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Research on Optimal Dynamic Shift Schedule of Six-Geared Automatic Transmission for Automobile

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***Abstract*— To meet the dynamic requirements of the automobile, the optimal dynamic shift schedule of the six-speed automatic transmission for automobiles is studied in this paper. Firstly, the maximum acceleration as the basis for formulation and the vehicle speed and accelerator pedal opening as variables of control parameter were selected, and then the vehicle speed at the intersection of the acceleration between the two adjacent gears as the speed of the up-shift point of the gear was taken. Finally, we performed polynomial fitting interpolation for each shift point by using Polynomial of MATLAB software to obtain the best dynamic shift schedule curve. The results show that it can effectively play the power of the engine and improve the dynamic performance of the vehicle.**

***Index Terms*— Dynamic Performance; Shift Schedule; Acceleration; Shift Point; Automatic Transmission**

I. Introduction

The shift schedule refers to the regular curve of the automatic shifting time between adjacent two gears as the control parameters change, and it is the key technology of automatic transmission. The shift schedule can divide into dynamic shift schedule, economic shift schedule and comprehensive intelligent shift schedule according to shift targets [1]. The shift schedule also can be divided into single parameter shift schedule, double parameters shift schedule, three parameters shift schedule and multi parameters intelligent shift schedule according to the control shift parameters. The establishment of single parameter shift schedule mainly uses vehicle speed as a control parameter. Because of the determination of the shifting point has no relationship with the accelerator pedal opening so that the driver cannot directly interfere with the shifting time. And it has great limitations, so it is rarely used at present. There are many control parameters for the double parameters shift schedule. The main choice is the accelerator pedal opening and the vehicle speed [2]. The three parameters shift schedule based on the double parameters shift schedule control parameters add acceleration as the control parameter, and the control process is more complicated. An excellent shift schedule can effectively improve the vehicle's dynamic performance, reduce vehicle fuel consumption, and increase its safety and comfort [3].

In order to improve the dynamic performance of vehicles, and obtain the best dynamic shift schedule, the double parameters shift schedule which uses the vehicle speed and accelerator pedal opening as control parameter variables was selected and the maximum acceleration as the basis for formulation was taken in this paper. We obtained shift points by MATLAB programming, and finally obtained the best dynamic shift schedule for the six-geared automatic transmission of the vehicle, which improved the dynamic performance of the vehicle.

II. VEHICLE PARAMETERS

In this paper, the optimal dynamic shift schedule of the six-geared automatic transmission for automobiles is studied based on a compact automobile. The main vehicle parameters are shown in Table 1.

Tab.1 Main vehicle parameters

Parameter	Numerical	Unit
L * W * H	4440/1670/1783	mm
Machines efficiency	0.93	--
Curb Weight	1270	Kg
Air resistance coefficient	0.36	--
Rolling resistance coefficient	0.015	--
Frontal area	1.89	m^2
Main reduction ratio	3.727	--
T r1	3.839	--
T r2	2.011	--
T r3	1.4003	--
T r4	1	--
T r5	0.851	--
T r6	0.785	--
Reverse gear ratio	4.151	--

III. CHARACTERISTICS OF THE ENGINE

As the power source of the vehicle, the performance of the engine will directly affect the performance of the vehicle [4]. The engine characteristics mainly include the relationship between the main engine performance indicators (dynamic performance, economic performance, etc.) changes with the operating conditions [5]. In this paper, precise engine torque characteristics are required to develop the best dynamic shift schedule. The engine torque characteristic refers to the relationship between the output torque of the engine and the engine speed and the accelerator pedal opening. We can obtain the torque characteristic surface 3D map by fitting and interpolating the experimental data of the steady-state torque characteristic of the engine in the MATLAB software, as shown in Figure 1. According to the 3D map, the output torque of the engine can be obtained at different speeds and different accelerator pedal opening.

