Design of Lithium-ion Battery Puncture and Crush Test System

Xiaoyang Li [1,2,3], Hongkui Zhang [1,2,3,*]

[1] Fushun CCTEG Inspection Center Co. Ltd, Fushun Liaoning, China

[2] CCTEG Shenyang Research Institute, Fushun Liaoning, China

[3] State Key Laboratory of Coal Mine Safety Technology, Fushun Liaoning, China

* Corresponding author Email: 18940021505@126.com

Abstract. Based on the analysis of the current domestic and international standards for lithium-ion batteries in electric vehicles, this paper provides a detailed introduction to the composition and functions of lithium-ion batteries, describes the process and result determination method of needle puncture and crush tests on lithium-ion batteries, and proposes a design scheme for the test system of needle puncture and crush tests for lithium-ion batteries.

Keywords: Lithium-ion, battery, needle puncture, test system.

1. Introduction

Lithium-ion batteries are a type of modern high-energy secondary battery that uses lithium-containing materials as the positive electrode material and carbon materials as the negative electrode material, with an organic electrolyte. With its high energy density, relatively long cycle life, rapid charging and discharging, and continuously decreasing production costs, lithium-ion batteries have become the preferred power source for electric vehicles and energy storage systems over the next decade or two. The safety of lithium-ion batteries in electric vehicles under extreme conditions has become a key factor restricting the development of the electric vehicle industry. The German Association of the Automotive Industry (VDA) has issued VDA 2007 (Test Specification for Lithium-ion Battery Systems in Hybrid Electric Vehicles), which mainly includes general tests (preconditioning cycles, standard cycles, standard charge, standard discharge, etc.), parameter tests (capacity, power, energy efficiency, high-temperature startup, self-discharge, etc.), life tests (cycle life, etc.), and mechanical safety tests (vibration, shock, humidity-heat alternating, etc.). This standard mainly specifies the performance and durability requirements for the battery. China is also gradually improving the lithium-ion battery testing standard system, and many industries have also formulated and issued relevant standards for lithium-ion batteries, which cover safety technical requirements and safety testing for batteries. In the automotive industry, QC/T 743-2006 “Lithium-ion Battery for Electric Vehicles” mainly includes safety requirements such as over-discharge, overcharge, short circuit, drop, heating, crush, and puncture. Puncture and crush tests are the main type test items to assess the safety of lithium-ion batteries and are important indicators of lithium-ion battery safety. Therefore, the design of puncture and crush test systems is of great significance.

2. Lithium-ion battery

Lithium-ion batteries are rechargeable high-energy, high-concentration batteries that involve the insertion and extraction of lithium ions in positive and negative electrodes. During charging, lithium ions are released from the positive electrode and embedded into the negative electrode through the electrolyte, causing the negative electrode to become lithium-rich and the positive electrode to become lithium-poor. At the same time, electronic charge compensation is supplied from the external circuit to the carbon negative electrode to ensure charge balance. During discharge, lithium ions are released from the negative electrode, embedded into the positive electrode through the electrolyte, causing the positive electrode to become lithium-rich. During normal charging and discharging processes, lithium ions are embedded and extracted between the layered structure carbon material and the layered structure oxide material, typically causing only the spacing between the layers to change without disrupting their crystal structure.

Figure 1. Physical diagram of lithium-ion battery

Lithium-ion batteries consist of positive and negative electrodes, a separator, electrolyte, and casing. The positive electrode is a key factor determining the safety, electrochemical performance (such as specific energy, charge and discharge rate, high and low-temperature performance, cycle capability, etc.), and price of lithium-ion batteries. The positive electrode generally consists of active materials and conductive materials, with the basic requirement being that lithium ions can reversibly extract and embed in the material structure during the battery's charge and discharge process while maintaining structural stability. The negative electrode, usually a layered structure with numerous micropores, has a significant impact on the charge and discharge performance, cycle life, and other aspects of lithium-ion batteries. Materials with low lithium potential and reversible lithium extraction can serve as negative electrode materials, typically characterized by high electrical conductivity.

