Simulation of Hydraulic Clutch in Automobiles for Torque Transfer during Slipping

Naveen Kumar S N

Assistant Professor,Dept of Mechanical Engineering,Sri Basaveshwara Institute of Technology,Tiptur, Karnataka India

Abstract: ***Automobiles are the major mode for the transportation, in this current era. Due to the technological advancements there were lot of new upgrades, new safety features available which comforts the driver and also the passengers.In automobiles the chemical energy of the fuel is converted to mechanical energy in engines as the rotation of the crankshaft. And the power developed in the engine in the form of rotation of the shaft is transferred to the wheels, through transmission or gearbox. The clutch is the key element which engages or disengages the crankshaft to the transmission. In an automobile the function of clutch is to connect and disconnect the engine with the transmission system in a vehicle. Such that the torque produced in the engine is transferred to the wheels of an automobile whenever it is necessary through the transmission. Either mechanical actuators, hydraulic actuators were used in automobiles. Simulation of clutch system gives idea of the transfer of the force from the clutch pedal to the force at the clutch disc and the torque that can be transferred through the clutch. This paper concentrates on simulation of hydraulic clutch of the automobile from clutch pedal force to the torque transferred through the friction clutch.***

Keywords: Clutch, Simulation, Torque

1. Introduction

A clutch is a mechanical device that is used to engage and disengage the power transmission in automobiles, from driving shaft to driven shaft. Clutches are used when there is a need to control the transmission of power or motion between two shafts, and also to transmit the required amount of torque between the two shafts. The application of the clutch is to connect and disconnect two rotating shafts. In clutches, one shaft is attached to a motor or to power unit (the driving shaft) while the other shaft (driven shaft) is typically connected to provide output power for work. In automobiles the engine and the transmission are the two ends of the clutch.

Internal combustion engines only provide useful power over a certain speed range. To be able to use this range for various driving conditions, vehicles must have a gearbox. The power from the engine is transmitted to the gearbox through the clutch. The engagement of an automotive clutch depends on the pedal movement controlled by the operator [1]. The pedal linkage movement causes displacement ofthe clutch release bearing which plays an important role in the engagement and disengagement of the clutch. This allows the engine to be started and run without the vehicle moving and the vehicle to be started from rest under control at various rates of acceleration.

Friction clutches work on the basis of the frictional forces developed between two or more surfaces in contact. During engagement of two surfaces there will be slip in friction clutch. This can be actuated through mechanical actuators or hydraulic actuators. Hydraulic actuators has its own advantage over mechanical actuators.

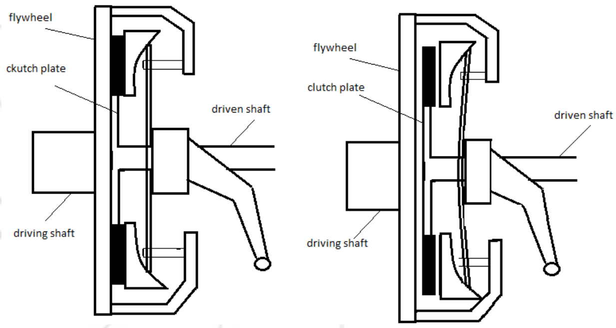

Figure 1: Clutch engaged disengaged position

The hydraulically actuated clutch systems consist of clutch pedal, clutch master cylinder (CMC), clutch slave cylinder (CSC) and a fluid reservoir. Fluid reservoir stores the hydraulic fluid. When the clutch pedal is pressed, pressure built up in the clutch Master cylinder forces fluid into the clutch slave cylinder, which causes the clutch release fork to move. The release fork and release bearing compress the diaphragm spring ofthe clutch cover to disengage the clutch disc, the below figure shows the parts of hydraulically actuated clutch in an automobile.

