Research on Thermal Out of Control of Lithium Battery in New Energy Vehicles

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Abstract. Lithium-ion batteries are widely used in the new energy automobile industry due to their high energy density, fast charging, high cycle life and no pollution. However, in actual use, lithium-ion battery systems may cause deflagration of the power battery system due to thermal runaway. In this paper, the causes of the thermal runaway of the power battery system are studied, and the existing related suppression methods at home and abroad are compared and analyzed, and the advantages and disadvantages of the relevant suppression methods are obtained.

1. Introduction
Lithium-ion batteries are widely used in the new energy automobile industry as the main source of power because of their high energy density, fast charging, high cycle life and no pollution. However, lithium-ion batteries are sensitive to temperature, and when the temperature is too high, thermal runaway is likely to occur, causing a safety accident. Thermal runaway refers to the phenomenon that the cell's exothermic chain reaction causes a sudden change in the temperature rise rate of the battery, causing overheating, fire, explosion, etc. The thermal runaway mainly includes mechanical triggering, electrical triggering and thermal triggering. The safety accident caused by thermal runaway has undoubtedly caused great impact on people's life and property safety, and has become a hot spot of concern for the automotive industry and battery companies. Therefore, in order to avoid the thermal safety of lithium-ion batteries, promote their widespread use in electric vehicles and accelerate the popularization of electric vehicles, the factors leading to the thermal runaway of lithium-ion batteries and the rationalization and comparative analysis of existing solutions appear to especially important.

2. Thermal battery runaway mechanism and several incentives

2.1. Battery thermal runaway mechanism
A thermally runaway battery can release energy in the form of effective chemical energy heat release, combustible heat of combustion under thermal runaway, entropy product during material phase change, and overcurrent heat generation (internal resistance). The battery release energy can be expressed by the following formula:

$$E_{\text{sum}} = UI + I^2R + m\Delta H_{\text{m}} + T\Delta S + \text{etc...}$$  \hspace{1cm} (1)

The first item in the formula is the main form of externally released electrical energy, which is controllable; the second and third items are the main forms of internal resistance power consumption, which are the most uncontrollable; the fourth item can be ignored. The heat accumulation during the
internal (external) short circuit of the battery and the combustion of internal combustibles due to heat accumulation are the root cause of the battery’s serious safety accident. When the battery is out of control, the heat generated is mainly expressed as:

\[ Q_x = \left( \frac{y^2}{(R_c + R_x)^2} \right) \cdot R_x \]  \tag{2}

Figure 1. Thermal temperature-reaction (HTR) cycle diagram

In Figure 1, when \( > > \), the value does not have much influence on batteries with different capacities, and the probability of thermal runaway is small (self-discharge is large); when \( \approx \), the ratio of to total energy of the battery increases sharply, and the specific surface area. The small battery has a faster thermal diffusion and the diaphragm fails. However, the large-capacity battery has a slower thermal diffusion and is prone to thermal failure, which is more demanding for the diaphragm. The battery with full energy storage, internal combustibles (regardless of the diaphragm), if the combustion heat accumulated during the combustion is not effectively released, and the battery capacity is large, it is difficult to dissipate heat, and as a result, an explosion may occur. The chemical reaction of this process is mainly:

\[ 2\text{Li} + \frac{1}{2} \text{O}_2 \rightarrow \text{Li}_2\text{O} \]  \tag{3}

\[ C_x\text{H}_y\text{O}_z \rightarrow \frac{2x+y}{2}\text{O}_2 \rightarrow x\text{CO}_2 + \frac{y}{2}\text{H}_2\text{O} \]  \tag{4}

The inside of the battery follows the heat balance, and the total heat generated by the battery is equal to the sum of the absorbed amount of the battery itself and the amount of heat released. The temperature rise of a lithium-ion battery is determined by the heat balance between heat generation and heat dissipation. The heat generation rate star index changes, and the heat dissipation rate star changes linearly. When the heat dissipation rate is lower than the heat generation rate, the heat can not be fully consumed, and heat accumulation will occur, causing the temperature of the lithium ion battery to rise continuously and the battery temperature to rise. The reaction rate, in turn, causes the heat generation to increase dramatically. When the heat accumulates to a certain extent, the battery temperature increases sharply and thermal runaway occurs. The parameters of the thermal runaway characteristics of different lithium-ion batteries are shown in Table 1.

| Number | /°C  | /°C  | /°C  |
|--------|------|------|------|
| 1      | 77.3 | 140.2| 13.9 |
| 2      | 100.9| 141.6| 2.9  |
| 3      | 68.6 | 160.1| 19.1 |
| 4      | 77.5 | 144.1| 28.6 |
| 5      | 102.1| 207.4| 6.9  |
| 6      | 107.2| 205.5| 9.1  |

Table 1. Table of thermal runaway characteristics of different lithium ion batteries
2.2. causes of thermal runaway

2.2.1. Mechanical trigger. Mechanical triggering refers to the situation in which the battery and battery pack are deformed by external forces such as external collision, extrusion, puncture, vibration, etc., causing deformation of the lithium battery cell and the battery pack, and relative displacement of different parts of the battery. Mechanical triggering may crack the battery cell separator, causing internal short circuit of the battery cell. Strong extrusion and puncture may cause leakage of flammable electrolyte of the battery cell, causing burning of the battery pack and even the electric vehicle.

