Coupled Vibration Simulation of High-Speed Maglev Vehicle-Track Beam

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Abstract: In the high-speed maglev transportation system, the fast running of vehicles requires high dynamic performance of the system, so it is necessary to study the dynamic coupling vibration of the high-speed maglev train-track system in depth. Based on TR08 vehicle and 24.768m pre-stressed concrete track beam of Shanghai Maglev Demonstration Line, a multi-degree-of-freedom complex vehicle-elastic track beam model is established, and its dynamic simulation and numerical simulation are carried out. The vibration acceleration response time history of vehicle body and the vibration displacement and acceleration response time history of track beam span are obtained respectively. Then the ride comfort and dynamic response of track beam are analyzed and summarized, which can provide reference for further optimization of the structure of train-rail system.

1. Introduction

With the rapid development of China's economy and the increasing demand for long-distance and fast traffic, high-speed maglev traffic has gradually been widely used. Because there is no contact between maglev train and guideway at high speed, maglev train has the advantages of high speed, energy saving, no wear and low noise compared with traditional wheel-rail traffic [1].

With the increase of the speed of high-speed maglev vehicle, the requirement of train stability is higher. In high-speed maglev transportation system, train-track beam coupling vibration is an important factor affecting the stable suspension operation of vehicles [2]. The excitation of trains will cause track vibration, and track has a great impact on ride quality and stability. How to ensure the safety of the train, passengers'comfort and the safety of the track beam structure in the process of high-speed maglev train running is an important issue in the study of high-speed maglev, which is also an important content of the study of Maglev vehicle-track beam coupling vibration [3].

In the past two decades, some simple analytical models have been proposed to study the train-track system. In this paper, a multi-body dynamic system model of maglev train with control system is established by using three-dimensional modeling software and dynamic simulation software. The coupled vibration between vehicle and track beam when maglev vehicle runs on track beam is simulated numerically. The simulation method and results can provide a train of thought for studying the mechanism and law of high-speed maglev vehicle-track coupling dynamics, and for researching the actual situation of Maglev train. At the same time, it can provide reference value for the optimization of maglev train and track structure [4-21].

2. Multi-DOF Complex Vehicle-Elastic Track Beam Model Simulation

2.1 Simulation Model

Under the dynamic simulation environment, the vibration of the vehicle and the track beam is simulated when the vehicle passes through the track beam at different speeds of 200 km/h, 300 km/h and 400 km/h. The simulation model can mainly obtain the vibration response of vehicle components, suspension guide clearance, force and deformation of elastic suspension, as well as the time history of vibration displacement and acceleration of track beam under different driving speeds. The mobile platform is shown in Figure 1.

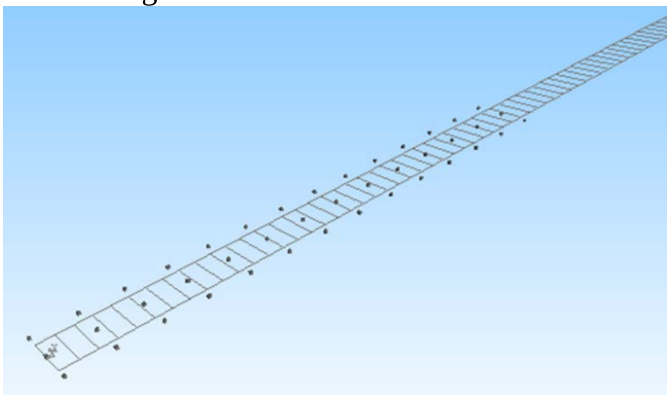

Figure 1. Mobile platform.

2.2 Modeling of Maglev Vehicle

The geometric structure of the maglev train body is very complex, but in the simulation, these parts are regarded as rigid bodies, and the complexity of the geometric shape need not be considered. Therefore, the above components are simplified in SolidWorks.

In addition, the simulation needs to know the quality parameters of each component, including the size of mass, the position of center of mass, the size of moment of inertia and so on. Since the moment of inertia of each component can not be measured directly, this paper gives each body a mass parameter, assuming that the mass of each body is uniformly distributed according to the geometric figure, and automatically calculates the moment of inertia and the position of the center of mass of each body by this software. The dynamic model of a maglev train is shown in Fig. 2.

