Modeling and analysis of vehicle driving dynamics based on Simulink

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ABSTRACT

Due to the adaptive transmission components of the hydraulic torque converter, compact planetary gear transmission mechanism and proportional valve precise control of the multi-clutch control system, AT transmission has good road adaptation, outstanding starting and acceleration characteristics, high power density, comfort shift process and other advantages. It is widely used in military, mining and other vehicles with complex road conditions and requiring high mobility flexibility. The combination of the multi-degree of freedom planetary transmission mechanism and the clutch highlights the power shift advantage of the AT transmission. Improving power performance and shifting comfort is an important design content of military and mining vehicles, which involves the design and matching of parameters from engine to transmission and each transmission part of the vehicle. Based on Simulink, this paper analyzes and studies the dynamic model of vehicle driving through, and examines its application in vehicle driving through.

Keywords: AT transmission, dynamic model, simulink

1. INTRODUCTION

Simulink can provide an integrated environment for dynamic system modeling, simulation and comprehensive analysis. Due to its intuitive modeling mode, customizable modules, fast and accurate simulations and complex system hierarchy, it is widely used in vehicle dynamic system modeling.[1][2]

The vehicle dynamics model can be divided into the following parts: engine module, hydraulic system module, mechanical system model, gear selection module, vehicle dynamics module (simulating vehicle parameters), etc. The overall simulation idea is as follows: The torque of the engine output goes into the mechanical system model, after the hydraulic torque converter goes to the planetary gear mechanism, under the action of the controller, the output pressure by the hydraulic system model acting on the clutch in the mechanical system model, produce the corresponding component motion connection. Finally the output shaft of mechanical system transmits the torque to the vehicle dynamics model to calculate the dynamic characteristics of the vehicle in Figure 1.[1]

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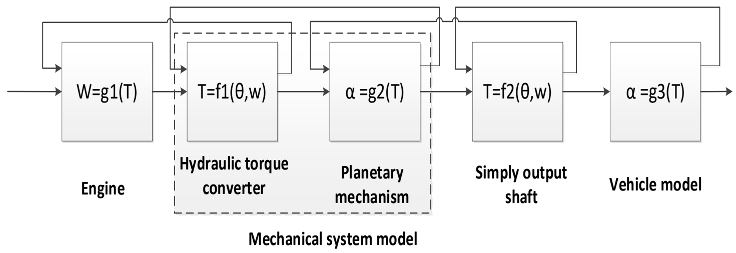

Figure 1. Global model framework

2. SIMULINK MODEL ANALYSIS OF EACH COMPONENT OF VEHICLE DRIVE TRAIN

2.1 Engine model

The engine is the source of vehicle power. The speed-torque value of each throttle opening of the engine is obtained by the method of looking up the table, and the influence of the inertia of related components, the torque of impeller and the torque of engine load on the output torque of the engine is considered comprehensively. The method requires relatively little test data, which can satisfy the accuracy of dynamic analysis.

The overall model has two inputs: engine throttle opening and torque feedback from the torque converter impeller. Two outputs: engine speed and engine fuel consumption.

The torque balance formula of the engine is as follows:

$$J\alpha = T_{conbustion} - (T_{impellerReaction} + T_{over-run} + T_{idleSpeedControl} + T_{friction}) \tag{1}$$

In the formula:

J represents the moment of inertia equivalent to the crankshaft of the engine, $kg \cdot m^2$;

α represents the angular acceleration value of the engine output, rad/s^2;

$T_{conbustion}$ represents the driving torque value generated by engine cylinder combustion, $N \cdot m$;

$T_{impellerReaction}$ represents the load torque value of the torque converter acting on the engine crankshaft, $N \cdot m$;

$T_{over-run}$ represents the engine load torque value, $N \cdot m$;

$T_{idleSpeedControl}$ represents the engine idle control torque value, $N \cdot m$;

$T_{friction}$ represents the frictional resistance torque value of the rotating part of the engine, $N \cdot m$.

Engine combustion torque is the average torque value of crankshaft after the energy generated by cylinder fuel combustion, which mainly depends on the throttle opening and speed and other parameters. In this model, the relevant data given by the engine manufacturer are sorted into a table to determine the combustion torque at each throttle opening and speed. Engine fuel consumption is similarly determined by looking up the table.

Based on the above analysis and calculation of engine driving torque and resistance torque, a complete engine Simulink model is built, as shown in Figure 2 below. By embedding it into the vehicle dynamics model, the dynamic characteristics of the vehicle can be calculated.

