Parameter optimal design and Simulation of Power System of Electric Vehicle Based on AVL-CRUISE

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Abstract. In order to meet demand of dynamic of electric vehicle, based on vehicle design method theory, power parameters of motor and transmission ratio are designed using method of theoretical calculation, model of vehicle is built and simulated in AVL-CRUISE software, transmission ratio is optimized to improve economic performance. Simulation result shows performance of the whole vehicle is improved. So It lays the foundation for development of EV.

1. INSTRUCTION
The dynamic performance and economy of EV are affected design level of dynamic system directly, the accurate of calculating power of motor and parameter matching between motor and the transmission are key of design¹. Through theoretical calculation, dynamic demand of motor and range of transmission ratio are determined²³. However, for different motor, the power is same, but the driving characteristic are different, so the demand for transmission ratio is different, and how to ascertain the optimal transmission ratio is a critical on the condition of certain motor⁴.

2. DESIGN DEMAND OF DYNAMIC

| Name of Parameter        | Values | Units |
|--------------------------|--------|-------|
| Kerb mass                | 980    | kg    |
| Gross Mass               | 1250   | kg    |
| Frontal area             | 2.10   | m²    |
| Drag coefficient         | 0.35   | -     |
| Rolling resistance       | 0.015  | -     |
| Wheel radius             | 0.33   | mm    |
| Transmission efficiency  | 96%    | -     |

Table 1. Parameters of vehicle.
Table 2: Overall performance index

| Performance demand | Item                     | Index       |
|--------------------|-------------------------|-------------|
| Speed demand       | Maximum speed           | ≥110 km/h   |
| Acceleration       | 0~50km/h ≤7s            | ≥50 km/h    |
|                    | 50~70km/h ≤8s           |             |
| Climbing performance| Maximum value of speed at slop of 6% | ≥50 km/h |
|                    | Maximum value of speed at slop of 9% | ≥20 km/h |
|                    | Maximum value of speed at slop of 20% | ≥10 km/h |
| Energy of consumption per one hundred kilometers | ≤15kWh |

3. PARAMETER DESIGN OF POWER SYSTEM

3.1 Parameter design of motor

Power demand can be acquired by the formula (1), formula (2) and formula (3) on 3 kind of states for maximum speed, acceleration and climbing.

\[
P_{el} = \frac{1}{\eta_f} \left( \frac{m g u_a}{3600} + \frac{C_D A u_a^3}{76140} \right), \quad (1)
\]

\[
P_{el} = \frac{1}{\eta_f} \left( \frac{m g u_a}{3600} + \frac{C_D A u_a^3}{76140} + \frac{f m u_a du_a}{3600} \right), \quad (2)
\]

\[
P_{el} = \frac{1}{\eta_f} \left( \frac{m g u_a}{3600} \cos \alpha + \frac{m g u_a^2}{3600} \sin \alpha + \frac{C_D A u_a^3}{76140} \right), \quad (3)
\]

The drive-line efficiency is \( \eta_f \), \( f \) is rolling resistance coefficient, \( m \) is full-load-quality, \( C_D \) is the air resistance coefficient, \( A \) is the frontal area, \( u_a \) is the maximum speed, \( \delta \) is moment of inertia conversion coefficient, and \( \alpha \) is climbing angle.

On the basis of formula (1), formula (2) and formula (3), the maximum dynamic requirement is estimated under kinds of condition, they are shown in Table 3.

Table 3: Estimated value of peak power

| Quality requirement | Power of motor (kW) |
|---------------------|---------------------|
| Maximum speed \( v_{max} \geq 110 \) km/h | 23.75 |
| Acceleration quality | 40.18 |
| Acceleration quality | 32.15 |
| Maximum steady speed at slop of | 18.09 |
Maximum steady speed at slop of 9% ≥ 30 km/h
11.39

Maximum steady speed at slop of 20% ≥ 10 km/h
7.48

To satisfy the dynamic performance, rated power of motor must satisfy the maximum speed, the peak power must satisfy the demand of acceleration quality. From the Table 3, the rated power is more than 23.75kW, peak power of motor is more than 40.18kW, and rated power of motor chosen is 25kW, peak power of power motor chosen is 45kW.