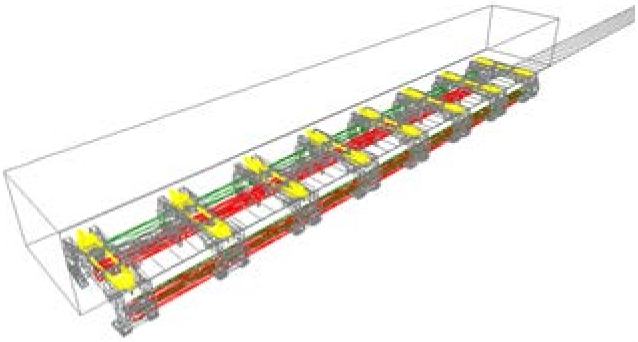

Figure 2. A Dynamic Model of Maglev Train.

Simulation Results of Vehicle Dynamic Response

The dynamic response time history, suspension clearance dynamic time history, guidance clearance dynamic time history, force and deformation of primary and secondary suspension springs can be obtained by the simulation of complex vehicle-rail coupling dynamic model at different driving speeds. This section will mainly start from the ride comfort and stability of suspension guidance system. The time history of vertical vibration response of vehicle body at 200 km/h, 300 km/h and 400 km/h is listed.

Three evaluation points on the front, middle and rear end of the car floor are selected to correspond to the center position of the front suspension frame, the center position of the car body and the center position of the suspension frame at the end. By analyzing the vertical vibration acceleration time history of the three evaluation points, the ride comfort of the front, middle and rear parts of the carriage is evaluated.

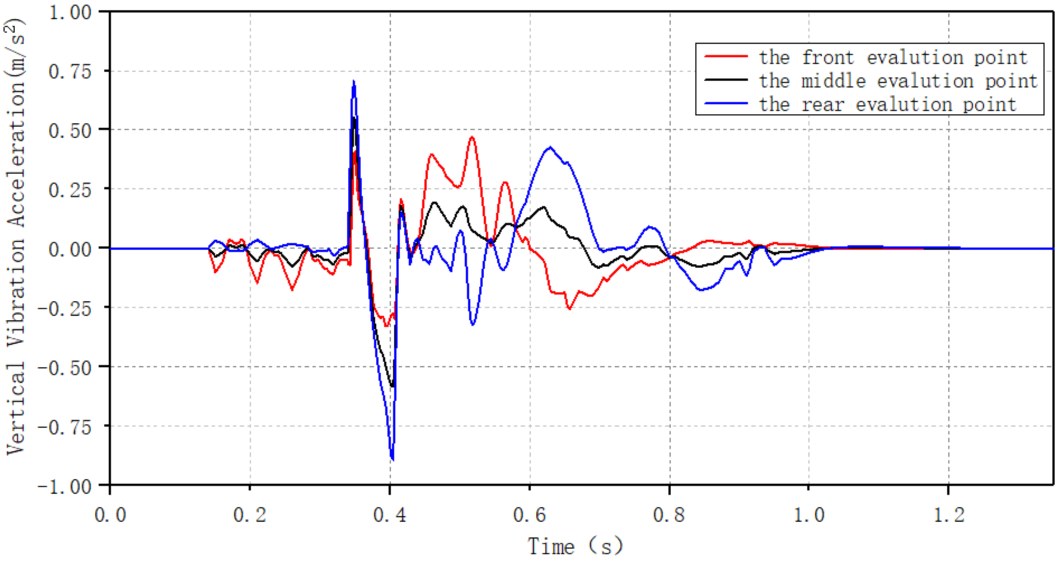

Figure 3. Vertical Vibration Acceleration Time History of Three Evaluation Points at Vehicle Speed 200 km/h

When the vehicle is traveling at 200 km/h speed, the vertical vibration acceleration time history of the front, middle and rear evaluation points on the floor surface of the carriage is shown in Fig. 3. After calculation, the root mean square values of vertical vibration acceleration of the three evaluation points are 0.163, 0.144 and 0.208 m/s^2 respectively, which are not more than 0.315 m/s^2. Generally speaking, the ride is comfortable.

