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Research and Application for Hydraulic Pressure Anti-lock Brake System Based on Fuzzy PID Control

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Abstract: Contraposing the current application of Anti-lock brake system in hydraulic pressure brake system, a new control strategy is brought forward. The brake characteristics of hydraulic pressure system and instantaneous dynamics of wheels are analyzed. On the base of relevant math model, simulation models are upbuilt by making use of MATLAB/SIMULINK. In order to keep yarage and improve brake efficiency, and considering the nonlinearity, time variant and uncertainty of ABS, the fuzzy control theoretics is adopted. For the shortage of single fuzzy controller, the fuzzy PID controller is designed. The fuzzy controller is optimized by traditional PID controller because of its better control precision. Simulation results indicated that the fuzzy PID controller gets the wheels obtain perfect circumrotate state in brake process all the time, ensures the vehicle having preferable direction maneuverability, stability, and also shorten the brake distance comparatively.

Keywords: Anti-Lock Brake; Hydraulic Pressure; Fuzzy Control; PID Controller; Simulation

1. Introduction

Anti-lock brake system(ABS) is one electromechanical liquid integrative device, which adopts electronic control technology, on the basis of traditional brake systems, controlling the slipratio in the reservation range through the automobile tire brake course, accordingly, improving the brake efficiency and transverse stability as well as the direction yarage[1].

To the hydraulic pressure ABS system, the controllers designed are used for controlling the change of the brake pressure mainly: When the biggish electric current enter into electromagnetic valve, the thoroughfares between master cylinder and wheel cylinder are blocked, wheel cylinder and hydraulic pressure fuel tank communicate, and the brake liquid stream from the former into the latter, so that, the brake pressure is reduced immediately. Meanwhile the driving electromotor start, drive the work of the hydraulic pump. The brake liquid flowed back to hydraulic pressure gasoline tank is forced and transported to master cylinder, which is prepared for the next one cycle; When entering smaller electric current openly for the electromagnetic valve, all thoroughfares are blocked, so that the brake pressure can be keeped; After the electromagnetic valve cuts out, the high pressure brake liquid(including the brake liquid exported from hydraulic pump)in master cylinder, Enter into wheel cylinder again, increasing the brake pressure. The speed of pressurization and decompression can be controlled through electromagnetic valve turnover oil.

ABS is a time-variable, non-linear and uncertain system. The control strategy is developed gradually from single control mode, such as PID control, fuzzy control, neural control, and so on, based on acceleration and deceleration logic threshold , or slip, to omnibus control mode, which integrate many kinds of control strategy. The designed fuzzy PID controller contraposing ABS, in this text, is a hybrid control mode, combined the advantage of single fuzzy control and PID control. This hybrid control system could take full advantage of the two kinds of control strategy, and achieve better control result.

2. ABS Dynamic Model

(1)Whole Vehicle Model

A seven degrees of freedom(including the rolling of four wheels, vehicle body lateral swing, longitudinal and lateral movement) vehicle model is established as Fig.1.

Considering the influence of tire rolling resistance and Aerodynamic drag forces, the basic equations about vehicle movement[2] are expressed as follows:

$$f_x = -\left[\left(F_{x1}+F_{x2}\right)\cos\delta + \left(F_{y1}+F_{y2}\right)\sin\delta + F_{x3} + F_{x4} \right]$$

$$f_y = \left[-\left(F_{x1}+F_{x2}\right)\sin\delta + \left(F_{y1}+F_{y2}\right)\cos\delta + F_{y3} + F_{y4} \right]$$

$$M_z = \left\{ B_f\left[\left(F_{x2}-F_{x1}\right)\cos\delta + \left(F_{y2}-F_{y1}\right)\sin\delta \right] + B_r\left(F_{x4}-F_{x3}\right) \right\}/2$$
$$+a\left[\left(F_{x1}+F_{x2}\right)\sin\delta - \left(F_{y1}+F_{y2}\right)\cos\delta \right] + \left(F_{y3}+F_{y4}\right)b$$

$$M\left(\dot{v}_x - \dot{\varphi}\cdot v_y\right) = f_x$$

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$M\left(\dot{v}_y+\dot{\varphi}\cdot v_x\right)=f_y$

