Research on Incomplete Output Fault-tolerant Control of Electromagnetic Suspension System for Semi-vehicles

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ABSTRACT: In order to investigate the effect of electromagnetic active suspension on vehicle performance in case of failure, this paper takes the four degree of freedom (DOF) semi-vehicle electromagnetic suspension system as the research object. Body acceleration, pitch angle acceleration, suspension dynamic travel and tire dynamic deformation are taken as indexes for research. Firstly, a 4 DOF semi-vehicle electromagnetic active suspension dynamics model is established, and then its suspension performance indexes when different actuator gain faults are analyzed according to the model, based on which, an incomplete output fault-tolerant (IOFT) controller is proposed to study and analyze the performance of the semi-vehicle electromagnetic suspension system. Finally, simulation analysis was carried out using MATLAB/Simulink to investigate the fault-tolerant control for front and rear actuator gain faults respectively, and the comparison was made through the root-mean-square (RMS) values. The results show that when an IOFT control strategy is used, the performance metrics of the individual suspensions may deteriorate slightly, but the improvement of the body droop acceleration and pitch angle acceleration, which have a greater impact on ride comfort, is significant.

KEYWORDS: Electromagnetic suspension, Fault tolerant control, Active control, Suspension systems, Semi-vehicle suspension systems

1. INTRODUCTION

Suspension is a component that connects the body and wheels, and can play a role in slowing down the vibration of the road surface[1]. The performance of the suspension determines ride comfort, operational stability and safety, and is an important part of the automobile. Electromagnetic (EM) suspension is the current research hotspot in the field of suspension due to its simple structure and good controllability [2]. Most of the current research focuses on the structural design and control methods under the intact state of the suspension [3]. However, when the suspension fails, it may lead to a decrease in the effect of these control methods, or even failure, which may cause serious safety hazards. Fault-tolerant (FT) control can keep the suspension performance within acceptable limits when the suspension is in a faulty state [4]. In this project, the electromagnetic suspension system of a semi-truck is analyzed, and the fault-tolerant controller is designed by studying the performance of the suspension actuator with non-full force, and the fault-tolerant control effect of the semi-truck under different force conditions is analyzed by simulation.

2. EM ACTIVE SUSPENSION MODEL

The EM active suspension 4 DOF semi-vehicle model. The tire stiffness is k_{tA} and k_{tC}. m_b is the spring-loaded mass and m_{wA}, m_{wC} are the unsprung masses. k_{sA}, c_{sA}, k_{sC}, c_{sC} are the stiffness and damping of the suspensions. k_{sA}, c_{sA}, k_{sC}, c_{sC} are the active forces are F_{iA}, F_{iC}, respectively. θ is the pitch angle of the vehicle, and x_b is the droop displacement of the vehicle. x_{bA}, x_{bC} are the front and rear suspensions spring-loaded mass displacements. Its dynamic equations are shown in equation (1):

$$\begin{cases} m_b\ddot{x}_b = \sum_j k_{sj}(x_{wj}-x_{bj}) + c_{sj}(\dot{x}_{wj}-\dot{x}_{bj}) + F_{ij} \\ I_p\ddot{\theta}_p = \sum_j \alpha_j[k_{sj}(x_{wj}-x_{bj}) + c_{sj}(\dot{x}_{wj}-\dot{x}_{bj}) + F_{ij}] \\ m_{wj}\ddot{x}_{wj} = \sum_j \begin{matrix} k_{tj}(x_{gj}-x_{wj}) - k_{sj}(x_{wj}-x_{bj}) \\ -c_{sj}(\dot{x}_{wj}-\dot{x}_{bj}) - F_{ij} \end{matrix} \\ F_{ij} = K_{uj}i_{uj}; j = A, C; \alpha_A = -a, \alpha_C = b \end{cases} \tag{1}$$

3. FT CONTROLLER DESIGN

The block diagram of the incomplete output fault-tolerant (IOFT) controller is designed for the semi-vehicle suspension system, which is shown in Fig. 1. The road excitation is used as an input and the accelerometer is used as a feedback signal. The vibration of the road surface is transmitted to the body through the electromagnetic suspension. The actuator outputs the main power through the control signal from the controller, which in turn controls the performance of the vehicle. When the actuator fails, the force output of the suspension may be affected, which in turn affects the performance of the suspension. The incomplete fault-tolerant control of the front and rear suspensions results in improved pitch angle acceleration and body sag acceleration, which have a greater impact on ride comfort. This in turn leads to a control effect that improves the suspension performance.

