Acta Technica 63 No. 1B/2018, 1–10

Study on PID control and Fuzzy-PID control of magnetic fluid semi-active suspension[1]

Weichi Pei[2], Jianwei Dong[2], Haiyang Long[2], Yaogang Li[2], Hongchao Ji[2,3]

Abstract. Automotive semi-active suspension of adjustable damping force, under the control strategy based on real-time dynamic adjusting damping characteristics roads and cars, reducing vehicle vibration, in order to improve the vehicle comfort and stability. The magnetorheological (MR) damper is an ideal element for vehicle suspension semi-active control. In this paper, the MR damper is used as the adjustable damping force device, and the mechanical properties of the MR damper are obtained by the test, and the conventional PID control and Fuzzy-PID control are designed for the semi-active suspension respectively. To as random road excitation are simulated, the simulation results show that compared with the passive suspension, two control schemes are make the suspension performance has improved, but the Fuzzy-PID control of suspension performance improvement is better than PID control.

Key words. MR, semi-active suspension, PID control, fuzzy-PID control, simulation.

1. Introduction

The safety and comfort of a car is an important requirement for its driving [1]. The smoothness and stability of the vehicle in the driving process depend on the adjustment of the characteristics of the suspension system [2]. Suspension as the influence of vehicle comprehensive performance of the key components, connect the body and the axle, plays a relief when the vehicles running on the road because of the uneven road, engine vibration and turn itself the role of the braking and

[1]This work is supported by the National Natural Science Foundation of China (Grant No. 50975076). This work is also supported by Hebei Province Science Foundation for Youths (Grant No.E2017209059).

[2]School of Mechanical Engineering, North China University of Science and Technology, Tangshan Hebei, 063210, China

[3]Corresponding author

[4]Workshop 3; e-mail: `jihongchao666@163.com`

other operation caused by vehicle vibration [3]. Traditional passive suspension has limited the performance of the car by its inherent defects, the controllable suspension has become the development direction of vehicle suspension technology [4]. The semi-active suspension has the advantages of both passive suspension and active suspension, and it can reach the control effect of the active suspension, which is the most promising controllable suspension form [5]. The semi-active suspension system exists in the adjustable damping force, through studying the characteristics of damper, control strategy and design dynamic adjust the damping force to reduce vehicle vibration, in order to improve the ride comfort and operation stability [6]. Pan [7] combines PID control with fuzzy control, the fuzzy-PID switching control system of semi-active suspension with MR damper is designed, and the simulation results show that the method has good damping effect. Jiang [8] combines adaptive fuzzy reasoning system (ANFIS) and PID control, an ANFIS-PID controller was designed for a quarter of a semi-active MR damper. The simulation proved that the strategy was superior to the conventional PID control.

This paper combines conventional PID control with fuzzy control, the fuzzy controller is used to realize the dynamic adjustment of the parameters to deal with the nonlinear and time-varying characteristics of the semi-active suspension. Based on the above two control methods, the conventional PID control and fuzzy-PID control strategy of semi-active suspension are designed respectively. Based on the performance of passive suspension, the improvement of suspension performance is compared.

2. A quarter of the semi-active suspension

The kinetic differential equation has the form

$$\begin{cases} m_2\ddot{z}_2 + c(\dot{z}_2 - \dot{z}_1) + k_2(z_2 - z_1) - F = 0, \\ m_1\ddot{z}_1 - c(\dot{z}_2 - \dot{z}_1) - k_2(z_2 - z_1) + k_1(z_1 - q) + F = 0, \end{cases} \tag{1}$$

where m_1 is the tire mass, m_2 is the body mass, z_2 is the vertical displacement of the body, z_1 is the vertical displacement of tire, k_1 is tire stiffness, k_2 is the suspension stiffness coefficient, c is the suspension damping spring stiffness, q is the road input and F is the adjustable damping force, which is also the research object of semi-active control strategy to realize dynamic regulation to improve suspension performance.

In the evaluation indexes of suspension performance, the most important is the vertical acceleration, suspension dynamic deflection and tire load, respectively corresponding to the $\ddot{z}_2$, $z_2 - z_1$ and $k_1(z_1 - q)$ in (1).