$I_z\cdot\ddot{\varphi}=M_z$

Where f_x 、 f_y denote longitudinal and lateral force of the vehicle, F_{xi} 、 F_{yi} denote friction produced by every wheel and ground, v_x 、 v_y 、 M_z 、 φ denote longitudinal and lateral velocity, moment of inertia and angular velocity of lateral swing, B_f、 B_r denote front and rear tread, M is total vehicle mass, I_z is the rotational inertia of the whole vehicle.

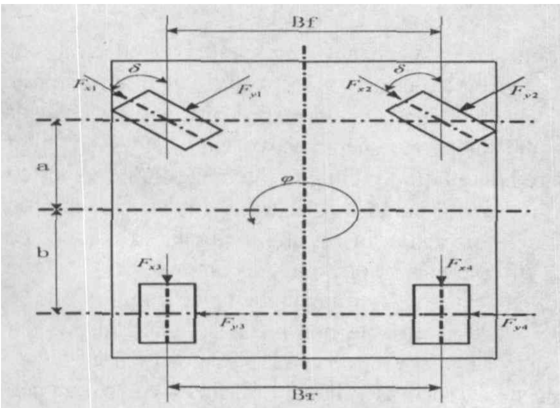

Fig.1. Vehicle Dynamic Model

(2)Tire Model

The differential eguations describing the rolling of four wheels are as follows[3]:

$$\dot{\omega}_i=\left(F_{xi}R_i-M_{bi}-M_{fi}\right)/I_{\omega i} \qquad i=1\sim 4$$

Where $\dot{\omega}_i$ is wheel angular acceleration, I_{wi} is wheel rotational inertia, M_{bi} is wheel brake torque, M_{fi} is wheel rolling resistance torque, R_i is wheel effective radius.

Wheel slip is defined as follow:

$$S=1-\omega\cdot R_i/v_x \quad , \quad a=\left|\sin(\arctan(v_y/v_x))\right|$$

Where Sand a are wheel longitudinal and lateral slip.

The relation about longitudinal coefficients of friction and slip between wheel and ground is expressed by bilinear model as Fig.2 (μ_x).

The function relations are as follows:

$$\begin{cases} \mu=\mu_h\cdot S/S_T & S\le S_T \\ \mu=\left[\left(\mu_h-\mu_g\cdot S_T\right)-\left(\mu_h-\mu_g\right)\cdot S\right]/(1-S_T) & S>S_T \end{cases}$$

Where μ、 μ_h、 μ_g denote accrete coefficient, peak value accrete coefficient, slippage accrete coefficient, S、 S_T denote slip and expected slip.

The relation about lateral coefficient of friction and slip adopts complex curve to express, as Fig.2 (μ_y).

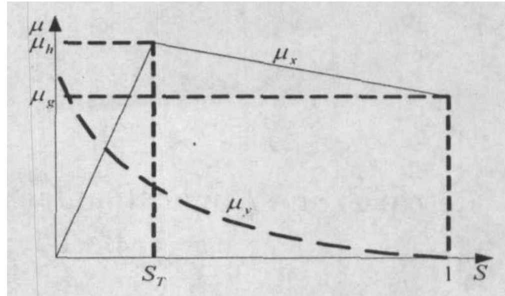

Fig.2. Tire Characteristic Curves

(3) Arrester Model

Setting up arrester model, the purpose is to establish the relation between the wheel brake moment and the brake pressure in arrester. The brake pressure gathered in separate wheel pump is regarded the input value of wheel brake pressure directly, when simulate. It cut off driver to control the brake pipeline pressure when ABS is working, and the wheel brake pressure is controlled directly by pressure adjustment[4], which is installed near brake pipeline. Therefore, the brake pressure value is produced by control algorithm of ABS controller.

3. Design of Fuzzy Controller

The control collocation, for simulation model, 4 channelses and 4 sensors of 4 wheels are adopted separately. The structure of every control channels is showed in Fig.3.

