

STUDY OF AUTOMATIC TRANSMISSION BASED ON ELECTRONIC CONTROL SYSTEM

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ABSTRACTS

Since 1980s, the electronic control units of automatic transmissions have been greatly advanced to make smooth gear shifting and improve fuel economy. Along with it, the solenoid valves as electro-hydraulic actuators have been rapidly developed which have high pressure and large flow capacity. In these days, it is not an expensive solution to adopt more electro-hydraulic actuators to get the better performance of the automatic transmission. This paper introduces a new scheme of full electronic control system, direct active shift control, using the proportional control solenoid valves to control the pressure of each friction element independently and without any passive hydraulic or mechanical component. At first, it reviews the structures of widely used control systems from the old-fashioned to the modern. Next, the concept of the direct active shift control scheme is introduced and the performance of the actuators discussed. Finally, you can show the simple test results compared with a commercially announced system recently developed and be sure that the proposed system will be feasible in the near future.

Keywords: *Automatic Transmission, Full Electronic Control System, Direct Active Shift Control.*

I. INTRODUCTION

The automatic transmissions for passenger cars have since 1930s. Starting from the 2-speed, the 3 and the 4-speed automatic transmissions have been commonly used until now. In 1990s, most of the major car and transmission manufacturers introduce 5-speed automatic transmissions successfully.

Until late 1970s, the automatic transmissions had adopted hydro-mechanical control systems for automatic gear shifting. From 1980s, the electro-hydraulic control systems of automatic transmissions have been greatly advanced to realize smooth gear shifting and improve fuel economy. Along with it, the solenoid valves as electro-hydraulic actuators have been rapidly developed which have high pressure and large flow capacity with small size and low cost. In these days, users require the better shift feeling and new functions like manual shift. To meet these needs, it is not an expensive solution to use more electro-hydraulic actuators and sensors.

This paper introduces the new scheme of a full electronic control system, direct active shift control (DASC), using proportional control solenoid valves (PCSVs). It can control the pressure of each friction element independently without any passive hydraulic and mechanical component such as second stage spool valves, accumulators, or one way clutches (OWCs), so that it is appropriate to the clutch-to-clutch shift with minimum friction members. At first, it will review the structures of widely used control systems from the old-fashioned to the modern. Next, the concept of the DASC will be introduced and the performance of the actuator, PCSV,

discussed. Finally, you will see the simple test results of the DASC system compared with those of a commercially announced system recently developed.

II. REVIEWS OF CONTROL SYSTEM

2.1 Hydro-Mechanical Control System

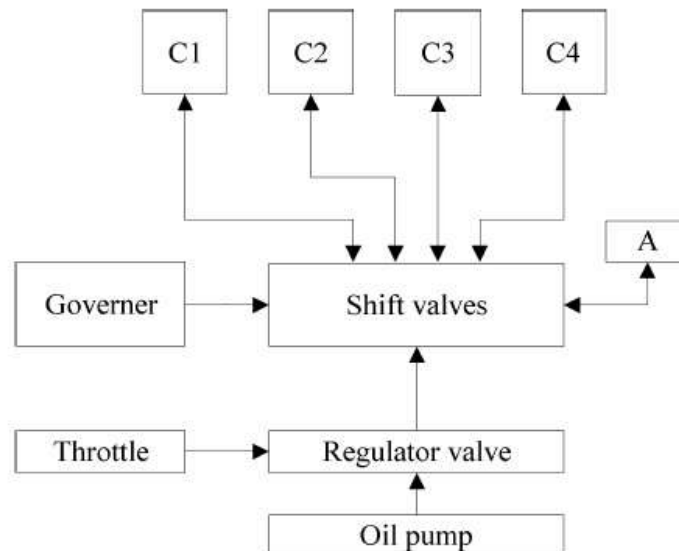


Fig (1) Hydro Mechanical Control System

Figure (1) shows the schematic diagram for the hydro mechanical control system of an early automatic transmission. The throttle valve mechanically linked to the accelerator pedal determines the system pressure appropriate to the output torque of an engine. The governor on the output shaft of the transmission moves the shift valves to apply and release the clutches to change gear appropriately. To avoid the shock during shift, accumulate or makes some delay of the pressure rising and falling. It has been generally used until 1970s in most of the automatic transmissions.[1][2][3]

2.2 Electro-Hydraulic Control System

In early 1980s, electronic control units (ECUs) were introduced and rapidly spread over the automotive industries. It replaced the hydro-mechanical components with the electro-hydraulic ones only for a few years. This trend made the actuators and the sensors cheaper and cheaper, and changed the system architecture from the passive to the active with the more advanced actuators and sensors.

