International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-5, Issue-7, July 2019

Optimization Design and Analysis of Speed Ratio of Three-Geared Transmission-By-Wire for Electric Vehicle

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***Abstract*— A new type of three-geared transmission-by-wire for electric vehicles is proposed, The preliminary matching of the powertrain parameters of the transmission-by-wire(TBW) is carried out to optimize the electric vehicle gear ratio with the shortest acceleration time and the maximum driving range. In order to verify the rationality and effectiveness of the optimization results, the vehicle model was built by the advisor simulation platform, and its dynamic and economic simulation was carried out under NEDC conditions. The simulation results show that compared with pre-optimization, the optimized vehicle mileage is increased by 2.16%, the 0-50km acceleration time is shortened by 4.88%, and the 50-80km acceleration time is shortened by 1.59%, the maximum speed is increases by 4.81% indicating that the proposed shifting device is reasonable and feasible.**

***Index Terms*— Transmission-By-Wire; Powertrain; Genetic Algorithm Simulation Analysis**

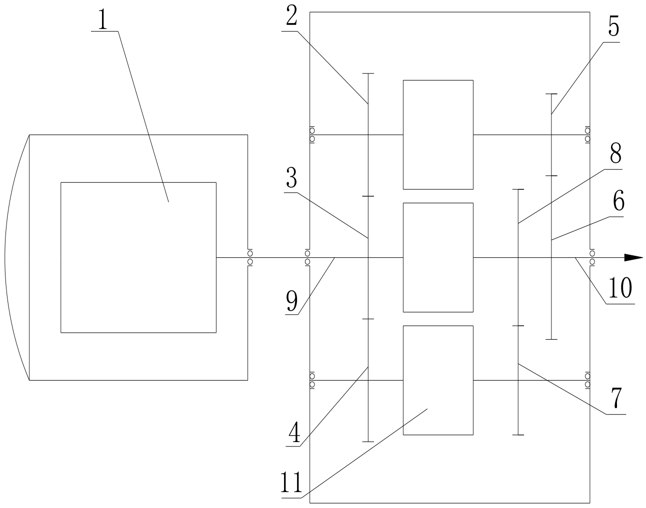
I. INTRODUCTION

The rapid development of the global economy has greatly stimulated the automobile consumer market, and the number of cars in the world has been rising[1]. In order to solve the increasingly severe energy crisis and environmental problems, electric vehicles have become more and more important in the world because of their diversification of energy allocation relative to traditional vehicles, reduction of conventional pollutants, greenhouse gas emissions, and easy handling[2]. The electric vehicle market has great development prospects, and vigorously developing electric vehicles is an important route for social development in various countries in the future[3]. Based on the above problems, this paper designs and develops a new type of automatic transmission-by-wire for electric vehicles[4], through the reasonable matching design of the power system parameters, combined with the simulation analysis, the transmission ratio is optimized, and finally the overall performance of the electric vehicle is improved.

II. TBW STRUCTURE

TBW is an automatic transmission for the electric vehicle powertrain system studied in this paper. It overcomes the shortcomings of the existing types of automatic transmissions, such as complex hydraulic system and shifting mechanism, and proposes a new parallel shaft type third gear TBW. The structure diagram is shown in Figure 1.

It can be seen from Figure 1 that the proposed three-speed TBW adopts the gear constant meshing variable transmission to change the gear ratio of different gears, and eliminates the complicated parts such as the hydraulic pressure, pneumatic system and shifting mechanism of the conventional automatic transmission. The remote power shifting element is arranged between the input gear and the driving gear on each gear shaft, so no additional external clutch is required between the driving motor and the TBW.



1.driving motor 2.input gear of first gear 3.center input gear 4.input gear of second gear 5.driving gear of first gear 6.driven gear of first gear 7.driving gear of second gear 8.driven gear of second gear 9.input shaft of transmission 10.output shaft of transmission 11.control-by-wire power shift element

Fig.1 The structural sketch of TBW

III. PAREMETER MATCHING

A. *Vehicle Parameters and Performance Requirements*

In this paper, based on the working characteristics and requirements of the electric drive system of electric vehicles, the parameters of the main components of electric vehicles are matched and optimized. In order to improve the power and economy of the car, and thus improve the overall performance of the car, it is very important to match and design the key components such as the drive motor and the shifting device. In this paper, a traditional internal combustion engine car is converted into a pure electric vehicle. The vehicle parameters and performance indicators are shown in table 1:

Table 1. The vehicle parameters and performance indicators

Parameter	Numerical	Unit
Curb Weight	1100	Kg
loaded with quality	1850	Kg
Frontal area	2.27	m^2
Air resistance coefficient	0.32	--
Rolling resistance coefficient	0.0165	--
Tyre rolling radius	280.5	mm
Tyre specification	165/70R13	--
Wheelbase	2570	mm
Rear wheelbase	1290	mm
Front wheelbase	1280	mm
Acceleration	10	s
Maximum speed	100	Km/h
Cruise speed	65	Km/h
Mileage	80	Km

B. Selection of Motor Parameters

As the only power source on the electric vehicle, the motor directly affects the overall performance of the electric vehicle. Therefore, the selection and parameter design of the electric vehicle drive motor is particularly important. When determining the power of the motor, the factors considered are similar to the traditional car power selection, which are determined according to the vehicle's dynamic performance evaluation index, ie the maximum speed of the car, the acceleration time and the maximum grade of the car. In determining the peak power of the motor, the power at which the peak power is greater than the three must be met. The formula is expressed as follows:

$$P_{\max} \geq \max[P_u, P_i, P_a] \quad (1)$$

Where $P_{\max}$ is the peak power of the motor, P_u is the power at the highest speed, P_i is the power at the maximum grade, P_a is the maximum power during acceleration.

C. Battery Pack Selection

When selecting the battery pack capacity, it is necessary to first meet the requirements of the vehicle's mileage and vehicle power, and also ensure that the battery pack can meet the energy consumption and maximum discharge power under various working conditions. However, the capacity of the battery pack should not be too large, because although the power will increase with the increase of the capacity of the battery pack, due to the restriction of the space of the automobile chassis, the quality of the whole vehicle will become large, which is not economical.

When determining the capacity of the battery pack, the power consumed in the maximum number of miles traveled by the constant speed method, that is, when the electric vehicle is traveling at a certain cruising speed:

$$P_d = \frac{u_e}{3600\eta_T}\left(mgf + \frac{C_d A u_e^2}{21.15}\right) \quad (2)$$

Therefore, the rated capacity of the power battery can be derived from the relationship between the mileage of the electric vehicle and the power consumption of the electric vehicle cruising speed, that is:

$$L = \frac{Q_e U \varepsilon}{1000 P_d} u_e \quad (3)$$

Where the average operating voltage is 108V, and the discharge depth is 90%, Q_e is the rated capacity (Ah).

D. Gear ratio selection

Unlike traditional cars, electric vehicles are a system of motors, batteries, and electronic control technology[6]. For pure electric vehicles, short mileage and no significant advances in battery technology have been the bottleneck in the development of electric vehicles. Electric cars are only suitable for use on the outskirts of the city or for short trips.

When determining the maximum transmission ratio of a car, it is necessary to consider the following aspects: maximum grade, adhesion rate, and minimum stable vehicle speed. When the car is climbing, because the speed is relatively low, it can ignore the air resistance that the car is subjected to during driving. The maximum driving force of the car is:

$$i_{g1} i_0 \geq \frac{r\left(mgf \cos\alpha_{\max} + mg\sin\alpha_{\max} + \frac{C_d A u_s^2}{21.15}\right)}{T_{\max}\eta_T} \quad (4)$$

When discussing the minimum gear ratio of a car, it is usually determined by various aspects such as the maximum speed $u_{\max}$ of the car, the backup power of the car, and the drivability of the car. The most important task in selecting the minimum gear ratio is to meet the design's gear ratio to reach the maximum speed of the car, so the relationship between the minimum gear ratio $i_{\min}$ and the design maximum speed can be obtained:

$$i_{\min} \leq \frac{n_{\max} r}{v_{\max}} \quad (5)$$

where $n_{\max}$ is the maximum rotating speed, $v_{\max}$ is the maximum vehicle speed.

E. Number of Gears Determined

In traditional cars, the more gears the gears have, the more they can increase the engine's economical working conditions, which is conducive to improving fuel economy. Therefore, traditional cars use 5 or 6 gears[7]. Similarly, in electric vehicles, as the number of gears increases, the drive motor will also be in a high-power condition, but the number of gears of the electric vehicle should not be too large. Generally, the second or third-speed transmission is used. The electric vehicle studied used a three-speed transmission, but since the third gear is a direct gear, the transmission ratio is 1, so it is equivalent to the second-speed transmission in principle, but the structure is different.

