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Modeling and Application in Vehicle Dynamics Model of Torque Converter Based on Simulink

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Abstract: Hydraulic torque converter is an important part of AT transmission. Its flexible connection characteristics and low-speed torque increase characteristics can significantly improve the adaptability of vehicles to road conditions, avoid engine stall or large speed change, and reduce the impact of transmission shaft components on off-road road. When the mechanical transmission ratio range is determined, the hydraulic torque converter can provide additional transmission ratio when the pump turbine speed ratio is large, and improve the vehicle's dynamic performance under starting acceleration and low-speed climbing conditions, and greatly improve the vehicle's acceleration and starting characteristics and climbing ability. In this paper, the modeling of the torque converter in the vehicle dynamics model based on Simulink is analyzed and studied, which lays a foundation for the establishment of the vehicle dynamics model and the adjustment and optimization of the shifting strategy.

Keywords: AT transmission; hydraulic torque converter; simulink; vehicle dynamics model

1. Overview of torque converter model

The hydraulic torque converter is an important component of the AT transmission, which is generally arranged in the input end of the AT transmission, its impeller is directly connected with the engine flywheel, the turbine output is used as the power input of the planetary gear transmission mechanism, and the guide wheel is fixed in the transmission housing through the hollow spline shaft. The relation between impeller-turbine speed and torque parameters of torque converter directly affects its application in transmission system, and its original characteristics are usually used to characterize the characteristic parameters of torque converter. The original characteristics reflect the functional relations of the impeller torque coefficient λ_p, efficiency η, torque ratio K and speed ratio i, as shown in Equation 1.[1-3]

The hydraulic torque converter studied in this paper is Y310, and its original experimental characteristic curve is shown in Figure 1 below. It can be seen from the torque coefficient curve of the impeller that it is a composite penetrating hydraulic torque converter, and the torque coefficient of the stall point is slightly lower than the

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highest value, which is conducive to the engine speed improvement during the vehicle acceleration.[1][8]

$$\begin{cases} \lambda_p = f_1(i) = \frac{T_p}{\rho g n_p^2 D^5} \\ K = f_2(i) = \frac{T_t}{T_p} \\ \eta = f_3(i) = Ki \end{cases} \tag{1}$$

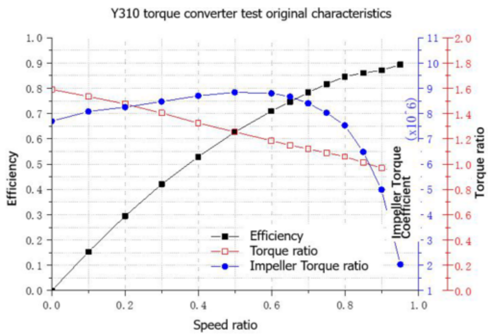

Figure 1. Y310 Torque Converter Test Original Characteristics

Because the torque converter is a flexible connection, it has self-adaptability. Based on the original characteristics of the torque converter and engine data, the common input and output characteristics of the two can be calculated, and the dynamic characteristics of the torque converter can be embedded into the vehicle power system, so as to complete the vehicle dynamics calculation.

The steps to obtain the common input characteristics of torque converter and engine operation are as follows:[1]

(1) Firstly, the speed and torque characteristic data of the engine under different throttle opening were obtained, and the engine characteristic curve was drawn;

(2) Obtain the characteristic parameters and original characteristics of the torque converter;

(3) A series of speed ratios are selected as typical working conditions for research;

(4) According to the selected working point, find the corresponding Impeller torque coefficient value on the original characteristic curve of the torque converter;

(5) Given the torque coefficient of the Impeller, draw the load parabola of the Impeller according to the formula $T_p = \rho g \lambda_p n_p^2 D^5$, and each typical working condition corresponds to a set of parabola;

(6) The characteristic curve of the engine and the load curve of the Impeller are drawn in the same proportion in the same axis to obtain the common input characteristics under different throttle opening.