2.2.1 Positive Shift Control

In early 1980s, the first electro-hydraulic control systems were introduced.[4][5] The on-off type solenoid valves replaced the function of the governor like figure (2). To determine the shift timing, the ECU should detect the angular velocity of the output shaft. Additionally, accumulators were applied to each friction elements to achieve optimal shift feeling. We can call this scheme passive shift control because the ECU has only a function of shift timing control.

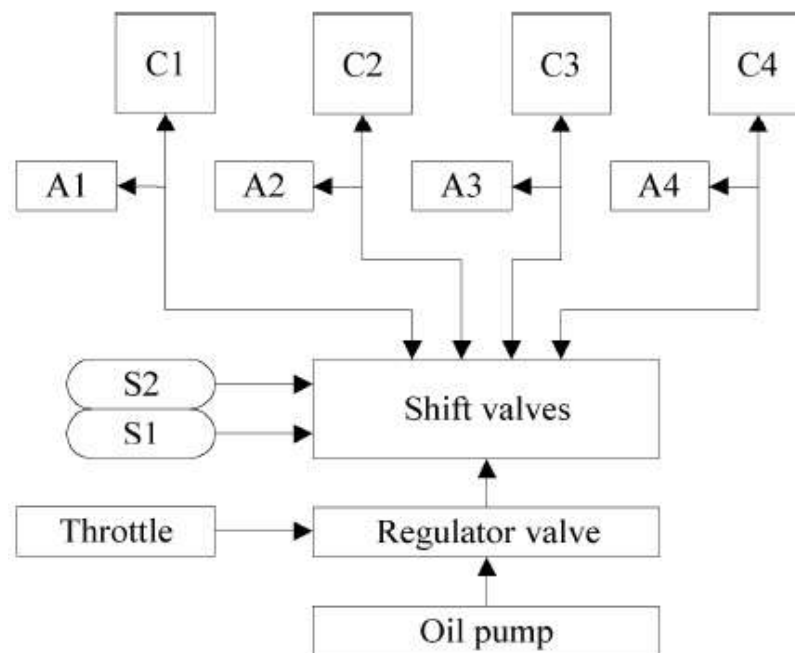


Fig (2) Electro-Hydraulic Control System passive Shift Control

2.2.2 Semi Active Shift Control

From mid-80s, more electronic control functions had been applied to the automatic transmissions. An electronically controlled solenoid valve substituted for the mechanical link to the accelerator pedal. The ECU read the information such as the throttle opening and the vehicle speed from the various sensors, and determined the shift timing and controlled the pressure of friction elements to get a better shift feeling.

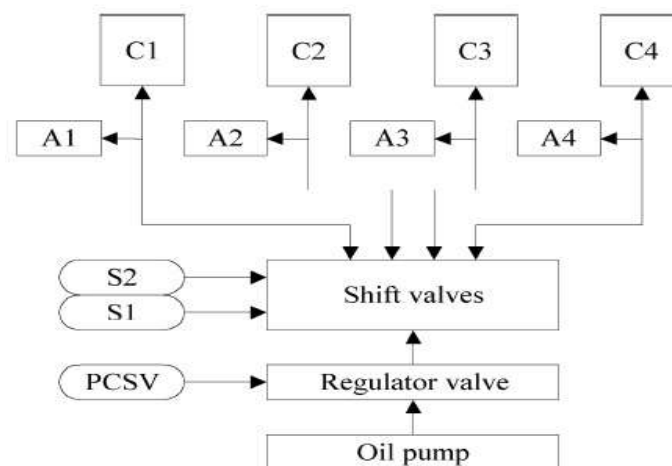


Fig (3) Electro-Hydraulic Control System semi Active Shift Control

So many variations of this system have been widely used until now from 3-speed to 5-speed. [6][7][8][9][10] In some of them, the back pressure of the accumulators are controlled by the system pressure according to the engine torque, but the shifting performance is mainly dependent on the characteristics of accumulators and orifices yet and the pressure cannot be controlled actively by the ECU. So that, we call the system semi-active. Figure 3 depicts the system schematic.