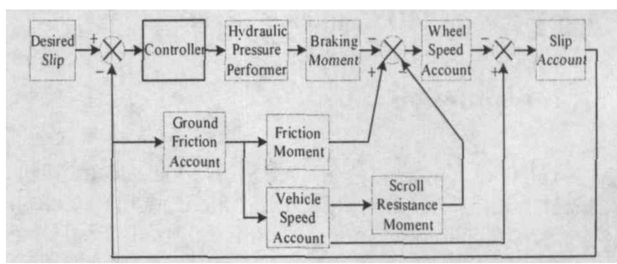

Fig.3. Structure of Single Control Channels

ABS fuzzy controller that this text design make wheel slip maintain nearby goal slip, in the hope of obtaining better brake performance, and transverse stability is within the range that is required. Slip control is one continuous quantity control, can adopt PID and optimized controlling etc.. Though PID method is simple and practical, but its parameter need be matched according to system situation, however, it is difficult to match parameter for vehicle operating mode levity and tire non-linearity. Fuzzy control can adapt the inconstant working situation and non-linear system.It also have the advantage of strong roburst.

The wheel slip error(e) and its change frequency (ec) are used as exact inputs of fuzzy controller. Mutative amount (Δ p) of brake pressure is used as exact output[5][6]. Slip error is defined as the difference between desired slip S0 and actual slip S. The e, ec and Δp are quantized in selected basic domain separately, thus get fuzzy inputs E and EC, as well as fuzzy output ΔP, in corresponding quantizated domain.

The domain and membership function of fuzzy controller variable are showed in Fig.4. Fuzzy controller input variable adopt E and EC. The ΔP of braking gasoline pressure in separate pump is used as output variable. Fig.4a,Fig.4b,Fig.4c show the memberships of two input variables and one output variable respectively. In order to obtain higher sensitivity, every variable membership adopts triangular function, and grades as follows:

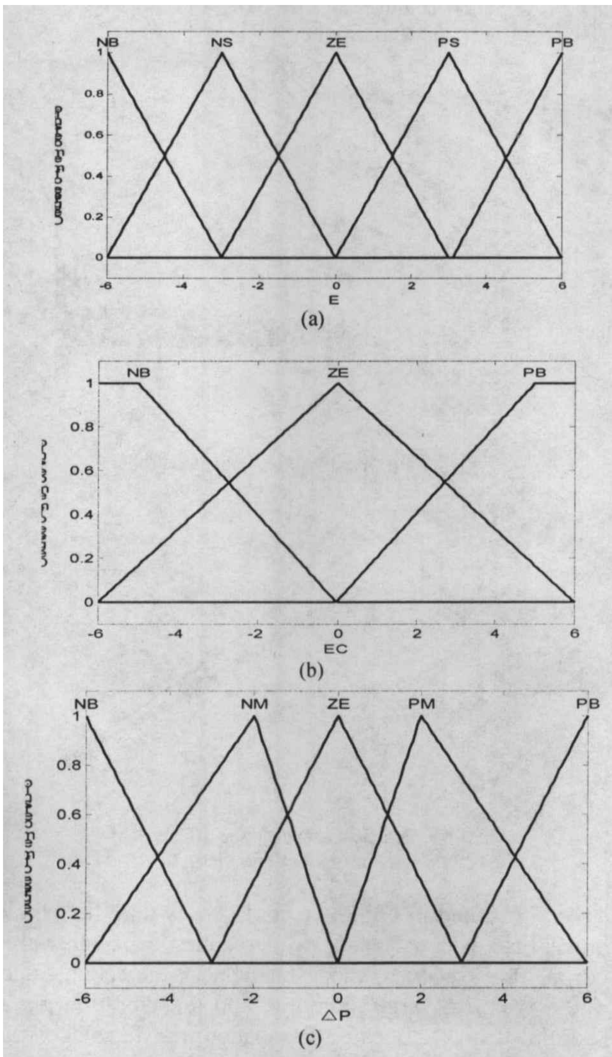

Fig.4. Degrees of I/O Variable Memberships

E is divided into five grades: "NB, NS, ZE, PS, PB"

