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Research on Dynamic Performance of Power Shift Clutch

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Abstract. Smooth shift and low shift shock are needed to improve power shift quality and comfort of construction vehicle. And higher dynamic performance of power shift clutch is needed. In this paper, the dynamic mathematical model and simulation model of the clutch engagement process were established, the factors affecting the shift quality were analyzed qualitatively and quantitatively. The simulation model of the transmission system was established based on the software AMESim, the corresponding vehicle tests were performed, and the shifting quality was improved by changing key parameters. Analysis results illustrate that the proposed mathematical model and simulation model are correct and effective and can be used to predict and evaluate construction vehicle shift-feel, which are the theoretical basis for analysis and research on the static and dynamic characteristics of the dynamic shifting process in the future.

1 Introduction

Shift quality is an important index to reflect the performance of the whole machine[1]. Most of the construction machineries are still using the hydraulic mechanical transmission nowadays. Because of the torque converter is arranged between the engine and gearbox, they can effectively reduce the load vibration and shift shock of the system. However, the construction machinery has more complicated working conditions such as frequent shift operation and bad working environment and etc. So the gear shifting shock greatly affects the performance and life of the transmission system, and greatly reduces the driving comfort.

Shift clutch is a key component to guarantee the good shift quality of vehicle. It uses a variable speed control valve to control the clutch engagement and disengagement to complete the shift process. If the engaging or disengaging time of the clutch is improper, it will lead to unsmooth shift. Premature lap will result in power interference, whereas late lap will produce power interruption[2]. By reasonable controlling the pressure characteristics of the oil that comes into the clutch cylinder through a variable speed control valve, it can effectively reduce shift shock in the process of shifting, reduce the friction of clutch disc, ensure dynamic performance in the process of shifting and get good shift quality. So it has important significance for improving shift quality by researching on the oil pressure characteristics, the binding time and the friction torque characteristics of clutch engagement[3].

2 Physical model of clutch engagement

Clutch shift process is mainly divided into three stages[4,5]：

(1) Rapid filling stage. The clutch cylinder is quickly filled with oil, and the clutch drive plate is driven to move under the action of the hydraulic pressure, and the clearance between the drive and driven plates is eliminated.

(2) Clutch sliding stage. With the pressure that entered into the clutch cylinder increasing, the torque transmitted by the clutch increases, and the rotation speeds of the clutch drive and driven plates are gradually uniform.

(3) Clutch fully integrated stage. In this stage, the clutch is fully integrated, the sliding wear is stopped, speeds of the clutch drive and driven plates are the same, and the transmission torque is stable.

In order to study the dynamic model of the clutch engagement, the following assumptions are made:① The clutch and oil channels have no leakage. ② The bearing and bearing seat are without flexibility, and the gear mesh elasticity and clearance are not considered.

The physical model of the clutch engagement during the shifting process is shown in Figure 1 [6]：

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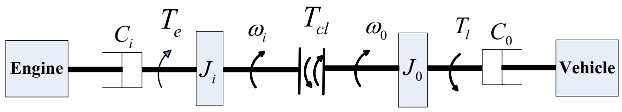

Figure 1. Schematic diagram of clutch engagement process

$$J_i \dot{\omega}_i = T_e - c_i\omega_i - T_{cl} \qquad (1)$$

$$J_o \dot{\omega}_o = T_{cl} - c_o\omega_o - T_l \qquad (2)$$

When the clutch is fully engaged, the model is shown in Figure 2：

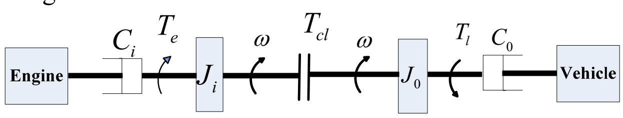

Figure 2. Schematic diagram after clutch engagement

$$(J_i + J_o)\dot{\omega} = T_e - (c_i + c_o)\omega - T_1 \qquad (3)$$

$$T_{cl} = \frac{T_eJ_o + T_lJ_i + (J_ic_o - J_oc_i)\omega}{J_i + J_o} \qquad (4)$$

