Research on Test Method for Low-Temperature Performance Consistency of Power Battery Pack

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Abstract. Under low temperature condition, the inconsistency that the internal resistance of the battery due to the influence of processing and manufacturing processes can't be effectively tested at constant temperature, therefore, this paper proposes a method for test of the electric performance consistence of the lithium-ion batteries at low temperature, this method can test the electric performance consistence of the lithium-ion batteries at low temperature, effectively solve the problem of cells that have good electric performance consistence under normal temperature condition, but have considerably different electric performance under low temperature condition.

1. Introduction
This project proposes a method for test of the electric performance consistence of the lithium-ion batteries at low temperature, this method can test the electric performance consistence of the lithium-ion batteries at low temperature, effectively solve the problem of cells that have good electric performance consistence under normal temperature condition, but have considerably different electric performance under low temperature condition, and can test a large quantities of lithium-ion cells to screen out the acceptable lithium-ion cells to form appropriate battery pack, to ensure the battery pack have a better consistency under low temperature environment, improve the quality of lithium-ion battery pack and save the costs of consumers for battery replacement, and has a certain economic and social significance.

2. Method and Procedures
The test steps are as follows:
- Adopt the voltage value reduction method to select the lithium-ion cells with higher self-discharge.
  The specific steps are as follows: (1) conduct chemical storage and aging storage of more lithium-ion cells for a certain period of time in turn, and conduct 10 cycles of charging and discharging activation of lithium-ion cells, and then charge to fully charged state; (2) measure the voltage value $V_1$ of each lithium-ion cell, store them for 7 days at room temperature $(20^\circ C \pm 2^\circ C)$ and measure the battery voltage value $V_2$ again, and then calculate the voltage drop value $\Delta V = V_1 - V_2$ before and after the storage of each lithium-ion cell; (3) if the $\Delta V \geq$ set voltage drop threshold, the lithium-ion cell has higher self-discharge and is unacceptable lithium-ion cell, if the $\Delta V <$ set voltage drop threshold, the lithium-ion cell has lower self-
discharge value and is acceptable lithium-ion cell B1. The set voltage drop threshold can be determined according to the battery type and use requirements.

- For the lithium-ion cell B1, select out the lithium-ion cells of the same capacity difference criterion after processing through capacity check. The specific steps are as follows: (1) measure the actual battery capacity $C_1$ of each lithium-ion cell B1; (2) grade the lithium-ion cells B1 according to the capacity differences: use 10% of the nominal capacity of lithium-ion cell as the capacity difference criterion $\Delta C_1$ for grading, i.e. to select the cell Bc1 by $(\text{actual battery capacity } C_1 - \text{nominal capacity}) / \text{nominal capacity} \times 100\% = \pm 10\%$.

- Charge and discharge the lithium-ion cells Bc1 at low temperature before grading again the lithium-ion cells BC1. The specific steps are as follows: (1) put the lithium-ion cells BC1 in a place under low temperature condition (low temperature range: -40°C - 0°C) for 4 hours, conduct 10 charge-discharge cycles and then charge them to fully charged state; (2) measure the actual battery capacity $C_2$ of each lithium-ion cell BC1; (3) grade the lithium-ion cells BC1 according to the low-temperature capacity difference criterion $\Delta C_2$: use 20% of nominal capacity of cell as the low temperature difference criterion $\Delta C_2$ for grading (i.e. $(\text{actual battery capacity } C_2 - \text{nominal capacity}) / \text{nominal capacity} \times 100\% = \pm 20\%$) to select by conducting capacity grading again to obtain more cells BC2 meeting the above capacity difference criterion; (4) grade and select, and then charge all the cells BC2 to the same state of charge.

- Select more lithium-ion cells BC2 to form appropriate battery pack.

3. Experimental Procedure

Test sample. The model and the parameters of cell in this paper as follows:

- The model: domestic battery, rated voltage 3.7 V, rated capacity 11 Ah, internal resistance < 6 mΩ, weight < 320 g.
- Dimensions: 133 mm×66 mm×18 mm.
- The composing of the battery: the cathode material is LiMn$_2$O$_4$, the anode material is graphite, the electrolyte is LiPF$_6$, EC and DMC, and battery separator is celgard 2325.

Test Instrument: thermostat box, model SPHH-101; Integrated battery tester, MACCOR battery performance test systems; Data acquisition system, model MV2000.

4. Results and Discussion

The examples for application of this method are as follows:

