Optimal Control of Gearshift in Automatic Mechanical Transmission

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Abstract. In order to solve the problems existed in gearshift process of automatic mechanical transmission(AMT), the control strategy base on fuzzy control was presented with regarding of engine running state and clutch engaging state. The wet clutch target pressure of shifting process was determined by the fuzzy controller. According to the error of target pressure and actual pressure, a wet clutch pressure intelligent control arithmetic base on Radial Basis Function Neural Network(RBFNN) was designed to realize accuracy control of clutch pressure. The vehicle gear shifting experiment was conducted to verify the control strategy.

1 Introduction

AMT is based on original manual transmission, it has the advantages of high transmission efficiency and low manufacturing cost compared with traditional hydrodynamic mechanical automatic transmission(AT). But power interruption existed during shifting, and shifting comfort is less than AT. Therefore, clutch control during shifting process was the core point and difficulty of AMT. It not only improves smooth and prevents excessive jerk and ensures the stable operation of the engine, also ensures that the friction is not too large. If the clutch engage too fast, will generate shifting jerk, on the contrary, the shifting time is too long, friction of clutch is violent, temperature of clutch oil rise, will affect the service life of the clutch.

On the analysis of shifting process, the writer improved the control strategy, designed a fuzzy controller to calculate the target pressure of clutch, through the real-time monitoring of the clutch pressure increment. The writer also make the design base on RBFNN, a wet clutch pressure intelligent control system to achieve a precise control of the clutch pressure, and the results were verified by experiment.

2 Clutch control strategy of shifting process

Wet clutch went through three kinds of state during shifting process: apart state, friction state, engaging state. In friction state, clutch engaged partly, not entirely, and transmitted friction torque. Therefore, the driving and the driven plates of the wet clutch and clutch oil temperature had grate effect on wet clutch dynamic friction coefficient.

A fuzzy control system was designed, which use the rotation speed difference between the driving and the driven plates of the wet clutch, clutch oil temperature, engine speed as input parameters, also changing rate of clutch pressure as output parameter[1，2]. However, in order to prevent engine flameout or shake, engine speed must be monitored in real time.

The control rules of fuzzy controller were fuzzy conditional sentence which was composed of several linguistic variables. According to the need of fuzzy pressure controller, select the input and output variables respectively as: the rotation speed difference between the driving and the driven plates of the wet clutch $\Delta\omega$ “very small”（VS）,“small”（S）,“middle”（M）,“big”（B）,“very big”（VB）; clutch oil temperature t_{tem} : “very small”（VS）,“small”（S）,“middle”（M）,“big”（B）,“very big”（VB）; engine speed ω_e : “very small”（VS）,“small”（S）,“middle”（M）,“big”（B）,“very big”（VB）; changing rate of clutch pressure Δp : “very small”（VS）,“small”（S）, “middle”（M）,“big”

（B）,“very big”（VB）.

The membership function of each fuzzy variable was triangular distribution. Each fuzzy subset membership curve was shown in fig.1.

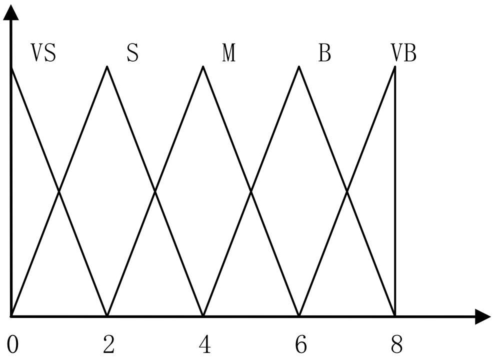

Figure 1: Membership function

Because fuzzy controller adopted a variety of input variables, in order to avoid large storage capacity and difficulty in adjustment, the writer designed the structure of two layers with multiple rules[3,11]. The schematic of fuzzy control was shown in fig.2. Fuzzy controller had two layers of inference, the first layer, made an inference from the rotation speed difference between the driving and the driven plates of the wet clutch $\Delta\omega$ and clutch oil temperature t_{tem}, got clutch dynamic friction coefficient μ, the second layer, made an inference from clutch dynamic friction coefficient μ and engine speed ω_e, got changing rate of clutch pressure Δp.