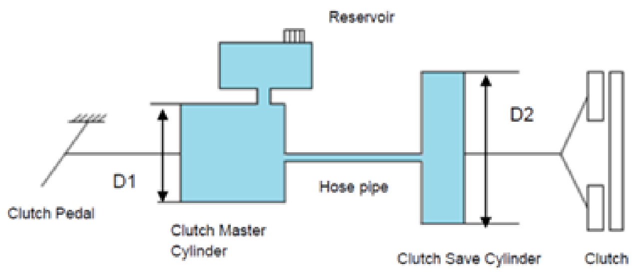

Figure 2: Hydraulic actuation of clutch

Usage of hydraulically actuated clutch systems are increasing when compared to cable controlled clutch systems. Hydraulically actuated clutch system need less force to actuate as the force multiplication happens in master and slave cylinders. The advantage of hydraulic clutch over the cable controlled clutch is that hydraulically actuated clutch needs less force to actuate than the cable controlled clutch and hydraulically controlled clutch is self-adjusting.

2. Literature Survey

The output from the power source that is power from the engine is controlled by a transmission system and driveline to deliver tractional effort to the wheels. And all these components, engine, clutch, transmission driveline and wheels collectively referred to as the powertrain system, and are controlled by the driver. [2]

The functions of powertrain include: Disconnecting the transmission and engine whenever required. Allowing the vehicle to start at varied rates, while the engine running continuously. Varying the speed ratio between the engine and wheels, allowing the driver to change the gear ratio as required, transmitting the drive torque to the wheels [3].

A manual transmission is characterized by gear ratios that are selectable by a driver operated clutch and a movable gear selector. It usually has four to six forward gears and one reverse gear and it is cheaper to manufacture, compared to advanced automatic transmissions. When the driver presses clutch pedal this disengages the engine with the transmission.

The control of the dry clutch engagement process for automotive systems has been considered. The presence of the clutch and, more specifically, its different operating conditions during the automotive cycles (slipping or engaged) makes reasonable the use of a piecewise linear time-invariant model for the description of the driveline dynamics. A sixth order model has been considered in order to detect the driveline oscillations after the lock-up, which drastically influence the driver comfort. [4]

Trinoy Dutta, and LopamudraBaruah [5] presented an engagement model of transient dynamics, which can be used for analysis of driveline motion under different engagement conditions. Different release conditions can be simulated using this mathematical model. The model can be used to calculate the angular acceleration of the clutch shaft, based upon the behaviour of the non–linear disc spring, as well as, the motion trajectory imparted to the release bearing. The angular velocity and displacement of the clutch shaft, total slippage time and angle of slippage of the clutch plate can also be obtained using this model.

3. MATLAB Simulation Model

The clutch system in this model consists of two plates representing engine flywheel and clutch shaft respectively. During clutch operations clutch can be in two states, one is locked state and the other is slipping state. Duringlocked condition there will not be any difference between engine shafts speed andclutch shaft. Complete torque transfer will happen. During clutch slipping state engine and clutch shaft will be rotating in different speeds and depending on the force applied on the clutch pedal torque transfer will takes place. In this project slipping state of the clutch is modeled in SIMULINK.

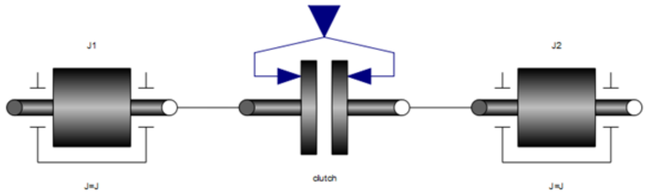

Figure 3: Torque transfer by clutch

3.1. Clutch pedal force

This block involves a map for clutch pedal force with respect to the different clutch pedal positions. And the force multiplication happening at the clutch pedal is because of the lever action of the clutch is also considered. Output of this block is the force acting at master cylinder input shaft with respect to the different clutch pedal positions.

