Project and Develop of Test Bench for Semi-Active Suspension

Zhen Wang*, Jinjun Zhen, Silun Peng and Yumeng Wang
College of Automotive Engineering, Jilin University, Changchun, China

*Corresponding author e-mail: wangzhen@jlu.edu.cn

Abstract. With the development of economy, the progress of science and technology, the development of automobile industry is more and more rapid. There are more and more kinds of automobiles in the world. Therefore, people have higher and higher requirements for automobile performance, comfort and smoothness. Therefore, this paper makes a series of research on the design and development of continuously adjustable damping test-bed. Firstly, this paper presents the principle and classification of continuously adjustable damping damper, because the traditional passive suspension structure and damping value cannot be changed once determined, and cannot meet the requirements of various road conditions. In order to meet the complex and changeable working environment, a continuously adjustable damping damper is designed. Secondly, this paper studies half of the active suspension, and half of the active suspension includes linear model and bilinear model, and designs a scale-up quarter car test-bed. The core components of the test-bed are MR damper and tuned mass damper. Finally, the results show that the MR damper has good damping dissipation energy characteristics, and the damping value of MR damper has a good linear relationship with the current.

Keywords: Continuously Adjustable Damper, MR Damper, Semi-Active Suspension, One quarter car test bench

1. Introduction
In recent years, the development of automobile industry is more and more fast, and people's demand for automobiles is more and more big. Therefore, the demand for automobiles is also higher and higher. Not only the appearance of automobiles is good, the color is bright, but also the automobiles are required to have good comfort. Therefore, the shock absorbers should be produced. The shock absorbers are used to accelerate the attenuation of frame and body vibration, so as to improve the ride comfort of automobiles, the suspension system of most cars is equipped with shock absorbers [1-3].

There are many types of shock absorbers, and this paper focuses on the continuously adjustable shock absorbers. Many scholars have done a series of research on this kind of shock absorbers [4]. In the author proposes an adaptive method to build the inverse model and describes the corresponding optimization algorithm. Unlike most of the inverse models, our self-renewal model can be used to describe the dynamic characteristics of MR dampers under external excitation. In [5], the author...
proposes a kind of inertia induced negative stiffness (apparent mass effect) and magnetic induced positive / negative stiffness, which integrate a vertical tuned mass damper with adjustable stiffness and a pendulum tuned mass damper for frequency adjustment. In [6], the author analyzes the performance of the single tube hydraulic adjustable damper by establishing its analytical model and thermal effect equation, which provides a theoretical basis for engineering design. The results of simulation and experiment show that the analysis of the characteristics of single tube hydraulic adjustable damper is reliable. In [7], the author studies a new CVT designed for a new tuned mass damper, and introduces its design and performance in detail. Finally, the experimental and numerical excitation torques of CVT are compared. In [8], in order to improve vehicle ride comfort, the author proposes a cuckoo search optimization proportional integral derivative (CS-PID) strategy for damping force control of semi acid suspension system. The results show that the proposed control strategy can effectively improve the vehicle performance. In [9], the author proposes a six degree of freedom conical vibration isolation platform with MR damper. The platform has a high degree of integration, which can partially replace the original connection device and improve the vibration environment. In [10], in order to solve the contradiction between the handling stability and smoothness of the IASs vehicle and reduce the energy consumption of the air suspension with adjustable spring stiffness, the author designs a dynamic performance coordinated control scheme based on the logic of switch connection mode and the countermeasure control of damper.

Based on the continuous adjustable damper, this paper analyzes and designs the continuous adjustable damper test-bed. The test-bed designed in this paper is a quarter car test-bed, and the specific research process is shown below.

2. Continuously adjustable damper

2.1 Principle
The traditional passive suspension structure and damping value cannot be changed once determined, and cannot meet the requirements of various road conditions. In order to meet the complex and changeable working environment, we need to change the suspension damping value in real time according to the change of working environment. Active suspension can output more accurate damping force, with the best damping effect, but it is difficult to popularize because of its high cost, high energy consumption, complex structure. The semi-active suspension with variable damping has the advantages of simple structure and low energy consumption, which can improve the comfort and control stability at the same time. The research work of semi-active suspension mainly consists of two parts, one is continuously adjustable damper, the other is semi-active control algorithm, and half of the four active vehicle models are shown in Figure 1.