In the formula：

J_i ——Moment of inertia before the clutch drive plate；

J_0 ——Moment of inertia after the clutch driven plate；

ω_i ——Clutch drive plate speed；

ω_0 ——Clutch driven plate speed；

ω ——Speed when the drive and driven plates of the clutch are synchronized；

T_e ——Engine output torque；

T_{cl} ——Clutch disc Torque；

T_1 ——Clutch output shaft torque which is translated from the road resistance；

C_i 、 C_0 ——Equivalent damping coefficients of the front-end and back-end of the clutch.

Formula (1) to (4) indicate that：when the clutch is in the process of sliding, T_{cl} is equal to the clutch friction torque. After the full engagement of the clutch, torque that the clutch can transmit is equal to the maximum value of T_{cl} .

3 Establishment of AMESim model and parameters setting

The Simulink MATLAB method, which is often used to do the dynamic simulation for the research of construction vehicle transmission system, is too dependent on the theoretical analysis in the modeling process. What's more, it usually ignores or equivalents some of the details of the factors. However, the transmission system involves the whole parameters of the vehicle, which leads to the calculation simulation require more details of the model. AMESim is a modelling and simulation platform that can be used in multidisciplinary fields for complex systems, through which the steady state and dynamic performance of any component or system can be studied. It can effectively improve the efficiency and accuracy of modelling and simulation analyzing.

In this paper, taking a certain type of loader as an example, the transmission system model was established with the AMESim software according to its working principle and actual structure, as shown in Figure 3. It contains some sub models such as the engine model, the torque converter model the tire model and etc.

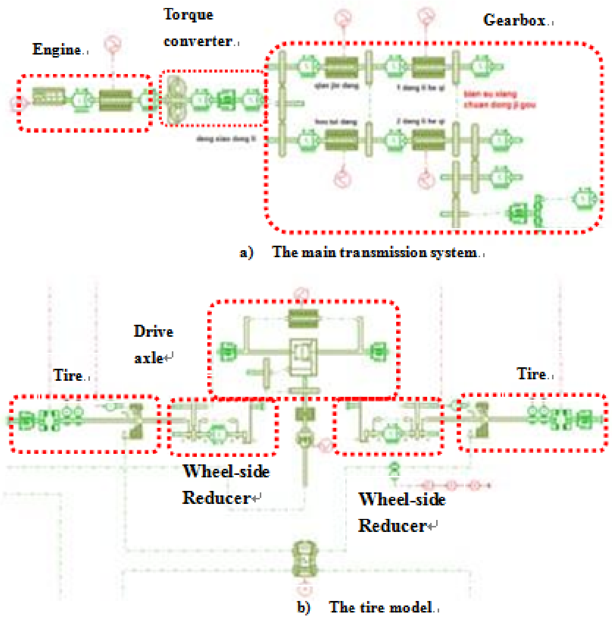

Figure 3. AMESim simulation model

To fully guarantee the accuracy of the model, parameters in the simulation model were set mainly on the basis of the actual structure parameters and values in practical conditions. For example, the engine was set on the basis of its outer characteristic curve, and the torque converter was set according to the sample and experimental measured data. Some of the simulation parameters are shown in table 1.

