Parameter Matching and Simulation Study on the Range Extender of Extended Range Electric Vehicles

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Abstract: Vehicles are used more and more widely as a means of daily travelling, which has led to serious problems such as air pollution and energy shortage. This has stimulated interests in development of electric vehicles in many countries. In recent years, the focus of the development is geared towards extended range electric vehicles in order to resolve the drawback from short continued driving mileage of traditional electric vehicles. The core of the extended range electric vehicle is the range extender. The parameter matching design for the range extender and the related power system components is carried out in the paper based on automobile theory while the simulation study is carried out by using Cruise software.

1 INTRODUCTION

As one of the greatest achievements of modern industrial development, vehicles have offered great convenience for people's daily travelling. But a large number of vehicle usages have caused a series of negative impacts to our society, such as air pollution, energy shortage and so on. To tackle aforementioned problems, electric vehicle development has attracted attentions worldwide. However, problems residing in the core components of electric vehicles, the technology and cost of power battery, the poor availability of charging stations, and the short driving range have imposed limits on promotion and usage of electric vehicles. This has become an imminent driving force for performance improvement of the extended range electric vehicle.

Extended Range Electric Vehicle (E-REV) is mainly driven by electric power. As an electric supplement, the range extender is composed of a small engine and a generator, and it can make up for the power supply of electric vehicles when the usual mileage is exceeded. This provides an advantage that the vehicle's power supply does not depend on the charging station.According to statistics, 80% user's daily travel mileage is less than 80km. The number of batteries equipped with 80km in the pure electric drive mode is greatly reduced compared with that for vehicles with driving range of 200km. As a result, this greatly reduces weight and cost of a vehicle.

2 PARAMETER MATCHING OF POWER SYSTEM RELATED COMPONENTS

2.1 Vehicle Parameters

In this paper, an extended range electric vehicle is selected as the study prototype, and its sample parameters are shown in table 1 and table 2.

Table 1: The design parameters of the vehicle

Parameter name and unit	Value
Curb weight m_0 (kg)	1500
Full load weight m_1 (kg)	1940
Frontal area A (m^2)	2.2
Air resistance coefficient C_D	0.32
Rolling resistance coefficient f	0.014
Tire radius r (m)	0.275
Reduction gear ratio $i_g i_0$	7.9
Transmission efficiency η	0.95

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Table 2: The technical index of vehicle performance

Index name and unit	Technical target
Maximum speed (km/h)	130
Acceleration time (0-100km/h) (s)	13.2
Maximum climbing degree	30%
Energy consumption rate under the pure electric mode (NEDC) (kWh/100km)	≤15
(90km/h) Extension mileage under the pure electric mode S_0 (km) (DOD＝70%)	≥80
(60km/h)Extension mileage under the pure electric mode S_1 (km)	≥80

2.2 Parameter Design of the Drive Motor

Motor is the critical component for good power performance of the extended range electric vehicle. In the parameter matching process, the smallest number of system parameters is used to meet the dynamic requirements of the design index. The main parameters such as the base speed n_0 , the maximum speed n_{max} , the rated power P_0 , the peak power P_{max} and the peak torque N_{max} need to be matched (Hu He, 2012). Prior to matching the parameters of the driving motor, the parameters of the transmission system have to be determined first. The motor has the characteristic of delivering constant torque at base speed and delivering constant power between the base speed and the maximum speed (Dong Xinyang, 2012), which makes it ideal to meet the speed and torque requirements of the vehicle. As shown in table 1, the speed ratio of the transmission system is tentatively defined as 7.9.

2.2.1 The Base Speed n_0 and the Maximum Speed n_{max}

The designed maximum speed of the drive motor should meet the requirement as stated in this formula:

$$V_{\max} \le \frac{0.377 n_{\max} r}{i_g i_0}$$

In the formula, v_{max}(km/h) is the designed maximum speed of the vehicle, r (m) is the tire radius, $i_g i_0$ is the total transmission ratio of the transmission system (value of 7.9 is taken in this paper). Values for each respective parameter are shown in table 1 and table 2. These input values yield results of $n_{max} \geqslant$ 9906r/min, and n_{max} = 10000r/min.

The relationship between the maximum speed n_{max} and the base speed n_0 of the motor is defined as below.

$$\beta = \frac{n_{\max}}{n_0}$$

In the formula, β is the constant power expansion coefficient. The greater its value, the greater the output torque of the motor at low speed, and the better the corresponding starting and climbing performance of the vehicle. But it will increase the size of the power converter if the value is too large. The reasonable value is 2-4(Deng Chunrong, 2014). Based on these values, $2500 \leqslant n_0 \leqslant 5000$ is obtained. In this paper, β is defined as 3.3, and the base speed n_0 equals to 3300 r/min.

