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Dynamic Simulator of a Wet Plate Clutch System for Automatic Transmission

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Abstract: Automatic transmission became a modern hydraulic system whose essential elements are the clutch and the valve that controls it. In this paper, an analytic model of a wet plate clutch actuated by a pressure reducing valve is developed. Next this model is converted into a Simulink model, with which simulation can be performed in an easy way. To validate the model a test bench, developed by Automotive Continental Romania, was used.

Keywords: Automatic transmission, clutch, valves, hydraulic actuators, displacement, simulators, nonlinear systems.

1. INTRODUCTION

The automatic transmission system was the subject for many other publications where the main idea was to improve the control algorithms or mechanical design to reduce energy losses. Attempts were made to keep the traditional clutch and gear stick untouched but removing the clutch pedal (Lévine and Rémond, 2000). This was replaced by an actuator controlling the clutch position and therefore the torque transmission. A two-level cascaded feedback design was used to control the vehicle speed with this clutch system. Another type of approach was made by (Sustersic *et al.*, 2003) where the automatic transmission is modelled in detail for each component. There, a dynamic model of a power transmission system for gear ratio changed was proposed. Later, (Farong, 2006) developed a mathematical model of a one-way clutch in belt-pulley systems, where a wrap-spring type of clutch is modelled as a nonlinear spring with discontinuous stiffness. In (Tripathi and Agrawal, 2008) a model is presented that includes the non-linear nature of the diaphragm spring, kinematics of the pedal motion during clutch release, and the dynamics of the driveline. Researches mentioned are presenting the modelling of some automatic transmission elements and tell that torque can be varied by modifying the clutch position.

Advantages of the wet plate clutches are related to the shifting speed considerably reduced by using independent clutch assemblies known as the dual-clutch system. They are built with multiple clutch disks that give a better grip which can be controlled by the pressure inside the clutch. A wet clutch is immersed in a cooling lubricating fluid, which keeps the surfaces clean and gives smoother performances and longer life. Disadvantages are related to the additional energy losses by always actuating a hydraulic pump and the use of high fluid pressure which is unsafe for the environment.

In this paper, a dynamic model of a wet plate clutch based on mathematical equations obtained with the help of physical laws and experimental measurements is developed. A hydraulic valve actuator is considered in order to analyze the general effect of the automatic transmission system. For validating the model and to procure all the experimental data needed, a test bench developed by Automotive Continental Romania was used. What brings new this model is the new simulator developed for a non standardized type of pressure reducing valve and wet plate clutch. This simulator can be then used to make diverse simulations in order to understand the behaviour of the system, to design complex strategies of control or to test and improve a controller performances already implemented.

The paper is organized as follows. In Section 2 the modelling of a pressure reducing valve and a wet plate clutch is discussed. In Section 3 both elements are evaluated and results are discussed by means of simulation. Finally, conclusions are drawn in Section 4.

2. PROBLEM FORMULATION

In this section the modelling of a wet plate clutch actuated by a pressure reducing valve is presented. Hydraulic control valves are devices that use mechanical motion to control a source of fluid power and are used as actuators in many control applications for automotive systems. Basically there are three types of control valves: directional control valves, pressure control valves and flow control valves. The type of valve and clutch analyzed in this paper are not standardized, they are designed for a certain application where some performances need to be achieved. In what follows it is presented the dynamics of the valve, then the dynamics of the clutch.

2.1 Pressure reducing valve model

Schematics of the three way pressure reducing valve used as clutch actuator is presented in fig. 1.

