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An Improved Method for Estimating the Charged State of Power Lithium Batteries

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Abstract

In order to solve the traditional Ann-open circuit voltage method charged state (state of charge, SOC) initial SOC0 error is big,ignored in the process of estimating temperature factors effect on the estimate accuracy, puts forward the improved Ann integral-open circuit voltage method: according to the experimental data under different temperature, cycle times, fitting the SOC and open circuit voltage (open circuit voltage, OCV), a function of temperature, the use of times, so as to obtain the accurate SOC0;The influence of temperature, discharge rate and frequency of use on ampere-hour integral was analyzed, and modified and optimized.Experimental results show that the improved ampere-open-circuit voltage method can improve the estimation accuracy to 97%.

Keywords

SOC estimation; Amp-open circuit voltage method; Power lithium battery; Ambient temperature; Cycle times.

1. Introduction

With the increasingly serious energy and environmental problems, electric vehicles have been widely developed.China's new-energy passenger vehicle sales in 2017 reached 98,366 units, up 132% year on year and 21.8 percent month-on-month, according to the China Passenger Federation.Due to its advantages of high energy density, high specific energy, low pollution, low self-discharge rate and no memory effect, lithium ion battery has become the preferred power source of electric vehicles, and thus has become a research hotspot in the field of electric vehicles.

As an important parameter of battery, the lithium-ion battery charged state (SOC) has always been the focus and difficulty in battery research.Said the battery SOC can provide actual power and the ratio of the rated capacity, battery can be drawn from the current status of the remaining power, at the same time is the electric car charge and discharge control and dynamic optimization management link of one of the key parameters, the use of power battery life, automobile power performance and range prediction has important influence [1].

At present, domestic and foreign studies on SOC have been relatively mature, and the main estimation methods include open-circuit voltage method, amping-hour integral method, kalman filtering method [2,3], neural network method [4,5] and internal resistance measurement method, etc..The latter three methods have a great advantage over the former two in theory, but the open-circuit voltage method and ampere hour integral method are more commonly used in engineering applications.Neural network method needs a lot of training data, and the size of estimation error depends largely on the correct selection of data and the appropriate training method.Kalman Filter (KF) method of the state equation and the selection of the observation equation are very complex;The defect of internal resistance measurement method lies in that, for multiple battery packs in series and parallel, the quantity demand of independent internal resistance measurement circuit becomes more and more,

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The measurement precision is very high, the circuit is complex and the cost is high.To this end, the open circuit voltage method and ampere-time integral method, which are easy to be realized and controlled, are selected to estimate SOC: according to the experimental data, the influence of temperature and aging factors on SOC-OCV SOC- open circuit voltage curve is quantified, and modified to obtain accurate SOC0 (initial value of SOC state).The influence of temperature, discharge rate and frequency of use on ampere - hour integral was analyzed, and modified and optimized.

2. Traditional ampere-hour open circuit voltage method

The conventional amp-open circuit voltage method can be expressed as:

$$\mathrm{SOC}_t = SOC_0 - \frac{1}{C_N}\int_0^t I dt \tag{1}$$

In equation (1): SOC_0 is the charged state at the starting time (t_0), and its value is provided by the open circuit voltage method;C_N is the rated capacity of the battery pack;I is the charge and discharge current, the discharge is positive, and the charge is negative.This method only considers two factors, charging and discharging current and time, so the measurement is simple and easy to achieve [6].The disadvantage is that the influence of other factors on SOC estimation process is ignored, resulting in the decrease of SOC estimation accuracy.The main influencing factors of SOC estimation can be briefly described as follows:

(1)Ambient temperature.When the temperature rises, the chemical reaction inside the battery will become violent, which will increase the actual battery power output. However, if the temperature is too high, the chemical reaction inside the battery will be inhibited, resulting in the degradation of the battery performance.As the temperature drops, the chemical reaction inside the battery weakens and the actual amount of energy released will decrease.

