Fire Fighting Design and Safety Management of Lithium Battery Based on Single-cell Level

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Abstract. With the rapid development of lithium battery technology and its wide application in various fields, the fire safety of lithium batteries has become increasingly prominent. Aiming at the high wastage and low precision problems existing in the current energy storage lithium battery fire protection scheme, we discuss the optimized design and application of single-cell level fire protection device by combining numerical model analysis and experimental simulation. The scheme realizes the precise and rapid fire-fighting of thermal runaway cores by opening the fire-fighting channel in a physical way and combining with the abnormality identification and command issuance of BMS. After simulation experiments and field tests, the feasibility and efficiency of the scheme are verified. The research results provide a new and reasonable solution for the development of energy storage fire fighting system and the safety management of energy storage battery.

Keywords: Energy storage safety, lithium battery fires, fire protection systems.

1 Introduction

As a high-energy, high-density power source, lithium batteries have been widely used in electric vehicles, mobile devices, aerospace and other cutting-edge fields due to their superior electrochemical performance[1-4]. However, due to the flammability of the internal materials of lithium batteries, once thermal runaway occurs, it is very easy to cause serious fire accidents, which not only causes huge loss of life and property, but also restricts the in-depth development of new energy applications[5-6]. Therefore, it is necessary to carry out research on the thermal runaway mechanism of lithium battery energy storage system and the corresponding fire safety technology, in order to ensure the safe and stable work of energy storage power stations.

At present, the fire protection system of lithium battery mainly focuses on the two levels of battery pack fire protection and whole box fire protection[7]. Pack-level fire protection takes the battery pack as the smallest unit, equipped with external detectors and fire extinguishing devices, and carries out composite detection on the battery pack to realize the early thermal runaway sensing of the battery pack, intelligent judgement

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and suppression[8]. The whole process takes a long time and the accuracy is relatively insufficient. The whole box fire protection is usually used in conjunction with pack-level fire fighting devices, although it can enhance the security of energy storage, but the loss is larger, and the practical feasibility needs to be improved[9].

To address these issues, we proposes and designs a single-cell level fire fighting device for lithium batteries. The device is capable of providing fast and accurate fire fighting treatment for thermal runaway cells directly. This innovative design greatly improves the safety and reliability of batteries. It is of great significance for optimizing the safety management of batteries.