F. Matching Results

The matching results of the electric vehicle are shown in Table 2.

Table 2. Electric vehicle matching parameters

Component	Parameter	Numerical
Permanent Magnet Synchronous Machine	Rated power/(kW)	15
	Maximum speed/(r/min)	6800
	Rated voltage/V	108
Storage battery	Single battery capacity/Ah	90
	single battery voltage/V	3.2
	Number of single battery	68
Gear ratio	T_{r1}	1.72
	T_{r2}	1.31
	T_{r3}	1

IV. OPTIMIZATION AND SIMULATION

A. Optimization Variable Determination

The parameters of the transmission system mainly include: the ratio of the final drive, the gear ratio of the transmission and the number of gears[8]. When optimizing the parameters of the transmission system, it is mainly to optimize the position of the common operating point of the engine during the whole driving process by optimizing the parameters of the final reduction gear ratio and the gear ratio of the transmission, so that the vehicle dynamics and fuel economy are improved. Since the main reduction ratio in this paper has been determined, the optimization variables in this paper are gear ratio of each gear, that is:

$$x = \left[i_{g1}, i_{g2} \right]^{\mathrm{T}} \tag{6}$$

B. Optimization Objective Function

The vehicle dynamic performance index is mainly evaluated by the three aspects of maximum speed, maximum grade and acceleration time. The acceleration time represents the ability of the vehicle to complete the load in a short time, and can fully represent its power system power level, so the vehicle acceleration time is often used as a dynamic objective function.

The shift strategy is mainly based on speed shifting and load shifting[8]. Speed shifting is more economical and therefore more suitable for passenger car, this article is also based on the speed shift strategy. The objective function of the acceleration time with respect to the speed ratio can be expressed as:

$$t = t_0 + \frac{1}{3.6}\left[\int_0^{u_0} \frac{\delta_1 m}{\frac{T_{\max} i_0 i_{g1} \eta_T}{r} - Gf - \frac{C_D A}{21.15} v^2} dv + \int_{u_0}^{80} \frac{\delta_2 m}{\frac{T i_0 i_{g2} \eta_T}{r} - Gf - \frac{C_D A}{21.15} v^2} dv\right] \tag{7}$$

Where t_0 is the shift time, $T_{\max}$ is the maximum torque.

Take the European low-speed cycle condition CYC_ECE as an example to calculate the energy consumed by a working condition. The working conditions are divided into a uniform process and an acceleration process, and the energy consumption analysis is performed separately for the two processes, and the energy consumption of the entire cycle condition is obtained by superimposing them.

Uniform process:

When the car is driving at a constant speed, the energy consumed by the electric vehicle during this time W_1.is:

$$W_1 = \frac{p_1 t_1}{\eta_t} \tag{8}$$

where p_1 is the power in uniform speed, t_1 is the constant speed travel time.

Accelerated process:

The energy consumed during the entire acceleration process W_2 is:

$$W_2 = \sum_{i=1}^{n} p_i \bullet \frac{t}{n\eta_t} \tag{9}$$

The energy consumption of the entire cycle is:

$$W = W_1 + W_2 \tag{10}$$

According to the above, the function of the driving range under the ECE cycle condition can be obtained[9]. When the battery pack parameters are determined, the total usable energy is divided by the energy consumed by each cycle and multiplied by the mileage of each working condition. The electric vehicle driving range can be obtained as a function of the speed ratio.

Through the above, the comprehensive optimization function is obtained, that is:

$$f(i_{g1}, i_{g2}) = \frac{\omega_1 t(i_{g1}, i_{g2})}{\omega_2 L(i_{g1}, i_{g2})} \tag{11}$$

where ω_1 is the dynamic weighting factor, ω_2 is an economic weighting factor.