(2)Cycle times.The side effects of lithium ion generation or consumption will lead to the change of battery capacity balance, which is irreversible, and will have a serious impact on the battery cycle performance through the accumulation of multiple cycles.The internal causes of this effect include the deposition of lithium metal, the decomposition of positive electrode materials, and the formation of solid Electroly Interface (SEI) membrane on the electrode surface.With the increase of the cycle times of lithium batteries, the internal resistance will increase and the capacity will decrease.

Discharge ratio.Without considering other factors, the discharge capacity of the battery is inversely proportional to the discharge ratio of the battery.There are a lot of side reactions in the battery, which are aggravated by the large discharge current and affect the transfer of lithium ion.That is, when the large current discharge, the available capacity of the battery will be smaller, making the battery utilization greatly reduced.

(3)The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

3. Improved ampere-hour-open-circuit voltage method

Based on the shortcomings of traditional ampere-open voltage method, an improved ampere-open voltage integration method is proposed. In practical application, the battery capacity is affected by

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current temperature, charge and discharge ratio and battery aging factors, and the expression of SOC is calculated more accurately as follows

$$\mathrm{SOC}_t = SOC_0^* - \frac{1}{\eta C_N}\int_0^t Idt + C_s(i,T,t) + C_t(i,T,t) \tag{2}$$

In Equation (2), SOC_0* refers to the initial SOC value considering the influence of temperature and aging factors on THE SOC-OCV curve. The traditional initial SOC value estimation method reads the initial SOC value according to the SOC-OCV curve in the ideal state, without considering the influence of temperature and battery cycle times on the curve, which may cause deviation in practical application [7].C_N represents the rated capacity of the battery;$\int_0^t Idt$ Represents the amount of energy discharged by the battery with current i during the period of 0 ~ t;C_s(i, t, T) represents the capacity loss caused by battery self-discharge, C_i(i, t, T) represents the capacity loss caused by temperature, and represents the influence coefficient of aging factor and discharge ratio on battery capacity.

Based on the above analysis, temperature, discharge ratio and battery aging need to be compensated and corrected in the estimation algorithm of SOC. The corrected estimation formula is

$$\mathrm{SOC}_t = SOC_0^* - \frac{1}{C_N}\int_0^t k_1k_2k_3Idt \tag{3}$$

In Equation (3), k_1 represents the temperature compensation coefficient;k_2 is the discharge ratio compensation coefficient;k_3 represents the compensation factor for the number of cycles.

3.1 The determination of SOC_0*

SOC_0^* is determined by the functional relation fitted by experimental data (the influence of temperature and cycle times on SOC-OCV curve).

3.2 The determination of k_1

According to the most commonly used temperature compensation formula:

$$\mathrm{k}_1 = 1 + 0.008(T_a - T) \tag{4}$$

The value of k_1 can be determined. In Equation (4), T_a represents the standard temperature;T stands for set temperature.The compensation formula of temperature factor to SOC is

$$C_T = \mathrm{k}_1 C_B \tag{5}$$

In Equation (5) : C_B is the battery capacity at standard temperature;C_T represents the battery capacity at temperature T.

3.3 The determination of k_2

The relation formula of usable power and discharge current obtained from Peukert equation is

$$K = AI^{n-1} \tag{6}$$

In Equation (6), I is the discharge current;A is the battery constant number related to the active substance;N is the structure constant of the battery (generally 1.15 ~ 1.42).If the initial conditions are the same, the values of A and n are the same, therefore:

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$$k_2 = \left(\frac{I}{I_N}\right)^{n-1} \tag{7}$$

IN Formula (7) : I_N is the rated current.

3.4 The determination of k_3

The aging process of the battery is simplified as a linear process, and then:

$$k_3 = \left(\frac{C}{C_N}\right) \tag{8}$$

In Equation (8) : C represents the current capacity of the battery.

