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Path tracking of Mr Fluid braking System based on PID control

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Abstract: With the rise of intelligent vehicle and driverless technology and the continuous improvement of vehicle speed, people have higher and higher requirements for vehicle safety performance. Mr Brake can be integrated with vehicle electronic control system to improve the corresponding speed of the braking system to a large extent and shorten the braking distance of the vehicle. This paper introduces the design theory and analysis of Mr Fluid. The working principle is introduced, and the torque required by the front and rear wheels of the vehicle braking process is deduced by the vehicle dynamics model. The Mr Fluid braking model based on PID control is built by using Matlab-simulink software. By tracking the straight line without fluctuation, the straight line with fluctuation and the right Angle path, the simulation results show that By adding PID control model to the magnetorheological braking control, it can effectively reduce the overshoot in the fluctuating route during the braking process, and the corresponding speed is faster and the path tracking effect is better, which provides an innovative thinking method for the development of vehicle brake and the development of driverless technology.

Keywords: Mr Fluid; PID; Matlab-simulink; Braking.

1. Introduction

In recent years, with the increasingly prominent energy and environmental problems, people's requirements for vehicles have been improved, and the development of the automobile industry has also put forward higher requirements for automobile braking system [1, 2]. At present, the mainstream braking system includes electronic hydraulic braking system and electronic mechanical braking system [3]. Mr Fluid braking system is a new linear control system available for electric vehicles. Using the advanced manufacturing technology of Mr Fluid and the special mechanical and magnetic properties of Mr Fluid, it can brake accurately and quickly, which puts forward an innovative idea and development direction for the development of vehicle brake [4, 5].

2. Design theory and analysis of Mr Fluid

2.1. Characteristics of Mr Fluid effects

The effect of Mr Fluid refers to that the viscosity of the fluid changes greatly under the action of the magnetic field. When the Mr Fluid reaches a critical value, the fluid no longer flows into a solid, and maintains its shape or has certain shear resistance. At the same time, it also has the unique yield phenomenon of solid.

Under the action of magnetic field, the viscosity of Mr Fluid increases with the increase of magnetic field intensity. When the critical magnetic field intensity is reached, the flow stops and becomes solid. However, when the magnetic field intensity is weakened, the Mr Fluid can become a fluid and return to the original viscosity.

Under the action of magnetic field, the Mr Fluid-solid liquid conversion is reversible and controllable, and requires less energy.

2.2. Working principle of Mr Fluid

When the magnetic fluid flows through the excitation coil with incoming current, the magnetic field passes through the magnetic fluid. Therefore, the magnetic fluid will produce needle-like bulge along the direction of the magnetic field. After the magnetic field passes for several hours, the magnetic fluid will change from the bulge state to the free-flowing state (Figure 1).

Figure 1. Magnetic liquid-solid transformation

According to its basic principle, Mr Fluids work in three modes: flow mode, shear mode and extrusion mode.

For the flow mode, the Mfluid is located between two sufficiently large plates that remain relatively stationary. There is a pressure difference between the front and rear sides of the liquid, which enables the mfluid to flow between the plates and thus create a certain friction force between the plates. This mode is commonly used in current dampers and shock absorbers. For the shear mode, the magnetic fluid is located between two plates in relative motion, and the magnetic chain generated in the magnetic fluid is constantly broken under the shear of two plates in relative motion, which is manifested as shear stress on a macro level, hindering the relative motion of two plates. Currently, the devices that apply this working mode include clutch, brake, etc. For the extrusion mode, the Mr Fluid is squeezed by the proximity of the relative position between the two plates. It is usually applied to vibration dampers with small motion and large damping force.

2.3. Derivation of braking torque of Mr Fluid brake

In the actual working process, Mr Fluid is complicated and affected by many small factors. In order to simplify the calculation of braking torque, our team makes the following assumptions about Mr Fluid brake:

(1) The velocity of Mr Fluid is only related to the radius.

(2) Although the Mr Fluid is affected by gravity and centrifugal force, it is still evenly distributed in the working gap of the brake.

(3) Under the influence of time and temperature, the basic properties of Mr Fluid remain stable and do not change.

(4) The volume of Mr Fluid is incompressible.

(5) Ignore the influence of Mr Fluid injection channel on brake performance.

For the disc Mr Fluid brake, the effective working face in the braking process is a torus (Figure 2).

