

Study on Dynamic Shift Schedule of Automated Mechanical Transmission in a Parallel Hybrid Electric Vehicle

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Abstract: Based on the analysis of dynamic performance of vehicles and characteristics of engine and motor, the dynamic shift schedule for parallel hybrid electric vehicle (PHEV) equipped with automated mechanical transmission (AMT) is designed. The model is built up on the MATLAB/CRUISE co-simulation platform. The simulation results show that the designed shift schedule can achieve the good dynamic performance and shifting stability in the driving process.

Introduction

Power train of hybrid electric vehicle (HEV) equipped with an AMT is made up of engine, electric motor, batteries and propulsion system. Shift schedule can't be worked out with the same way of conventional AMT vehicle [1-2]. When the vehicle is running straightly on the good road, the average running velocity reached and determined by the longitudinal external force of vehicle, is the dynamic performance of vehicle. The dynamic performance is the most basic and important in the various performances of vehicle, which can affect the transportation efficiency. There are three evaluation indexes for the dynamic performance, which are maximum velocity, acceleration time and grade ability.

In this paper, the optimal dynamic shift schedule for PHEV is designed based on the analysis of dynamic performance of vehicles and characteristics of engine and motor.

Characteristics of Engine and Motor

The switched reluctance motor with the good speed regulation and wide range of speed is adopted in this paper. According to the characteristics of engine and motor, the output torque of the power system is shown in Fig.1. Due to the assist characteristic of motor, the engine torque can be compensated. The output torque of power system is steady, especially in the low speed [3].

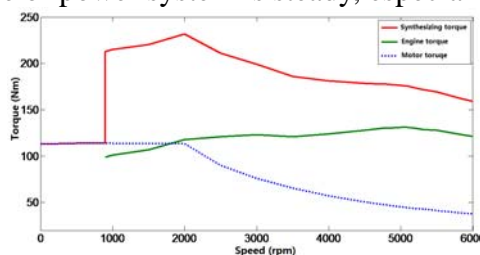


Fig. 1 The output torque of power system

Dynamic Shift Schedule

In the dynamic shift schedule, tractive characteristic of vehicle is demanded to get the best use to achieve excellent acceleration performance, grade ability and maximum velocity. There are two methods to choose the shift points. One is that in the same velocity, the value of acceleration on each gear is taken as the shift basis. The other one is that in the same velocity, the value of driving force on each gear is taken as the shift basis. As the different moment of inertia on each gear, the driving force is large and the acceleration may be small. Therefore, the acceleration is taken as the basis to design the dynamic shift schedule [4].

The driving equation of vehicle is shown as follow,

$$F_{t(n)} = \frac{T_{em} i_{g(n)} i_0 \eta_T}{r} - F_w - F_f - F_i - \delta_n \frac{du}{dt}. \quad (1)$$

Where, $F_{t(n)}$ is the driving force on the n gear ($n=1^{\text{st}}, 2^{\text{nd}}, \dots, 5^{\text{th}}$), T_{em} is the synthesizing torque of power sources, $i_{g(n)}$ is the transmission ratio on the n gear, i_0 is the main reducer ratio, η_T is the mechanical efficiency of transmission system, r is the tire radius, F_w is the air resistance, F_f is the rolling resistance, F_i is the climbing resistance, m is the gross weight, δ_n is the coefficient of the revolving mass changes to linear mass.

The equation of the coefficient of the revolving mass changes to linear mass is shown as follow,

$$\delta_n = 1 + \frac{I_f i_{g(n)}^2 i_0^2 \eta_T + \sum I_w}{mr^2}. \quad (2)$$

Where, I_w is the moment of inertia for wheel, I_f is the moment of inertia for flywheel.

When the vehicle is shifting on the straight road, the climbing resistance F_i is zero. At the shifting moment, the velocities and accelerations on the adjacent two gears are equal. Therefore, the equation of acceleration is shown as follow [5],

$$(T_{em} i_{g(n)} i_0 \eta_T / r - F_f - F_w) / \delta_n = (T_{em} i_{g(n+1)} i_0 \eta_T / r - F_f - F_w) / \delta_{(n+1)}. \quad (3)$$

In the two-parameter shift schedule, the downshift point of automatic transmission is later than upshift point, which is called downshift delay. According to change of shift delay with change of throttle opening, downshift delay can be divided into equal delay downshift, convergent downshift, divergent downshift and combination downshift. In the equal delay shift schedule, downshift delay doesn't change with change of throttle opening, and the time of shift reduces.

According to the above equations and the downshift delay theory, the optimal dynamic shift schedule can be designed as shown in Fig. 2 based on the synthesizing torque characteristics of power sources.

