Study on Fuzzy PID Algorithm for a New Active Front Steering System

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Abstract-**Based on the structure and principle of a new active front steering system (AFS), the control strategy and algorithm of active front steering system are analyzed and the dynamic model of AFS is established. In order to improve the AFS steering characteristic, the PID controller and Fuzzy-PID controller are discussed. The simulation results show that rising time of the new control strategy is reduced a lot compared with traditional PID algorithm. The system performance is optimized and the fast tracking of AFS system is realized.**

Keywords-active steering; control strategy; Fuzzy-PID control

I. INTRODUCTION

The development of modern vehicle steering system has experienced five stages: the mechanical steering system (MS); hydraulic steering system (HPS); electro hydraulic power steering system (EHPS); electric power steering system (EPS); active steering system (AFS)[1]. Active front steering system can realize steering intervention independent of the driver, optimize vehicle's response to driver's input and enhance the stability in emergencies by add an additional steering angle to the input of driver. In low-speed section, reduces steering gear ratios, in order to achieve steering lightweight and flexible requirements; In High speed section, increases the steering gear ratios, in order to enhance the high-speed steering stability. So far as safety and steering feelings are concerned, active front steering is a main trend of the development of current steering system [2-4].

II. THE FRAME AND PRINCIPLE OF AFS

With the maturity and widespread use of the vehicle electric power steering system (EPS), the active front steering system (AFS) has become the hotspot of research and development."Active Steering" improves the vehicle handling performance and handling stability, and prepares for the implementation of the future autopilot, automatic collision avoidance and autonomous navigation.

As a new technique, the principle of AFS is add an additional angle to the steering wheel input by motor, so as to improve the stability, maneuverability and keep track ability.Figure1 shows the physical construction of AFS[5]. According to different angle superposition style, AFS can be classified into two styles: mechanical AFS and electronic AFS. AFS retains the mechanical components of traditional steering system including steering wheel, steering column, steering rack, pinion institutions, steering tie rod and etc.

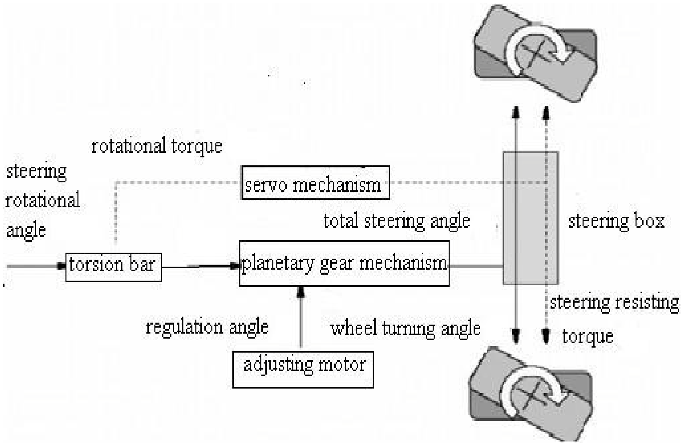

Figure 1 Structure of AFS

Beyond that, AFS mainly includes two core components: a set of planetary gears which are used to change the drive ratio by applying an additional angle to steering box; Electronic servo steering system, which provides assist steering power for driver. Driver's steering input can be divided into torque input and angular input, both will be passed to the torsion bar. The input angle is added to the dual planetary gear mechanism. Figure2 shows the steering angle superposition principle.

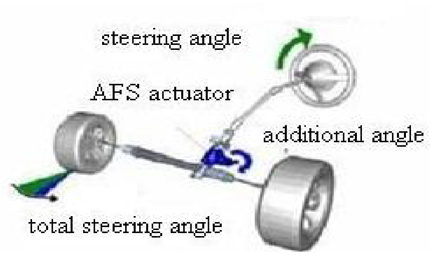

Figure 2 Corner Superposition Principle

The significant difference with conventional steering system is that AFS can not only adjust steering torque, but also regulate the steering angle and make it match the current vehicle speed perfectly.

