Research on Energy Consumption Test Methods of Light-Duty Pure Electric Vehicles Based on China Automobile Test Driving Cycle

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Abstract. Referring to GB/T 18386-2017, the impact of NEDC, WLTC and CLTC on the energy consumption of pure electric vehicle is simulated and analysed. Combined with the characteristic parameters of the driving cycles, from the perspective of energy flow loss of each system of the vehicle, the influences of driving cycles on the energy consumption of each part of the vehicle and the working efficiency of the power components are analyzed in detail, and the internal mechanism of the influence rule of driving cycles on energy consumption is revealed. Based on the CLTC, the effects of load mass, ambient temperature and air conditioning on the energy consumption of the electric vehicle are explored. The research results show that the electric vehicle has the longest driving range and the lowest energy consumption under CLTC; as the loading quality increases, the driving range decreases, and the energy consumption per 100 kilometers increases; test temperature and the air conditioner have a great influence on the driving range, especially in the low temperature environment.

1. Introduction
Energy consumption is the core indicator for evaluating the performance of pure electric vehicles. The energy consumption test results of pure electric vehicles are mainly related to the test cycles and test conditions used. Automotive product testing driving cycle is an important common basic technology in the automotive industry, which is the basis for vehicle energy consumption and emission testing, as well as the formulation of limit standards [1]-[2]. At the beginning of this century, in the absence of basic data accumulation, my country directly adopted the European NEDC to implement light-duty vehicle energy consumption and emission certification, which effectively promoted the development of vehicle energy-saving and emission-reduction technologies. In recent years, with the rapid growth of car ownership, my country's road traffic conditions have undergone great changes. Governments, enterprises, and the public are increasingly discovering that the energy consumption of pure electric vehicles calibrated under the current NEDC and the actual deviations are increasing [3]-[4]. In addition to the test cycles, a large amount of data shows that the test conditions of my country's current regulations are too ideal and do not consider the impact of actual driving conditions such as load, temperature, and air conditioning on energy consumption.

This paper selects a mainstream light-duty pure electric vehicle in the market as a reference prototype, and uses the method of simulation analysis to explore the impact of different test cycles and test conditions on the energy consumption of light-duty pure electric vehicles from the perspective of the energy loss of each part of the vehicle. It has certain reference significance for the further supplement and optimization of China Automobile Test Driving Cycle and the modification and improvement of energy consumption test methods. It has important theoretical guidance and practical significance for
accelerating the introduction of Chinese Automobile Test Driving Cycle, improving the label management of new energy vehicles, and improving the energy-saving technology of new energy vehicles and key components.

2. Build the whole vehicle model

2.1. Establishment of vehicle model

The basic parameters of the pure electric vehicle model in this article are shown in Table 1. Build the vehicle model in Cruise, as shown in Figure 1.

**Table 1. Basic parameters of pure electric vehicles.**

| Parameter name                      | Parameter value |
|-------------------------------------|-----------------|
| Curb mass (kg)                      | 1950            |
| Maximum mass (kg)                   | 2330            |
| Length × width × height (mm)        | 4740×1770×1490   |
| Wheelbase (mm)                      | 2670            |
| Air resistance coefficient          | 0.3             |
| Windward area (m²)                  | 2.3             |
| Total capacity of battery pack (kWh)| 64.8            |
| Maximum motor speed (r/min)         | 12000           |
| Maximum torque of motor (Nm)        | 310             |
| Maximum motor power (kW)            | 160             |
| Tire rolling radius (mm)            | 333             |
| Transmission ratio                  | 9.0             |
| Transmission efficiency (%)         | 92              |
| Accessories power consumption (W)   | 300             |

**Figure 1.** Vehicle model.

**Figure 2.** Light-duty passenger car operating curve
2.2. Validation of the model

According to the pure electric vehicle test standard "GB/T 18385-2016 Electric Vehicle Power Performance Test Method" and "GB/T 18386-2017 Electric Vehicle Energy Consumption Rate and Driving Range Test Method", the dynamic performance and economic verification of the built vehicle simulation model are carried out. The simulation results are compared with the performance indicators of the prototype, as shown in Table 2.

| Parameter                          | Performance Indicator | Simulation result |
|------------------------------------|-----------------------|-------------------|
| Maximum velocity (km/h)            | ≥160                  | 167               |
| Acceleration time per hundred kilometers (s) | ≤10                  | 8.21              |
| Maximum gradeability (%)           | ≥30                   | 35.31             |
| Driving range under NEDC (km)      | 400                   | 408               |
| 60 km/h constant speed driving range (km) | 500                   | 559               |