2.2.2. Electrical Trigger. Electrical triggering includes external short circuits, overcharging, and over discharge.

The external short circuit of the power battery system is generally caused by the collision of the automobile, the contamination of the diffused water conductor, or the electric shock during maintenance. At this time, when two conductors with a pressure difference are connected outside the battery core, an external short circuit occurs. Overcharging of the power battery system is mainly caused by a malfunction of the charger, or the BMS fails to monitor the voltage of each individual battery. When the battery is overcharged to a certain limit, the electrolyte will undergo a violent oxidation reaction, and the heat will continue to dissipate heat, causing the internal temperature of the battery to rise rapidly. Since the energy of the battery is full when overcharging, overcharging is also the most harmful type of electrical triggering. Over-discharge of the power battery system mainly occurs when the BMS monitors the fault, causing the lowest voltage of the battery to be over-discharged.

2.2.3. Heat spread. The thermal spread of the power battery system rarely exists independently, often developed by mechanical triggering and electric triggering, and is a part of the final direct trigger of thermal runaway. Once the temperature rises abnormally under the abuse condition, the chemical side reaction will occur, followed by a thermal temperature reaction (HTR) cycle that eventually forms a chain reaction until thermal runaway occurs.

3. power battery thermal runaway suppression means

The three main causes of mechanical triggering, electric triggering and heat spread of thermal runaway of power battery are mainly divided into battery material modification and external prevention management.

3.1. cell material modification.  
By modifying the cell material to block the thermal runaway chain reaction, thereby improving the ability of the cell to resist thermal runaway, the current research focuses on the material modification of the four main materials of the positive electrode material, the negative electrode material, the electrolyte solution and the separator. For example, the surface coating of the positive and negative materials is modified to prevent contact between the positive electrode material and the electrolyte, and the thermal stability of the battery element is improved by the heterometallic element of the positive electrode material, the flame retardant additive.

3.2. External prevention management.

3.2.1. Structural design prevention. Structural design The main preventive measures to prevent thermal runaway are heating barriers, vibration isolation, collision protection, and increased gas discharge points.
3.2.2. **Thermal Management Design Prevention.** The thermal insulation system of the battery is very important to prevent thermal runaway. Therefore, the thermal management design prevention mainly reduces the thermal expansion of the battery from the aspect of suppressing thermal expansion. Compared with natural cooling and forced air cooling, liquid cooling is a thermal efficiency. A kind of thermal management method, so the liquid cooling system is an existing means to effectively prevent the thermal runaway of the battery system.

3.2.3. **BMS monitoring.** BMS monitoring is an effective means of suppressing thermal runaway caused by electrical triggering and heat spread. Mainly by improving the estimation accuracy of the battery state, avoiding the thermal runaway well caused by excessive charge and discharge and setting the temperature classification report, the system will issue a warning at the beginning of the heat spread.

4. lithium ion battery thermal safety recommendations

4.1. **Over temperature protection**

It can be seen from the above analysis that high temperature seriously affects the thermal safety of lithium ion batteries. Therefore, the temperature of the lithium ion battery should be strictly controlled and prevented from rising abnormally.

4.1.1. **Lithium-ion battery temperature is too high for high temperature heat source.** 160 °C is the critical safe temperature at which the simulated battery is thermally runaway. Increasing the heat dissipation condition can significantly improve the thermal runaway phenomenon. For example, when the external temperature is 175 °C, under the condition of natural air cooling, the battery has thermal runaway and the peak temperature is as high as 650 K, and no thermal runaway occurs when forced cooling is performed. Therefore, the vehicle should be minimized or avoided for long-term driving and placement under high temperature conditions to prevent the lithium ion battery temperature from being higher than 160 °C due to high temperature heat source, and there is a risk of thermal runaway.

4.1.2. **Lithium-ion battery itself is too hot.** Due to the increased heat generation inside the battery during overcharge, the temperature is too high, and the lithium ion battery has thermal runaway at 0.1C, 0.3C and 0.5C overcharge. Therefore, in order to prevent the temperature of the lithium ion battery from being higher than 160°C, an over temperature warning and protection device should be set, and different temperature values and devices should be set according to the performance and temperature resistance characteristics of different types of batteries. Perform different alarm prompts or protection actions according to the monitored temperature. When the battery temperature reaches 160°C, forcibly power off to prevent thermal runaway.