In Simulink, the simulation model as shown in Fig. 1 is created by using the semi-active suspension differential equation of a quarter of the car shown in (1). After removing the adjustable damping force F, the model becomes a passive suspension simulation model. The damper used in this paper is the RD-8041-1 MR damper of American lade company. The selection of the model suspension parameters: $m_1 =$

30 kg, $m_2 = 264$ kg, $k_1 = 160000$ N/m, $k_2 = 16000$ N/m, $c = 1100$ N.s/m.

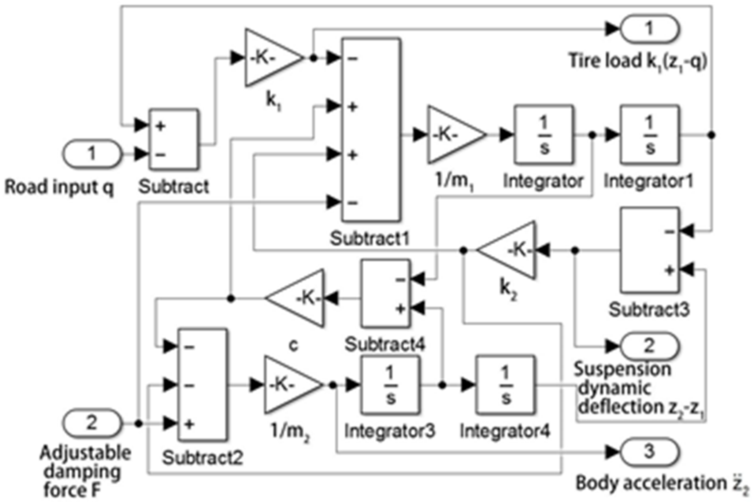


Fig. 1. Semi-active suspension simulation model

During the moving process, the vehicle will be subjected to the vibration of the body caused by the change of the ground, the vibration of the engine itself, and the turn braking. In this paper, the rough pavement excitation is the most important incentive. In the study of the dynamic performance of automotive suspension, an effective pavement input model must be established.

In the simulation of suspension performance, the pavement input usually adopts the simple harmonic signal and the white noise signal. In this paper, the white noise method is used to simulate the surface input, and its differential equation is shown in (2).

$$\dot{q}(t) = 2\pi n_0 \sqrt{VGq(n_0)}w(t) - 2\pi f_0 q(t)\,, \tag{2}$$

where $q(t)$ is a random road incentive, $w(t)$ is the Gaussian white noise signal, n_0 is the reference space frequency, V for vehicle speed (m/s), Gqn_0 is the pavement spectrum value, which can query the national standard, and f_0 is the space cutoff frequency.

By (2), a random road simulation model is established in Simulink, as shown in Fig. 2.

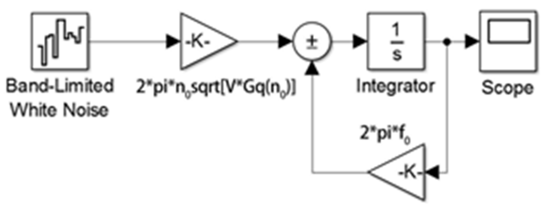


Fig. 2. Input model of road

3. Mechanical experiment and modeling of MRD

The adjustable damping force of semi-active suspension is the RD-8041-1 MR damper of the U.S. The instrument used in the test is the dampers test system produced by Hangzhou YiHeng science and technology. The loading method is loaded by the displacement control sine wave, the loading current is 0 A, 0.3 A, 0.6 A and 0.9 A, the loading frequency is 0.5 Hz, 1.0 Hz, 1.5 Hz, and the amplitude is 5 mm, 10 mm and 15 mm respectively. The experiment of $4 \times 3 \times 3 = 36$ working conditions was carried out.

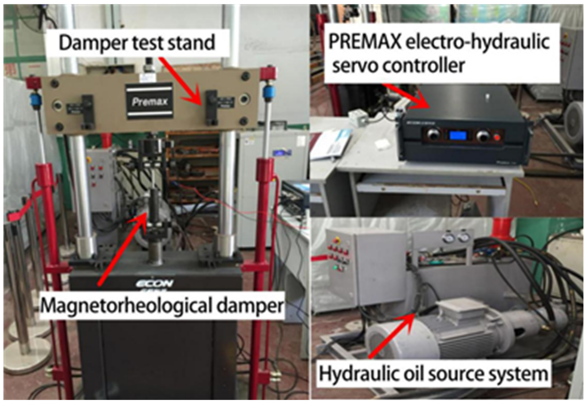


Fig. 3. Damper test system

When the excitation frequency is 1.5 Hz and the amplitude is 15 mm, the real-time damping force-velocity and damping force-displacement curve of 0 A, 0.3 A, 0.6 $\dot{\text{A}}$ and 0.9 A are shown in Fig. 4. As can be seen from Fig. 4, right part, the damping force–displacement curve is approximately square, and the damping force-velocity curve has a noticeable hysteresis characteristic. In the same vibration displacement or velocity, the larger the current, the greater the damping force.

