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Research of Optimizing Dynamic Performance Shift Schedule for Five-Geared Automatic Transmission-by-Wire in Vehicle

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***Abstract* – The shift schedule of the automatic transmission is the core technology of the control system, and the choice of control parameters directly affects the dynamic and economy of the vehicle. In this paper, the research on the optimal dynamic shift schedule of the five-speed automatic transmission of the automobile is carried out, and the method for formulating the dynamic upshift and downshift is fully analyzed, and the best shift is obtained by using MATLAB programming. At the point, the optimal dynamic shifting curve of the five-speed automatic transmission of the car was obtained, and the power of the engine was utilized to improve the dynamic performance of the vehicle.**

***Keywords* – Vehicle, Automatic Transmission-by-Wire (TBW), Dynamic Performance, Shift Schedule.**

I. Introduction

Formulation of automobile shift schedules is a key technology for the control of automatic transmissions-by-wire [1]. The shift schedule refers to the regularity of the automatic shifting time between two gears of the transmission as a function of the vehicle status parameters. It directly influences the matching of the performance of the transmission system and the optimization of the overall performance [2]. The vehicle's power performance can be improved, fuel consumption can be reduced, and comfort and durability can be improved.

The mechanical and hydraulic systems are replaced in X-By-Wire technology by a series of operation that is based on wires and electronic controller. Driver's steering movements are transmitted to electrical signals through the sensors and electronic control unit generates control signals for driving actuators according to the input signals [3]. The optimizing dynamic performance shift schedule for the five-geared TBW in electric vehicle is researched. The shift schedule is theoretically analyzed, the shift point speed between two gears is got by using MATLAB programming, at last the optimizing dynamic performance shift schedule curve is obtained, the vehicle's dynamic performance is improved.

II. Vehicle Parameters

Nowadays, with the rapid development of the automobile industry, more and more automobiles use automatic transmissions instead of the conventional manual transmissions [4]. In this paper, a five-speed automatic transmission is designed which is based on a certain model. The vehicle parameters of the selected target models are shown in Table 1.

Table 1. The basic parameters of vehicle

Parameter	Numerical	Unit
L*W*H	4508/1760/1715	mm
Wheelbase	2790	--
Curb Weight	1320	kg
Full quality	1690	kg
Radius of the wheel	0.296	m
Frontal area A	1.96	m^2
Air resistance Coefficient C_D	0.35	--
Train efficiency η_T	0.98	--
Main reduction ratio i_0	4.3	--
Ti_1	3.857	--
Ti_2	2.104	--
Ti_3	1.339	--
Ti_4	1	--
Ti_5	0.838	--

III. Engine Operating Characteristics

A. *Torque Characteristics of the Engine*

The optimal dynamic shift schedule of the vehicle is based on the torque characteristics of the engine and is obtained through corresponding calculations. Therefore, the accurate drawing of the engine torque characteristic surface will directly limit the accuracy of the optimal dynamic shift schedule [5]-[6]. In order to ensure the formulation of the dynamic shift schedule, it is necessary to establish an engine torque output model that meets the accuracy requirements. The engine torque characteristic surface can be obtained by interpolation fitting the engine steady state experimental data. The torque characteristic surface represents the output torque value of the engine in any state, and is fitted by MATLAB software interpolation. The engine steady-state torque characteristic surface can be obtained, as shown in Figure 1.

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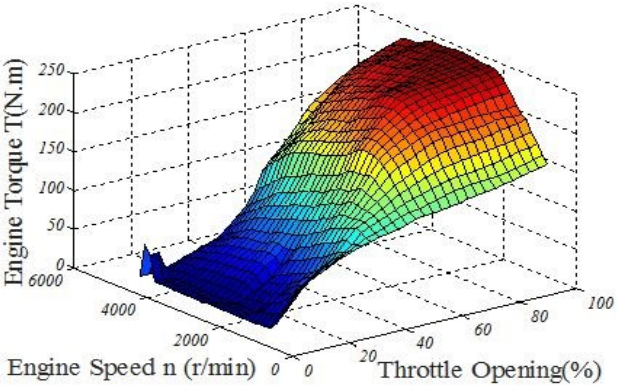

Fig. 1. The engine's torque characteristic curved.

B. *The Formulation of Dynamic Shift Schedule*

The dynamic shift schedule is that the vehicle can fully exert the traction characteristics of the vehicle during driving, and maximize the power of the engine. So that the vehicle can always obtain the maximum acceleration before and after the shifting, and have a good acceleration performance during driving, a strong climbing ability and a higher average speed.

According to the number of shift control parameters, the shift schedule can be divided into single parameter shift schedule, double parameters shift schedule and three parameters shift schedule [7]-[8]. In this paper, the double parameter shift schedule is adopted the control parameters that are the speed and the opening of accelerator pedal. According to the difference of shifting speed, the double parameters shift schedule can be divided into equal delay, convergent, divergent and combination which is shown as figure 2.

