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# Research of the vehicle with AFS control strategy based on fuzzy logic

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**ABSTRACT** ***:*** *Vehicle stability is an important index for automobile safety. With the rapid development of auto industry, more attention was emphasized on active front wheel steering technology. A wheel angle control strategy of active front wheel steering was present in this paper. Research was conducted based on Carsim and Simulink. Carsim software was used to establish whole vehicle model. The fuzzy logic angle controller was designed based on MATLAB/Simulink. Yaw rate error and error rate of change were the input variables of the controller, and additional angle of front wheel was the output variable to validate the simulation. Through the analysis of simulation results, it was confirmed that the control method can control the Yaw rate of the vehicle effectively, which improved the stability of vehicle.*
**Keywords -** *Active front steering; Yaw rate; Fuzzy control; Stability; Simulation*

## I. INTRODUCTION

With the rapid development of auto industry, all kinds of high and new technology constantly emerging, higher quality demand of vehicle is getting more and more important for consumers.As an essential component of an automotive brake system and transmission system, steering system plays an important role in the safety in the process of driving. Its performance directly affects the vehicle steering stability and safety comfort, etc. Active front steering system is the effective combination of the reliability and flexibility. Its improvements in the larger development space for the automotive steering performance. The core of the active front steering technology is through to the additional angle of front wheel on a not dependent on the driver's steering wheel input to improve the performance of vehicle handling stability and keep track[1].According to the different way of additional angle overlay, and it can be divided into mechanical and electronic type[2].

In order to maintain the safety of the vehicle handling characteristics, people need to control the Yaw rate of the vehicle. So there are two main methods to control. One of them is the DYC, it by using different longitudinal force side of the car, to make the car can generate external stability Yaw rate of the vehicle. Another is by controlling the front wheel steering angle of the vehicle. The most practical and most effective steering angle control method is the active front steering system, AFS. This method is the driver on the basis of the existing steering input added a superposition of the steering angle $\delta_{cor}$ [3].

This paper presents a wheel angle control strategy of active front wheel steering. This strategy is by adjusting the front wheel angle actively to correct the Yaw rate of the vehicle. And then it can realize the stability control of the vehicle. According to the fuzzy control theory, using Simulink simulation platform, Yaw rate as control variables to make corresponding control strategy. And doing the simulation study in double lane change conditions is that the vehicle model with a fuzzy controller and without it in vehicle dynamics software, Carsim. By analyzing the simulation results, it can be confirmed that the control method can control the vehicle's Yaw rate effectively and improve the stability of the vehicle.

## II. ARCHITECTURE DESCRIPTION

In this paper, the Architecture Description diagram is shown in Fig.1.The control system was mainly composed of two module, Carsim vehicle model and AFS controller. Carsim outputs steering wheel angle, velocity and vehicle Yaw rate to AFS controller by car in running condition. Then they through the control strategy of the operation of the controller output vehicles' additional steering angle $\delta_{cor}$ of front wheel, and they feedback to Carsim vehicle model. The system corrects the Yaw rate of vehicle completely by circle. That means the vehicle stability control.

