Launch Control of a Dual Clutch Transmission Using a Detailed Hydraulic Component Model

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Abstract

Dual clutch transmissions (DCTs) have emerged as a viable alternative to conventional planetary automatics and continuously variable transmissions (CVTs) with the development of precise control strategies. Although technology advancement greatly improves the transmission performance in recent years, undesirable vibration and noise is still the draw backs to DCT application. The hydraulic sub-component is a particular source of nonlinear response that influences launch performance. Clutch engagement judder, as part of vehicle noise, vibration and harshness (NVH), is an important vehicle attribute in the design of DCT which combines the advantages of manual transmission (MT) and conventional automatic transmission (AT). This paper studies the vehicle vibration during launch. In this paper, a system analytical model including detailed hydraulic control module will be presented for clutch engagement control during launch for vehicles having a DCT. And the control method mainly includes determining the engine throttle position and clutch pressure of the transmission to make the vehicle accelerate smoothly. In particularly, the attributes between launching with two clutches or one clutch are compared and evaluated, which are validated through simulation in MATLAB/Simulink.

Keywords: Launch Control; Vibration; NVH; DCT; Hydraulic Control System.

1. Introduction

While technology advancement greatly improves the transmission performance in recent years, undesirable vehicle noise, vibration and harshness (NVH) is still the draw backs in the process of designing any vehicle type and also an everlasting research focus on the powertrain development in the automobile industries(1). Vehicle comfort can be improved greatly by reducing vibration and noise emissions. It is apparent that growing ride comfort requirement is the development trend for all types of powertrain including traditional manual transmissions (MT), conventional planetary automatic transmissions (AT), continuously variable transmissions (CVT) and new kind of transmission as dual clutch transmissions (DCT). Particularly, DCT which combines the advantages of MT and AT features the convenience and comfort of AT and the fuel economy even better than MT. Additionaly, as DCT shares similar structure and components with MT, it costs less to manufacture in comparison with automatic transmission.

Due to its advantages, DCT has become a hotspot topic that attracts extensive development interests in the automotive industry in recent years. The general descriptions on DCT development status can be find in the reference[(2),(3),(4)]. There are two main focus in the investigation of DCT control, gearshift control and launch control. A gearshift control strategy for wet DCT was developed and embedded with engine control to achieve synchronization during the transfer of engine torque from clutch to clutch through clutch slip control [(5)]. A system control approach study was conducted by Goetz, et al [(6)]; Livshiz , et al [(7)]; Paul.D. Walker, et al [(8)], involving various control loops including engine control, clutch slip control, and transmission output torque control was developed for gear shifts of DCT. For launch control, S.Kirschstein [(9)] studied the impact of launch control on the vibration behaviour of powertrain equipped with a DCT. Zhang et al. [(10)] developed a dynamic simulation model with two clutches for launch control analysis. The launch strategy with two clutches was proposed to share the friction work and extend the life of both clutches by QIN Datong et al [(11)]. Except the above ones, there are few reports on DCT launch control, especially with detailed hydraulic component model.

In this paper, a system analytical model including detailed hydraulic control module will be presented for clutch engagement control during launch with two clutches for vehicles having a DCT. And the control method mainly includes determining the engine throttle position and clutch pressure of the transmission to make the vehicle accelerate smoothly. In particularly, the attributes between launching with two clutches or one clutch are compared and evaluated, which are validated through simulation in MATLAB/Simulink.

2. Dynamic Model and Analysis of DCT

The 13 degree of freedom is shown in Figure 1. The system is connected by shaft elements or frictional contact. It is mainly including engine, flywheel, coupled clutch drum, dual clutch, transmission, differential, wheels etc. The drum and clutches inertia are linked via frictional contact (clutch engagement). With no normal forcing the system can be looked as uncoupled, with normal forcing and non-zero relative speed between contact surface the system can be looked as having sliding friction. Lastly, with normal forcing and zero slip speed the sub-systems can be considered as one system, i.e. with one or two engaged clutches.

