Study on the effects of temperature On $LiFePO_4$ Battery life

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***Abstract*-$LiFePO_4$ battery is considered to be an important component for making future transportation more energy-efficient and less dependent on petroleum through hybrid, plug-in hybrid, electric, or fuel cell vehicles. This paper focuses on the impacts of ambient temperate on the cycle life of $LiFePO_4$ battery. The experimental procedures for batteries are developed, and a test plan on the cycle of charge and discharge with the current of 1C is made. Lower or higher test temperature is divided with a step length of 10℃. At each temperature, the discharge capacity and impedance are measured every 20 cycles. After 100 cycles testing, the discharge capacity and impedance curves are plotted. With the help of the curves, this paper analyzes the influence of temperature on discharge capacity and impedance. Finally, some suggestions about how temperature influences battery cycle life are presented.**

***Keywords*-Electric vehicles, $LiFePO_4$ battery, Temperature, Lithium-ion battery cycle life**

I. INTRODUCTION

With the issues of the energy shortage and the environment pollution, electric vehicle becomes a hot point nowadays. As one power source of the electric vehicles, the performances of the Li-ion battery are very important. Study on the factors that influence the life of Li-ion battery becomes more and more important as the Li-ion battery life can impact on the battery application. Especially, extreme temperature will influence the battery life, which determines the economic benefits. The battery life changes according to different ambient temperature. The plot which shows how the battery life changes when it works at higher or lower temperature will help us analyze the trend of the temperature influence.

In the past several years, many researches on the relationship between the battery cycle life and ambient temperature has been carried out [1][2][3]. The researchers usually focused on two things, one is the change of discharge capacity of Lithium-ion battery at different temperature, and another is the change of the discharge capacity of Lithium-ion battery with the increasing of the cycle at one fixed temperature. However, both of them cannot completely describe the cycle life change of the battery.

Most studies on Li-ion battery life focus on the factors or the mechanisms that influence the battery life. This paper just focuses on how temperature influences the battery life by the cycle life tests. The battery capacity and internal resistance are tested as the symbol of the battery cycle life. What's more, we presents the aging mechanism of the Li-ion battery. Then some useful suggestions on the usage of the battery and the way to extend the battery life are given according to the result of the tests.

II. TESTS

A. Test platform

In the test, the battery has a recommended voltage range of 2.5V to 3.7V, and a capacity of 180Ah. The maximum charge current is 180A, and maximum discharge current is 360A. Fig.1 shows the testing battery.

Hardware system of test platform consists of battery test bed and computer system, data of the battery is acquired by Battery Management System, and communicated with the host computer system by means of CAN bus. Fig 2 shows the structure of the battery cycle life test platform.

Software system of test platform consists of control programs of cycle life test bed and battery data acquisition system. Programs of cycle life test bed are used to set the battery charge and discharge steps and decide how long each step lasts. Each step is controlled by a schedule document. With the limit in each schedule, the battery is discharged or charged. Fig 3 shows the schedule of the program.

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Fig. 1 Picture of testing battery

