Study on Environmental Adaptability of Electric Vehicle based on WLTC cycle

Bo Deng, Lu Li, Yang Ou, Yi Wang, Zhichao Zhao, Zaiqiang Meng, Qianlu Zhou
China Automotive Engineering Research Institute CO., Ltd. Chongqing, 401122, China
*Corresponding author’s e-mail: dengbo@caeri.com.cn

Abstract. By employing the energy-flow testing technique, this study probes into the environmental adaptability of electric vehicles based on the worldwide harmonized light duty driving test cycle. The following conclusions were reached. Compared with the conditions under normal temperatures, the AC system and the PTC consume 18%-20% energy of the battery, the mileage reduces by 32% to 48%, and the energy consumption per 100 km increases by 49% to 81%. From the perspective of single cycles, the total mileage divides into three stages, among which the first stage shows the largest cycle difference. A correction factor is proposed based on the energy equilibrium relations, and the correction factor for the first stage under normal, high and low temperatures are 1.022, 1.050 and 1.184 respectively. Meanwhile, the discharging internal resistance of the battery under low temperatures differs significant from those under high or normal temperatures, showing an increase by 2%-5%, while the charging internal resistance shows no significant differences.

1. Introduction
As environmental protection gains momentum around the world, it has become inevitable to reduce energy consumption, adjust the energy consumption structure and develop alternative energies to move towards a sustainable society[1-2]. Though China has caught up with the world in its fast development of electric vehicles (EVs) in these years, statistics show that EVs are mostly adopted in areas like Beijing, Tianjin, Hebei, the Yangtze River Delta and the Pearl River Delta. The major reason is that in northwestern and northeastern China where the winter with an extremely low minimum temperature lasts long, EVs have a shorter mileage and a higher energy consumption, and thus cannot meet the travelling needs of residents there. The adaptability of EVs to high and low temperatures hence become a hot research topic. Many scholars have performed studies in this regard. Xu et al.[3] probed into the adaptability of EVs to low temperatures. They selected data of batteries of six EVs in different regions, and analyzed the low-temperature performance of the batteries under varied temperatures, mileages, and driving cycles. Chen et al.[4] tested the charging and discharging performance of the battery units under different temperatures, and analyzed the impacts of the temperature on the mileage through equivalence calculation and on-site measuring. Han et al.[5] studied the adaptability of EVs to low temperatures by testing nine performance indicators of the EVs under extremely low temperatures. All these studies focused on high to improve the low-temperature performance of the batteries, but coupling with the vehicle was not performed. Based on the energy flux testing technique, this study probes into the adaptability of EVs and the vehicle’s energy consumption distribution based on the WLTC in terms of the features of single cycle to provide a basis for positive simulation.
2. Test devices and methods

2.1. Sample vehicles for testing
Table 1 shows the technical specifications, including parameters of the vehicle, the motor, the battery, the transmission, the tire, and so on.

| Category      | Name          | Unit | Parameters                        |
|---------------|---------------|------|-----------------------------------|
| Vehicle       | Unladen mass  | kg   | 1625                              |
|               | Wheelbase     | mm   | 2600                              |
|               | Drive mode    | -    | FF                                |
|               | Motor type    | -    | Permanent magnet synchronous motor|
| Motor         | Peak power    | kW   | 150                               |
|               | Maximum torque| N.m  | 360                               |
| battery       | Battery type  | -    | Li-ion                            |
|               | Battery capacity| kW.h | 60                                |
| Transmission  | Transmission type| - | Single reduction gear          |
|               | Speed ratio   | -    | 7.05                              |
| Tire          | Front wheel type| - | 215/50 R17                      |
|               | Rear wheel type| - | 215/50 R17                      |

2.2. Test devices
The test venue is a four-wheel driving rotating hub. To evaluate the energy flux distribution, the following devices are used to obtain relevant data: a data collector, current, voltage and energy flux sensors, temperature, pressure sensors. Table 2 shows the specifics of these devices.

Fig 1 The schematic diagram of energy flow test
Tab. 2 The equipment of energy flow test

| Device                          | Manufacturer | Type | Measuring range | Precision |
|---------------------------------|--------------|------|-----------------|-----------|
| Data acquisition system        | HBM          | CAN  | /               | /         |
|                                 |              | K    | /               | /         |
|                                 |              | Pt100| /               | /         |
|                                 |              | Analog| /              | /         |
| Electromagnetic Flow-meter     | Rosemount    | 8711SSA005 | 0–141L/min | ≤ ±0.5%   |
| Turbine flow-meter             | DM           | TF4-8 | 0–12L/min      | ≤±0.05%   |
|                                 |              | TF-10 | 0–60L/min       |           |
| Current sensor                 | LEM          | IT 65-S | 0–60A     | 0.03%     |
|                                 |              | IT 405-S | 0–400A    | 0.01%     |
| Voltage sensor                 | LEM          | CV3-100/SP3 | 0–85V   | 0.2%      |
|                                 |              | CV3-1000 | 0–700V   | 0.2%      |
| Temperature sensor             | Khan, w      | PT100 | 0–300°C       |           |

2.3. Testing methods
The sample vehicle is refitted as per the distribution plan of the energy flux testing sensors; the sensors are installed, and the devices are debugged. The environment of the testing rotating hub is adjusted to three temperatures, -7°C, 23°C, and 35°C to test the mileage of the vehicle based on the WLTC. The data about “motor-battery-heat-liquid” are obtained. Based on the theories of the energy flux, we obtain the transient distribution and energy distribution of the energy flux of the vehicle, and the testing scores for each single cycle are accumulated to obtain the distribution pattern of the single-cycle energy distribution. Figure 2 shows the distribution scheme of the energy flux testing sensors, and these sensors are used to measure the “motor-battery-heat-liquid” data.