4.2. **Improve heat dissipation conditions**

4.2.1. **Improved cooling solution.** Under the conditions of high temperature and overcharge abuse, the heat dissipation condition can improve the thermal safety of lithium ion batteries. For example, when the ion battery is overcharged at 0.1C, the heat dissipation coefficient is 10 W/time, the thermal charge is out of control when the overcharged 1250s ion battery is generated, and the heat dissipation coefficient is increased to 25 W/, the thermal runaway occurs when the overcharge is 1730s: when the heat is dissipated When the coefficient is 45 W/, the battery does not have thermal runaway. It can be seen that good heat dissipation conditions can effectively prevent heat from getting out of control.

4.2.2. **Optimize the design of the battery pack structure.** The design of the battery module also has a certain impact on the heat dissipation and temperature of the battery. The high thermal conductivity sheet can be attached to the surface of the battery cell and the module, and the arrangement and gap arrangement between the cells can be improved, so that the battery can dissipate heat well, and the
heat dissipation performance of the battery case can be further improved by improving the material of the battery case body. So that it dissipates heat well to prevent thermal runaway.

4.3 Improve material stability.

4.3.1. Positive electrode material constituting a lithium ion battery. Through the analysis of the internal side reaction of the ion battery, when the 0.5C overcharge occurs, the positive electrode material reacts with the electrolyte to generate the most heat, up to 3.3W/, which is the main cause of thermal runaway of the lithium ion battery. Therefore, research and selection of materials with better stability as the positive electrode of lithium ion batteries or technical means such as material modification to improve the thermal stability of the positive electrode material can greatly improve the safety of lithium ion batteries.

4.3.2. Anode material constituting a lithium ion battery. The reaction between the negative electrode material and the electrolyte increases the process of thermal runaway. For example, when 0.5C is overcharged, the negative reaction heat release amount is 2.5W/, which is another important cause of thermal runaway of the key ion battery. Therefore, improving the stability of the negative electrode material and reducing the heat generation thereof can further weaken or prevent the occurrence of thermal runaway. The stability of the graphite anode can be improved by certain technical means or the material with high stability can be continuously developed and selected as the anode material of the battery.

4.3.3. electrolyte. Improving the stability of the electrolyte of the ion battery is of great significance for the improvement of its safety. Adding a flame retardant or using a solvent with a high point such as a fluorine-based solvent can improve the stability of the electrolyte to a large extent. Improve the safety of lithium-ion batteries at high prices.

4.3.4. SEI film. Although the SEI membrane has less liberation heat, it is the pre-condition for causing thermal runaway. Therefore, improving the thermal stability of the SEI film and reducing the heat release during decomposition thereof have a certain effect on preventing thermal runaway. A coating layer may be added to the surface of the negative electrode or a film-forming additive may be added to the electrolyte to improve the thermal stability of the EIS film.

4.4. overcharge protection

Through the simulation of the over-charging thermal runaway, it is known that when the lithium-ion battery is overcharged, especially when the current is overcharged, the risk of thermal runaway will occur. Therefore, overcharge of the lithium ion battery should be avoided.

4.4.1. Charging protection. The larger the overcharge current, the more easily the thermal runaway occurs. For example, when the heat dissipation coefficient is 10 W/, the battery 0.5C overcharge is 1000s ahead of the 0.1C overcharge, and the battery is prone to thermal runaway.

4.4.2. Personnel aspects. When charging the lithium-ion battery, the responsible person should check the charging status of the lithium-ion battery in time. When the battery is full, cut off the charging power in time to prevent overcharging.

4.4.3. Intelligent design of charging pile. The design of the charging column of the lithium-ion battery should have a charging intelligent management system to realize the automatic detection and judgment of the abnormality of the rechargeable battery. The system detects that the battery to be charged is damaged, and the charging intelligent management system displays and prompts the relevant personnel; In addition, the system should be able to monitor the voltage during battery charging in real time to prevent overcharging; at the same time, the system monitors the battery temperature. When the
battery temperature is too high, it should have the function of alarm and automatic power off to prevent the battery temperature from being higher than 160°C.

4.5. **Thermal runaway warning**
In practical applications, due to various factors, the thermal runaway of lithium-ion batteries is difficult to completely avoid. In order to further reduce the risk of thermal runaway, it is necessary to prevent it first and prevent it from happening. Therefore, it is especially important to set up a protective early warning mechanism for the thermal runaway of the ion battery.

5. **Conclusion**
According to the previous theoretical analysis and comparative study, the main factors causing the thermal runaway of ternary lithium-ion battery are analyzed, and relevant suggestions are proposed from different aspects such as over-temperature protection, improved thermal conditions, over-charge protection, and thermal runaway warning. Thermal safety provides a reference and basis.

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