Research on modular modelling for the hydraulic system of a vehicle shift

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Abstract: A vehicle-integrated transmission system is a complex system composed of mechanical, electronic, and hydraulic systems whose components work together. The hydraulic system of a vehicle shift is an important part of the vehicle-integrated transmission system. In order to improve the efficiency of the building model, the hydraulic system of a vehicle shift is analysed in detail using the modularisation theory. Also, the modularised simulation model of the system is obtained based on AMESim. The correctness of the module simulation model is verified by building a single-hydraulic-circuit test platform.

1 Introduction

The hydraulic system of a vehicle shift is a large and complex hydraulic system. Its structure is complex and has many hydraulic components. Building its model is cumbersome work. The greater the scale of the system, the worse the coordination. Also, the model is more difficult to modify. The modular modelling method provides an effective solution to reduce the complexity of modelling and improve the portability and readability of the model [1].

In modular modelling, a system is divided into multiple sub-modules which build the models, the sub-modules are connected, and then the model of the whole system is obtained. Compared with traditional modelling methods, modular modelling uses a sub-module to describe a subsystem or a component. With this method, a small number of modules can be organised to describe large systems which contain many parts or subsystems. The module can be standardised or parameterised according to demand, and thus its utilisation can be improved. Also, the sub-module can be modified to quickly update the system model with new features, thereby increasing the modelling speed. At present, the modular modelling method is mainly used in vehicle transmission system modelling. Ford Motor Company’s Rubin [2] and other people used the modular modelling method to establish a multi-wheeled armoured vehicle components of a model and used the hierarchical structure to organise each model of the module. National Renewable Energy Laboratory’s Markel [3] and others introduced a system analysis tool for advanced vehicle modelling—Advanced Vehicle Simulator (ADVISOR). ADVISOR software uses a modular structure design, but the specific process is not further elaborated. Domestic researchers [4–8] also applied modular modelling to build the model of a vehicle system, and realised rapid modelling and simulation. In the literature [4–6], the model of a vehicle transmission system is established, the hydraulic system of the vehicle shift is not considered in detail, and many factors are neglected.

In this paper, the hydraulic system of a vehicle shift is simulated. Through analysing the component structure of the hydraulic system of the vehicle shift, the system is divided based on functional requirements. Also, each submodule of model is established based on AMESim.

2 Hydraulic system of a vehicle shift

2.1 Working principle

In order to carry out the modular simulation research for the hydraulic system of a vehicle shift, firstly, it is necessary to analyse the structure of the hydraulic system of the vehicle shift. As shown in Fig. 1, the hydraulic system of a vehicle shift consists of seven independent control circuits and emergency manual circuit. The independent control circuit has a hydraulic buffering valve which is used to control the pressure of the clutch. When the automatic shift fails, the emergency manual circuit can make sure that the vehicle works properly.

The hydraulic pressure source consists of an oil pump, a main constant pressure valve, and a safety valve. It maintains the pressure of the hydraulic system of the vehicle shift. There are nine shift clutches in the hydraulic system of the vehicle shift. They are actuators which work together to complete the vehicle shift. There are no hydraulic-buffering valves in clutch reverse (CR)-, clutch 3 left (C3L)-, and clutch high (CH)-independent control circuit. Also, C3 and C3L shift clutches are connected to the two-three-way directional control valve, similar to the clutch high (CH) and CHL clutches, so that, in general, the C3L and CHL shift clutches work.

2.2 Gear control method

In a heavy vehicle, each shift in the automatic mechanical transmission has a specific function. The selection of the shift of the vehicle is determined by the calculation of the electronic control unit (ECU). [9] In order to have reasonable control over the operating conditions of heavy vehicles, it is necessary to make reasonable gear allocation and shift logic. Vehicle gear allocation depends on the interaction between the various clutches in the vehicle shift hydraulic system. Nine shift clutches constitute the actuators of the vehicle shift system. The electromagnetic directional valve is the control element in each shift hydraulic circuit. The logical relationship between the actuators and the

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Fig. 1 Hydraulic system of the vehicle shift

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control element is the key to the shift system. Table 1 is a shifting logic which shows the gear from one to six gear logic. The column shows Neutral N and seven gears, form Forward 1 to Forward 6. The row represents seven shift clutches, from C1 to CHL. A check in the table indicates that the clutch is in the engaged state in the corresponding gear.

### Table 1 Shifting logic

| Gear | C1 | C2 | C3 | CH | CL | C3L | CHL |
|------|----|----|----|----|----|-----|-----|
| n    | —  | —  | —  | —  | —  | √   | —   |
| 1    | √  | —  | —  | —  | √  | √   | —   |
| 2    | —  | √  | —  | —  | √  | √   | √   |
| 3    | —  | —  | √  | —  | √  | —   | —   |
| 4    | √  | —  | —  | —  | —  | —   | —   |
| 5    | —  | √  | —  | —  | √  | —   | —   |
| 6    | —  | —  | √  | —  | —  | —   | —   |

3.2 Module integration

After the system is divided into some modules, the modules need to be integrated. The function modules are mutually combined to realise the function of the system. Therefore, it is necessary to define the interface and causality of each model. Fig. 3 shows the relationship between various modules.

Through the module division and interface analysis of the vehicle shift hydraulic system, the model of each function module is established using super component function of AMESim. Then the simulation module library of the vehicle shift hydraulic system is formed. Finally, we select the appropriate module from the library to build the model of the vehicle shift hydraulic system with the interface principle, as shown in Fig. 4.