Table 1. Main parameters of transmission system

Effective friction radius of clutch	100mm
Gross mass	5600kg
Maximum longitudinal force	12400N
Maximum transmission torque of clutch	700Nm
Each moment of inertia	0.001Kgm^2
Speed ratio of each gear	2.4693 0.8784 2.5242 0.8980
Differential speed ratio	5.883
Tire inertia	0.5 Kgm^2
Tire radius	0.5m

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Longitudinal slip ratio threshold	0.1
Road slope	0deg
Air density	1.226kg/m^3
Frontal area	4m^2
Resistance coefficient	0.3

4 Analysis of simulation and experiment results

The hydraulic pressure can be controlled easily. Reasonably controlling the hydraulic pressure change during the shifting process can effectively limit the torque disturbance on the output shaft of the gear box, and get good shift quality[7]. According to the research need, the experiment mainly measured the clutch pressures of the first gear, the second gear, the forward gear and the reverse gear, the inlet pressure of the variable speed control valve and the flow value. The arrangement of the measure points is shown in Figure 4.

Pressure sensor measurement range is 0~7MPa. Flow sensor measurement range is 100L/min. The 1~5V voltage output signals are converted to the 0~7MPa pressure output signals and 0~100L/min traffic signals.

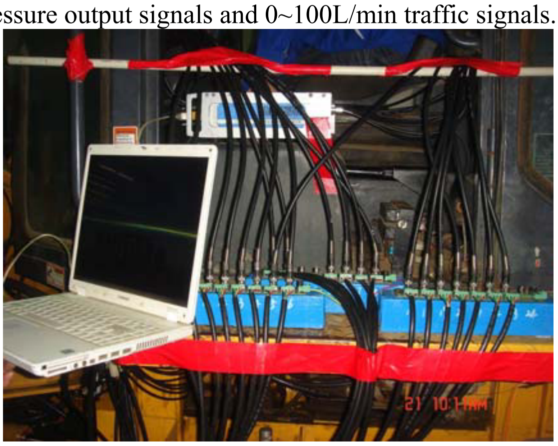


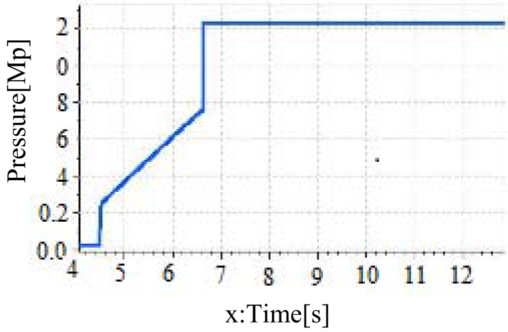
Figure 4. Experimental arrangement of the transmission system

Table 2. Details of test points for the transmission system

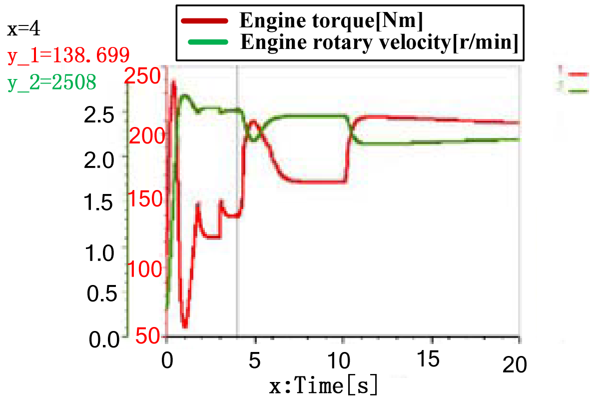
No.	Signal type	Test point name	Range
P1	pressure	The inlet pressure of the variable speed control valve	7MPa
P2	pressure	The first gear clutch pressure	7MPa
P3	pressure	The second gear clutch pressure	7MPa
P4	pressure	The forward gear clutch pressure	7MPa
P5	pressure	The reverse gear clutch pressure	7MPa
Q1	flow	The inlet flow of the variable speed control valve	100L/min

5 Analysis results of simulation

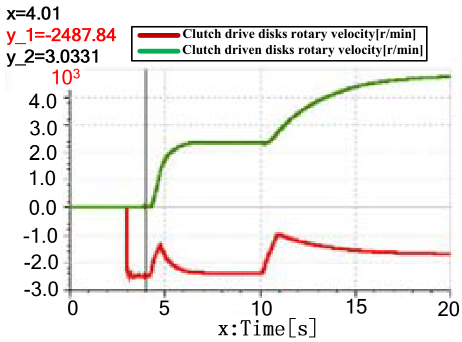
This paper did a simulation research on a certain type of loader's shifting process. The simulation was set as follows: the system is in high speed no-load condition, start the car with the first gear, throttle maintains the maximum opening, shift to the second gear after travelling for about 10 seconds, keep travelling for about 10 seconds and then park and shut off the engine. The main parameters' characteristic curves of the prototype during the shifting process are shown in Figure 5.