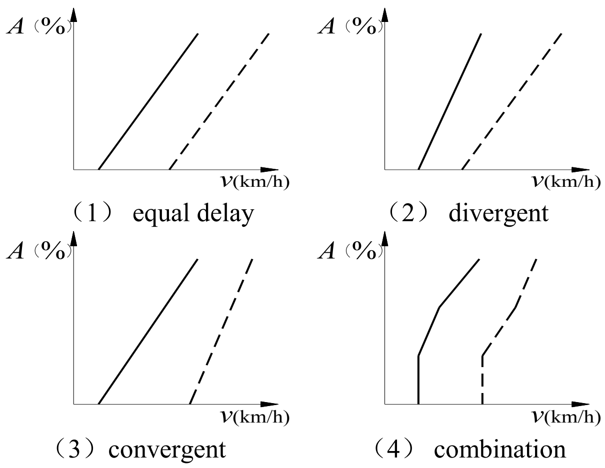

Fig. 2. The classification of the shift schedule.

1) *Dynamic Upshift Pattern*

To ensure the optimizing dynamic characteristics of electric vehicle, the intersection of two adjacent gear acceleration curves under the same accelerator opening is used as the optimizing dynamic performance shifting point, which is

$$\frac{dv}{dt_n} = \frac{dv}{dt_{(n+1)}} \tag{1}$$

The vehicle runs with certain acceleration drove by motor and the transmission system, and it overcomes rolling resistance, air resistance, grade resistance and acceleration resistance. The electric vehicle's running equation is [9]:

$$F_t = F_f + F_w + F_i + F_j \tag{2}$$

Where, F_t is the driving force; F_f is rolling resistance; F_w is the air resistance; F_i is the grade resistance; F_j is the acceleration resistance.

This can also be written as:

$$\frac{T_m i_g i_0 \eta_T}{r} = mgf + \frac{C_D A v^2}{21.15} + mgi + \delta m \frac{du}{dt} \tag{3}$$

Kinematic differential equation is:

$$\delta m \frac{du}{dt} = \frac{T_m i_g i_0 \eta_T}{r} - mgf - \frac{C_D A v^2}{21.15} - mgi \tag{4}$$

This can also be written as:

$$\delta m \frac{du}{dt} = \frac{T_m i_g i_0 \eta_T}{r} - \frac{C_D A v^2}{21.15} - mg\psi \tag{5}$$

Where: δ is the correction coefficient of rotating mass; m is the full mass; v is driving speed; T_m is motor dynamic output torque; i_g is the transmission ratio; i_0 is the main reducer gear ratio; η_t is the transmission efficiency; r is wheel rolling radius; g is the acceleration of gravity; f is rolling drag coefficient; C_D is air resistance coefficient; A as windward area; i is the road gradient; Ψ is road resistance coefficient.

Simultaneous (1) and (5), we have:

$$\frac{\frac{T_m i_g^n i_0 \eta_T}{r} - \frac{C_D A v^2}{21.15} - mg\psi}{\delta_n} = \frac{\frac{T_m i_g^{n+1} i_0 \eta_T}{r} - \frac{C_D A v^2}{21.15} - mg\psi}{\delta_{n+1}} \tag{6}$$

Where: δ_n and δ_{n+1} are rolling resistance coefficients of transmission n gear and n+1 gear.

The rolling resistance coefficient δ is mainly affected by the inertia of the flywheel (I_f), the inertia of wheel (I_w) and the driveline gear ratios, the relationship is

$$\delta = 1 + \left(\frac{1}{m}\right)\frac{\sum I_w}{r^2} + \left(\frac{1}{m}\right)\frac{I_f i_g^2 i_0^2 \eta_T}{r^2} \tag{7}$$

As we all know, the whole vehicle mass moment of inertia and crankshaft flywheel mass moment of inertia is not easily obtained, therefore according to experience, this article uses approximate calculation, that is:

$$\delta = 1 + \delta_1 + \delta_2 i_g^2 \tag{8}$$

Wherein, δ_1 、 δ_2 are related to the vehicle model, $\delta_1 = 0.05 \sim 0.07$ 、 $\delta_1 = 0.03 \sim 0.05$.

The engine partial load characteristic curve can be recognized as a function about engine speed and throttle percentage under the engine output torque. The engine experimental data obtained can be fitted to the data by the least square method to obtain an engine numerical model that satisfies the accuracy. After fitting, we know that the engine torque characteristic function $T_m = f(n_e)$ is quadratic curve, that is:

$$T_m = e_1 n^2 + e_2 n + e_0 \tag{9}$$

The relationship between motor speed and vehicle travelling speed is:

$$v = 0.377 \frac{rn}{i_g^n i_0} \tag{10}$$

Relationship between each gear's driving force F_t^n and the motor output torque is:

$$F_t^n = \frac{T_m i_g^n i_0 \eta_T}{r} \tag{11}$$

Simultaneous (9) ~ (11), the expression for each gear's driving force F_t^n is:

$$F_t^n = A_n v^2 + B_n v + C_n \tag{12}$$

Simultaneous and simplify above mentioned expression, a quadratic equation with one unknown about dynamic shift speed v is gotten, that is:

$$a_n v^2 + b_n v + c_n = 0 \tag{13}$$

Solve the equation, the speed gotten is n gear and n+1 gear's shift speed, that is:

$$v = \frac{-b_n \pm \sqrt{b_n^2 - 4a_n c_n}}{2a_n} \tag{14}$$

In a certain throttle opening, compare the obtained positive root with the gear's maximum speed $v_{n\max}$ and the minimum speed of the next gear $v_{(n+1)\min}$, if $v_{(n+1)\min} < v_n < v_{n\max}$, so v_n is the optimizing dynamic shifting point speed.

