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The Research on Economical Shift Schedule of Vehicle based on Specific Fuel Consumption

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Abstract **– Shift schedule is one of the key technologies of automatic transmission control of automobiles, which have a great influence on vehicle performance of the vehicle. In this paper, the optimal economic shift schedule of the six-speed automatic transmission for automobiles is studied. Firstly, the minimum specific fuel consumption 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 fuel consumption 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 economic shift schedule curve.**

Keywords **– Economical Shift Schedule; Automatic Transmission; Specific Fuel Consumption; Shift Point.**

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 [1]. It affects the performance of the entire vehicle and directly affects the dynamic and economic performance of the vehicle. An excellent shift schedule can effectively improve the vehicle's dynamic performance, reduce vehicle fuel consumption, and increase its safety and comfort.

The shift schedule can divide into economic shift schedules, dynamic shift schedules and comprehensive intelligent shift schedules according to shift targets. 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 parameter [2]. 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. Petrov has first proposed the many control parameters of the double parameters shift schedule in 1963, which mainly chosen accelerator pedal opening and speed as the main control parameters [3]-[4]. 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.

II. Vehicle Parameters

In this paper, based on a small car, the optimal economic shift schedule of the six-speed automatic transmission for automobiles is studied. The main vehicle parameters are shown in Table 1.

Table 1. Main vehicle parameters.

parameter	numerical	unit
curb weight	1270	kg
rolling resistance coefficient	0.015	--
air resistance coefficient	0.36	--
frontal area	1.89	m^2
maximum speed	150	km/h
t_{r1}	3.839	--
t_{r2}	2.011	--
t_{r3}	1.4003	--
t_{r4}	1	--
t_{r5}	0.851	--
t_{r6}	0.785	--
final drive ratio	3.727	--
machines efficiency	0.93	--

III. Operating Characteristics of the Engines

As the power source of the vehicle, the performance of the engine will directly affect the performance of the vehicle. The engine characteristics mainly include the relationship between the main engine performance indicators (dynamic performance, economic performance, etc.) changes with the operating conditions [5]-[6]. In this paper, precise engine torque characteristics and fuel consumption characteristics are required to develop the best economic 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, and the fuel consumption characteristic refers to the relationship between the engine fuel consumption and the speed and the output torque. 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 obtain at different speeds and different accelerator pedal opening. We can obtain the fuel consumption characteristic 3D map by fitting and interpolation the experimental data of the engine's fuel consumption characteristic, as shown in Figure 2. According to the 3D map, the fuel consumption of the engine can obtain at different speeds and different output torque.

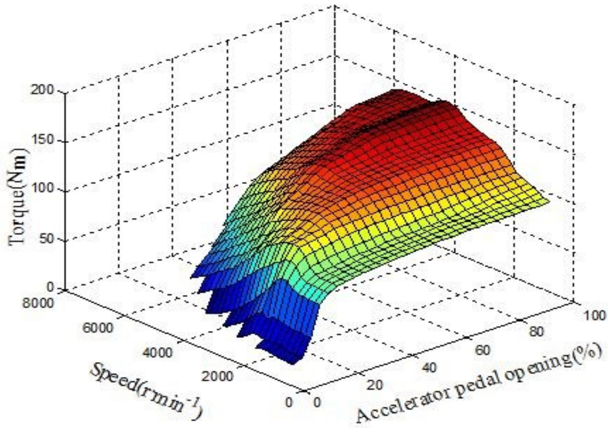

Fig. 1. Torque characteristic diagram.

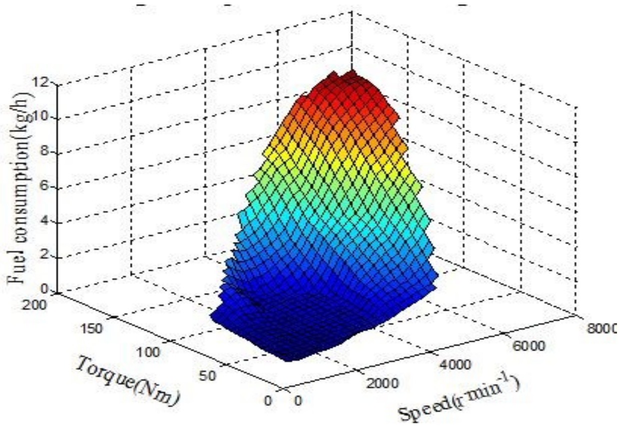

Fig. 2. Fuel consumption characteristic map.