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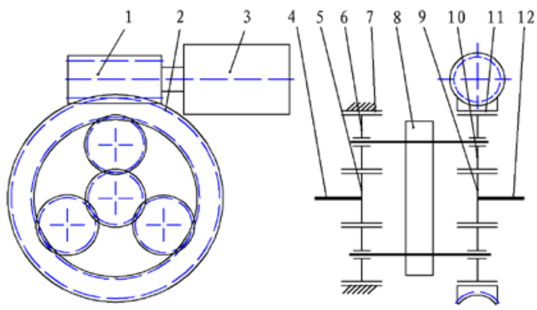
Active Steering technology research currently focuses on Steer by Wire system (SBW) and mechanical active front steering system (AFS). Although SBW has been studied extensively by many top auto firms, the problem of safety and reliability has not been solved. Hardware redundancy is costly and limits the promotion of SBW. In 2002, ZF and BMW AG developed a new active front steering system, which enabled driver dependent as well as automatic steering interventions and resolved the problem of SBW above successfully.

The BMW's steering system consists of the hydraulic steering booster and the AFS actuator. Figure3 shows the components and subsystems of the latter. The actuator includes the planetary gear set with two mechanical inputs and a single mechanical output. The steering wheel is fixed on the input shaft (4). The second input shaft is driven by the motor (3) and is connected to the planetary gear set's carrier (that is the worm wheel (2)) which is fixed on the inner gear (11) [6]. As long as the planetary set's carrier remains fixed, the input shaft input rotation is faithfully conveyed to the output shaft (12) without alteration, that means the transmission ratio of the input shaft to the output shaft equals to 1. When the steering wheel is fixed on, the operation of steering can be implemented by controlling the motor. In the normal state, the motor and the steering wheel operate at the same time for changing the transmission ratio and stability control.



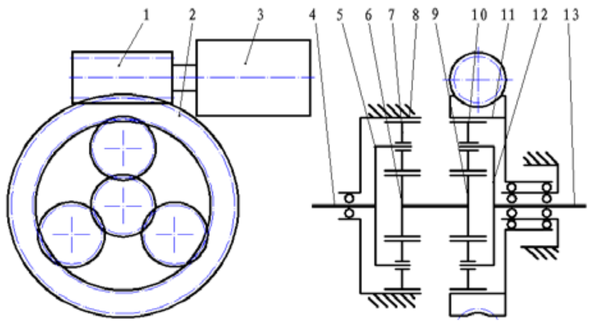
1. worm, 2.worm wheel, 3. motor, 4.input shaft, 5, 9.sun wheel,6,10. planet wheel, 7,11.inner gear, 8. planetary carrier, 12.output shaft

Figure 3 Schematic Representation of the BMW AFS Actuator

The principal of the BMW AFS actuator is that it relates an electronically controlled superposition of an angle with the hand steering wheel angle that is prescribed by the driver. If the motor breaks down, the steering system can be operated as the common one, because the permanent mechanical connection between steering wheel and road wheels remains. So the BMW AFS combines the advantages of an electronically controlled superposition of an additional angle to the steering wheel angle with the reliability of a permanent mechanical connection between the steering wheel and the road wheels [7].However, the actuator is mounted in the compact engine room. Due to the limited space, the steering system may easily interfere with other components. Therefore, the smaller the device is designed, the better the installed positions and shapes are. Besides, owing to that the heart of the BMW AFS is the planetary gear train incorporated into the steering column, so the gear clearance is inevitable and affects the rotational positioning accuracy of the output shaft. Based on the above issues, a new active steering actuator is introduced in this paper. Compared with the BMW AFS actuator, the volume of the new device is obviously reduced , the transmission efficiency is increased, the rotational positioning accuracy is improved, the manufacturing cost is cut down.