2 Design of Single-cell Level Fire Fighting Strategy

2.1 Analysis of Fire Fighting Strategy Rationale

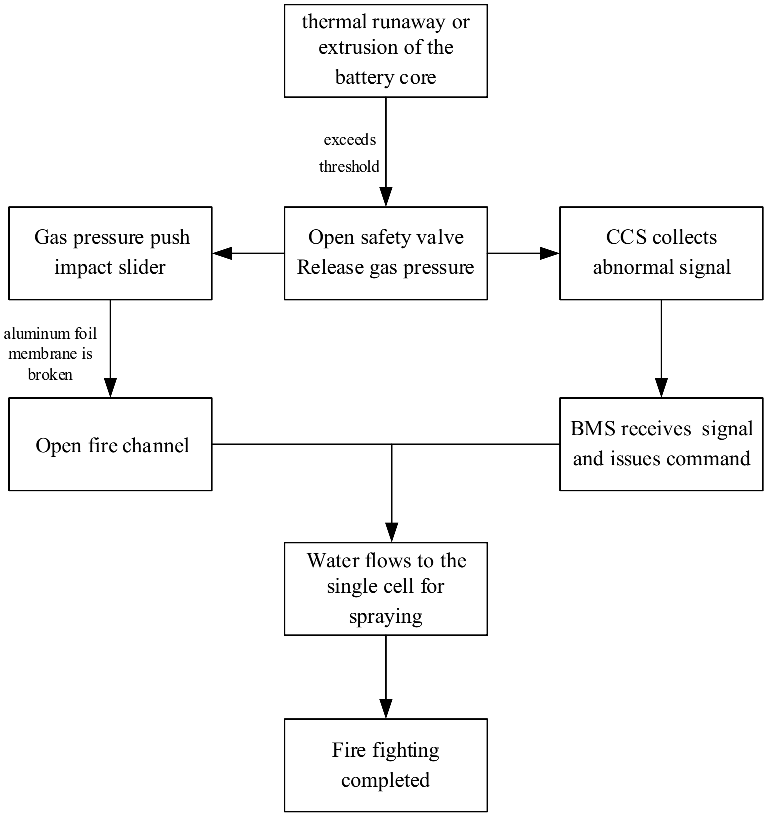

Fig. 1. The fire strategy workflow

Aiming at the fire safety of lithium battery, we propose an active-passive matching fire strategy. When the internal pressure of the battery core surges due to thermal runaway or external extrusion, exceeding the preset threshold, the safety valve will be activated rapidly, automatically opening and releasing the accumulated high-pressure gas inside. The gas pressure will be used as a power source to open the fire channel by pushing the impact slider inside the fire fighting device to break through the aluminum foil membrane used to stop the water. At the same time, the core control system (CCS) will monitor the status of the core in real time. Once an abnormality is detected in the battery cell, the CCS will immediately collect the relevant information and transmit it to the battery management system (BMS). BMS will receive the abnormal signal and issue a water injection command to precisely guide the water to the location of the battery cell through the preset pipeline to realize targeted fire-fighting by spraying. The overall fire strategy workflow is shown in Fig. 1.

2.2 Single-cell Level Fire Fighting Device

In this paper, we innovatively propose a single-cell level fire fighting device design, which integrates the functions of independent water circuit and pressure relief holes, and the core components include the impact slider, plastic shell, and water-stopping membrane, etc., as shown in Fig. 2.

The design of the impact slider adopts the structure of a round platform[10], which aims to better fit the mechanical characteristics of pneumatic impact to ensure that it can quickly respond and trigger the fire fighting action in case of abnormalities in the battery core.

The shell is based on the commonly used sprinkler structure with a "temporary water reservoir" at the connection to the fire channel. This reservoir not only effectively enhances the water storage capacity of the device, but also its pipe wall evenly distributed three slots, constituting a dedicated fire water flow channel, to avoid the water pressure and gas pressure direction of the problem of mutual exclusion.

The water-stopping membrane is made of low-cost, waterproof and easy-to-break aluminum foil, which ensures that the fire channel can be opened quickly and effectively in case of emergency.

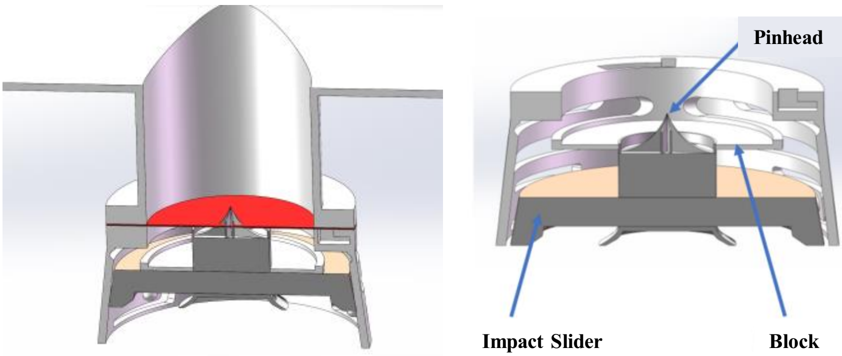

Fig. 2. Fire fighting device components

3 Thermal Runaway Fire Fighting Experiment

3.1 Airtightness Test

The airtightness test verifies the reasonableness of the leakage-proof design of the fire fighting device by filling it with water[11]. The airtightness is not only related to whether it can smoothly spray the water onto the abnormal cells to realize rapid fire extinguishing, but also directly related to the safety and independence of the battery pack inside.

The experimental process is as follows:

1) The fire fighting pipeline is closed and connected to the fire fighting device, and an aluminum foil membrane is placed between the two as a water-stopping flap.

2) Fill the fire fighting device with water to simulate the water pressure and liquid flow when it is actually used.

3) Observe whether there is water leakage around the aluminum membrane.

Three kinds of customized aluminum foil membranes were selected for testing, and the experimental results are shown in Table 1. It was found that the fire fighting pipeline, the sealing ring, the fire fighting device itself and the aluminum foil membrane were closely matched with each other without any gap, exhibiting excellent sealing performance. Aluminum foil membranes of different thicknesses were all effective in preventing liquid leakage under the joint action of the upper and lower pipelines and the sealing ring.

Table 1. Airtightness test result

Thicknesses	0.05mm	0.1mm	0.2mm
First Time	Watertight	Watertight	Watertight
Second Time	Watertight	Watertight	Watertight
Third Time	Watertight	Watertight	Watertight

3.2 Barometric Pressure Test

In order to verify the applicability of the fire fighting device and to determine the optimal design of its shell and impact slider, barometric experiments were conducted in this research[12]. The air pressure environment when the safety valve of the battery core is opened is simulated by an air pump. We use an inflatable pump with an upper limit of 1.5 MPa, equipped with an air tube and a safety valve simulation port.

The experimental process is as follows:

1) Start the inflatable pump and adjust the air pressure value according to the experimental demand.

2) Connect the inflatable pump, the output air tube, the branch pipe and the safety valve simulation port.

3) Open the output air tube, blowing outward.