(a) Variation characteristics of hydraulic pressure



(b) Engine variation characteristics



(c) Speed variation characteristics of the clutch drive and driven plates

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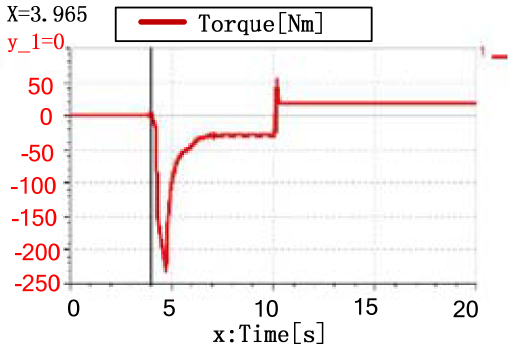
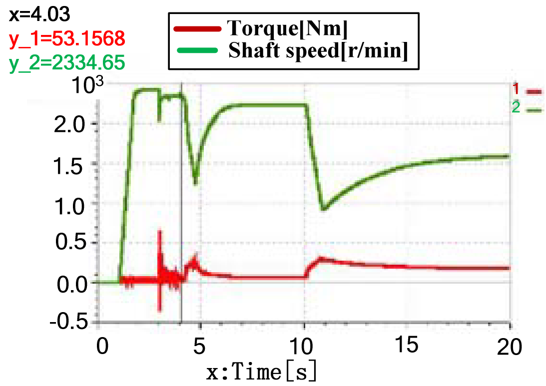


(d) Variation characteristics of the torque transmitted by clutch



(e) Variation characteristics of torque converter

Figure 5. Simulation graph of parameters in shifting process

Simulation result indicates that：it begins to shift at the time of 4S and 10s. In the shifting process, the engine speed is reduced and the torque is increased. Figure (a) is the variation characteristics of hydraulic pressure that from the variable speed control valve acting on the clutch cylinder in process of shifting. Figure (b) is the speed and torque variation characteristics of the engine at this time. Figure (c) is the speed variation characteristics of the clutch drive and driven plates. Figure (d) is the variation characteristics of the friction torque transmitted by the clutch. Figure (e) is the speed and torque variation characteristics of torque converter. In this process, the clutch experiences the rapid filling stage, clutch slipping stage and fully integrated stage to complete the shifting process. In the rapid filling stage, the clutch drive and driven plates vary from the separation state to the beginning of contact state, the torque transmitted by the clutch increases rapidly, and the first shift shock is formed. The torque transmitted by the clutch is gradually increased with the increase of the control pressure. However, after the end of the sliding stage, the transmitted torque is quickly reduced to the torque value of vehicle acceleration, and another shift shock is formed.

6 Analysis of the vehicle tests results

Through simulation analysis, it is known that the main factors that affect the dynamic characteristics of the dynamic clutch are orifice diameter, preload and stiffness of the pressure regulating spring and energy storage spring. Therefore, during the experiment, the vehicle test was done by changing the damping hole diameter of shift buffer valve, the stiffness of pressure adjusting spring, the stiffness and preload of energy storage spring, and data mining equipment was used to collect data. Figure 6 to Figure 9 are the measured test curves.

