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Research Article

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Comparative Study on Methods of Dynamic Crash Test of Power Batteries

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Abstract
There are multiple dynamic crash events in reality, and power batteries may have great safety hazards after crashing; therefore, the safety of power batteries in such cases has attracted much attention from vehicle manufacturers and the public. Currently, there are no clear standards for the impact and harm of crash on batteries. In this study, the authors intended to identify the characteristic parameters of simulated crash test of power batteries based on typical crash scenarios of NEVs, so as to develop test tools that can simulate the dynamic crash of power batteries, and analyze their performance under different dynamic crash parameters, thus providing a method for further studying the dynamic crash of power batteries.

Keywords: Lithium Battery; Dynamic Contact; Crash; Damage Analysis

Introduction

The safety of electric vehicles has always been a major concern of the public [1-4]. With the promotion of electric vehicles, more attention has been attached to their safety and the safety evaluation system; wide attention has also been attached to the methods for comprehensive and effective safety assessment of electric vehicles [5-7]. The dynamic crash of power batteries, as key components of electric vehicles, is a focus issue in the process of safety test. However, the existing evaluation methods are mainly based on static and non-contact crash, and there is a lack of analysis on dynamic crash of power batteries in actual accidents [8-10]. In view of the incomplete evaluation system, and the lack of test methods and devices, it can be concluded that the dynamic crash test of power batteries will be the key to safety evaluation of electric vehicles in the future [11].

In the domestic market of electric vehicles at present, the safety of battery packs is mainly protected from three aspects.

Firstly, they are protected with vehicle structure. Vehicle structure can protect the battery packs; in specific, it can withstand general crash and chassis scratching, thus protecting the shells of battery packs from deformation and internal batteries from damage.

Secondly, they are protected with shells of battery packs. The shells of battery packs and bearing beams on both sides and at the bottom, with certain bearing capacity, can protect the cells of internal battery modules from collision, and high-voltage components from breakage and short circuit.

Thirdly, they are protected with the structure of battery modules and high-voltage components. Based on certain resistance to crash, impact and puncture, they can protect the batteries from fire or explosion after bearing a certain degree of mechanical load.

As for crashing, key parameters include the crash position, acceleration, and crash speed. In the dynamic crash test of power batteries, the crash speed, energy, depth, and shape of contact end were taken as the key parameters, to simulate the real situation.

The study on dynamic crash test of power batteries dynamic crash was mainly performed in two aspects: Exploring the safety margins corresponding to different crash conditions with the same sample; and exploring the reliability of structure of different samples. In this paper, the dynamic crash test of power batteries was studied based on the designed test, for resolving the above-mentioned key issues.

Test Design

Development of Test Tools

In this study, through identifying the parameters of the dynamic crash test, the parameters of the simulated crash test were determined based on typical crash scenarios of NEVs, which were used to study the methods of dynamic crash test, thus determining the test flow. At the same time, the dynamic theory and electrical control theory were used to develop the test tools for typical dynamic crash test of power batteries; the three-coordinate gauge, tachymeter and high-speed camera were used to analyze the performance of power batteries in the dynamic crash test, and obtain the law of change of the relevant parameters, and performance judgment indicators, thus providing data support and analysis basis for the dynamic crash test of power batteries.

According to the Actual Conditions, three Crash Modes were Analyzed

1. Dynamic crash test with controllable crash speed: Assuming that the weight of the crash head and the crash speed were known, the acceleration, crash force, crash depth and status after crashing of the modules were tested.
2. Dynamic crash test with controllable crash energy: The test tool should have a crash head with adjusted weight, and should be able to generate acceleration and the corresponding crash speed; in addition, it should also be able to measure the acceleration, force, and depth of crash.
3. Dynamic crash test with controllable crash energy: Assuming that the modules were crashed with the fixed crash depth, the acceleration, crash force, and status after crashing of the modules were tested.

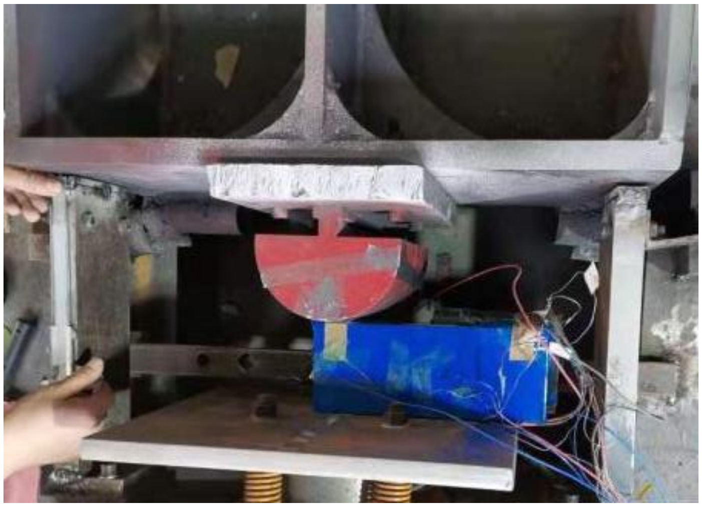
In the actual test, battery cells and modules were selected for the crash tests with controllable depth, to comprehensively investigate the conditions of different levels of power batteries in dynamic crash.

