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Experimental investigation of thermal and strain management for lithium-ion battery pack in heat pipe cooling

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ABSTRACT

Thermal and strain management is required for a considerate lithium-ion battery management system (BMS) to depress the operating temperature and strain. In this paper, non-destructive temperature equipment and strain gauges are used simultaneously to monitor the temperature and strain of 18650 lithium-ion battery pack with a heat pipe cooling device (HPCD) which is used to depress temperature. At the steady-state and dynamic-state discharge processes, the temperature of pack is dramatically different with cooling device or not, and the optimal operating temperature is kept when HPCD is embedded in the center of pack with forced convection. The strain decreases in discharge progress after the pack is equipped with HPCD and has the same trend of temperature change in charge-discharge cycle process. The battery management system of temperature and strain is also effective during multiple charge-discharge processes. Furthermore, this system has the superiority of low power consumption.

1. Introduction

Lithium-ion battery has developed rapidly with the advantages of high power and energy density, good recyclability and so on. It has been widely applied in various fields such as electronic products, electric vehicles [1,2]. But a series of chemical reactions will be triggered in the process of charge/discharge of lithium-ion battery, which leads to the release of heat [3,4] and the potential security problems such as overheating, swelling. When the lithium-ion batteries work continually under high temperature conditions, its life will be shortened quickly [5–7], which will block the development of battery. The research [8] shows that the heat accumulation of cells in the battery pack not only increases the temperature of each cell, but also increases the temperature difference among the cells, resulting in different capacity and decaying. The heat or gas production of battery ultimately leads to the deformation of battery and will be hazardous to battery at abnormal operating condition [9,10]. If the temperature and stresses related to the deformations of battery can be monitored and taken measures in real-time, the hazards such as swelling and explosion will be efficiently prevented.

The thermal management technology of the battery mainly includes air cooling, liquid cooling and phase change materials, in which air cooling and liquid cooling technology are extensively applied due to its low cost and layout advantages [11–16]. It's found that heat pipe can be used to enhance heat transfer [17–19]. In recent years, heat pipe cooling technology has been studied [20–23]. Rao et al. [21] did experiment on $LiFePO_4$ battery by using the plate heat pipe, as for the heat generation rate of battery less than 30 W, the plate heat pipe can not only control the battery temperature within 50 °C, but also maintain the maximum temperature difference of the battery surface within 5 °C. Tran et al. [22] studied the feasibility of installing heat pipe to the heat evaporation of lithium-ion battery, and analyzed the cooling performance of heat pipes under different inclinations of heat pipes and fins. When the battery is operated especially under high rate discharges or in critical applications, the pressure is out of control, which is mainly caused by the gas production inside. The mechanism of the battery expansion has been studied [24–30]. Kong et al. [6] studied the swelling of 18650 lithium-ion battery and found that gas would generate in the normal process of charge and discharge, which was related to the oxidation of positive electrode. The strain of lithium-ion battery also has been investigated in recent years. Gao et al. [29] studied the stress-strain relationships of Li_xSn and the evolution of stress-strain relationships at different change states.

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Nomenclature

T1-T5	Position of K-type thermocouples
S1-S5	Position of strain gauges
C	Rate of charge/discharge current
BMS	Battery management system
HPCD	Heat pipe cooling device
BTMS	Battery thermal management systems

The heat pipe thermal management system is used extensively on prismatic lithium-ion battery because of its handiness, but the effect of the system has not been researched on cylindrical lithium-ion battery. The control of thermal and pressure is vital for battery, which has been verified in the study of heat dissipation and gas evolution [5,6]. However, there is no effective solution of thermal and strain management on lithium-ion battery.

In this work, thermal and strain monitors are combined to monitor the temperature and strain of cylindrical lithium-ion battery pack, which used a new design combined heat pipe and fins to manage it. The results demonstrate that HPCD with fan system can help to maintain the temperature of entire pack to meet the operation temperature requirement with the low energy consumption, and the strain also decreases obviously. It means that the thermal and strain BMS can improve the performance of battery and enhance its safety.

2. Experimental

In the test, 24 cells were attached closely for battery pack by 3 batteries in series and 2 × 4 in array (shown in the top of Fig. 1). The specifications of the batteries were shown in Table 1. The pack was put in an adiabatic and insulated plastic case. The battery thermal management systems (BTMS) were classified as two main classes in the tests: pack with heat pipes in ambient and pack with heat pipes in forced convection.

Table 1
Basic parameters of the battery.

