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Study on Hydraulic Steering System of Automatic Driving Agricultural Machinery

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ABSTRACT : *The hydraulic steering system plays an important role in the automatic driving agricultural machinery, its dynamic characteristics directly affect the accuracy and reliability of the automatic driving. In this paper, a set of hydraulic steering system is designed. The response characteristics of the hydraulic steering system are tested by experiments. The mathematical model for transfer function is established according to the response characteristics of hydraulic steering system. The simulation model is built. The PID parameters are adjusted. The performance of the response characteristic of hydraulic steering system is improved. Finally, the design of the hydraulic steering system is proved to be effective by square wave signal and sine wave signal tracking experiments.*

Key words- *hydraulic steering, dynamic characteristics, PID, automatic driving*

I. Introduction

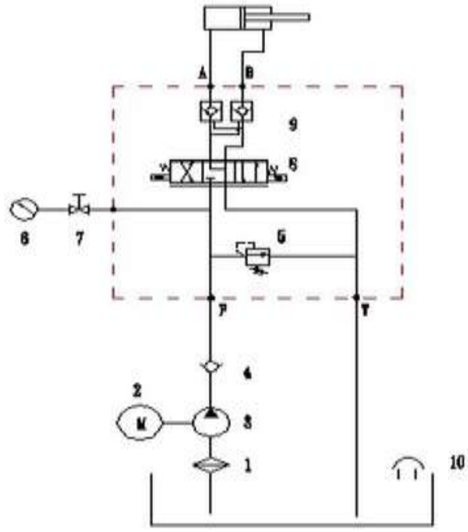
To carry out the research on the automatic driving agricultural machinery is of great significance for reducing labor intensity, improving working efficiency and ensuring food production. At the same time, it is an important technical support to speed up the modernization of agriculture and the development of precision agriculture. Many researchers have carried out a thorough study on the automatic driving of agricultural machinery. A. Fernando discussed the main components and functions of the automatic driving agricultural machinery [1]. Kayacan Erkan proposed a nonlinear model predictive control method to improve the automatic driving control accuracy of agricultural machinery [2]. Lv Antao proposed an optimal control method to improve the accuracy of agricultural machinery steering control [3]. Zhang Zhigang, Li Jun, Zhang Zhigang, Li Jun, Wu Xiaopeng designed the automatic steering system of agricultural machinery, improved the agricultural machinery path tracking accuracy [4-6]. These studies have achieved good results, but neglect the study of the characteristics of the agricultural machinery steering system itself. As the hydraulic steering system is a key part of the automatic driving system of agricultural machinery, its dynamic performance directly influences the accuracy and stability of the automatic system.

According to above situation, this paper designed a set of hydraulic steering system of agricultural machinery. The research on dynamic performance of steering system is carried out on this platform, and the method of steering tracking algorithm and hydraulic system calibration is designed. A simple and effective method for testing and calibrating the dynamic performance of the hydraulic steering system is explored by simulation and experiment.

II. Hydraulic Steering System Design

Automatic hydraulic steering control is one of the key technologies of automatic driving agricultural machinery, which determines the agricultural machinery whether or not can accurately complete the field operation. On the basis of studying the electric hydraulic steering system of the tractor, this paper designed a kind of portable hydraulic steering system of vehicle, which is used to simulate the hydraulic steering system of real agricultural machinery, and to study the dynamic characteristics of steering system.

In this paper, the overall structure of the hydraulic steering mechanism is shown in Figure 1, mainly including the hydraulic pump, motor, hydraulic cylinder, three position four-way directional proportional solenoid valve, relief valve, non-return valve, pressure meter, hydraulic oil pipe, etc. Hydraulic pump as power components, which can make the mechanical energy into hydraulic energy; hydraulic cylinder and motor as the implementation of components, which can make the hydraulic energy into mechanical energy; electronic control three position four-way directional proportional solenoid valve as control components, which connected the microcontroller through the driving circuit to receive control commands, switch hydraulic circuit in order to realize the front wheel steering control of agricultural machinery. The function of the rest of the valve is to control the pressure, direction and flow of hydraulic oil. Hydraulic tank, filter, pipeline is used as auxiliary component, hydraulic oil is used as the working medium.



