Shifting Control Strategy Research in the Hard Accelerating Condition Based on the AMT Vehicle

Yang Gao, Yong Chen, Daguo Luo, Wenzhong Liu, Mingqi Gu and Fuquan Zhao

Abstract This paper presents the gear optimization control strategy of the automated mechanical transmission (AMT) vehicles in the acceleration condition, analyzes the down shifting principle of the AMT vehicles in the acceleration condition, and establishes the in-loop simulation platform of the automatic transmission with Matlab/Simulink software. Further, the condition that the driver stepped on the accelerator pedal suddenly when the vehicle does not slow down the speed is simulated with the optimization control strategy and the traditional control strategy respectively. The results show that the proposed optimization control strategy can identify the driver's intention and reduce the shift times and the power break time, thereby improving comfort ability, and making the vehicle achieve the maximum speed faster.

Keywords AMT · Hard acceleration · Control strategy · Simulation platform

1 Introduction

The target gear of the tradition AMT shift schedule is determined according to the throttle and the speed, which can make the vehicle work in a better power and economy condition [1]. When the driver increases throttle opening suddenly, the transmission control unit will make the engine work in reasonable conditions according to the shift schedule curve. At this time, the transmission target gear will be lower. If it is not restricted the vehicle will take the state that it downshifts and

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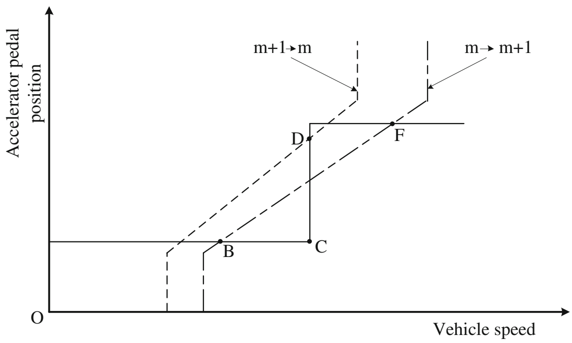

Fig. 1 Downshift process of the hard accelerating condition

then rises to the original gear immediately. If it is shifted according to the target gear, the ground gained traction will be increased. But the AMT power interruption time will also be increased. The power interruption time is too long to satisfy the driver's intentions, which also reduces the power, the economy, and the transmission life. According to analysis of the transmission downshift principle in the accelerating conditions and estimation of whether the shift is reasonable, it presents the gear optimization control strategy of the automated mechanical transmission (AMT) vehicles in the accelerating condition. The software in-loop simulation platform of the automatic transmission was built with Matlab/Simulink software. The correctness of the proposed control strategy is verified by the simulation results.

2 Downshift Principle in the Accelerating Conditions

At present, a two-parameter shift schedule determined by the throttle opening and the vehicle speed is mainly used in automatic transmission. The shift process in the hard accelerating condition is shown in Fig. 1. When the vehicle speed rises to the point C and the driver steps on the accelerator pedal suddenly, the transmission will downshift because it goes across the current downshift curve. The driving force will increase after downshifting. But the power break time is too long during the shift process of the AMT vehicle. The transmission will also upshift when the vehicle speed arrives to the upshift point. So the shift in the hard acceleration condition will not always increase the power.

3 Optimization Control Strategy

It is an assumption that the wheel slip is neglect, the average wheel edge speed is equal to the vehicle speed, and the target vehicle includes six forward gears.

The outputting driving force of the engine can be calculated using the equation below:

$$F_{drive} = \frac{\eta * i_g * i_0 * \left(T_e - \frac{i_g * i_0}{R}\dot{v} * I_e\right)}{R}$$

In this equation:

η	Transmission gear efficiency;
i_g	Transmission speed ratio;
i_0	Differential speed ratio;
T_e	Engine torque;
R	Average rolling radius of the wheel;
$\dot{v}$	Vehicle acceleration;
I_e	Engine inertia.

The resistance sum except the slope resistance can be calculated using the equation below:

$$F_{resistance} = \frac{1}{2} * \rho * C_D * A * v^2 + f_r * M * g + \frac{\dot{v} * I_{all\_on\_wheel} * i_0^2}{R^2}$$

In this equation:

ρ	Air density;
C_D	Coefficient of air resistance;
A	Effective frontal area of the vehicle;
v	Vehicle speed;
f_r	Coefficient of rolling resistance;
M	Fully loaded mass;
g	Acceleration due to gravity;
$I_{all\_on\_wheel}$	Total vehicle wheel inertia.