Different crash trolleys were arranged, as shown in Fig. 1(a)-(b).

Testing Methods

The prepared subject was fixed on the table, and its center was made on the same horizontal plane of the center of the crash head through adjusting the height control device; the servo motor was used to drive the trolley, and the setting values were controlled with a displacement sensor, so as to stop the trolley with the limit switch when the displacement value was reached. The tripper was controlled by a solenoid valve, which could pull the tripper, so as to fix the trolley and implement tripping. The acceleration and impact testing systems was turned on, the data acquisition system was debugged, and working status of the acquisition system was confirmed; the release height of the trolley was adjusted according to the test speed; the weight of the trolley was adjusted according to the determined crash energy, to make the kinetic energy reach the value required. At the same time, the trolley limit was adjusted according to the determined crash depth, to realize crashing at fixed depth. When the test was started, the system would release the detacher by the solenoid valve, and the trolley would slide along the track, and reach the position of crashing, where the crash head would get in contact with the test sample, and finally, the test was completed. The data would be saved according to the set conditions.

(a)



(b)

Figure 1: (a) crash trolleys of cells. (b) crash trolleys of modules

Results and Discussion

Test Samples

In view of the higher energy density, NCM lithium batteries are quite popular, but their stability is weaker than that of lithium iron phosphate batteries. Therefore, two NCM batteries were selected for testing by battery cells, modules and systems, and the dynamic crash tests with the crash depth of 10mm, 20mm and 30mm were conducted. The parameters of the selected samples are shown in Table 1.

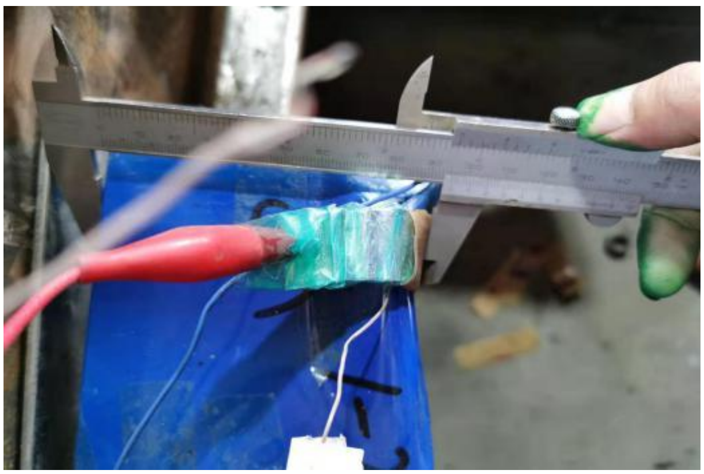
Table 1: Dynamic crash sample parameters

Category	Battery cell	Module
Battery system	NCM	NCM
Size (mm)	260×100×35	388×120×40
Weight (kg)	2.0	7.2

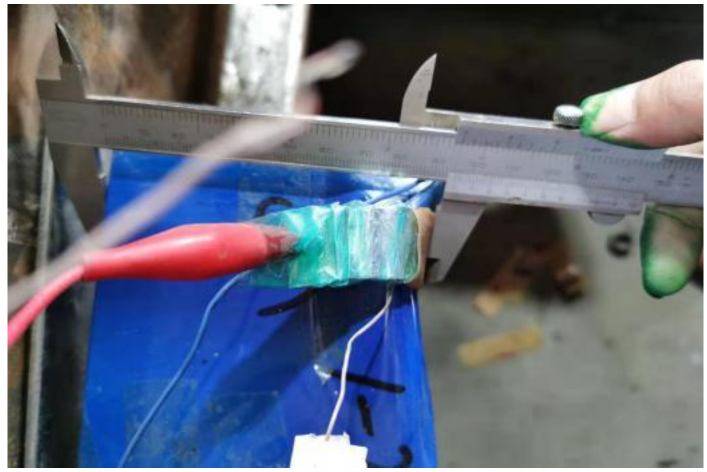
3.1.1 Dynamic crash test of battery cells

The dynamic crash test with controllable depth was conducted for battery cells, and the deformation is shown in the following figures; the results of deformation obtained from the dynamic crash test with controllable depth at positive and negative anodes are shown in Fig. 2(a)-(c).