![Figure 1. Half quarter active vehicle model](image)

2.2 Classification
There are many kinds of continuously adjustable damper, among which intelligent material damper includes magnetorheological damper, electrorheological damper, valve-controlled damper includes electromagnetic valve-controlled damper, magnetorheological valve-controlled damper.
3. Design and development of test bed

3.1 Quarter active suspension
The semi-active suspension consists of two parts, one is its linear model, the other is its bilinear model. The linear model can simplify the control of semi-active suspension, but it can only solve the control problem of semi-active suspension to a certain extent. The characteristic of the linear model is to simplify the control input into the damping force, and its essence is the active suspension model. Semi-active suspension model has many advantages, but the most important one is simple, easy to achieve control simulation, suitable for a variety of control strategies.

Because there are many parameters to determine the suspension model, and the spring, damping, tire and so on have obvious nonlinear characteristics, in which the damper fluid viscosity, spring element stiffness and so on change with time, so the rationality of only simplifying the semi-active suspension model to linear model is poor, so the obtained control law cannot play the desired control Effect. In order to improve the reliability of the control law and not make the control simulation too complex, it is reasonable to simplify the semi-active suspension model to bilinear model. Bilinear system is actually a kind of special nonlinear system with a relatively simple form, so simplifying the semi-active suspension model to bilinear mathematical model can not only reflect the characteristics of the suspension more reasonably and improve the control effect, but also keep the control simulation relatively simple.

3.2 Quarter car test bench
On the basis of continuously adjustable damper, a quarter car test-bed is designed and developed in this paper. The test-bed is mainly designed to verify the effect of semi-active control algorithm, which is the software foundation of semi-active suspension. The core part of the scale-up quarter car test-bed is the magnetorheological damper. In the second section, it has been introduced that the magnetorheological damper is also called the electrorheological damper. Its working principle is that when the damper is internally connected with an external power supply, it will generate an excitation (magnetic field or electric field) on the intelligent material. When the intelligent material is excited, the physical properties will change reversibly, specifically from fluid to false Solid materials. Another core part of the test-bed is tuned mass damper (TMD), which is a commonly used energy absorption device in engineering. TMD is installed on the main vibration structure, and the secondary mass is connected with the main vibration structure through elastic elements and energy dissipation elements. When TMD vibrates, the vibration energy of the main structure can be transferred to the secondary mass, and then dissipated through the energy dissipation elements, so as to achieve the purpose of vibration reduction. The other parts of the test-bed include sensor, sprung mass, suspension spring, tire stiffness spring, non-sprung mass, road surface, actuator, etc. The specific test-bed device is shown in Figure 2.

Figure 2. Test bench for quarter car
3.3 Composition of hardware in the loop test platform

Hardware in the loop test structure diagram, including software and hardware modules. The software part includes simulation model and RTI module in DSPACE, and the hardware part includes signal processing circuit and DSPACE IO board. The software platform runs 1 / 4 of the vehicle dynamics model, and sends out the vertical acceleration of sprung and non-sprung mass. DSPACE sends the sprung and non-sprung acceleration from 2202 board card, and gets the speed signal through the signal processing circuit. The ad module of 2202 board card collects and sends back to the controller module and damper module in the software model for the calculation of ideal damping force, and completes the closed-loop control.

![Figure 3. Controller and the hardware interface model of Simulink structure](image)

**Figure 3.** Controller and the hardware interface model of Simulink structure

Figure 3 shows the structure of the controller and hardware interface model Simulink, including the software ceiling controller module, damper module and hardware interface module developed based on STATEFLOW.