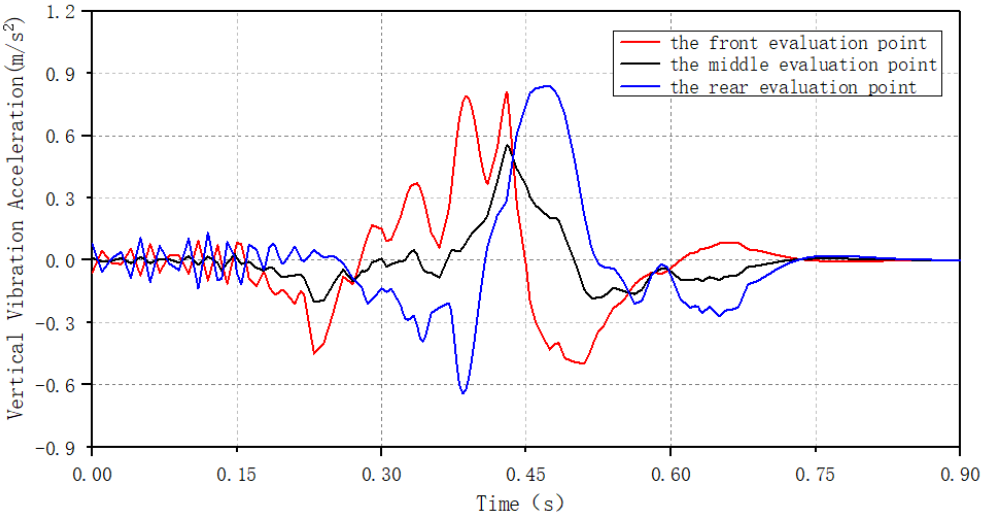

Figure 4. Vertical Vibration Acceleration Time History of Three Evaluation Points at Vehicle Speed 300 km/h

When the vehicle travels at 300 km/h, the vertical vibration acceleration time history of the front, middle and rear evaluation points on the floor surface of the carriage is shown in Fig. 4. After calculation, the root mean square values of vertical vibration acceleration of the three evaluation points are 0.307, 0.148 and 0.281 m/s^2, respectively, which are not more than 0.315 m/s^2. Generally speaking, the ride is comfortable.

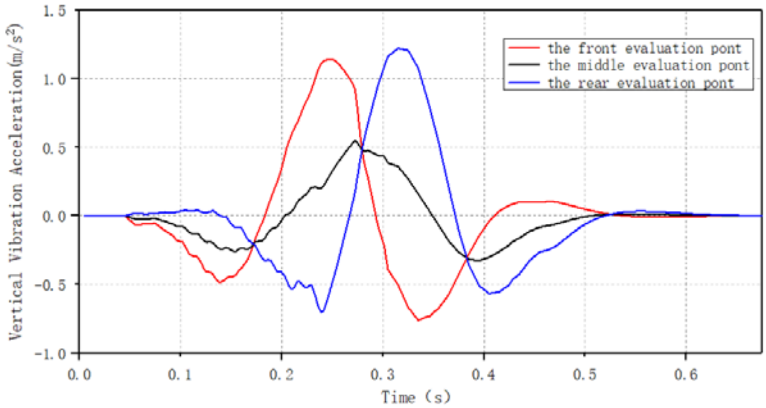

Figure 5. Vertical Vibration Acceleration Time History of Three Evaluation Points at Vehicle Speed 400 km/h

When the vehicle travels at 400 km/h speed, the vertical vibration acceleration time history of the front, middle and rear evaluation points on the floor surface of the carriage is shown in Fig. 5. After calculation, the root mean square values of vertical vibration acceleration of the front, middle and rear evaluation points are 0.518, 0.227 and 0.395 m/s2, respectively. Therefore, in general, the middle of the carriage is comfortable while the front and rear ends are slightly uncomfortable.

According to the results of the simulation analysis and the comfort evaluation criteria, when the speed of the car is 200 km/h and 300 km/h, the vertical vibration acceleration of the three evaluation points on the floor is less than 0.315 m/s2 in most time periods, and the ride comfort can be guaranteed in most time periods when the speed of the car is 400 km/h. There are different degrees of discomfort during the travel time, generally slight discomfort.

3. Simulation Results of Dynamic Response of Track Beam

By adding modal force, the track beam is prestressed to counteract gravity. The single-span track beam weighs about 144.4 tons. Under the action of self-weight, the vertical deflection of 4.5 mm is generated in the middle of the beam span. With the modal force, the mid-span deflection becomes 0, and the track beam remains straight.