The expected acceleration can be calculated using the equation below:

$$a_{exp} = \frac{F_{drive} - F_{resistance}}{M}$$

The broad-based slope resistance can be calculated using the equation below:

$$F_{slope} = M * (a_{exp} - \dot{v})$$

It is an assumption that the slope resistance is fixed during the modifying process. The acceleration can be calculated using the equation below:

$$\dot{v} = \frac{F_{drive} - F_{resistance} - F_{slope}}{M} = \frac{\frac{\eta * i_g * i_0 * (T_e - \frac{i_g * i_0}{R} \dot{v} * I_e)}{R} - \left(\frac{1}{2} * \rho * C_D * A * v^2 + f_r * M * g + \frac{\dot{v} * I_{all\_on\_wheel} * i_0^2}{R^2}\right) - F_{slope}}{M}$$

The acceleration function of the hard accelerating condition can be calculated using the equation below:

$$\dot{v} = f(\eta, i_g, T_e, I_{all\_on\_wheel})$$

The initial acceleration function keeping the current gear can be calculated using the equation below:

$$\dot{v}_{currentgear} = f(\eta_{currentgear}, i_{g\_currentgear}, T_{e\_currentgear}, I_{all\_on\_wheel\_currentgear})$$

In this equation:

$\eta_{currentgear}$	Transmission gear efficiency of the current gear;
$i_{g\_currentgear}$	Transmission speed ratio of the current gear;
$T_{e\_currentgear}$	Engine torque of the current gear;
$I_{all\_on\_wheel\_currentgear}$	Total vehicle wheel inertia of the current gear.

The initial acceleration function after changing to the target gear can be calculated using the equation below:

$$\dot{v}_{desiredgear} = f(\eta_{desiredgear}, i_{g\_desiredgear}, T_{e\_desiredgear}, I_{all\_on\_wheel\_desiredgear})$$

In this equation:

$\eta_{desiredgear}$	Transmission gear efficiency of the target gear;
$i_{g\_desiredgear}$	Transmission speed ratio of the target gear;
$T_{e\_desiredgear}$	Engine torque of the target gear;
$I_{all\_on\_wheel\_desiredgear}$	Total vehicle wheel inertia of the target gear.

When the target gear is current-1, the vehicle speed function keeping the current gear can be calculated using the equation below:

$$v_{currentgear} = v_0 + \int_0^{t_{currentgear}} \dot{v}_{currentgear} dt$$

In this equation:

v_0	Initial vehicle speed;
$t_{currentgear}$	Time during the current gear.

It is an assumption that the outputting average driving force of the engine is F_{shift} at shifting.

The action speed function of changing to the target gear can be calculated using the equation below:

$$v_{desiredgear} = v_0 + \int_0^{t_{downshift}} \frac{F_{shift} - F_{resistance} - F_{slope}}{M} dt + \int_{t_{downshift}}^{t_{upshift}} \dot{v}_{desiredgear} dt + \int_{t_{upshift}}^{t_{desiredgear}} \frac{F_{shift} - F_{resistance} - F_{slope}}{M} dt$$

In this equation:

$t_{downshift}$ Downshift time;
$t_{upshift}$ Upshift time;
$t_{desiredgear}$ the time that it rises to the target gear.

The vehicle speed is v_f on the F point. If $v_{currentgear} = v_f$ then, $t_{currentgear} = t_{d1}$. If $v_{desiredgear} = v_f$ then, $t_{desiredgear} = t_{d11}$.

Using above method, the values can be calculated (Gdes is the desired gear; Gcur is the current gear; Gcom is the commanded gear.). If Gdes = Gcur −2, the time that does not execute downshift is t_{d2}, the estimated time is t_{d21} executing Gcom = Gcur −1, the estimated time is t_{d22} executing Gcom = Gcur −2. If Gdes = Gcur −3 the time that doesn't execute downshift is t_{d3}, the estimated time is t_{d31} executing Gcom = Gcur −1, the estimated time is t_{d32} executing Gcom = Gcur −2, the estimated time is t_{d33} executing Gcom = Gcur −3. If Gdes = Gcur −4 the time that doesn't execute downshift is t_{d4}, the estimated time is t_{d41} executing Gcom = Gcur −1, the estimated time is t_{d42} executing Gcom = Gcur −2, the estimated time is t_{d43} executing Gcom = Gcur −3, the estimated time is t_{d44} executing Gcom = Gcur −4. If Gdes = Gcur −5 the time that doesn't execute downshift is t_{d5}, the estimated time is t_{d51} executing Gcom = Gcur −1, the estimated time is t_{d52} executing Gcom = Gcur −2, the estimated time is t_{d53} executing Gcom = Gcur −3, the estimated time is t_{d54} executing Gcom = Gcur −4, the estimated time is t_{d55} executing Gcom = Gcur −5.

