Research on hydraulic control system of shift gear clutch of hydro mechanical automatic transmission

Qingwen Ren, Shutao Zheng*, Junwei Han, Dacheng Cong
Harbin Institute of Technology, Harbin, China.

*Corresponding author e-mail: 1925192627@qq.com

Abstract. The dynamic model of the hydraulic control system of the shift clutch is established through the flow equation of the valve port, the flow continuity equation and the balance equation of the valve core force, the piston motion of clutch cylinder is divided into three stages. And simulate the dynamic curves of the hydraulic pressure of the hydraulic inlet of the hydraulic cylinder during different stages.

1. Introduction
The hydraulic control system plays an important role in AT automatic transmission [1]. The essence of the shift process is the process of separating and combining the clutch [2]. The combination and separation of the driving and the driven disc of the clutch is realized by the movement of the hydraulic control system to control the piston of the hydraulic cylinder of the shift clutch. The transmission ratio of the gearbox have speed ratio difference before and after the gear shift. If the separation process of the clutch and the combination of the clutch is mismatched, the torque of the transmission output shaft will be abrupt, so that the whole vehicle will have a violent shift impact [3]. Therefore, we need to deeply analyze the working principle of the transmission hydraulic control system and grasp its dynamic performance.

2. Structure and Working Principle of Hydraulic Control System for Shift Solenoid Valve
The principle diagram of the hydraulic control system of Allison3500R automatic transmission is shown in Figure 1, mainly made up by shift solenoid valve 1, throttle valve 3, throttle valve 10, accumulator (valve body 4, reset spring 5, piston 6), clutch hydraulic cylinder (piston 7, clutch friction plate 8, spring 9), clutch pressure regulating valve (shift electromagnetic valve control chamber 2, The reset spring 11, the valve core 12 and the valve body 13.

Shift solenoid valve structure as shown in Figure 2. The control chamber pressure of the pressure regulating valve is determined by the duty ratio of the shifting electromagnetic valve. The valve control chamber is connected with a spring accumulator to eliminate the fluctuation of the oil pressure in the control chamber [4]. When the pressure of the pressure control valve is small, the valve core is at the top of the valve body under the action of spring force. The piston of the clutch cylinder is at the right end of the cylinder body under the action of the spring. When the solenoid valve is electrified, the control chamber of the pressure regulating valve rises, after reaching a certain value, the valve core overcomes the spring force to move down, the opening of the overflow opening gradually decreases until it is closed. After closing, the pressure relief opening is opened, and the clutch hydraulic cylinder establishes pressure. The opening of the overflow opening gradually decreases until it is closed. After
closing, the decompression port is opened, and the clutch hydraulic cylinder establishes pressure. Feedback to the sensitive chamber of the regulating valve the pressure is very small, the valve core continues to move down. The opening of the reducing outlet continues to increase, the hydraulic cylinder is quickly filled with oil, and the piston moves to the left fast to the active piece of the clutch friction plate, reducing the duty cycle of the solenoid valve, the pressure of the pressure chamber of the pressure regulating valve decreases, the valve core moves upward, and the opening of the decompression port decreases. The hydraulic pressure of the inlet of the clutch cylinder decreases, and the piston speed decreases. The clutch driving plate moves slowly under the driving of the piston of the hydraulic cylinder and contacts with the driven disc and transmits torque. After full contact, the duty ratio of the solenoid valve increases to the maximum. The pressure of the inlet of the hydraulic cylinder increases rapidly, and the torque transmission capability between the clutch driving plate and the driven plate increases, feedback to the sensitive cavity of the pressure regulating valve by the damping hole 10. under the action of the valve sensitive cavity, the valve core moves upwards and turn down the reducing outlet. Clutch hydraulic cylinder inlet pressure stabilized to a specific value, reached the stable state. This is the pressing process of the clutch.