The mid-span deflection of the simply supported beam is 2.322 mm when the vehicle is suspended at rest. Through the numerical simulation of the multi-degree-of-freedom complex vehicle-simply supported elastic beam model, the vibration response of the track beam at different speeds is obtained. The calculation results of the vertical vibration displacement and acceleration of the track beam at 200 km/h, 300 km/h and 400 km/h are listed below.

When the speed of the vehicle is 200 km/h, the running time of the vehicle is 1.35 s, the maximum vertical deflection of the track beam span is 2.561 mm, the maximum vertical acceleration is 0.178 m/s2, and the negative amplitude is -0.194 m/s2, as shown in Figure 6 and 7.

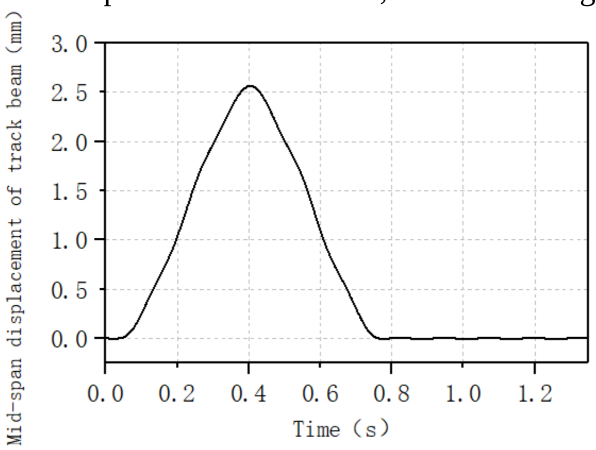

Figure 6. Vertical Displacement Time-History Curve of Mid-span at Vehicle Speed of 200 km/h

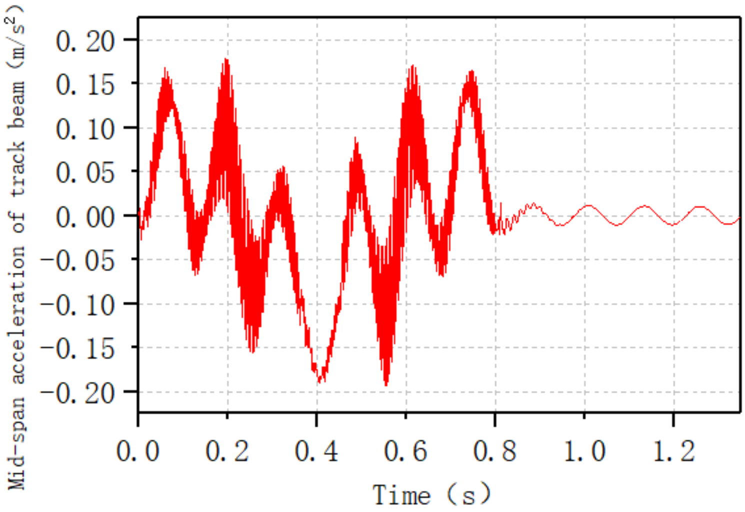

Figure 7. Vertical Acceleration Time-History Curve in Mid-Span at Vehicle Speed of 200 km/h

When the speed of the vehicle is 300 km/h, the running time of the vehicle is 0.9 s, the maximum vertical deflection of the track beam span is 2.635 mm, the maximum vertical acceleration is 0.392 m/s2, and the negative amplitude is -0.41 m/s2.

When the speed of the vehicle is 300 km/h, the running time of the vehicle is 0.9 s, the maximum vertical deflection of the track beam span is 2.635 mm, the maximum vertical acceleration is 0.392 m/s2, and the negative amplitude is -0.41 m/s2, as shown in Figure 8 and 9.

