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Research Article

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Research on Internal Resistance Characteristics and Thermal Characteristics of 18650 Lithium-ion Power Battery

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Abstract Understanding the internal resistance and thermal characteristics of lithium-ion power batteries is crucial to give full play to the battery performance. This paper takes 18650 lithium-ion power battery as the research object, and accurately measures the ohmic internal resistance and polarization internal resistance of lithium battery at different ambient temperatures and charge states through the experiments of thermal properties of battery internal resistance and temperature rise characteristics, and at the same time measures the temperature changes under different discharge multipliers and ambient temperatures. The results show that the internal resistance of Li-ion power battery is greatly affected by the ambient temperature and SOC, and the internal resistance of the battery increases with the decrease of SOC and the decrease of ambient temperature. The battery temperature exceeds the safe range when the lithium battery is cooled only by natural convection under high temperature environment or high-rate discharge condition, and it needs to be cooled by thermal management system.

Keywords lithium-ion power battery, internal resistance characteristics, thermal characteristics

1. Introduction

With the rapid development of electric vehicles, lithium-ion power batteries, which are the main power source of electric vehicles, have received widespread attention [1-3]. The performance of the power battery is greatly affected by temperature, and its optimal operating temperature range is 20~45°C, and the temperature is too high or too low to the performance and cycle life of the battery to a certain extent [4]. Lithium-ion batteries generate a large amount of heat during operation, which can cause thermal runaway accidents if not evacuated in time, so it is crucial to understand the internal resistance characteristics and thermal characteristics of batteries under different operating conditions.

Many scholars have carried out research on the internal resistance and thermal characteristics of lithium-ion power batteries. Onda et al. [5] measured the internal resistance and entropy change of lithium-ion batteries using a variety of methods to calculate the temperature rise and the heat generation rate of the battery in the discharge process, and the calculated results match well with the temperature rise measured by thermocouples and heat generation rate measured by calorimeters in the experiments. Bernardi et al.[6] established the heat generation equation of the battery based on the thermodynamic energy balance principle, pointing out that the heat generation of the battery mainly consists of four parts, including irreversible heat, reversible heat, heat of chemical side reaction and heat of polarization reaction, and investigated the influence of electrochemical reaction, phase transition, mixing effect and Joule heat on the temperature distribution of the battery, and Bernardi's model is one of the most commonly used models for calculating the heat generation rate of the battery. Inui et al. [7] proposed a model for 18650 Li-ion batteries. 18650 lithium-ion battery, proposed a two-dimensional heat generation model, numerically calculated the temperature change of the battery under different discharge multiplicity conditions, and compared with the experimental test results, and found that the temperature difference between the two was kept within 0.6 K, which verified the accuracy of the simulation model. Sato [8] corrected the two-dimensional model of porous electrodes, and proposed that the heat generation of a battery consists of four parts, i.e., the ohmic heat, the polarization heat, the reaction heat, and the side reaction heat, heat of reaction and heat of side reaction. This model has been widely used to study the electrochemical and thermal performance of Li-ion batteries. Saw et al [9] studied the discharge performance of Li-FePO4 batteries based on a two-dimensional electrochemical-thermal coupling model, and found that the heat of reaction is the main source of heat at low discharge multiples.LI et al [10] developed an electrochemical-thermal model for commercial Li-ion batteries and predicted the electrochemical and thermal behaviors of the batteries during discharge. DU et al [11] discussed the process of irreversible heat generation in Li-ion batteries. Du et al [11] discussed the process of irreversible heat generation in lithium-ion batteries, and found that the anode particle size has a significant effect on the generation of irreversible heat. Lyu et al [12] investigated the positive correlation between lithium battery heat generation and discharge multiplicity by numerical simulation, and proved the reliability of the simulation study through physical experiments.