III. STRUCTURE OF THE NEW AFS ACTUATOR

The new AFS actuator is similar to the BMW's, but the drive route is different. The components and subsystems of the new device are as follow (see figure 4): a motor, a worm couple and a superposition gear system (a pair of NGW planetary gear sets). The aforementioned planetary gear train blends mechanical and electrical steering commands. At its left end, a planetary pinion carrier (5) is rotated by steering wheel motion. That gear meshes with three planet gears which in turn drive a second planetary pinion carrier (12) attached to the output shaft (13). It's a 2-DOF system that the steering wheel fixed on the input shaft controls one DOF and another DOF is controlled by the motor (3). When the motor is braked, the AFS actuator is the same as the normal steering system (const transmission ratio). The transmission ratio of the input shaft (4) to the output shaft (13) equals to 1. If the steering wheel is fixed on, the steering operation could be implemented by controlling the motor. In the normal state, the motor and the steering wheel operate at the same time for changing the transmission ratio on demand [8-9]. Besides, the worm wheel can be mounted on inner gear (8), that means the installed position of the input shaft can interchange with that of the output shaft. So it makes the layout of the steering system more flexible in the compact engine room.



1.worm, 2.worm wheel, 3. motor, 4.input shaft, 5,12.planetary carrier, 6,9. sun wheel, 7,10.planet gear, 8,11.inner gear, 13.output shaft

Figure 4 Schematic Representation of the New AFS Actuator

IV. DYNAMICAL MODEL OF AFS

By kinematical equation, we know that steering transmission ratio has changed in turning of vehicle, steering

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transmission ratio has excellent controllability. So AFS based on the dual planetary gear mechanism can improve the poor controllability and small speed ratio change range of the ordinary mechanical steering gear.

According to the static equation of gears system, AFS has similar static characteristics with human steering system. Dual planetary gear mechanism as a torque separation device, drivers can predict the percentage of motor driving force in the whole load, the motor overcome the load separated by differential gear train, make the motor rotate to definite position. Actually, Dual planetary gear mechanism is a power assisting device which can reduce load from pinion and rack and make drivers steer lightly.

Take the system's dynamic model as analysis starting point, the paper designs the whole control system. Figure5 shows an overview of the control construction.

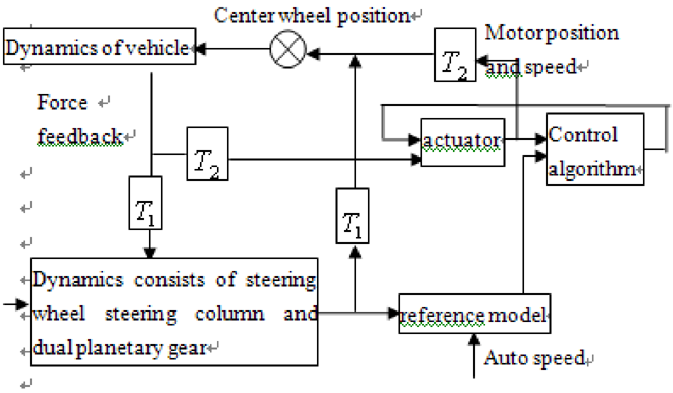

Figure 5 Control Chart of AFS

The system takes an angle generated by steering system as its input, side force of wheels and aligning torque are the responses of vehicle to command. Design a position-tracking control system according to simplified dynamic model of AFS, then the system track reference position in accordance with the driver's input.

Motor model expresses as a stability of second order differential equations. The input quantity θ_{sw} is the steering angle proposed and output quantity is position velocity and acceleration we want the motor to turn The reference dynamical equation is:

$$\ddot{\delta}_m + (2\zeta\omega_n)\dot{\delta}_m + \omega_n^2\delta_m = K_b\omega_n^2\delta_s \quad (1)$$

In the equation , k_b is DC gain, ζ is damping ratio, ω_n is motor bandwidth.

Steering sensitivity which is defined as a rate of change lateral acceleration relative to the angle of steering column, shows auto front wheels' response capacity to input angle, directly affects operating performance of a vehicle. Relationship between steering sensitivity and turning rate under a given speed can be expressed as:

$$S = \frac{100}{57.3R}\frac{1}{(\frac{Lg}{u^2}+\frac{K_{us}}{57.3})} \quad (2)$$

When the velocity is constant, we obtain the following equation:

$$R = \frac{100}{57.3\frac{\gamma}{\delta_s}}\frac{1}{(\frac{Lg}{u^2}+\frac{K_{us}}{57.3})} \quad (3)$$

S is steering sensitivity, R is steering rate,
L is wheel base, K_{us} is body's gradient,
u is speed, g is gravitational acceleration.