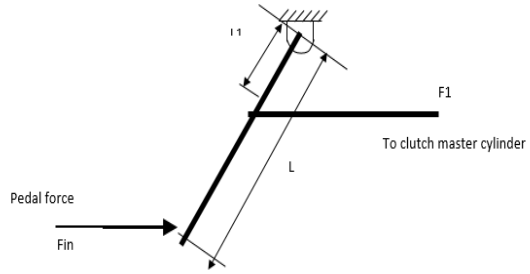

Figure 4: Clutch pedal

The above figure shows the diagram representing clutch pedal. In the above figure L represents the total length of the clutch pedal and L1 represents clutch lever length. Total force acting on master cylinder piston depends on below relation

$$\mathrm{F_{in}} \times \mathrm{L} = \mathrm{F_1} \times L_1$$

$$F_1 = \frac{L_1}{L} \times F_{in}$$

Where
L= Total length of clutch,
L_1 =Clutch pedal lever length
F_{in}= Clutch pedal force
F_1= Force acting on master cylinder piston

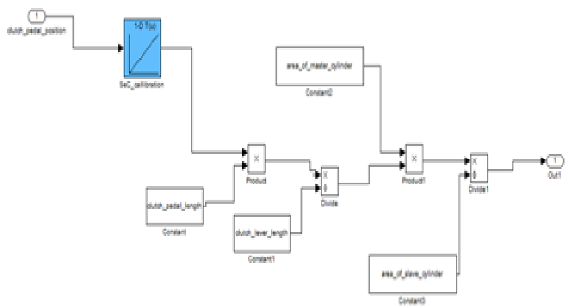

Figure 5: Simulation model for clutch pedal

3.2. Hydraulic line calculations

According to the Pascal's law "A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the line." Hence the pressure in any hydraulic line remains constant. Hydraulic line of clutch consists of a

Master Cylinder hoses and a slave Cylinder. The following calculations are carried out to find the maximum pressure and flow rate in hydraulic line.

Pressure inside hydraulic line, $P = \frac{F_2}{A_1}$

Flow rate, $\dot{Q}_{max} = A_2 \times V$

3.3. Clutch torque calculations

The amount of torque transferred by the clutch plate depends on the stickiness or slip between the clutch plate and the flywheel. The position of clutch plate with respect to the flywheel directly depends on the clutch pedal position. As the force on the clutch pedal increases the distance between the clutch plateand the flywheel increases thus decreasing the torque transferred through the clutch plate. When the clutch plateis not pressedthetorque transferred will be zero. And when the clutch pedal position increases torque transferred will also increases. Depending on the size of the clutch plate the maximum torque that can be transferred by clutch will be limited. The maximum clutch transferred by the clutch can be calculated from two theories.

- Constant pressure theory
- Uniform wear theory

3.4. Constant pressure theory

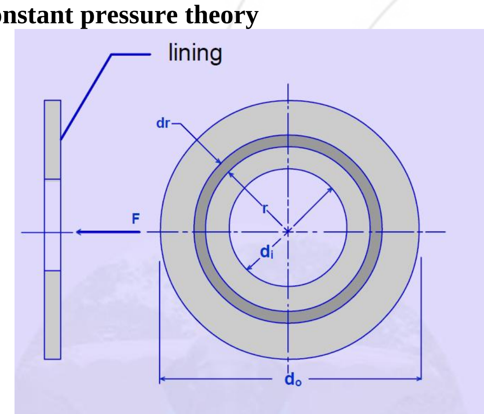

Figure 6: Constant pressure Theory

Assuming constant pressure and considering an elementary area in the complete clutch disc, the area can be given as,

$$dA = 2\pi \cdot rdr \qquad (1)$$

The normal force acting on this elemental area is given by,

$$dN = dA \cdot p$$

$$dN = 2\pi \cdot rdr \cdot p \qquad (2)$$

Therefore the frictional force on this area dF is,

$$dF = f \cdot dN$$

$$dF = f \cdot 2\pi \cdot rdr \cdot p \qquad (3)$$

Torque transferred due to elemental force is given by,

$$T = dF \cdot r$$

$$T = f \cdot dN \cdot r$$

$$T = f \cdot p \cdot A \cdot r$$

$$T = f \cdot p \cdot 2\pi \cdot rdr \cdot r \qquad (4)$$

Where f is frictional constant

By integrating the above equation between the limits of inner and outer radius r_i and r_o respectively we get the total maximum torque that could be transmitted,

