Review on development progress of automatic manual transmissions control

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Abstract: In recent years, the sustainable development of automatic manual transmissions (AMTs) control in vehicles is conspicuous. The control applications have grown fast and steadily due to the tremendous progress in power electronics components and the control software that enhance the requirements for delivering higher vehicles performance. AMTs control strategies achieve a reduction in the driveline dynamic oscillations behavior during gear shifting and clutch starting up processes. AMTs future expectations are an increase of torque capacity, more speed ratios and the development of advanced and efficient electronic control systems. This paper concerns with the progressing view of AMTs in the past, today and future, gives an overview of the potential dynamic problems concerned with AMTs and some control strategies used to solve those problems.

Keywords: AMTs control strategies; clutch dynamic response; pneumatic transmission control

Introduction

The research carried out during the last few years on manual transmission systems are considered as a foundation for automatic manual transmission research, upgrading the old manual style by inserting electronic equipment and software to improve shift quality, enhance fuel economy, and develop more efficient and reliable systems. In 1970 Scania and Daimler Benz began to use half automation control mode as the first stage for AMT progress. In their model the gear shifting process was operated by electro-pneumatic system after pressing the clutch pedal. An electronic monitor gave suggestion to the driver for optimal gear shifting [1]. American Eaton’s Smart improved the previous model by adding control strategies for both the clutch and the engine. In the second stage, a full automatic control system was generated and the first product was delivered to the market by Isuzu in 1984 followed by Nissan, Ford and Renault, using throttle pedal as a controlling parameter for speed control. The third stage was an intelligent automatic control, in which Isuzu and Nissan promoted the preceding models, picking up modern control theory such as Fuzzy logic, including environmental parameters and vehicle running conditions in their models [2]. Currently, vehicle manufactures of AMTs are focusing on the customer’s demand that means better shift quality and more efficient transmission system, in addition to further reduction of fuel consumption.

European light vehicle market has low penetration of AMTs and automatic transmission in the past ten years. It has grown slowly from 8% to just over 14% because consumers are reluctant to choose automatics. In the U.S., AMT demand has grown strongly and steadily so that 84% of cars are automatic currently. In Japan, the move to automatics came later than in the U.S. mainly due to heavy traffic congestion that limits the opportunity to achieve maximum acceleration or high speed; anyway, AMTs have come to dominate the market [3]. China enrolled in AMTs researches in 1984 and Xin Yuan Sheng company is currently constructing an electromechanical system consists of DC motor for actuating the clutch and shifting unit for selecting and shifting processes [4]. AMT control strategies are very important issues required to reduce fuel consumption and deliver smooth acceleration by minimizing unwanted oscillations which have adverse effects on vehicle performance.

1 Configurations of AMT control system

An AMT control system of a vehicle consists mainly of the engine, clutch and gear shift control units operated by computer software, as is shown in Fig.1 where the transmission control unit (TCU) communicates...
with the engine control unit (ECU) through a standard CAN or a serial bus [5]. A signal from the sensor of an acceleration pedal shows the operation magnitude of the accelerator pedal, and this signal is fed to the gear shifting control unit and the ECU. In the gear shifting control unit, the vehicle speed and the data of gear position sensors are used to determine the gear shifting point.

Electromagnetic sensors are used to indicate the position of pneumatic actuators. The shifting mechanism is driven to a desired position according to a scheduler map that defines actuating sequences. This system uses low pressures (0.5 MPa to 0.8 MPa) for actuators. Nevertheless, it has disadvantages such as air leakage from a clearance, large size and low positioning precision for actuators. Moreover, it is feasible only for trucks.

2 Classifications of AMTs control system

According to the driving actuator’s forces that operate the gearshift and clutch movements, AMT falls into the following categories.

2.1 Pneumatic transmission

For this type, the gear shifting and clutch control processes are implemented by pneumatic servo-system. The AMT pneumatic control system [6] shown in Fig. 2 consists of vertical and horizontal shift actuators which are mounted on the transmission gearbox for the generation of driving forces that are proportional to the cylinders’ internal pressure for actuating shift levers. Pressures are controlled by using pneumatic-activated valves to regulate the compressed inflow and outflow air (drain) in response to control signals to give the desired position depending on a scheduler map.