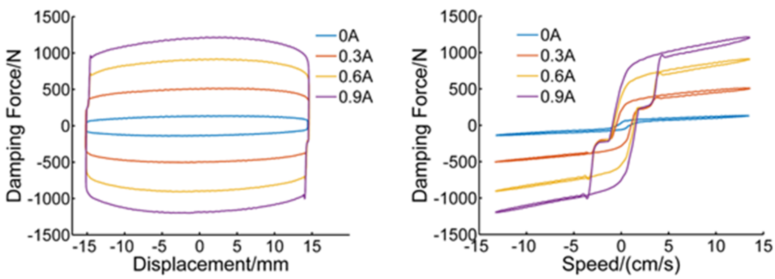


Fig. 4. Mechanical property curve of damper

The MR damper has a variety of mechanical models, and the modified Dahl model has fewer parameters and can well describe the hysteresis characteristics of the dampers. The model expression is

$$\begin{cases} F = K_0 x + C_0 \dot{x} + F_{\mathrm{d}} Z - f_0, \\ \dot{Z} = A\dot{x}\left[1 - Z\,\mathrm{sgn}(\dot{x})\right], \end{cases} \tag{3}$$

where K_0 is the stiffness coefficient, C_0 is the viscous damping coefficient, f_0 is the initial force, F_{d} is the adjustable coulomb friction force, A is the shape parameter of hysteresis curve, x is the relative displacement of the piston and cylinder body, and Z is the delayed displacement. In addition, there is a linear relationship between C_0, F_d and current in the form

$$\begin{cases} C_0 = C_{0\mathrm{s}} + C_{0\mathrm{d}} I, \\ F_{\mathrm{d}} = F_{\mathrm{ds}} + F_{\mathrm{dd}} I. \end{cases} \tag{4}$$

As can be seen from Table 1, the parameters change with current. In the further description of parameters and current relationship, if all parameters are taken into account, it can improve the precision of mechanical model, but it will increase the number of parameters and increase the identification complexity. The force F_{d} and C_0 of the redefined parameters after fixing the above parameters are as Table 2. Using Matlab to fit the relationship between F_{d}, C_0 and current I, the conclusion was drawn that F_{d} and C_0 were shown in a linear relationship as shown in (4).

Table 1. Results of each current parameter identification

I	C_0	A	f_0	F_{d}	K_0
0	0.627	51.076	1.933	50.828	1.011
0.3	1.638	25.390	2.213	296.779	1.397
0.6	2.893	10.572	7.864	541.569	2.028
0.9	3.695	6.977	12.600	734.848	2.217

Table 2. F_{d} and C_0 identification results

I	C_0	F_{d}
0	0.652	48.313
0.3	1.647	295.943
0.6	3.027	524.954
0.9	4.069	688.653

The total parameters of Dahl model with the modified Dahl model for the experimental magnetic MR dampers are shown in Table 3.

By identifying the parameters, the modified Dahl model of (3) can accurately describe the mechanical properties of the dampers used in the experiment, and describes the hysteresis characteristics of the MR damper. This expression reflects the relationship between the current and the output damping force in different states.

The damping force of the semi-active suspension can be obtained by adjusting the control current in the MR damper with the current generator.

Table 3. Modified Dahl model parameter identification results

Parameter	Numerical	Parameter	Numerical
A	23.504	$C_{0\mathrm{s}}$	0.604
f_0	6.152	F_{dd}	716.677
K_0	1.663	F_{ds}	66.961
$C_{0\mathrm{d}}$	3.878		

4. Semi-active suspension Fuzzy-PID control

The semi-active suspension system as a nonlinear time-varying systems, the conventional PID control parameters presented the dynamic adjustment shortcoming, thus the PID control and compound control method combined with other control methods. This study combines PID control with Fuzzy control to form Fuzzy-PID control. The principle is shown in Fig. 5, and the real-time correction of PID control parameters is realized by Fuzzy theory to meet the time-varying characteristics of the suspension system so as to achieve better control effect.

