Checking and Optimum Design of Damping Hole in Lubricating Oil Circuit of DCT Complex Valve Body

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Abstract: The complex hydraulic valve body in the DCT is an important controlling and influencing factor to realize the function of dual clutch transmission. This paper took a damping hole in the cooling lubricating oil circuit of DCT as the research object, analyzed the flow field of the oil circuit based on the modeling software of CATIA and Fluent, discussed the influence of the size of the damping hole on pressure establishment of the complex valve body related oil circuit, checked the structural design of damping hole in lubricating oil circuit, and proposed the scheme and method of structure optimization. The analysis results after optimization reached the expected inlet pressure of the damping hole, which proved the rationality of the optimized structure.

1. Introduction

Dual Clutch Transmission (DCT) can utilize the continuous separation and combination of dual clutch structures to achieve unpowered interruption in the shifting process [1], of which the utilization rate is getting higher and higher in major brands of cars. All the shifting fork movement required by the combination and disengagement control of two clutches and by each gear is controlled by the hydraulic system. The hydraulic control system of DCT is a complex hydraulic valve body system consisting of hydraulic power source subsystem, main oil circuit pressure regulating subsystem, lube regulating subsystem, clutch torque control subsystem, gear shift control subsystem and other modules [2].

At present, automakers and research institutes at home and abroad have done more research on the structure, combined characteristics and control systems of DCT and less research on their hydraulic systems [3]. M.Goetz et al. studied the shifting strategy of DCT and proposed a shift process control method ofrationally controlling the output torque of the transmission [4]. Yuan et al. used Fluent to analyze the flow field of the wet clutch friction plate [5]; Manyala had designed a method to improve the quality of shift levers through dynamic analysis of the DCT shift lever [6]; In hydraulic system research, Gee Soo Lee et al. used Fluent to study the relationship between pressure sensitivity and VFS valves and oil temperature [7]; Li from Jilin University established a simulation model of hydraulic control system, and studied the key parameters of the model [8]; Han from Xi'an University of Science and Technology established a static model of the hydraulic system and verified the rationality of the experimental design through the comparison of simulation and experimental data [9].

Damping holes with different functions are commonly used in the design of oil circuits of complex hydraulic valve bodies. The structure of these functional damping holes (damping hole size) and
damping effect directly influence the relevant oil circuit distribution and pressure establishment, thus affecting the realization of expected function of complex hydraulic valve body. The automotive system has particularly significant requirements for component control performance. Therefore, on the basis of meeting the general requirements of structural design, the influence of the internal flow state on the performance of complex valve bodies must be further considered.

Under the premise of ensuring the complete system design, this paper combined the working conditions and related technical data, used the flow field analysis software Fluent to carry out simulation study on a damping hole in lubricating oil circuits in DCT complex valve body, discussed the influence of the size of the damping hole on pressure establishment of the complex valve body related oil circuit, checked the structural design of damping hole in lubricating oil circuit, found out the problems and proposed the scheme and method of structure optimization.

2. Function analysis of the damping hole in oil circuit

The hydraulic principle of complex valve body is shown in Fig. 1. There are three main oil circuits, including main oil circuit, control oil circuit and cooling lube oil circuit. The cooling lubrication zone is mainly composed of a lube regulator valve and a pilot control valve, and the pilot control valve is used to control the lube regulator valve. When each control valve is fully open, the flow of each branch must be maintained in a certain distribution relationship. Therefore, there are a plurality of damping holes in the lubricating oil circuits, and the lubricating flow distribution to the axis and the clutch is controlled by controlling the size of the adjustable liquid resistance. For this reason, it is necessary to perform preliminary verification of damping holes in the control oil circuit, to confirm whether the size of damping holes can realize the expected flow distribution of the complex valve body and the function of establishing the system pressure. This paper took the damping hole 1 as the research object, and checked and optimized its structural design.

3. Determination of research method

This paper utilizes Catia 3D design software and fluid analysis software ANSYS Fluent to simulate, analyze and optimize the flow field of the damping hole 1. The specific technical route is shown in Fig. 2:
Checking the damping hole in lubricating oil circuit

The pressure and flow distribution of the pressure points before and after the damping hole 1 (as shown in Fig. 1) under working conditions are shown in Table 1.