In this paper, NCM18650 lithium-ion power battery is selected as the research object, and the internal resistance characteristics at different ambient temperatures and state of charge (SOC), and the temperature rise characteristics at different discharge multipliers and ambient temperatures are investigated through the battery internal resistance test experiments and the battery thermal characterization experiments.

2. The Experimental Platform and Methods

2.1 Experimental platform construction

(1) Experimental object: currently widely used lithium-ion power batteries are mainly lithium iron phosphate and lithium ternary batteries, of which lithium ternary batteries have the advantages of high energy density and excellent performance in low-temperature environments compared with lithium iron phosphate batteries. Therefore, 18650 type ternary lithium-ion batteries are selected as the object of study, and their appearance, specific specifications and performance parameters are shown in Figure 1 and Table 1.

Figure 1： 18650 lithium-ion battery

Table 1： Specification parameter of 18650 lithium-ion battery

Parameter Name	Value
Battery size (diameter*height)	18mm*65mm
Weight	45g
Nominal Capacity	2500mAh
Nominal Voltage	3.7V
Charge cut-off voltage	4.2V
Discharge cut-off voltage	2.5V
Maximum discharge rate	12C
Maximum discharge current	30A

(2) Experimental system: The test experiment system is shown in Figure 2. The experimental platform is mainly composed of lithium-ion power battery, temperature monitoring and recording system and battery charge/discharge control system. The high and low temperature experimental chamber in the experimental system provides a constant temperature for the battery during the working process, simulating different external environments. The temperature control range of this equipment is -40~150°C, the heating rate is 3°C/min, the cooling rate is 1°C/min, and the temperature control accuracy is within 5%. Battery charge/discharge tester has 8 channels to realize constant current and constant voltage charge/discharge, constant power charge/discharge and other experimental conditions. The temperature monitoring equipment adopts K-type thermocouple temperature sensor and temperature recorder, which mainly monitors the temperature change of the battery in the working process and prevents the thermal runaway phenomenon from occurring when the temperature of the battery is too high. Battery in the working process of positive and negative pole heat production is significantly higher than other positions, so in the battery's positive pole, negative pole and the middle of the installation of a k-type thermocouple, the specific location of the monitoring point as shown in Figure 2 (b), through the temperature recorder to accurately record the surface temperature of the battery in the process of work changes. Put the battery monomer into the high and low temperature experimental chamber and connect the charging and discharging equipment as well as the temperature recorder.