$$T = \int_{ri}^{ro} 2\pi p f r^2 \, dr$$

$$T = \frac{2}{3}\pi p f (r_o^3 - r_i^3) \qquad (5)$$

The normal force that needs to be applied to transmit the torque can be obtained by integrating the normal force between the above same limits,

$$F_a = \int_{r_i}^{r_o} 2\pi p r dr$$

$$F_a = \pi(r_o^2 - r_i^2) \cdot p$$

$$p = \frac{F_a}{\pi(r_o^2 - r_i^2)} \qquad (6)$$

By combining equation for pressure (6) and torque (5) we get,

$$T = f F_a \frac{2}{3} \frac{(r_o^3 - r_i^3)}{(r_o^2 - r_i^2)} \qquad (7)$$

This is the friction torque available at the output of the driven shaft.

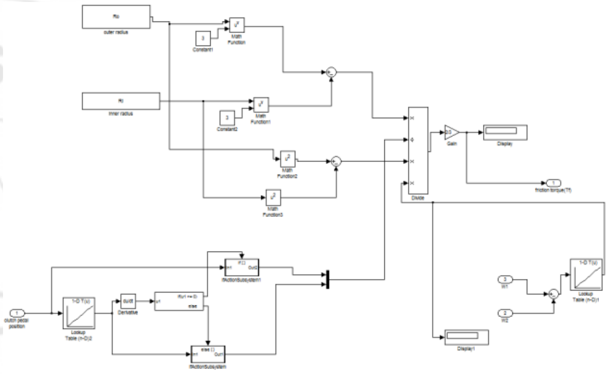

Figure 7: Simulation model for constant pressure theory

3.5. Uniform wear theory

One of the important parameter that affects the clutch torque transferred is wear. The wear in the mechanical system is assumed to be proportional to the product of pressure and sliding velocity. Where p is the constant pressure and V is sliding velocity.

Hence the in uniform pressure theory the constant wear rate $R_w$assumed to be proportional to pV

$$R_w = pV = Constant = c \qquad (8)$$

At any point on the clutch plateconsidering the constant angular velocity ω the velocity is given by,

$$V = r\omega \qquad (9)$$

Combining the above two equations (8) & (9) and we get,

$$pr = Constant = K \qquad (10)$$

Therefore only at smallest radius $r_i$largest pressure p_{max}will occur. Hence,

$$K = p_{max} \cdot r_i$$

Then at any point in contact region pressure is given by the equation,

$$p = p_{max} \frac{r_i}{r} \qquad (11)$$

As in previous section uniform pressure theory Normal force is given by the equation (2),

$$dN = 2\pi \cdot p \cdot rdr$$

And integrating the above equation and replacing the p value we get axial force,

$$F_a = \int_{r_i}^{r_o} 2\pi \cdot p \cdot rdr$$

$$F_a = \int_{r_i}^{r_o} 2\pi \cdot \left(p_{max} \frac{r_i}{r}\right) \cdot rdr$$

$$F_a = 2\pi \cdot p_{max} r_i (r_o - r_i) \quad (12)$$

Similarly from uniform pressure theory torque is given by,

$$T = \int_{r_i}^{r_o} f \cdot 2\pi \cdot p_{max} r_i \cdot rdr \; T = f\pi p_{max} r_i (r_o^2 - r_i^2) \quad (13)$$

By substituting equation for p_{max} in torque equation we get,

$$T = fF_a \frac{(r_o + r_i)}{2} \quad (14)$$

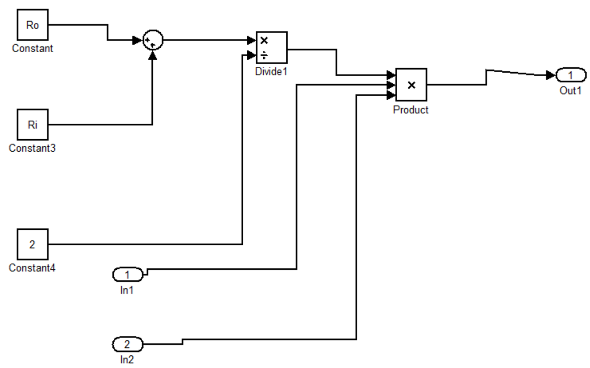

Figure 8: Simulation model for Uniform wear theory

3.6. Torque at flywheel during slipping

In slipping block there are two discs which are rotating at different angular velocities. The friction torque from the equation is computed for this part. This torque and the clutch input torque will give the angular velocity and torque at first disc (flywheel). The slip diagram is show in figure 4.20 for reference.

