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Ultrasonic Scanning for Lithium-ion Battery Inspection

Jianyan Wang *, Yapeng Zhou, Qinghua Bai, Yonggang Zhao

China Merchants Testing Vehicle Technology Research Institute Co., Ltd. China
*** Corresponding author:** Jianyan Wang (Email: wangs135@163.com)

Abstract: With the rapid development of electric vehicles, energy storage and other fields, the application of lithium-ion batteries is becoming more and more widespread. As a result, the testing technology of lithium-ion batteries has also had higher requirements. Ultrasonic scanning, as a non-destructive testing technique, has good application prospects for lithium-ion battery inspection. In this paper, we summarize the research progress of the application of ultrasonic scanning in lithium-ion battery inspection in recent years from three aspects: principle, method and result, and prospect the development of the application of ultrasonic scanning in lithium-ion battery inspection.

Keywords: Ultrasonic Scanning; Lithium-ion Battery; Inspection.

1. Introduction

Lithium-ion battery has been widely used in electric vehicles, energy storage and other fields. However, with the popularization of applications, safety accidents of lithium-ion battery have been occurring, and the main reasons include internal defects, performance degradation, and insufficient safety performance. Therefore, it is particularly important to carry out nondestructive, rapid and accurate detection of lithium-ion battery.

2. Principle of Ultrasonic Scanning for Lithium-Ion Battery Inspection

Ultrasonic is a sound wave with a frequency higher than 20KHz, which has good penetrability and directionality, and is widely used for article transmission and defect detection. Ultrasonic inspection is a non-destructive technology that utilizes ultrasonic waves to probe the internal structure of materials. Ultrasonic waves undergo significant attenuation in the gas phase, while in the solid and liquid phases, the attenuation is small, and reflection occurs at the gas-liquid and gas-solid interfaces. Poor gas production or wetting of the cell can lead to decreased ultrasonic transmission and slower propagation. This phenomenon can be utilized to probe the distribution of gas production within the cell. In addition, ultrasonic scanning also emits high-frequency sound waves, and the ultrasonic data acquisition card can be used to collect and analyze the ultrasonic beams passing through the interior of lithium batteries, and according to the ultrasonic characteristics of the received ultrasonic waves can be used to assess the internal structure of the lithium batteries and the characteristics of the defects, and at the same time, it can also be used to assess the performance and safety performance of the batteries.

3. Ultrasonic Scanning Method for Lithium-Ion Battery Inspection

3.1. Application of Ultrasonic Scanning to the Detection of Internal Defects in Lithium-Ion Battery

Battery liquid injection is carried out under negative pressure. There is a vacuum cavitation in the area where the electrolyte is not completely wetted, and the vacuum is not able to transmit ultrasonic. The use of ultrasonic scanning microscope transmission imaging mode can be very intuitive to find the lithium battery internal medium voids as well as the distribution of electrolyte infiltration. Therefore, ultrasonic scanning is an effective means to measure the battery electrolyte infiltration status.

Prof. Yunhui Huang's group, together with Jeff.R. Dahn's team from Dalhousie University, Canada[2] Using a focused ultrasonic beam with a diameter of less than 1mm to accurately scan soft pack batteries and cylindrical batteries, a sub-millimeter detection resolution has been achieved. And by utilizing the characteristic of different transmittance of ultrasonic waves in the electrolyte wetted area and poorly wetted area, we have restored the wetting and aging of electrolyte by ultrasonic transmission imaging.

Cui H[3] et al. employed in situ ultrasonic scanning and OCV monitoring techniques to observe and analyze the electrolyte penetration process in batteries assembled with different partitions. The effects of open-circuit voltage on battery performance during electrolyte filling were clearly demonstrated by precise experimental data and detailed analysis results.