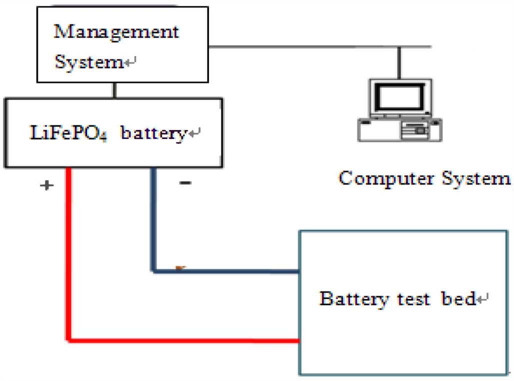

Fig. 2 Structure of car battery cycle life test platform

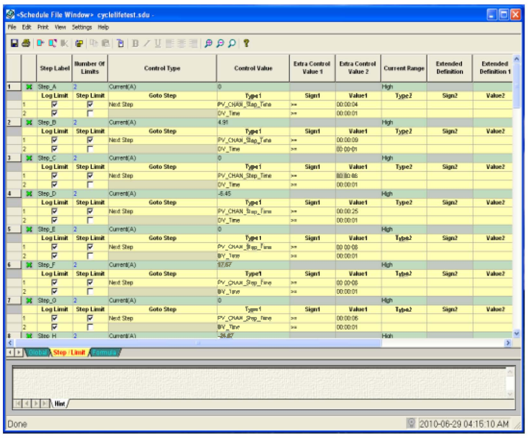

Fig. 3 Schedule of the program

B. Cycle life test method

Firstly, the test should be carried out under ambient temperature and the discharge/charge manner should be the same as prepared standard cycle. We can get the discharge capacity and the internal resistance of the Li-ion battery.

Method of measuring the battery capacity and internal resistance:

The charge/discharge capacity of the battery should be measured according to the National Car Industry Standard《Lithium-ion battery on electric vehicle(QC/T743-2006)》.

(a) Charge the battery with a current of 1/3C until the voltage reaches 3.7V, then charge with the constant voltage 3.7V until the current declines to 1/30C, after that let the battery stand by for at least one hour;

(b) The ambient temperature remains 20℃±5℃, discharge the battery with a current of 1/3C until total voltage declines to 2.5V;

(c) Let the battery stand by for an hour;

(d) Measure the discharge capacity and internal resistance as the symbol of the battery cycle life.

Secondly, the cycle life test method is made.

(a) Put the battery under the condition with a test ambient temperature which we want;

(b) Discharge the battery with a current of 1C (180A) until voltage of the single cell reaches 2.5V;

(c) Charge with a current of 1C(180A) until voltage of the single cell reaches 3.7V, then charge with the constant voltage 3.7V until the current declines to 1/30C(6A), after that let the battery stand by for at least one hour;

(d) Keep the ambient the temperature unchanged, repeat (b) and (c) until the cycle number reaches 20;

(e) Measure the discharge capacity and internal resistance;

(f) Let the battery standby for 5 minutes;

(g) Keep the ambient the temperature unchanged, repeat from (a) to (g) until the cycle number reaches 100, then change the temperature and start a new series of tests.

C. Set of temperature point

There will be totally 7 temperature points during the tests, including 3 higher points, 3 lower points and 1 room temperature point.

The test temperature is divided with the step length of 10℃. Therefore, the high temperature consists of 60℃, 50℃, 40℃ and the low temperature consists of 10℃, 0℃, -10℃. Besides, the room temperature is 25℃.

III. RESULTS AND DISCUSSION

Generally, if the capacity of a battery drops to 80% of its original value, we can think that the battery cycle life is to the end. So, we take this as a judgment if the experiment should be stopped. But it takes a long time to fail the battery. Therefore, this judgment doesn't work. In this paper, we measure several capacities after certain charge/discharge cycles, and get a declining curve of battery capacity, then analyze the curves to find the impact of the temperature on the cycle life of battery.

In the test at each temperature, we finished 100 cycles on the battery, after every 20 cycles, the capacity of the battery was measured. The original capacity was measured before the test beginning.

A. Discharge capacity change

1) Change at high temperature

Here, we define p as the remained discharge capacity percent. It presents the percentage of the discharge capacity left.

$$p = \frac{C_{100}}{C_0} \times 100\% \tag{1}$$

p - the percentage of the discharge capacity lef t

C_{100} - discharge capacity after 100 cycles

C_0 - original discharge capacity

Table 1 shows that the discharge capacity decreases as the cycle numbers increase. What's more, the higher the temperature is, the lower the percentage is. Especially, when the temperature is 60℃, the percentage fiercely drops to 80.63% after only 20 cycles. It is obvious that 60℃ has already been beyond the normal limits.

2) Change at low temperature

The capacity change at low temperature is shown in table 2.