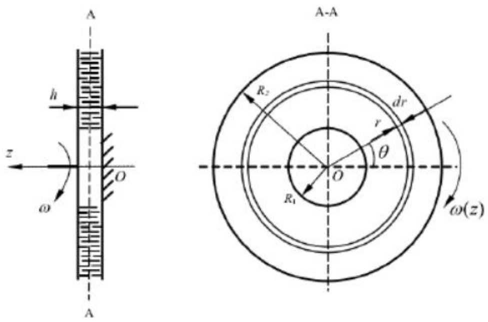

Figure 2. Disc brake torque analysis and calculation diagram

The shear strain rate at any point on the working surface can be expressed as:

$$\gamma = \frac{r\omega}{h} \quad (1)$$

r represents the radius of rotation of the selected point. ω represents the rotational angular velocity of the torus. h represents the working clearance of the Mr Fluid brake. A miniature torus with radial width is taken at radius r, and its area dA can be calculated as follows:

$$\mathrm{dA} = 2\pi \mathrm{rdr} \quad (2)$$

In this case, the force dF generated by the miniature torus is:

$$\mathrm{dF} = \tau \times \mathrm{dA} \quad (3)$$

The acting moment dT generated by the miniature torus is:

$$\mathrm{dT} = \mathrm{r} \times \mathrm{dF} = 2\pi\tau \mathrm{r}^2 \mathrm{dr} \quad (4)$$

By integrating the braking torque generated by the miniature torus, the braking torque generated by the Mr Fluid brake on torus R_1 to R_2 can be obtained as follows:

$$\mathrm{T} = \int_{R_1}^{R_2} 2\pi\tau r^2 dr = 2\pi \int_{R_1}^{R_2} [\tau_y(B) + \gamma\eta] r^2 dr = \frac{2\pi}{3}\tau_y(B)(R_2^3 - R_1^3) + \frac{\pi\eta\omega}{2h}(R_2^4 - R_1^4) \quad (5)$$

Considering that the above equation is only an analysis of a disc surface, while the Mr Fluid brake has two working faces, the total braking torque is:

$$\mathrm{T} = \frac{2\pi}{3}\tau_y(B)(R_2^3 - R_1^3) + \frac{\pi\eta\omega}{2h}(R_2^4 - R_1^4) \quad (6)$$

The braking torque $T_m = \frac{4\pi}{3}\tau_y(B)(R_2^3 - R_1^3)$ is mainly controlled by the magnetic field intensity of Mr Fluid and belongs to the controllable part, while the braking torque $T_m = \frac{\pi\eta\omega}{2h}(R_2^4 - R_1^4)$ is determined by the vehicle speed, the working gap of Mr Fluid, the viscosity of Mr Fluid and the radius of brake disc, and belongs to the uncontrollable part of the braking torque. Therefore, in the design of Mr Fluid brake, the controllable part should be adjusted around.

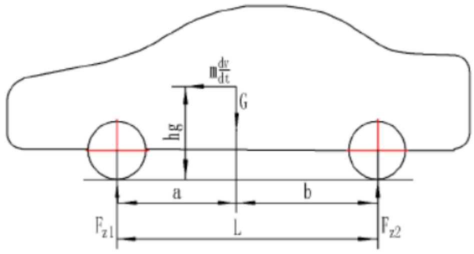

Figure 3. Automobile brake force diagram

According to the vehicle dynamic model (Figure 3), the balance equation of front and rear wheel torque can be written:

$$\begin{cases} F_{Z1}L = Gb + m\frac{dv}{dt}h_g \\ F_{Z2}L = Ga - m\frac{dv}{dt}h_g \end{cases} \quad (7)$$

When the car is locked on the road surface with adhesion coefficient is, the sum of braking force generated by the vehicle is equal to the adhesion of the road surface to the wheel, and the braking force $F_{\mu1}$ and $F_{\mu2}$ generated by the front and rear wheels of the vehicle are equal to the respective adhesion of the road surface:

$$\begin{cases} \mu G = F_{\mu1} + F_{\mu2} \\ F_{\mu1} = \mu F_{Z1} \\ F_{\mu2} = \mu F_{Z2} \end{cases} \quad (8)$$

By combining the above two formulas, we can get:

$$\begin{cases} F_{\mu1} = \mu\left(\frac{mgb}{L} + m\frac{d_v}{d_t}\frac{h_g}{L}\right) \\ F_{\mu2} = \mu\left(\frac{mga}{L} - m\frac{d_v}{d_t}\frac{h_g}{L}\right) \end{cases} \quad (9)$$

