

Development of Semi-active Lateral Damper System for Railway Vehicles Based on H^∞ Control

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Abstract. In order to meet the riding comfort requirements of high-speed trains when running between high-speed lines and the existing low-speed lines, it is necessary to develop active damper system to further suppress vehicle vibration. A semi-active lateral damper system with H^∞ control is developed. The performance of that system is tested on roller rig under different track irregularities. The experimental results show that the semi-active lateral damper based on H^∞ control can effectively suppress the lateral vibration of the car body, especially the low frequency vibration of 0.5 ~ 3 Hz.

Keywords: H^∞ control, semi-active lateral damper, roller rig test.

1. Introduction

Facing the strategic needs of the rapid development of railway transportation, railway vehicles need to meet the cross-line operation between high-speed lines and existing low-speed lines. The complex line conditions and changeable operation environment are great challenges to the stability and comfort of railway vehicles. Passive dampers are difficult to meet the requirement of stability and riding comfort in different lines. Active dampers become a very effective solution. One of the key steps in designing active damper is the design of control algorithm.

H^∞ control is a typical robust control, which can control the vibration in the resonance region of the car body through frequency domain shaping, so as to effectively attenuate the vibration of the car body. Some railway vehicles have equipped the active suspension system with pneumatic actuator based on H^∞ control to improve lateral riding comfort [1]. However, there are some problems about pneumatic system. First problem is air consumption. Second problem is the limit of the force. To solve these problems, an electrical actuator based on H^∞ control has been developed that has no air consumption and higher response [2], which shows a good suppression on lateral acceleration of the car body. Otherwise, Wu [3] designed H^∞ controller for vehicle yaw and roll vibration, and carried out joint simulation analysis to verify the H^∞ control for low frequency vibration of vehicle body.

The above H^∞ control research focuses on the full-active damper. Due to the high cost of the full-active damper, and many changes need to be made to the vehicle structure. We have tried to develop a semi-active damper system based on H^∞ control with compact structure, low cost and safe mode.

2. System Configuration

2.1 Hardware of Semi-active Lateral Damper System

The semi-active lateral damper system is constructed one control box, two accelerometers, and four SALDs, as shown in Fig.1.

The control box is carried under the car body. It contains the signal processing boards which receive signals from the accelerometers and generates control signals to the SALDs.

The accelerometers are installed under the car floor. These devices detect lateral and vertical acceleration of car body and set to calculate the yawing, lateral, rolling and lateral mode vibrations.

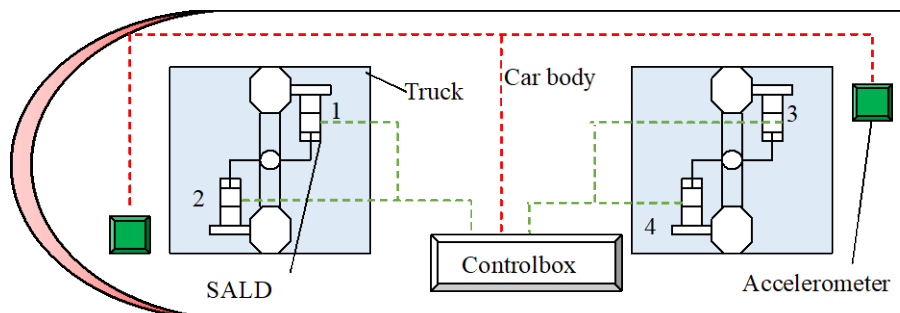


Fig. 1 Allocation of the components

The SAYD consisting of oil cylinder and servo valves are fitted between the car body and the truck as shown in Fig.2.