As shown in Fig. 4, the third interface of the power module, which is the output oil pressure of the system connects, respectively, to the fifth interface of the manual emergency module and the third interface of the shift action module. The power module provides the oil pressure for these modules. In the system, there are five I-type shift action module. Its sixth interface connects, respectively, to C1, C2, CR, CL, and clutch brake (CB) shift clutches. There are two II-type shift action modules. Its sixth and seventh interfaces connect, respectively, to C3, C3L and CH, CHL shift clutches. The second, third, and fourth interfaces of the manual emergency module connects, respectively, to the fifth interface of the shift action modules in the CR, C1, and CL shift hydraulic circuits. Output signal which the signal control module output respectively connects to the fourth interface of shift action module. In the system, in addition to the CR, CHL, and C3L shift hydraulic circuits, other circuits connect to the drive module through the buffer module.
3.3 Mathematical model of the shift

By establishing the mathematical model of the shift, it is possible to analyse the effect and influence of each physical quantity on the vehicle shift hydraulic system. Then, we get the main factors that affect the system performance and use AMESim to further simulate it [11, 12].

The maximum friction torque of the clutch $T_m$ is

$$ T_m = \beta P R_d z k_0 $$  

(1)

where $\beta$ is the reserve coefficient, $\mu$ is the friction coefficient, $R_d$ is the equivalent radius, $P$ is the pressure on the clutch piston, $z$ is the number of friction pairs, and $k_0$ is the pressure loss factor.

The formula of the pressure $P$ is

$$ P = \frac{\pi^2 q \psi}{4}(D_2 - D_1)^2 $$

(2)

The equivalent radius of friction is

$$ R_d = \frac{D_1 + D_2}{4} $$

(3)

where $D_1$ is the inner diameter of friction plate, $D_2$ is the outer diameter of the friction plate, $\psi$ is allowable specific pressure.

Substituting (2) and (3) into (1), we obtain

$$ T_m = \frac{\pi^2 \mu}{16}(D_2 + D_1)(D_2 - D_1)z k_0 \psi q $$

(4)

The friction torque actually transmitted by the clutch during operation is

$$ T_m' = \mu P' R_d z k_0 $$

(5)

where

$$ P' = \frac{\pi}{4}(D_2^2 - D_1^2)p $$

(6)

Substituting (6) into (5), we obtain

$$ T_m' = \frac{\pi^2}{16}(D_2 + D_1)(D_2 - D_1)\mu z k_0 p $$

(7)

From the above formula, it can be seen that the friction torque of the clutch is not only related to the friction coefficient of the friction plate, the diameter of the friction plate, but also to the oil pressure in the clutch cylinder during the shift process. For the determined clutch, the friction torque is only related to the instantaneous pressure on the clutch piston. Therefore, the influence of the change of pressure on the shift is the key content of this paper.

4 Simulation analysis and experimental verification

4.1 Simulation analysis

In order to explore the dynamic characteristics of the hydraulic system of the vehicle shift, it is needed to simulate the modular simulation model, starting from 0 s, experiences from Neutral N, then from Forward 1 to Forward 6, and lasting back to Neutral N. The simulation time lasts for 15 s. The simulation results are shown in Fig. 5.

As shown in Fig. 5, the changes of the pressure of the clutch in the independent control circuit during the shift process.

From 2 to 8 s, the C1, C2, and C3 shift clutches obtain oil pressure in turn, respectively, last for 2 s. At the same time, the CL shift clutch is in a pressed state, and the CH shift clutch does not actuate. Combined with the shifting logic, Table 1 shows the vehicle shift process from Forward 1 to Forward 3 at this stage.

From 8 to 14 s, the C1, C2, C3 shift clutches obtain oil pressure in turn, respectively, last for 2 s. At the same time, the CL shift clutch unloads, and the CH shift clutch is in a pressed state. Combined with the shifting logic, Table 1 shows the vehicle shift process from Forward 4 to Forward 6 at this stage.

4.2 Experimental verification

According to the introduction of the previous sections, the hydraulic system of the vehicle shift is composed of several similar control circuits. Therefore, the representative one of them is selected as the experimental object, and the test experimental is set up for experimental verification. The test platform is shown in Fig. 6.

The pressure gauge is used to display the system working oil pressure, which is installed at the relief valve. The pressure transducer is used to display the inlet pressure of the hydraulic buffering valve in the CL shift hydraulic circuit. The flowmeter...
shows the system flow rate. The oscilloscope is used to display and record the pressure in the CL clutch. The resultant comparison curves of the experiment and simulation are shown in Fig. 7.

As can be seen in Fig. 7, when the buffering valve is opened, the pressure of the clutch fluctuates in the shift hydraulic circuit. Also, the result, which is obtained through simulation, is more intense because of the volume and elastic element in the modular simulation model. From the perspective of the coincidence trend of the two curves, the test and simulation results are consistent. The simulation model of the shift hydraulic circuit can accurately reflect the actual working state. So the modularisation of the vehicle shift hydraulic system can be further simulated and analysed.

5 Conclusion

In this paper, the hydraulic system of the vehicle shift is studied using the modularisation theory. It is divided into functional modules. Also, the simulation module library is built on the basis of AMESim. A modular model of the hydraulic system of the vehicle shift is built up using the module library. The test platform is built to verify the simulation model. The test and simulation results are consistent through the experimental data. Moreover, the correctness of the buffering module model is verified. By changing the parameters of the module model or the module model in the model library, a simulation model of the hydraulic system of the heavy vehicle can be set up quickly, which improves the modelling efficiency and prepares for the deepening of the simulation model.

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7 References

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Fig. 7 Test and simulation of the comparison curve