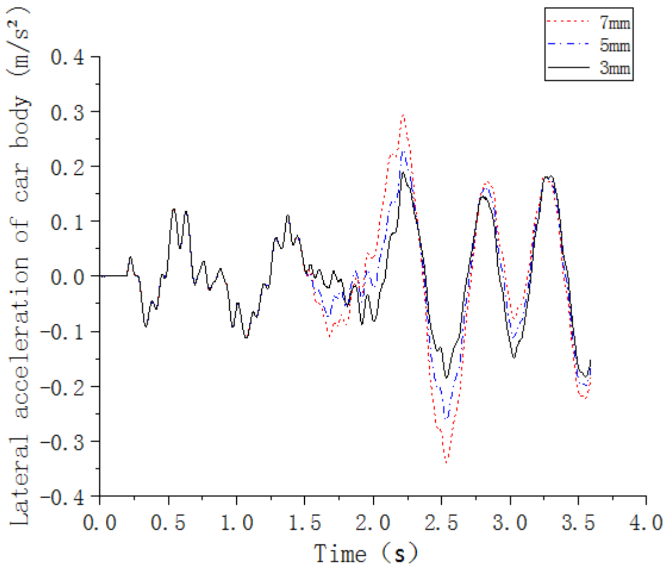
6. Result analysis

Through dynamic simulation, the lateral acceleration and clearance changes of the car body under different deviation amplitudes are calculated. As shown in Figure 2, it can be seen from the figure that in the area where the deviation amplitude changes, the lateral vibration of the car body increases obviously, and the clearance also changes. It can be seen from the curve that the lateral acceleration and clearance of the car body increase rapidly with the increase of deviation; after 1.0 seconds, the influence of different deviations becomes prominent; within the range of 0-7 mm deviation, the guiding clearance always increases rapidly. In this paper, the comfort evaluation criterion is ISO2631[8], which is the standard of International Standard Organization (ISO). Its comfort level is classified as follows:

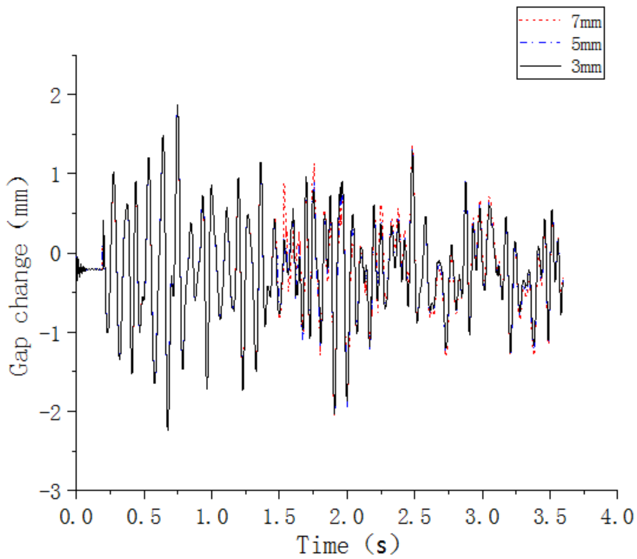
Table 2. Classification of Comfort Level.

Comfort Level	Vibration acceleration magnitude (m/s2)	Comfort Description
1	<0.315	No uncomfortable
2	0.315~0.63	Mildly uncomfortable
3	0.5~1.0	A little uncomfortable
4	0.8~1.6	Discomfort
5	1.25~2.5	Very uncomfortable
6	>2	Extremely uncomfortable

If 0.315m/s2 is taken as the control index of lateral comfort, the magnitude of lateral irregularity should not exceed 5mm.



(a)Changes of Lateral Acceleration and Clearance of Car Body under Different Deviation Amplitude Conditions.



(b)Changes of Lateral Acceleration and Clearance of Car Body under Different Deviation Amplitude Conditions

Figure 2. Dynamic Response Law under Different Guiding Surface Deviation Conditions.

Table 3. Relationships between Guiding Surface Deviation and Train Operation Related Indicators.

deviation	Maximum acceleration of car body	Maximum gap variation
	m/s2	mm
3mm	0.19	1.9
5mm	0.27	2.3
7mm	0.34	2.3

7. Conclusion

The dynamic characteristics of track beam and maglev locomotive should be considered in the modeling of high-speed maglev system, and the electromagnetic contact medium should be considered, and the simulation of electromagnetic force is the key to the dynamic analysis of locomotive line.

Through analysis, the lateral irregularity of maglev track has a significant impact on driving performance and comfort. Therefore, it is of great significance to reduce the irregularity of maglev track through maintenance of Maglev track.

According to the dynamic simulation data, the lateral irregularity of maglev track will affect the suspension clearance, which must be paid attention to in the dynamic analysis and later maintenance.

Driving speed will also magnify the adverse effects of lateral irregularity. The influence of driving speed can be analyzed through multiple driving data samples of computer in-depth learning test line, and subsequent design and maintenance schemes can be generated.

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References

[1] Yaghoubi H, Ziari H. Development of a Maglev vehicle/guideway system interaction model and comparison of the guideway structural analysis with railway bridge structures. J Transp Eng 2011; 137:140-54.

[2] Wu Xiangming. Construction of Shanghai High Speed Maglev Demonstration Line [J]. Journal of Tongji University (Natural Science), 2002, 30(7):814-818.

[3] Zhang, L., & Huang, J. (2018). Stiffness of Coupling Connection and Bearing Support for High-Speed Maglev Guideways. Journal of Bridge Engineering, 23(9), 04018064.

[4] Yau, J. D. (2009). Response of a maglev vehicle moving on a series of guideways with differential settlement. Journal of Sound and vibration, 324(3-5), 816-831.

[5] Zhao, C. F., & Zhai, W. M. (2002). Maglev vehicle/guideway vertical random response and ride quality. Vehicle System Dynamics, 38(3), 185-210.

[6] Zhang, L., & Huang, J. (2019). Dynamic interaction analysis of the high-speed maglev vehicle/guideway system based on a field measurement and model updating method. Engineering Structures, 180, 1-17.

[7] Zhang, L., & Huang, J. (2018). Thermal effect on dynamic performance of high-speed maglev train/guideway system. STRUCTURAL ENGINEERING AND MECHANICS, 68(4), 459-473.ISO2631

[8] Wu, Xiangming and Jingyu Huang. "Guideway Structure, Maglev Demonstration Line, Shanghai." Structural engineering international 14.1 (2004): 21-23.