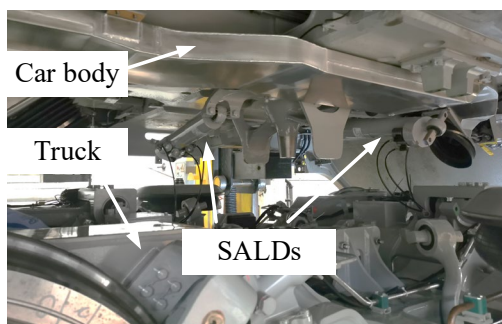


Fig. 2 Attachment to the car body

2.2 Outline of Semi-active Control Algorithm Based on H_∞

We mainly consider the yawing mode vibration of the car body and then the lateral and rolling mode vibrations for the controlled vibration. Because two vibrations are independent, we could design each controller based on H_∞ control theory [4].

Since ride comfort strongly depends on vibration frequency, especially 0.5~ 3Hz, it is easy to understand the relationship between the reduced frequency and the weighting function. H_∞ control can ensure the performance through the design of weight functions according to the vibration modal of the vehicle, without a large number of line tests for parameter correction.

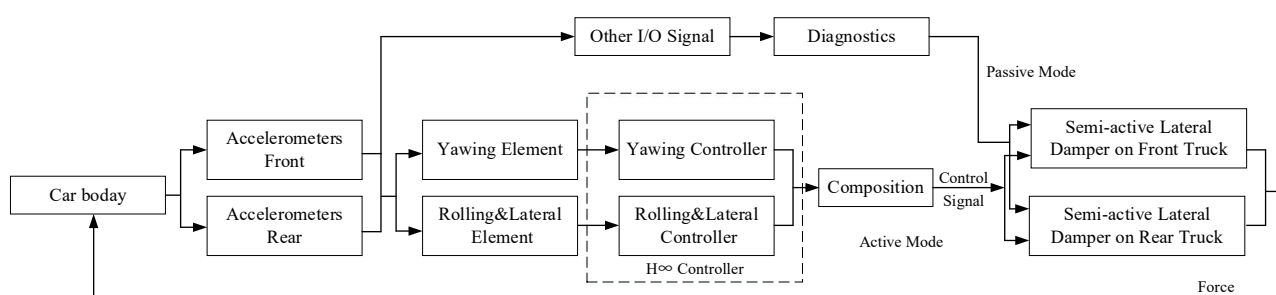


Fig. 3 Outline of H_∞ control algorithm

3. Design of Semi-active Lateral Damper

The principle of SALD is shown in Fig. 4. It can achieve the change between active mode and safe mode. Valve 1 and valve 2 are tension unloading valve and compression unloading valve respectively, and valve 3 is passive safety valve. In active mode, the direction of damping force is controlled by changing the state of valve 1 and valve 2, and the amplitude of damping force is controlled by adjusting the current of electromagnetic proportional valve (EPV). When the system breaks down or other faults occur, the damper automatically switches to a safe mode. The safe mode can ensure the normal operation of the vehicle.