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1 absorbing oil filter 2 gear pump 3 motor 4 relief valve 5 non-return pipe valve 6 pressure meter switch 7 pressure meter 8 solenoid proportional directional valve 9 stacked unidirectional valve 10 air filter

Fig 1 hydraulic steering system principle diagram

The main function of the three position four-way directional proportional solenoid valve is to control the flow rate of hydraulic oil and the steer the model car, which in order to control the direction and speed of the steering. When the proportional directional solenoid valve is energized, the car is in automatic navigation mode, the hydraulic oil flows through three position four-way directional proportional solenoid valve in the system, which control the oil quantity of the rod chamber and the non-rod chamber in the hydraulic cylinder to steer. For the safety of the system, a non-return pipe valve is installed at the input front part of the solenoid proportional directional valve as a safety valve to control the oil pressure of the hydraulic circuit. In order to speed up the oil discharge rate of the two chambers in hydraulic cylinder, and improve the response speed of the steering control, which installed A, B two hydraulic control non-return pipe valves in the rod chamber and the non-rod chamber. In the steering cycle, it should maintain the pressure of the hydraulic circuit, which ensures the value of front wheel steering angle of agricultural machinery be the value of predetermined steering angle.

Hydraulic system transfer control signal by the hydraulic pressure. From hydraulic system receives the value of predetermined steering angle from the host computer to the agricultural machinery front wheel to start turning takes a certain time. At the same time, the working environment of agricultural machinery in the field is complex, especially when working in paddy field soil and water resistance is relatively large, which is not conducive to control the agricultural machinery. Therefore, the hydraulic system of agricultural machinery steering control is large time delay system. The research on the dynamic characteristics of the hydraulic system is a difficult problem for the automatic control of agricultural machinery.

III. Calibration of Hydraulic Steering System

In order to test the dynamic characteristics of hydraulic steering system, this paper designed a test method, the basic process is as follows: on the basis of the desired angle, the host computer sends command to the hydraulic system, which driving the hydraulic system, and the hydraulic cylinder rod drives the front wheel rotation, while the angle sensor is installed on the front wheel of the machine ,so the actual angle of the front wheel is measured, At the same time, when the host computer sends out the steering command, the steering angel collection procedure is started, the actual changes of the front wheel angle in the steering process are measured. In this paper, the response curves of front wheel angle of ±10°, ±15° are obtained experiments, as shown in Figure 2 and Figure 3.

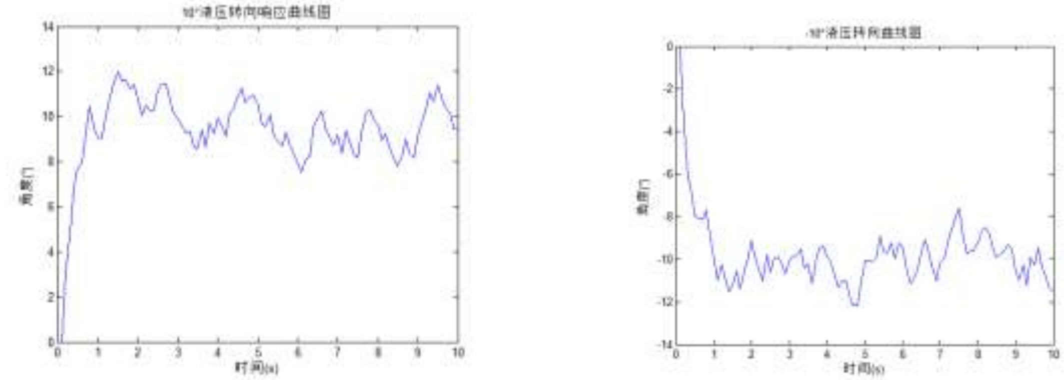

Fig 2 hydraulic steering response curve at ±10°

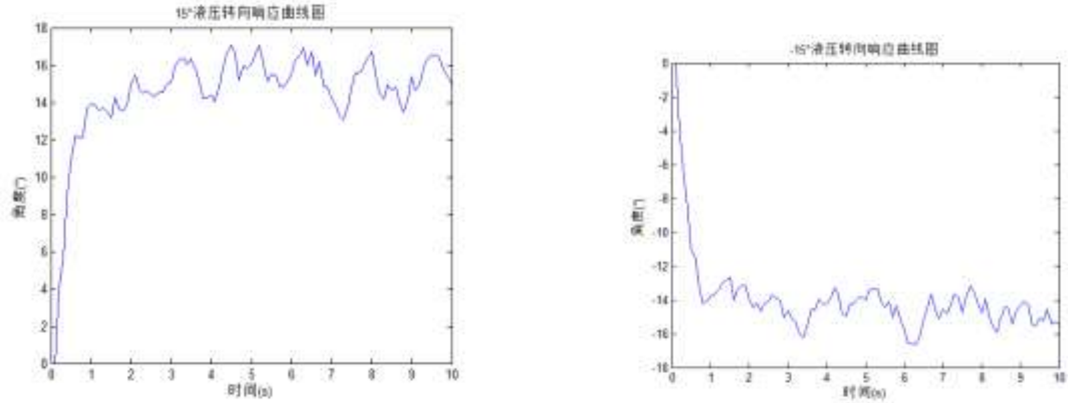

Fig 3 hydraulic steering response curve at ±15°

As shown in figure 2 and 3, the hydraulic steering system will take a long time when system is stably, and the vibration of the wheel is intense, the overshoot of the system is large , the performance of control is poor. In the practical use, it may cause path tracking error, and it may even lead to path tracking failure. The overshoot and peak time of the response curves in the graph are both calculated, and the average value of the response curves is used as the overtime and peak time of the hydraulic steering system, which the overshoot is σ=16.30% , and the peak time is t_p=1.5625s . According to the system response curve, the hydraulic steering system can be regarded as the second-order system, and the parameters of the system transfer function are obtained, and the damping of the system is shown in Figure 1.