The method of the optimization project is shown in Table 1. The building process of the optimize shift control strategy [2–4] is shown in Fig. 2. Dkd is the accelerator pedal position gradient; HardAccPedGradient is the limit of the accelerator pedal position gradient; Kd is the accelerator pedal position; PedalHigh is the upper limit of the accelerator pedal position; PedalLow is the lower limit of the accelerator pedal position; and Review Timer is the waiting timer state. Gdes is the desired gear; Gcur is the current gear; and Gcom is the order gear.

4 Software-in-the-Loop Simulation Platform

A built vehicle transmission system software in- loop simulation platform with Matlab/Simulink software is shown in Fig. 3. The simulation platform mainly includes the vehicle model and the control strategy model. Kd_pad is the

Table 1 Method of the optimization project

	Prescient time (s)						Optimization project
	No shift	Drop 1 gear	Drop 2 gear	Drop 3 gear	Drop 4 gear	Drop 5 gear	
Gdes = Gcur −1	t_{d1}	t_{d11}	–	–	–	–	Min(t_{d1}, t_{d11})
Gdes = Gcur −2	t_{d2}	t_{d21}	t_{d22}	–	–	–	Min(t_{d2}, t_{d21}, t_{d22})
Gdes = Gcur −3	t_{d3}	t_{d31}	t_{d32}	t_{d33}	–	–	Min(t_{d3}, t_{d31}, t_{d32}, t_{d33})
Gdes = Gcur −4	t_{d4}	t_{d41}	t_{d42}	t_{d43}	t_{d44}	–	Min(t_{d4}, t_{d41}, t_{d42}, t_{d43}, t_{d44})
Gdes = Gcur −5	t_{d5}	t_{d51}	t_{d52}	t_{d53}	t_{d54}	t_{d55}	Min(t_{d5}, t_{d51}, t_{d52}, t_{d53}, t_{d54}, t_{d55})