C. Restrictions

The upper and lower limits of the gear ratio of the vehicle can be determined by the maximum motor speed and the highest stable speed and the maximum grade, that is:

$$\begin{cases} g_1(x) = (Gf + \frac{C_D A}{21.15} u_{\max}^2) \frac{r}{T_{tq} i_0 \eta_T} - i_{g2} i_0 \le 0 \\ g_2(x) = \frac{G(f\cos\theta_{\max} + \sin\theta_{\max}) r}{T_{tq\max} \eta_T} - i_{g1} i_0 \le 0 \\ g_3(x) = \frac{T_{tq\max} i_{g1} i_0 \eta_T}{r} - N\phi \le 0 \\ g_4(x) = i_{g3} i_0 - 0.377 \frac{nr}{v_{\max}} \le 0 \end{cases} \tag{12}$$

D. Optimization Results

For solving multi-variable multi-objective nonlinear optimization problems, the genetic algorithm is selected to solve the problem. Through the matlab genetic toolbox, the optimization function and constraints are substituted, the population size is set to 150, and the maximum genetic algebra is 50. The optimized transmission ratio results are shown in Table 3.

Table.3 Transmission ratio optimization result comparison

Gear ratio	i_{g1}	i_{g2}	i_{g3}
Optimized result	1.71	1.29	1
Pre-optimization results	1.72	1.31	1

E. Simulation Analysis

After the vehicle model is built in ADVISOR[10], as shown in Figure 2, the power and economic performance of the electric vehicle are simulated under NEDC standard cycle conditions according to the matched power system parameters. The simulation results are shown in Table 4.

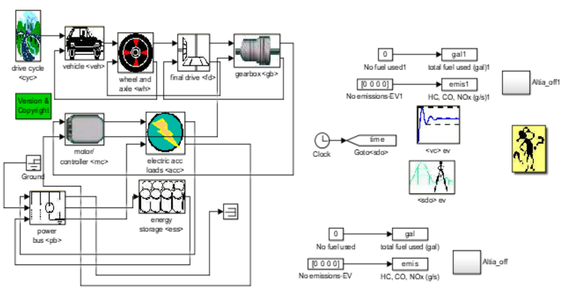


Fig.2 Vehicle Model

Table 4. Simulation results

Simulation project	Before optimization	After optimization	Change rate
Maximum speed/(km/h)	110.2	115.5	4.81%
0-50km Acceleration/s	4.1	3.9	-4.88%
50-80kmAcceleration/s	6.3	6.2	-1.59%
NEDC Mileage	107.05	109.36	2.16%

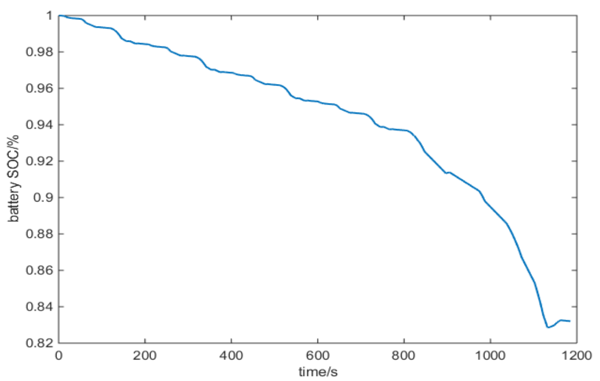


Fig.3 The SOC curve at NEDC driving conditions

Figure 3 shows the SOC simulation result curve of the NEDC cycle condition battery. It can be seen from the figure that the initial stage of the operating condition requires less power due to lower vehicle speed, and the SOC curve decreases slowly. In the later stage of operation, as the vehicle speed increases, the power demand as the size becomes larger, the SOC curve drops rapidly; the rear stage SOC curve does not change significantly because the electric vehicle does not need to idle at the idle speed. After completing an NEDC cycle condition, the power battery SOC is reduced from the full power state to 83.6%, and the single NEDC cycle condition mileage is 10.9km, so the calculated energy consumption rate is 0.126 kWh/km, which satisfies Vehicle performance target.

In summary, the vehicle's maximum speed, acceleration capability and driving range are higher than the previous performance of the electric vehicle. At the same time, the rationality of the design of the transmission system parameters of the automatic transmission and the established whole are verified. The car simulation model is correct and effective.

V. CONCLUTION

This paper proposes a new type of three-geared transmission-by-wire for electric vehicle, Theoretical research and analysis on the parameters of pure electric vehicle power system, in order to quickly match the appropriate power system parameters for research purposes, combined with simulation software ADVISOR for simulation to verify the rationality of the matching parameter method.

The optimized power system parameters are simulated again in ADVISOR, and the simulation results before and after optimization are compared. The power and economy of the electric vehicle are improved, and the rationality of the optimization method is verified.

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