Conduct 10 charge-discharge cycles of 10 lithium-ion cells under room temperature (20°C±2°C) condition by using the constant-current and constant-voltage charge system and constant-current discharge system, i.e. discharge the batteries to be tested at 3500 mA under the test temperature condition until the battery voltage reaches 2.7 V, put them in a place for 1 h, and conduct constant current charge at 3500 mA until the battery voltage reaches 4.2 V, conduct constant-current charge and then stop charging as the charging current drops to 350 mA, so repeat 10 charge-discharge cycles, and measure the voltage value $V_1$ of each lithium-ion cell and store them at room temperature (20°C±2°C) for 7 days, then measure the voltage drop value $\Delta V = V_1 - V_2$ of each cell before and after storage, and measure and calculate the results as shown in Table 1.
Table 1. The measure and calculate result

| Sample No. | voltage $V_1$/V | voltage $V_2$/V | voltage drop value $\Delta V$ |
|------------|-----------------|-----------------|-------------------------------|
| 1          | 4.197           | 4.175           | 0.022                         |
| 2          | 4.197           | 4.191           | 0.006                         |
| 3          | 4.196           | 4.187           | 0.009                         |
| 4          | 4.199           | 4.196           | 0.003                         |
| 5          | 4.198           | 4.194           | 0.004                         |
| 6          | 4.198           | 4.192           | 0.006                         |
| 7          | 4.196           | 4.191           | 0.005                         |
| 8          | 4.193           | 4.173           | 0.020                         |
| 9          | 4.197           | 4.185           | 0.012                         |
| 10         | 4.197           | 4.191           | 0.006                         |

The voltage drop threshold set for this experiment is 0.20V, we can see from Table 1 that, for the lithium-ion cells No. 1 and No. 8, the $\Delta V \geq$ set voltage drop threshold, i.e. $\Delta V \geq 0.020V$, they are lithium-ion cells with higher self-discharge (unacceptable lithium-ion cells), and the rest of cells are acceptable cells B1 (battery No.: 2,3,4,5,6,7,9,10).

Measure the actual battery capacity $C_1$ of each lithium-ion cell B1, and calculate their corresponding capacity differences, as shown in Table 2.

Table 2. The calculate results

| Sample No. | actual battery capacity $C_1$/mAh | $\Delta C_1$ /% | capacity differences /mAh |
|------------|----------------------------------|-----------------|---------------------------|
| 2          | 10683.87                         | -0.03           | 6.84                      |
| 3          | 10675.01                         | -0.03           | 6.75                      |
| 4          | 10659.94                         | -0.03           | 6.60                      |
| 5          | 10646.68                         | -0.03           | 6.47                      |
| 6          | 10352.08                         | -0.06           | 3.52                      |
| 7          | 10364.25                         | -0.06           | 3.64                      |
| 9          | 10352.88                         | -0.06           | 3.53                      |
| 10         | 10338.21                         | -0.06           | 3.38                      |

Table 2 shows that, the capacity differences of lithium-ion cells are in the range of capacity difference criterion $\Delta C_1$ ($\Delta C_1 = (\text{actual battery capacity } C_1 \text{ - nominal capacity} )/ \text{nominal capacity} \times 100\%$), therefore all lithium-ion cells listed in Table 2 are batteries $B_{C1}$ after grading of capacity differences (battery No. 2, 3, 4, 5, 6, 7, 9, 10), and charged to 100% state of charge.

Put the cells $B_{C1}$ in a place under low temperature condition (-30°C ±2°C) for 4 hours, conduct 10 charge-discharge cycles, and calculate the cycle life $L_{10}$ after 10th charge-discharge cycle (i.e. the discharge capacity at 10th charge-discharge cycle / discharge capacity at 1st charge-discharge cycle x 100%), as shown in Table 3.

Table 3. The results

| Sample No. | cycle life / % |
|------------|----------------|
| 2          | 95.38          |
| 3          | 94.86          |
| 4          | 95.97          |
| 5          | 95.57          |
| 6          | 93.11          |
| 7          | 96.21          |
| 9          | 93.98          |
| 10         | 95.66          |
The cycle life criterion of lithium-ion cells set for this experiment is 95%, i.e. the lithium-ion cells with cycle life \( L_{10} > 95\% \) are the batteries selected under low temperature environment. The cycle lithium-ion cells with cycle life \( L_{10} > 95\% \) selected according to Table 3, are the batteries No. 2, 4, 5, 7, 10, they are the acceptable lithium-ion cells selected under low temperature environment.

In the lithium-ion cells \( \text{B}_{1}\text{C}_{2}\), select the batteries no.5 and No.10 to connect in series into a battery pack 1. Figure 1 and Figure 2 are the charge capacity curve and discharge capacity curve, respectively, when conducting 5 charge-discharge cycles of battery pack 1 and pack 2 (packs obtained by using ordinary method to conduct voltage difference, internal resistance difference and capacity difference screening) at 0.2C rate under condition of \( -30^\circ\text{C}\pm 2^\circ\text{C} \). We can see from the comparison in Figure 1 and 2 that the battery packs obtained by using the method of this invention have low decay of charge and discharge capacity, relatively high discharge capacity and good consistency of packs under low temperature.

![Figure 1. Charge Capacity Curve.](image1)

![Figure 2. Discharge Capacity Curve.](image2)
5. Conclusions
It is thus clear that, this project provides a test method for consistency of electric performance of the lithium-ion battery compared with the existing technologies, which can test the consistency of electric performance of the lithium-ion battery under low-temperature condition in a fast and convenient way, effectively solve the disadvantage of various cells that have good electric performance consistency under normal temperature condition, but have considerably different electric performance under low temperature condition, and can be promoted to be applied in testing large quantities of batteries and screening to group batteries. It can improve the quality of lithium-ion battery pack and save the costs of consumers for battery replacement, and has certain economic and social significance.

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