At this time, the distance between the wheel axle and the ground is R_r, so the maximum braking torque of the front, rear and axle of the vehicle is M_1 and M_2 are:

$$\begin{cases} M_1 = \left(\frac{mgb}{L} + m\frac{dv}{dt}\frac{h_g}{L}\right)\mu R_r \\ M_1 = \left(\frac{mga}{L} - m\frac{dv}{dt}\frac{h_g}{L}\right)\mu R_r \end{cases} \quad (10)$$

3. Establishment of simulation model of Mr Fluid braking system

3.1. PID braking system model

Since the Mr Fluid brake itself does not have a braking system, the braking torque can be adjusted through its own control of the current in the electromagnetic coil, so as to realize the braking process. The PID model has a simple algorithm, good robustness and high reliability. Figure 4 shows the adaptive variable damping controller model.

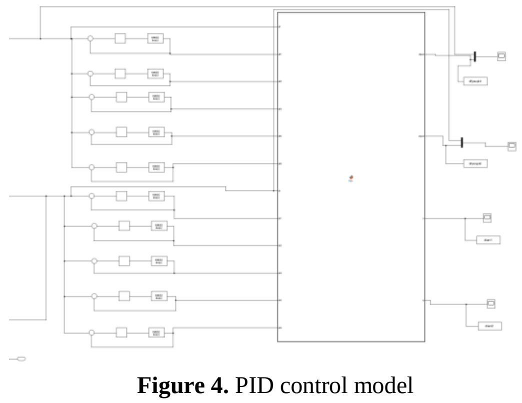

Figure 4. PID control model

This paper simulates an electric vehicle, and its relevant parameters are shown in the following table 1.

Table 1. Correlation parameter table

Name	Code name	Unit	Numerical value
total mass	m	Kg	1710
wheelbase	L	Mm	2730
height of center of mass	h_g	Mm	0.8
horizontal distance from center of mass to front axle	a	Mm	1530
horizontal distance from center of mass to rear axle	b	Mm	1200
front axle load	m_f	Kg	1020
rear axle load	m_r	Kg	690
wheel rolling radius	R_r	Mm	345

3.2. Straight-line path tracking

3.2.1. Undulating line tracking

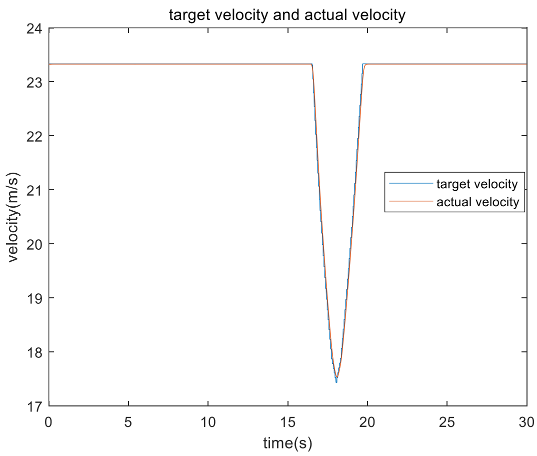

Figure 5. Target speed and tracking speed

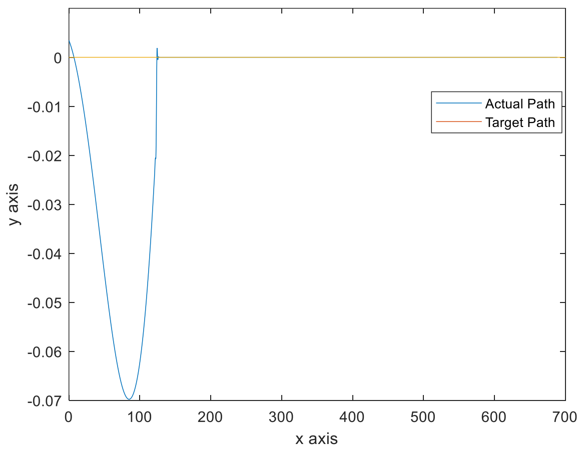

Figure 6. Target path and tracking path

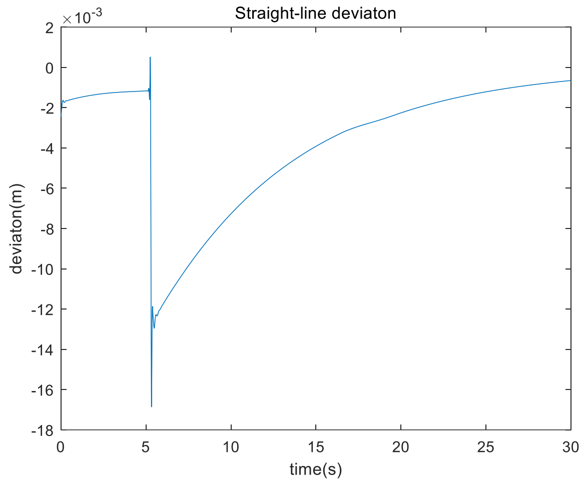

Figure 7. Deviaton

In the linear path without fluctuation, the linear path can be well tracked under the condition that the speed can be reasonably tracked in the control model without overshoot. The maximum control error is within 10cm, which can be well applied to the path tracking of the linear path without fluctuation (Figure 5, Figure 6 and Figure 7).