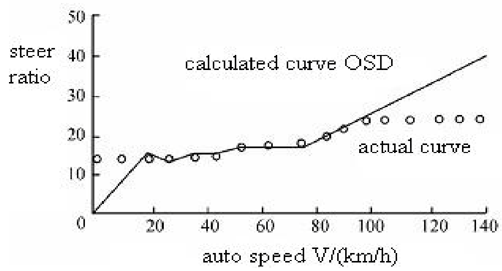

Figure 6 The Relationship Between Steering Ratio and Speed

As it is shown in Figure 6, when the car speed is $30\,km/h$,the steering ratio is smaller, this can help to reduce the driver's steering force, thus enhance the steering mobility and flexibility of the system and it is tally with the actual situation; and when the car speed is more then $100\,km/h$, system has a bigger, constant steering ratio, this kind of design and characteristics can guarantee that it has excellent steering stability and sensitivity; When the speed changes between $30-100\,km/h$, simulation curve coincide with the calculation curve very well. This proofs that AFS adopt dual planetary gear institutions can improve steering sensitivity, there by improve auto's maneuvering performance.

V. CONTROL ALGORITHM DESIGNING AND SIMULATION

AFS should realize not only controlling steering performance and steering torque while steering, but also real-time control of maneuvering performance, suppressing jitter and making sure the system has a very high response speed and good road feel. This paper mainly studies the control to front wheel additional angle of AFS, adopts cascade PID combined with fuzzy algorithm, designs control structure for the whole system and then the results are analyzed and tested.

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Although the traditional PID algorithm has simple structure, stronger robustness features, it is difficult to guarantee system not only has quicker response speed, but also has a small overshoots and better static performance, so we have to improve the traditional PID control algorithm, make it juggle various performance indicators wheel. The paper adopts compound PID controller, namely traditional PID plus fuzzy PID. If the offset between input and output is big, using fuzzy PID controller to improve the response speed of system, otherwise using normal PID controller to eliminate static error, improving the control precision. The advantages of doing that are we can keep the traditional PID controller's advantages and overcome the problems of fuzzy control steady precision.

A. Traditional PID Algorithm Design and Simulation

Position loop adopt traditional PID control algorithm, the main technical problem lies in how to adjust K_P, K_I, K_D parameter of PID controller. According to the design criterion of controller parameters, after repeatedly debugging we obtain $K_P = 0.022$, $K_I = 0.001$, $K_D = 0.002$. Figure7 shows the response curve of traditional PID position loop. As it shows, the overshoot is almost reduced to 0, but its rising time is longer and response slowly, if the interference increased, it is hard to have ideal robustness.

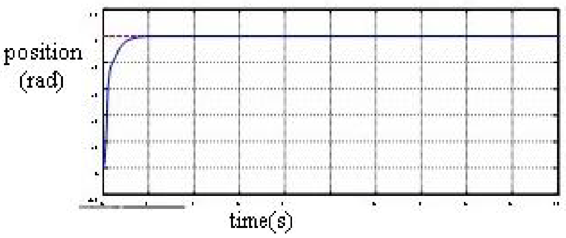

Figure 7 The Response Curve of Traditional PID Position Loop

B. Fuzzy PID Algorithm Design and Simulation

Fuzzy PID controller consists of PID controller that parameters can be adjusted and fuzzy inference unit. The fuzzy inference unit takes deviation E and deviation rate as its inputs, K_P, K_I, K_D parameter of normal PID controller as its outputs[10]. Figure8 shows the basic structure of Fuzzy-PID.