2.2.3 Active Shift Control

In figure 4, the active shift control scheme is illustrated.[11]The on-off solenoid valves carry out the shift timing control same as the case of the semi-active, but a pulse width modulation (PWM) solenoid valve or a PCSV controls the pressure of the friction elements. In most cases, because the solenoid valve outputs only limited pressure and flow rate, the second stage spool, pressure control valve (PCV), should be used.

This is the mostly advanced scheme in the electro-hydraulic control systems. However, the changing gears in automatic transmissions needs to control at least 2 friction elements simultaneously. Because there is only one active actuator, one element has to be controlled by passive hydraulic parts, or an OWC involved for the smooth shifting.

2.3 Full Electronic Control System

Gott[12] used the terminology, full electronic control, in his book at the first time. In the viewpoint of hydraulic systems in automatic transmissions, the meaning of full electronic control is that each friction element can be controlled by the ECU independently. In 1990s, along with the advanced technologies of the electronic control and sensors and actuators, it is possible to realize this concept with low cost and high reliability.

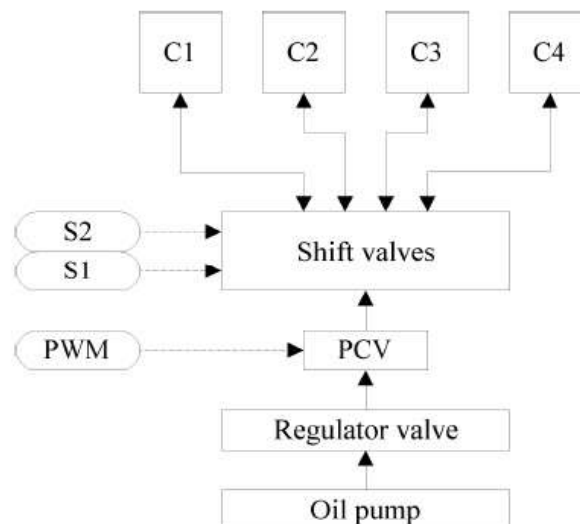


Fig (4) Electro-Hydraulic Control System – Active Shift Control

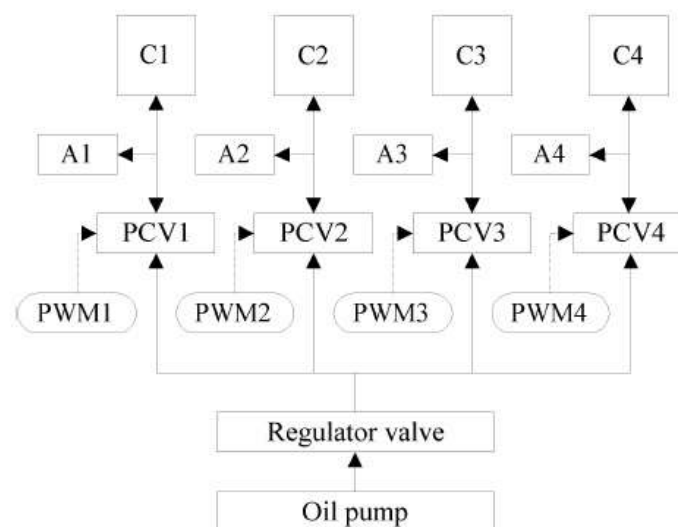


Fig (5) Full Electronic Control System – Indirect Semi Active Shift Control

2.3.1 Indirect Semi-Active Shift Control

The active electro-hydraulic control system which consists of a solenoid valve and a second stage spool valve can be expanded for each friction element. This system, shown in figure (5), offers the maximum degree of freedom to control the automatic transmission. Some of the manufacturers introduced it in 1990s.[13][14]