Table 2. Dynamic up-shifting points.

Throttle Opening	Speed v(km/h)			
	1-2	2-3	3-4	4-5
10%	8.36	14.69	22.29	30.27
22%	13.87	21.34	30.18	40.05
29%	16.10	24.30	33.75	44.75
38%	16.90	26.01	35.64	49.35
45%	17.89	27.72	38.83	53.12
54%	21.25	29.43	46.86	63.61
62%	23.16	32.82	51.46	69.72
73%	25.28	35.36	55.53	75.25
85%	27.69	35.56	59.84	81.27
100%	28.65	37.57	60.90	82.97

Finally, the optimizing dynamic performance shift schedule of vehicle is developed as shown in Fig. 3.

Fig. 3. The optimizing dynamic performance shift schedule.

2) *Dynamic Downshift Pattern*

The optimal power upshift speed is obtained by selecting the appropriate convergence factor to obtain the corresponding dynamic downshift speed. For the determined shift overlap range, neither too small nor too large. If it is too small, it will cause the shift cycle when the vehicle is downshifted [10]. To avoid this happening, the vehicle speed at the downshift point should be 2~8km/h lower than the corresponding upshift speed. If the overlap range is too large, it is not conducive to improving the power of the vehicle and the economy of the engine. At this time, the speed of the downshift point should not be less than the minimum vehicle speed for the corresponding gear position. The shift schedule can be expressed using the divergence or the convergence degree relationship A as following expression:

$$A_n = \frac{v_n \uparrow - v_{n+1} \downarrow}{v_n \uparrow} \tag{15}$$

Where: A_n is vehicle shifting divergence and convergence degree; $v_n \uparrow$ is the corresponding upshift point speed when the vehicle is in full open throttle state; $v_{n+1} \uparrow$ is the corresponding downshift point speed when the vehicle is in full open throttle state;

When engine throttle opening is [0, 22%], select the lowest speed under this gear as the vehicle power downshift point; When engine throttle opening is [22%, 38%], use such delay law to downshift, usually downshift speed is 2～8km/h lower than the upshift speed. In this paper, when the

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throttle opening is [22%, 38%], set the downshift speed 5km/h lower than the upshift speed; when the throttle opening is [38%, 100%], choose a smaller vehicle shift divergence degree A_n to guaranty a favorable dynamic performance. Optimizing dynamic down-shifting points obtained are shown in Table 3.

Table 3. Dynamic down-shifting vehicle speed.

Engine throttle opening	Vehicle speed （km/h）			
	2-1	3-2	4-3	5-4
10%	5.58	9.79	14.86	20.18
22%	8.87	16.34	25.18	35.05
29%	11.10	19.30	28.13	38.75
38%	13.52	20.81	28.51	39.48
45%	14.31	22.18	31.06	42.50
54%	17.03	23.54	37.49	50.89
62%	18.53	26.26	41.17	55.78
73%	20.22	28.29	44.42	60.20
85%	22.15	28.45	47.87	65.03
100%	22.92	30.06	48.72	66.38

At last, the dynamic down-shifting regularity curve is gotten as shown in Fig. 4.

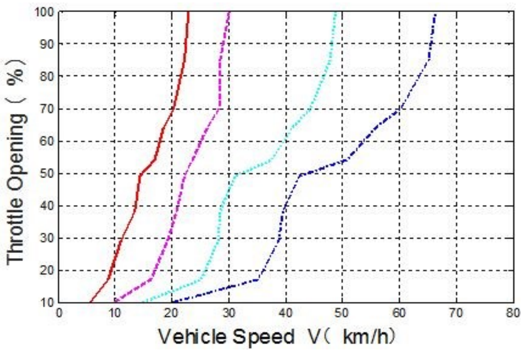

Fig. 4. Dynamic performance down-shifting regularity curve.

IV. Conclusion

In this paper, the five-geared automatic transmission-by-wire in vehicle was introduced briefly. Then, the optimizing dynamic performance shift schedule of the five-geared automatic transmission-by-wire in vehicle is theoretical analyzed and researched, and the mathematical model of the optimizing dynamic shifting point speed is obtained. The optimizing dynamic performance shift schedule for the five-geared automatic transmission-by-wire is developed. The shift schedule could improve the vehicle performance, and increasing driving range. This research laid foundation for the latter part of the real vehicle tests.

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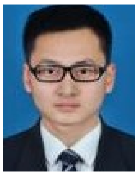
Authors' Profiles



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