3. Impact of test driving cycles on driving range and energy consumption

According to the test procedure of GB/T 18386-2017, the pure electric vehicle is simulated under NEDC, WLTC, and CLTC-P (hereinafter referred to as CLTC), as shown in Figure 2. Comparing the characteristic parameters of the three test driving cycles, as shown in Table 3, it can be seen from Table 3 that the CLTC are dominated by urban and suburban travel, which have the characteristics of low average velocity, high idle speed ratio, and frequent acceleration and deceleration. The simulation conditions are set to load 100kg, the simulation temperature is 20°C, and the air conditioner is turned off. The simulation results are shown in Figure 3.

| Test driving cycle | NEDC | WLTC | CLTC |
|--------------------|------|------|------|
| Time (s)           | 1180 | 1800 | 1800 |
| Driving range (km) | 11.03| 23.21| 14.48|
| Average velocity (km/h) | 33.6 | 46.4 | 29.0 |
| Average operating velocity (km/h) | 43.50 | 53.20 | 37.18 |
| Idle speed ratio (km/h) | 22.6 | 12.7 | 22.1 |
| Maximum velocity (km/h) | 120 | 131.3 | 114 |
| Average deceleration (m/s²) | -0.75 | -0.58 | -0.49 |
| Deceleration ratio (%) | 16.60 | 28.60 | 26.44 |
| Average acceleration (m/s²) | 0.53 | 0.53 | 0.45 |
| Acceleration ratio (%) | 23.20 | 30.90 | 28.61 |

It can be seen from Figure 3 that the lowest energy consumption under CLTC is 15.44kWh/100km, NEDC is slightly higher than CLTC at 15.56kWh/100km, and WLTC energy consumption is the
highest at 17.41kWh/100km. In terms of driving range, the longest driving range of CLTC is 444km, the middle of NEDC is 408km, and the shortest of WLTC is 383km. Compared with NEDC, CLTC has increased its driving range by 8.8%, and its energy consumption has been reduced by 0.8%.

The specific energy consumption of each part under the three test driving cycles is shown in Figure 4. It can be seen from Figure 4 that the energy in the three test driving cycles is mainly used to overcome driving resistance (air resistance and rolling resistance) and motor loss. The energy consumed by driving resistance accounts for about 60% of the total energy, and the motor energy consumption accounts for about 11%.

The following will combine the characteristic parameters of the test driving cycles to analyze the energy consumption of each part in Figure 4 in detail.

3.1. The energy loss of overcoming air resistance
According to the vehicle dynamics, air resistance is proportional to the quadratic power of velocity. By comparing the characteristics of the three test driving cycles, it can be drawn that the average velocity: WLTC>NEDC>CLTC; the distribution ratio of WLTC in the ultra-high velocity zone is much larger than the other two test driving cycles, and the distribution proportion in the idle zone is much smaller than the others; CLTC has a larger distribution in the idling and low-velocity zones, and a smaller distribution in the high-velocity and ultra-high-velocity zones, so the energy loss to overcome the air resistance is WLTC>NEDC>CLTC. This is also the main reason for low energy consumption and long driving range under CLTC.

3.2. The energy loss of overcoming rolling resistance
The rolling resistance is proportional to the rolling resistance coefficient. The rolling resistance coefficient of this model has a certain relationship with the vehicle velocity, that is, the rolling resistance is related to the vehicle speed.

The rolling resistance does not change much when the vehicle velocity is less than or equal to 120km/h, and when the velocity is higher, the rolling resistance gradually increases. In the three test driving cycles, only the maximum velocity of the WLTC exceeds 120km/h, so the energy loss to overcome the rolling resistance under the three test driving cycles is basically the same, and the WLTC is slightly higher.

3.3. Energy loss of the motor
The power loss of the motor is related to the efficiency of the motor. This model uses a permanent
magnet synchronous motor, and its high efficiency area is mainly concentrated in the high speed and large torque area, and the efficiency is low under low speed and light load, low speed and heavy load, high speed and light load [5]. The motor operating points are distributed on the efficiency MAP diagram under the three test driving cycles, as shown in Figures 5-7.

Figure 5. Motor operation area distribution under NEDC.

