The Research Analysis of Economical Shift Schedule for Three Gears Transmission-By-Wire in Electric Vehicle

Pan Zhang, Chen Qi, Nana Lv, Zhengbin Guo, Jinyu Qu

***Abstract*— The optimization of electric vehicles' parameters and control strategy is one of the important means to improve the performance of electric vehicles. This paper chooses the pure electric vehicle of the automatic transmission-by-wire (TBW) with three stalls designed and developed by the research group to study the economical shift schedule. Compared with a variety of methods for creating shift schedule, and ultimately developed the final economical shift schedule curve by using the two-parameter economical shift schedule based on the motor efficiency, so that the drive motor works in the efficient area to achieves the purpose of saving energy and improving endurance mileage.**

***Index Terms*— Automatic Transmission-By-Wire; Pure Electric Vehicle; Best Efficiency; Shift Schedule Curve.**

I. INTRODUCTION

With the development of transmission technology, in order to improve the efficiency of the drive motor, the number of pure electric vehicles equipped with automatic transmission is increasing [1-3]. The shift control strategy of automatic transmission is the core technology of control system, the selection of control parameters directly influences the dynamic performance, fuel economy and the driving range of the vehicle. The development of the shift schedule as a part of the shift control strategy for improving the performance of pure electric vehicles has a very important role. The development of pure electric vehicles' shift schedule is different from that of internal combustion engine automobiles [4]. At present, some studies have been carried out on the shift schedule of pure electric vehicle at home and abroad. There are the best dynamic shift rules and the shift rules based on urban road conditions. However, the research on economical shift schedule based on motor efficiency is less, and the TBW in this paper is designed and developed by the research group, so the existing shift schedule cannot be applied. Therefore, we choose the pure electric vehicle equipped with three-speed TBW as the object, focusing on the study of optimization method of economical shift schedule based on motor efficiency and making the shift schedule curve.

II. SELECTION OF WHOLE VEHICLE'S PARAMETERS

At present, the energy and environment has become a global problem [5]. Automobile industry has also brought serious pollution while promoting economical development. In the current technical conditions, the development of is undoubtedly a choice for the development of the automobile industry. With the development of new energy, the evelopment space of electrical vehicles is growing, and has become the main force in the current automobile market [6]**.** This paper choose the pure electric vehicle equipped with three-speed TBW as the object to study the economical shift schedule based on motor efficiency. The whole vehicle parameters studied in this paper are shown in Tab.1.

Tab.1 The whole vehicle parameters

parameter	numerical	unit
length*width*height	3797/1510/1820	mm
train efficiency	0.96	--
curb weight	1030	Kg
full quality	1310	Kg
radius of the wheel	0.2805	M
air resistance coefficient	0.6	--
frontal area	2.27	m2
axle base	2500	Mm
main reduction ratio	3.182	--
T r1	1.7	--
T r2	1.3	--
T r3	1	--

III. THE WORKING CHARACTERISTICS OF THE DRIVE MOTOR

The drive motor is the only power source on the electric vehicles, its performance directly affects the electric vehicles' economy and power. And because the drive motor is installed in the electrical vehicles and the ambient temperature and road surface are constantly changing, the working conditions of the drive motor are terrible. The drive motor's overload capacity, maximum speed, controllability, steady-state accuracy, dynamic performance and efficiency are required to be high. Currently the drive motors used on the electric vehicles are brushless DC motor, AC induction motor, permanent magnet synchronous motor, switched reluctance motor and wheel hub motor .This paper chooses the YBQ132-15-108V01 permanent magnet synchronous motor

and the technical parameters of the drive motor are shown in Tab. 2.

Tab.2The comparison between the magnetic circuit and the circuit

rated voltage (V)	108	system efficiency	90%
peak power (K w)	28	rated power (K w)	15
peak speed (r/min)	6800	rated speed (r/min)	3000
peak torque $(N \cdot m)$	170	rated torque $(N \cdot m)$	46

The 3D map of motor speed, torque and efficiency is shown as Fig.1.