![Fig.2 The schematic diagram of test sensor point of energy flow test](image-url)
3. Analysis of test results

3.1. Impact of the environment on the energy distribution of whole cycle

Table 3 shows the testing result of energy consumption of the vehicle under different temperatures. Under high and low temperatures, to ensure necessary functions and comfortability, the air conditioner or the PTC battery consumption reduces the mileage by 32% to 48%, and the power consumption per 100 km increases by 49% to 81%.

| Cycle        | Driving range (km) | Power consumption (kWh/100km) |
|--------------|--------------------|-------------------------------|
| 23°CWLTC     | 395                | 16.70                         |
| -7°CWLTC     | 204                | 30.39                         |
| 35°CWLTC     | 268                | 25.00                         |

The impact of the environment on the mileage and power consumption per 100 km is significant. Figure 3 shows the impacts of the environment on the energy flux distribution of the EV. As the figure shows, under normal temperatures, the power discharged by the battery goes mainly to the auxiliary parts, the motor (8%) and the transmission system (1.98%), and 87% of the energy can be used to keep the vehicle driving forward. During the low-temperature cycle, 19.34% of the power discharged by the battery goes to the heating PTC, 1.27% goes to the battery PTC, and 7% to the motor, and thus the power transmitted to the half axis that drives the vehicle forward is just 66.88%. In the high-temperature cycle, the power discharged by the battery goes to the air conditioning system (18.21%), the motor (7%) and the rest 70.74% can be used to keep the vehicle driving forward.

3.2. Impacts of the environment on the energy distribution of every single cycle

Figure 4 shows the energy consumption of the vehicle in different cycles throughout the mileage, i.e., the single-cycle energy flux characteristics. As Figure 4 a) shows, under normal temperatures, the energy consumption shows no significant changes in the whole cycles throughout the mileage and the battery discharging process can be divided into three stages. The first cycle is the first stage, the second cycle to the 10th cycle comprise the second stage, and the 11th to the 17th cycle comprise the...
third stage. In the first stage, the battery discharging power and the input power of the motor controller is high, the major reason of which is that when the vehicle is started, the temperature of the tire, the bearing system and the lubrication system is low, leading to a “cold” start; in the second stage, the power consumption of each part remains largely unchanged and is lower than that in the first stage. In the third stage, however, the battery discharging power and other power consumption reduce.

Figure 4 b) and c) reveal that under high and low temperatures, there are also three stages, but the corresponding number of cycles changes. Under high temperatures, the power consumption of the motor controller is the same as under the normal temperatures, and the power consumption of the air conditioner fluctuates between 0.88 and 1.1 kWh. Under low temperatures, the power consumption of heating PTC first declines from 1.5 kWh before levelling off at 1.2 kWh. That’s because a vehicle long exposed to low temperatures needs more heat. The battery PTC power consumption occurs in the first cycle, at 0.5 kWh, and consumes no power in the later cycles, because when the first cycle ends, the temperature of the battery has already reached the working temperature.

In sum, the power consumption of the EV differs in different cycles, and the differences in the first cycle is most drastic. Thus, a correction factor is calculated based on the energy equilibrium relations. The correction factor in the first cycle for the normal temperature condition, the high temperature condition and the low temperature condition is 1.022, 1.050 and 1.184, respectively, which provides a basis for economical simulation of vehicles of the same model.
3.3. Impacts of the environment on the battery’s performance
The battery is the major energy storage tool of the EVs and is the key to analysis of the vehicle’s adaptability to the environment. By analyzing the working site of the battery driving and braking in a single cycle, this study fitted the internal resistance of the battery during charging and discharging based on the battery SOC, as shown in Figure 5. As Figure 5 a) shows, the battery internal resistance is high on both ends but low in the middle as the SOC decreases; when the SOC is high, the internal resistance of the battery remains largely unchanged at a middle value as the SOC reduces; when the SOC is at a medium-and-low value, the internal resistance of the battery first decreases and then levels off as the SOC decreases; when the SOC is low, the internal resistance rises as the SOC increases before reaching the maximum. The lower the temperature is, the higher the internal resistance of the battery is. In normal- and high-temperature cycles, the internal temperature of the battery is above 20 ℃, and the fitted discharging internal resistance is largely the same; in low-temperature cycles, the temperature of the battery is 0-11 ℃, and internal resistance is 2-5% higher than that under normal temperatures.

As Figure 5 b) shows, within a high- or normal-temperature high- or medium-SOC range, the discharging internal resistance remains largely the same around 0.02; in a low-SOC area, the charging internal resistance climbs up. In a low-temperature cycle, the charging internal resistance is slightly higher than in a normal- or high-temperature cycle.
4. Conclusions

Based on theories of energy flux, this study tested the energy flux of sample electrical vehicles under different environments, and analyzed the EV’s adaptability to the environment. The following conclusions were drawn.

1) Compared with the conditions under normal temperatures, the air conditioning system and the PTC consumes 20% of the energy released by the battery under high and low temperatures, leading to a decrease of 32%-48% in the vehicle’s mileage, and an increase of 49% to 81% in the energy consumption per 100 km.

2) The impact of the environment on the single cycle is analyzed, and a correction factor is proposed based on the energy equilibrium theory to provide a statistical basis for cost-efficient development of vehicle models. The correction factors for normal-temperature, high-temperature and low-temperature conditions are 1.022, 1.050 and 1.184.

3) The impact of the environment on the battery’s performance is analyzed. Under low temperatures, the discharging internal resistance of the battery differs significantly from that under normal and high temperatures, with an increase of 2%-5%; while the charging internal resistance barely shows any difference.
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