Study on the Influence of Damping Hole of DCT Complex Valve Body Lubricating Oil on System Dynamic Characteristics

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Abstract. The dual clutch automatic transmission (DCT) technology can realize powerless interruption of the shifting process, and its hydraulic control system is a complex hydraulic valve body. The cooling lubricating oil circuit is very important for the lubrication of the clutch and the adjustment of the transmission oil temperature. This paper mainly analyzed the influence of the damping hole on the dynamic characteristics of the system in the lubricating oil circuit. Based on AMESIM software, the simulation model of the lubrication regulating main valve was established. The influence of the size of the damping hole on the output pressure, the lubrication flow of the output clutch and the lubrication flow of the output gear shaft were analyzed under the flow rate step condition. Combined with the vibration of the system, it was found that the reasonable diameter interval of the damping hole was 1.8~2.3 mm.

1. Introduction
The DCT (Dual Clutch Transmission) has attracted extensive attention in many large automobile manufacturers at home and abroad because it can eliminate the shortcomings of the electronically controlled mechanical automatic transmission interrupting power shifting. When the DCT shifts gear working, the clutch generates a lot of heat due to sliding friction. If the heat is not dissipated in time, it will cause local high temperature on the clutch friction surface, which seriously affects the performance and life of the clutch [1]. Therefore, the cooling lubricating oil circuit in the DCT complex valve body plays a very important role.

In recent years, research on DCT hydraulic systems has gradually increased at home and abroad. Jafari K et al. [2] conducted a systematic study on the DCT hydraulic system control power source; Junge C. et al. [3] conducted a systematic study on the pressure control of the DCT hydraulic system; Mustafa R. [4] carried out mathematical modeling on the DCT clutch hydraulic system; Cho B.H. et al. [5] simulated and experimentally studied the solenoid valve characteristics of DCT clutch; Lee G.S. [6] used Fluent software to simulate the flow field in the VFS valve in DCT hydraulic valve body; In domestic, Li Qinghe, Li Lei, Yu Huilong, Lu Cheng, etc. [7-10] modeled and analyzed each module of DCT complex valve body.

Based on AMESIM software, this paper analyzes the influence of the orifice on the dynamic characteristics of the system.
2. Analysis of lubrication control valve function
The DCT control valve body mainly realizes the following three functions: clutch engagement pressure control, shift pressure control, and flow distribution between clutch lubrication and gear shaft lubrication. The lubricating oil circuit not only acts as a lubricant, but also acts as a temperature regulator for the transmission oil. The lubrication system is mainly composed of lubricating adjustment slide valve, VBS valve for lubrication adjustment control, lubrication cooling and sprinkler. The lubricating oil path regulating valve includes a flow input port P, two flow output ports A and B, and a VBS control port. The main function is to distribute the flow of the gear shaft lubrication and the clutch lubrication, and the distributed flow comes from the outlet flow of the main oil regulating valve. The schematic diagram of the lubricating oil circuit regulating valve system is shown in Figure 1.

![Fig. 1 Schematic diagram of lubricating adjustment valve system](image1)

The lubrication flow distribution of the gear shaft and the clutch is mainly realized by the lubricating oil path regulating valve. The distribution method is shown in Figure 2, where the liquid resistance $R_{\text{tooth}}$ of the gear shaft lubricating oil path is not adjustable, and the distribution of the upstream flow rate $Q$ is realized by adjusting the value of the equivalent liquid resistance $R_{\text{clutch}}$ on the clutch lubricating oil road. $R_{\text{clutch}}$'s initial liquid resistance is smaller than $R_{\text{tooth}}$. By increasing the control current, $R_{\text{clutch}}$'s liquid resistance can be adjusted, and the flow of the gear shaft lubrication and clutch lubrication can be distributed as needed to ensure normal clutch lubrication level and clutch operating temperature, and ensure clutch and shift control stability.

![Fig. 2 Flow distribution schematic diagram of lubricating oil circuit](image2)

3. Dynamic Characteristics Analysis of Lubricating Oil Road Conditioning Subsystem
To analyze the dynamic characteristics of the lubricating oil road adjusting subsystem in the DCT complex hydraulic valve body, it is firstly need to find out and analyze the parameters affecting its dynamic characteristics and the effect.
There are many key parameters affecting the dynamic characteristics of the lubricating oil circuit regulating subsystem, such as the processing quality of the lubricating oil regulating valve, the leakage
amount, the volume of the cavity, the damping hole connected with the cavity of other key components of the DCT complex hydraulic valve body, the spring rate of the lubrication regulating valve, the initial compression of the spring, and the size of the damping hole of the lubrication regulating valve.

3.1. Lubricating oil line regulating valve

According to the structural diagram of the lubrication regulating valve, a schematic diagram of the lubrication regulating valve is drawn, as shown in Figure 3.

Adjust the spool position of the lubrication regulating valve by changing the pilot pressure of the VBS valve connected to the lubrication regulating valve, control the size of the A and B ports, and adjust the lubrication flow of the input clutch.