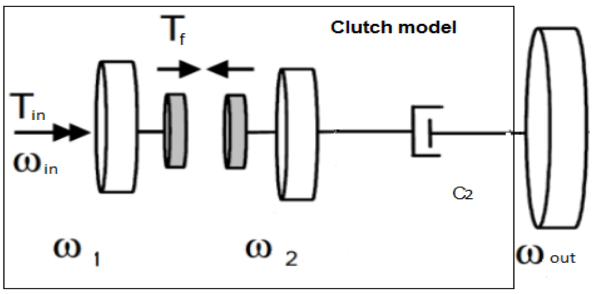

Figure 9: Torque transfer

On applying the equation of motion for first disc,

$$T_1 = T_{in} - T_f - C_1(\omega_{in} - \omega_1) \quad (15)$$

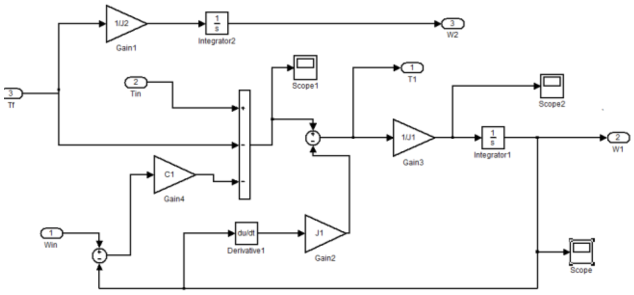

Figure 10: Torque at Flywheel during Slipping

The above figureshows the implementation of equation of motion,this block gives angular velocity of first disc and torque at the first disc. Output of this block is used to find the torque and angular velocity at the clutch output shaft.

Where T_{in} = Input torque from engine
ω_{in} = Input engine angular velocity
ω_1 = Angular velocity at flywheel
C_1 = Damping offered by first disc
J_1 = Inertia of first disc
J_2 = Inertia of second disc
T_1 = Torque at first disc
ω_1 = Angular velocity at first disc

3.7. Torque at output shaft of clutch

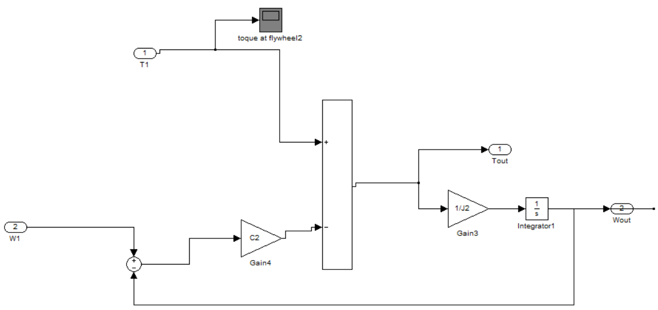

Figure 11: Torque at Output Shaft of Clutch

During slipping condition complete frictional torque developed at the first disc (flywheel) is not transferred to the second disc. Torque transferred between the two discs is frictional torque which is calculated from constant pressure theory or uniform wear theory. Hence torque at the second disc is given by,

$$T_2 = T_f$$

And applying equation of motion for the second disc,

$$T_{out} = T_f - J_2(\omega_{out} - \omega_2) \quad (16)$$

From the above equation we can get the torque at the output shaft of the clutch.

Angular velocity can be calculated using the formula

$$T_{out} = J_2 \dot{\omega}_{out}$$

$$\omega_{out} = \int \frac{T_{out}}{J_2} \quad (17)$$

4. Results

Results of SIMULINK clutch pedal simulation model are shown in the following figures. The figure 12 represents the clutch pedal position with respect to time. X axis represents time in seconds and Y axis represent clutch pedal in terms of %.