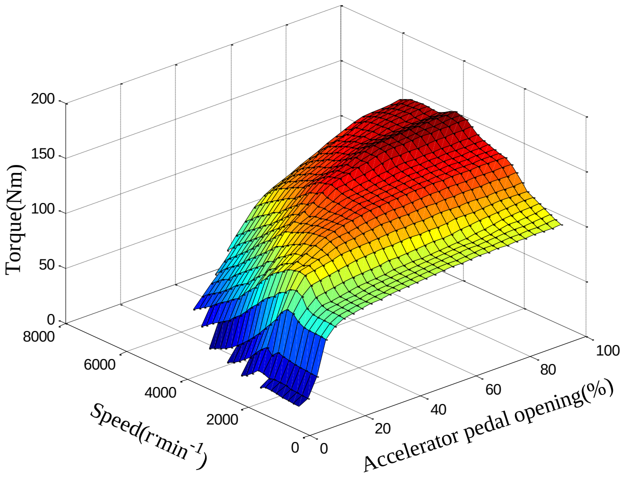

Fig.1 The map of torque characteristic

IV. FORMULATE THE OPTIMIZING DYNAMIC SHIFT SCHEDULE

The formulating principle of the dynamic shifting curve is to ensure that the vehicle is geared with good power requirements, and the power of the engine and the traction characteristics of the vehicle can be maximized [6]-[7]. In this paper, the determination of the shift point is based on the maximum acceleration of the vehicle. Under the same throttle opening, the speed of the intersection of the speed-acceleration curves between two adjacent gears is used as the shift of the corresponding gear point. That is:

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

In turn, the best up-shift points for each gear obtained, and then the speed of the downshift point of each gear can be obtained by the delay of the constant speed difference. Finally, perform polynomial fitting interpolation by using MATLAB software to obtain the best dynamic shift schedule curve.

During the driving process, the automobile can be analyzed by force analysis. Under certain driving force, the vehicle overcomes certain rolling resistance, air resistance, grade resistance and acceleration resistance, and drives at a certain speed. The driving equation is [8]:

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

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

The relationship between vehicle driving force and engine torque is satisfied with:

$$F_t = \frac{T_e i_g i_0 \eta_t}{r} \tag{3}$$

Where: i_g is the gear ratio of the corresponding gear, i_0 is the gear ratio of the main reducer, η_t is the driveline efficiency, r is the wheel radius.

Simultaneous (2) and (3), and expressed as differential form, we have

$$\frac{T_e i_g i_0 \eta_t}{r} = Gf\cos\alpha + \frac{C_D A}{21.15}u^2 + G\sin\alpha + \delta m\frac{du}{dt} \tag{4}$$

Where: m is the full mass, G is the gravity acting on the vehicle, f is rolling drag coefficient, α is road grade angle, C_D is air resistance coefficient, A is windward area, u is driving speed, δ the correction coefficient of rotating mass.

Where in, $\delta = 1 + \frac{1}{m}\frac{\sum I_W}{r^2} + \frac{1}{m}\frac{I_f i_g^2 i_0^2 \eta_t}{r^2}$, Where: I_W is the inertia of wheel, I_f is the inertia of the flywheel. According to the gear position and the total gear ratio, the value δ of each gear can be determined in the vehicle rotation mass conversion coefficient map[8], the value is respectively $\delta_1 = 1.31$, $\delta_2 = 1.09$, $\delta_3 = 1.07$, $\delta_4 = 1.05$, $\delta_5 = 1.04$, $\delta_6 = 1.03$.

Since the subject is that the vehicle is driving on a normal road, its grade angle is not large. that is $\cos\alpha \approx 1, \sin\alpha \approx \tan\alpha$, equation (4) can be simplified to:

$$\frac{T_e i_g i_0 \eta_t}{r} = Gf + \frac{C_D A}{21.15}u_a^2 + Gi + \delta m\frac{du}{dt} \tag{5}$$

Equation (5) can be expressed as the equation of acceleration:

$$\frac{du}{dt} = \frac{1}{\delta m}\left(\frac{T_e i_g i_0 \eta_t}{r} - Gf - \frac{C_D A}{21.15}u_a^2 - Gi\right) \tag{6}$$

According to the engine torque characteristic curve, the relationship between engine torque, speed and throttle opening can be obtained. That is:

$$T_e = f(n, \alpha) \tag{7}$$

In order to improve the accuracy of the results, the relationship between engine torque and speed can be fitted to a quadratic function at the same throttle opening. The functional relationship is

$$T_e = t_1 n^4 + t_2 n^3 + t_3 n^2 + t_4 n + t_5 \tag{8}$$

Where: t_1, t_2, t_3, t_4, t_5 are the constant coefficients.