Compared with the traditional amp-OPEN circuit voltage method, this method can greatly improve the accuracy of SOC estimation.

4. Subjects and equipment

4.1 The subjects

The 18650 lithium battery produced by Panasonic was selected for the experiment, and the specific information is shown in Table 1

Table 1 Detailed information of battery

Parameter	Value
rated capacity/(mA·h)	2900
Rated voltage/V	3.6
charging voltage	4.2
Discharge cutoff voltage/V	2.5
Internal resistance/Ω	20

4.2 Experimental equipment

The experimental equipment includes LRH --CL /CA /CB series low-temperature incubator (thermostat), WT1600 digital power meter produced by Yokogawa Of Japan, ARRAY3710A programmable electronic load, Chroma charger and computer, as shown in Figure 1.

Fig. 1 Test platform

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5. Determination of compensation coefficient

In the experiment, SOC was 1 when the charging current was reduced to 5% of the rated current.When the discharge voltage decreases to the discharge cut-off voltage, SOC is 0.The open-circuit voltage method is to estimate SOC by measuring the open-circuit voltage of the battery according to the corresponding relation between the open-circuit voltage of the battery and the battery discharge depth.At a constant temperature of 25 ℃, the battery is set to rest at different SOC initial values, and the terminal voltage changes are shown in Figure 2. After 10 min, the change is very small, but remains unchanged after 100 min, and then the terminal voltage of the battery is the open-circuit voltage.Therefore, the battery standing time was set as 2h in the experiment.

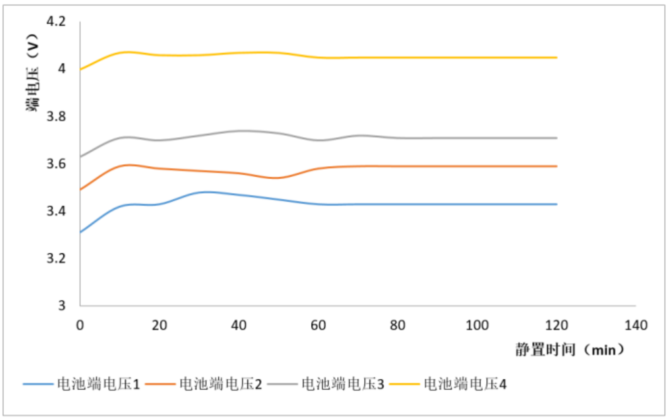

Fig. 2 Varying curve of battery voltage under different SOC0

5.1 Open circuit voltage compensation

According to the analysis, the ampere-hour integral method has a high dependence on the initial value of SOC, which is verified by using the method of constant current discharge: under the constant temperature of 25 ℃, the battery is discharged with a constant current of 1C, and the SOC curve under different initial values is obtained, as shown in Figure 3.It can be seen from FIG. 3 that the curve of SOC differs greatly from the initial value of SOC [8].

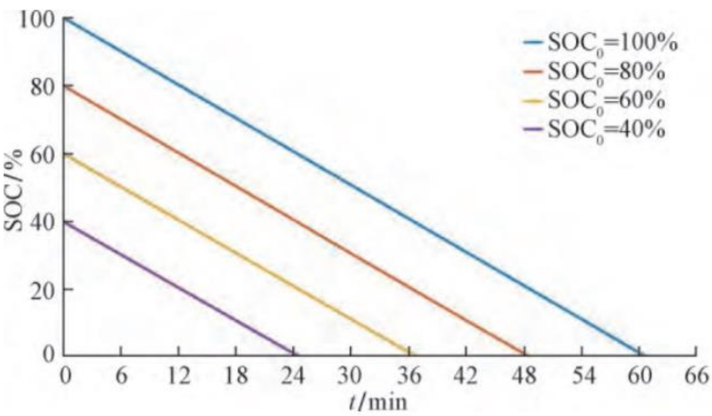

Fig. 3 Discharge curve under different initial value of SOC0

The initial SOC value of the ampere-open voltage method is obtained according to the SOC-OCV curve relation, while the SOC-OCV curve obtained by the traditional open voltage method is less accurate.In order to solve this problem, literature [9] proposed an OcvKalAh method: Kalman filtering method was used for SOC_0 calculated by open-circuit voltage method, which made it rapidly

