Mechanical Systems and Signal Processing 60-61 (2015) 742–752

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Optimal shifting control strategy in inertia phase of an automatic transmission for automotive applications

Fei Meng [a], Gang Tao [b], Tao Zhang [c], Yihuai Hu [a], Peng Geng [a,*]

[a] *Merchant Marine College, Shanghai Maritime University, Shanghai, China*
[b] *School of Mechanical Engineering, Beijing Institute of Technology, Beijing, China*
[c] *Powertrain Electronic Control Department, SAIC Motor Corporation Limited Passenger Vehicle Co., Shanghai, China*

ARTICLE INFO

Article history:
Received 21 November 2014
Received in revised form
21 December 2014
Accepted 23 December 2014
Available online 5 March 2015

Keywords:
Automatic transmission
Inertia phase
Shift control
Automotive

ABSTRACT

Shifting quality is a crucial factor in all parts of the automobile industry. To ensure an optimal gear shifting strategy with best fuel economy for a stepped automatic transmission, the controller should be designed to meet the challenge of lacking of a feedback sensor to measure the relevant variables. This paper focuses on a new kind of automatic transmission using proportional solenoid valve to control the clutch pressure, a speed difference of the clutch based control strategy is designed for the shift control during the inertia phase. First, the mechanical system is shown and the system dynamic model is built. Second, the control strategy is designed based on the characterization analysis of models which are derived from dynamics of the drive line and electro-hydraulic actuator. Then, the controller uses conventional Proportional-Integral-Derivative control theory, and a robust two-degree-of-freedom controller is also carried out to determine the optimal control parameters to further improve the system performance. Finally, the designed control strategy with different controller is implemented on a simulation model. The compared results show that the speed difference of clutch can track the desired trajectory well and improve the shift quality effectively.

1. Introduction

Multi-speed transmissions utilize torque-transmitting-mechanisms such as clutches to transfer torque at various speed ratios through the transmission. When shifting between gear ratios, the transmission control unit (TCU) should synchronize the engagement of the on-coming clutch and the disengagement of the off-going clutch [1–3], this process is called clutch-to-clutch shift control [4,5]. Clutch-to-clutch shift control system for automatic transmission is designed to provide smooth transients for passenger comfort and better component durability [6,7]. It has many advantages over the conventional free-wheeler bearing automatic transmissions such as simpler transmission designs and lower costs [8–11]. However, the clutch-to-clutch transmission must maintain the same level of shift quality as conventional transmissions, which poses a challenge to transmission controller design.

Many works have given a deep insight in the transmission control. With the increasing demand of transmission efficiency and performance, a more precise clutch shift control is necessary, which calls for a more effective closed-loop clutch control.

* Corresponding author. Tel.: +86 21 38282916.
E-mail address: gploveqq2006@126.com (P. Geng).

http://dx.doi.org/10.1016/j.ymssp.2014.12.025
0888-3270/

There are two possible ways of measuring the clutch motion directly: by measuring the clutch piston displacement or measuring the pressure inside the clutch chamber. In [12–15], the authors have shown satisfied results with the displacement feedback. Song and Sun [16] also given promising results with the pressure in the chamber as a feedback signal. However, in practise, to meet the low cost and physically compact demand, there always lack of a feedback sensor. In [17], the author has presented a model-based estimation for a stepped automatic transmission to provide real-time information about some necessary but un-measurable variables. Gao et al. [18] reported the backstepping design and obtained some simulation results, for the clutch-slipping control using the clutch rotational speed as the feedback signal.

A typical gear ratio change of clutch-to-clutch shift is accomplished by selectively engaging and disengaging clutches and proceeds through the process of: low gear, torque phase (L), inertia phase, torque phase (H) and high gear. However, the torque phase (H) in the case of upshifts and the torque phase (L) in case of downshifts may be absent [19–21]. When the on-coming clutch develops enough torque, the off-going clutch is released, marking the beginning of the inertia phase. During the inertia phase, the on-coming clutch torque is adjusted to reduce its slip speed toward zero. When the oncoming clutch slip speed reaches zero, the inertia phase is completed. During the inertia phase in shifting process, the shift jerk always exist, which degrades shift comfort for passengers. The pressure control of hydraulic actuators is essential in improving shift feeling by achieving smooth torque transients. Several applications of control strategy such as methods based on turbine torque estimation or tracking reference turbine rotation speed are reported [22–26]. However, the potential error of torque estimated model is quite large. Thus, it is difficult to conduct a precise control using a model-based control method for inertia phase control.

In this paper, a control strategy of tracking the reference clutch speed difference is adopted for improving the shifting performance during the inertia phase. In order to deal with the complexity and uncertainty caused by the electro-hydraulic actuators and fluctuating operating environment, a 2DOF PID controller is designed. The controller is structured to update at three different rates: every time instance, every shift, and every *n*th number of shifts.

The outline of this paper is as follows. The dynamic models of the shift system for the transmission are introduced in Section 2, followed by characterization analysis in inertia phase (Section 3). Control strategy according to the ideal control objective is then presented. The 2DOF PID controller based on the investigation of dynamic models is designed in Section 4. The simulated results are then presented and conclusions are given at the end of the paper.

2. Dynamic models

In this paper, we simplified the powertrain in the vehicle as a two-speed automatic transmission, as schematically shown in Fig. 1. The system contains a torque converter, a power transmission system, a drive line and a electro-hydraulic actuator for the clutch control. Two clutches are used as the shift actuators, a high-speed proportional solenoid valve (PSV) pilot operated pressure reducing valve (PRV) will produce a fluid pressure, and the fluid force will act on the piston. The pressure would force the clutches and brakes to engage or disengage. This will realize the function of power-on shifting. In Fig. 1, two proportional pressure valves are used to control different clutches, respectively. When clutch A is engaged and clutch B disengaged, the power train is operating in the low gear, while clutch A is disengaged and clutch B engaged, the vehicle is driven in high gear. Following text we will model the system based on the pervious classification.

2.1. Powertrain model

During the upshift process from low gear to high gear, the shift process is divided into the torque phase where the turbine torque is transferred from clutch A to clutch B, and in the inertia phase where clutch B is synchronized [27], the

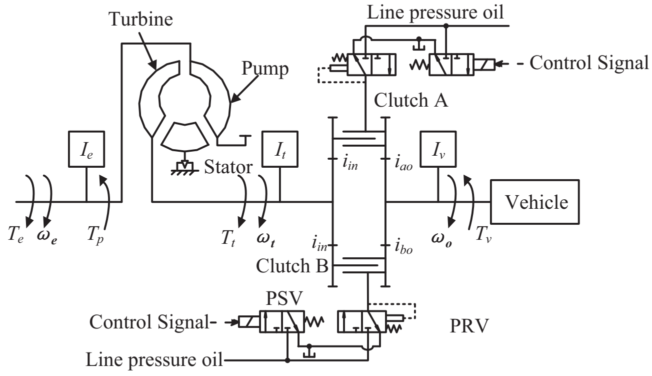

Fig. 1. Schematic graph of automatic transmission.