3.2.2. Linear path tracking with fluctuation

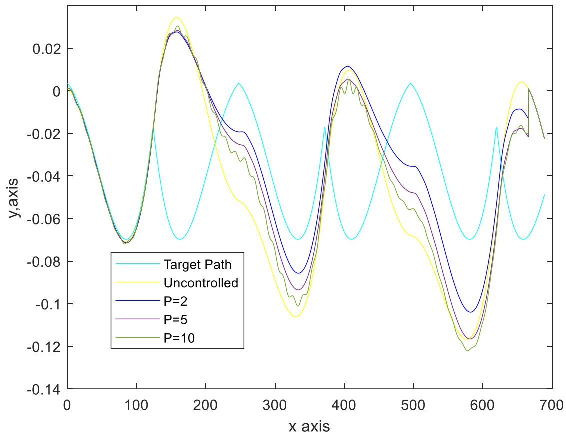

Figure 8. Target path and tracking path

Considering that it is ideal for the vehicle to keep a straight line completely in the process of straight driving, this paper simulates the linear path to track the relevant fluctuations. Under the PID control model, I=0 and D=3 are maintained, and the Mr Fluid is controlled by adjusting P. According to the results, under the PID control model, It can well reduce the overshoot of the car in deceleration swing, and can better track the path with a straight line of fluctuation (Figure 8).

3.3. Limit right-angle path tracking

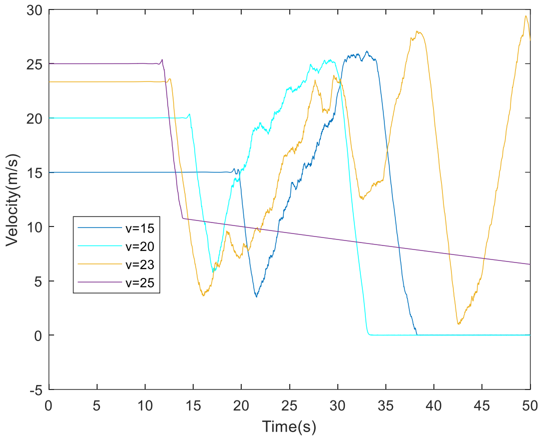

Figure 9. Target velocity and tracking velocity

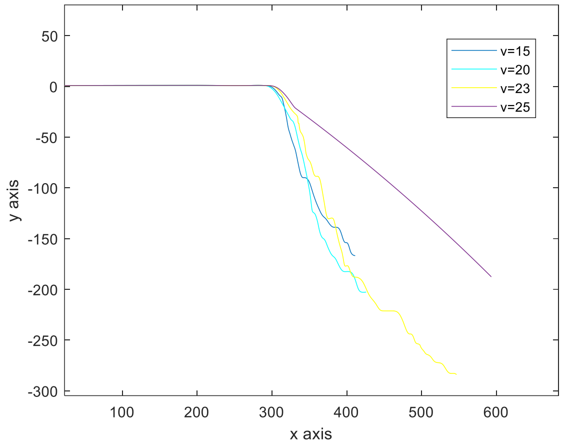

Figure 10. Target path and tracking path

In the path simulation of limit right-angle turn, PID model braking control is carried out on the car by giving different initial speeds to the car. The results show that the car can adjust its own speed adaptively to plan a path to the final point (Figure 9 and Figure 10).

4. Summarize

In summary, by introducing the design theory of Mr Fluid and correlation analysis, this paper introduces the working principle of Mr Fluid, deduces the braking torque of Mr Fluid brake, obtains the braking force torque of front and rear wheels through the vehicle dynamics model, and establishes a braking system model based on PID control to track the road surface without fluctuation and the road surface with fluctuation and the right-angle turning path. It can fully reduce the overshoot of the vehicle in the process of braking deceleration, and better track the target path, thus increasing the development space of the vehicle driverless.

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