$$\zeta = \sqrt{\frac{\ln^2 \sigma}{\pi^2 + \ln^2 \sigma}} = 0.5012 \tag{1}$$

$$\omega_n = \frac{\pi}{t_p \sqrt{1-\zeta^2}} = 2.3235 \tag{2}$$

According to the damping and natural frequency, the system transfer function is obtained:

$$G(S) = \frac{\delta(s)}{\delta_u(s)} = \frac{\omega_n^2}{s^2 + 2\omega_n \zeta s + \omega_n^2} = \frac{5.3988}{s^2 + 2.3291s + 5.3988} \tag{3}$$

$\delta_u(s)$ Is expected to turn the corner, $\delta(s)$ is the response of the steering angle.

The hydraulic system model shown in the model (3) is built , and the Simulink simulation system is shown in Figure 4. The PID parameters are adjusted. Through the adjustment of the 3 parameters, such as proportional, integral and differential, the response curve of the hydraulic steering system is shown in Figure 5 and Figure 6, the average overshoot is 8.6%, the peak time is 0.6s, the hydraulic steering response curve is good, the overshoot and the settling time are improved obviously.

In order to increase the anti-interference ability of the system, the dead zone of PID control is set up in this paper. Assuming that the angle of the steering angle of the front wheel is D, the value of dead zone is H, and assuming the desired steering angle is reached when the current steering angle is [D-H, D+H], the value of dead zone is determined to be 2 degree.