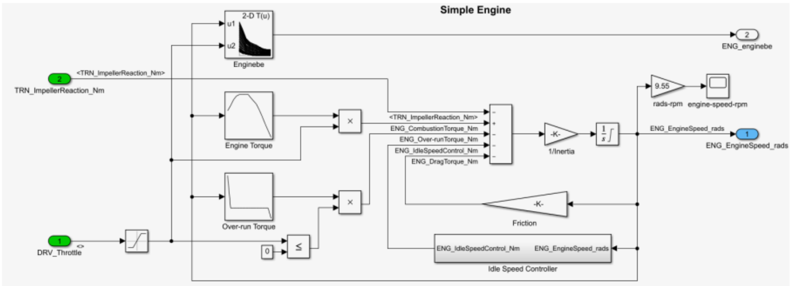

Figure 2. Engine model

2.2 Hydraulic torque converter model

The torque converter model obtains the torque of the impeller and turbine according to the engine output speed and turbine speed.[3][4]

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

In the formula:

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

T_{drag} represents the gearbox idle torque, Nm, which is the function of the turbine speed;

r_{speed} represents the speed ratio of the torque converter;

k represents the torque converter coefficient, which is related to velocity ratio, oil viscosity and circulating circle diameter;

$T_{turbine}$ represents the turbine torque, Nm;

r_{torque} represents the torque ratio of the torque converter;

$\omega_{impeller}$ represents the turbine speed, /min;

$T_{impeller}$ represents the turbine torque, Nm.

2.3 Planetary variable speed mechanism model

The connecting member between the planetary rows is set as a flexible connecting member with a certain stiffness, so as to separate each planetary row. The typical dynamics model of planetary rows has a wide range of generality and reusability. The characteristic quantity of the typical planetary array dynamic model contains 10 variables: sun gear angular speed and displacement, planetary gear angular speed and displacement, carrier angular speed and displacement, ring gear angular speed and displacement, sun gear and planetary gear meshing force, ring gear and planetary gear meshing force, as shown in the Figure 3.

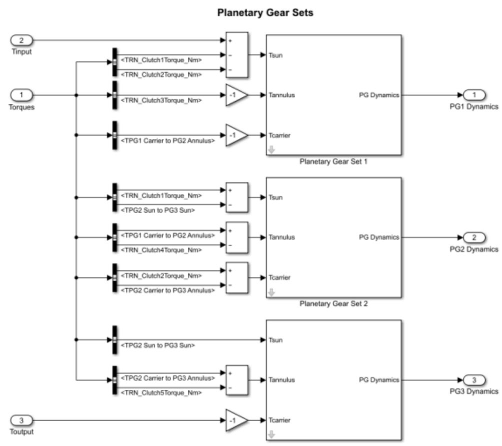

Figure 3. Planetary row connection relation simulation model

2.4 Clutch and internal connection relation model

The planetary row and the clutches are closely related in structure and function, and through the cooperation relationship of different clutches, the power of the input planetary transmission mechanism gets different output transmission ratio through different transmission routes. In the model, the two are packaged in a large frame, and the input includes the output torque of the turbine shaft, the output torque of the third planetary carrier, and the pressure curve of each clutch. The input speed (i.e. the rotational speed of the turbine shaft) and the output speed (the rotational speed of the third planetary row carrier) of the planetary gearshift mechanism are calculated through the internal dynamic relation module.

The clutch and internal flexible connection torque module are shown as follows Figure 4:

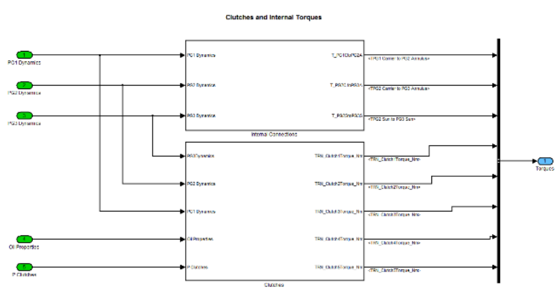

Figure 4. Clutch and internal flexible connection torque module

The torque transmission relationship of the internal connection isshown in the Figure 5 below:

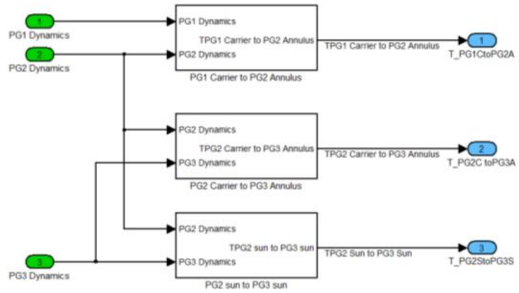

Figure 5. Internal torque transfer model

2.5 Simple shaft model

The shaft model considers the stiffness and damping effects of the shaft in the process of power transmission.

$$T = k\left(\theta_{output} - \theta_{wheel}\right) + c(\omega_{output} - \omega_{wheel}) \tag{3}$$

In the formula:

θ_{output}、ω_{output} represent the rotation angle and angular velocity of the output shaft respectively, r, r/min;

T represents the output torque of the drive shaft, Nm;

θ_{wheel}、ω_{wheel} represent the rotation angle and angular velocity of the wheel, r, r/min;

k, c represent the stiffness coefficient and damping coefficient of the drive shaft.