The performance of the separator not only affects the interface structure and internal resistance of lithium-ion batteries but is also closely related to capacity, cycle life, and high-rate discharge performance. The main function of the separator is to separate the positive and negative electrodes and prevent them from coming into contact, thereby avoiding short circuits. The separator is a non-conductive material for electrons while allowing the passage of electrolyte ions. The electrolyte has a significant impact on the capacity, operating temperature range, cycle life, and safety performance of the battery. It fills the space between the positive and negative electrodes and the separator, facilitating the transfer of lithium ions and communication between the positive and negative electrodes. The casing directly encapsulates the electrolyte and the positive and negative electrodes and comes in four main types: plastic, steel, aluminum, and pouch (aluminum-plastic film).

3. Puncture and crush test system design

Puncture and crush test are key indicators of the safety of lithium-ion batteries and important inspection items in type testing. The puncture test mainly simulates the safety of lithium-ion batteries in the event of internal short circuits. If the internal short circuit does not cause an explosion or fire, but only results in simple smoke, the battery is considered safe. The crush test mainly simulates various scenarios of lithium-ion batteries being crushed during use and artificially presents the different conditions that may occur when the battery is subject to pressure, with the aim of ensuring that the battery does not easily catch fire, explode, or leak after the prescribed test period. The puncture and crush test system for lithium-ion batteries mainly consists of a motor, pressure sensor, controller, crush fixture, and tungsten steel needle, as shown in the schematic diagram in Figure 2. The motor and controller are used to control the process of crush and puncture testing of lithium-ion batteries and to adjust the travel and speed of the crush and puncture. The pressure sensor is used to test the pressure during the crush test of lithium-ion batteries.

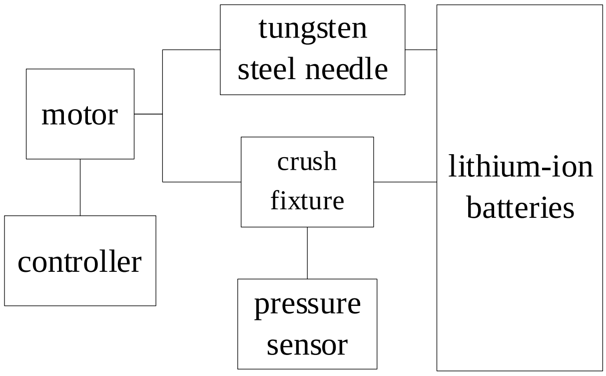

Figure 2. Structural diagram of inspection platform

The puncture test for lithium-ion batteries is conducted at a temperature of 20℃ ± 5℃. The fully charged lithium-ion battery is placed on the fixture, and a tungsten steel needle with a diameter of φ3-φ8mm (the cone angle of the needle tip is 45°-60°, the needle surface is smooth, free from rust, oxidation, and oil stains) is inserted into the center of the battery surface at a speed of 25mm/s ± 5 mm/s. The needle remains in the battery for an hour, and if the battery does not explode or catch fire, it is deemed to have passed. For the crush test, the battery is fully charged according to the specified test method and placed between two flat surfaces, with pressure applied perpendicular to the direction of the pole plate. A crush force of 13KN+0.78KN is applied between the two flat plates during the crush test for lithium-ion batteries. Once the pressure reaches the maximum value, the crush test can be stopped. Throughout the test, the battery must not experience an external short circuit.

4. Conclusion

The safety of lithium-ion batteries under crush and puncture conditions in electric vehicles has become a major issue constraining their use in the electric vehicle industry. Based on an analysis of domestic and international lithium-ion battery standards, this paper has provided a detailed introduction to the composition and structure of lithium-ion batteries, designed a puncture and crush test system, and implemented puncture and crush testing of lithium-ion batteries. This has provided a testing platform for market supervision of lithium-ion batteries in electric vehicles and improved the safety of lithium-ion batteries in electric vehicles.

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