Analysis of the Causes of Fire of Lithium Batteries and Improvement Measures

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Abstract. In recent years, China's new energy vehicle fleet has been growing, and China's new energy vehicle production has reached 3.5 million units in 2021 and is expected to exceed 20% of the country's annual vehicle production in 2023. However, the biggest problem plaguing the industry is the safety of new energy vehicles, especially the lithium battery fire problem (accounting for more than 60%). The paper is mainly proposing improvement measures through the analysis of multiple causes, introducing new materials, new technologies and safe design from the technical point of view to reduce thermal runaway. By grasping the pre-design, process control and testing at all levels from the production and use point of view to improve the yield rate and reduce the problematic batteries into the automobile consumer market, it will surely improve the safety of new energy vehicles significantly and help the healthy and sustainable development of the new energy vehicle industry.

Keywords: Lithium Battery, Safety Issue, Thermal Runaway.

1. Introduction

The Chinese government has proposed the "carbon peak and carbon neutrality" dual carbon goal, which clearly states that China should reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060. In order to achieve this goal, the development of new energy vehicles instead of traditional fuel vehicles is an important direction. While the traditional real estate industry is gradually fading out as the pillar industry of China's economic development, the new energy automobile industry has gradually become the most important industrial direction in China. New energy vehicles are positioned as one of the seven strategic emerging industries in China, and are a top priority for China's future development. According to statistics, as of the end of August 2022, China's new energy vehicle ownership has reached 10.99 million units, accounting for more than half of the world; China's new energy vehicle production reached 3.97 million units in the first eight months of 2022, and the sales ratio of new energy passenger cars has reached 28.3%. 2022 annual sales of new energy vehicles in China are expected to exceed 6.5 million units, with sales expected to reach 60% of global sales. Compared to 1.367 million units in 2020 and 3.521 million units in 2021, the growth rate is breathtaking, and it can be said that the trend of electrification in China's auto industry is unstoppable.

However, the main factor that restricts the development of the new energy vehicle industry at this stage is the problem of car fires caused by various quality defects of new energy batteries. In particular, electric vehicles catch fire relatively quickly and even burst into flames, which can easily cause casualties. in early 2022, the Chinese Consumers Association announced the auto consumer complaints, where the safety of new energy vehicles is a hot area, and four out of the eight main problems are about battery quality. Therefore, battery safety is also the most concerned hot issue for the sustainable development of new energy vehicles. According to statistics from the Ministry of National Emergency Management, there were 640 new energy vehicle fires in the first quarter of 2022, with an average of seven vehicles per day. New energy battery companies and car companies are facing a lot of social pressure. In addition to the accidents that have occurred, major new energy vehicle manufacturers are also recalling vehicles due to potential fire risks. For example, LG of South Korea recalled 81,701 vehicles in 2021 because of fire risks, BAIC recalled 32,000 vehicles in 2021 because of hidden battery safety problems, and GM recalled 142,000 vehicles because of battery problems.

The causes of spontaneous combustion in new energy vehicles are complicated. Statistics show that the main causes of fire are the quality of the battery itself, aging components, external collisions, hot weather, high load and thermal runaway. Thermal runaway is the main problem, accounting for more than 60% of the total accidents. The so-called thermal runaway refers to irreversible rapid rise in the temperature of the battery core due to some objective reasons leading to violent exothermic, and finally a fire or even an explosion. The cause of thermal runaway is2her causes and internal short circuit and other reasons. Therefore, it is necessary to analyze and research from multiple horizontal dimensions and the whole life cycle of vehicle use to find better solutions in order to reduce the risk of spontaneous combustion and avoid thermal runaway.

2. Analysis of the causes of thermal runaway

New energy vehicles are divided into many kinds of situations from the state when they catch fire. In the state of flooding, collision, overcharge, driving and long-term placement, there have been cases of fire, and there are more cases of fire in summer than winter. The reason is that flooding will lead to external short circuit of the battery; collision will lead to internal structure damage, insulation failure will lead to internal short circuit; overcharge will lead to cell failure and excessive heat release; long-term placement or low temperature environment will lead to over-discharge and cell failure; overheating in summer will lead to higher temperature of the battery box, aging of the components, easy to heat up and spontaneous combustion when fast charging.