![Figure 1. Schematic diagram of hydraulic control system for Allison3500R transmission.](image)

The clutch boost process can be divided into three stages. The first stage is the rapid oil filling stage. This stage of the solenoid valve control signal causes the control chamber of the pressure regulating valve to quickly establish pressure to promote the rapid movement of the hydraulic cylinder piston to the clutch active disk. The second stage is the slow contact stage of clutch driving and driven plate. At this time, the duty cycle of the solenoid valve control signal is reduced, so the piston speed of the hydraulic cylinder is reduced, so that the torque transmitted between the clutch driving plate and the driven disk increases slowly. After the driving contact and the driven disk are fully touched, they enter the third stage of high-speed oil charging. The duty ratio of the control signal of the solenoid valve is 1. Ensure the clutch has a great pressure between the driving and the driven disc, so as to improve the torque transmission capability of the clutch.

3. **Mathematical Model of Pressure Control System of Shift Clutch**

Using valve port flow equation, flow continuity equation and valve core force balance equation to establish the nonlinear mathematical model and describe the dynamic characteristics of the hydraulic control system of the shift clutch [5].

Mathematical model of shift solenoid valve
As shown in Fig. 2, the inlet port of the shift solenoid valve is a ring fixed throttle, and the outlet port is a variable throttling port. The overflow area is proportional to the displacement of the valve core.

The flow rate of inlet valve are as follows:

\[ Q_{in} = C_{dv1} A_{dv1} \sqrt{\frac{2}{\rho} (P_{in} - P_t)} \]  

(1)

Where: represents the oil pressure of supply port, represents the control oil pressure

The flow from the outlet of the valve are as follows:

\[ Q_{out} = C_{dv2} A_{dv2} \sqrt{\frac{2}{\rho} P_c} \]  

(2)

The flow of the control cavity of the flow pressure regulating valve is as follows:

\[ Q_c = Q_{in} - Q_{out} = C_{dv1} A_{dv1} \sqrt{\frac{2}{\rho} (P_{in} - P_t)} - C_{dv2} \pi A_{dv2} \sqrt{\frac{2}{\rho} P_c} \]  

(3)

The flow continuity equation of pressure control valve control chamber is as follows:

\[ Q_c \cdot Q_a = A_{dv1} \frac{d_{in}}{dt} + V_c \frac{dP_c}{d_t} \]  

(4)

Where: \( Q_c \) represents the control cavity ET flow, represents the flow to accumulator

Mathematical model of pressure regulating valve

The flow through the overflow outlet and the pressure outlet is respectively:

\[ Q_{om} = C_{dv1} A_{dv1} \sqrt{\frac{2}{\rho} (P_{in} - P_t)} \quad \text{for} \quad Q_{ob} = 0 \quad (x_s \geq 0) \]  

(5)

Where: represents the main oil road pressure, represents the hydraulic cylinder oil pressure

When the piston of the clutch hydraulic cylinder is not pressed with the clutch active disk, the output flow of the pressure regulating valve is mainly used for the rapid movement of the clutch cylinder, and the flow continuity equation is as follows:

\[ Q_{s1} \cdot Q_{s2} = C_{ec} P_L = A_l \frac{dx_{s}}{dt} + V_L \frac{dP_L}{d_t} \]  

(6)

Where: represents the flow rate of pressure regulating valve, \( Q_{s2} \) represents the flow over the damped hole 2, \( x_s \) represents the piston displacement of hydraulic cylinder

When the driving disc and driven disc of the clutch are pressed, the hydraulic cylinder of the clutch is not moving at the maximum displacement, and the output flow of the pressure regulating valve is mainly used to provide the pressure produced between the clutch main and the driven disc. The flow continuity equation at this time is as follows:

\[ Q_{s1} \cdot Q_{s2} = C_{ec} P_L \]  

(7)

The flow continuity equation of pressure sensitive valve is:

\[ A_{s2} \frac{dx_{s}}{dt} + Q_{s2} = V_c \frac{dP_c}{d_t} \]  

(8)

The flow over the damped hole 2 is:
\[ Q_{i2} = C_{d2} A_{d2} \left( \frac{2}{\rho} (P_L - P_{L'}) \right) \]  

(9)

Force balance equation of the valve core of pressure regulating valve is as follows:

\[ P_s A_{s1} - P_L A_{s2} = m_s \frac{d^2 x_s}{dt^2} + B_s \frac{dx_s}{dt} + k_s (x_s + x_{s0}) + F_s + F_t \]  

(10)

Where: represents steady liquid power, represents the Transient hydrodynamic force