2.6 Vehicle driving model

When the vehicle runs in a straight line, the external forces it receives include rolling resistance F_f, ramp resistance F_i, air resistance F_w and acceleration resistance F_j, so the total resistance of the vehicle is:[4]~[10]

$$F = F_f + F_i + F_w + F_j \tag{4}$$

In the formula:

$$F_f = mgf cos\theta \tag{5}$$

$$F_i = mgsin\theta \tag{6}$$

$$F_w = \frac{1}{2}\rho C_d A v^2 \tag{7}$$

$$F_j = F_{brake} = \delta m \frac{du}{dt} \tag{8}$$

$$\delta m = m + \frac{I_{FD}+I_{wheels}n_{wheels}}{R_r^2} \tag{9}$$

In the formula:

I_{wheels}、n_{wheels} represent the moment of inertia and speed of the wheel respectively, $kg \cdot m^2$、rpm;

m represents the totle mass of the vehicle, kg;

C_d represents the air resistance coefficient;

v represents the vehicle velocity, km/h;

θ represents the road slope angle, rad;

g represents the gravity, m/s^2;

f represents the rolling resistance coefficient;

R_r represents the radius of the wheel, m;

A represents the windward area of the vehicle, m^2;

I_{FD} represents the inertia of the vehicle, $kg \cdot m^2$;

du/dt represents the vehicle acceleration, $m \cdot s^{-2}$;

δ represents the conversion factor of vehicle rotating mass.

Then the moment equation of vehicle driving is: [4]~[10]

$$\frac{T_{wheel}}{R_r} = \frac{1}{2}\rho C_d A v^2 + (A_d + B_d v)mgcos\theta + mgsin\theta + F_{brake} + \left(m + \frac{I_{FD}+I_{wheels}n_{wheels}}{R_r^2}\right)\frac{du}{dt} \tag{10}$$

The expression for conversion to acceleration is: [4]~[10]

$$\frac{du}{dt} = \frac{\frac{T_{wheel}}{R_r} - \left(\frac{1}{2}\rho C_d A v^2 + (A_d + B_d v)mgcos\theta + mgsin\theta + F_{brake}\right)}{m + \frac{I_{FD}+I_{wheels}n_{wheels}}{R_r^2}} \tag{11}$$

The model is established as shown in the Figure 6.

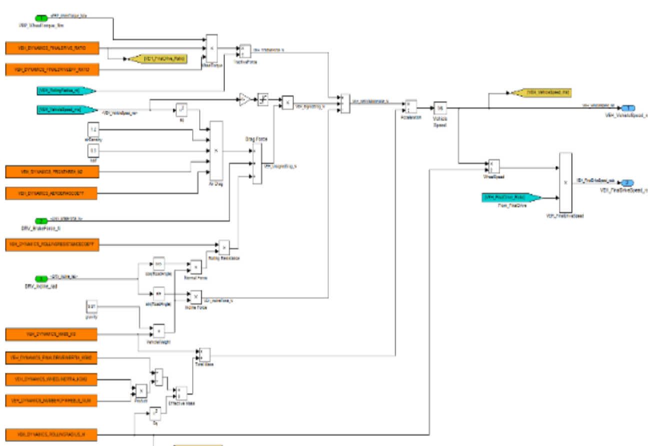

Figure 6. Vehicle driving dynamics model

2.7 Gear selection model

Gear selection part is modeled by state flow module. This paper adopts two-parameter model, input real-time speed and throttle opening value, output gear signal. The gear signal is transmitted to the clutch module, and through the separation and combination of different clutches, the internal connection relationship of the planetary transmission mechanism is transformed to realize the transmission ratio, that is, the shift of gear in Figure 7.[2]

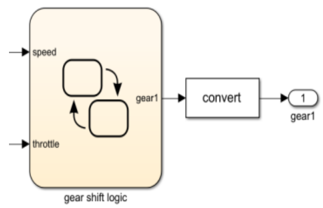

Figure 7. Gear selection model

2.8 Vehicle dynamics model

By connecting and combining the above-mentioned models, the vehicle dynamics model is obtained as follows Figure 8:

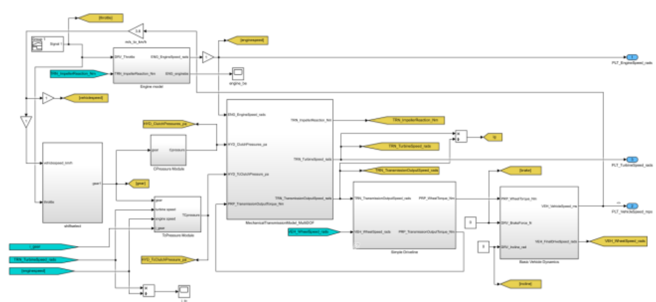

Figure 8. Complete model of vehicle dynamics

3. ANALYSIS OF VEHICLE SYSTEM SIMULATION RESULTS

Based on the vehicle dynamics model of the aforementioned clutch model, simulation calculations were carried out under 100% and 50% throttle opening respectively, and each curve was obtained as shown in the Figure 9 and Figure 10 below.

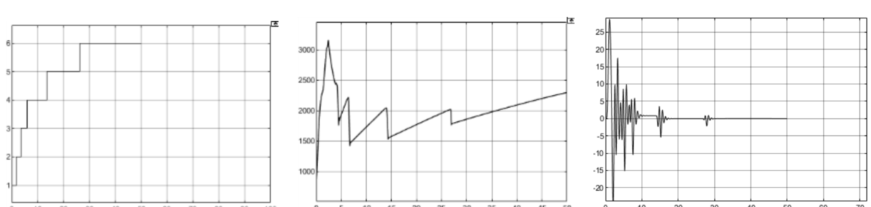

Figure 9. Simulation curve of gear position, engine speed and shift impact at 100% throttle opening

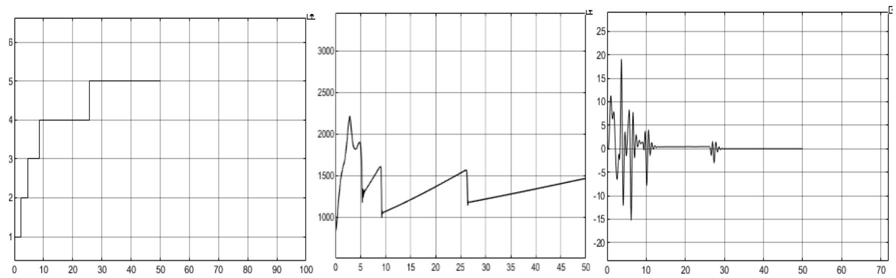

Figure 10. Simulation curve of gear position, engine speed and shift impact at 50% throttle opening

As can be seen from the comparison in the Figure 9 and Figure 10, the acceleration process of the vehicle under 100% throttle opening has faster gear elevation, higher engine speed, and greater shift impact value. Consistent with real vehicle testing and experience.

4. CONCLUSION

According to the above calculation results and analysis, it can be seen that the vehicle dynamics model can reflect the calculation of various dynamic parameters in the running process of the vehicle more efficiently, capture the shifting impact information in the running, and meet the overall vehicle dynamics calculation and investigation of the dynamic parameter changes in the shifting process of the vehicle. It is of certain value to optimize vehicle parameter matching and shift comfort research.

REFERENCES

[1] Gao, Z, Y., Research on shifting rule and dynamic correction of automatic transmission of new tactical vehicle , Master's thesis of the CHINA RESEARCH AND DEVELOPMENT ACADEMY OF MACHINERY EQUIPMENT, 04,16(2019)

[2] Shi, L, C., Matlab/Simulink System Simulation Super Learning Manual, People's Posts and Telecommunications Press, 2014.

[3] Zhu, J, C., Design and Calculation of Hydraulic Torque Converter, The National Defense Industry Press, 1, 1991.

[4] Zhou, L, S., Qu, X, C., Zhou, D, S., Sun, J, L., Peng, M., Automobile Power Transmission Train and Power Performance Calculation, Machinery Industry Press, 05, 2020.

[5] Manfred, M., Henning, W., Chen, Y, S., Yu, Q., Vehicle Dynamics, Tsinghua University Press, 11, 2019.

[6] Alma, H., Hillier’s Fundamentals of Motor Vehicle Technology, Machinery Industry Pres, 08, 2020.

[7] Xiang, J., MATLAB/SIMULINK system modeling and simulation [M]. Tsinghua University Press, 04, 2021.

[8] Yu, Z, S., Automobile theory, Machinery Industry Press, 12, 2023.

[9] Yu, F., Automobile system dynamics, Machinery Industry Press, 07, 2023.

[10] Min, H, T., Wang, J, H.. Automobile design, Machinery Industry Press, 05, 2024.