The output of the torque converter is the speed and torque output of the turbine, which can be obtained by the following two formulas:

$$\begin{cases} n_t = i \times n_p \\ T_t = K \times T_p \end{cases} \tag{2}$$

According to the output parameters of torque converter, the output characteristic curve of engine and torque converter working together can be obtained.

As mentioned above, the hydraulic torque converter discussed in this paper is arranged between the engine and the planetary gear variable speed mechanism. Through the analysis of the common input and output characteristics of the hydraulic torque converter and the engine, the undertaking role of the hydraulic torque converter in the whole power flow transmission process can be clearly known, and detailed modeling can be carried out on this basis.

2. Specific modeling analysis of hydraulic torque converter

In order to improve the efficiency of the overall transmission chain, the torque converter in the transmission generally has a locking function, that is, when the speed is high and the speed difference between the impeller and the turbine is small, part or all of the power flow can be transferred directly through the mechanical connection through the clutch combination, so as to avoid the torque converter completely working in the hydraulic condition and improve the work efficiency. Under the condition of rapid start or complex road conditions, the locking clutch is unlocked, giving full play to the advantages of low speed torque increase and strong adaptability of the torque converter.

In the specific modeling work of the torque converter, the Simulink model is established by analyzing the working characteristics of the hydraulic transmission, the locking time and process of the locking clutch, and the power flow transmission of the torque converter considering the locking clutch.

2.1. Analysis of impeller-turbine working characteristics under hydraulic conditions

The torque converter model obtains the torque of the impeller and turbine according to the engine output speed and turbine speed.[3]

$$\begin{cases} r_{speed} = \frac{\omega_{turbine}}{\omega_{impeller}} \\ k = f(r_{speed}) \\ r_{torque} = \frac{T_{turbine}}{T_{impeller}} = g(r_{speed}) \\ T_{impeller} = k \cdot \omega_{impeller}{}^2 \\ T_{actualTurbine} = T_{impeller} \cdot r_{torque} - T_{drag}(\omega_{turbine}) \end{cases} \tag{3}$$

In the formula:

$\omega_{turbine}$—turbine speed, r/min;

T_{drag}—gearbox idle torque, m, it is a function of the rotational speed of the vortex shaft;

r_{speed}—torque converter speed ratio;

k—torque converter coefficient, which is related to the speed ratio, the viscosity of the oil and the diameter of the circulating circle;

$T_{turbine}$—turbine torque, Nm;

r_{torque}—torque converter torque ratio;

$\omega_{impeller}$—impeller speed, r/min;

$T_{impeller}$—impeller torque, Nm.

2.2. Analysis of working characteristics of locking clutch

By analyzing and calculating the engine and turbine speed, the pressure on the clutch and the oil temperature, the clutch torque, the friction plate temperature and the oil output temperature of the clutch are obtained. It mainly includes four parts: centrifugal oil pressure calculation, clutch slip calculation, clutch torque capacity calculation and clutch thermal model. The establishment of this model is also applicable to the mathematical model of shifting clutch.[1]

$$\begin{cases} T_{slip} = k_{slip} \times \omega_{slip} \\ if\ |T_{slip}| < T_{capacity} \\ \quad T_{clutch} = T_{slip} \\ \quad\quad else \\ \quad T_{clutch} = T_{capacity} \end{cases} \tag{4}$$

In the formula:

T_{slip}—slip torque of the locking clutch, Nm;

ω_{slip}—the speed difference between the driving and driven plates of the locking clutch, rad/s;

k_{slip}—Clutch friction stiffness, Nm/(rad/s);

$T_{capacity}$—Clutch capacity of the torque converter, Nm;

T_{clutch}—The actual torque transmitted by the clutch, Nm.