Mathematical model of clutch hydraulic cylinder

The force balance equation of the piston of a clutch hydraulic cylinder is as follows:

\[ P_L A_L = m_L \frac{d^2 x_L}{dt^2} + B_L \frac{dx_L}{dt} + k_L (x_L + x_{L0}) \]  

(11)

4. Dynamic Characteristic Simulation of Shift Clutch Pressure Control System

According to formula (1) - (11), idling the dynamic model of shift clutch hydraulic control system, carry out Simulink simulation for the model. The model block diagram is shown in Figure 2. The system input contains pressure \( P_{in} \) supplied for solenoid valve, main oil pressure \( P_m \) and solenoid valve control signal duty cycle \( \tau \). Output is clutch hydraulic cylinder inlet oil pressure \( P_L \). The simulation results are shown in Figure 3.

As shown in Fig 3, in the rapid oil filling stage of the clutch hydraulic control system, the duty ratio of the shift solenoid valve is 0.7, the pressure regulating valve control chamber is rapidly setting up the pressure, The valve core is moved down from the top end of the valve body, the pressure reducer
opens a certain degree of opening, the clutch hydraulic cylinder enters the oil inlet to establish certain pressure. When the pressure reaches the pressure of the clutch hydraulic cylinder piston, the clutch piston moves quickly to the left under the pressure of liquid, which is ready for the combination of the driving and the driven disc of the clutch. After 0.2 seconds, the clutch enter the "slow contact phase of driving plate and driven plate". The piston of the clutch hydraulic cylinder is driven by the hydraulic oil to drive the clutch driving disc slowly to the left and the driven disc. This process is the process that the clutch drive disk gets the same speed as the driven disc and transfers the torque gradually the friction state from the dynamic friction to the static friction. The friction coefficient between the driving and driven plates is large, so as to reduce the abrupt value of transfer torque, it is necessary to reduce the piston speed of the clutch cylinder. At this time, the duty ratio of the shifting solenoid valve is reduced to 0.55, the pressure of the pressure control valve is reduced, and the valve core moves upward under the action of the spring force. The opening of the reducer is reduced. The pressure of the hydraulic oil in the inlet of the clutch cylinder decreases. The moving speed of the piston is reduced. When the driving disc and the driven disc are fully integrated into the high speed oil filling stage. The duty ratio of the solenoid valve becomes 1, the control chamber oil pressure of regulating valve is rapidly rising, the valve core moves downward to the full opening of the pressure reducing outlet, and the pressure of the inlet port of the shifting clutch hydraulic cylinder rises rapidly. The pressure of the inlet of the hydraulic cylinder is feedback to the sensitive cavity of the pressure regulating valve through the damping whole 10. The valve core is moved to a certain value until it reaches steady state, and the shift ends.

5. Conclusion
The shift process is divided into three stages. The duty ratio of the solenoid valve controls the motion state of the piston of the hydraulic cylinder, In the in the rapid oil filling stage, the clutch piston gets a larger motion speed, and the slow motion in the slow contact phase of driving plate and driven plate ensures a smooth shift. There is a greater pressure between the main and the driven disks of the last phase, which can transmit greater torque. Using this control mode to shift gears can not only increase the shifting speed but also ensure the smoothness of shifting

Acknowledgments
This project is supported by National Natural Science Foundation of China (Grant No. 51475116). The authors would like to thank the reviewers.

References
[1] Watechagit S, Srinivasan K. Modeling and Simulation of a Shift Hydraulic System for a Stepped Automatic Transmission[C]/ Sae International. 2003.
[2] Zhang Y, Zhan J, Li H. Simulation of hydraulic automatic transmission starting based on fixed speed control strategy[J]. Hoisting & Conveying Machinery, 2017.
[3] Margraf C, Brom S. Hydraulic system for an automatic transmission[J]. 2017.
[4] Shi G, Liu Y, Han X, et al. Control strategy of vehicle automatic transmissions matching with start-stop system[J]. Nongye Gongcheng Xuebao/transactions of the Chinese Society of Agricultural Engineering, 2017, 33(12):91-98.
[5] Shifting Control of Automatic Transmission and Real-vehicle Validation[J]. Mechatronics, 2017.