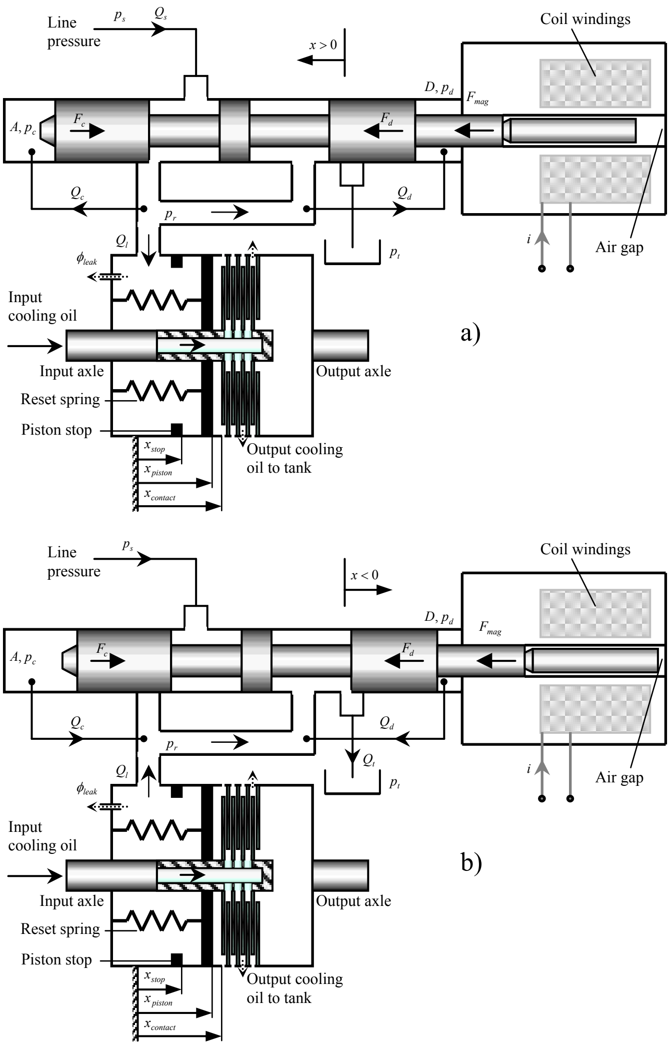

Fig. 1 Schematic draw of the valve connected to the clutch: a) Charging phase; b) Discharging phase

The input for this hydraulic system is represented by the line pressure p_s and current i passing through a solenoid which generates a magnetic force F_{mag}, while the output of the system is represented by the pressure p_r. The physical construction of the valve implies the presence of three pressure variables corresponding to each chamber: p_c, p_r and p_d for the left chamber, the middle chamber and the right chamber respectively.

The hydraulic valve has a self controller by using a mechanical feedback through left and right tubes. Because differences in pressure appear between the middle chamber and the left/right chambers, flows Q_c and Q_d are generated. The feedback force is composed from the force F_c applied on the left sensed pressure chamber, and the force F_d applied on the right sensed pressure chamber. These two forces composed with the magnetic force F_{mag} are used to actuate the spool valve which controls the pressure p_r inside the middle chamber. In the charging phase (Fig. 1, a), the magnetic force given by solenoid current, is grater than the feedback pressure force moving the plunger to the left, connecting the source with the clutch. In the discharging phase (Fig. 1, b), the magnetic force is less than the feedback force implying that plunger will move to the right, connecting the clutch to the tank.

The mathematical connection between electric current trough solenoid and magnetic force generated by the magnetic flux is given by the following equations (Gibilisco, 2002):

$$H = \frac{N \cdot i}{l}, \; B = \mu(H + M), \quad M = -\frac{N q_e^2 a^2 B}{4 m_e}, \; F_{mag} = \frac{B^2 A_d}{2\mu}, \tag{1}$$

where, A_d represents the air gap area which is variable with the displacement, B is the magnetic flux density, H represents the magnetic field intensity, μ represents the permeability, i is the current, l is the length of the coils, N represents number of turns, M is the magnetization, m_e is the mass of electron and a represents the orbit radius of an electron.

Feedback pressure force and magnetic force are the most important forces that give the forces balance applied on the valve plunger. Based on Pascal equations which transform the hydraulic pressure into mechanic force we can simulate the feedback pressure by next equation:

$$F_{feedback} = A p_c - D p_d, \tag{2}$$

where, p_c , p_d are the pressures of the left and right chambers, A is the left plunger area of pressure contact, D is the right plunger area of pressure contact.

Using the magnetic force and feedback force created by the pressure inside the left and right chambers the movement of the plunger, which governs the output pressure, can be approximated with a mass spring damper system given by:

$$F_{mag} - F_{feedback} = M_v \ddot{x} + c\dot{x} + K_e x, \tag{3}$$

where, $F_{feedback}$ represents the feedback force, M_v is the spool mass, x represents the plunger displacement, $\dot{x}$ is the plunger speed, $\ddot{x}$ is the plunger acceleration, K_e represents the flow force spring rate and c is the damper coefficient.

To restrict the motion of the plunger between the left and the right bounds a double-side mechanical translational hard stop was implemented:

$$F_{restrict} = \begin{cases} K_p x + D_p \dot{x}, x \geq x_{\max} \\ 0, x_{\min} < x < x_{\max} \\ K_n x + D_n \dot{x}, x \leq x_{\min} \end{cases}, \tag{4}$$

where, $F_{restrict}$ is the dynamic balance force between the plunger and the mechanical limits, $x_{\min}$ is the gap on the