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convergent to the truth value. SOC_1 was obtained at the end of Kalman filtering method, and SOC_1 was used as the initial value in subsequent calculation.The disadvantage of this method is that the Kalman filtering relies on the accurate battery model and the calculation process is complex.In order to solve this problem, the reasons for the low accuracy of SOC-OCV curve are analyzed. The main reason is that the influencing factors such as temperature and number of cycles are not taken into account when determining the curve.

5.1.1 Influence of temperature on SOC-OCV curve

SOC-OCV curves at different temperatures were obtained by using constant current discharge method. The experimental steps are as follows.

(1) Put the zero-power battery in a constant temperature environment and let it stand for 2 hours, so that the battery temperature is consistent with the ambient temperature.

(2) Use 1 C current to charge the battery to a full charge state.

(3) After standing for 2 h, the current terminal voltage is measured as open circuit voltage.

(4) Discharge 10% at a constant current of 1 C, and measure the open-circuit voltage after standing.

(5) Repeat step (4) until the battery is discharged.

(6) Change the ambient temperature and repeat steps (1) ~ (5).

Thus, the SOC-OCV curve at different temperatures is shown in FIG.4. The corresponding relationship between OCV(open circuit voltage) and SOC is different at different temperatures.In the 0~30% SOC range, the higher the temperature is, the lower the curve will be.For SOC interval of 80% ~100%, the higher the temperature is, the higher the curve is.In the SOC range of 30%~80%, temperature has relatively small influence on the curve [10].

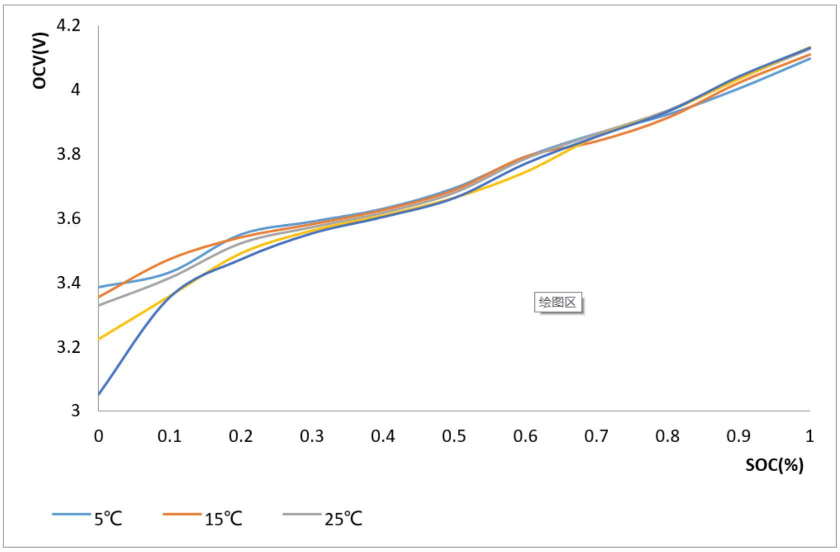

Fig. 4 Curve of SOC-OCV under different temperature

MATLAB was used to fit the experimental data, and the functional relationship between SOC and open circuit voltage and temperature could be obtained:

$$SOC = 5214 + 14.51X - 4628Y + 1324Y^2 - 0..3441X^2 - 6.59XY + 0.001X^2Y + 0.732XY^2 - 121.8Y^3, R^2 = 0.2571 \quad (9)$$

In Equation (9), X represents the open circuit voltage;Y is temperature;R_2 represents the sum of the squared errors of the fitting formula.

