The Concept of early monitoring and warning of thermal runaway of lithium-ion power battery using parameter analysis

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Abstract. Considering the key factors affecting the fire rescue of lithium-ion power battery, such as timely early warning, monitoring, delaying the runaway process and sharing the causes of safety accidents, this paper analyses the thermal runaway mechanism of lithium-ion power battery. In addition, this paper puts forward the intelligent fire safety design of lithium-ion power battery, from the real-time monitoring technology of lithium-ion power battery safety, to bring the fire safety of lithium-ion power battery into the urban intelligent fire protection system.

1. Introduction

As an energy carrier that can realize the mutual transformation of electric energy and chemical energy, lithium-ion battery is widely applied in electric bicycles, energy storage, toys, electronic products and other industries because of its high working voltage, high specific energy, long cycle life. However, since the advent of lithium-ion battery, its fire safety has attracted much attention. Once the heat of lithium-ion battery is loss of control, the existing fire rescue means are difficult to deal with it effectively. In recent years, with the increasingly prominent fire safety problems of lithium-ion batteries, scholars have carried out a lot of research work, and fully analyzed the evolution mechanism and behavior law of thermal runaway of lithium-ion batteries under various situations. Many scholars have studied the thermal stability of battery material components. Some scholars use accelerated calorimeter and differential scanning calorimeter to measure the heat release curve of battery components in high temperature environment, and calculate the dynamic parameters of each heat flow peak according to the heat flow curve [1]. Some scholars have studied the runaway behavior of lithium-ion battery in various external environments, simulated the thermal runaway of battery under the conditions of extrusion, overcharge, over discharge and heating, and obtained a series of laws and conclusions [2, 3]. Some scholars have established relevant thermal models of lithium-ion batteries by using simulation software, such as ANSYS, FLUENT or COMSOL, to simulate and analyze the thermal property of lithium-ion batteries under various abuse conditions [4-6]. In this paper, based on the analysis of the causes of thermal runaway of lithium-ion battery, the author will put forward the idea of early warning the thermal runaway behavior of lithium-ion power battery by the monitoring the key parameters of lithium-ion power battery.

2. Causes of thermal runaway

Ideally, there will be no side reactions and irreversible consumption of Li + when the lithium-ion battery works, however, under some extreme conditions, lithium ion batteries will have irreversible
consumption and even some side reactions. These irreversible reactions and consumption will break the balance of lithium-ion battery capacity and affect the service performance of lithium-ion battery. When the damage reaches a certain level, it will cause battery failure. In serious cases, it may cause battery smoke, explosion or combustion, which brings great hidden danger to life and property safety.

The internal of the lithium-ion battery follows the heat balance, that is, all heat production of the lithium-ion battery is equal to the sum of the absorption and heat dissipation of the lithium-ion battery itself. The heat production rate changes exponentially, while the heat dissipation rate changes linearly. When the heat dissipation rate is greater than the heat production rate, the battery does not absorb heat and its temperature does not rise, so it will not lose control of heat. However, when the heat accumulation exceeds one value, the temperature of the battery will increase rapidly and the heat will be out of control. Thermal runaway may occur in the process of charging, standing, transportation and use of lithium-ion batteries. Usually, the thermal runaway of lithium-ion battery is affected by mechanical abuse, electrical abuse and overheating abuse. Mechanical abuse includes drop, impact, acupuncture, extrusion, vibration and acceleration, electrical abuse includes internal short circuit, over discharge, over charge, and forced discharge, and overheating abuse includes incineration, thermal shock, hot plate, microwave heating, etc. In fact, these three abuse situations are not completely independent, but there is a chain relationship. The inducement analysis of thermal runaway is shown in Figure 1.

![Figure 1. Inducement analysis of thermal runaway](image)

3. **Thermal runaway state and diffusion mechanism analysis**

When the heat of battery gets out of control, the interaction between its internal materials and electrolyte will release a lot of heat, resulting in combustion and internal material sputtering. In addition, due to the volatilization of electrolyte and the combustion of internal materials, lithium-ion batteries will release a large number of toxic, harmful and combustible gases in the process of thermal runaway, which further increases the risk of battery fire. At the same time, it also puts forward new challenges to the fire rescue of battery fire.