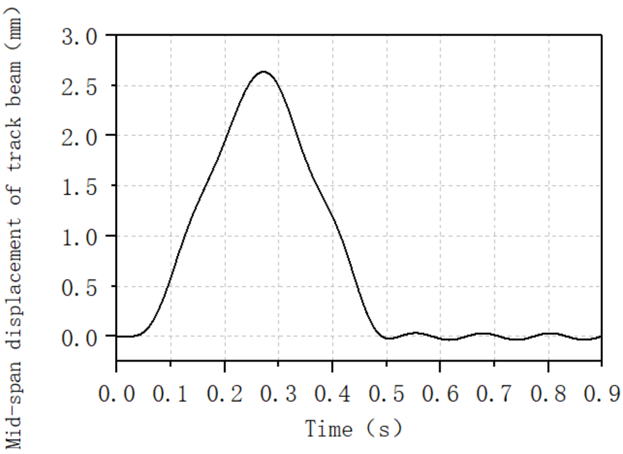

Figure 8. Vertical Displacement Time-History Curve of Mid-span at Vehicle Speed of 300 km/h

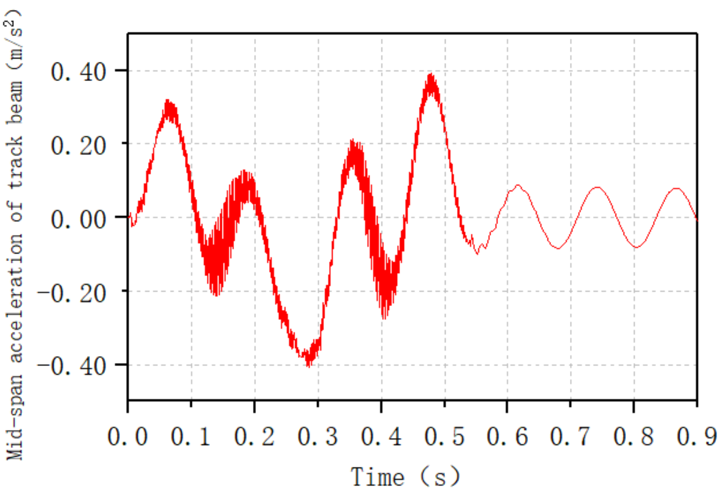

Figure 9. Vertical Acceleration Time-History Curve in Mid-Span at Vehicle Speed of 300 km/h

When the speed of the vehicle is 400 km/h, the running time of the vehicle is 0.675 s, the maximum vertical deflection of the track beam span is 2.64 mm, the maximum vertical acceleration is 0.804 m/s^2, and the negative amplitude is -0.912 m/s^2, as shown in Figure 10 and 11.

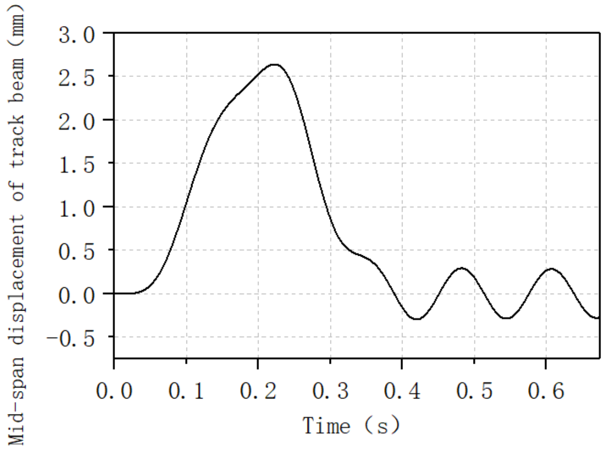

Figure 10. Vertical Displacement Time-History Curve of Mid-span at Vehicle Speed of 300 km/h

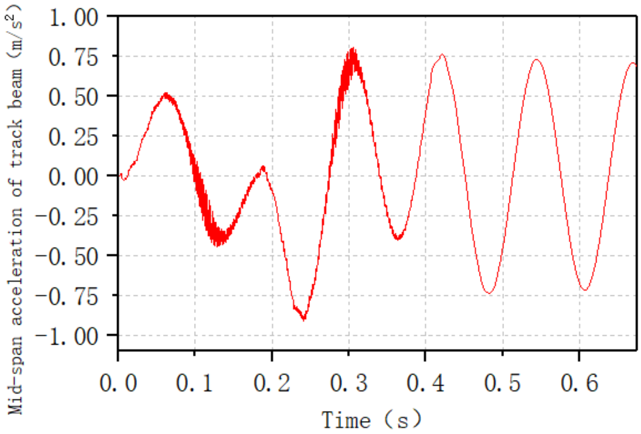

Figure 11. Vertical Acceleration Time-History Curve in Mid-Span at Vehicle Speed of 400 km/h

From the above displacement time history curves, it can be seen that the vertical deflection of the simply supported beam increases with the vehicle entering, and reaches the peak approximately when the vehicle center reaches the mid-span. As the vehicle moves away from the span beam, the deflection decreases gradually. When the vehicle leaves completely, the free vibration of the track beam occurs and the mid-span deflection decreases continuously.