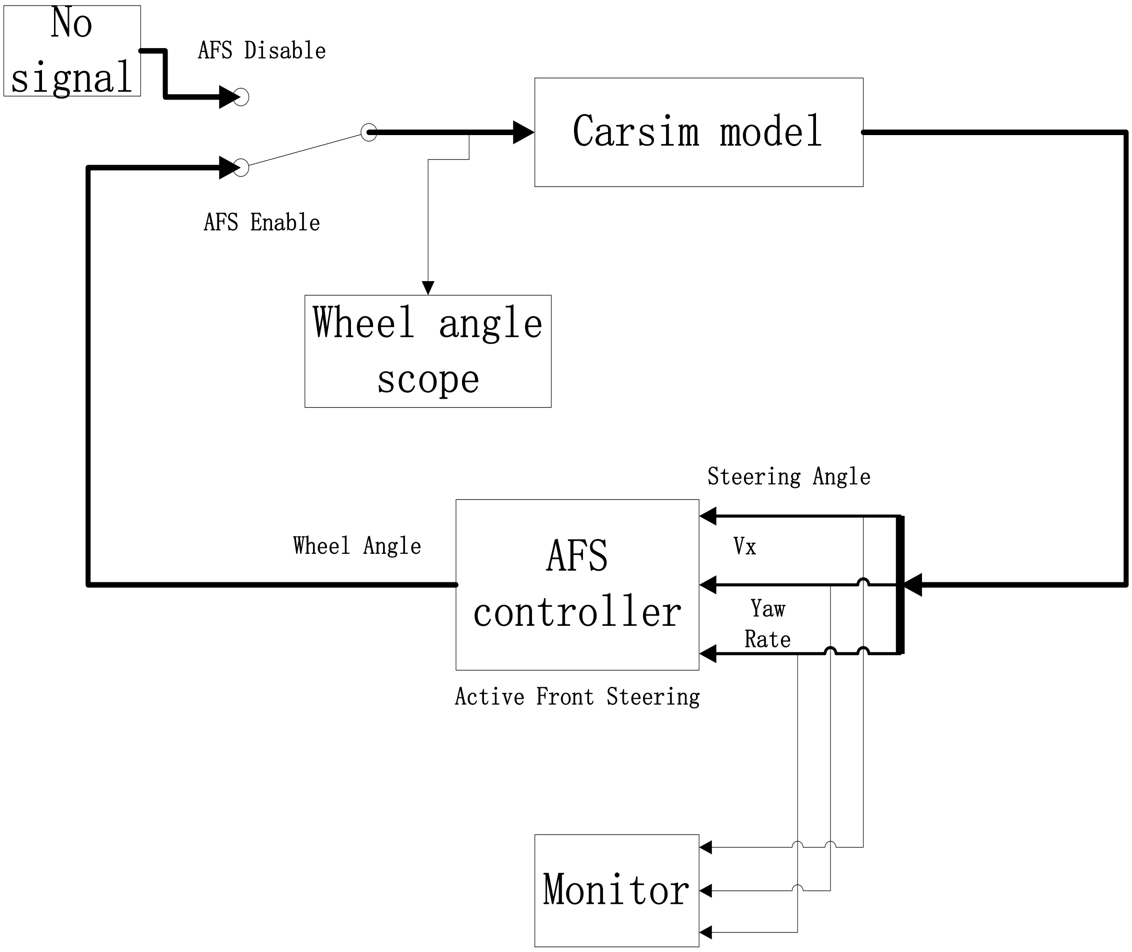


**Fig.1 architecture description diagram**

## III. AFS CONTROL SYSTEM DESIGN

The Yaw rate and the side-slip angle of vehicle are important control parameters of the stability of the auto control system. But the side-slip angle can not be measured directly. And in most cases it is usually calculated indirectly by the method of estimation. Yet Yaw rate of the vehicle is obtained by Yaw rate sensor, so the Yaw rate is quite exact parameter[4].Therefore, when the controller is designed, putting the error $e$ and error rate of change $e_c$ between the actual Yaw rate $r$ and theory Yaw rate $r_d$ as the input of the controller, and the output variables $u$ provide additional angle $\delta_{cor}$ of the wheel. As shown in Fig. 2 was the AFS control strategy.