In the process of thermal runaway, batteries will experience the following processes: high temperature capacity attenuation, diaphragm decomposition, negative electrolyte reaction, diaphragm melting, positive-electrode decomposition reaction, negative-electrode and binder reaction, electrolyte combustion and so on. Before the internal chemical reaction of the battery generates heat, a high-temperature capacity attenuation process will occur, followed by diaphragm decomposition, negative electrolyte reaction, diaphragm melting, positive decomposition, negative electrode and binder reaction, electrolyte combustion and other processes. In particular, in the case of dendrite growth (as shown in Figure 2) and poor thermal management at some locations, the thermal runaway of lithium-ion battery will occur during normal use or standing, which brings huge potential safety hazards to fire safety management.
Figure 2. Thermal runaway of lithium-ion battery caused by dendritic growth

As shown in Figure 3, after the thermal runaway is induced, the heat released after the local monomer thermal runaway propagates to the surrounding, which may heat the surrounding battery and lead to the thermal runaway of the surrounding battery, also known as the "expansion" of the thermal runaway in the battery pack. There's a limit to the amount of energy that can be released by a thermal runaway, but if the chain reaction causes the expansion of the thermal runaway, the energy of the whole battery pack will be released through the thermal runaway, which will cause great harm.

Figure 3. Uncontrolled heat transmission

4. Monitoring technology and assumption of early warning

From the perspective of fire protection, more attention should be paid to the real-time monitoring and early warning technology of lithium-ion power battery. At present, the widely used Battery Management System is mainly to improve the utilization rate of the battery, prevent over discharge and overcharge of the lithium-ion battery, prolong the running time of the lithium-ion battery and monitor the status of the lithium-ion battery. The Battery Management System can estimate the status of charge of the lithium-ion battery pack, that is, the remaining power of the lithium-ion battery, in the meanwhile, it is ensured that the feedback energy can be absorbed as much as possible without damaging the battery during braking, and greater power can be provided during acceleration to obtain greater acceleration without damaging the battery. Battery Management System can also monitor the health status of the battery, including the changes of ampere hour capacity and power. It is generally believed that when the ampere hour capacity is attenuated by 20% or the output power is attenuated by 25%, the service life of the battery will be the end. Based on this, the Battery Management System can manage the charge and discharge state of the battery and improve the service efficiency of the battery, but it cannot monitor and alarm the thermal runaway phenomena.

The author believes that the lithium-ion battery should be monitored on the basis of the traditional Battery Management System. Meanwhile, the changes of battery voltage, battery current, battery
temperature and other parameters corresponding to various thermal runaway hazards should be deeply studied. On this basis, build a fire lithium-ion battery monitoring platform to monitor the safety of important lithium-ion battery use links, carry out early warning and control for lithium-ion battery safety, delay the fire process, and strive for valuable time for fire rescue.

Furthermore, the lithium-ion battery fire safety monitoring can be integrated into the intelligent fire protection platform. Through multi-dimensional comprehensive perception, including voltage, current, temperature, early decomposition gas, etc., the generation and simple processing in the early stage of fire are judged in real time in advance by using the edge calculation and processing capacity of the intelligent terminal. Further calculation results and processing opinions can also be given through the intelligent algorithm of the remote cloud platform. Some functions of edge processing can also be realized through the Battery Management System.

The core algorithm of the platform should be linked with the Battery Management System. In addition, it is based on a lot of historical data to analyse and use big data on the platform, and even establish some expert systems to calculate the status of battery safety failure or battery monitoring damage, and give an early warning value in time.

5. Conclusion
By analysing the causes, the process experienced, and the propagation of the lithium-ion power battery thermal runaway, this paper puts forward the idea of lithium-ion power battery monitoring technology and early warning. Through in-depth study of the variation laws of parameters such as voltage, current, temperature, and other parameters corresponding to hidden dangers of thermal runaway, on the basis of the traditional Battery Management System, it is integrated into the Intelligent Fire Protection Platform, comprehensive monitoring and early warning of thermal runaway of lithium-ion battery.

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