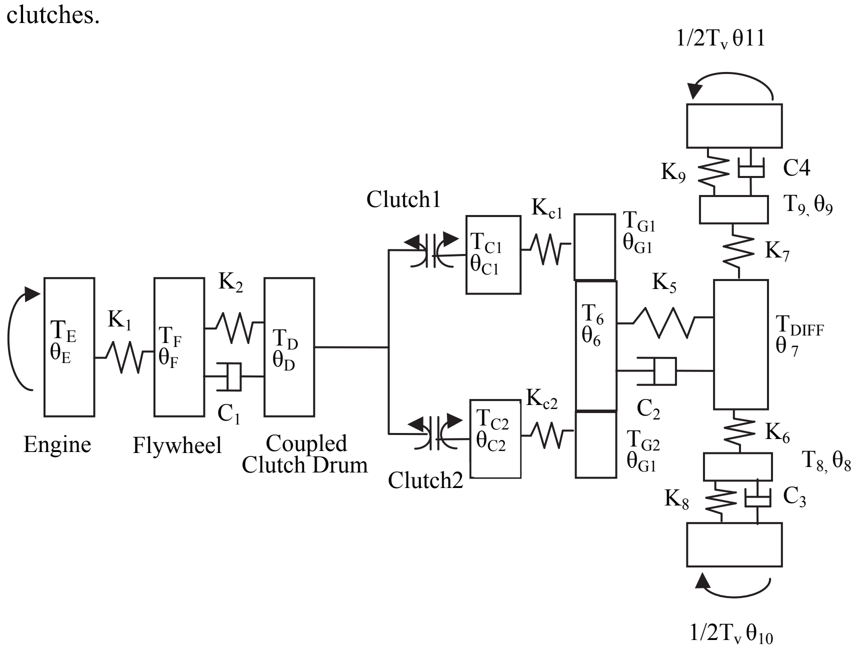

Fig. 1 Dynamic model of powertrain system equipped with DCT

Equations of motion for the powertrain system with the dual clutch ($J_{c1}$and J_{c2}) either in stiction or sliding are:

$$J_E\ddot{\theta}_E = T_1 - K_1(\theta_E - \theta_F) \quad (1)$$

$$\left.\begin{aligned}
J_F\ddot{\theta}_F &= K_1(\theta_E - \theta_F) - K_2(\theta_F - \theta_D) - C_1(\dot{\theta}_F - \dot{\theta}_D)\\
J_D\ddot{\theta}_D &= K_2(\theta_F - \theta_D) - T_{C1} - T_{C2}\\
J_{c1}\ddot{\theta}_{c1} &= T_{C1} - K_{c1}\left(\theta_{c1} - \frac{R_2}{R_{G1}}\theta_6\right)\\
J_{c2}\ddot{\theta}_{c2} &= T_{C2} - K_{c2}\left(\theta_{c2} - \frac{R_2}{R_{G2}}\theta_6\right)\\
\frac{R_2}{R_{G1}}J_{G1}\ddot{\theta}_6 &= K_{c1}\left(\theta_{c1} - \frac{R_2}{R_{G1}}\theta_6\right) - R_{G1}F_{G1}\\
\frac{R_2}{R_{G2}}J_{G2}\ddot{\theta}_6 &= K_{c2}\left(\theta_{c2} - \frac{R_2}{R_{G2}}\theta_6\right) - R_{G2}F_{G2}
\end{aligned}\right\} \text{Sliding} \quad (2)\text{-}(7)$$

$$\left.\begin{aligned}
J_F\ddot{\theta}_F &= K_1(\theta_E - \theta_F) - K_2(\theta_F - \theta_{D\&c1\&c2}) - C_1(\dot{\theta}_F - \dot{\theta}_{D\&c1\&c2})\\
(J_D + J_{c1} + J_{c2})\ddot{\theta}_{D\&c1\&c2} &= K_2(\theta_F - \theta_{D\&c1\&c2}) - C_1\dot{\theta}_{D\&c1\&c2}\\
&\quad -K_{C1}\left(\theta_{D\&c1\&c2} - \frac{R_2}{R_{G1}}\theta_6\right) - K_{C2}\left(\theta_{D\&c1\&c2} - \frac{R_2}{R_{G2}}\theta_6\right)\\
\frac{R_2}{R_{G1}}J_{G1}\ddot{\theta}_6 &= K_{C1}\left(\theta_{D\&c1\&c2} - \frac{R_2}{R_{G1}}\theta_6\right) - R_{G1}F_{G1}\\
\frac{R_2}{R_{G2}}J_{G2}\ddot{\theta}_6 &= K_{C2}\left(\theta_{D\&c1\&c2} - \frac{R_2}{R_{G2}}\theta_6\right) - R_{G2}F_{G2}
\end{aligned}\right\} \text{Stiction} \quad (8)\text{-}(11)$$