Fuzzy controller works following language rules, which based on the experiences of the operator. Most fuzzy inference methods use Mini-max value at present. This paper also uses this method. The fuzzy inference rules are:

Rule 1: A1 and B 1 = > C1

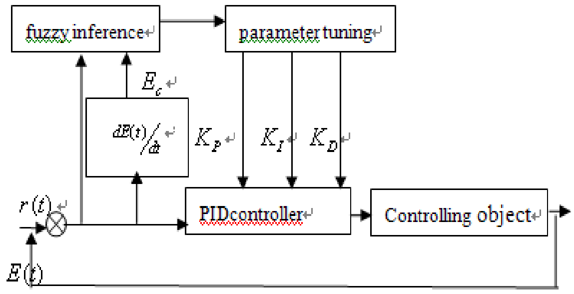

Figure 8 Basic Structure of Fuzzy- PID

Rule 2：A2 and B 2 = > C2

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Rule n：An and Bn = > Cn

Premise： X0 and Y0

Conclusion：C

The fuzzy control volume of observation value deviation and error can be obtained by the field of the elements, which worked by their respective and quantification factors. Fuzzy reasoning results are fuzzy values, which can not directly used for controlling the controlled object. They need to be converted into a precise amount which can be accepted by the actuators. In fact, it is a mapping from fuzzy space to clear space. Commonly used against blur calculation methods are maximum membership degree function method,gravity method and weighted average method. In this paper, the gravity method [9] is adopted. which takes the gravity of the area rounded by fuzzy membership function curve and abscissa as the final output value,

$$v_0 = \frac{\int_V v\mu_v(v)dv}{\int_V \mu_v(v)dv} \qquad (4)$$

Discrete domain situation with m outputs of quantitative series :

$$v_0 = \frac{\sum_{k=1}^{m} v_k \mu_v(v_k)}{\sum_{k=1}^{m} \mu_v(v_k)} \qquad (5)$$

The model output curving surface of fuzzy control shows as Figure 9:

Table1 shows the results of anti-fuzzy using gravity method.

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TABLE1. THE RESULTS OF ANTI-FUZZY

error variable quantity E_c \ error E	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
-6	5.84	5.34	5.36	4.40	4.10	3.96	3.94	3.70	1.98	0.99	0.15	0.05	0.00
-5	5.45	5.36	4.99	4.41	3.99	3.99	3.82	2.98	1.97	0.99	0.34	0.02	0.00
-4	5.35	5.34	5.10	4.31	3.98	3.84	3.69	2.98	1.94	0.86	0.00	-0.1	-0.11
-3	5.41	5.34	4.9	4.62	4.22	3.81	2.98	2.60	1.86	-0.76	-1.25	-1.65	-1.66
-2	5.36	5.36	5.1	4.84	4.06	2.80	2.02	1.44	0.00	-1.46	-3.94	-3.52	-4.01
-1	5.33	5.34	4.89	4.48	4.00	1.99	0.82	-0.73	-1.52	-2.46	-3.85	-4.22	-4.21
0	5.22	5.16	5.0	4.76	3.99	1.96	0.00	-1.96	-3.99	-4.76	-5.0	-5.16	-5.24
1	4.21	4.22	3.85	2.46	1.52	0.73	-0.82	-1.99	-4.00	-4.88	-4.89	-5.34	-5.33
2	4.01	3.52	3.94	1.46	0.00	-1.44	-2.02	-2.80	-4.06	-4.84	-5.1	-5.36	-5.36
3	1.66	1.65	1.25	0.76	-1.86	-2.6	-2.98	-3.81	-4.22	-4.62	-4.9	-5.34	-5.41
4	0.12	0.10	0.00	-0.86	-1.94	-2.98	-3.69	-3.84	-3.98	-4.31	-5.1	-5.34	-5.36
5	0.01	-0.02	-0.34	-0.99	-1.97	-2.98	-3.82	-3.99	-3.99	-4.41	-4.99	-5.36	-5.45
6	0.02	-0.05	-0.15	-0.99	-1.98	-3.70	-3.94	-3.96	-4.10	-4.40	-5.36	-5.34	-5.84