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5.1.2 The influence of aging factors on SOC-OCV curve

Under the constant temperature environment of 45 °C, the battery was charged and discharged with constant current at the rate of 1 C, and the cycle was carried out for 100 times. Experiments (3) ~ experiments (5) were carried out in section 5.1 and section 5.1 of section 10, 20, 40, 70 and 110, respectively, and 5 corresponding curves of SOC-OCV were obtained.

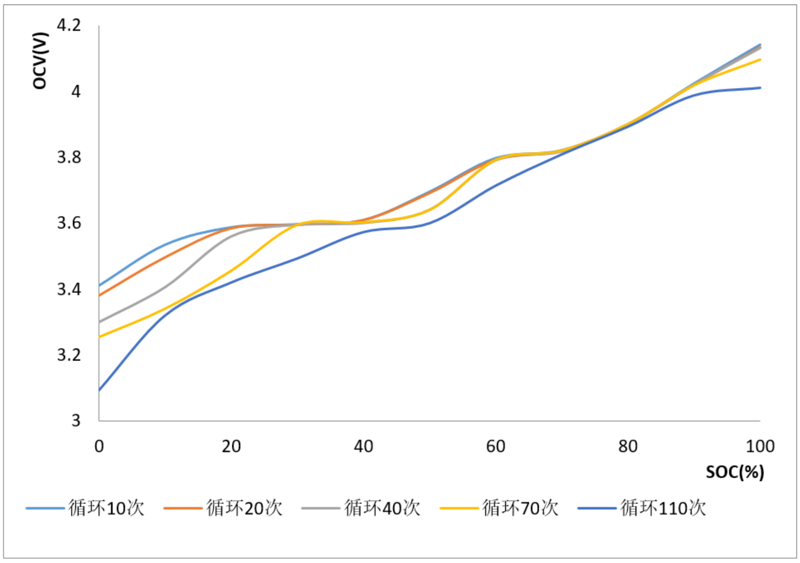

Fig. 5 Curve of S0C-OCV under several numbers of usage

As can be seen from FIG. 5, the SOC-OCV curve becomes lower and lower with the increase of battery cycle use times. The reason is that the increase of battery use times will lead to the change of the material inside the battery, which will lead to the decrease of the total capacity of the battery.According to the analysis of experimental data, the functional relationship between SOC and usage times can be obtained:

$$\begin{cases} SOC = 4.021 + 10^5 X - 5.114 \times 10^5 Y + 2088XY + 0.4512X^2 - 316.5Y^5 \\ +2.463 \times 10^5 Y^2 - 827.5XY^2 - 5.858 \times 10^4 Y^3 - 0.007951X^2Y^3 + \\ 145.4XY^3 + 6868Y^4 + 9.562XY^4 - 0.3533X^2Y + 0.09196X^2Y^2 \\ R^2 = 2.2689 \end{cases} \tag{10}$$

In Equation (10), X represents the number of cycles;Y said OCV;R^2 is the sum of squared errors.

To sum up, according to the experimental data at different temperatures and times of cycle use, the compensation relation of SOC to the influencing factors of temperature and times of cycle use was obtained.Therefore, the SOC_0^* in Equation (3) can be obtained by combining equation (9) and Equation (10), which can provide a more accurate initial SOC value for the calculation of ampere hour integration method.

5.2 Temperature compensation factor

Other conditions remain unchanged. Carry out 1C charging experiment on the battery at different temperatures. The experimental steps are consistent with experiments (1), (2) and (6) in Section 5.1.1

It can be seen from FIG. 6 that, in the range of 5~45℃, the charging capacity increases as the temperature rises.In the range of 45~55℃, the charging capacity decreases with the increase of temperature.That is, when the temperature rises, the chemical reaction inside the battery intensifies, and the amount of electricity available increases with it. However, when the temperature is too high, the internal chemical reaction will be inhibited, and the performance will be reduced, and an explosion

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will occur in severe cases.According to the fitting curve, the functional relationship between SOC and temperature can be obtained, and its expression is as follows:

$$\begin{cases} k_1 = -1.192 \times 10^{-7}T^5 + 1.74 \times 10^{-7}T^5 - 0.0012T^3 + 0.03458T^2 + 0.0345T + 79.21 \\ R^2 = 1.6156 \times 10^{-27} \end{cases} \tag{11}$$

In Equation (11), T represents temperature;R^2 is the sum of squared errors.