TABLE 1
THE PERCENTAGE OF THE DISCHARGE CAPACITY AT HIGH TEMPERATURE

Temperature	Percentage
60℃	80.63%
50℃	88.32%
40℃	91.47%

TABLE 2
THE PERCENTAGE OF THE DISCHARGE CAPACITY AT LOW TEMPERATURE

Temperature	Percentage
10℃	97.80%
0℃	97.74%
-10℃	85%

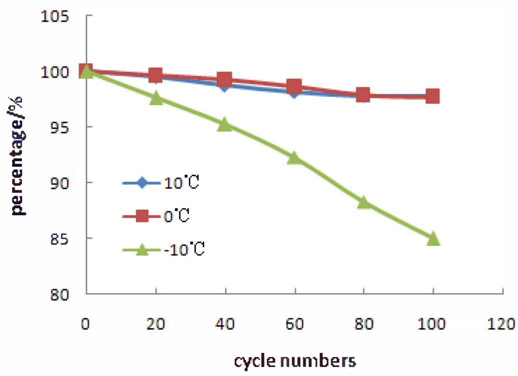

Fig. 4 Declining curve at low temperature

The declining curve at lower temperature is shown in Fig 4. From the curve we can find that the curve at 10℃ and 0℃ are almost the same. However, the curve at -10℃ decreases more fiercely than the other two. So it can be inferred that the battery cycle life at -10℃ is obviously shorter than the other two.

3) Change at different temperature

Curves at different temperature are shown in Fig 5, including room temperature.

We can find in the figure that curve at 60℃ drops the most fiercely. Curves at higher temperature decrease more fiercely than lower temperature. Obviously, higher temperature has more influence on the battery cycle life than lower temperature. In addition, battery temperature rise leads to heavy discharge capacity decreasing at 40 ℃ and room temperature. Temperature rise at these two temperature reaches even 20℃ after about 7 cycles. Therefore, the curves of the two temperature change irregularly.

B. Internal resistance change

The internal resistance is also an important parameter for the battery cycle life. The internal resistance can represent the difficulty of the electron transmission in the battery. If internal resistance is too large for the battery, it will produce large amount of heat when the battery works, which will raise the temperature of the battery and lead to the shortage of the battery cycle life. So internal resistance plays an important role for the battery cycle life.

1) Change at higher temperature

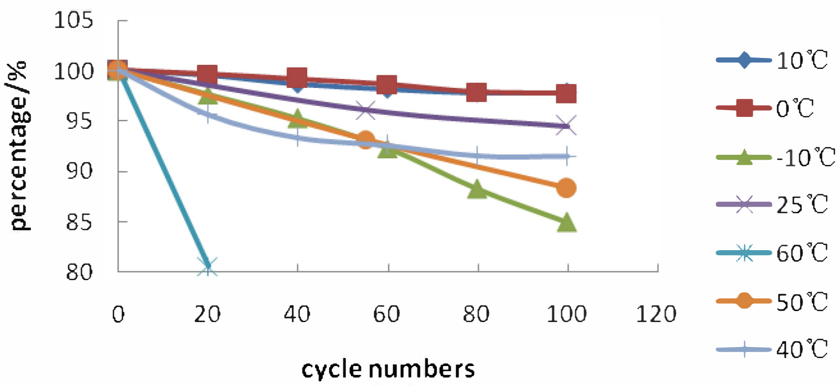

Fig. 5 Discharge capacity curves at different temperature

Here we also define P as the increase percentage of the internal resistance.

$$P = \frac{R_{100}}{R_0} \times 100\% \qquad (2)$$

P - the increase percentage of the internal resistance

R_{100} - internal resistance after 100 cycles

R_0 - original internal resistance

The test data are shown in Table 3. We can find that the internal resistance increases as the cycle numbers increase. What's more, the higher the temperature is, the higher the percentage is. Especially, when the temperature is 60℃, the percentage fiercely increases to 350% after only 20 cycles. It is obvious that 60℃ has already been beyond the normal limits.

2) Change at lower temperature

The internal resistance change at low temperature is shown in Table 4 and the curves at lower temperature are shown in Fig 6.