3.2. Application of Ultrasonic Scanning to Lithium-Ion Battery Performance Test

Ultrasonic scanning can evaluate battery SOC, SOH and other performance parameters.[4] Professor Daniel and his team first reported the correlation between ultrasonic properties and SOC of batteries in 2015. They fixed two ultrasonic probes on both sides of a lithium-ion soft pack battery, with one probe transmitting ultrasonic signals that was received by the other probe, while charging and discharging the test electrodes. It was found that there is a stable correspondence between the time of flight (ToF) of the ultrasonic transmission signal and the SOC of the battery. They concluded that the embedding of ions in the active material of the battery during the charging and discharging process caused a change in the material stress, which in turn changed the material speed of sound, leading to a change in ToF. Subsequently, they simulated the ToF during the battery charging and discharging process by electrochemical-physical-acoustic model, which reproduced the experimental phenomena well and confirmed this conjecture.

Lukas Gold et al., from German[5], proposed a method to determine the SOC of lithium-ion battery by means of ultrasonic detection. Instead of relying on point measurements, the method relies on ultrasonic detection of structural changes in the anode to calculate the lithium-embedded state of the anode and thus obtain the battery SOC.

Prof. Yi's group at Nanjing University of Aeronautics and Astronautics [6], a whole set of system was designed to realize the collection of ambient temperature, charging and discharging data, impedance data, ultrasonic emission signals and other information during the working process of the battery, to jointly analyze the SOH changes of the battery, and to develop a corresponding SOH prediction algorithm.

Meng Kangpei [7] and others expounded the attenuation process of ultrasonic wave propagation from the microscopic mechanism of ultrasonic wave propagation in lithium-ion battery, and finally proposed a new damping parameter only related to the change of electrochemical properties in lithium-ion battery to detect the SOC of lithium-ion battery. This study provides a new idea for lithium-ion battery state detection, which can be combined with the TOF (Time of Propagation) and signal amplitude, which is extended to the detection of the health state of lithium-ion batteries and the detection of lithium dendrite growth.

Prof. Yunhui Huang's team at Huazhong University of Science and Technology[8] developed a deep learning algorithm to analyze ultrasonic transmission signals and successfully mined out the corresponding SOCs from complex ultrasonic shapes. Combined with step scanning technique, the method can achieve non-destructive in-situ SOC distribution imaging of soft pack batteries with 1 mm in-plane resolution. Compared with other methods, this method has the advantages of non-destructive, high resolution, low cost, and good compatibility with commercial large-scale batteries, and it is more capable of revealing the inhomogeneity of SOC distribution inside lithium-ion battery.