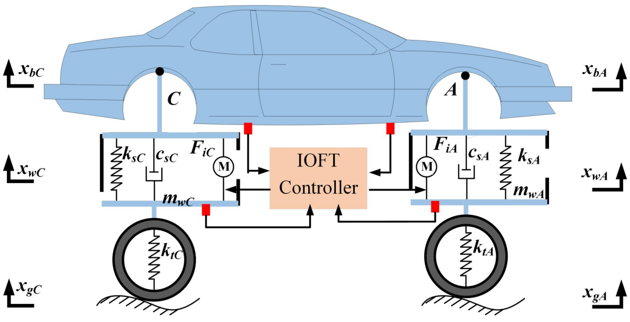
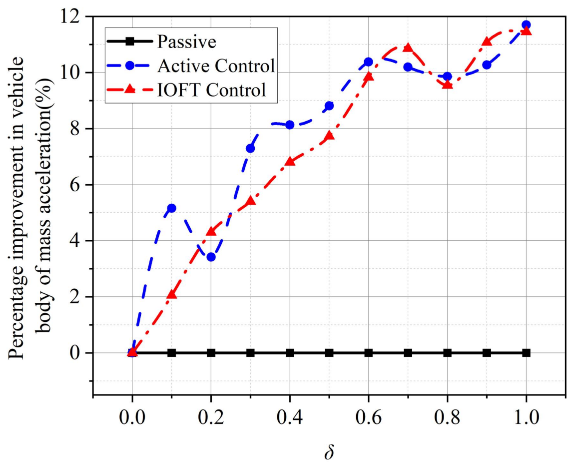


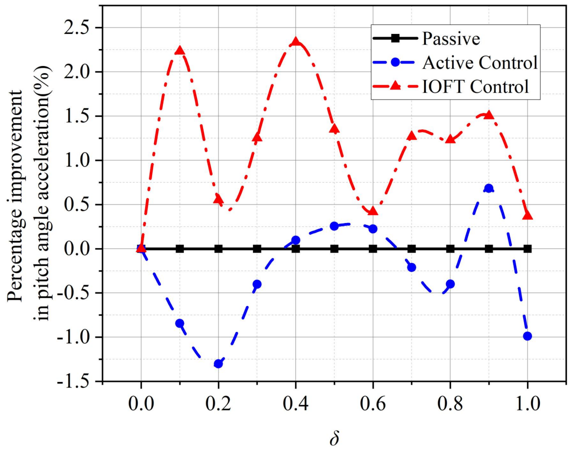
Figure 1 Control Block Diagram

4 SIMULATON ANALYSIS

The percentage improvement in the performance of the electromagnetic suspension system of the semi-vehicle is shown in Fig. 2. From the figure, it can be seen that the percentage of improvement in each performance of the suspension system varies when the suspension actuator fails at different levels. A comparative analysis is performed with the suspension improvement as the control objective and the semi car as the control objective for improvement. At δ<0.6, the improvement with suspension as the control target is slightly better; however, the improvement in pitch angle acceleration is the opposite.



(a)



(b)

Figure 2 Percentage improvement in system performance

5 CONCLUSION

In this paper, the electromagnetic suspension system of a 4 DOF semi-vehicle was modeled, the performance of the electromagnetic suspension system at different actuator failures was analyzed, and a IOFT controller was designed. Subsequently, simulations were performed and the results showed that when the suspension fails, the suspension system can be actively controlled by designing an appropriate fault-tolerant controller, which can substantially improve other suspension system performances such as pitch angle acceleration at the expense of some improvements in center-of-mass acceleration.

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