TABLE 3
THE PERCENTAGE OF THE INTERNAL RESISTANCE AT HIGH TEMPERATURE

Temperature	Percentage
60℃	350%
50℃	188%
40℃	167%

TABLE 4
THE PERCENTAGE OF THE INTERNAL RESISTANCE AT LOW TEMPERATURE

Temperature	Percentage
10℃	113%
0℃	110%
-10℃	140%

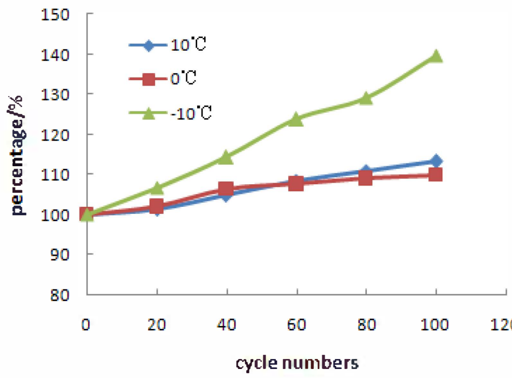

Fig. 6 Curves at low temperature

The trend in Fig 6 is almost the same as in Fig 4. Internal resistance slightly increases at 10℃ and 0 ℃ compared with the curve at -10℃. So it can be inferred that the lower temperature will be a more important factor to the battery internal resistance when battery working temperature is below 25℃.

3) Change at different temperature

Internal resistance curves at different temperature are shown in Fig 7, including room temperature.

From Fig. 7, It can be seen that internal resistance at higher temperature raises more than one at lower temperature. Extreme high or low temperature still influences the battery internal resistance heavily. Therefore, it is better for battery to work at normal temperature rather than at extreme temperature. What's more, the test battery works better at lower temperature than at higher temperature.

IV. CONCLUSION

By taking the battery cycle life test at different temperature, and from them we get some useful conclusions.

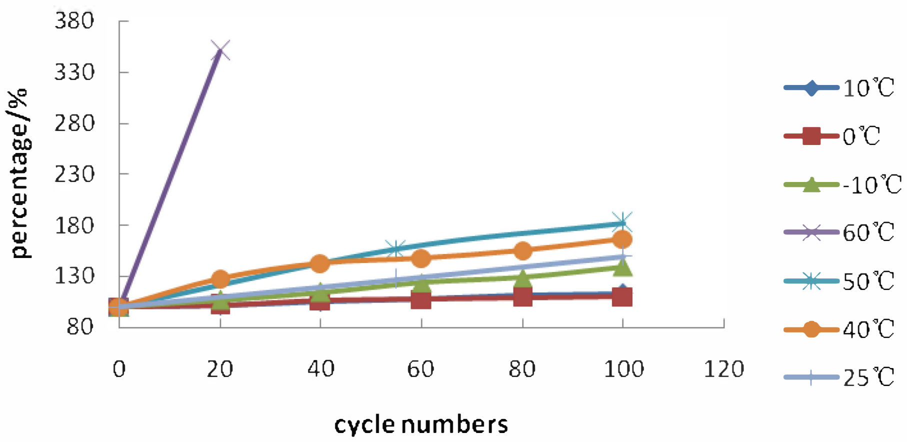

Fig. 7 Internal resistance at different temperature

1) When the battery works at higher temperature, battery discharge capacity decreases and internal resistance increases following with the ambient temperature raising. When the battery works at lower temperature, battery discharge capacity decreases and internal resistance increases following with the ambient temperature decreasing. The curve at room temperature is between higher and lower temperature.

2) $LiFePO_4$ battery will achieve its cycle life limit rapidly when battery works at extreme temperature, which will cause battery cycle life decrease.

3) By analyzing discharge capacity and internal resistance data, we can give some suggestions on $LiFePO_4$ battery application. On the whole, the normal working temperature for $LiFePO_4$ battery is between 0℃ and 40 ℃. If we provide a limit for discharge capacity and internal resistance to guarantee that the two factor change in a certain range, then it's better for battery to work between 0℃ and 25℃.

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