Research on Echelon Utilization of Lithium Battery

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Abstract. This thesis finds a form of cascade use for retired lithium batteries by analysis, tests, screens and reorganizes retired lithium batteries into new standard energy storage modules, which are successfully applied to stadium scooters. The results show that this form can effectively extend the life cycle of lithium batteries.

Keywords: Lithium battery; echelon use; battery life.

1. Introduction
In the new energy vehicle industry, the performance of the vehicle power battery is critical, usually, when its full capacity can not reach 80% of the initial rated capacity, the power battery will not continue to be used. The echelon use technology of lithium battery can effectively prolong the life cycle of the battery, relieve the pressure of resources in the production process, and form a good recycling mode.

In this paper, the 18650 Ni-Co-Mn ternary lithium battery with a wide range of applications is selected to study a form of echelon use for lithium battery and its practical effect. Through batch screening of batteries and modularized circuit design, the lithium batteries used in echelon is designed as standard energy storage modules to be used in scenarios with low battery quality requirements, such as stadium scooter power supplies and small solar and wind power storage, and so on.

2. Battery screening scheme
When the batteries are grouped, the consistency of the battery parameters has a direct influence on the working state of the entire battery pack. When the capacity of single cell is different greatly, the phenomenon of low capacity battery charging full charge and high capacity battery insufficient charge will occur in the charging process, resulting in the battery capacity of the whole battery is less than the sum of the capacity of single cell, and the battery life is lost. Therefore, it is necessary to conduct a reasonable quantitative screening of cell monomers through the flow chart in Fig. 1 before battery grouping.
Considering the difference between the new battery and the echelon battery, the consistency between the static parameters and the dynamic parameters of the lithium battery is relaxed under the premise of safety.

3. Battery test and data analysis

In this section, 124 Ni-Co-Mn ternary lithium batteries of different batches were tested for internal resistance, charge and discharge, and the results were analyzed.

3.1. Internal resistance test and analysis

The static internal resistance of lithium batter was tested with R203 Internal Resistance Tester of Degong instrument, and the scatter plot of internal resistance of lithium batter was obtained as shown in Fig. 2.

Analyzing the internal resistance data, we can get:

1) The distribution of the internal resistance of the 124 batteries measured this time is complex, mostly distributed between $20 \, \text{m} \Omega \sim 60 \, \text{m} \Omega$;
(2) The internal resistance of the battery numbered 9 is zero, which can be judged as the battery is damaged and cannot be used;
(3) There are 25 batteries whose internal resistance exceeds or is at the critical internal resistance of 50mΩ, which are not suitable for echelon utilization, so they will not be charged and discharged.

3.2. Charge and discharge test and analysis
After removing the battery with inappropriate internal resistance according to the conclusion in Section 3.1, the EBC-X 8-channel lithium-ion battery charge and discharge tester is used to test the remaining 98 batteries in groups of 8. The charge and discharge process is shown in Figure 3. Show.

![Figure 3. Charging and discharging process of lithium battery](image)

Battery charging uses a combination of constant current and constant voltage, complementing the advantages and disadvantages to ensure the safety and efficiency of charging. As shown in Figure 4, at the beginning of charging, it belongs to the constant current charging stage, the battery voltage is not high, the current of the circuit is constant, the voltage slowly increases until it reaches the charging cut-off voltage, and reaches the constant voltage charging stage. At this time, the voltage of the circuit will stabilize to the cut-off voltage, and the current gradually weakens and gradually enters the trickle charging stage until the cut-off current is reached, and the battery will be fully charged.

![Figure 4. Charging curve of lithium battery](image)

The red line is the trend of current change and the blue line is the trend of voltage change.

When the lithium battery is discharged, the current should not be too large, and the problem of over-discharge cannot occur. In general, the conventional constant current discharge mode is adopted, the discharge current is constant at the set value of 0.5c, and the voltage is always reduced. When the voltage is reduced to the cut-off voltage, the discharge is stopped. The discharge curve is shown in Figure 5.
Figure 5. Discharge curve of lithium battery
The red line is the trend of current change and the blue line is the trend of voltage change. The specific data of the tested ternary lithium battery capacity is shown in Figure 6.

Figure 6. Scatterplot of ternary lithium battery capacity
Analyzing the capacity data, we can get:
(1) Different batches of batteries are subject to different usage conditions, and their capacities are also different. The capacity consistency of the second and third batches is better;
(2) The batteries whose ternary lithium battery is above 80% of the rated battery capacity account for about 68% of the number of test batteries, indicating that in addition to the attenuation of some battery capacity, some of the lithium battery retirements are affected by the same group of retirement batteries Retire
(3) The capacity of some test batteries is too low, there may be overcharge and over-discharge problems, which will affect the safety of the battery pack and will not be used.

4. Battery group

In order to ensure the maximum safety and reliability of the battery pack, according to the formula in Qian Zhang's "Research on Recycling Mechanism of Electric Vehicle Recycling Battery". Assuming that the reliability of the battery cells $R_i(t)$ does not affect each other and is independent of each other during operation, the reliability of the two connection methods when $m$ batteries are connected in series and $n$ batteries are connected in parallel are:

$$R_{12}(t) = 1 - \prod_{i=1}^{n} \left(1 - R_i(t)^m\right)$$  \hspace{1cm} (1)

$$R_{21}(t) = \prod_{i=1}^{n} \left[1 - (1 - R_i(t))^n\right]$$  \hspace{1cm} (2)

Set $R_i(t) = 0.8, m = 8, n = 9$, and then substitute (1) and (2) to calculate:

- Series first, then parallel

$$R_{12}(t) = 1 - (1 - 0.8^8)^9 = 0.808$$

- Parallel first, then serial

$$R_{21}(t) = (1 - (1 - 0.8)^9)^8 = 0.999$$

From this, it can be concluded that the battery pack method of selecting the parallel connection and then the series connection is more reliable.

After completing the battery parameter test and data analysis, according to the battery screening process and parameter consistency theory, the batteries with a battery capacity similar to the internal resistance of the battery are selected to form a battery pack, and 72 retired lithium batteries with good consistency are obtained. The more stringent and parallel methods and battery attenuation characteristics make up 9 and 8 series 24V battery packs to ensure that the battery pack power and voltage meet the needs of use. The arrangement is shown in Figure 7.

![24V battery pack](image)

**Figure 7.** 24V battery pack

According to the battery type of the battery pack, charge and discharge rate, cycle performance and other factors, select the ant monomer display ternary lithium battery pack balanced protection board BMS management system to monitor itself in real time, energy management, balanced charging, and
add an AC / DC conversion module, Emergency switch and ABS material shell and other modules to improve the safe operation of the battery pack, and finally complete the standard energy storage module.

Through the real-time monitoring of BMS, the status of the battery pack can be detected:
The voltage is 29.5V, the remaining capacity is 49.783AH, and the single cell voltage difference is 0.1 V. The BMS performs temperature and voltage detection on 8 series-connected batteries, and reduces the battery pack voltage deviation less than 100mV under equilibrium.

Finally, the battery pack was applied to the stadium car provided by the National Eastern Tech-Transfer Center. The voltage and power can meet the needs of the vehicle. The vehicle is running well and there are no problems during use.

5. Conclusion
The form of tiered utilization described in this article will test, screen, and reorganize the retired lithium battery into a new standard energy storage module, and successfully applied it to the stadium scooter. The results show that this form can effectively extend the life cycle of lithium batteries.

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