This system is good for the clutch-to-clutch shift combined with modern intelligent control algorithms such as model based robust control. [15] However, the control system of each friction elements consists of many devices, and as a result it is hard to design the system to satisfy the performance goal. In addition, there are so many pressure control valves and accumulators in the hydraulic system, so that the cost is high and the size is large. It may be not a good solution for 5 or more multi-speed automatic transmissions.

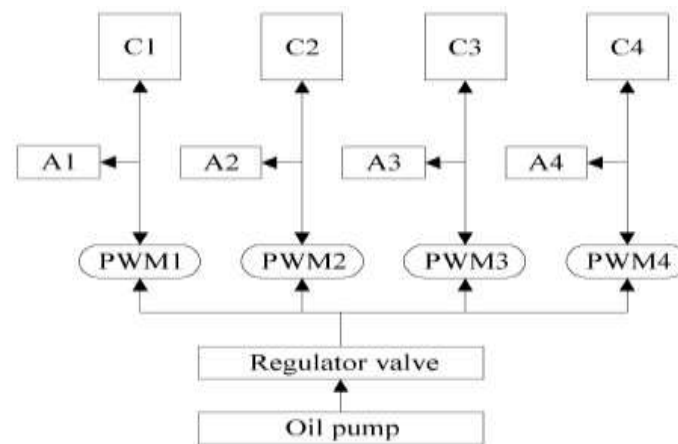


Fig (6) Full Electronic Control System – Direct Semi Active Shift Control

2.3.2 Direct Semi-Active Shift Control

Figure 6 shows the mostly advanced scheme until now, direct semi-active control. It is along the lines of the indirect concept with more improved actuators. It has a simple circuit, but needs the great performance of the actuators. The first commercial products with this concept were released in early 1990. [16][17]

They adopted specially designed high capacity PWM solenoid valves as actuators. However, to reduce the pressure ripples, accumulators were used in each. Additionally, because PWM solenoid valves basically control the flow rate without any pressure compensation, it is hard to control the system pressure to optimize the fuel economy without additional sensors. [18]

III. DIRECT ACTIVE SHIFT CONTROL

3.1 Concepts

As mentioned in introductions, it is the main subject of this study to introduce the full electronic control system for automatic transmissions with proportional control solenoid valves.[19] Figure 7 depicts the new concept, DASC scheme. For each friction element, only a PCSV is used, that is single stage control system. It has some advantages as followings:-

- The modern control theories can be applied to the full electronic control system with the high degree of freedom
- Simple structure without the second stage spools and accumulators reduces the weight, size, and cost of the hydraulic system.
- Minimum number of parts can guarantee the stable quality control in the mass production

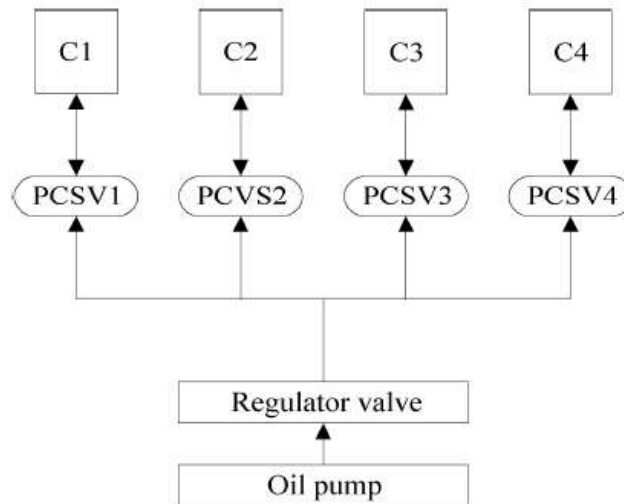


Fig (7) Full Electronic Control System – Direct Active Control Scheme

3.2 Type of Actuator

As seen in the previous section, most of the automatic transmissions adopt several electronically controlled solenoid valves to control the pressure. Two types of them are widely used, the PWM types and the PCSVs. We choose the PCSV because of the following advantages.