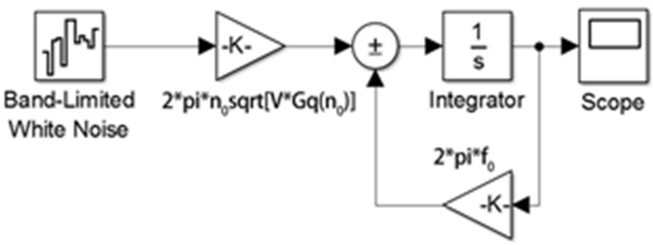


Fig. 5. Schematic diagram of Fuzzy-PID control

In this suspension Fuzzy-PID control, the difference between the real value and the default value of the body vertical velocity is selected as e, and the change rate is input to the Fuzzy controller as ec. Set the preset value to zero, at this point, e is the vertical speed of the body, ec is the vertical acceleration of the body. The output of fuzzy controller is the adjustment of the three parameters of PID controller, Δk_{p}, Δk_{i}, Δk_{d}, and through PID controller, the final k_{p}, k_{i} and k_{d} are obtained, and the output is adjustable damping force F. The relationship between k_{p}, k_{i}, k_{d} and Δk_{p}, Δk_{i} and Δk_{d} is shown in (5).

$$k_{\mathrm{p}} = k_{\mathrm{p0}} + \Delta k_{\mathrm{p}},\ k_{\mathrm{i}} = k_{\mathrm{i0}} + \Delta k_{\mathrm{i}},\ k_{\mathrm{d}} = k_{\mathrm{d0}} + \Delta k_{\mathrm{d}} \tag{5}$$

where k_{p0}, k_{rmi0}, k_{d0} are the initial parameters before the whole setting. The parameters of conventional PID control are selected, Δk_{p}, Δk_{i} and Δk_{d} are proportional, integral and differential coefficient adjustment k_{p}, k_{i} and k_{d} are the final PID controller parameters. In real life, the approximate range of the vertical velocity of the body is [-0.3, 0.3] m/s, and the vertical acceleration of the body is [-3, 3] m/s^2. The fuzzy field of input and output is as follows:

$$E,\ ec = [-3,-2,-1,0,1,2,3]\Delta k_{\mathrm{p}},\ \Delta k_{\mathrm{i}},\ \Delta k_{\mathrm{d}} = [0,1,2,3]\,.$$

The input and output variables are selected by the triangle membership function. Fuzzy reasoning using Mamdani method, a total of 3 × 49 control rules are established. The solution to blur is to use the center of gravity method, create a simulation model based on the above design, as shown in Fig. 6.

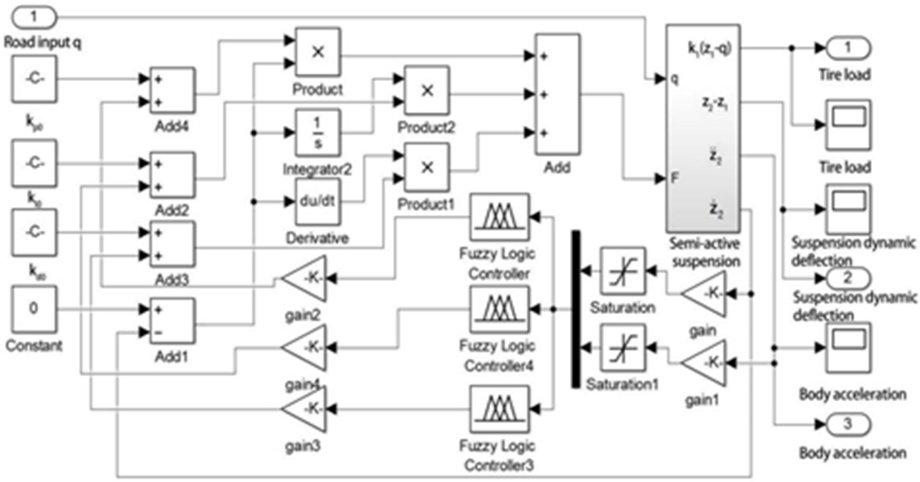
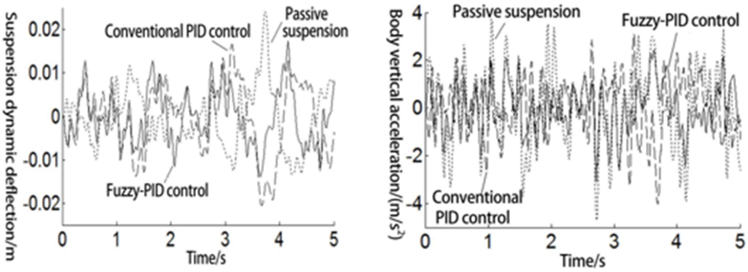