Figure 6. Motor operation area distribution under WLTC.

Figure 7. Motor operation area distribution under CLTC.
The motor frequently works in the low-efficiency area of light load under NEDC, which leads to higher energy consumption; compared with WLTC, CLTC more points fall in the low-efficiency area of the motor; the average efficiency of the motor under CLTC and NEDC is basically the same, but the coverage area of CLTC is obviously larger than that of NEDC, indicating that CLTC can better reflect the actual operating characteristics of the vehicle.

3.4 Changes in energy consumption of various parts with test driving cycle

Figures 8 - 10 show the changes in energy consumption of each part with test driving cycles.

From Figures 8-10, it can be seen that in the high-velocity and ultra-high-velocity sections, the energy consumption of air resistance increases rapidly, and the growth rate is higher than other forms of resistance. The final air resistance energy consumption is close to the energy consumption of rolling resistance under WLTC. It shows when the velocity is high the rapid increase in air resistance is the main reason for the significant increase in the energy consumption; in the high-velocity and ultra-high-velocity sections, the energy consumption of the transmission system, motor and battery also increases significantly; The energy loss of mechanical braking in the deceleration is large, and the increase is faster when the deceleration is frequent.

4. The impact of load on driving range and energy consumption

Choose standard load (+100kg), half load (+190kg), full load (+380kg), and load 142 kg according to...
the National Sixth Standard for simulation under CLTC. The simulation results in Cruise are summarized, as shown in Figure 11. The energy loss of each part under different loading masses is shown in Figure 12.

![Figure 12. Energy distribution under different loads.](image)

It can be seen from Figure 12 that as the load increases, the driving range becomes shorter and the energy consumption becomes larger. It can be seen from Figure 12 that as the load increases, the energy consumed for overcoming the air resistance and the accessories of the vehicle is almost unchanged. And as the load of the vehicle increases, the power required by the wheels increases, and the energy loss of the motor, transmission system, and battery increases slightly, but the change is not significant. The main reasons for the change in energy consumption are to overcome the rolling resistance energy and braking energy.

5. The influence of temperature and air conditioning on driving range and energy consumption

In order to study the influence of temperature and air conditioning on the driving range and energy consumption of pure electric vehicles, based on the CLTC, the simulation was carried out in Cruise. Set the low temperature to -7°C, the heating power to 3kW, the high temperature 35°C, and the cooling power to 1.5kW. Select the General Map module to control the opening and closing of the air conditioner. This simulation set the air conditioner to run intermittently for 200 seconds. The simulation results are shown in Table 4.

| Temperature (°C) | Driving range (km) | Energy consumption (kWh/100km) |
|------------------|--------------------|-------------------------------|
| -7               | 306                | 22.17                         |
| 20               | 444                | 15.44                         |
| 35               | 377                | 18.05                         |

It can be seen from Table 4 that the energy consumption during low-temperature heating is increased by 44% compared to 20°C at normal temperature (without air conditioning), and the driving range is reduced by 31%. When high temperature refrigeration, energy consumption is increased by 17% compared with normal temperature of 20°C (without air conditioning), and the driving range is reduced by 15%. It can be seen that the outside temperature and the opening of the air conditioner have a great influence on the driving range and energy consumption of pure electric vehicles. Since the illumination under high temperature conditions and the immersion of the car under low temperature conditions during the actual test cannot be considered in the simulation process, the
simulation result is larger than the cruising range value obtained from the actual test, and the energy consumption value is lower. Draw energy flow diagrams at three temperatures, as shown in Figure 13.

It can be seen from Figure 13 that the main reason for the change in energy consumption is the energy consumption of the air conditioner and battery energy consumption. The relationship between internal resistance and SOC at three temperatures is shown in Figure 14. It can be seen from Figure 14 that as the temperature decreases, the internal resistance of the single cell increases and the energy lost by the battery's own heating increases. And at low temperatures, the temperature difference between inside and outside is large, and when the battery loses energy to the outside world higher than normal temperature and high temperature, combining the above two factors, the battery loses more energy at low temperatures.

6. Conclusion
(1) The pure electric vehicle model in this article has the longest driving range and the lowest energy consumption under the CLTC;
(2) As the loading mass increases, the driving range decreases and the energy consumption increases. The main reason is the rolling resistance and braking energy consumption increase;
(3) The temperature and air conditioner opening have a great impact on the driving range and energy consumption, especially at low temperatures.

7. References
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