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2.2 Electro-mechanical transmission

In such a system, actuator control is implemented by servo electric drives such as DC motors, stepper motor or linear electromagnetic actuators working synchronously to achieve the desired positions. One of this system’s advantages is that actuators use energy only in actuating period. It is easy to control the drives, and the cost for the electrical components are low. These factors make the system more efficient and reliable than pneumatic and hydraulic systems.

2.3 Hydroelectric transmission

In 1980 hydroelectric AMT control system was integrated to a powertrain. Fig. 3 shows a hydraulic system consisting of passages and tubes containing hydraulic oil of high pressure (3 MPa to 6 MPa) controlled by an electric-solenoid valve or motor-operated valve to achieve required positions at each time for clutch or gear change. The valve is under the control of an electronic control unit. A pressure relay controls the pressure in the hydraulic circuit when the pressure is changed by switching the pump’s motor. An accumulator is used to damp down pressure pulsation and soften the system pressure transient. The advantages of this system are fast response movement and high precision in positioning the actuator. The disadvantages of this system are fast response movement and high precision in positioning the actuator. The disadvantage of this system is that it is feasible only for trucks.
tages include pressurized oil leakages through clearances, gaseous cavities generated in the working fluid leading to reduction of bulk modulus (cavitation), and corrosive wear of components caused by contaminated fluid [7]. Moreover, AMT hydraulic system is high in price and difficult in maintenance, and needs extra supply power to actuate the drives.

4 Outlook for AMTs control strategies

Feasible control strategies are indispensable to achieving target drive shaft torque, fast response for the desired vehicle speed, quite steady state acceleration during running conditions, and the optimal requirements to increase the transmission efficiency.

4.1 Vehicle speed and output torque control

In order to control the vehicle speed or regulate the driving shaft torque to a target value, ignition timing adjustment or electronic control throttle (ECT) is used as control parameters for the desired task.

Several vehicle control systems have been developed up to now. Takahashi [8] developed automatic speed control system employing self-tuning fuzzy logic rules to have the speed of the vehicle matching a driver’s individual preference. This control strategy shortens the time required to determine optimum control parameters for speed control. Pettersson and Nielsen used a linear flexible drive shafts model to design a vehicle speed controller that reduced the low frequency (less than 6 Hz) powertrain oscillations for a heavy truck [9]. They suggested for their dynamic model that the oscillation should be captured sufficiently with a simple powertrain model that consists of two rotational inertias connected to each other with a damped torsional flexibility. Alexander and Loukianov [10] presented a robust stabilizing controller for internal combustion engine and the model structure comprises of two loops, the engine and the driving loops. Sliding mode control strategy is used in the drive loop to provide fast and precise tracking of the throttle plate angle. In Ref [11], an adaptive control structure was investigated under different vehicle running conditions by using slow adaptation and sensitivity based gradient algorithms; the gains of a PI controller was adjusted to minimize a quadratic cost function formulated from experimental and simulation studies. Martin Sommerville [12] presented a switching control scheme for pneumatic throttle actuator controlled by using three solenoid-activated valves to attain the desired speed; he also developed two linear models respectively for throttle actuator and throttle plate system.

For output torque control, Magnus and Lars [13], proposed a method based on engine torque control by estimating the transmitted torque and controlling it to zero during different phases of gear shifting using a feedback controller. The system has to wait until satisfactory gearshift conditions are reached and neutral gear can be engaged. Minowa and Kurata [14] presented a control technique based on PID controller and the characteristics of the torque converter for engine torque compensation, adjusting the throttle valve to attain the target driven shaft torque. When an electronic throttle is used as the control parameter in speed or torque control, it should be controlled to give a fast response, smooth movement and zero steady state error, so accurate control of the opening is essential to maintain a desired speed or torque at varying road conditions.

4.2 Clutch dynamic response control

Clutch allows engine power to be applied gradually when a vehicle is starting up and power is interrupted when shifting to avoid gear crunching. Clutch slipping phase is a crucial point in AMTs control. Due to the speed difference of the clutch plates, some effects are generated during this phase such as torsional vibration (judder) that increases the driveline oscillation, particularly on small trucks with diesel engine. The excitation of this resonant vibration is usually within the range of 10 Hz to 20 Hz. In addition, the amount of energy dissipated into heat is proportional to the slipping phase time that ranges within 0.5 s to 2.0 s. Moreover, the effect of repeated applied load generates surface wear, which reduces the lifetime of the clutch frictional plates material. Fig. 4 illustrates the variable parameters
during clutch slipping phase. The clutch torque increase that depends on the rate of the applied clamping force till it reaches the maximum value at the lock up point, where the engine and the clutch speeds are equal. The increase of heat energy depends on the torque and the slip speed.