2.2.2 The Rated Power P_0 and the Peak Power P_{max}

The power balance equation for the vehicle driving is shown as below.

$$P_e = \frac{1}{3600\eta}\left(mgfu_a \cos\alpha + mgu_a \sin\alpha + \frac{C_D A}{21.15} U^{2} + \delta m u_a \frac{du}{dt} \right)$$

In the formula, P_e (kW) is the drive motor power, η is the transmission efficiency, m (kg) is the vehicle weight, g (m/s^2) is the gravitational acceleration. f is the rolling resistance coefficient, α(°) is the slope angle, C_D is the air resistance coefficient, A(m^2) is the frontal area, δ is the rotary mass conversion coefficient, du/dt(m/s^2) is the acceleration.

- The motor demand power and the maximum speed.

The relationship between the motor demand power and the maximum speed must satisfy the formula below (Yu Zhisheng, 2006).

$$P_u = \frac{1}{\eta}\left(\frac{mgf}{3600} v_{\max} + \frac{C_D A}{76140} v_{\max}{}^{3} \right)$$

The vehicle weight for the test is taken as, $m=m_0+180kg$ (Wang Da, 2015). Using values from table 1 and above vehicle weight produces P_1 = 22.3kW.

- The motor demand power and the acceleration time between 0 km/h to100km/h.

The motor power required to meet the acceleration performance of the vehicle is stated as below(Yu Zhisheng, 2006).

$$P_a = \frac{1}{1000\eta}\left[\frac{\delta m}{2t_a}\left(v_f{}^2 + v_b{}^2\right) + \frac{2}{3} mgfv_f + \frac{1}{5}\rho_a C_D A v_f{}^3 \right]$$

In the formula, δ is a constant with value of 1.06, t_a(s) is the acceleration time between 0 to 100 km/h. v_f (m/s) is the speed at the end of acceleration, which equals to 12m/s. ρ_a is the air density, which equals to 1.202Ns^{2}m^{-4}. The other parameters are same as above. These input values yield P_2 = 74.33kW.

- The motor demand power and the maximum climbing degree and the corresponding climbing speed.

Substituting the vehicle weight with full load weight (m=m_1), the motor power demand under the requirements of different speed and climbing degree of the vehicle can be obtained.

$$P_i = \frac{mgv_a}{3600\eta}\left(\sin\alpha + f\cos\alpha + \frac{C_D A}{76140}V_a^{\ 3}\right)$$

In the formula, α is the maximum climbing degree. v_a is the climbing speed, which is 20km/h. The other parameters are same as above. These input values produce P_3 = 22.3kW.

In the design, the drive motor rated power is usually based on P_1, and the peak power is determined by P_2 and P_3 as below (Xu Chengfu, 2014).

$$P_0 \geq P_1$$

$$P_{\max} \geq \max\{P_2, P_3\}$$

For the conditions of the drive motor rated power P_0 = 25kW, and the peak power P_{max} = 75kW, the overload coefficient of the motor is 3.

2.2.3 The Rated Torque T_0 and the Peak Torque N_{max}

The relationship between power, torque and speed is stated as below.

$$T = \frac{9550P}{n}$$

Using n=n_0, the rated power P_0 and the motor peak power P_{max}, the motor rated torque T_0 from the above formula is 79.6 Nm, and T_0 is rounded to 80 Nm. The peak torque P_{max} equals to 239 Nm, and is rounded to 240 Nm. The drive motor characteristic parameters are shown in table 3.

Table 3: The drive motor parameters

Parameter name and unit	Value
Rated power P_0（kW）	25
Peak power P_{max}（kW）	75
Rated speed n_0（r/min）	3300
Maximum speed n_{max}（r/min）	10000
Rated torque T_0（Nm）	80
Peak torque T_{max}（Nm）	240

3 PARAMETER MATCHING OF THE RANGE EXTENDER

3.1 Generator Parameter Design

When the power drawn from the battery is insufficient during vehicle running, the range extender begins to work and provides energy to the vehicle. In the paper, the range extender output power can ensure that the vehicle runs at the constant speed of v_c, which is 130km/h.

$$P_{RE} \geq \frac{\left(mgfv_c + \frac{C_D A v_c^{\ 3}}{21.15}\right)}{3600\eta\eta_{mc}}$$

In the formula, η_{mc} is the drive motor efficiency, and η_{mc} with value of 0.9 is used here. The other parameters are same as above. Using these values produces, P_{RE} ⩾ 33.49kW, and this is rounded to 36kW. The parameter matching of the generator is shown in table 4.