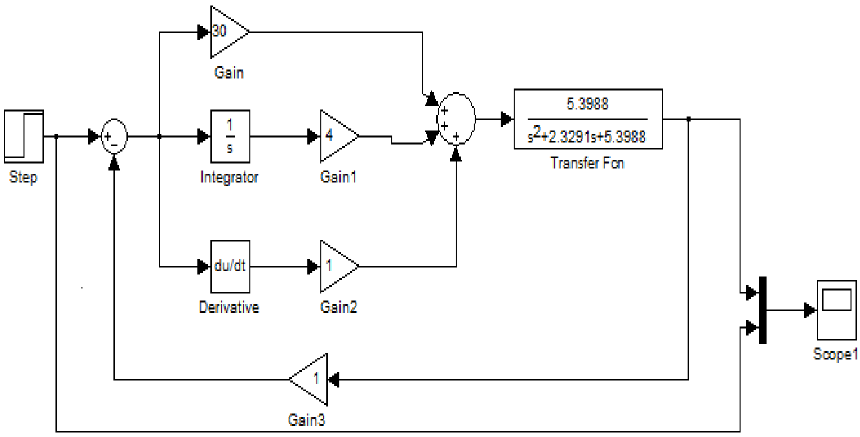

Fig 4 Hydraulic steering system simulation model

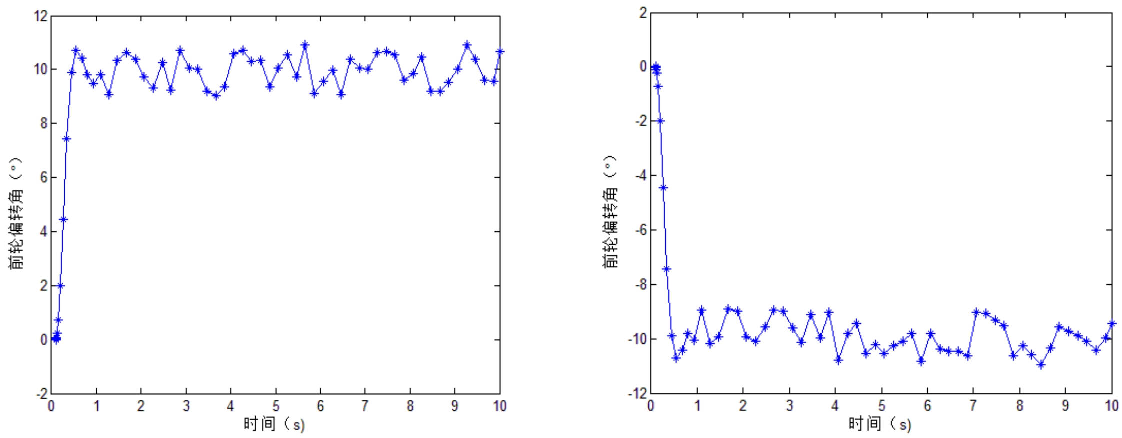

Fig 5 hydraulic steering response curve at ±10° by PID control

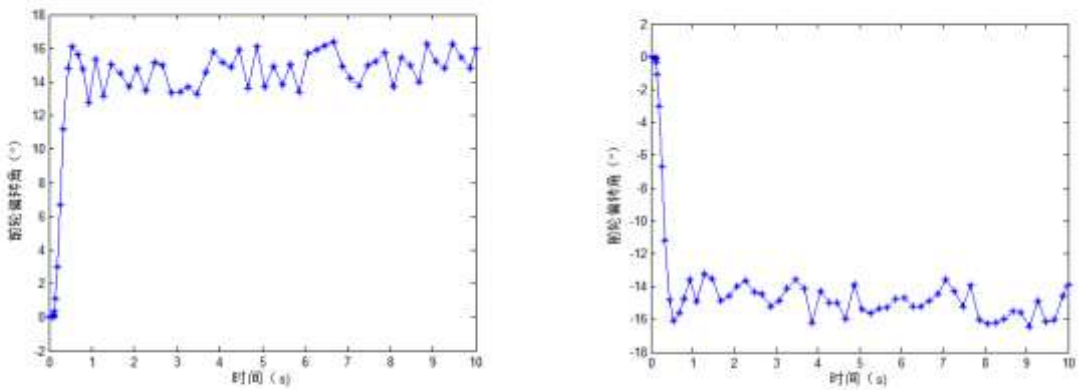

Fig 6 hydraulic steering response curve at ±15° by PID control

IV. Research on Steering Hydraulic Experiment

In order to test the performance of hydraulic steering control system, the hydraulic system is set up, and the system is installed on an electric model car, the experimental platform is composited, as shown in Figure 7. The angle sensor is installed on the left front wheel of the model car, as shown in Figure 8. The performance of the hydraulic steering system is tested on the experimental platform, which is based on the step signal and sine signal experiment

Fig 7 experiment model vehicle

Fig 8 steering angle measurement

First of all, square wave signal tracking experiment of ±15°, the cycle of 10s signal was carried out , the model of the steering effect of the front wheel was recorded, setting PID adjustment parameters $K_p = 9.5, K_i = 4, K_d = 1.5$, the experimental tracking effect as shown in Figure 9, the tracking curve shows that the hydraulic steering control system in the case of square wave signal, the steering response of the model car is faster, it takes1.5s when it reached the desired steering angel, the overshoot time is smaller, there is no obvious fluctuations when the car is steering.

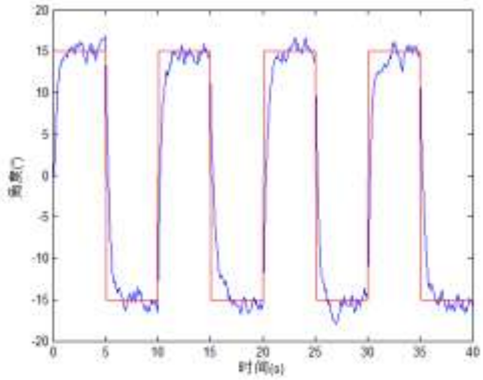

Fig 9 steering angle tracking curve at square wave

Secondly, the experiment of the sine tracking is carried out, and when the model car is steering, the angle of steering wheel is usually larger. In the experiment, the desired angle range from -25°to 25°. Setting PID adjustment parameters as $K_p = 9.5, K_i = 4, K_d = 1.5$, the experimental tracking effect as shown in Figure 10, characteristic curve shows that the hydraulic steering system of the model is stable and the system response time is 0.31s, the maximum differences of between expectated steering angel and actual steering angel is 2.6 °

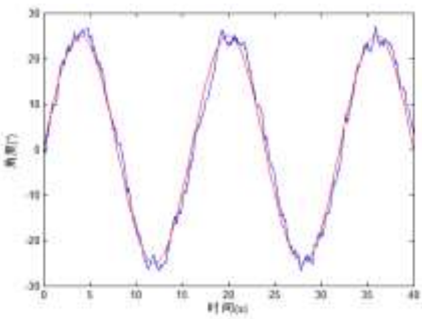

Fig 10 steering angle tracking curve at sine wave

V. Conclusion

This paper designed a set of hydraulic steering system of agricultural machinery. The steering response curve is established by collecting the data of hydraulic system. The dynamic characteristics of hydraulic system are analyzed. The equal-order transfer function is established according to the rise time and the natural frequency of the hydraulic steering system. The Simulink simulation model is built. The PID parameters are adjusted. Square wave signal and sine wave signal tracking experiments show that the system response time is reasonable, the overshoot is less, and the system is stable.

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