Fig. 6. Semi-active suspension Fuzzy-PID simulation model

5. Simulation analysis

From Fig. 7 and Table 4, when the vehicle travels with velocity of 25 m/s along B level road compared with the passive suspension, the performance response curve of semi-active suspension under the control of conventional PID control and fuzzy-PID control has dropped. Tyre dynamic load body vertical acceleration, suspension dynamic deflection and the root mean square of the conventional PID control was reduced by 4.8 %, 8.6 % and 9.3 %, respectively, Fuzzy-PID control makes the suspension performance indexes reduce by 13.5 %, 26.5 % and 13.5 % respectively.

Table 4. The root-mean-square of suspension performance



(a) Suspension deflection (b) Body vertical acceleration

Fig. 7. Simulation results of suspension three indicators

Control scheme	Body vertical acceleration m/s^2	Suspension dynamic deflection (m)	Tire load (N)
Passive suspension	1.365	0.007799	550.6
PID control	1.238	0.007129	524.2
Fuzzy PID control	0.9937	0.005731	476.3

6. Conclusion

In this paper, the vehicle semi-active suspension is simplified to obtain a two-degree of freedom and one-fourth vehicle dynamics model, and the road input model is established by using the integral white noise method. Then the mechanical test and the mechanical model of the adjustable damping force device of the semi-active suspension is studied. Then in order to reduce the suspension key performance indicators that tyre dynamic load body vertical acceleration, suspension dynamic deflection, for the purpose of the semi-active suspension design PID control and Fuzzy-PID control method, with simulation as an incentive for random road, compared with passive suspension at the same time, simulation experiment is carried out under the same roads in perfect condition. The results show that PID control and Fuzzy-PID control can improve the performance of semi-active suspension. Fuzzy-PID control is better than PID control for suspension performance, and provides reference for future research of automotive suspension.

References

[1] Z. Z. Peng, J. Q. Zhang, J. Yue, L. Zhang, D. Huang: *Design and analysis of magnetorheological damper with parallel normal holes.* Journal of mechanical engineering (2015), No. 8, 172–177.

[2] Z. L. Yang: *Analysis of PID control of semi-active suspension stability of automobile.* Journal of Chongqing University of Science and Technology (Natural Science Edition) *19* (2015), No. 5, 102–104.

[3] X. P. Wang, X. P. Chen, L. N. Ji, L. Wu: *Simulation study on two-degree-of-freedom semi-active suspension based on fuzzy PID control strategy.* Journal of Guangxi university of science and technology *28* (2015), No. 2, 35–41.

[4] J. H. Zhang, L. S. Hong, W. Z. Yang, et al.: *Overview of vehicle suspension system and its performance evaluation.* Mechanical design and research (2015), No. 6, 147–153.

[5] H. E. Tseng, D. Hrovat: *State of the art survey: Active and semi-active suspension control.* International Journal of Vehicle Mechanics and Mobility *53* (2015), No. 7, 1034–1062.

[6] M. Kaldas, K. Caliskan, R. Henze, F. Kücükay: *Rule optimized fuzzy logic controller for full vehicle semi-active suspension.* SAE International Journal of Passenger Cars - Mechanical Systems *6* (2013), No. 1, 332–344.

[7] D. Y. Pan, Y. Tang, P. C. Shi, et al.: *Application of fuzzy-PID switching control in magnetorheological semi-active suspension system.* Mechanical Science and Technology (2017), No. 2, 292–297.

[8] K. Jiang, T. Zhang, Z. X. Feng: *Semi-active damper suspension a ANFIS-PID control strategy in combination with the automatic machine processing technology.* Journal *9* (2016), No. 4, 80–82.

Received October 12, 2017