EC is divided into three grades: "NB, ZE, PB"

ΔP is divided into five grades: "NB, NS, ZE, PS, PB"

In Fig.4, every variable membership function is graded less, for preventing too much rule from control course respond slowly. Comparatively, we hope variable EC is a little smaller to the susceptibility that is outputted, so it is tertiary to only divide it into. In order to improve the sensitivity of controlling, high- distinguishing fuzzy sets are adopted in less error areas, and low-distinguishing fuzzy sets are adopted in bigger ones, so that the system hold better stability. Consequently, more close to the zero point, more control strategy is adopted by the membership function of variable ΔP.

Setting up ABS fuzzy control rules is to express the experience relation, when ABS is working, between input and output variable as logic consequence rules between input and output linguistic variable. The number of the rules in control rule set is confirmed by both the input language variable number and number of its membership. The fuzzy rules that this text adopts are showed in table 1. Fuzzy logic of the four channels adopt the same control rules. The fuzzy logic organon adopts Mamdani maximum and infinitesimal consequence, and the barycenter method is adopted in defuzzification.

Table1. Fuzzy Logic Control Rules

EC	E				
	NB	NS	ZE	PS	PB
NB	PB	PB	PS	ZE	ZE
· ZE	PS	PS	ZE	ZE	NS
PB	ZE	ZE	NS	NS	NB

The simulation results, on the basis of fuzzy control, are showed in Fig.5 and Fig.6. The initial condition is set as V0=30km/h. In these figures, FL、FR、RR、RL express left front wheel, right front wheel, left rear wheel, right rear wheel respectively. Vx is vehicle velocity.

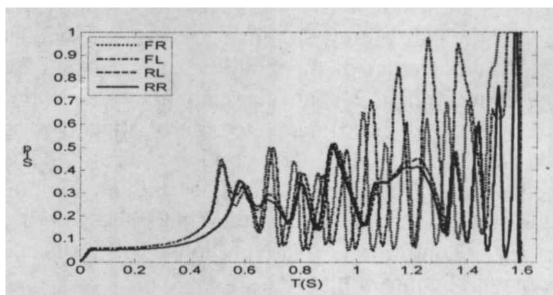

Fig.5. Slip Curves of Fuzzy Controller

Analysing the slip curve, vehicle velocity and wheel velocity cueves in the tow figures, we transpire that, adopting fuzzy control could restrict actual slip closed to the desired one, prevent wheels locking and get the vehicle not beyond controlling. However, the slip fluctuates greater near expected value. This proves that fuzzy controller is lower in control precision, as well as

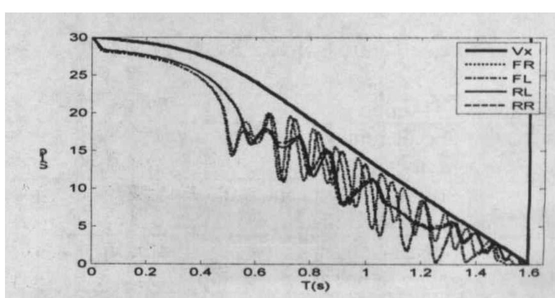

Fig.6. Vehicle and Wheel Speed Curves of Fuzzy Controller

The ability to avoid systematic stable state error. In order to overcome the defect produced by single fuzzy control, PID controller is made use of to improve the precision of controlling.

4. Design of Fuzzy PID Controller

The design idea of fuzzy PID controller is that: When slip error is greater, fuzzy control is adopted, because of its predominance in celerity and strong anti-jamming ability. When slip error is less, PID control method is adopted, for its predominance in better stability and higher control precision. The structure of ABS, on the basis of fuzzy PID control, is showed in Fig.7.