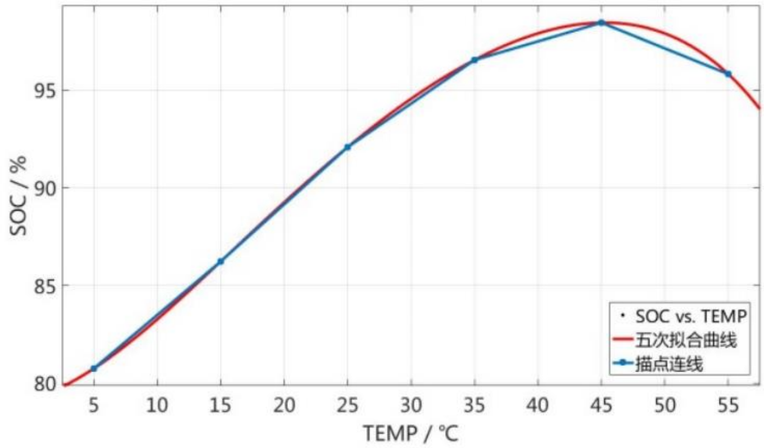

Fig. 6 Charging capacity under different temperature

5.3 Charge-discharge ratio compensation coefficient

At a constant temperature of 25℃, discharge experiments with a C multiplier of 0.5, 1 and 2 were carried out on the battery with the same amount of power, and the power discharged by the battery was shown in Figure 7.As can be seen from FIG. 7, the discharge capacity gradually decreases with the increase of discharge ratio.When discharging at a rate of 0.5C, the discharge capacity can reach 101.5% of the rated capacity. Therefore, the discharge rate is an important factor influencing SOC estimation.According to the above experimental data, the quadratic fitting curve of SOC and discharge ratio can be obtained, and the relation coefficient 2 between SOC and discharge ratio is as follows:

$$\begin{gathered} k_2 = 2.867I^2 - 9.7I + 105.6 \\ R^2 = 1.8175 \times 10^{-27} \end{gathered} \tag{12}$$

In Equation (12), I represents the discharge ratio;R2 is the sum of squared errors.

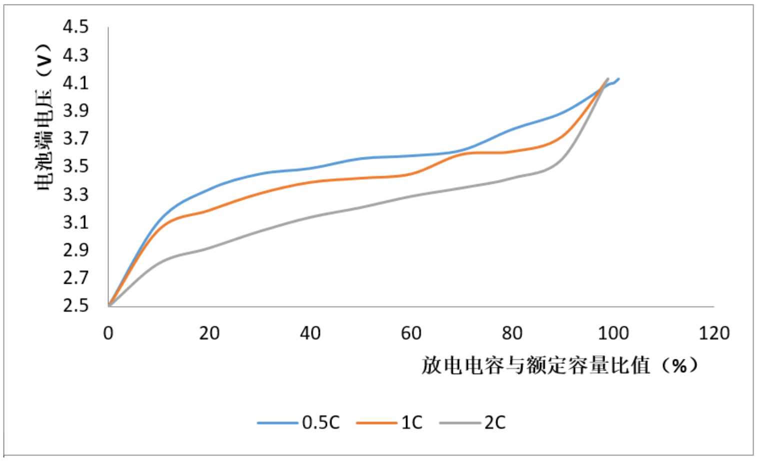

Fig. 7 Discharging capacity under different discharging rate

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5.4 Aging factor compensation coefficient