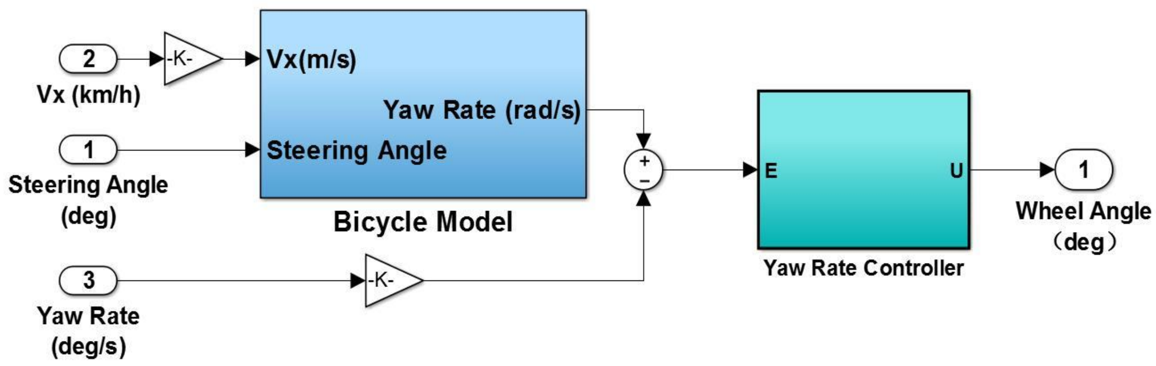


**Fig.2 AFS control strategy**

**3.1 The Theory Arithmetic of Yaw rate**

As shown in Fig.2, the Bicycle Model module is the theory arithmetic of Yaw rate. It is a model of a two-degree of freedom. Through the input of velocity $V_x$ (km/h) and steering wheel angle (deg), method of logic threshold was used, to calculate the theory arithmetic of Yaw rate (rad/s), and its computation formula was as follows:

$$\gamma_d = v_x \delta_{driver} / l + k_u v_x^2 \quad (1)$$

Fig.2 also showed the error of Yaw rate. It is defined as:

$$e_\gamma = \gamma_d - \gamma \quad (2)$$

Among them, $\gamma$ is the actual Yaw rate, $\gamma_d$ is the theory Yaw rate.

**3.2 Fuzzy Logic Controller Design**

Fuzzy control can adapt to variable nonlinear system control well, and it has strong robustness[5].For the characteristics of the front wheel active steering control, the fuzzy controller is designed according to the error $e$ and error rate of change $e_c$ of the vehicle Yaw rate as the input signal of fuzzy system. The output signal is additional steering angle $\delta_{cor}$ of front wheel. Then the fuzzy controller was designed. With fuzzy controller of the system block diagram was shown in Fig. 3.

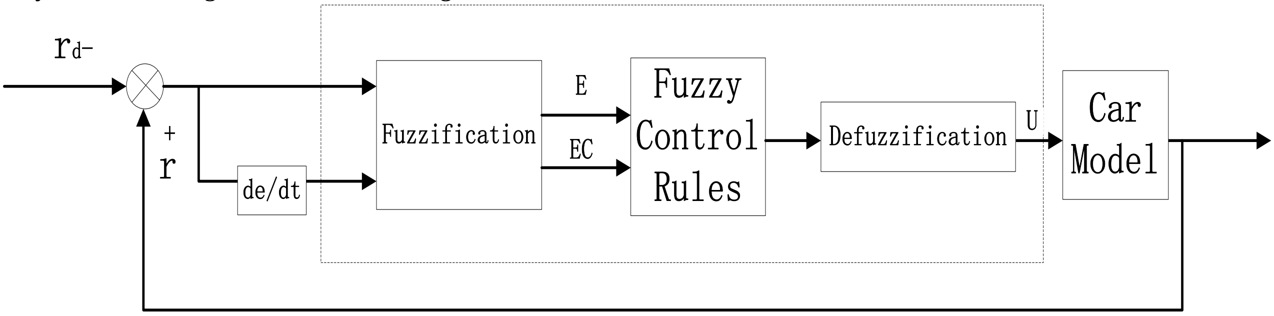


**Fig.3 fuzzy controller system block diagram**

According to the size of the error between the actual Yaw rate and the theory Yaw rate of the output of the reference model car, quantificational field of fuzzy variable E,EC,U have been established[6].Defines as follows:

The quantificational field E：{-6，-5，-4，-3，-2，-1，0，1，2，3，4，5，6}

The quantificational field EC：{-1，-0.8，-0.6，-0.4，-0.2，0，0.2，0.4，0.6，0.8，1}

The quantificational field U：{-6，-5，-4，-3，-2，-1，0，1，2，3，4，5，6}

In each domain, the fuzzy subset of membership function was defined as seven language variables respectively，PB(Positive Big)，PM(Positive Medium)，PS(Positive Small)，ZE(Zero Error)，NS(Negative Small)，NM(Negative Medium)，NB(Negative Big).The language variables of the input and output adopt gauss membership function. As shown in figure 4 to 6.