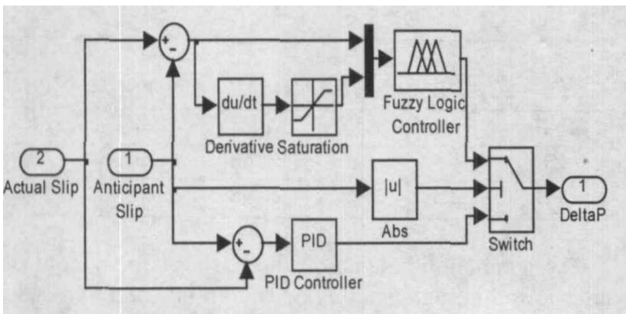

Fig.7. Structure of Fuzzy PID Controller

In this text, the absolute value of slip error is adopted as the threshold. When it is less than threshold, PID control is adopted, otherwise, fuzzy control method is adopted. The selection of threshold affect the length of working time both PID controller and fuzzy controller directly, and take great influence to control effect. If it is choosed too big, the controller working time of PID is relatively long, and will influence the systematic characteristic of moving. If it is too small, the working time of fuzzy controller is relatively long, will influence the precision of controlling.

5. Simulation Results and Analyzing about Fuzzy PID Controller

The initial condition is V0=30km/h, the controller threshold is set as 0.08. The simulation results are showed in Fig.8 to Fig.11. The vehicle brake data[7] is showed in table 2.

Table 2. Vehicle Brake System Data

Symbol	Meaning	Value
g	acceleration due to gravity	9.8N/m
a	distance from center of gravity to front axle	1.220m
b	distance from center of gravity to rear axle	1.255m
h_s	height of the sprung mass	0.6m
h_f	eight of front unsprung mass	0.25m
h_r	height of rear unsprung mass	0.3m
M	total mass of the vehicle	1500kg
m_s	sprung mass of the vehicle	1342kg
m_f	front unsprung mass	90kg
m_r	rear unsprung mass	119kg
I_f	moment of inertia of the front wheel	0.6856kgm^2
I_r	moment of inertia of the rear wheel	1.4852kgm^2
R	radius of tire	0.326
I_z	moment of inertia of the whole vehicle	1735kgm^2

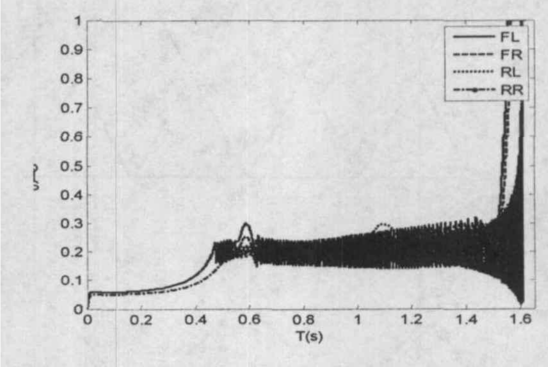

Fig.8. Slip Curves of Fuzzy PID Controller

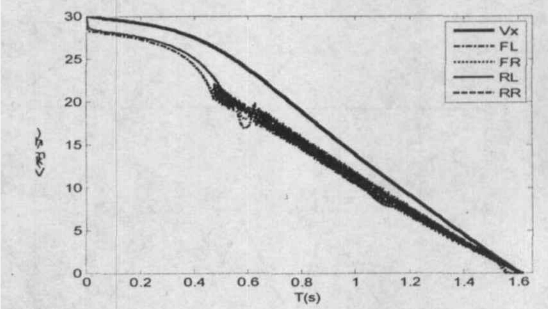

Fig.9. Vehicle and Wheel Speed Curves of Fuzzy PID Controller

As illustrated in Fig.8, we could know that, the whole brake time is 1.6seconds. Slip reaches expected value during 0.45 seconds, then steady near expected value. There is no too large dithering, and the vibration range keep in -0.1~0.1. Because the loaded transfer makes the friction produced between wheel and ground change greater, in the course of turning brake, in the condition of considering transverse movement only, and ignoring list and pitching movement, it will lead to the fact that where will be a little error in the distribution of brake force certainly. As a result, the front wheels have the tendency to lock in the in the 1.56 second, and the rear wheels still run well. We can know from the Fig.9 that, after ABS begins to work ,wheel velocity could well follow vehicle velocity. Wheels keep on decelerating stage for its slip as well as rolling all the time, so that the direction stability of the vehicle body can be controlled. Compared with single fuzzy controller, the steady error of fuzzy PID controller is obviously lower, and brake stability is better.