Also know that the relationship between engine speed and vehicle speed is [6],

$$u = 0.377\frac{rn}{i_g i_0} \tag{9}$$

Equation (9) can also be written as:

$$n = \frac{i_g i_0 u}{0.377 r} \tag{10}$$

Simultaneous (7) ~ (10), we can obtain the relationship between the engine torque and the speed of the vehicle under the same throttle opening, that is:

$$T_e = f\left(\frac{i_g i_0 u}{0.377 r}\right) \tag{11}$$

The above analysis shows that the vehicle speed can be expressed as a function of the rotational speed, and at the same throttle opening, the torque can be expressed as a function of the rotational speed, then the engine torque can be expressed as a function of the vehicle speed, therefore, the equation of acceleration only contains an unknown number of vehicle speeds, that is, the acceleration can be expressed as a function of the vehicle speed.

Based on the above analysis, the shift point equation can be obtained as:

$$\frac{1}{\delta_n m}\left(\frac{T_e i_g^n i_0 \eta_t}{r} - Gf - \frac{C_D A}{21.15}u^2 - Gi\right) = \frac{1}{\delta_{n+1} m}\left(\frac{T_e i_g^{n+1} i_0 \eta_t}{r} - Gf - \frac{C_D A}{21.15}u^2 - Gi\right) \quad (12)$$

Where: δ_n and δ_{n+1} are rolling resistance coefficients of transmission n gear and $n+1$ gear. i_g^n and i_g^{n+1} are respectively n and $n+1$ gear ratios.

According to the programming in MATLAB, the curve between the acceleration and the vehicle speed of each gear can be obtained under different accelerator pedal opening, and the shift points of each gear also can be obtained. The following is an example of taking the speed of each gear up-shift point under the 100% accelerator pedal opening as an example for detailed description. Firstly, the engine torque and the speed of the accelerator pedal opening are curve-fitted to obtain their functional relationship curves. Then, combined with the above modeling of the up-shift point equation, after programming, the curve of the acceleration and speed of the first gear and the second gear can be obtained, as shown in Figure 2. The vehicle speed at the intersection point is the up-shift point at first and second gear under 100% accelerator pedal opening in the figure.

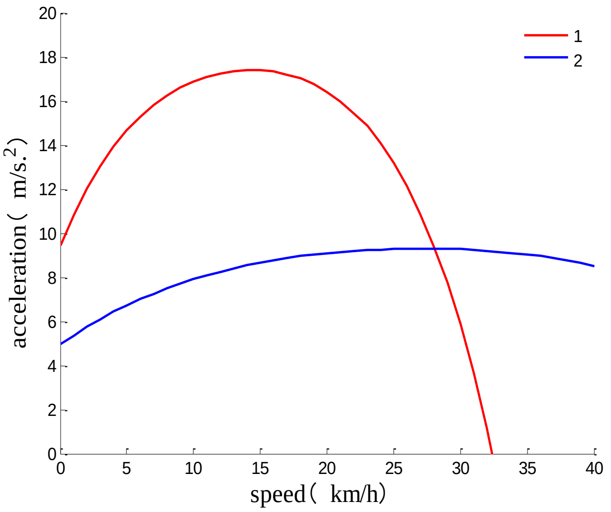

Fig.2 Up-shift point of first gear

In the same way, the up-shift points of each gear position under the 100% accelerator pedal opening can be obtained, and the curves of the acceleration-vehicle speed of each gear positions are appropriately simplified and partially enlarged to obtain the up-shift point under the accelerator pedal opening, which is shown in Figure 3.

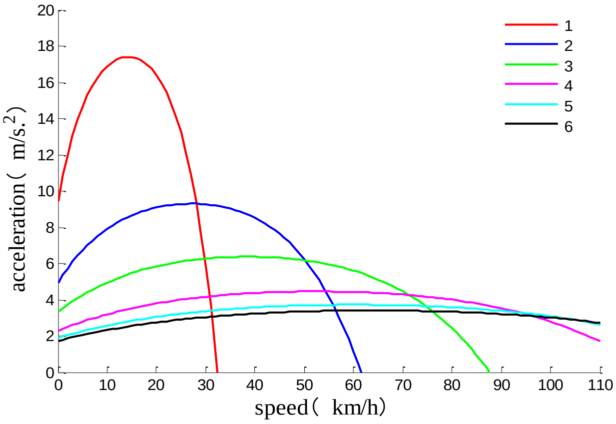

Fig.3 Up-shift point of each gear

Similarly, the speed of the up-shift point of each gear can be taken out under the accelerator pedal opening is 10%, 20%, 30%, 45%, 70%, 80%, 100% in this paper. The up-shift point speeds of each gear are summarized in Table 2.