With the increase of the number of USES, the total capacity of the battery continues to decay. When the battery is used 100 times, the capacity has been reduced to 82.3 percent of the rated capacity.Therefore, when estimating battery SOC, the influence of battery usage times should be considered and compensated to improve the estimation accuracy of SOC.According to the experimental data, the relation curve (FIG. 8) and the functional relation between usage times and capacity ratio can be fitted, and the functional relation can be expressed as follows:

$$\begin{cases} k_3 = -7.272 \times 10^{-9} N^5 + 2.208 \times 10^{-6} N^4 - 0.00024 N^3 + \\ \qquad 0.01062 N^2 - 0.3019 N + 98.56 \\ \qquad R^2 = 2.9592 \end{cases} \tag{13}$$

In Equation (13), N is the number of cyclic usage.

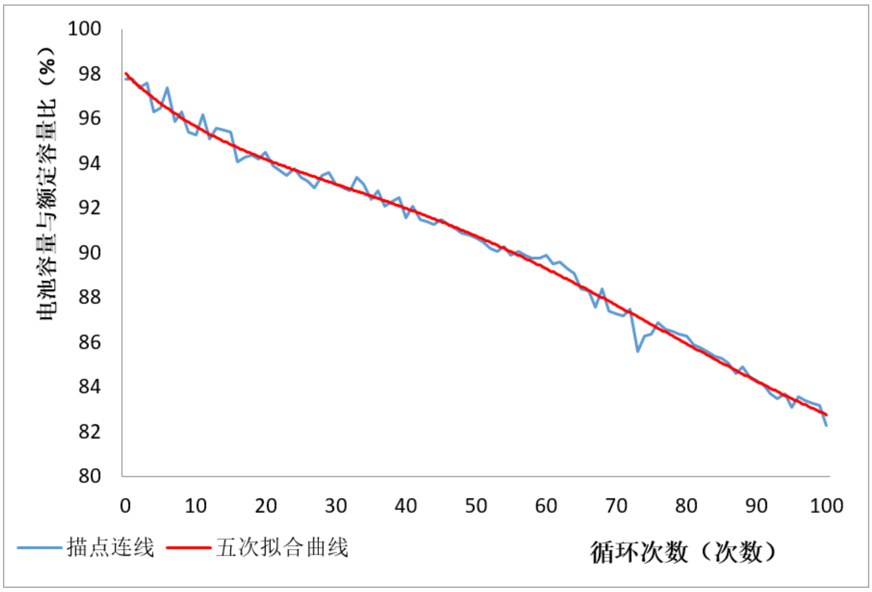

Fig. 8 Curve of correlation between capacity and numbers of usage

6. SOC estimation experiment based on improved Ampere -hour integration method

Analyze and modify the influencing factors in the process of SOC estimation, and use the modified formula to perform SOC estimation. In the room temperature environment, the fully charged battery is left to stand fully, and the current temperature is recorded in real time by the temperature sensor. The battery was discharged at a constant current of 1 C, and the current was removed after 25 min. The experimental data were substituted into SOC calculation Formula (3), and the calculated values and errors were shown in Table 2.

Table 2 Experimental

Standing time/min	Calculated values/%	Measured values/%	Error/%
1	55.6	58.3	3
6	55.6	58.3	3
12	58.3	58.3	0
30	58.3	58.3	0
60	58.3	58.3	0

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7. Conclusion

An improved ampere-hour integration-open circuit voltage method was proposed to obtain accurate initial VALUE of SOC and improve the estimation accuracy of SOC by studying the factors affecting the battery, such as ambient temperature, discharge ratio and times of cycle use.The experimental results show that the SOC estimation based on this method not only reduces the time used for SOC estimation, but also greatly improves the estimation accuracy of SOC, which has practical significance for the SOC estimation of power lithium batteries.

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