Table 4: The generator parameters

Parameter name and unit	Value
Rated power（kW）	36
Peak power（kW）	46
Rated torque（r/min）	3000
Peak torque（r/min）	4000

3.2 Engine Parameter Design

In the paper, the generator will start working only when the SOC of the power battery reaches the lower limit. At this point, the battery will be recharged and then transmits the energy to the drive motor. In this way, the vehicle can continue to move forward at certain speed, while the maximum power meets the power demand of the vehicle's maximum speed.

For the case of the speed v_c = 130km/h, the motor output power is calculated as follows:

$$P_{mc} = \frac{v_c}{3600\eta_{mc}}\left(mgf + \frac{C_D A v_c^{\ 2}}{21.15}\right) = 31.72kW$$

With motor efficiency η_{mc} of 0.9, the power supplied to the motor by the battery is 31.72kW/0.9=35.24kW. With battery discharging efficiency η_b of 0.95, the power of the generator provided to battery charging is 35.24kW /0.95=37.09kW. In the end, the continuous output power of the engine is selected as 40kW.

The engine peak power P_{fc_max} should be satisfied with the following formula.

$$P_{fc\_\max} \geq \frac{P_{RE\_\max}}{\eta_{gen}}$$

In the formula, P_{RE_max}(kW) is the peak power of the range extender, which is also the generator peak power. η_{gen} is the generator efficiency, which equals to 0.9. These input values yield, $P_{fc_max} \geqslant 51.1$kW. The final selected engine parameters are shown in table 5.

Table 5: The engine parameters

Parameter name and unit	Value
Displacement（L）	1.5
Peak power（kW）	52
Maximum speed（r/min）	4200

4 PERFORMANCE SIMULATION AND ANALYSIS

4.1 Pure Electric Mileage in the NEDC Conditions

In the paper, Cruise is used for simulation of pure electric driving mileage according to the NEDC conditions. The simulation results show that the pure electric mileage is close to 80km, which meets the design requirements.

4.2 Drive Motor Torque under the Pure Electric Mode

From the curve of the drive motor torque, it can be seen that the vehicle speed trends well under the NEDC conditions, while the drive motor executes the energy recovery function smoothly, as shown in figure 1.

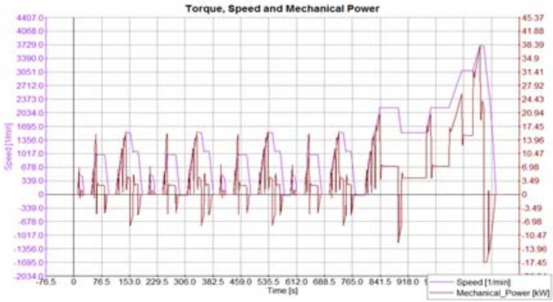

Figure1: The curve of the drive motor torque

4.3 The Generating Torque of the Range Extender

It can be seen from the curve of the range extender torque that the range extender starts up when the starting conditions are met and stops when the shut-down conditions are encountered, as shown in figure 2.

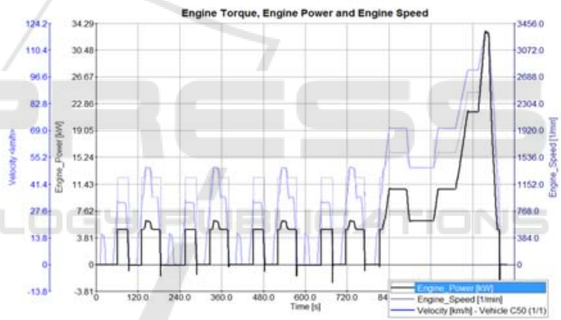

Figure 2: The curve of the range extender torque

5 CONCLUSIONS

In the paper, parameter matching and design on a prototype vehicle are carried out according to pertinent automobile theory.

This study has demonstrated that the pure electric driving mileage meets the design requirements. The study further illustrated that the drive motor can achieve good energy recovery, and the range extender can meet the start-up and shutdown requirements.

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REFERENCES

Hu he. Parameters design and performance optimization of the power system of the range extended electric vehicle [D], Changchun, Jilin University, 2012.

Dong Xinyang. A study of control strategy design and optimization for the powertrain of the range extended electric vehicle [D], Hefei, Hefei University of Technology, 2012.

Deng Chunrong. Design and study on the permanent magnet synchronous motor used in electric vehicles [D]. South China University of Technology, 2014.

Yu Zhisheng. Automobile theory [M]. Beijing, Machine Press, 2006.

Xu Chengfu. Study on parameter matching and optimization of driving system and control strategy for Range-extended electric vehicles [D].Hefei, Hefei University of Technology, 2014.

Wang Da, Wang Bo. Research on Driving Force Optimal Distribution and Fuzzy Decision Control System for a Dual-motor Electric Vehicle [A]. Chinese Control Conference[C]. Hangzhou: Institute of Electrical and Electronics Engineers, 2015.