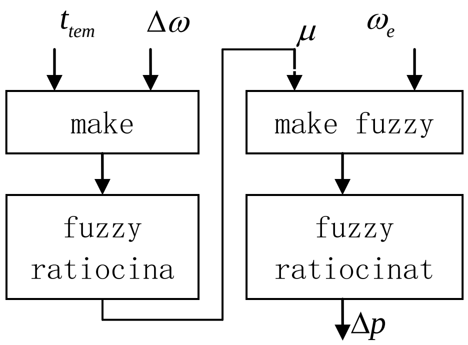

Figure 2: Schematic diagram of fuzzy control

Tab.1 is the fuzzy rule table of dynamic friction coefficient μ. Tab.2 is the fuzzy rule table of changing rate of clutch pressure Δp.

$\Delta\omega$	t_{tem}				
	VS	S	M	B	VB
VS	VS	S	M	B	VB
S	S	M	B	M	S
M	M	B	M	B	M
B	S	M	B	M	S
VB	VS	S	M	S	VS

Table 1: Fuzzy rule table of μ

ω_e	μ				
	VS	S	M	B	VB
VS	VS	S	S	VS	VS
S	M	M	S	S	S
M	B	B	M	M	M
B	B	B	M	M	S
VB	VS	VB	B	B	M

Table 2: Fuzzy rule table of Δp

The paper used Mamdani direct reasoning method and “max-min” method to do synthetic operation of fuzzy relation, and used gravity method for defuzzification, obtained the dynamic friction coefficient μ l, as shown in fig.3.

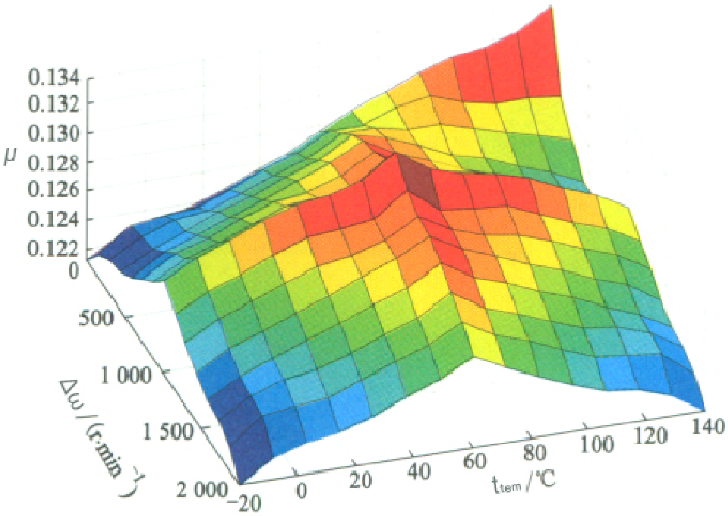

Figure 3:Fuzzy rule surface of μ

3 Evaluation index of shifting quality

Jerk and friction were the main evaluation index of shifting performance. Jerk is defined as the changing rate of longitudinal acceleration in unit time, usually use $j = \frac{d^2 v}{dt^2}$, v was vehicle speed.

From $v = \frac{\omega r}{i_g i_0}$, the mathematical expressions for j is:

$$j = \frac{d^2 v}{dt^2} = \frac{r}{i_g i_0}\frac{d^2 \omega}{dt^2} = \frac{1}{\delta m}\frac{i_g i_0 \eta}{r}\frac{dT_c}{dt} \quad (1)$$

In this formula, r represents wheel radius, i_g represents main reduction ratio, i_0 represents, gear ratio, η represents transmission efficiency, δ represents rotary mass coefficient of vehicle, m represents quality of vehicles, T_c represents clutch torque.

Friction is sliding friction work between the driving and the driven plates of the wet clutch, the mathematical expressions is:

$$L = \int_{t_0}^{t_1} T_c(\omega_e - \omega_c)dt \quad (2)$$

In this formula, t_0 represents the time when clutch engaging and starting transfer torque, t_1 represents the time rotation speed between the driving and the driven plates of the wet clutch achieve synchronization.