- The PCSV can accurately control the pressure proportional to the input current regardless of the supplying pressure variation.
- The PCSV is robust for the environmental disturbances such as oil temperature change.
- The PCSV has little pressure ripple and operating noise. Of course, there are some disadvantages.
- More complex electrical hardware is required to drive to feedback the current through the PCSV
- The PCSV has more complex structure, so that it is weak for contaminated oil
- The cost of PCSV is higher than that of the PWM solenoid valve yet

However, hardware of the ECUs and filtration technologies are being greatly improved, and the cost of erased parts can cancel the increased cost. Therefore, it is sure that this system is the competitive solution in the near future.

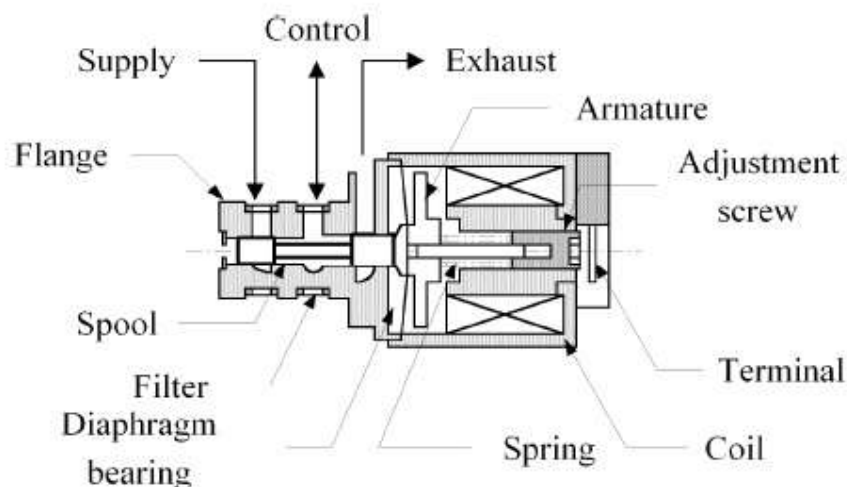


Fig (8) Structure of the Proportional Control Solenoid Valve

3.3 Performance of Actuator

Figure (8) shows the structure of the PCSV used in this Study.[20] Some characteristics of the PCSV are following.-

- Normally open type solenoid valve : Inverse characteristic between current vs. pressure
- Spool type PCSV : Solenoid valve combined with 3- way reducing type spool valve.
- Closed loop system : Internal feedback by the difference between pressurized areas of spool lands to the output pressure

Authors have studied the dynamic characteristics of the solenoid valve in past few years, and figure (9) shows the results of the PCSV. [21][22][23]