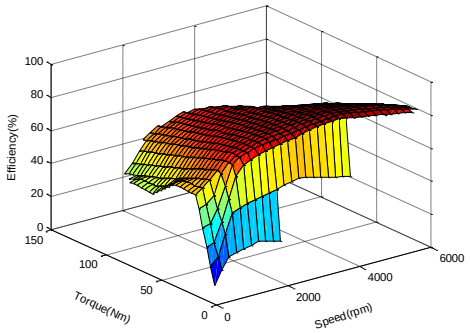

Fig.1 The 3D map of motor speed, torque and efficiency

The 3D map of motor speed, torque and opening of the accelerator pedal is shown as Fig.2.When the motor speed is constant, if the accelerator pedal opening becomes greater, the output torque of the drive motor will be greater ; when the accelerator pedal opening is constant, if the speed of the drive motor becomes greater, the output torque of the drive motor will be smaller. The performance characteristics of the drive motor meet the requirements of the vehicle's economic performance.

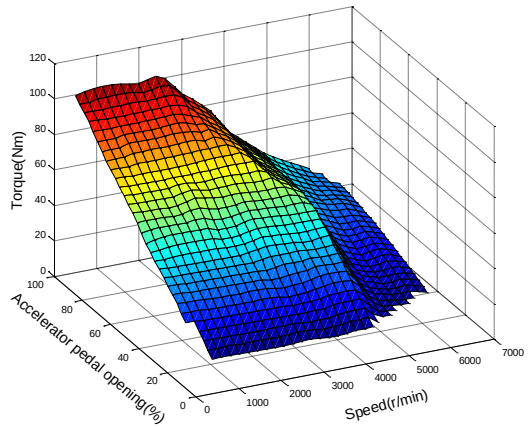

Fig.2 The 3D map of motor speed, torque and opening of the accelerator pedal

IV. THE DEVELOPMENT OF THE BEST ECONOMICAL PERFORMANCE SHIFT SCHEDULE

The best economical shift schedule refers that the vehicle shifts at the lowest economical shift point, in order to achieve the purpose of minimum fuel consumption [7-8]. This shift schedule is the most talked about by people. The principle of economical shift schedule is: When the accelerator pedal is under a certain opening, the drive motor's efficiency of adjacent gear stage is the largest. In other words, the current drive motor's running point efficiency of first speed is lower than the drive motor's running point efficiency of second speed, and then the speed is the best economical shift schedule point. Otherwise it does not need to shift. The economy shift schedule makes the engine or motor always run in high efficiency area, so that the energy consumption of the vehicle is improved.

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. In this paper the double parameter shift schedule is adopted and the control parameters 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 3.

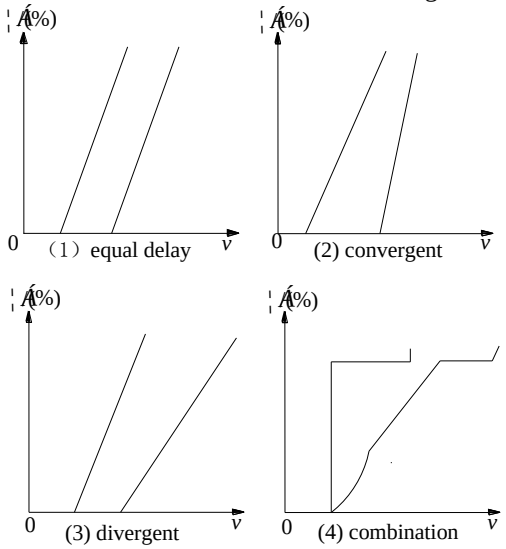

Fig.3 The classification of the shift schedule

The drive motor is the power source of the electric vehicle, and its energy utilization level is usually expressed in terms of efficiency. Therefore, the economical shift schedule is based on the efficiency of the drive motor, so that the transmission system is always running as much as possible in the drive motor's high efficiency area.

The automobile running equation is[9]:

$$F_t = F_f + F_w + F_i + F_j \tag{1}$$

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.

The formula is deduced as follows :

$$\frac{T_{tq} i_o i_g \eta_t}{r} = mgf\cos\theta + \frac{C_D A u^2}{21.15} + mg\sin\theta + \delta m\frac{du}{dt} \tag{2}$$

Where, $\delta = 1 + \frac{1}{\mathrm{m}} \times \frac{\sum I_w}{r^2} + \frac{1}{\mathrm{m}} \times \frac{I_f i_g^2 i_o^2 \eta_t}{r^2}$

Where, T_{tq} is the drive motor's output torque; i_o is the main reducer gear ratio; i_g is the transmission ratio; η_t is the transmission efficiency; r is wheel rolling radius; f is rolling drag coefficient; C_D is air resistance coefficient; A is frontal area; θ is the road gradient; u is the vehicle speed; δ is the correction coefficient of rotating mass.