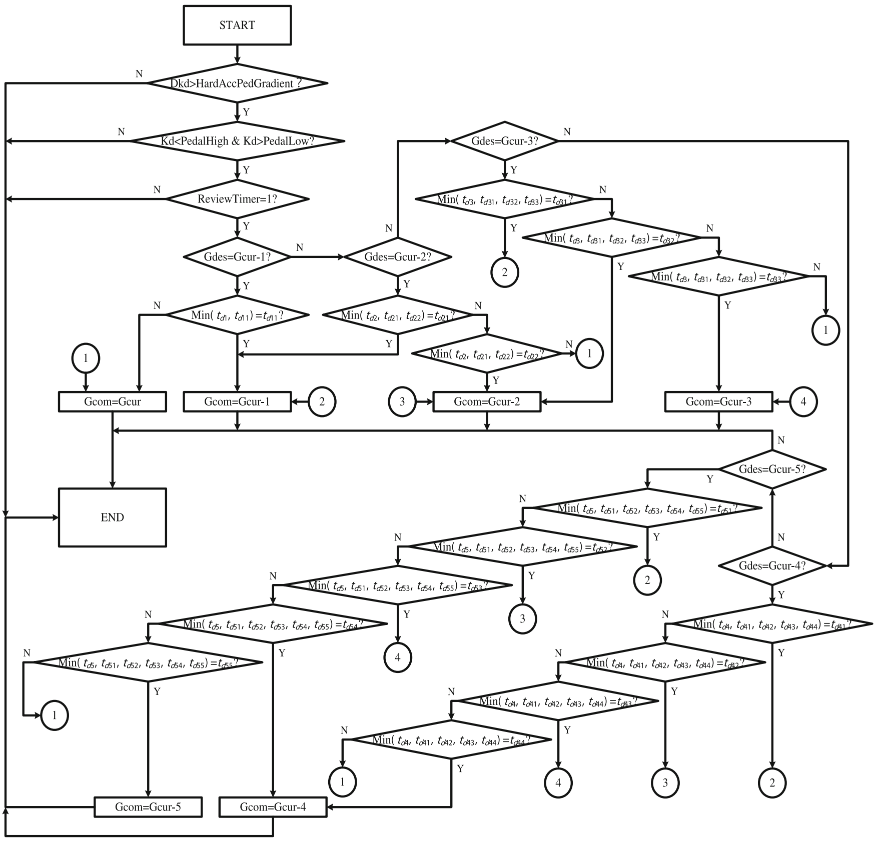

Fig. 2 Flow of the optimize shift control strategy

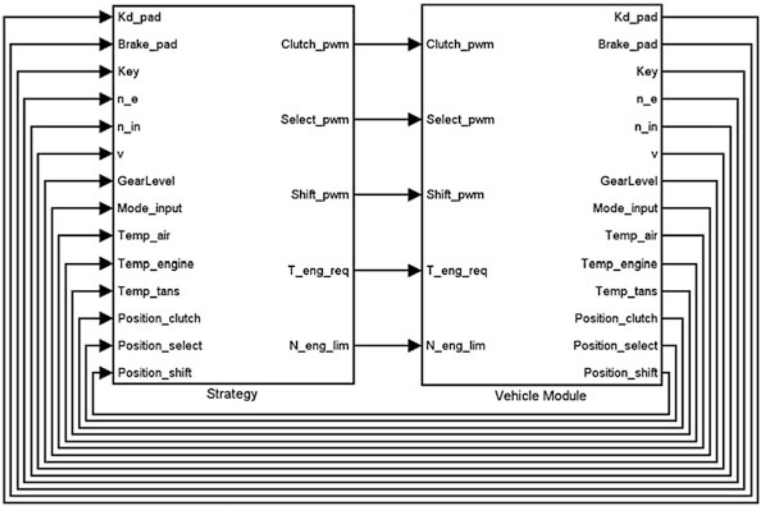

Fig. 3 Simulation platform interface

accelerator pedal position; Brake_pad is the brake pedal position; Key is the ignition switch; ne is the engine speed; n_in is the input shaft speed; v is the vehicle speed; GearLevel is the gear level position; Mode_input is the mode signal; Temp_air is the air temperature; Temp_engine is the engine temperature; Temp_tans is the transmission temperature; Position_clutch is the clutch position; Position_select is the select gear position; Position_shift is the shift gear position; Clutch_pwm is the control signal of the clutch actuator motor; Select_pwm is the control signals of the select gear motor; Shift_pwm is the control signals of the shift gear motor; T_eng_req is the engine requiring torque; and N_eng_lim is the engine speed limit.

5 Simulation Analysis

The vehicle equipped with automatic mechanical transmission and electronically controlled engines is taken as the study object. The conditions that the driver stepped on the accelerator pedal suddenly using the optimal control strategy and the traditional control strategy are simulated respectively on the built drive system software in- loop simulation platform [5, 6]. The Simulation conditions includes the initial speed 19.8 km/h, the first gear transmission ratio 6.194, the second gear transmission ratio 3.894, the third gear transmission ratio 2.260, the fourth gear transmission ratio 1.428, the fifth gear transmission ratio 1.000, the sixth gear transmission ratio 0.780, the transmission initial gear of the third gear, the rolling resistance coefficient 0.02, the road ramp angle 0 rad, and the head-on wind speed 0 km/h. The accelerator pedal position is defined in Fig. 4.

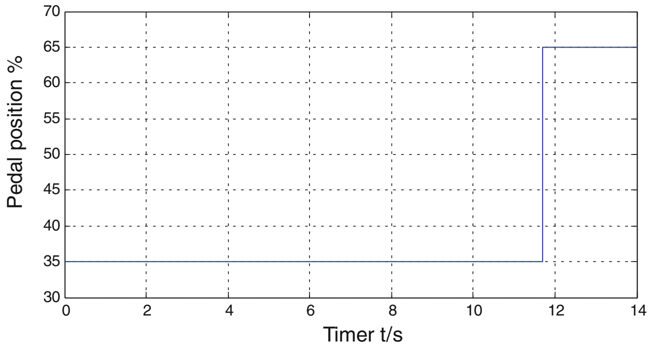

Fig. 4 Accelerator pedal position

Figure 5 shows the simulation curve that the vehicle speed, the current gear and the estimated time change with the acceleration time for the traditional shift schedule. t_{d1} is the estimating time when it does not downshift. t_{d11} is the estimating time when it reduces one gear. Figure 6 is the simulation curve that the vehicle speed, the current gear and the estimated time change with the acceleration time for the optimize shift schedule. From Fig. 5 it can be seen that the vehicle speed is 27.5 km/h when increasing the throttle suddenly and the transmission has been promoted to the fourth gear before the accelerator pedal position increases, the increased accelerator pedal position is 65 %, the transmission drops to the third gear from the fourth gear, the vehicle speed arrives at 29.2 km/h after 14 s accelerating. From Fig. 6 it can be seen that the vehicle speed is also 27.5 km/h when increasing the throttle suddenly and the transmission has been promoted to the fourth gear before the accelerator pedal position increases, the increased accelerator pedal position is 65 %, the transmission does not downshift, vehicle speed arrives at 29.6 km/h after fourteen seconds of acceleration.