Tab.2 Dynamic up-shifting points

Accelerator pedal opening	Speed (km/h)				
	1-2	2-3	3-4	4-5	5-6
10%	16.15	24.68	30.94	43.67	62.51
20%	19.60	29.53	43.68	54.64	78.74
30%	23.08	43.01	65.09	72.50	89.12
45%	25.51	47.13	67.53	90.06	105.39
70%	27.47	49.70	70.82	93.18	105.45
80%	28.35	49.96	71.08	93.41	105.45
100%	28.08	50.24	71.29	93.65	105.45

According to the data in Table 2, the polynomial fitting interpolation of the above shift points can be performed by using Polynomial of MATLAB software, and the optimal dynamic up-shifting curve can be drawn, as shown in Figure 4.

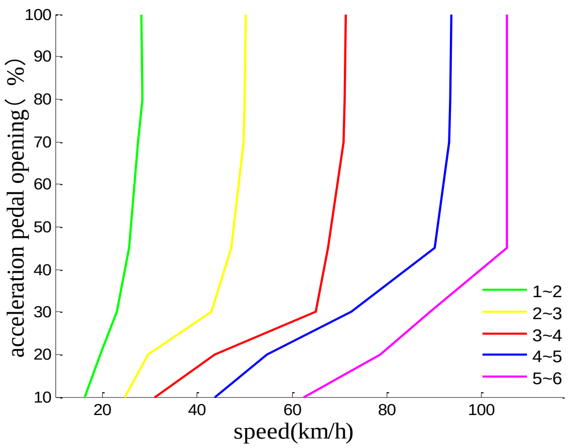

Fig.4 Curve of dynamic up-shift schedule

In the development of dynamic downshift speed, in order to ensure dynamic requirements and get the large output torque, the speed of dynamic shift points is relatively large, called delayed shifting [9]-[11]. Therefore, in order to avoid the occurrence of cyclic shift, the 4.3km/h constant speed difference shift delay is adopted as the speed point at the time of downshifting based on the up-shift shift point. Finally, polynomial fitting interpolation is performed on the up-shift and downshift speeds of each gear position under different accelerator pedal opening respectively, and the optimal dynamic shifting curve is obtained, as shown in Figure 5.

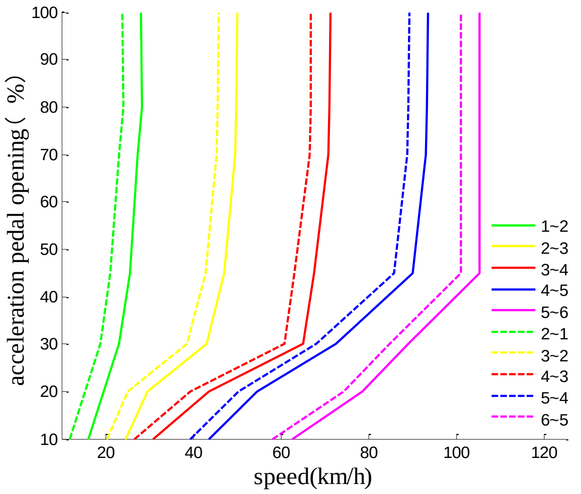

Fig.5 Curve of dynamic shift schedule

V. CONCLUSION

In this paper, the optimal dynamic shift schedule of six-geared automatic transmission for vehicle has analyzed and researched. According to the torque characteristics of the engine, we establish the mathematical model of the best dynamic shift point speed which is based on the maximum acceleration. Then, we use the MATLAB programming solution to obtain the best dynamic shift speeds of two adjacent gears with different accelerator pedal opening and apply the best dynamic shift schedule by fitting and interpolating the shift point speed of each gear. The results show that the best dynamic shift schedule of the six-geared automatic transmission which obtained by this study is conducive to improving the dynamic performance of the vehicle and fully utilizing the power of the engine, laying a theoretical foundation for the vehicle test in the later period.

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