By summarizing the simulation results at different speeds, the maximum vertical displacement of simply supported beam span varies with vehicle speed as shown in Fig. 12, and the corresponding dynamic amplification factor varies with vehicle speed as shown in Fig. 13.

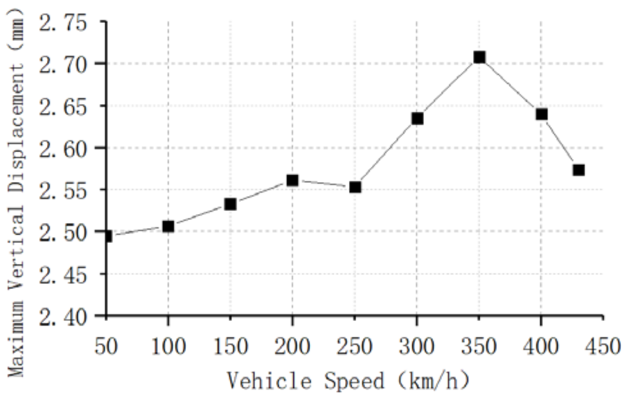

Figure 12. Maximum Vertical Displacement-Vehicle Speed Diagram of Simply Supported Beam

Span

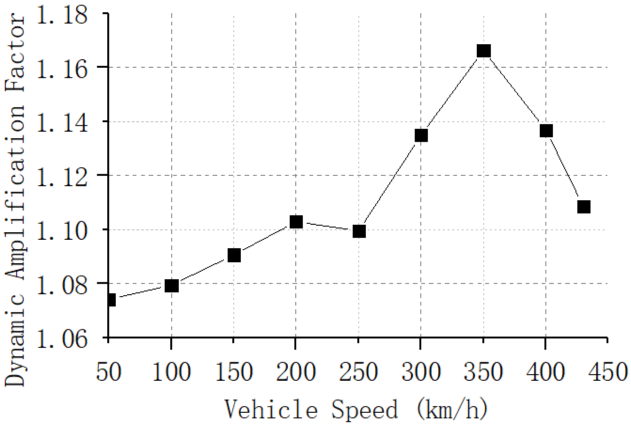

Figure 13. Dynamic Amplification Factor-Vehicle Speed Diagram of Simply Supported Beams in Mid-span

The results show that the influence of vehicle speed on the vertical vibration of the track beam is obvious. The maximum deflection of the simply supported beam at different vehicle speeds ranges from 2.494 mm to 2.708 mm, which is less than L/4000=6.192 mm, and meets the deformation requirements of the high-speed maglev track beam under vehicle loads. The dynamic amplification coefficient of the track beam is between 1.074 and 1.166, and the maximum is 1.166 when the speed is 350 km/h. In addition, the absolute maximum vertical vibration acceleration in the span of track beam reaches 0.912 m/s2 when the vehicle travels at 400 km/h.

4. Conclusion

Based on TR08 vehicle of Shanghai Maglev Demonstration Line and 24.768 m pre-stressed concrete track beam, a multi-degree-of-freedom complex vehicle-elastic track beam model is established, and its dynamic simulation and numerical simulation are carried out. The following conclusions are drawn:

1) When a vehicle passes through a simply supported beam, when the speed is less than 300 km/h, it is generally comfortable in the carriage. When the speed is greater than 300 km/h, the middle area of the carriage can also ensure comfort in most of the time, but the front and rear ends have different degrees of discomfort, which is slightly uncomfortable in general.

2) When a vehicle passes through a simply supported beam at different speeds, the maximum vertical deflection of the span of the simply supported beam is 2.708 mm, and the dynamic amplification factor is between 1.074 and 1.166, which meets the deformation requirements.

3) If the vehicle speed is further increased, it is necessary to continue to optimize the structure of the rail system to meet higher requirements.

Acknowledgments

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