(a)



(b)



(c)

Figure 2: Dynamic crash test of different depth. (a)10mm (b)20mm (c)30mm.

Table 2: Dynamic crash test results of battery cells

Crash depth (mm)	Test results
10	No leakage after testing; no accident, fire or flame; no explosion; no reaction or thermal runaway; the battery was obviously deformed, its temperature rise reached 4.5K, and the voltage had no obvious change
20	No leakage after testing; no accident, fire or flame; no explosion; no reaction or thermal runaway; the battery was obviously deformed, its temperature rise reached 14.9K, and the voltage gradually dropped from 4.12V to 0V
30	The battery caught fire and exploded, the temperature rise reached 503.8K, and the voltage rapidly dropped to 0V

Dynamic Crash Test of Modules

The dynamic crash test with controllable depth was conducted for power batteries at positive and negative anodes, and the results of deformation are shown in Fig. 3(a)-(c).

(a)

(b)

(c)

Figure 3: Test results of dynamic crash of different depth.(a)10mm (b)20mm (c)30mm

The test results are shown in Table 3.

Table 3: Dynamic crash test results of modules

Crash depth (mm)	Test results
10	No leakage after testing; no accident, fire or flame; no explosion; no reaction or thermal runaway; no obvious damage to the module, the temperature rise of the impacted battery cell reached 1.2K, and the voltage had no change
20	No leakage after testing; no accident, fire or flame; no explosion; no reaction or thermal runaway; there was damage to wiring harness after testing, the temperature rise of the impacted battery cell reached 17.2K, and the voltage had no obvious change
30	No leakage after testing; no accident, fire or flame; no explosion; no reaction or thermal runaway. There was visible damage to the module after testing, the temperature rise of the impacted battery cell reached 20.4K, and the voltage dropped from 4.03V to 0V

Analysis of Test Results

In combination with the dynamic crash test resulting in different degrees of damage to battery cells, it can be showed that with the increased damage, there would be more signs indicating the damage of battery. In the case of 10 mm deformation, the battery only had a slight temperature rise, and there was almost no change in voltage; in the case of 20 mm deformation, the temperature of the battery increased significantly, and the voltage gradually dropped to 0V; while in the case of 30 mm deformation, the battery caught fire and exploded, the temperature rose sharply, and the voltage quickly dropped to 0V.

It can be seen that when the battery cell was under dynamic impact, voltage would not quickly reflect the damage to the battery, but the temperature would increase in a positive correlation with the damage; therefore, it can be taken as a good characterization parameter.

Similarly, the dynamic crash test on integrated modules showed that with the increased damage to the battery, both the temperature and voltage were changed. When the deformation was 10 mm, the battery had no obvious deformation, there was only a slight temperature rise, and the voltage did not change; when the deformation reached 20 mm, the temperature of the module showed significant damage, the temperature of the battery cell under impact increased, and the voltage decreased to 0V; when the deformation reached 30 mm, there was obvious deformation, the battery cell under impact had a greater temperature rise, and the voltage gradually dropped to 0V.

Similar to battery cells, the modules also had corresponding changes in voltage and temperature after dynamic crash. As for the impacted battery cells, the temperature could reflect the degree of damage more significantly than voltage, and showed a positive correlation with damage.

However, being different from battery cells, the modules protected with shells had stronger resistance to impact and were safer under the same degree of impact by virtue of the integrity of the overall structure and shell protection.

Conclusion

In this paper, the dynamic crash of power batteries was analyzed, and a test platform that can conduct dynamic crash test for single batteries and modules was established. Through carrying out the corresponding dynamic crash tests, the damage caused by dynamic crash to the safety of power batteries was explored. At the same time, the voltage and temperature in the power battery management system was compared and analyzed, and it was pointed out that the battery temperature would be a superior characteristic parameter to voltage in the case of dynamic crash. The comparative analysis based on single batteries without shells and the shell-protected modules showed that the protective structure of the modules could withstand greater crashing damage.

In further research, a complete battery system can be tested under the same conditions, and the results should be compared with those obtained based on single batteries and modules, which will be a meaningful direction. Meanwhile, it is also necessary to carry out a comparative study regarding the dynamic crash of single batteries and modules at different positions, so as to determine the safer and more effective protection manners in actual accidents.

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