$$J_6\ddot{\theta}_6 = R_{G1}F_{G1} + R_{G2}F_{G2} - K_5(\theta_6 - \theta_7) - C_2(\dot{\theta}_6 - \dot{\theta}_7) \quad (12)$$

$$J_{Diff}\ddot{\theta}_7 = K_5(\theta_6 - \theta_7) - K_6(\theta_7 - \theta_8) - K_7(\theta_7 - \theta_9) \quad (13)$$

$$J_8\ddot{\theta}_8 = K_6(\theta_7 - \theta_8) - K_8(\theta_8 - \theta_{10}) - C_3(\dot{\theta}_8 - \dot{\theta}_9) \quad (14)$$

$$J_9\ddot{\theta}_9 = K_7(\theta_7 - \theta_9) - K_9(\theta_9 - \theta_{11}) - C_4(\dot{\theta}_9 - \dot{\theta}_{11}) \quad (15)$$

$$\frac{1}{2}J_V\ddot{\theta}_{10} = K_8(\theta_8 - \theta_{10}) \quad (16)$$

$$\frac{1}{2}J_V\ddot{\theta}_{11} = K_9(\theta_9 - \theta_{11}) \quad (17)$$

$\ddot{\theta}_{D\&c1\&c2}$ means that the two clutches are locked together (stiction) with coupled clutch drum and have the same solution in this state. In numerical solutions for convenience both states can be solved respectively, whether the state is sliding or stiction.

Assuming constant pressure across the surface of the clutch plates, the equation for clutch torque is (Design Practices 1994[12]):

$$T_c = N_s R_m \mu_s F \quad (18)$$

Where N_s is the number of friction surfaces, R_m is the clutch mean radius, μ_s the coefficient of sliding friction and F the clutch actuating force.

The parameters used for the system are given in the Table 1

Table 1 Main Parameters of Vehicle Equipped with DCT

Parameters	Value	Parameter	Value
	kgm^2		Nm/rad
Engine Inertia	0.4	K1	9500
Flywheel Inertia	0.2	K2	20000
Clutch Drum	0.2	Kc1	21000
Clutch hub	0.0072	Kc2	87000
Gear1	0.0006	K5	165000
Gear2	0.0013	K6,	165000
Final drive	0.16	K7	165000
Differential	0.16	K8,	20000
1/2Vehicle+tyre	67.5585	K9	20000

3. Hydraulic Control System

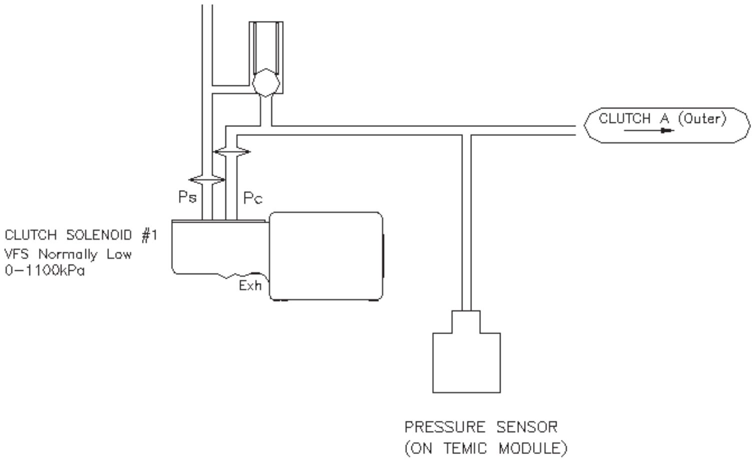

Fig. 2: Schematic of clutch control system

Fig. shows the layout for the hydraulic system for a single clutch, and the same model is duplicated for both clutches. The system comprises of a normally low variable force solenoid directly feeding each clutch pack, integrated with a hydraulic damper to reduce the pressure fluctuations under transient conditions. Further detailed formulation of the hydraulic control system can be found in our group recent work (13) .