IV. Formulate the Optimal Economic Shift Schedule

The economic shift schedule refers to the shifting schedule in which the shifting point of the vehicle meets the economic requirements is ensured, and the fuel consumption is minimized as much as possible [7]. In order to obtain the best shifting point, select the minimum specific fuel consumption as the basis for formulation, and then take the vehicle speed at the intersection of the fuel consumption between the two adjacent gears as the speed of the up-shift point of the gear in the specific fuel consumption-vehicle speed curve. That can express as,

$$g_{e(n)} = g_{e(n+1)} \tag{1}$$

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

The relationship between specific fuel consumption g_e and fuel consumption B and power P_e of engine is,

$$g_e = \frac{B}{P_e} \times 10^3 \tag{2}$$

And the relationship between power, torque and speed of engine is,

$$P_e = \frac{T_e n_e}{9550} \tag{3}$$

According to formula (2) and formula (3), combined with the fuel consumption characteristics of the engine, the relationship between engine specific fuel consumption and engine speed and torque can be obtained. It is,

$$g_e = g_e(n_e, T_e) \tag{4}$$

Since the corresponding relationship between the engine's specific fuel consumption and its speed and torque is relatively complex. In order to increase the accuracy, it can be performed polynomial fitting interpolation into a binary five-power function, and the expression is,

$$g_e = f\left(T_e, n_e\right) = g_0 + g_{01}n_e + g_{10}T_e + \cdots + g_{50}T_e^5 \tag{5}$$

Where, $g_0, g_{01}, g_{10}, \cdots$ are constant coefficient.

And because the relationship between engine speed and vehicle speed is [8],

$$u_a = 0.377 \cdot \frac{rn_e}{i_g^n i_0} \tag{6}$$

Where, u_a is speed, r is wheel radius, i_g^n is current gear ratio, i_0 is final drive ratio.

Convert equation (6) to

$$n_e = \frac{i_g^n i_0 u_a}{0.377 \cdot r} \tag{7}$$

According to the torque characteristics of the engine, as the same accelerator pedal opening α, the relationship between engine torque and speed can be expressed. It is,

$$T_e = T_e(n_e, \alpha) \tag{8}$$

That is, at the same accelerator pedal opening, the relationship between engine torque and speed can be fitted to the biquadratic function $T_e = T_e(n_e)$ is

$$T_e = t_1 n_e^4 + t_2 n_e^3 + t_3 n_e^2 + t_4 n_e + t_5 \tag{9}$$

Where, t_1, t_2, t_3, t_4, t_5 are constant coefficient.

Thus, the simultaneous (5) to (9) can obtain the relationship between the engine specific fuel consumption and the rotational speed and the accelerator pedal opening, that is,

$$g_e = g_e(n_e, \alpha) \tag{10}$$

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Substituting equation (7), the relationship between engine specific fuel consumption and vehicle speed and accelerator pedal opening is

$$g_e = g_e(\frac{i_g^n i_0 u_a}{0.377 \cdot r}, \alpha) \quad (11)$$

It can be seen from the above analysis that under the same accelerator pedal opening, the torque can be expressed as a function of the rotational speed, and the relationship between the engine specific fuel consumption and the engine speed and torque can be expressed as the relationship between the engine specific fuel consumption and the rotational speed. In other words, it can be expressed as the relationship between the engine specific fuel consumption and the vehicle speed, which is $g_e = g_e(\frac{i_g^n i_0 u_a}{0.377 \cdot r})$.

As is known to all, the gear ratios of the various gear positions are different. In summary, the up-shifting point equation is,

$$g_{e(n)}(\frac{i_g^n i_0 u_a}{0.377 \cdot r}) = g_{e(n+1)}(\frac{i_g^{n+1} i_0 u_a}{0.377 \cdot r}) \quad (12)$$

According to the programming in MATLAB, the curve between the specific fuel consumption 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 upshift 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 and the engine specific fuel consumption and the speed and torque are respectively curve-fitted to obtain their functional relationship curves. Then, combined with the above modeling of the upshift point equation, after programming, the curve of the specific fuel consumption and speed of the first gear and the second gear can be obtained, as shown in figure 3. 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.

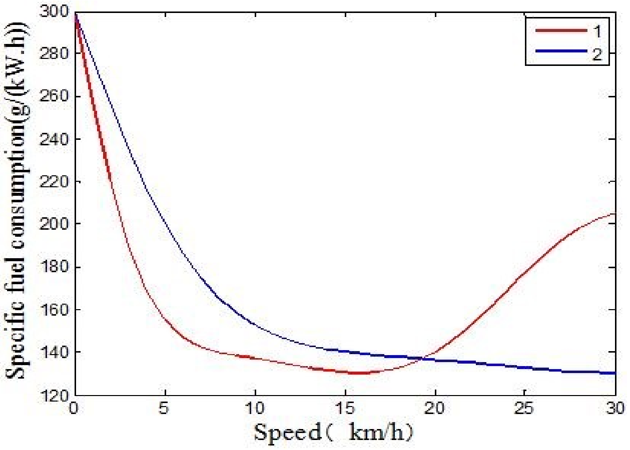

Fig. 3. Upshift point of first gear.