2.3. Simulink model construction of locking clutch

Based on the above analysis of the specific arrangement, power flow transmission and mathematical characteristics of the hydraulic torque converter in the AT transmission, as well as the characteristics and working characteristics of the relevant locking clutch, the following Simulink model is established, and the parameter flow relationship between the input and output parameters and other parts of the vehicle dynamics model is established in Figure 2:[1][2][7]

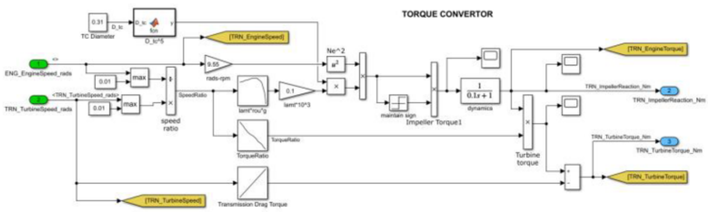

Figure 2. Simulink Model of the Y310 type Hydraulic Torque Converter

The torque of the turbine shaft is composed of two parts: the torque transmitted by the hydraulic force and the torque transmitted by the locking clutch. The load torque of the impeller is composed of the torque output of the hydraulic force, the torque transmitted by the locking clutch and the torque required by the oil pump. The heat flow of the torque converter assembly loss is composed of two parts: the hydraulic loss and the clutch plates heat loss (the clutch plates idle loss, that is, the plates shear oil film and oil mixing loss when the clutch is not under pressure).[3-10]

In this model, input the engine speed (that is, the impeller speed of the torque converter) and the turbine speed, and calculate the impeller torque and turbine torque according to the characteristic data of the torque converter. The impeller torque (also known as engine torque) is iterated into the engine model, and the turbine torque is iterated into the planetary gear transmission mechanism.

3. Analysis of vehicle system simulation results

Three groups of throttle opening are set as follows for vehicle simulation calculation, which are 100% throttle opening, 50% throttle opening and a group of random throttle opening respectively in Figure 3-5.

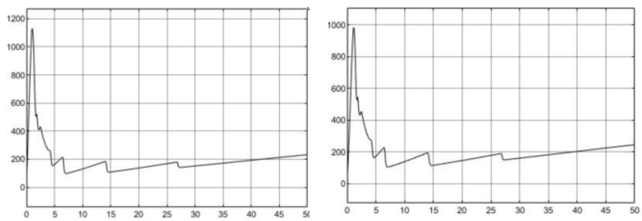

Figure 3. Torque curves of turbine shaft and impeller shaft at 100% throttle opening

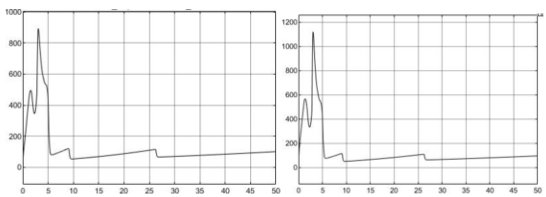

Figure 4. Torque curves of turbine shaft and impeller shaft at 50% throttle opening

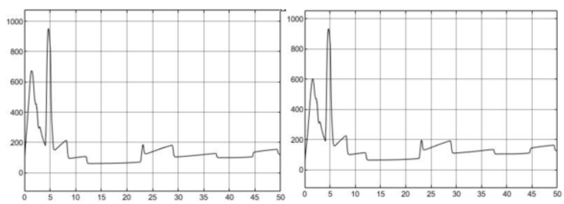

Figure 5. Torque curves of turbine shaft and impeller shaft at random throttle opening

It can be seen from the torque curves of the turbine shaft and the impeller shaft that the torque of the turbine shaft is greater than the torque of the impeller shaft in the starting stage of the vehicle, which reflects the torque increase characteristic under the unlocked condition of the torque converter. After the speed and gear are raised, the two values are equal, which reflects the high efficiency of the torque converter after locking.

4. Conclusion

According to the above calculation results, it can be seen that the torque converter model considering the locked and unlocked condition can reflect the calculation of the dynamic parameters of the vehicle more efficiently. In terms of macroscopic effect, it can satisfy the vehicle dynamics calculation and investigate the dynamic parameter change process of the vehicle shifting process, which has certain value for the high-efficiency vehicle model modeling and parameter research.

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