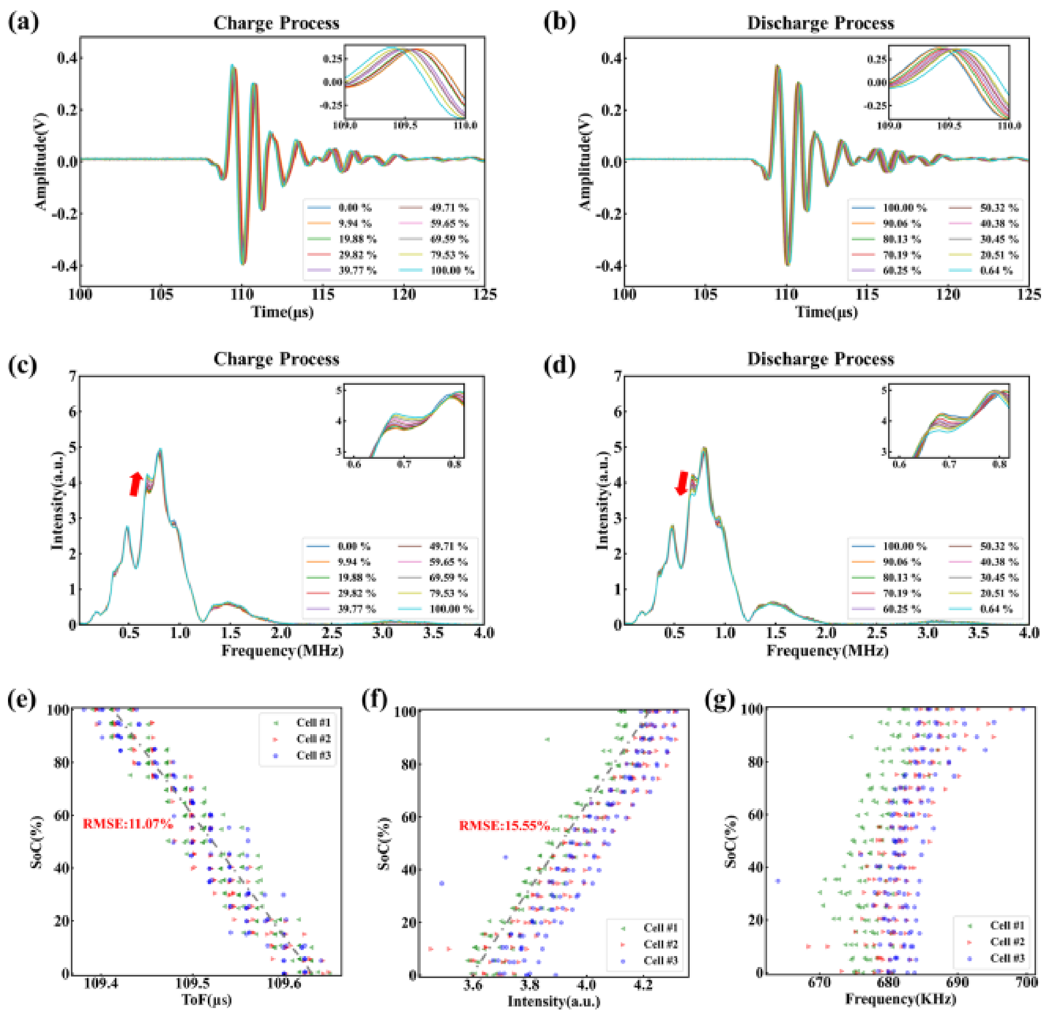

Figure 1. Response between SOC and acoustic

In Figure 1, Figures (a) and (b) show the ultrasonic signals in the time domain during charging and discharging across lithium-ion battery No. 1 at different states of charge; Figures (c) and (d) show the performance in the frequency domain; Figure (e) shows the correlation between the SOC and the ultrasonic signals' time-of-flight on batteries No. 1, No. 2, and No. 3; and Figures (f) and (g) respectively demonstrates the correlation between the SOC and the intensity of the shoulder peaks near 0.7 MHz (Figure f) and the shoulder peaks frequency (Figure g) correlations.

3.3. Application of Ultrasonic Scanning on Safety Performance Test of Lithium-Ion Battery

Ultrasonic scanning can be used to assess the safety performance of batteries by detecting physical changes inside the battery. Clement [9] et al. determined the occurrence of side reactions within a battery by measuring changes in the ultrasonic signal in the central region of the battery. Jeffrey A. Kowalski, U.S.A.[10] et al. established an early warning system capable of avoiding lithium-ion battery safety accidents by triggering the thermal runaway of a 0.950 Ah lithium-ion battery and using ultrasound to monitor the material properties of the battery components to measure the battery state. This study validated the use of ultrasonic to detect battery failures by detecting ultrasonic data during thermal runaway failures of lithium-ion batteries. By comparing the ultrasonic dates during overcharging with the ultrasonic data of the initial state, two different fault indicators were identified: battery overcharging alarm and emergency stop. Thus, the implementation of ultrasonic detection in the system can provide operable battery safety detection, thus greatly reducing the chance of battery-triggered dangerous events.

Figure 2 shows the constant current (CC) charging and CV cycling profiles of the battery at 65°C for the detection of battery overcharge failures. During CC overcharging, the warning criterion is reached about 76 minutes before failure, while the time-dependent ultrasonic signal signature increases dramatically. The emergency stop failure criterion was reached 58 min before battery failure. For CC overcharge experiments at high temperatures, the battery expanded and outgassed slightly faster than at room temperature.