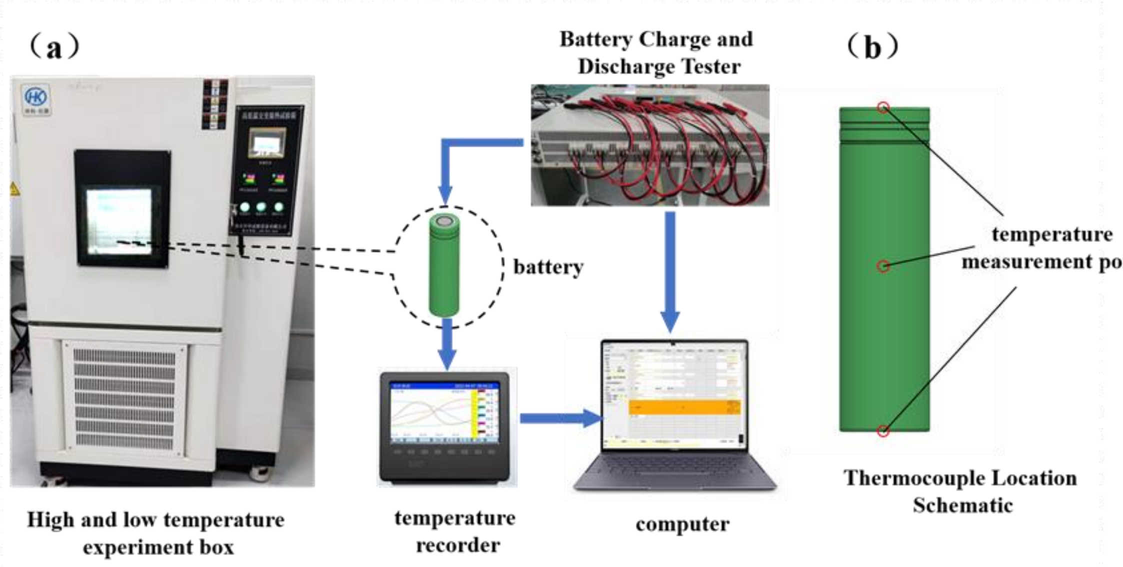

Figure 2： Battery measurement system

2.2 Principle of internal resistance test

It can be seen from the heat generation mechanism of Li-ion power battery that the polarization heat and ohmic heat of the battery are the main sources of heat generation of the battery. At the same time, according to Bernardi battery heat generation rate equation, accurately obtaining the ohmic internal resistance and polarization internal resistance of the battery is the key to accurately obtain the battery heat generation rate. Currently, the most widely used method for obtaining the internal resistance of Li-ion batteries is the hybrid pulse power characterization method, which is mainly used to test the pulse power capability of batteries at a specific temperature and SOC state with different charging and discharging pulse currents. The main working principle is shown in Figure 3. In the battery internal resistance measurement experiment, the battery is set at a specific temperature and SOC state, and a specific pulse current is applied to the battery through the external battery charging and discharging system to carry out constant-current discharging (the figure shows the application of a t1~t2 constant discharging current with a constant discharge current of 1C multiplication for a continuous period of 10s), and the voltage of the battery at this time under the action of the pulse current will At this time, the voltage of the battery under the action of the pulse current will produce a step response (the battery voltage changes from U1 to U2 in the figure), this part of the voltage step response is due to the existence of the ohmic internal resistance; after that, the voltage of the battery produces a small increase in the voltage (the voltage changes from U2 to U3 in the figure), this part of the voltage changes slowly because of the existence of the polarization internal resistance. Through the difference of battery voltage change and the magnitude of constant discharge current, according to Ohm's law, we can find the polarization internal resistance, ohmic internal resistance and total internal resistance in this state.

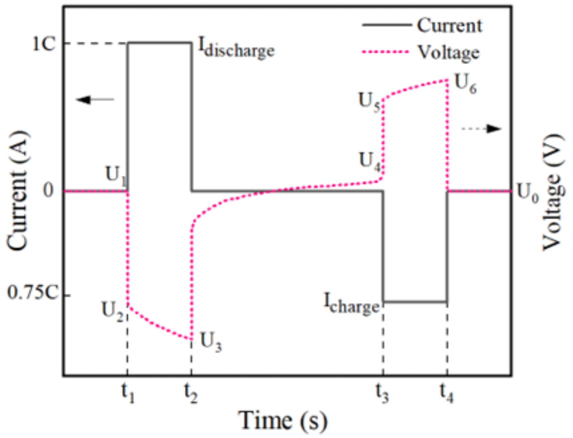

Figure 3： Battery Internal Resistance Measurement Schematic

3. Results and Discussion

3.1 Measurement results of battery internal resistance

Through the calculation and processing of the above data results, the total internal resistance of lithium batteries at different ambient temperatures and SOC are obtained as follows:

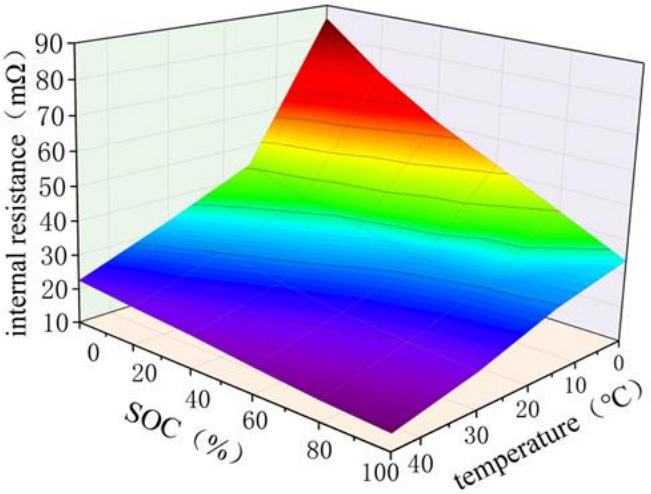

Figure 4： Total internal resistance of the battery

Figure 4 illustrates a cloud plot of the total internal resistance of the battery versus temperature and the SOC of the battery. From the figure, it can be seen that the internal resistance of the battery is greatly affected by temperature and SOC. As the SOC of the battery decreases, the internal resistance of the battery increases, when the SOC is reduced from 100% to 0, the internal resistance increases by 52.06 mΩ (153.4%) at a temperature of 0°C, and at a temperature of 45°C, the internal resistance increases by 7.78 mΩ (52.7%); the internal resistance of the battery also increases with the reduction of the ambient temperature, and when the temperature is reduced from 45°C to 0°C, the internal resistance of the battery increases by 7.78 mΩ (52.7%). SOC of 100%, the internal resistance increased by 19.2 mΩ (130.0%); at SOC of 0, the internal resistance increased by 63.46 mΩ (281.7%).

3.2 Maximum temperature change of batteries with different discharge multipliers

The experimental data of temperature rise of single battery is exported from the temperature recorder and processed to obtain the temperature change curve of the battery working at 25°C ambient temperature with different discharge multiplication rates, as shown in Figure 5.

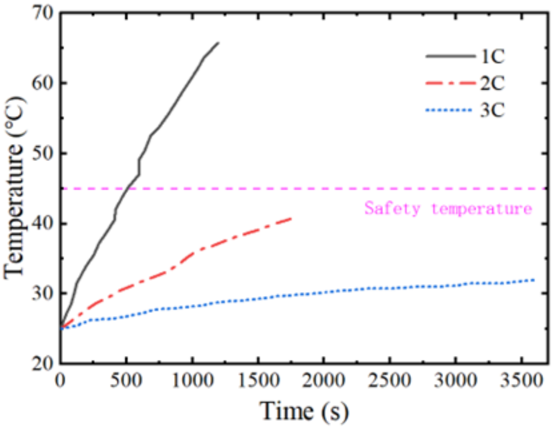

Figure 5： Battery Temperature Changes at Different Discharge Ratios

As can be seen from the figure, the maximum temperature on the surface of the battery is increasing with the increase of the discharge time during the working process. When the battery is working at 1C discharge multiplier, the temperature of the battery grows slowly, and the discharge time is about 3600s when the discharge ends. The maximum temperature of the battery surface at the end of the discharge time reaches 31.4°C, and the temperature increases by 6.4°C. When the battery is working at 2C discharge multiplier, the temperature of the battery rises at an increased rate, and the discharge time ends at about 1800s, at which time the maximum temperature of the battery reaches 40.6°C, and the temperature rises by 15.6°C. When the battery is working at 3C discharge multiplier, the discharge time continues to be about 1200s, and the maximum temperature of the battery at the end of the discharge time is about 3600s, and the maximum temperature of the battery at the end of the discharge time is about 3600s. When the battery is operated at 3C discharge rate, the discharge time lasts for 1200s, and the maximum temperature of the battery reaches 65.4°C at the end of discharge, and the temperature rises by 40.4°C. The rate of heat generation of the battery has a square growth relationship with the discharge current, and the rate of heat generation will be quadratic under the same environmental conditions with an increase of the discharge current. With the increase of the discharge rate, the discharge time of the battery with the same amount of power will be shortened, and the heat production of the battery will be increased. As the thermal and physical parameters of the battery remain unchanged, the larger the discharge multiplier, the rate of temperature increase is also rapidly accelerated. The optimal working temperature range for lithium batteries is 20~45°C. Therefore, at 25°C ambient temperature, when the battery is working at 3C and above discharge rate, the thermal management system needs to dissipate the heat for the battery pack to ensure the working performance and safety performance of the battery pack.