![Fig. 4 Clutch starting up characteristics](image)

Researcher’s control strategies lead to conflicting objectives such as small facing wear, small friction losses, minimum time needed for the engagement and regulation of the slip acceleration at the lock up point for reducing the undesirable driveline oscillation. A non-linear multibody dynamic model was developed by Centea and Rahnejat to study the effect of the slip variation and the coefficient of friction during the judder. The results indicated that various friction materials of positive gradient coefficient of friction with respect to the slip speed provide a better damping effect and little self-excited vibrations [15]. Franco and Luigi developed a slip control technique which was formulated as a piecewise linear time invariant model for the dry clutch based on closed loop with feedback controller [16]. Recently, Fuzzy logic control has been proposed for analyzing clutch dynamic response characteristics during slipping phase [17].

### 4.3 Shift shock control in AMTs system

AMTs shift shock criterion is one of the most significant factors, which has influence on the steady state acceleration. The shift shock occurs when inserting the target gear into the drive shaft gear and that can not be accomplished smoothly due to the speed difference between the transmission gears during engagement. So the result of this criteria is a deterioration of the vehicle driving comfort, friction loss as heat, mechanical wear and noise. Fig. 5 illustrates the fluctuation of the driven shaft torque during gears shifting. This mainly involves under shock at the initial stage when gears start to engage (the torque phase), overshoot shock due to the inertia torque generated by the speed change and the torque step shock.. Today, control of this process is significant and more desirable to improve the fluctuating torque, which is an important performance-limiting factor for drivability, if it is not damped down. The control strategies offer to optimize the time needed for a gearshift, especially in the drive situation like overtaking or driving uphill with heavy loads. A shift control technique was proposed by Kazumi and Yasunori [18], which detects the road gradient for either uphill or downhill roads without adding sensors and chooses the appropriate gear position. In Ref. [19], a control method was introduced to perform shift control using the road data obtained from a navigation system and the current vehicle speed to determine the optimal gear for shifting. Minowa proposed a method based on engine steady state map where the fuel flow rate is a function of the engine speed and torque, to choose the desired gear, which gives the lowest fuel flow rate, in addition to a reduction in the gear shift timing [20].

![Fig. 5 Gear shift shock criteria](image)

### 5 Future progress of AMTs control

The prospect of AMTs technology is to overcome the torque interruption during power shifting in order to improve the acceleration feeling and the reliability of the system. Beyond 2005, AMT with double clutch transmission (DCT) control techniques is expected to grow up, to provide good shift quality and improvement in the fuel consumption at a price below that of a conventional AMT. Future researches on AMTs will focus on increasing the number of transmission speeds that has obvious benefits of allowing the engine to operate closer to its optimum operation line. In addition, the development of shift–by-wire technologies will be enforced. There will be an increasing use of advanced electronic control equipments such as digital signal processing for control engineering (dSPACE), as a
viable alternative in virtual environment for rapid control prototype testing. Also, much progress will appear in the adaptive logic control software that includes more identification functions for the drive style and driving conditions. Fig. 6 gives some forecasted data for transmissions technologies up to 2005 and shows that the five-speed AMTs demand will fall by 2.4 units while the six-speed will grow up by 2.5 units. This is due to desirable advantages in the wide range of speed ratios, saving in fuel consumption (5% to 6%), a reduction in emissions and 5% better acceleration. Likewise, the five-speed automatic transmission (AT) system will decline while the six-speed grows by 1 unit [3].

6 Conclusions

Recently, the continuously increasing volume of AMTs control systems’ hardware equipment and software control functions has been leading AMTs to a great stature in the vehicles transmissions global community. Today, AMTs technology is focusing on the production of electro-mechanical transmission system other than the hydraulic and pneumatic systems. This is due to the lower capital cost for the equipments and the operating maintenance. In addition, the control of the system electric drives is easy. The fundamental prospective evolution of AMT control strategies lies on the application of the modern control theory such as Fuzzy logic, linear quadratic optimization and neural network techniques for improving the clutch dynamic response, reducing the torque shift shock and more efficient gear shifting control mechanism. An AMTs system has merits over other transmission systems in its high delivery torque, small time consuming for operating the actuators in response to the electronic control units. All these factors enable AMTs systems outweigh in the transmissions environment.

References