VI. EXPERIMENTS

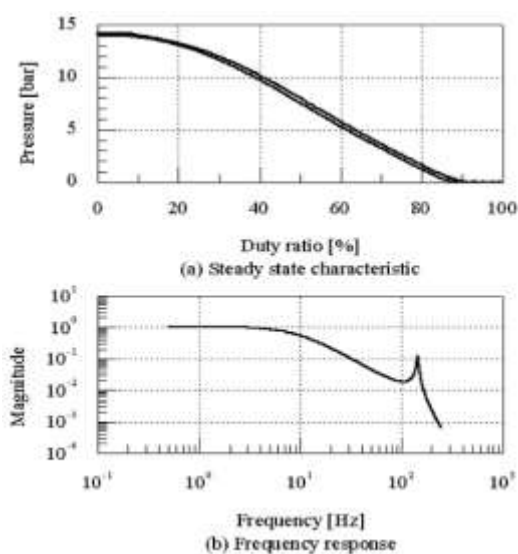


Fig (9) Characteristics of PCSV

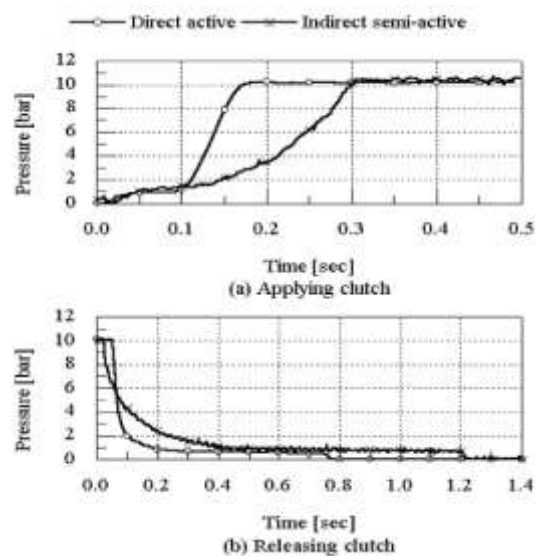


Fig (10) Comparison of Step Responses

4.1 Comparison of Step Response

To evaluate the DASC system, we chose the available indirect semi-active system that has the clutch-to-clutch shift mechanism. Without any modification of the power train, only the hydraulic systems were switched and the step responses of these systems were compared. The results are shown in figure (10).

The response of the DASC system is faster than that of indirect semi-active system both in applying and releasing. In the semi-active system, the accumulators limit the system response. That is, the accumulators not only reduce the pressure ripple but also decrease the system bandwidth. The initial delay of the DASC may be caused by the electrical circuit to feedback current, and should be improved to achieve the better initial response.[24]

4.2 Open Loop Pressure Control

To compare the system performance totally in the automatic transmission, 1-2 up-shift was performed in the same condition. At first, pressure profiles of the semi-active system during the up-shift were measured under certain condition. Then, we tuned the parameters of the DASC system and tested it under the same condition. The command duty ratio and the pressure profiles are like figure (11).

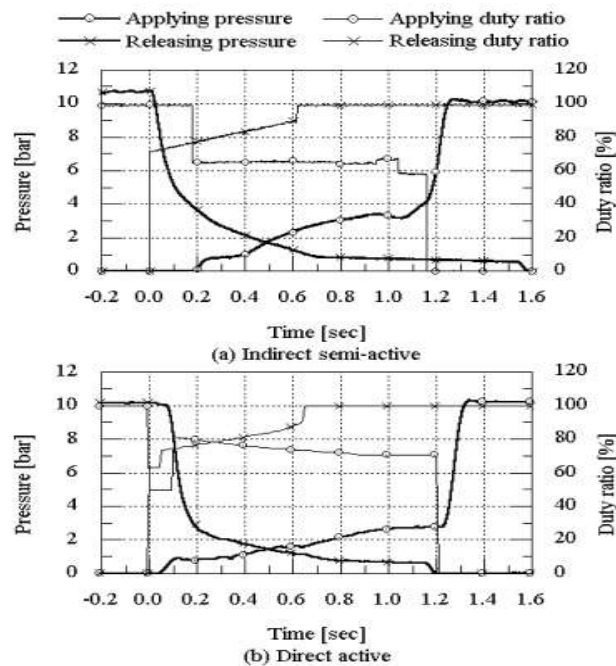


Fig (11) Comparison of Upshift

Even though more complex profiles of command duty ratio is required, it is sure that the DASC system works very well. However, the time lag is quite big in the applying pressure so that the total shift time is slightly longer than the semiactive system. It may be caused by the small flow rate capacity of the PCSV. As a result, it is necessary to improve the flow capacity of the PCSV for better performance of the DASC system

V. CONCLUSIONS

Followings are some conclusions of this study:-

- This paper reviewed the shift control schemes from the early hydro-mechanical system to modern full electronic control system. It was certain that the future system needs the simple structure and more degree of freedom.
- The new concept, DASC scheme of full electronic control system using PCSVs was proposed. It is competitive than any others in the functionality and the reliability with the equal or less cost.
- From the experimental results, we can conclude that the DASC system has a reasonable performance but the initial time delay caused by the electrical circuit and the small flow capacity of the PCSV should be improved to increase the overall response.

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