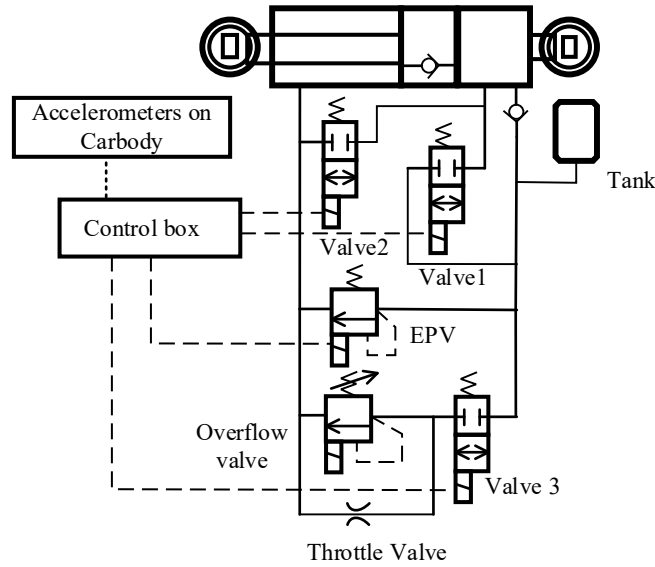


Fig. 4 Schematics of semi-active damper

According to the above principle, a SALD is designed as shown in Fig. 5. The F-V characteristics of the SALD under different control currents is tested as shown in Fig. 6. In semi-active mode, the maximum damping force is 14 kN and the minimum damping force is 0.2 kN. In semi-active mode, the damper has two working states: damping state and unloading state. When the required damping force F_r direction is opposite to the speed direction of the piston v_d , the damper is in a damping state, and the damper generates damping force F_d according to the H_∞ control algorithm. Otherwise, it is necessary to switch the damper to the unloading state through valve 1 and valve 2 to avoid the damping force increasing the vibration of the car body.

$$F_d = \begin{cases} -\text{sign}(v_d) \cdot I(F_r, v_d) & (\text{if } v_d \cdot F_r < 0) \\ \text{unloading force} & (\text{if } v_d \cdot F_r \geq 0) \end{cases}$$

(1)

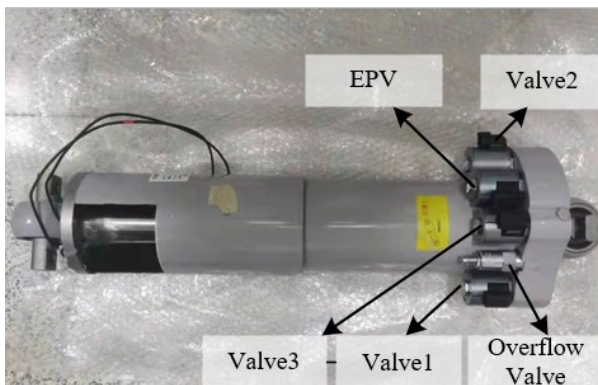


Fig. 5 Semi-active lateral damper (SALD)

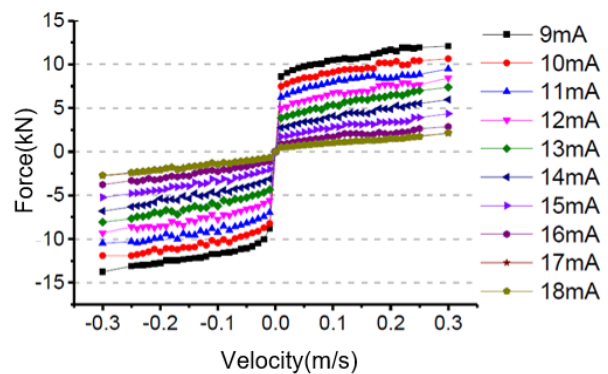


Fig. 6 F-V characteristics of the SALD

4. Performance Test on Roller Rig

4.1 Method of Performance Test

To prove the performance of that SALD system, we have done a full-scale test on Chengdu Roller Rig [5]. In this section, the method of the test is explained. The equipment for the full-scale test is shown in Fig. 7.

The roller rig has four roller sets with the two rollers of each set constrained to have the same rotational speed. The linear motions of the two rollers in the Y and Z directions and also the rotation

of the two rollers about the Y axis are controlled during the roller rig operation, which enable the wheelsets to move with the following degrees of freedom.

- 1) Movement of the two rollers independently in the Y direction simulates the track irregularities of gauge and lateral alignment.
- 2) Movement of the two rollers independently in the Z direction simulates the track irregularities of cross level and vertical profile.
- 3) Rotation of the two rollers at the same speed about the Y axis is to simulate the forward speed of vehicle on straight track.