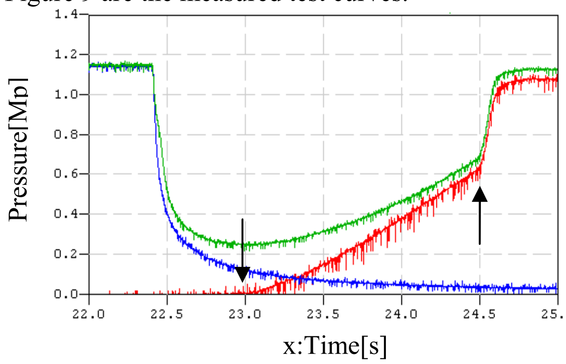


Figure 6. Experiment curves before improving the first gear

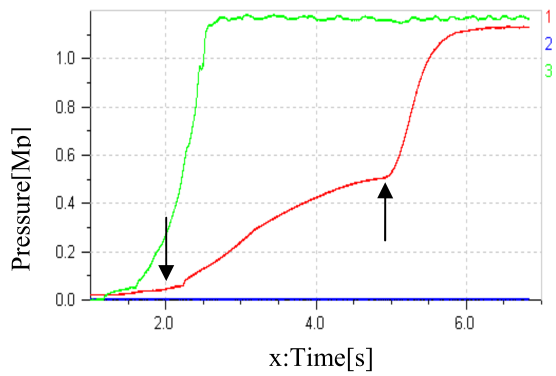


Figure 7. Experiment curves after improving the first gear

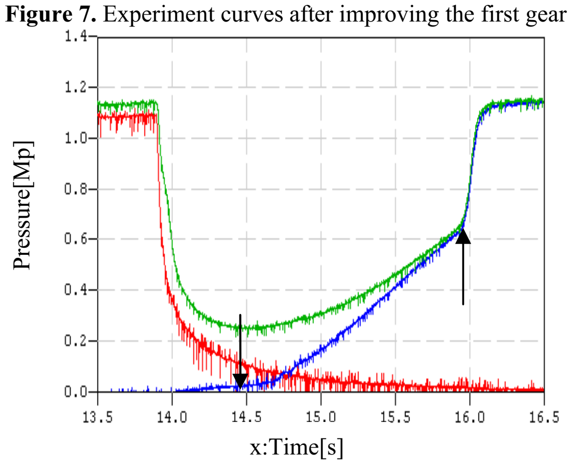


Figure 8. Experiment curves before improving the second gear

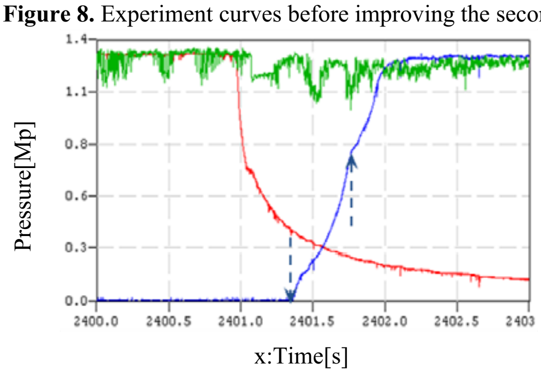


Figure 9. Experiment curves after improving the second gear

The experiment curves show that the buffer time after improving the first gear is changed to 3.5s, the pressure building process is more stable and the shift shock is effectively reduced. The buffer time after improving the second gear is changed to 0.5s, and the pressure of the forward gear is not affected, which effectively mitigates the "stall phenomenon"

7 Conclusions

(1) Through the analysis of the clutch engagement process in the transmission system, the simulation model of the transmission system was established using the AMESim simulation software. The correctness and validity of the simulation model were verified by the experiment of the vehicle, which provides a theoretical basis for the analysis and research on the static and dynamic characteristics of the dynamic shifting process in the future.

(2) The key parameters were tested using the vehicle experiment, and the shift quality of the vehicle was improved by changing the key parameters. This also indicates that the AMESim simulation can play an important role in designing and analysis of the vehicle transmission system.

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