4) Close the tube, observe whether the impact slider in the fire device to produce effective impact, and assess the size of the aluminum foil membranes rupture.

As shown in Tables 2-3, we tested four different types of fire fighting shells with different elastic catches. The results showed that the long and double bonds had excessive fixation forces, resulting in a blocked slider impact. The short bond reduces friction, but the overall impact difficulty is still high. The bump ball connection method in the experiment is outstanding, the impact pressure at all points can effectively push the slider upward impact, and fixed stable, no slider fall or loose phenomenon. Therefore, it is concluded that the connection method of bump ball can significantly improve the practical performance of the fire fighting device. In addition, the experiment also tested different thicknesses of aluminum foil membranes. The results show that 0.05mm aluminum foil membrane can be effectively broken under various air pressures, which can better ensure the stability of the fire fighting process compared to other thicknesses.

Table 2. Aluminum foil membranes breakage under different connection methods

	0.05mm	0.1mm	0.2mm
Long bond	Unbroken	Unbroken	Unbroken
Double bond	Unbroken	Unbroken	Unbroken
Short bond	Unbroken	Unbroken	Unbroken
Bump ball	Broken	Broken	Broken

Table 3. Size of aluminum foil membranes breakage under different barometric pressure

	0.5MPa	0.6MPa	0.7MPa	0.8MPa	0.9MPa	1MPa
0.05mm	15mm	15mm	16mm	18mm	18mm	18mm
0.1mm	10mm	10mm	10mm	15mm	15mm	16mm
0.2mm	8mm	8mm	9mm	9mm	13mm	14mm

3.3 Fire Fighting Test

The fire test judges the reliability of the designed device through the fire fighting of the thermal runaway battery cell[13-14]. Specific experiments for the first overcharging of the core to achieve thermal runaway state, prompting the fire device channel open, the implementation of water spraying.

The experimental process is as follows:

1) Fix the lithium iron phosphate battery and add insulating plates between the two sides and the sheet metal parts to prevent current leakage and accidental short circuit.

2) Fix the fire fighting device above the battery and make sure the bottom is 1mm away from the safety valve to ensure timely response.

3) Connect the charging cable and turn on the charger to start charging the battery cell.

4) Continue charging until the battery cell is overcharged and thermal runaway is triggered, and immediately turn off the charger after observing the safety valve open.

5) After the thermal runaway occurs, remove the fire fighting device and observe the degree of breakage of the aluminum foil membrane and the effect of the fire fighting spray.

During the whole process of the experiment, the 280Ah lithium iron phosphate battery was overcharged and expanded, with the subsequent opening of the safety valve, the gas was released in the expected direction, with no hedging phenomenon with the water flow. The gas pressure successfully pushed the impact slider, triggering the fire device. From Fig.3 and Fig.4, it can be seen that after being impacted by the slider, the aluminum foil membrane is broken and the perforated area is large, so the fire-fighting water can flow smoothly through the aluminum foil membrane to the battery core to achieve effective fire extinguishing. In addition, the bursting of the safety valve of a single cell only triggers its corresponding fire fighting device, and the other cells are not affected. This further proves the rationality of the proposed design of the fire device and material selection.

Fig. 3. Breakage of aluminum foil membrane

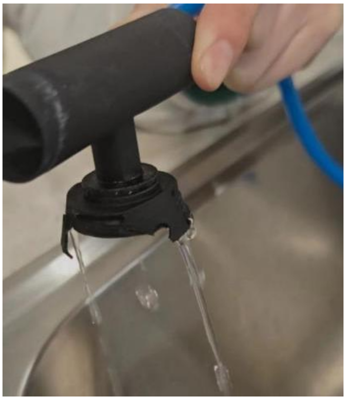

Fig. 4. Condition of fire water flow

4 Conclusions

Lithium battery energy storage technology, despite occupying a central position in the field of modern energy storage, its potential risk of thermal runaway and combustion explosion has always been the focus of attention in the industry and scientific research. In view of this major safety challenge, we thoroughly explore and design a set of lithium battery fire fighting strategy for a single cell, and at the same time conducts thermal runaway fire tests on the whole fire device. The results show that the designed fire device has great airtightness. Under the thermal runaway scenario, the device can be triggered quickly and accurately, realizing fast and effective fire fighting for the single cell.

In the future, we will deepen the verification of its functionality, explore the integration path between proposed single-cell level fire fighting device and CCS, BMS and other information management systems, improve the reliability of the fire management system, and reduce the operation risk of lithium battery energy storage system. In addition, we will focus on material innovation, use more advanced and environmentally friendly materials to improve the fire extinguishing and thermal insulation performance of the fire device, optimize the design to reduce material waste, and realize its engineering application in the fire protection of energy storage systems.

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