3.3 Maximum battery temperature change at different ambient temperatures

The experimental data of temperature rise of single battery is exported from the temperature tester, and data processing is carried out to obtain the temperature change curve of the maximum temperature of the battery temperature monitoring point with the discharge time when the ambient temperature is 25°C, 30°C, 35°C and 40°C respectively, as shown in Figure 6.

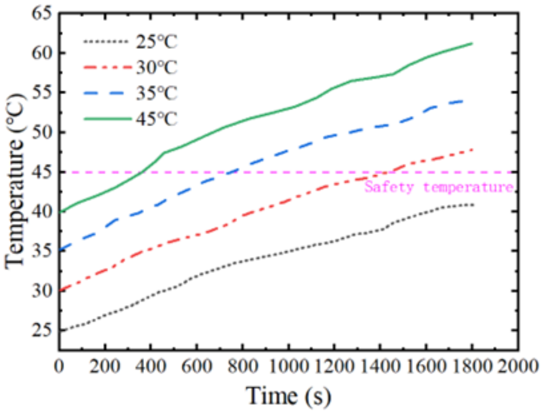

Figure 6 : Battery temperature change under different ambient temperatures

As can be seen from the figure, the temperature rise of the battery varies when the Li-ion battery is discharged at 2C multiplication rate at different ambient temperatures. At ambient temperatures of 25°C, 30°C, 35°C and 45°C, the maximum temperature of the battery increases by 15.6°C, 17.2°C, 18.9°C and 20.6°C. With the increase of the ambient temperature, the maximum temperature of the battery increases with the same discharge multiplication rate, which indicates that the increase of the ambient temperature enhances the chemical reaction rate inside the battery and increases the heat generation. When the ambient temperature is 30°C and above, the battery pack will exceed the safe working range of the battery pack if it is operated at 2C discharge rate. Therefore, when the battery is discharged at a high rate in a high-temperature environment, the risk of thermal runaway of the battery pack increases dramatically, and it is even more necessary for the thermal management system to control the battery temperature in a reasonable manner.

4. Conclusions

(1) The internal resistance of the lithium-ion power battery is greatly affected by the ambient temperature and SOC, with the decrease of the battery SOC, the internal resistance of the battery increases continuously, when the SOC is reduced from 100% to 0, the internal resistance increases by 52.06mΩ and 7.78mΩ at the temperatures of 0°C and 45°C, respectively; the internal resistance of the battery also increases with the decrease of the ambient temperature, when the temperature is reduced from 45°C to 0°C, the internal resistance of the battery increases by 19.2mΩ and 63.46mΩ at the SOC of 100% and 0, respectively. C, the internal resistance increases by 19.2mΩ and 63.46mΩ at SOC of 100% and 0, respectively.

(2) At the same ambient temperature, the discharge time of the lithium-ion power battery decreases with the increase of the discharge multiplier. At an ambient temperature of 25°C, the maximum temperature of the battery surface reaches 31.4°C, 40.6°C and 65.4°C for 1C, 2C and 3C discharge multipliers, respectively, and the maximum temperature of the battery with 2C discharge multiplier is increased by 15.6°C, 17.2°C, 18.9°C and 20.6°C for ambient temperatures of 25°C, 30°C, 35°C and 40°C. Therefore, when the battery is in a high ambient temperature, the maximum temperature of the battery with 2C discharge multiplier is increased by 15.6°C, 17.2°C, 18.9°C and 20.6°C, respectively. Therefore, when the battery is discharged at high ambient temperatures or high multiples, natural convection heat dissipation cannot meet the thermal management requirements.

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