The road roughness is a random signal in the time domain when the vehicle speed is constant. Because of the infinite time, the road function cannot be integrated in the time domain and cannot be Fourier transformed. In order to describe the road characteristics, the random road power spectral density of statistical characteristics is used for spectral analysis, and the fitting function expression is (1).

\[
G_q(n) = G_q(n_0)(\frac{n}{n_0})^{-w}
\]  

Where n is the spatial frequency, in m-1; n0 is the reference spatial frequency, n0 = 0.1; GQ(n) is the power spectral density of the vertical displacement of the road surface, in m2/m-1; GQ(n0) is the road roughness coefficient, that is, the road spectrum value under n0, in m2/m-1; W is the frequency index, which determines the frequency structure of the road power spectrum. According to the measured results and data of domestic and foreign data, for most of the roads, the frequency index W=2. When the vehicle passes the road roughness of spatial frequency n at a certain speed u, the input time frequency f is the product of u and n, that is

\[
f = u \cdot n
\]  

Then the expression of time frequency spectral density GQ(f) is derived

\[
G_q(f) = G_q(n_0)(\frac{f}{n_0})^{-w}u^{w-1}
\]

The independent variable f is divided into N intervals. When N is large enough, the center frequency \(f_i\) (i=1, 2, …, N) in each cell can be set the power spectral density GQ(\(f_i\)) corresponding
to, n) is regarded as the mean value of the interval. Therefore, in the time domain, the random road roughness can be expressed by harmonic superposition:

\[ Q(x) = \sum_{i=1}^{N} \sqrt{2G_i(f)\Delta f} \sin(2\pi f t + \phi_i) \]  

(4)

Based on the M file programming of MATLAB, the relationship between the random unevenness of different pavement grades and the time is obtained, as shown in Figure 4, which is the unevenness of A-level pavement.

![Figure 4: a level road unevenness curve](image)

In this paper, the controller adopts the classic ceiling algorithm. By judging the vertical speed symbols of spring loaded and non-sprung loaded masses and calculating the damper target damping force \( F_{d} \), the vehicle body smoothness control is realized.

\[ \begin{align*}
F_{d} & = -C_{dy} \cdot \dot{x}_y & (\dot{x}_y - \dot{x}_n) \cdot \dot{x}_f > 0 \\
F_{d} & = C_{ma} (\ddot{x}_y - \ddot{x}_n) & (\dot{x}_y - \dot{x}_n) \cdot \dot{x}_f \leq 0
\end{align*} \]  

(5)

The hardware interface model is set by RTI module in DSPACE, which is connected with signal processing circuit.

3.4 Hardware in the loop test of signal processing circuit

In order to facilitate the test and calibration of signal processing circuit, a calibration platform is built based on DSPACE / CONTROLDESK, and the CONTROLDESK interface is convenient for the calibration of AD and DA signals. On the basis of hardware in the ring platform and CONTROLDESK interface, the processing effect of sprung mass and non-sprung mass vertical speed signals is compared, and the speed signals obtained by integral filter circuit and calculated by software model are compared. As shown in Figure 5, it is the comparison diagram of sprung and non-sprung mass vertical speed. The green signal is the target speed signal in the software model, and the red signal is the actual speed signal obtained through the integral filter circuit. The right figure shows that the actual speed signal after the integral filter follows the target speed signal well, with a short delay (about 0.01s), meeting the control requirements.
Figure 5. Signal processing circuit filtering effect comparison chart

Figure 6 is the control effect comparison diagram of the canopy algorithm including the signal processing circuit, and the comparison signal is the sprung mass vertical acceleration signal. It can be seen from the figure that the control greatly attenuates the vertical acceleration amplitude of the sprung mass and effectively improves the ride comfort. At the same time, it is verified that the signal processing circuit can effectively complete the signal filtering and use the signal in the closed-loop control.

Figure 6. Hardware in the loop control effect figure

4. Conclusion

In this paper, based on the continuous adjustable damper, a test-bed of the continuous adjustable damper is designed. Firstly, the principle and classification of the continuous adjustable damper are put forward. The research work of the semi-active suspension mainly consists of two parts, one is the continuous adjustable damper, the other is the semi-active control algorithm. Secondly, aiming at the acquisition of speed signal of semi-active suspension, the signal integral filter circuit is analyzed and designed. Based on DSPACE system, the hardware in the loop platform including signal processing circuit is designed to complete the comparison of signal processing effect and control effect. The test results show that the signal processing circuit designed in this paper obtains the speed signal from acceleration signal in real time and effectively. It lays a foundation for the peripheral hardware circuit design of semi-active suspension system.
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