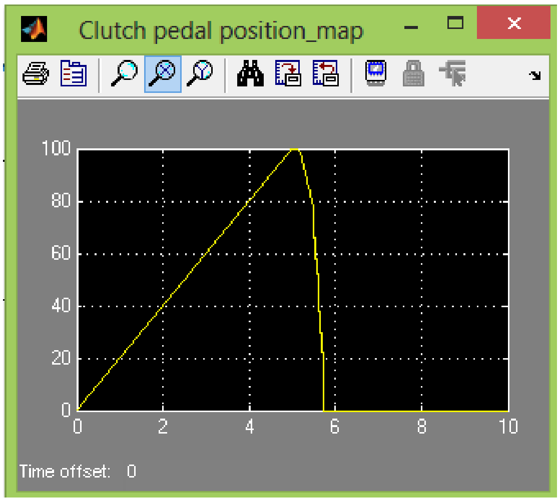

Figure 12: Clutch Pedal Position

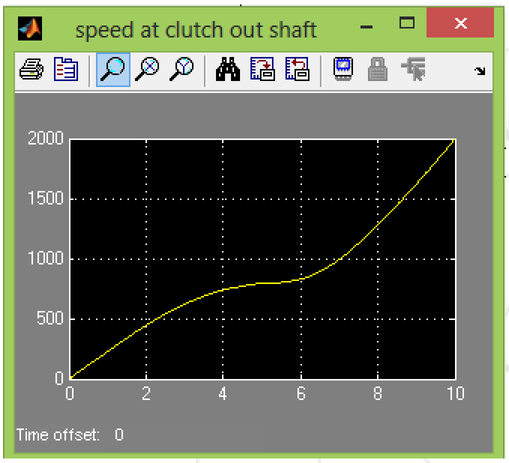

Figure 13: Angular Velocity Curve at Clutch Output Shaft

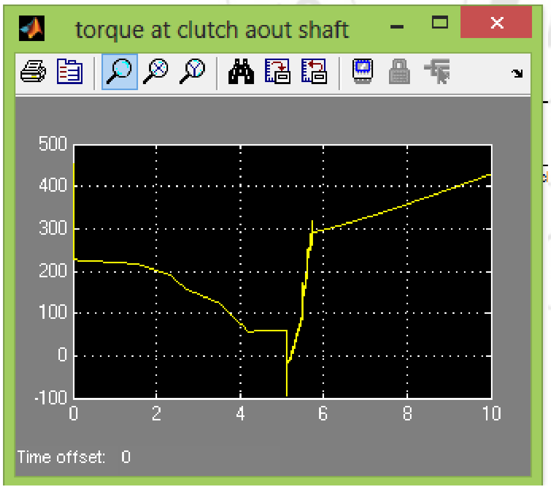

Figure 14: Torque Variation at Clutch Output Shaft

Figure 13 and 14 shows the results of clutch SIMULINK model. Figure 13 gives the angular velocity of the shaft at clutch output with respect to time. Figure 14 shows torque at output clutch shaft with respect to time.

From the above figures of SIMULINK model we can observe the changes in torque at the output shaft of clutch depending on different clutch pedal position.

5. Conclusion

This paper is concentrated about the simulation modelling of the automobile clutch for the torque transferred through it. For this the automobile clutch is modelled from clutch pedal to the clutch output shaft. The input for this model is clutch pedal position, and it is varied from 0 to 100% and again in reverse direction.

From the above result we can see that when the clutch is completely closed that is clutch pedal position is zero, and during slipping condition depending on the clutch position the torque transferred will also increases. And when the clutch pedal is 100 % the torque transferred is zero. Again while releasing depending on the clutch pedal position the torque will also varies.

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Author Profile

Naveen Kumar S N received his B.E in Mechanical engineering from JNNCE,Shimoga and M.Tech degree in CIMfrom MSRIT, Bangalore. Currently he is working as Assistant professor in the department of Mechanical Enginnering SBIT, Tiptur.