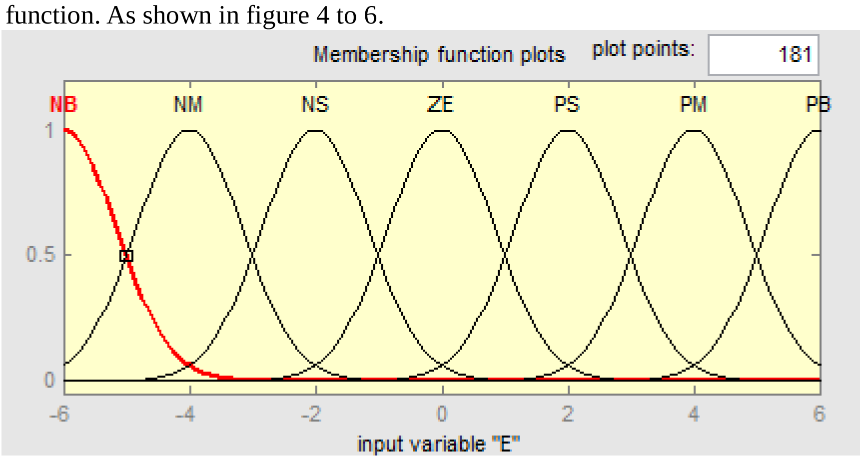


**Fig.4 The membership function of input variable E**

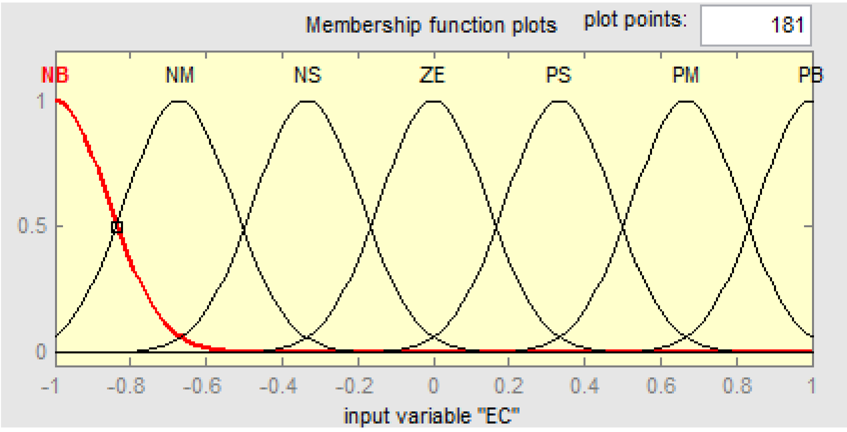


**Fig.5 The membership function of input variable EC**

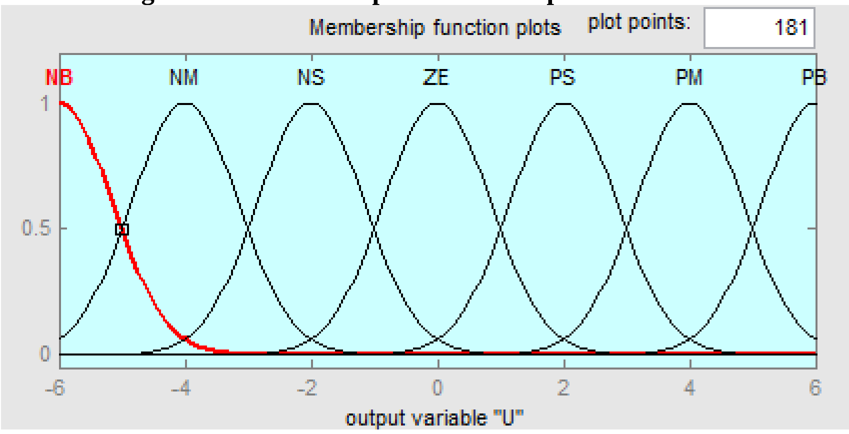


**Fig.6 The membership function of output variable U**

In order to make the fundamental field of the actual variable error e, error rate of change ec, controlled quantity u correspond the field of the after standardization variable error E, error rate of change EC, controlled quantity U, it can be concluded that the following quantitative factor according to the range of field:

Quantitative factors of e: $k_e = 2$

Quantitative factors of ec: $k_{ec} = 10$

Quantitative factors of u: $k_u = 15$

Considering error was negative. When the error was NB, no matter what the error rate of change was. In order to eliminate deviation, it should increase the controlled quantity. So controlled quantity should be PB. When the error was NS or Zero, the main contradiction is converted to the stability problem of the system. In order to prevent overshoot amount is too large, and make the system stable as soon as possible, it will be determined the change of controlled quantity according to the error rate of change. When the error rate was negative, the deviation had a tendency to increase. At this time it should increase the controlled quantity to prevent further deviation[7].According to the analysis, fuzzy control rule table can be got, and it produced 49 fuzzy rules in total.

In this paper, fuzzy control approach was “Mamdani”.Reasoning method was “max-min”. The method of defuzzification was the center of gravity.

## IV. SYSTEM SIMULATION AND EXPERIMENTAL ANALYSIS

In this paper, the use of Simulink modules in MATLAB software was used to set up simulation model of vehicle stability control system. The fuzzy control toolbox was in the software MATLAB. Using it to establish fuzzy control rules and membership functions and putting it into Simulink. In order to make the vehicle more in line with the actual condition of the vehicle, whole vehicle model was established in the software Carsim. Simulation was conducted based on Carsim and Simulink [8][9].

This paper introduced the double lanes change experiment on the vehicle dynamics simulation test platform Carsim. In the test, the conditions were set as follows, Road adhesion coefficient was 0.85, velocity was 50km/h, simulation time was 8s.Vehicle model selection was D-Class SUV, in which one was with AFS controller, and the other one was not with AFS. As shown in Fig 7-10 were double lane change experimental results of the vehicle.

