A study of the effect of short-term relaxation on the EIS test technique for EV battery cells

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I. Introduction

Investigation of the electrochemical processes within a Li-ion cell can be achieved by using electrochemical impedance spectroscopy (EIS). As each process has a different time constant or time domain or frequency of excitation [1, 2], EIS allows for the separation of most of these processes [3]. Therefore, EIS always interests academic and industrial researchers as a diagnostic and research tool. Recently EIS has received attention for its potential to be incorporated as an integral part of a battery management system (BMS) to estimate state of charge (SoC) and state of health (SoH) in electric vehicles [4-6].

For on-board EIS measurement systems (incorporated as part of the BMS), fast measurement time is a key requirement. However, fast measurement time implies that the cells will be measured very shortly after cycling. Recently the cell relaxation period has been identified as a source of impedance variation [7, 8]. This research focuses on the impedance variation of the cell within a short period (0-10min) after removing an electrical load from the battery cell.

II. Experimental method

Five commercially available li-ion cells of three different chemistries were used as part of this study. These cells were selected based on their power and energy rating. Table 1 summarises the chemistry, capacity and format of each cell.

TABLE I. Cell details

Cell Number	***Chemistry***	***Capacity (Ah)***	***Format***
1	NCM	40	Pouch
2	LFP	20	Pouch
3	NCM	2.2	Cylindrical
4	LTO	13	Puuch
5	NCM	3.4	Cylindrical

In order to isolate the effects of cell relaxation, temperature and SoC were kept constant for each test; tests were carried out at 25 °C and 50 % SoC. To precisely adjust the cell SoC to 50 %, the cells were discharged at 1C rate to the manufacturer's recommended cut-off voltage, subsequently allowed to rest for 3 hours before being fully recharged according to the manufacturer's recommended charge protocol, using a commercial li-ion cell cycler. At the end of charging, the cells were allowed to rest for 3 hours prior to being discharged to 50 % SoC at 1C rate.

To study the short-term effect of relaxation, measurements were performed in galvanostatic mode using a commercial EIS system. Impedance measurements between 500 mHz and 10 kHz with 5 frequency points per decade were taken. This frequency range and number of measurement points were selected as a balance of test duration and number of measurement points. In this setup a measurement will take around 10 seconds. Recording of the EIS data started as soon as the SoC adjustment was completed (i.e. immediately after the 1C discharge to 50 % SoC), and every minute thereafter.

III. Results

The shape of the Nyquist plots at high frequency is similar to that of found in literature. However, at low frequency, cells 1, 2 and 4 show a spiral shape (Figure 1 (a), (b) and (d)) which has not been reported in previous related literature. The spiral shape in the Nyquist plot starts to shrink from the second test done at 1min after SoC adjustment, and finally disappears 10min after SoC adjustment when the EIS plot is similar to the Nyquist plots found in the literature [5-8]. The change of shape of Nyquist plots from 1min to 10min for cells 1, 2 and 4 happens at a different rate. Cell 3 and 5 (Figure 1 (c) and (e)) shows this spinal shape only for very first test which was performed just after discharge was stopped. Afterward the shape is similar to the Nyquist plots found in the literature. For all 5 cells measured values of pure Ohmic resistance (Ro) fall within experimental error bounds, therefore can be considered as constant, regardless of relaxation time. To investigate the experimental setup as a probable cause of the shape, the experiment has been repeated with different leads which connect EIS equipment with test cell, even different set of EIS equipment, however in all the instances similar results were found.

Results presented in this section suggest Ro does not change with relaxation period between 0-10 minutes, therefore this could be used as online measurement parameter. In contrast to Ro, the charge transfer resistance and double layer capacitance will be inconsistent within 0-10 minutes after cycling, due to spinal shape in Nyquist plot.

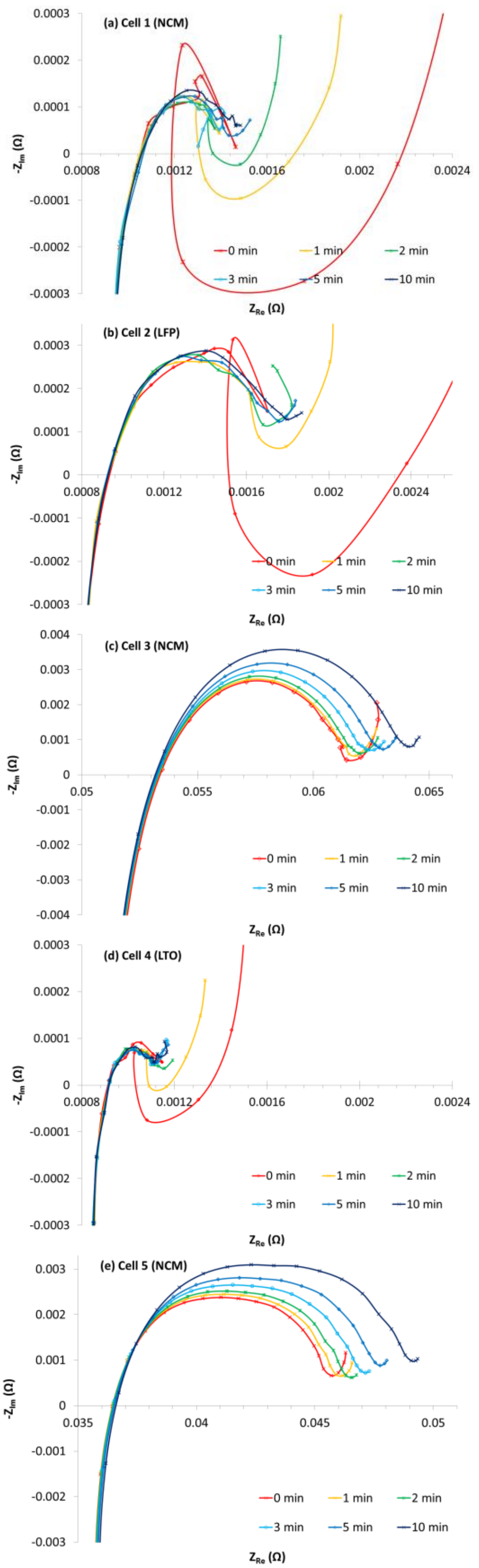

Figure 1: Nyquist plots of the cell from 0 – 10 min. Note that two different scales have been used for figures (a), (b) and (d), and (c) and (e).

IV. Conclusion

In this research, the variation of cell impedance as a function of relaxation period after removing an electrical load has been investigated for five different commercially available li-ion cells. It was concluded that the pure ohmic resistance Ro of the cell was independent of the relaxation processes occurring within the cell for the test duration. Therefore, Ro could be used for direct comparison irrespective of the relaxation period used for the test.

The charge transfer resistance and double layer capacitance were found to be inconsistent within 0-10 minute of relaxation. Therefore, when these two parameters are used as a fast on-line measurement parameter, they will produce unreliable results, which could affect SoC and SoH estimation. This new knowledge shows the possible inconsistency of SoC and SoH results via an EIS measurement system integrated as part of BMS, which have been proposed by researchers previously.

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