Friction had relationship with clutch oil temperature in wet clutch, when friction was large, oil temperature rose fast. Friction was represented by oil temperature in the paper. Jerk was related to clutch engaging speed by eqn(1). Friction was related to rotation speed difference between the driving and the driven plates of the wet clutch, clutch torque and friction time by eqn(2). Therefore, jerk and friction were contradictory as evaluation index[4,5].

In wet clutch, clutch temperature has the close relationship with the friction, when the friction become too large, oil temperature will increases rapidly, so the paper use the clutch oil temperature to reflect friction. During the shifting process, how to balance the jerk and clutch oil temperature, is the core point of the control strategy

4 Optimal control of clutch pressure during shifting process

The clutch torque is related to many factors, which is a nonlinear complex model. Secondly, after long time using, clutch model will be distortion and clutch torque will certainly change, even if the initial phase of the clutch model is accurate[6,7,8]. Solenoid valve also has the same problems after long using, the accuracy of the model will be decreased. Meanwhile, the machining precision of each part with different batches of production can not be completely the same, there will be certain errors[9,10]. In conclusion, the writer used RBFNN adaptive controller to compensate for the clutch and solenoid valve model. According to the error between the clutch target pressure and actual pressure value, the controller generated control current to amend, to improve the control accuracy of clutch pressure, and to compensate model distortion automatically.

The RBFNN simulation model was established using Simulink, as shown in fig.4. Solenoid value module was the simulation module of clutch pressure control valve, RBFNN module was the simulation model of RBFNN, Signal was signal generation module of the model. p_t was the clutch target pressure, p_r was the clutch actual pressure, i was the control current. The target pressure p_t and the actual pressure p_r were the input of RBFNN, output was the control current i. Solenoid value module calculated the actual clutch pressure according to the input control current i. The simulation curve was shown in the fig.5, it had high precision in following and small control error.

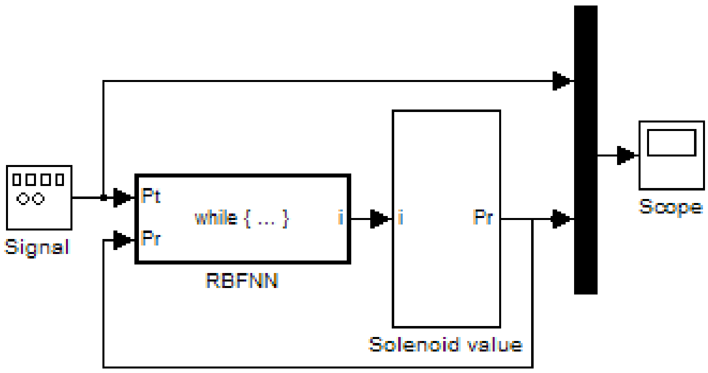

Figure 4: RBFNN simulation model

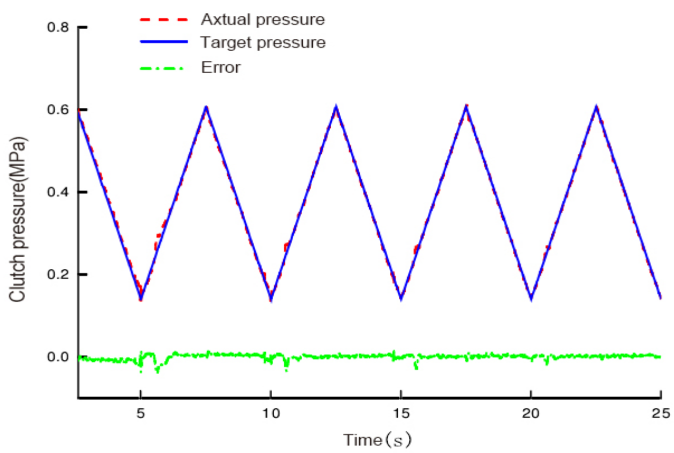

Figure 5: Simulation curve of pressure

5 Experiment results and analysis

The controller of the test vehicle used IFINEON C164CI microprocessor as the main control chip, analog signal used RC filter circuit for signal filtering, pulse signal used photoelectric isolation chip to do isolation processing, the data collected through the CAN communication interface to upload to the computer.