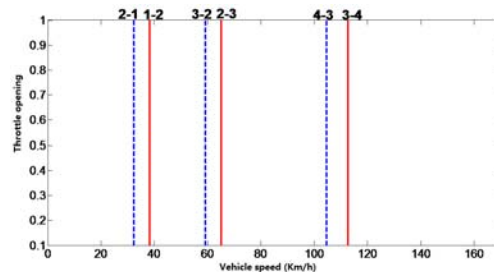


Fig.2 The optimal dynamic shift schedule

Simulation Analysis

Analysis on driving cycle. In this paper, the dynamic performance on NEDC driving cycle is simulated on MATLAB/CRUISE co-simulation platform [6]. The main parameters of vehicle and powertrain are shown in Table 1. The simulation results are shown in Fig. 3.

Table 1 The main parameters of vehicle and powertrain

Components	Parameters	Parameters Values
Vehicle	Curb weight (kg)	2325
	Frontal area (m ²)	3.042
	Drag coefficient	0.4
Motor	Maximum power/ torque	24kW/115Nm
Engine	Maximum power/ torque	82kW/131Nm
Battery	Type	lithium-ion
	Capacity /Voltage	20Ah/375V

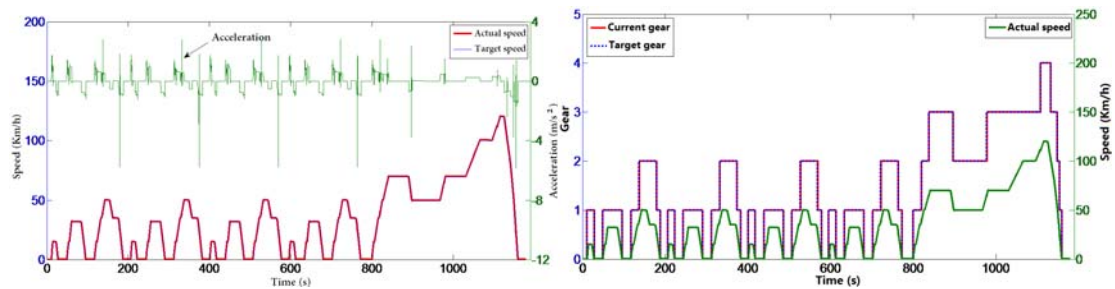


Fig. 3 The simulation results

As shown in Fig. 5 and Fig.6, the actual speed can well follow the change of target speed, and the current gear well follow the change of target gear. Due to the high shifting speed of the dynamic shift schedule and delayed shifting, tractive characteristic of vehicle can get great use. Therefore, on the driving cycle, the vehicle is driving on the low gear.

Analysis of dynamic performance. As shown in Fig. 4, through the simulation test of acceleration performance with full load, the maximum speed is 158.76 km/h. The current gear can well follow the change of target gear.

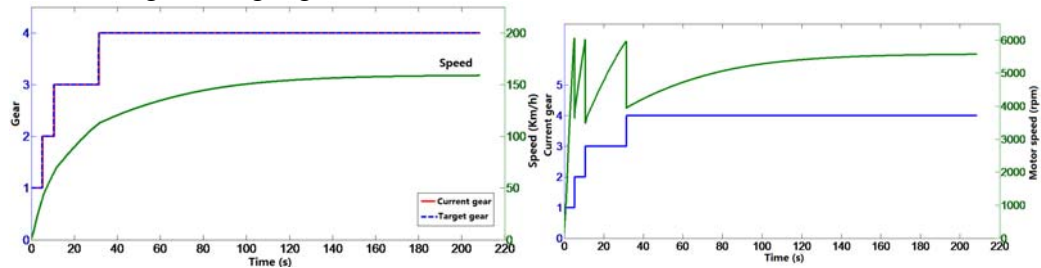


Fig. 4 Simulation results of dynamic performance

According to the range of speed on each gear and analysis of grade ability, the maximum grade ability on each gear is obtained as shown in Table 2. When the vehicle is driving on the 2nd gear, the maximum grade ability of vehicle is 45.26%. The simulation results of acceleration time are shown in Table 3. In the condition of full load, the acceleration time is 24.74s when the vehicle speed is from 0 to 100 km/h.

Table 2 The maximum grade ability on each gear

Gear	The maximum grade ability(half load)	Vehicle speed (km/h)	Engine/motor speed(rpm)
1	45.26	13.00	2031.37
2	24.30	22.00	2022.18
3	13.04	37.00	1969.82
4	7.63	57.00	2000.46

Table 3 The acceleration time

Speed (km/h)	Gear	Time (s)	Driving distance (m)	Engine/motor speed (rpm)
20	1	2.37	6.35	3125.19
40	2	5.22	30.70	3676.70
60	2	9.26	87.59	5515.04
80	3	15.87	218.19	4259.07
100	3	24.74	440.50	5323.84
120	4	39.52	899.81	4211.48
140	4	70.13	2013.28	4913.40
150	4	98.13	3145.41	5264.36

Conclusions

(1) Based on the analysis of dynamic performance of vehicles and characteristics of engine and motor, the dynamic shift schedule for PHEV equipped with AMT is designed.

(2) The model is built up on the MATLAB/CRUISE co-simulation platform. The simulation results show that the designed shift schedule can achieve the good dynamic performance and shifting stability in the driving process.

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