From the perspective of the intrinsic causes of new energy vehicle fires, they can be divided into three forms: mechanical, electrical and thermal causes. The mechanical aspects include needle punctures and extrusions that cause the battery diaphragm to break and tear, contact short circuit of positive and negative materials, or electrolyte leakage that leads to external short circuit. Electrical triggers include external short circuit, overcharge and overdischarge. Some of the cells themselves are poorly aligned leading to monomer overcharging. Overcharging and overdischarging can lead to dendrite growth gradually penetrating the diaphragm, which in turn leads to short circuit and electrochemical reaction, and thermal runaway will occur when it reaches a certain level. Because of heat induced by the presence of contact resistance in the connecting elements, loose joints can lead to abnormal heating and trigger thermal runaway. A common problem caused by above three factors is the failure of the diaphragm inside the battery, and then the positive and negative contact, resulting in heat, the chemical energy stored in the battery is released, which consequently leads to spontaneous combustion accidents [1].

3. Technical improvement measures

At present, the whole new energy industry is constantly innovating, trying to make "never spontaneous combustion" cars. Each new energy vehicle company has introduced different design solutions, and the whole industry is improving and upgrading from design, production and use. From the design stage, new safety design is introduced through further research and development, including the use of new materials, new constructure and new systems to reduce thermal runaway to improve the safety of new energy vehicles; from the production stage, new processes are adopted and good testing is grasped to improve the rate of good products and reduce the problematic batteries into the automobile consumer market; from the usage stage, good process control is done to promptly investigate the problematic batteries and avoid the problematic cars from taking the disease to the road.

3.1. Design solutions to improve and prevent thermal runaway

The safety of new energy vehicles should be improved first from the most basic design. The basic structure of the new energy vehicle lithium battery can be viewed from four levels respectively, materials, cells, modules and systems, so to improve the design from these four levels.

3.1.1 Selection of materials

Lithium battery materials mainly include positive and negative electrode materials, electrolyte, battery separator and other materials. At present, the mainstream enterprises choose ternary lithium and lithium iron phosphate two major technical routes, both of which have their own advantages. Lithium iron phosphate battery has the advantages of high temperature resistance, good safety, low cost, better cycle performance, etc.; ternary lithium battery has the advantages of high energy density, low temperature resistance and high charging efficiency. Major companies are actively studying advanced materials with ultra-high stability. The current key research directions include the transformation of ternary batteries from low nickel to high nickel, the development of high nickel and low cobalt or cobalt-free ternary cathode materials, carbon cathode and alloy cathode and other high-capacity cathode materials. Anode materials, layered nickel cobalt manganese ternary transition metal oxide as an important choice with high multiplier performance and good fast charging performance is highly favored, while lithium iron phosphate cathode is also modified by metal doping such as magnesium aluminum titanium, and surface coating of stable nano-layer to improve the safety performance. In the negative electrode materials, silicon-based anode compared to carbon-based anode has the characteristics of both high energy density, ability to improve the battery energy density of 20-40%, not easy to form "dendrites", good safety performance, and its volume expansion multiplier and rapid capacity decay characteristics have also been significantly improved through material compounding and nanosized [2]. In terms of safety, $LiFePO_4$ is currently the most recommended cathode materials for its satisfactory cycling stability.

The three main roles of diaphragm materials are to isolate the contact between positive and negative electrodes, store electrolyte and ensure the transport of lithium ions. The current diaphragm research and development consists of three aspects, first, is to develop a diaphragm with higher thermal stability, interfacial properties and multiplier characteristics; second is the introduction of solid electrolyte particles in the porous diaphragm void, such as nano-alumina ceramic coated diaphragm, both strength to avoid punctures, but also high porosity, and thin and light characteristics, help improve the fast charging speed and get a longer cycle life, is the key development direction; third is the future to develop high-temperature resistance, the High-voltage lithium-ion conductor film [3].