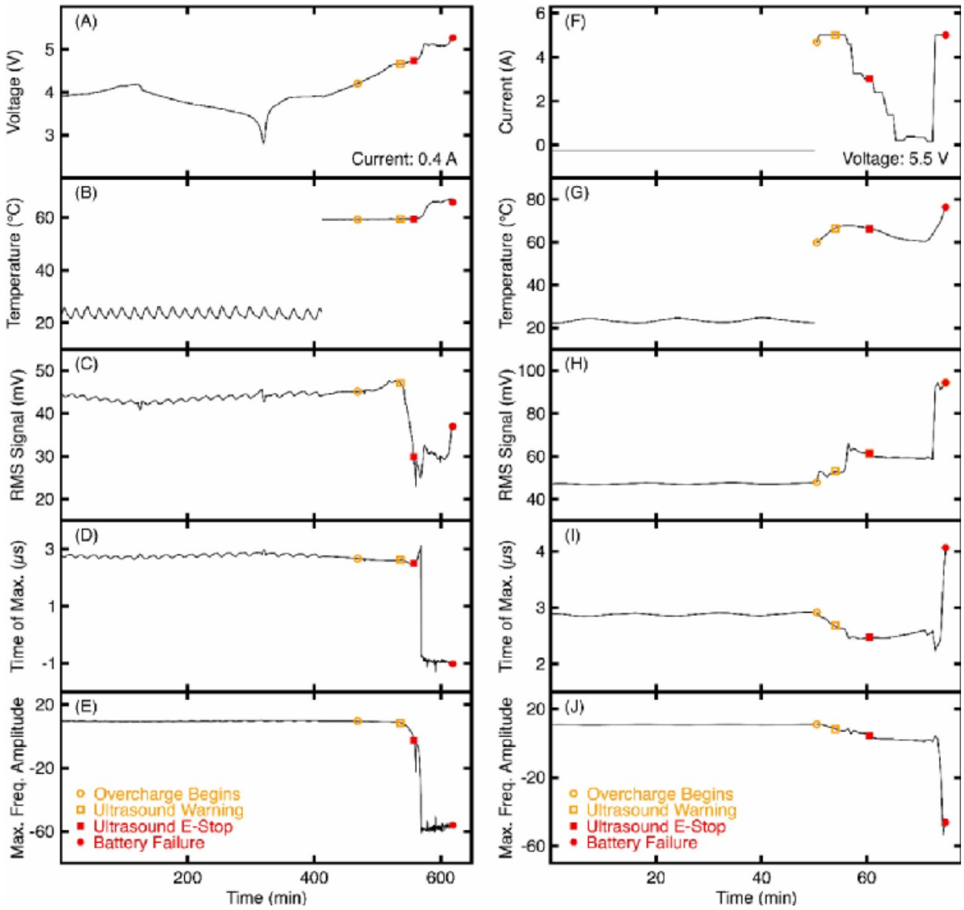

Figure 2. Failure analysis of battery at high temperature

3.4. Results of Ultrasonic Scanning on Lithium-Ion Battery Inspection

Inspection of lithium-ion batteries by ultrasonic scanning technology can realize the accurate assessment of internal defects, performance and safety performance of batteries. However, the current application of ultrasonic scanning in lithium-ion battery detection still has some problems and shortcomings, such as: the single scanning time is too long, the accuracy of air coupling is low, and the water coupling will cause lithium battery safety risks, etc. Therefore, in order to further promote the application of ultrasonic scanning in lithium-ion battery inspection, it is necessary to continue to strengthen the technology and research, and optimization of equipment.

4. Conclusion

In summary, ultrasonic scanning, as a nondestructive test technique, can provide a comprehensive and accurate inspection of the battery without damaging it. It includes internal defect detection, performance detection and safety performance detection. However, the current application of ultrasonic scanning in lithium-ion battery inspection still has some problems and shortcomings, which needs to be further studied and optimized. The future research directions and priorities mainly include improving the accuracy and stability of ultrasonic scanning equipment, researching more advanced signal processing and analysis methods, combining with other nondestructive test techniques to achieve a more comprehensive and accurate inspection of lithium-ion battery, and strengthening the testing and validation in practical application scenarios.

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