In the same way, the upshift points of each gear position under the 100% accelerator pedal opening can be obtained, and the curves of the specific fuel consumption-vehicle speed of each gear positions are appropriately simplified and partially enlarged to obtain the upshift point under the accelerator pedal opening, which is shown in figure 4.

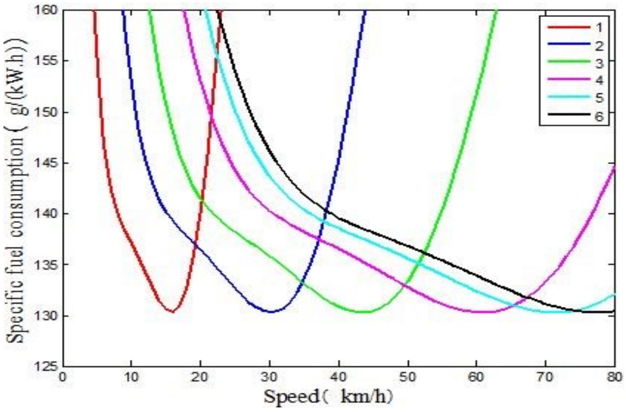

Fig.4 Upshift point of each gear

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

Table 2. Economical up-shifting points.

Accelerator pedal opening	Speed (km/h)				
	1-2	2-3	3-4	4-5	5-6
10%	11.30	19.33	30.29	39.14	45.98
20%	16.09	24.05	35.38	45.05	51.43
30%	17.01	26.35	38.45	47.78	55.58
45%	17.72	28.86	39.22	53.68	60.82
70%	18.19	33.84	49.61	65.49	74.47
80%	19.32	34.18	49.61	65.42	74.35
100%	19.92	34.56	49.61	65.33	74.19

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 economic upshifting curve can be drawn, as shown in Figure 5.

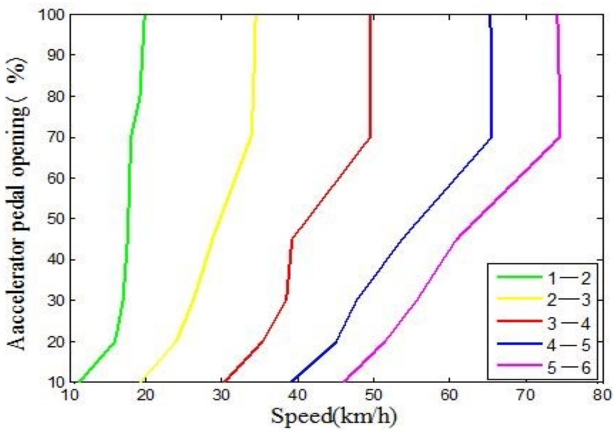

Fig. 5. Curve of economical upshift schedule.

In the development of economic downshift speed, in order to ensure economical requirements and reduce fuel consumption, the speed of economic shift points is relatively small, called advance shifting [9]-[10]. Therefore, in order to avoid the occurrence of cyclic shift, the 4.1km/h constant speed difference shift delay is adopted as the speed point at the time of downshifting based on the upshift shift point. Finally, polynomial fitting interpolation is performed on the upshift and downshift speeds of each gear position under different accelerator pedal opening respectively, and the optimal economic shifting curve is obtained, as shown in Figure 6.

In this paper, the shift schedule based on the minimum fuel consumption compared with the method of fuel consumption as the shift basis, which meets the performance index of the selected model, and the shift point can satisfy the economic demand of the vehicle, better play the power of the engine and improve the performance of the vehicle.

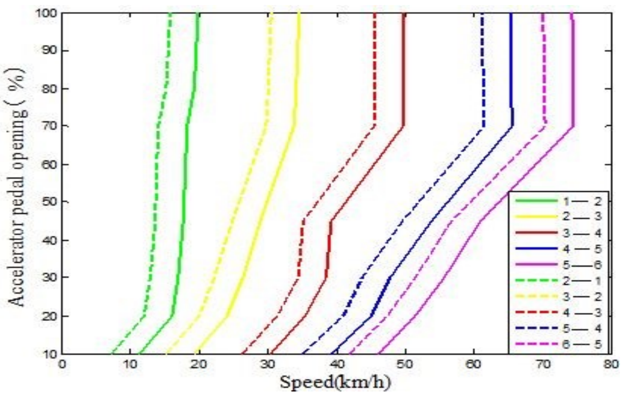

Fig. 6. Curve of economical shift schedule.

V. Conclusion

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

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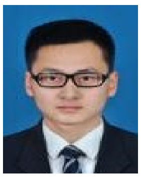

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