4. Simulation Results and Analysis

The following figures show the results of launching with one clutch and two clutches respectively. Figure 3 shows the pressure of clutch one which are controlled by hydraulic control system. Figure 5 shows the pressure of clutch two. Figure 7 shows the results of Engine speed and vehicle, while the figure 9 shows the torque of clutch one. And the figures of 4, 6, 8, 10 which show the similar means. However, there is a little different: the pressure of clutch 2 is not zero during launching process showed in figure6.
Compared with figure 9 and figure 10, it is obvious that when launching clutch with two clutches , the vibration from engine can be reduced, and the jerk can also be relieved a lot, which contribute to vehicle's comfort. The results between figure 9 and 10 shows that using two clutches to launch can extend the life of clutch since the stick-slip times are largely reduced by using two clutches to launch.

Launching with one clutch

Launching with two clutch

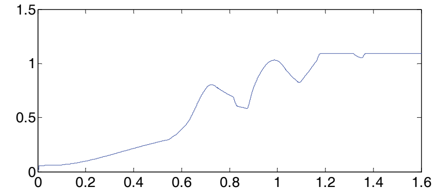

Fig. 3 Pressure of Clutch 1

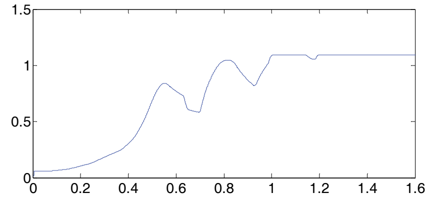

Fig. 4 Pressure of Clutch 1

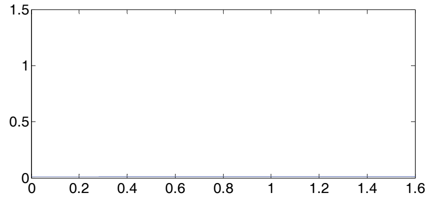

Fig. 5 Pressure of Clutch 2

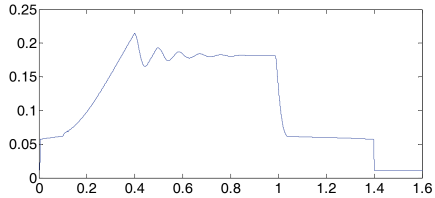

Fig. 6 Pressure of Clutch 2

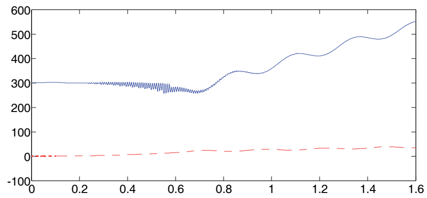

Fig. 7 Speeds of Engine and Vehicle

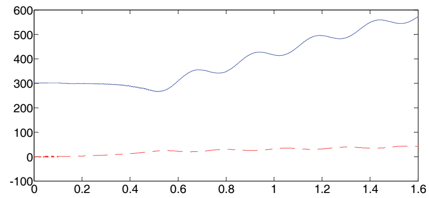

Fig. 8 Speeds of Engine and Vehicle

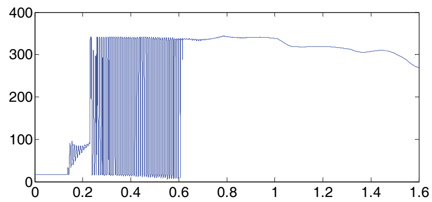

Fig. 9 Clutch 1 Torque

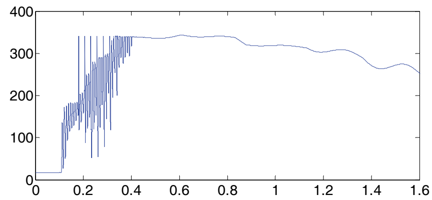

Fig. 10 Clutch 1 Torque

5. Conclusions

This paper studies the vehicle vibration during launch. In this paper, a system analytical model including detailed hydraulic control module has been presented for clutch engagement control during launch for vehicles having a DCT. And the control method mainly includes determining the engine throttle position and clutch pressure of the transmission to make the vehicle accelerate smoothly. The attributes of two kinds of launching including launching with two clutches and one clutch are compared and evaluated, which are simulated through simulation in MATLAB/Simulink. The simulation results show that launch with two clutches can make the best use of the advantage of dual clutch transmission structure. It is demonstrated that launching with two clutch can reduce vibration, which does a favor to vehicle comfort.

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