The improvement of energy density and fast-charging performance of electrolyte is inseparable from electrolyte. The current R&D direction of electrolyte is mainly to develop flame retardant and high voltage resistant electrolyte. Adding new high-voltage electrolytes such as sulfone, nitrile, ionic liquid and fluorine substitute electrolytes with high-voltage resistant solvents can significantly improve the stability of electrolytes, and adding highly concentrated lithium salts such as commonly used $LiPF_6$, LiTFSI, etc., can also improve electrolyte electrochemical window and cycle stability [4].

In order to make lithium batteries with higher energy density and better safety, all-solid-state lithium batteries as an alternative to traditional lithium future battery technology is also stepping up research and development. At present, there are two research and development directions, one is the metal solid-state battery, the other is the solid-state lithium-ion battery. Japan, Germany, France and China are stepping up research and development, but in the solid electrolyte materials, interface performance optimization, electrode material selection, as well as the cost and process, there is still a long way to go.

3.1.2 Selection of electric cell

The increase of energy density of the core and the improvement of fast charging performance are the two main directions for the improvement of the core, which also brings more challenges to the safety of the core. The larger the size of the single cell is, the higher the percentage of active material is, the higher the energy density of the cell will be. Therefore, the choice of core size, package form and structural design has a lot to do with it. Compared to 4680 battery, the energy density of 18650 battery increases by 5 times, and the range increases by 16% [5]. Three types of packaging structure, cylindrical, soft package and square have their own advantages and disadvantages. Different routes

of battery enterprises are in the continuous improvement, there is still no final decision. Up to now, the soft pack battery has the highest energy density, high life reliability, good safety performance and high cost; the cylindrical battery monomer process is the most mature, low production cost, but the high-power discharge and life is poor. Square cells have lower internal resistance and can sustain high power discharge, but the consistency and cycle performance are poor. In addition to this, the cores with laminated manufacturing process have better heat dissipation performance than those with winding process, and will bulge or crack in case of thermal runaway. Therefore, they are not easy to explode, and the safety performance is better.

3.1.3 Module design

Module as an intermediate product between the cell and the battery pack, one of the common uses is to play a supporting and protective role, the second is to meet the electrical performance; the third is to meet the temperature control of the cell, the fourth is to timely power off in the event of abnormalities, blocking the thermal runaway propagation. Current design improvements focus on improving the utilization of space inside the battery module, using new materials for lightweight design to reduce battery weight, and enhancing safety redundancy.

3.1.4 System design

The three main forms of battery pack are soft pack battery pack, square battery pack and cylindrical battery pack. The battery pack design is concerned with flame retardant, explosion-proof, anti-aging and other characteristics, and most importantly, it should have the characteristics of no fire and no explosion by extrusion. The design of the latest research achievement blade battery is a masterpiece. The blade battery passed the pinprick test and extreme crush test, with the test range covering internal short circuit, external short circuit, overcharge, collision, high voltage, connection and dangerous gas, etc., it has been proved to be a relatively large innovation in the battery pack process.

In terms of risk control, Shan et al. have proposed a risk assessment model for the evolution of thermal runaway of power battery in five levels of "fault-smoke-leakage-fire-explosion", which helps to determine the critical threshold through thermal runaway characteristic parameters and make timely prediction and warning [6]. For this development path, it can be targeted in the structural design to increase the active safety protection system, set a timely induction when the temperature is too high by cutting off the current and cooling. A safety valve is set to timely relieve the pressure to avoid explosion when the internal pressure is too high. The Internet of Things (IOT) technology is used for the design of a comprehensive grasp of the battery status. These require the battery management system (BMS) to be constantly updated and upgraded, so as to achieve control of the problem at the early stages of failure and avoid small failures from escalating into big accidents.

3.2. From the production point of view to reduce costs and improve safety

Scientific research should be actively carried out and various new technologies to be adopted in order to improve the rate of good products while reducing safety risks and reducing production costs. The production process also needs good quality control to improve product performance at the stage of the product testing, to reduce the problem battery into the car consumer market, so as to improve the safety of new energy vehicles.