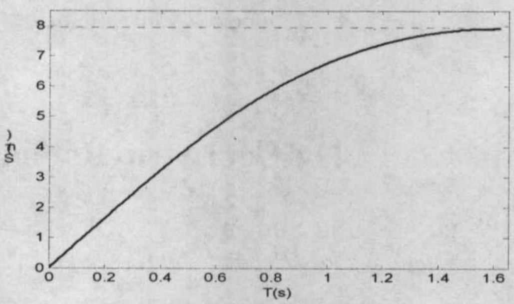

Fig.10. Brake Distance

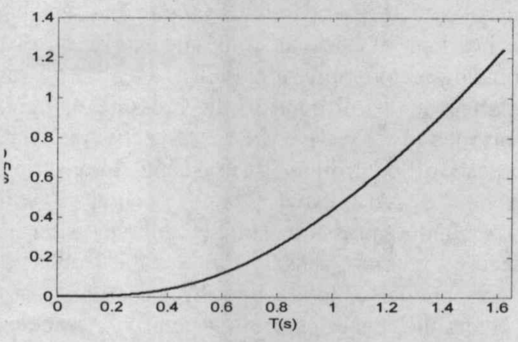

Fig.11. Lateral Offset of Vehicle

As showed in Fig.10 and Fig.11, the brake distance is 7.9 meters and lateral offset of vehicle is 1.22 meters. The brake distance is not very ideal, the reason is that, in the beginning of brake, ABS is not working, so that the wheel speed drop slowly, and prolong the distance appreciably . The lateral offset of vehicle is within the allowable range[8]. This proves that Fuzzy PID controller could control the direction stability and yarage better.

6. Conclusion

This text, through the research of vehicle brake model, considering the non-linear and uncertainty of ABS model, one fuzzy controller was designed, and carried on simulation to the system, and then analysed the simulation result. The simulation result proves that the fuzzy controller could control the vehicle brake effectively. Considering the limitation of fuzzy controller in controlling precision, fuzzy PID controller was designed, in the condition of adopting the same fuzzy rules. The simulation result indicates that, fuzzy PID controller makes the wheel keep in the more ideal rotation state all the time in the brake course, guarantees better performance of handing direction, stability and brake capability. It proves that fuzzy PID controller can achieve more ideal brake control performance.

Reference

[1] Michael A. Mollenhauer, Thomas A. Dingus, Anti-lock Brake Systems: An Assessment of Training on Driver Effectiveness , Accident Analysis & Prevention, 29, No.1 (1997) 97.

[2] G. Z. Zhao, Z. D. Fang, Study of Sliding Model Control for Vehicle Dynamic Stability System, China Mechanical Engineering, 14, No.2 (2003) 152. (in Chinese)

[3] H Liang, K T Chong, Vehicle Longitudinal Brake Control using Variable Parameter Sliding Contrl, Control Engineering Practice, No.11 (2003) 403.

[4] J. Sun, Simulation of Anti-lock Brake System Based on Fuzzy Control, Computer, 21, No.10 (2004) 160. (in Chinese)

[5] K.H.Guo, H.Y. Wang, Application of Fuzzy Control in Anti-lock Brake System, Design-Calculation-Research, No.3 (2000) 7. (in Chinese)

[6] Will A.B, Antilock Brake System Modeling and Fuzzy Control, Vehile Design, 24, No.6 (2002) 633.

[7] S G Kong, B Kosko, Adaptive Fuzzy System for Braking up a Truck-and-Trailer, IEEE Trans on Neural Networks, 3, No.2 (1992) 211.

[8] Nagai Masao, Shino Motoki Gao, Study on Integrated Control of Active Front Steer Angle and Direct Yaw Moment, JSAE Review, No.23 (2002) 309.