Table 1. Pressure and flow distribution before and after damping hole 1 (temperature is 0 ℃)

| point | Pressure(bar) | Flow(L/min) |
|-------|---------------|-------------|
| ①     | 11.8          | 32          |
| ②     | 2.8           | 32          |

4.1. Extraction and simplification of fluid domain

According to the three-dimensional model of a complex valve body, the Catia software was used to inversely calculate the total graph of the oil circuit in a complex valve body (Fig. 3). Besides, full oil circuits in the complex valve body were simplified repeatedly (Fig. 4), and the oil circuit section was obtained where the damping hole 1 in lubricating oil circuit was located (Fig. 5). The measured radius of the damping hole 1 is 1.5 mm:

4.2. Grid division of target oil circuit

ANSYS software was used to import the target oil circuit, define the oil inlet, outlet, and oil circuit wall according to the actual work, and divide the grid, as shown in Fig. 6. The inspection found that the quality of grids was greater than 0.34, meeting the requirements of further calculations.
4.3. Setting the boundary conditions, physical model and solution method
In the Ansys-Fluent module, the grid file generated in the previous step was imported; The turbulence model (Viscous-Laminar) was selected, and the fluid material was taken as "engine oil". The inlet and outlet boundary conditions were defined, with the set relevant parameters shown in Table 2. Initialization was performed, and the calculation was started after setting the number of iteration steps to 1000.

| Table 2. Setting values of relevant parameters |
|-----------------------------------------------|
| engine oil                                    | density                        | 843Kg/m³                  |
|                                               | viscosity                      | 0.21Kg/m-s                |
| inlet Boundary Conditions                     | Velocity magnitude             | 2.167M/s                  |
| outlet boundary conditions                     | Hydraulic diameter             | 10.356mm                  |
|                                               | Gauge pressure                 | 2.8bar                    |
|                                               | Backflow hydraulic diameter    | 6.5mm                     |

4.4. Post-processing of calculation results
The pressure cloud chart and trajectory are shown in Fig. 7-8.

5. Result analysis and optimization design
It can be found in the analysis of the pressure cloud chart, under the premise that the designed outlet pressure and the inlet flow rate meet the requirement of the working conditions (as shown in Table 1), the inlet pressure of the oil circuit where the damping hole 1 is located reaches 46.5 bar, much larger than the expected inlet pressure of 11.8 bar, indicating that the current design has excessive damping in the oil circuit section, which results in more pressure loss than expectation. That is to say, there is a case where the flow path with variable diameters has an increasing pressure loss in the oil circuit, which proves that the size design of the damping hole 1 is unreasonable, with a too small size.

The structure of the damping hole was optimized and improved. The size of the damping hole 1 was changed with a radius d=2.5 mm. Using the above flow field analysis method, the optimized structure and the optimized pressure cloud chart and trajectory are shown in Fig. 9 and Fig. 10.
Fig. 9 3D model of damping hole 1 before and after optimization of local oil path in lubricating oil circuit

Fig. 10 Pressure nephogram and track map of damping hole 1 before and after optimization of local oil path in lubricating oil circuit

Table 3. Comparison of results before and after optimization of damping hole 1 in local oil way of lubricating oil circuit

| condition            | results                  |
|----------------------|--------------------------|
|                      | Diameter (mm) | Inlet flow rate (L/min) | Outlet pressure (bar) | Inlet pressure (bar) |
| expected value       | --            | 32                       | 2.8                    | 11.8                   |
| Before optimization  | 3             | 32                       | 2.8                    | 46.5                   |
| After optimization   | 5             | 32                       | 2.8                    | 13.3                   |

The analysis results in Table 3 show that the optimized design increases the diameter of the damping hole. Under the same conditions, the pressure established at the inlet is 13.3 bar, close to the desired inlet pressure. It is recommended to use the optimization scheme.

6. Conclusions
In this paper, the flow field analysis method was used to check the function of the damping hole in the lubricating oil circuit of the complex hydraulic valve body. It is found that the designed size of the damping hole 1 in the lubricating oil circuit cannot achieve the expected function of the design well. The flow field analysis on the above problems was carried out, and the improvement suggestion was put forward. After increasing the radius of the damping hole from 1.5 mm to 2.5 mm, under the working conditions, the pressure value established at the entrance of the damping hole was close to the expected value, proving that the structural optimization and improvement scheme is reasonable.

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