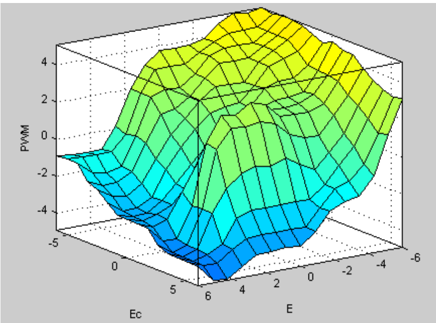

Figure 9 The Model Output Curving Surface of Fuzzy Control

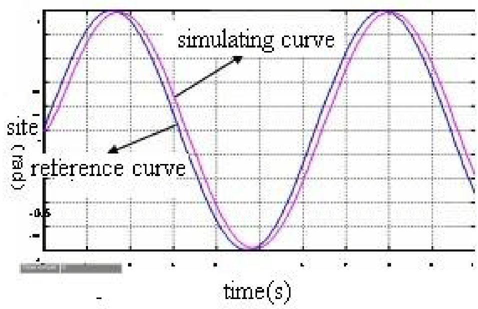

Figure 11 Position Loop of Fuzzy-PID Sinusoidal Input Tracking Curve

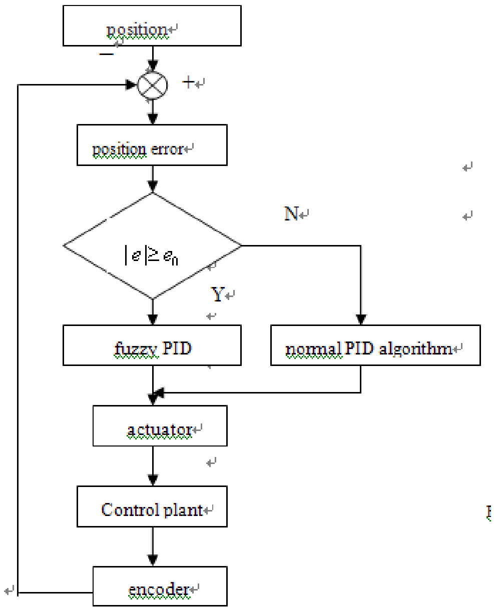

Figure 10 Flow Chart of Fuzzy-PID Position Control

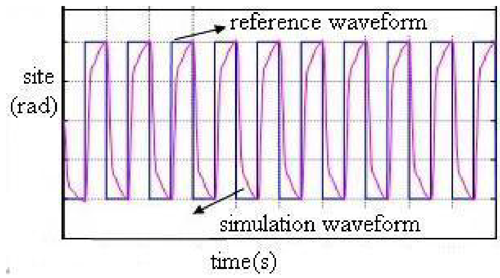

Figure 12 Position Loop of Fuzzy-PID Square-wave Input Tracking Curve

Using fuzzy reasoning method for parameters adjustment, to satisfy the deviation and deviation alteration ratio requirements on PID parameters self-tuning.Figure10 shows the flow chart of Fuzzy-PID position control.

The paper has designed the fuzzy control algorithm with considering all factors, adopts double input and single output structure. Take the whole three-ring control system's displacement error E and displacement error rate Ec as fuzzy system input, and the PWM signal as output. Figure11 shows

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position loop of Fuzzy-PID sinusoidal input tracking curve, Figure12 shows position loop of Fuzzy-PID square-wave input tracking curve. Sine curve tracking error of position loop only has 0.15s time-lag, and has good tracking performance to square signal, that is much better than traditional PID.

VI. CONCLUSION

The experimental platform is also put up in the laboratory, including hardware design and coding the program. The simulation is verified in the bench test. The final experimental results verify the control effect of the designed controller. As a result of adopting the fuzzy PID combined with the traditional PID control structures, after long time parameter testing and algorithm adjust, rising time has been greatly decreased, overshoots are zero by and large, and comes to good position tracking effect, the system performance is optimized. The control strategy's structure and adjust are simple and suitable for the engineering application.

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