

Multi-domain Modeling and Simulation of Clutch Actuation System Based on Modelica

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ABSTRACT

Clutch actuation systems are complex systems where hydraulic, pneumatic, mechanical and electrical components are coupled. This paper presents a detailed clutch actuation model composed of components from multi-domains like mechanical and pneumatic actuation system, hydraulic boosting system, etc. Various components and subsystem models, such as the driver, engine, gear pairs, clutches, etc., are integrated into an overall vehicle system model according to the transmission power flow and control logic. The model is implemented using the Modelica programming language. The simulation of the clutch actuation system was carried out for the analysis of drivability, shift quality and vehicle overall performance.

INTRODUCTION

Clutches in cars, trucks and other vehicles are gradually engaged after selecting the different gears, avoiding unpleasant shocks and jerks. A clutch has two plates that can be joined together by an actuator that exerts a force on one of the two plates. As the clutch engages the plates are pushed together by the actuator. To achieve a successful engagement, the right input force has to be applied by the actuator. This can be done by the driver through a foot pedal or automatically by a programmed actuator force.

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components are coupled. Such systems coupled with various physical domains have great influence on driveability and dynamic behavior of the vehicle, such as pedal force, compliance with the pedal action, shift quality, etc [1]. However, many previous works considered the clutch actuation system as an ideal system and neglected the transient behavior of the clutch actuation due to time delays, non-linear dynamic characteristic, external disturbance and parameter uncertainty of the pneumatic, hydraulic, mechanic and electric components [2]. Manish [3] has built a model to study the variation in output torque in response to different clutch pressure profiles during shifts. However, the effect of clutch actuation system acted on the vehicle has been ignored. The papers [4-6] also consider the clutch actuation system as an idea system. Morselli [7] proposed an energy-based detailed dynamic model of a hydraulic multi-plate clutch actuator controlled by an electro valve with internal pressure feedback. However, this paper only analysis closed-loop tracking performances for the clutch pressure, and the effect of clutch actuation systems acted on the vehicle are not presented. Lei [8] built an electro-hydraulic clutch engagement simulation system with Matlab/Simulink. However, the purpose of the paper is also to control the actuator tracing the target position or speed accurately.

This paper presents a detailed clutch actuation model composed of components from multi-domains like mechanical and pneumatic actuation system, hydraulic boosting system, etc. Analytical formulations and look-up tables are both used for modeling of powertrain and

other transmission components. Various components and subsystem models, such as the driver, engine, gear pairs, clutches, etc., are integrated into an overall vehicle system model according to the transmission power flow and control logic. The model is implemented using the Modelica programming language in an object-oriented environment. Standard component models available in the Modelica/Dymola library are directly used for the avoidance of the lengthy derivations of mathematical equations governing component characteristics [9]. The simulation of the clutch actuation system was carried out for the analysis of drivability, shift quality and vehicle overall performance.

The paper is organized as the follows. Section 2 introduces the modeling for clutch. The clutch actuation system is discussed in section 3. Section 4 describes the dynamic modeling of a car transmission system. The simulation results and discussions are illustrated in section 5. Section 6 offers our conclusions and further study.

CLUTCH MODELING

The function of an engaging friction clutch is to transmit torque gradually, to avoid high accelerations or jerks, when the engine is connected to the rest of the driveline. This torque is transferred from the engine through the pressure plate onto one or more friction plates connected to the transmission input shaft. These plates are pushed apart by a diaphragm springs. When the clutch is fully disengaged the clutch plates are not in mechanical contact and no torque is transmitted. When the clutch is engaged a normal force on the pressure plate pushes the clutch plates towards each other. The clutch now starts slipping and an increasing amount of torque can be transmitted. The velocities of the plates will become equal and the plates stick. The clutch is now fully engaged and can transmit torque from the engine up to the maximum static friction torque. Consequently, there are three distinct modes of operation: free, where the two plates transmit no torque; slipping, where the two plates have differing angular velocities; and lockup, where the two plates rotate together. The clutch system was analyzed using a lumped-parameter model, according to the configuration shown in figure 1.

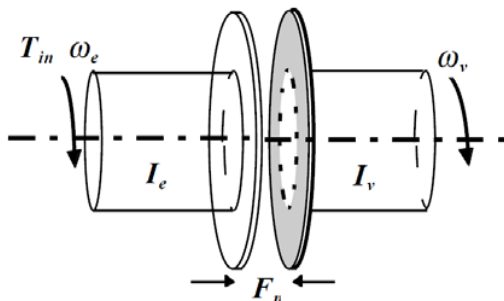


Fig.1 The Clutch System

The torque capacity of the clutch is a function of its size, friction characteristics, and the normal force that is applied.

$$T_{f \max} = \mu F_n n \left(\frac{2}{3} \right) \left(\frac{R_o^3 - R_i^3}{R_o^2 - R_i^2} \right) \quad (1)$$

Where μ is coefficient of friction that can be formulated as a function of clutch slip, F_n is normal force on clutch face that depends on the apply pressure, R_o is outside radius of friction disc, R_i is inside radius of friction disc, n is the number of friction discs.

When the clutch is slipping, the clutch systems can be described as follows:

$$J_c \dot{\omega}_c = T_c - T_d - b * (\omega_c - \omega_t) \quad (2)$$

$$T_d = (\omega_c - \omega_t) \quad (3)$$

The torque through the clutch while slipping is given by:

$$T_c = F_n \mu R_a \text{sign}(\omega_e - \omega_t) \quad (4)$$

In which μ is the friction coefficient of the clutch surface material, R_a is the active radius of the clutch plates and the normal actuation force on the clutch plate is given by F_n .