Fig.6 to fig.8 was the experiment result. As shown in fig.6, engine speed was pulled down slowly, the shifting process lasted about 1 second, the shifting action was quickly. As shown in fig.7 vehicle speed was changing stably, the throttle was stable at 10%, the maximum of jerk was not more than 9m/s³. As shown in fig.8, after shifting several times, oil temperature was stable at about 70℃, the maximum was not more than 80℃. The results show that shifting control strategy meets the requirements of smooth and rapid ride in gear shift process.

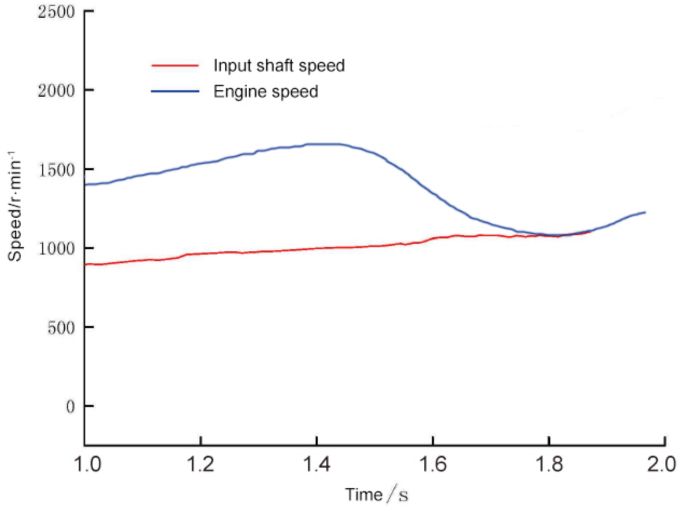

Figure 6: The engine speed, input shaft speed in 1-2 upshift

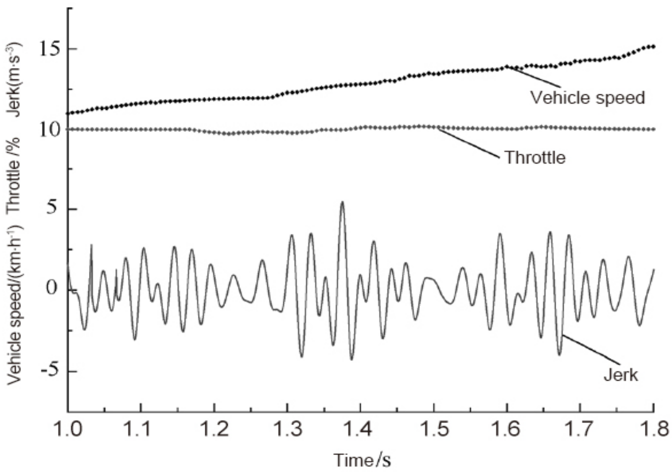

Figure 7: The vehicle speed, throttle, jerk in 1-2 upshift

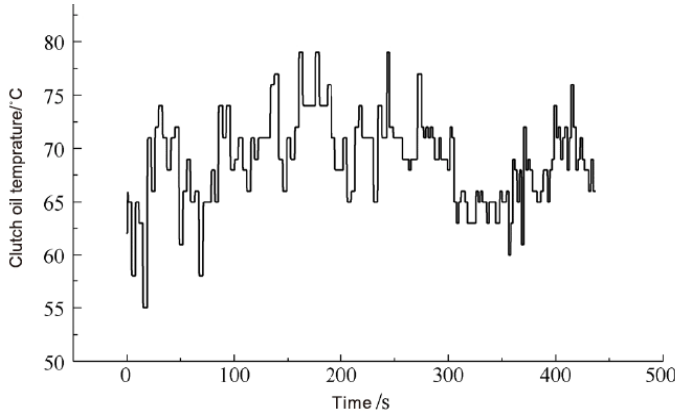

Figure 8: Oil temperature during multiple continuous gearshifts

6 Conclusion

On the analysis of shifting process of AMT with wet clutch, fuzzy control was used to calculate the target pressure of clutch. RBFNN adaptive controller was established to realize accuracy control of clutch pressure. The optimal control meet the requirements of shifting process, provided a reference control method for problems of shifting.

Acknowledgment

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