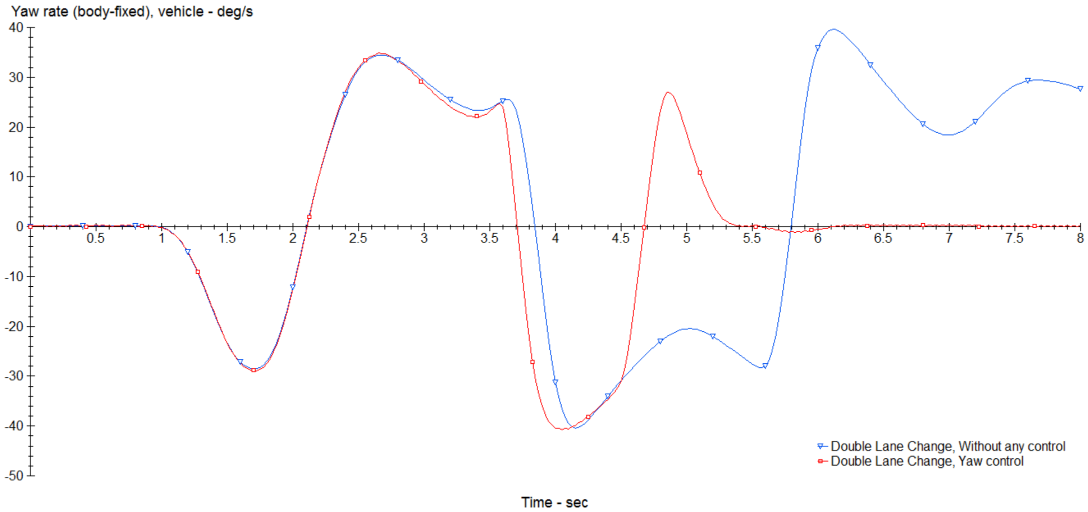


**Fig.7 Yaw rate response curve**

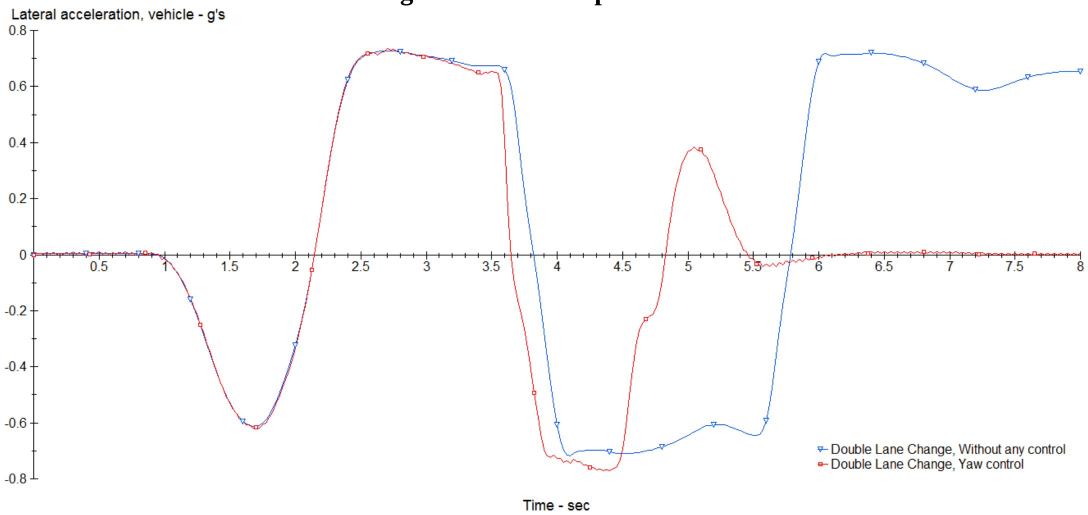


**Fig.8 Lateral acceleration response curve**

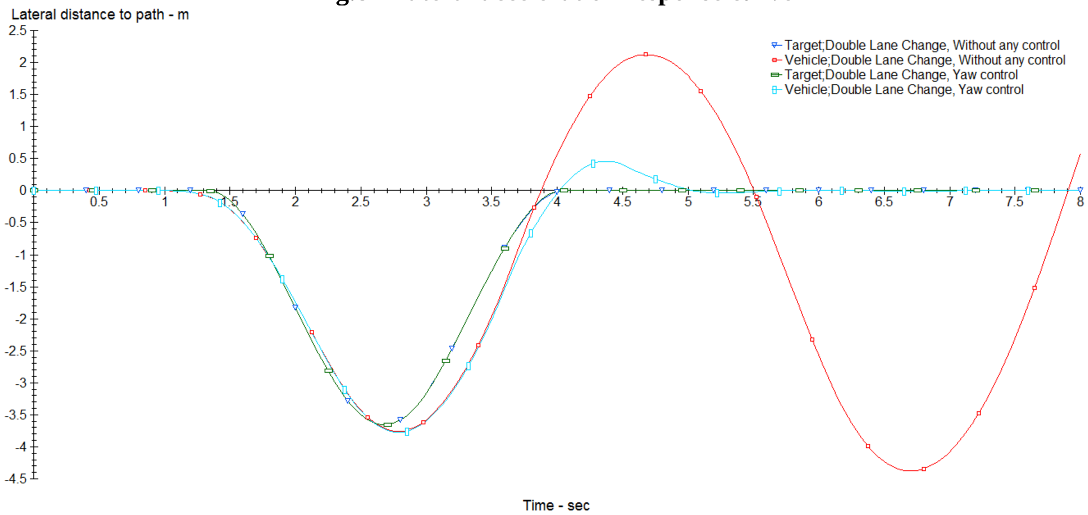


**Fig.9 Target trajectory tracking**

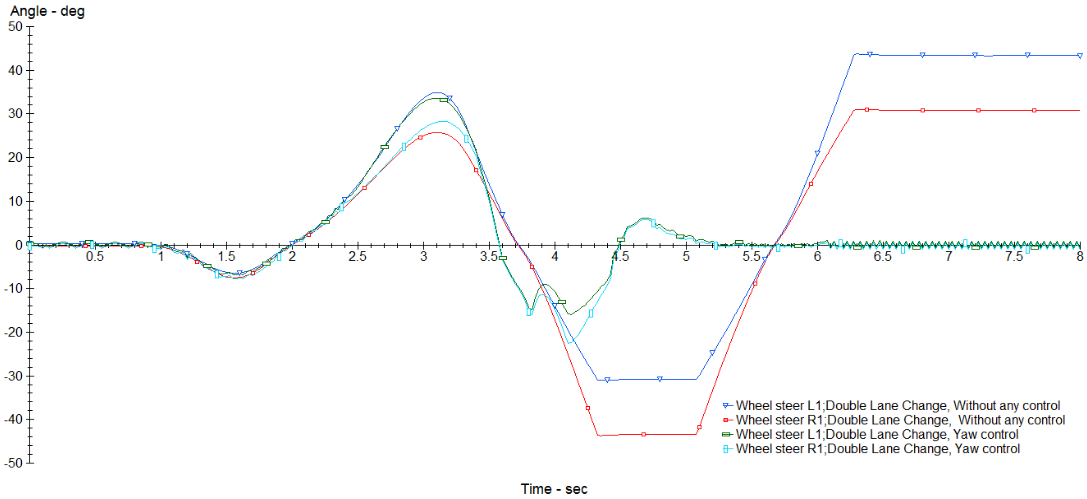


**Fig.10 The front wheel steering Angle curve**

Fig.7 and Fig.8 were Yaw rate response curve and lateral acceleration response curve. It can be seen from the figures in red curve that was the vehicle equipped with the controller. Comparing with the blue curve, it has obvious improvement. At around 4.5s, the vehicle's lateral parameter began to be controlled. AFS controller played an important role in it. Controller made the Yaw rate error recovery gradually. Close to 5.5s, equipped with the controller of the vehicle's lateral parameter is the convergence, and shortening response time. The trend was to restore to a stable state in the end. It was indicated that the vehicle had good stability with control.

Fig.9 was target trajectory tracking. It can be seen from the diagram that the car had better tracking performance with the stability control. Compared with no controller vehicles, its running wide range was narrow. It can be a relatively good in accordance with the driver's intention.

Fig.10 was the front wheel steering angle curve. Within 3.5s to 4.5s, wheel steering angle rotated in advance due to the restrain of AFS controller. It reduced the yaw rate error of the vehicle in both left and right wheels. While without controller, steering angle were up to the maximum, which induced to bad tracking. After about 5s, AFS wheel base in a steady state. But it can be seen from the curve of serrated, the front wheel steering angle continues to correct in order to make the stability control of the car.

## V. CONCLUSION

This paper used fuzzy controller design of active front wheel steering system. Its purpose was to improve steering stability of the vehicle. As it can be seen from the simulation results, the Yaw rate and the lateral acceleration curve peak of the vehicle with a fuzzy controller were smaller than that without control, and also stable time was relatively short. It can been seen its security and stability of vehicle control system. Through the software Carsim under the condition double lane change of test, the simulation data show the effectiveness of the fuzzy control strategy is proposed in this paper. It had a certain positive role in improving the traffic safety.

## VI. Acknowlegement

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