The relationship between the vehicle speed and the drive motor's speed is[10]:

$$u = \frac{0.377nr}{i_g i_o} \tag{3}$$

From the formula (2) ~ (3), the drive motor's torque can be recorded as follows:

$$T_{tq} = f_1(i_g, n) \tag{4}$$

At the same time, according to the characteristics of drive motor's torque and speed can be seen:

$$T_{tq} = f_2(\alpha, n) \tag{5}$$

Where, f_2 is the interpolation function of drive motor's torque; α is the specific value of accelerator pedal stroke/ whole stroke and $0 \le \alpha \le 1$.

From all of the above formulas, we can get that the relationship between motor efficiency and vehicle speed, transmission ratio and accelerator pedal stroke is:

$$\eta_m = f_3(f_2(\alpha, \frac{i_g i_o u}{0.377}), \frac{i_g i_o u}{0.377}) \tag{6}$$

Where, f3 is the efficiency's interpolation function of drive motor's 3D map.

The constraint is:

$$f_1(i_g, \frac{i_g i_o u}{0.377}) = f_2(\alpha, \frac{i_g i_o u}{0.377}) \tag{7}$$

In summary, the formula of best economical shift schedule points is:

$$f_3(f_2(\alpha, \frac{i_{g1} i_o u}{0.377}), \frac{i_{g1} i_o u}{0.377}) \le f_3(f_2(\alpha, \frac{i_{g2} i_o u}{0.377}), \frac{i_{g2} i_o u}{0.377}) \tag{8}$$

Taking the whole vehicle parameters into the formula (8), the best economical shift schedule points can be obtained when the accelerator pedal opening is a certain value. The first efficiency-speed curve and second efficiency-speed curve is shown in figure 4 when the opening of the accelerator pedal is 100%. We can get the best economical shift schedule by connecting the shift schedule points when the accelerator pedal opening is different. The best economical shift schedule points are shown in Tab. 3.

Tab. 3 The best economical shift schedule points

accelerator pedal opening (%)	Speed 1-2(km/h)	Speed 2-3(km/h)
0.1	18.23	44.67
0.2	17.36	47.23
0.3	24.64	50.03
0.4	24.66	49.21
0.5	34.68	54.73
0.6	28.17	59.16
0.7	47.48	58.06
0.8	46.33	58.98
0.9	47.96	61.26
1.0	51.00	67.00

For the downshift law, in order to avoid the shift cycle, we will use the same delay downshift law and the downshift delay is 4km/h. In summary, we get the two-parameter economical shift schedule curve, as shown in Fig.5.

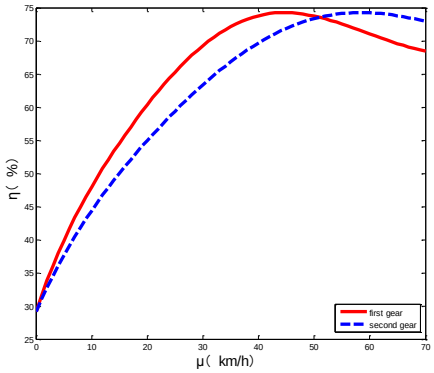

Fig.4 The first efficiency-speed curve and second efficiency-speed curve

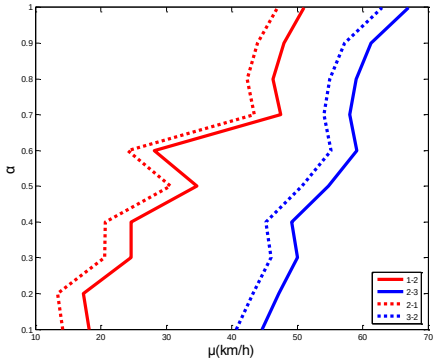

Fig.5 The economical shift schedule curve

V. CONCLUSION

In this paper, the object of study is the pure electric vehicle of the three-speed TBW designed and developed by the research group. Firstly, this paper analyzes the gearshift law, and takes the vehicle accelerator pedal position and the vehicle speed as the shift schedule parameters to make the economical shift schedule and make the shift schedule curve. The two-parameter economical shift schedule based on the motor efficiency achieves the purpose of saving energy and improving endurance mileage. It provides an effective method and means for the electric vehicle's design, the prediction and analysis of dynamic performance, and lays the foundation for the follow-up research.

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