3.2.1 New process design

Taking 4680 cylindrical battery production as an example, the structural design has led to the simplification of the production process, and the increase in the cell of the new battery has significantly reduced the connection materials and control system between the batteries, increased volume utilization, improved safety design, and increased safety performance. At the same time, the weight is reduced, and the amount of batteries used per vehicle is reduced to 1/5, and the capacity of the new production line is increased by 7 times; at the same time, the production process of cathode is improved to reduce the investment cost of the production line by 66% and the production cost by 76%.

3.2.2 Process control

The production of lithium batteries varies from company to company, and is generally divided into three major sections: pole production, cell production and battery assembly. The production process should maintain strict environmental cleanliness, and avoid impurities such as foreign matter, laser melt beads and welding slag in each process such as pulp making, coating, laminating, slitting, winding and assembly; alignment, burrs, scratches and poor consistency in the manufacturing process will cause hidden problems later, which need continuous improvement [7].

3.2.3 Upgrade inspection

The traditional battery quality inspection is mainly by 2D X-ray scanning, and most companies only use sampling mode in the application. However, with the increase of battery energy density and the improvement of packaging technology, defects in the battery production process include, positive and negative electrode alignment, mixed metal or non-metal impurities in the electrode sheet, bubbles, welding defects, electrolyte height measurement, uniformity of positive and negative electrode material coating, electrode folds, structural fractures, etc. The traditional 2D X-ray inspection is no longer able to meet the requirements, so it is necessary to use 3-dimensional computed tomography (CT) inspection [8]. In order to ensure the quality of products, the trend is that offline sampling inspection is transitioning to online full inspection. That is, in accordance with the new energy battery production line beat, synchronously equipped with 3D online CT inspection, automatic discrimination through AI technology, timely detection of problematic products, to avoid unqualified products factory to reach the consumer chain.

3.3. Quality surveillance of usage stage

In the use of new energy vehicles, nondestructive testing of the aging degree of new energy batteries should be demanded in auto 4S stores or large exchange stations to ensure timely detection of problematic batteries. According to experimental records, some battery samples will produce significant and substantial deformation inside the electrode after 2000 times of cycling leading to the separation of the positive and negative electrodes of the battery, which is prone to internal short circuit [9]. Therefore, it is necessary to equip a large number of testing equipment during the warranty period of new energy vehicles or the power exchange link in order to conduct timely tracking and testing of the battery status to avoid the problematic cars from traveling with risks. When the battery decay to unsuitable for car-end applications, it can also engage in laddering, applied to the energy storage end, the secondary use of residual value [10]. This area of work is still in its infancy.

4. The prospect of new energy battery safety technology

With the popularization of new energy vehicles and the rapid development of their production, lithium battery technology continues to upgrade. It is inextricably linked to transportation, logistics, and energy storage technology needed for clean production are inseparable, including the subsequent recycling of used batteries have a large number of commercial opportunities. It can be expected that enterprises and the country's investment in new energy batteries will continue to increase, and the industry's new technology will breakthrough day by day. The development of new materials technology, Internet of Things technology and artificial intelligence advances have brought new vitality to new energy battery safety technology, and the stability of battery materials, the continuous improvement of range, early warning and control of safety issues, intelligent driving will have continued development. The new energy industry is an important pillar industry for China's development in the next 20 years. With fierce market competition, the companies with advanced new energy battery safety technology will eventually stand out and win the first opportunity and status of development.

5. Conclusion

This paper focuses on the current phenomenon of new energy vehicle battery fires and its related safety hotspots, sorting out the various forms of new energy battery fires and the mechanical, thermal and electrical triggers behind them, and proposing measures that can be improved from three aspects: design, production and the whole life cycle of use. At the design level, the latest scientific research results on battery anode and cathode materials, diaphragm materials and electrolyte materials are analyzed, while new progress and research directions are analyzed from the perspectives of cell design, module selection, and system design, and suggestions are given at the production and use levels on cutting-edge technology breakthroughs, process control, and testing upgrades. Through the analysis of this paper, it is hopeful to improve the understanding of the development of new energy safety technology.

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