Fig. 7 Test on roller rig

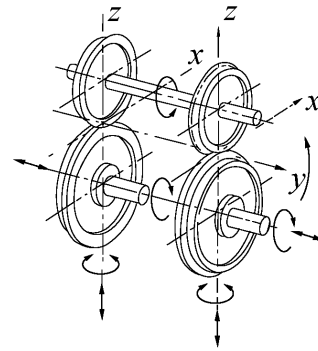


Fig. 8 Freedom of the rollers

We simulate the running state of vehicles at different speeds by applying the measured track irregularities of gauge on the wheelsets. In the test, we have applied Wuhan-Guangzhou (WG) line track irregularities and Jiaozhou-Jinan (JiaoJi) line track irregularities at a speed of 350km/h and 250km/h respectively.

4.2 Results of Performance Test

Fig. 9 and Fig. 10 show the lateral vibration acceleration of the car body front under WG track irregularities when the vehicle speed is 250 km/h and 350 km/h respectively. It can be seen from the figure that when H_∞ control is applied, the lateral vibration acceleration of the car body is significantly suppressed, especially when the low-frequency vibration amplitude of the car body is reduced by more than 50 % within 0.5~3 Hz, which makes a significance for riding comfort.

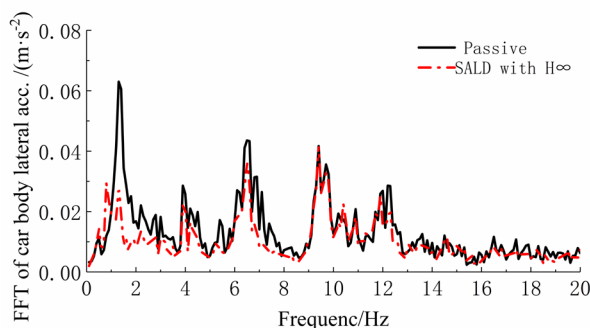


Fig. 9 FFT of lateral acc. (WG, 250km/h)

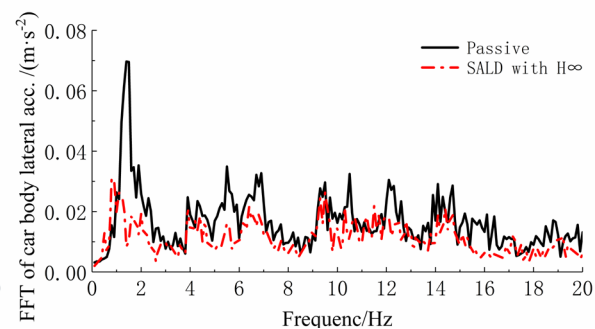


Fig. 10 FFT of lateral acc. (WG, 350km/h)

Fig.11 shows the lateral acceleration of the car body front at a speed of 250km/h under JiaoJi track irregularities, which is the highest speed of the existing line. It can be seen from the diagram that the SALD system with H_∞ control shows better suppression performance for the lateral acceleration of the car body than the passive damper.

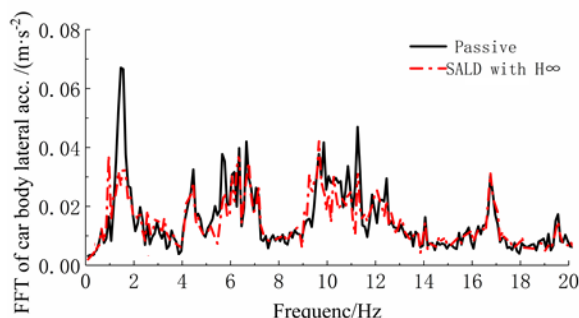


Fig. 11 FFT of lateral acc. (JiaoJi, 250km/h)

5. Conclusion

A semi-active lateral damper system based on H_∞ control for the railway vehicles has been developed to take the place of passive damper. From the results of performance test, it is proved that the SALD system based on H_∞ control can effectively suppress the lateral vibration of the car body, especially the low-frequency vibration within 0.5~3 Hz, which can be attenuated by more than 50 % whether under WG line track irregularities or Jiaoji line track irregularities. Then we will carry out durability tests on SALD system and put it into use.

References

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