Linear and nonlinear ultrasonic techniques for NDE of Li-ion batteries

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Accurately estimating the state of charge (SoC) in battery management systems (BMSs) requires the measurement of numerous parameters and advanced algorithms. In this work, linear and nonlinear ultrasonic nondestructive evaluation (NDE) techniques were investigated for battery SoC estimation. A pouch-type NMC622|graphite battery cell with a capacity of 2.4 Ah was designed and fabricated at the Battery Fabrication Facility of Oak Ridge National Laboratory. Linear and nonlinear ultrasonic waves were used to monitor the material changes during the charge/discharge of Li-ion batteries. The correlation between linear and nonlinear ultrasonic wave parameters and battery SoC was studied for SoC estimation. For the linear ultrasonic testing, an ultrasonic monitoring system was developed to monitor the battery during charge/discharge at 750 kHz, 1 MHz, and 1.5 MHz. Signal processing algorithms are proposed for extracting the wave velocity and attenuation. The wave velocities of all three frequencies have an approximately linear relationship with the SoC, which can be used for SoC estimation. However, hysteresis behavior is observed for the wave velocity in terms of a larger slope in the discharge process and velocity drop after a charge/discharge cycle. The wave attenuation was found to be able to capture the material phase transitions of the cathod material NMC622 during charge/discharge processes.

For the nonlinear ultrasonic testing, second harmonic generation at 5 MHz was used with a through-transmission setup, and the relative nonlinear parameter β was measured periodically during the charge/discharge process. Temperature compensation was applied to the measurement. The correlation curves between the nonlinear parameter and the actual SoC aligned well for a four-cycle and a eight-cycle test, and a robust linear relationship was observed for both correlation curves. A linear model was applied to fit the correlation using all data points from both tests. The model was employed to validate the SoC prediction on a second battery by using another four-cycle test. The results indicate that both models can predict the SoC with an accuracy of approximately 3%.

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