When the clutch is sticking, the engine degree of freedom is rigidly coupled to the clutch disk at the friction interface. The clutch systems can be described as follows:

$$(I_e + I_v) \dot{\omega}_e = T_e - T_d - b_c (\omega_e - \omega_t) \quad (5)$$

The sticking of the clutch sustains as long as the torque transmitted through clutch remains below the maximally transmittable torque $T_{f \max}$.

CLUTCH ACTUATION SYSTEM MODELING

A basic hydraulic and pneumatic clutch actuation system with its components and the release bearing is presented in figure 2.

When the driver pressed the clutch pedal, the piston in the master cylinder moves from the right side to the left side, and compressed the hydraulic oil in the pipe. The high pressure oil drives the piston of the slave cylinder leftwards. The piston rod of the slave cylinder push the clutch lever, and drag the release bearing on the other side to separate the clutch plate. So engine power cannot flow through to the transmission. When the drive

release the foot, the return spring of the master cylinder push the piston to the right side, and the diaphragm spring make the clutch return to the original state, and press the two plates of the clutch together. So engine power can flow through to the transmission.

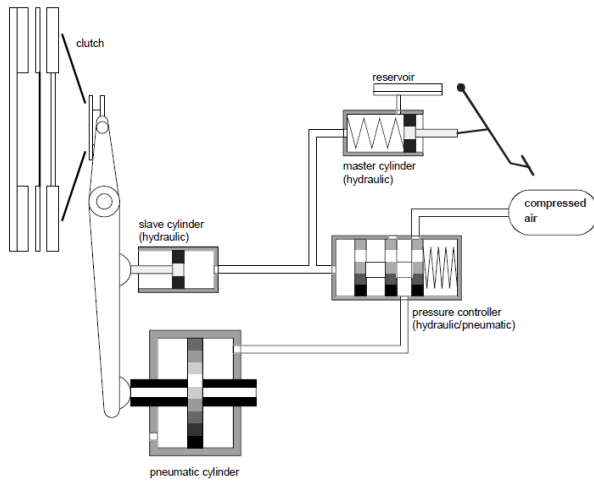


Fig.2 Principle Structure of a Hydro-pneumatic Clutch Actuation

When the driver pressed the clutch pedal, the piston in the master cylinder moves from the right side to the left side, and compressed the hydraulic oil in the pipe. The high pressure oil drives the piston of the slave cylinder leftwards. The piston rod of the slave cylinder push the clutch lever, and drag the release bearing on the other side to separate the clutch plate. So engine power cannot flow through to the transmission. When the drive release the foot, the return spring of the master cylinder push the piston to the right side, and the diaphragm spring make the clutch return to the original state, and press the two plates of the clutch together. So engine power can flow through to the transmission.

The clutch booster is applied in the commercial vehicle with a hydraulic operating clutch gear. When operating the clutch to disengage or engage, the assembly can increase output force. The assembly is mounted between clutch and hydraulic clutch pump, no additional mechanical drive components are required. When the driver pressed the clutch pedal, the high pressed hydraulic oil act on the pressure controller. The piston moves rightwards to open the air inlet. The compressed air flows into the pneumatic cylinder through the channel of the pressure controller. The high compressed air push the piston rod of the pneumatic moves leftwards, and make a booster force on the clutch lever.

MASTER CYLINDER MODELING

The function of the master cylinder in clutch actuation system is to convert foot action to the hydraulic energy. In the modeling of the master cylinder, the seal friction is considered, and the Leakage, Fluid compressibility and housing compliance are neglected. The principle structure of the master cylinder can be seen in figure 3.

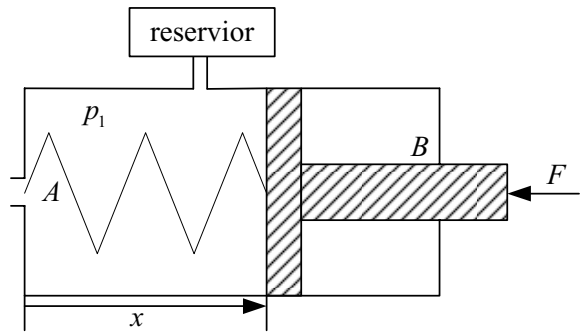


Fig. 3 The Structure of Master Cylinder

The equation of the master cylinder can be described as:

$$m\ddot{x} = p_1 A - K_s(x - x_0) - F - F_{Fric} \quad (6)$$

$$Q_1 = A_1 \frac{dx}{dt} \quad (7)$$

Where m is the mass of the piston, p_1 is the pressure of the chamber; A is the piston areas of side A; Q_1 is the flow rate of side A; x is the displacement of the piston, x_0 is the initial length of the return spring, K_s is the stiffness of the return spring, F is the force transmitted from the foot pedal acted on the piston rod, and F_{Fric} is the total friction force acted on the piston.

And F_{Fric} can be described as:

$$F_{fric} = f_{prop} v + [F_{Coulomb} + F_{strobeck} e^{-f_{exp}|v|}] sign(v) \quad (8)$$

$$v = \frac{dx}{dt} \quad (9)$$

Where, f_{prop} is coefficient of viscous force, $F_{Coulomb}$ is constant Coulomb friction force and speed independent, $F_{strobeck}$ is strobek force, f_{exp} is coefficient of decay for Strobeck force. More details can be referred to [10].

PNEUMATIC CYLINDER MODELING

The function of the pneumatic cylinder is supply booster force on the clutch lever. The principle structure of the pneumatic cylinder can be seen in figure 4.