	NCM18650-260
Type	Normal Cylindrical
Mass(g)	45
Nominal voltage(V)	3.6
Capital capacity(Ah)	2.6
Maximum continuous charge current(A)	1.3
Maximum continuous discharge current(A)	2.6
Operation temperature(°C)	Charge: 0–45 Discharge: −20 to 60

The charge-discharge cycling test of the above batteries was carried out with different potential windows and current rates on a battery testing instrument (Neware BTS-CT-3008-15V3A-S1). The cells temperature at different locations (as shown in the middle of Fig. 1) in the pack was measured by five K-type thermocouples with the accuracy of 1 °C connected with 24-channel temperature equipment (JK-24U). The resistance strain gauges (BE120) with the size of 0.3 × 1.8 mm were chosen for measuring the strains because the testing battery is a sealed container composed of SPCC steel plate. The maximum strain range, accuracy and the resistance of gauge are 2%, 1 με and 120 ohm respectively. The strain gauge consisted of a wire filament grid on an insulated rear side supported by a metallic foil pattern. Glue was pasted on the cleaned side shell surface to adhere the strain gauge. After being well adhered to the battery side shell surface, the gauge was connected to a stress-strain testing system (DH3821). The strain gauge was required to be mounted properly onto the battery side shell surface so as to allow the strain transferred from the test specimen to the stress-strain testing system through the strain gauge and adhesive.

The HPCD consisted of two cooling modules which had three heat pipes. These heat pipes with an outer diameter of 8 mm were

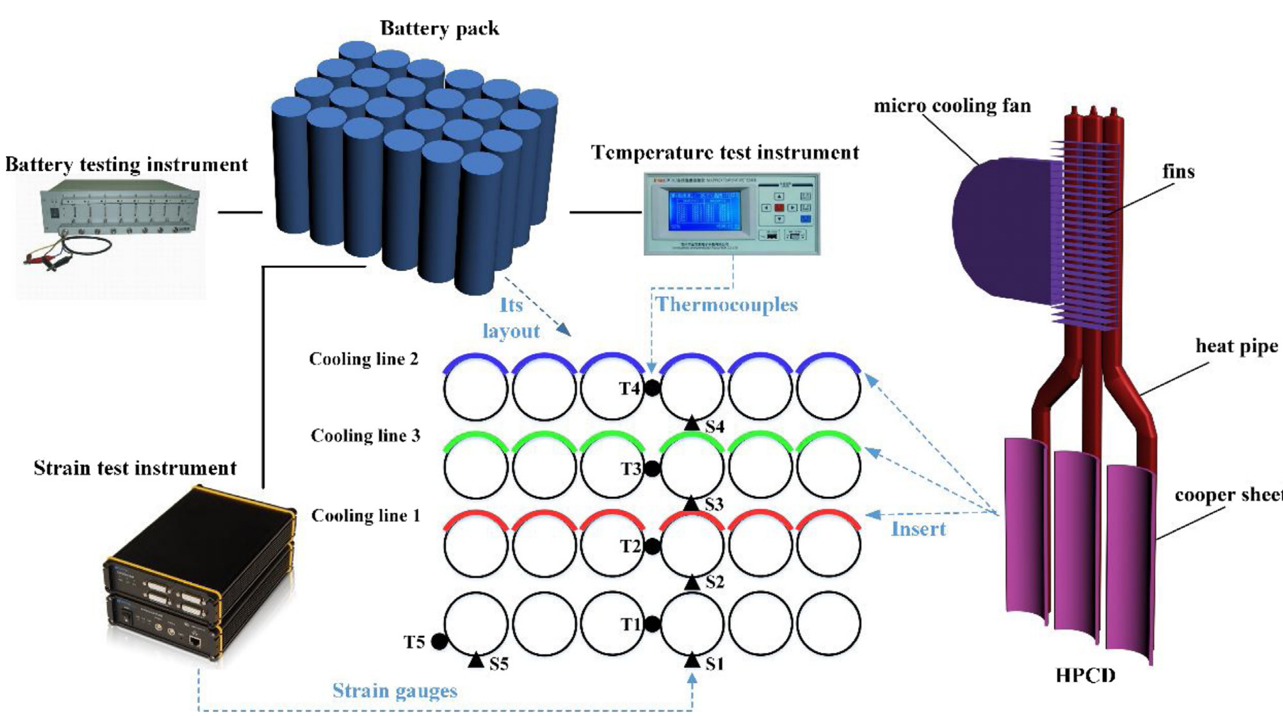

Fig. 1. Schematic illustration of set up.