According to the flow continuity equation: , the total flow to the load is:

\[ Q_L = Q_{AR} + Q_B \]  \hspace{1cm} (1)

In the formula, \( Q_L \) is the total flow to the load; \( Q_{AR} \) is the flow rate flowing to the load through the orifice A of the valve port A; \( Q_B \) is the flow rate flowing through the port B to the load;

![Fig. 3 schematic diagram of the lubrication regulating valve](image)

3.2. Construction of simulation model

In the AMESIM software, the HCD simulation model was established according to the structure of the lubricating oil path regulating valve, as shown in Figure 4.

![Fig. 4 The HCD simulation model of lubricating oil path regulating valve](image)

1—Pilot control pressure signal from VBS valve input; 2—Lubrication flow input signal; 3—Output system pressure; 4—Output clutch lubrication flow; 5—Output gear shaft lubrication flow; 6—Two equivalent damping of gear shaft lubricating oil circuit

3.3. Simulation

This paper mainly studies the influence of the damping hole size of the lubrication control valve on the dynamic characteristics of the lubrication control subsystem.

In order to better study the dynamic characteristics of the lubricating oil regulating valve, it is assumed that:

(1) The flow at the throttle window is turbulent;
(2) The leakage inside and outside the valve is laminar;
(3) The pipeline leakage is not considered;
(4) The transient hydraulic power is ignored.

The simulation time was set to 1s, the viscosity of the oil was 0.01 kg/(m·s⁻¹), the engine signal and the VBS valve current of the lubricating oil circuit regulating subsystem were constant, and the flow of the control end of the given lubrication regulating valve was a step signal. The purpose was that, when the engine speed was constant, changing the lubrication flow of the clutch by changing the flow of the control end of the lubrication oil path regulating valve, so that the lubrication flow response problem under different orifice diameters was studied. The simulation conditions are shown in Table 1. The simulation conditions and results are shown in Table 2-4 and Figure 5-7.

### Table 1. Simulation conditions

| Working condition | Control pressure(bar) | Input flow (L/min) | Damping hole diameter(mm) | Simulation time(s) |
|-------------------|-----------------------|--------------------|---------------------------|-------------------|
| Input flow step   | 7                     | 20.4-22            | 0.8; 1.3; 1.8; 2.3; 2.8   | 1                 |

![Simulation Diagram](image)

Fig. 5 Effect of damping hole on output pressure response

### Table 2. Step response of output pressure corresponding to the size of damping hole

|                | 0.8mm | 1.3mm | 1.8mm | 2.3mm | 2.8mm |
|----------------|-------|-------|-------|-------|-------|
| Response time  | 0.08s | 0.035s| 0.03s | 0.025s| 0.028s|
| Steady-state error | 0     | 0     | 0     | 0     | 0     |
| Output pressure response | 5.523258bar |
Fig. 6 Effect of damping hole on output clutch lubrication flow response

Table 3. Step response of output clutch lubrication flow corresponding to the size of damping hole

| Diameter (mm) | Response Time (s) | Steady-state Error | Output Clutch Lubrication Flow (L/min) |
|--------------|-------------------|--------------------|----------------------------------------|
| 0.8          | 0.085             | 0                  | 17.23-18.58                            |
| 1.3          | 0.045             | 0                  |                                        |
| 1.8          | 0.035             | 0                  |                                        |
| 2.3          | 0.03              | 0                  |                                        |
| 2.8          | 0.03              | 0                  |                                        |

Fig. 7 Effect of damping hole on output gear shaft lubrication flow response

Table 4. Step response of output gear shaft lubrication flow corresponding to the size of damping hole

| Diameter (mm) | Response Time (s) | Steady-state Error | Output Gear Shaft Lubrication Flow (L/min) |
|--------------|-------------------|--------------------|-------------------------------------------|
| 0.8          | 0.085             | 0                  | 3.17-3.42                                 |
| 1.3          | 0.04              | 0                  |                                          |
| 1.8          | 0.035             | 0                  |                                          |
| 2.3          | 0.03              | 0                  |                                          |
| 2.8          | 0.03              | 0                  |                                          |

3.4 Simulation result analysis

It can be seen from the above simulation results that when the input control flow rate is a step signal, the response time of the different diameter damping holes to the output pressure, the output clutch lubrication flow rate, and the output gear shaft lubrication flow rate is different.

When the diameter of the damping hole was 0.8mm, the system response speed was slow, and for the actual system, hysteresis may occur; as the diameter of the damping hole increased, the response speed of the system was faster; when the diameter of the damping hole was larger than 1.8mm, the response time of the system was relatively close; When the diameter of the orifice was 2.3mm and
2.8mm, the response time were very short, both were 0.03s. However, as the diameter of the orifice increased, the amplitude of the vibration increased. Therefore, if the system response is satisfied, the orifice should be minimized to reduce the vibration amplitude and reduce the fluctuation. Therefore, the reasonable size of the hole is between 1.8mm and 2.3mm.

4. Conclusion
Through the simulation analysis of the lubrication regulating valve damping hole to the step dynamic response of the lubricating oil path system input flow, it is found that the clutch output flow response time and the gear shaft output flow response time become shorter as the diameter of the damping hole increases (Table 3 and Table 4). It can be concluded that the larger the diameter of the orifice, the better the dynamic characteristics of the system. However, if the diameter of the hole is too large, the amplitude of the vibration is also larger. Therefore, when selecting the diameter of the orifice, it should be considered comprehensively, and it is more reasonable to choose a larger diameter.

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