The simulation results show that using the proposed optimal control strategy the driver intention can be identified, the shift times and the power break time will be reduced thereby, the comfort ability is improved, and the time that the vehicle achieves the maximum speed is reduced visibly after increasing the accelerator pedal position suddenly in the same condition.

6 Conclusion

The gear optimization control strategy of the AMT vehicles in the acceleration condition was presented according to analysis of AMT vehicles downshifting principle in this condition. The traditional control strategy is to compare with the optimal control strategy according to the simulation results from the software in-loop simulation platform of the vehicle transmission system. The results show that

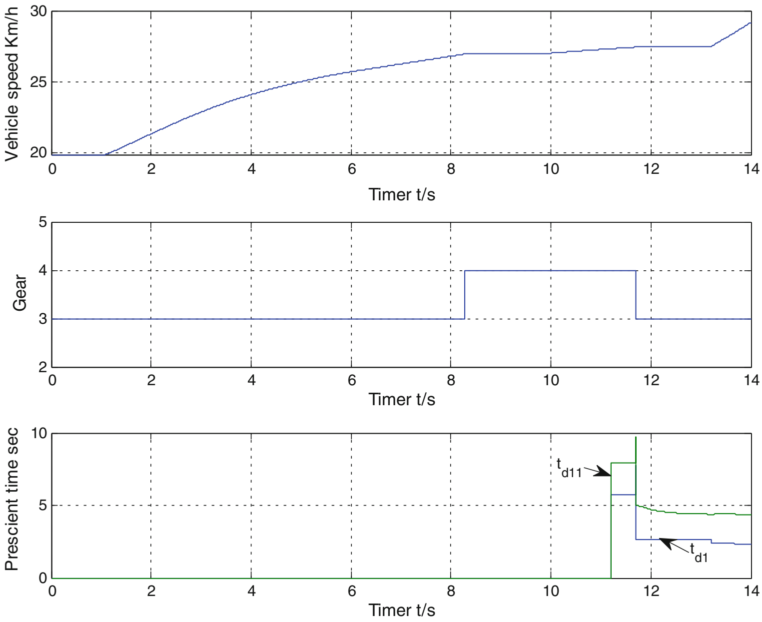

Fig. 5 Simulation curve of the traditional control strategy

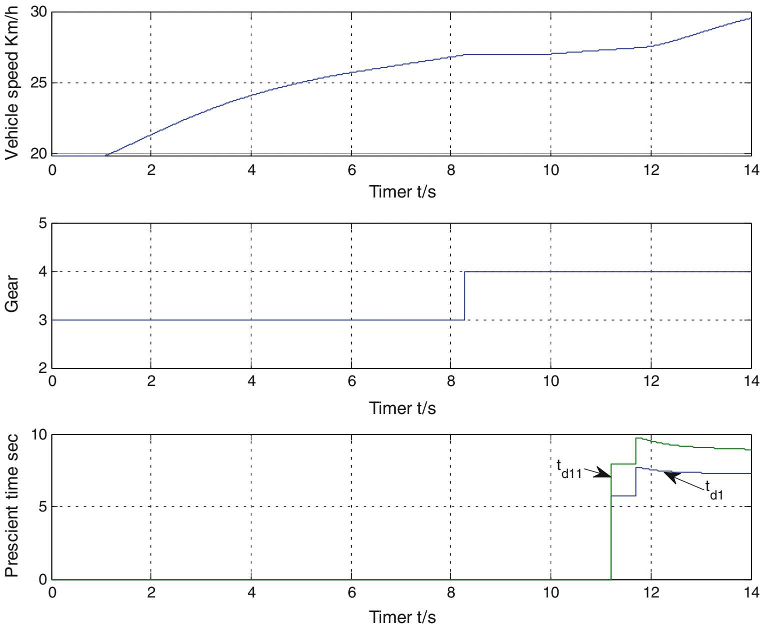

Fig. 6 Simulation curve of the optimize control strategy

the proposed optimization control strategy can identify the driver's intention, reduce the power break time and enhance comfort ability. The simulation results also verify the validation and the advantages of the proposed control strategy.

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