Permanent magnet motor possess characteristic of high power density and high efficiency. Its voltage is between 100V and 400V, maximum speed is between 4000 r/min and 10000 r/min, constant power factor is 2.25, all parameter of motor designed are shown in Table 4.

| Parameter          | Values |
|--------------------|--------|
| Rated power        | 25kW   |
| Overload coefficient| 1.8    |
| Base speed         | 3000rpm |
| Voltage of motor   | 320V   |
| Peak value of power| 45kW   |
| Peak value of torque| 14Nm  |
| Peak value of speed| 8000rpm |

3.2 Design of transmission system
Transmission ratio must satisfy the requirement of largest climbing gradient, and it also must assure the greatly desired maximum speed. Transmission ratio required must satisfy formula (4) and formula (5).

\[
i_0 \geq \frac{mg(f \cos \alpha_{max} + \sin \alpha_{max})r}{T_{max}\eta} \quad (4)
\]

\[
i_0 \leq \frac{0.377n_{max}r}{v_{max}} \quad (5)
\]

\(i_0\) is gear ratio, \(r\) is radius of wheel, \(T_{max}\) is the peak torque, \(n_{max}\) the maximum speed of revolution of motor. \(6.2 \leq i_0 \leq 8.29\) can be calculated.

4. SPEED RATIO OPTIMIZATION
4.1 Optimization of speed ratio optimization

The whole vehicle model is built in software of AVL-CRUISE, the transmission ratio is 7.5, 7.0, 6.5, and vehicle performances are simulated; the simulation diagram of energy consumption and acceleration condition are shown in Figure.1, Figure.2 and Figure.3 under condition of NEDC.
(a) Simulation diagram of acceleration condition

(b) Simulation diagram of energy consumption on NEDC condition

Figure.2 Simulation result when transmission ratio is 7.0

Figure.3 Simulation diagrams when gear ratio is taken as 7.5

From Figure.1, Figure.2, Figure.3, when gear ratio is taken as 6.5, 7.0, and 7.5, acceleration performances and energy consumption of vehicle are shown in Table 5.

| Gear ratio | Acceleration Time 0~50km/h | Acceleration Time 50~70km/h | Energy consumption 10~50km/h (kWh/100km) |
|------------|-----------------------------|-----------------------------|-----------------------------------------|
| 6.5        | 7.76s                       | 6.22s                       | 14.36 (kWh/100km)                      |
| 7.0        | 7.26s                       | 6.44s                       | 14.42 (kWh/100km)                      |
| 7.5        | 6.76s                       | 6.31                        | 14.43 (kWh/100km)                      |
Figure 4 Simulation results of under NEDC condition

From the Table 5, with growing of gear ratio, acceleration performances is improving, and energy consumption also adds. To satisfy the demand of acceleration performance, at same time improving economy, the gear ratio is design as 7.25 in the design.

5. THE ANALYSIS OF VEHICLE PERFORMANCE

When the gear ratio is taken as 7.25, on NEDC condition, the whole vehicle performance is shown in Figure 4, dynamic index and economy index are shown in Table 6.

Table 6 Simulation results of power dynamic and economy

| Performance demand | Item                          | Simulation result | Reference Index |
|--------------------|-------------------------------|-------------------|-----------------|
| Speed demand       | Max speed                     | 156.6 km/h        | ≥120 km/h       |
|                    | 0~50km/h                      | 6.98s             | ≤7s             |
|                    | 50~80km/h                     | 6.29s             | ≤8s             |
| Climbing performance | Maxi-speed at slop of 6%     | 67 km/h           | ≥60 km/h        |
|                    | Max-speed at slop of 9%       | 58 km/h           | ≥30 km/h        |
|                    | Max-speed at slop of 20%      | 33 km/h           | ≥10 km/h        |
| Energy consumption | 14.43 kWh/100km              |                   | ≤15kWh/100km    |
From Figure 5, under NEDC condition, the torque range of motor is between 30Nm and 70Nm, speed is from 2000 to 5000r/min, that is the efficient region of motor, the motor designed is rational. In Table 6, it is seen that requirement of dynamic and economy are satisfied.

6. CONCLUSION
The simulation result indicated that in range of gear ratio calculated, gear ratio increases, dynamic also improves, but economy descends, dynamic and economic is mutually contradictory, dynamic improves, at the same time, energy consumption also increase.

Through the power balance equation, parameters of motor is determined and range of gear ratio is determined too, and gear ratio is optimized according to simulation diagram, in order to ensure power, energy consumption reduces, the whole performance of vehicle is improved greatly, that lay foundation for whole vehicle’s development.

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