Automotive lithium-ion cell scattering investigations by means of electrochemical impedance spectroscopy

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In the following, a parameter scattering study of automotive lithium-ion cells is presented, which was performed with cells of two series-production vehicles by electrochemical impedance spectroscopy (EIS) using Gamry hard- and software [1].

INTRODUCTION

Finite accuracy during the lithium-ion battery manufacturing process results in minimal differences in material compositions, overall component connectivity, and electrode thickness, among other factors. These variations can lead to different cell capacities, impedances, and self-discharge rates, which can affect the performance of the entire battery pack system. Without initial screening and selection, the probability of a negative outlier increases especially for battery packs with numerous cells. For realistic modeling and simulation of automotive battery packs, it is therefore of considerable interest to identify the actual inherent cell scattering in battery modules of current series-production vehicles.

EXPERIMENTAL SETUP

In order to classify the actual dispersion of electrical properties of automotive cells, vehicle modules from two manufacturers were disassembled, with the process being illustrated in Figure 1 for both vehicle types. The cells, now individually accessible, can thus be characterized extensively and without the influence of neighboring cells or the interconnection topology.

Table 1: Battery pack specifications [1]

	Vehicle ID	Architecture of module	Architecture of pack	Cell capacity	Cell format	Cathode chemistry
Volkswagen ID.3 Pro Performance	①	12s2p	108s2p	78.0 Ah⁺	Pouch⁺	NMC⁺
Undisclosed vehicle	②	25s1p	106s1p	161.2 Ah⁺	Prismatic⁺	LFP⁺

⁺Taken from vehicle registration documents and literature

Three characteristic quantities were used to compare the electrical properties: The individual cell capacity C, the respective ohmic cell resistance R_0 and the individual charge transfer resistance R_{ct}. The capacities were determined using an initial CCCV charge and a consecutive C/3 CCCV discharge with a cut-off current of C/20 (performed with a MRS battery cycler (BaSyTec GmbH, Germany) inside of a climate chamber (Vötsch GmbH, Germany and BINDER GmbH, Germany) at 20 °C ± 0.2 °C). After this procedure, all cells were directly charged to 50% SOC and relaxed for more than 4 h to reach an equilibrium state. Subsequently, EIS measurements were conducted.

All EIS measurements were performed with a calibrated Interface 5000E potentiostat (Gamry Instruments Inc., USA), using the hybrid EIS mode with a desired AC RMS voltage of 4 mV (vehicle①) and 1.2 mV (vehicle②).

The applied hybrid EIS mode combines the advantages of both galvanostatic and potentiostatic measurement modes: The technique uses galvanostatic cell control, though the amplitude of the applied AC current is changed to obtain a nearly constant desired AC voltage response. Constant adjustment of the AC current ensures that the AC voltage is not extended beyond the linear range. The sense and source wires were routed away as independently as possible. Nevertheless, due to the large-format and low-impedance cells, effects caused by the measurement setup, especially in the high-frequency range, cannot be entirely ruled out. A frequency range from 5 kHz to 10 mHz with ten points per decade was chosen for vehicle① , while twelve points per decade were chosen for vehicle② . All EIS tests were performed at 20 °C ± 0.2 °C ambient temperature inside of climate chambers (Vötsch GmbH, Germany and BINDER GmbH, Germany). Values for R_o and R_{ct} were calculated from the resulting Nyquist plots using the zero crossing of the x-axis and the local minimum with the y-axis flipped.

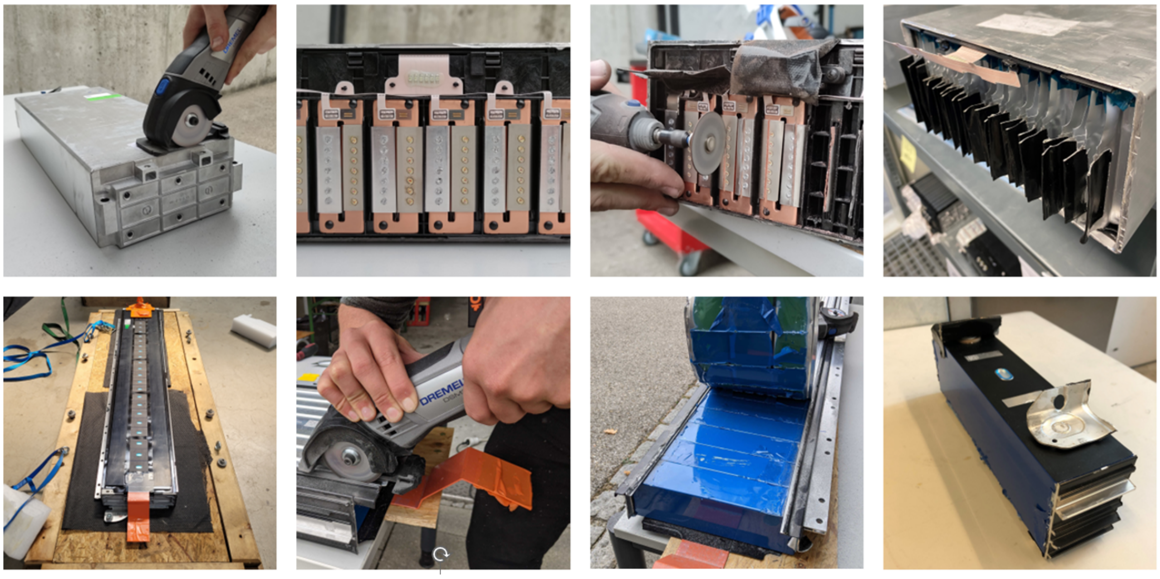

Figure 1: Tear-down procedure of the modules with tray opening and cell separation.
Top row: vehicle (1) . Bottom row: vehicle (2).

RESULTS AND CONCLUSIONS

The results, presented in Figures 2, show a cell capacity scatter of up to 8.43%, an R_o scatter of 2-3% and an R_{ct} scatter of up to 16.4%. The higher dispersion of vehicle② is due, in part, to possibly damaging performance tests of the module prior to this study. The results therefore do not represent the actual scatter to be expected in the production vehicle, which is why the vehicle type is undisclosed in this study. The vakue ranges of vehicle① largely coincide with the literature and are discussed extensively in publication [1]. Overall, the demonstrated application of the EIS measurement allows an evaluation of the mentioned cell characteristics at a manageable effort. The use of a multiplexer could further accelerate the measurement sequence for future analyses on additional energy storage systems.

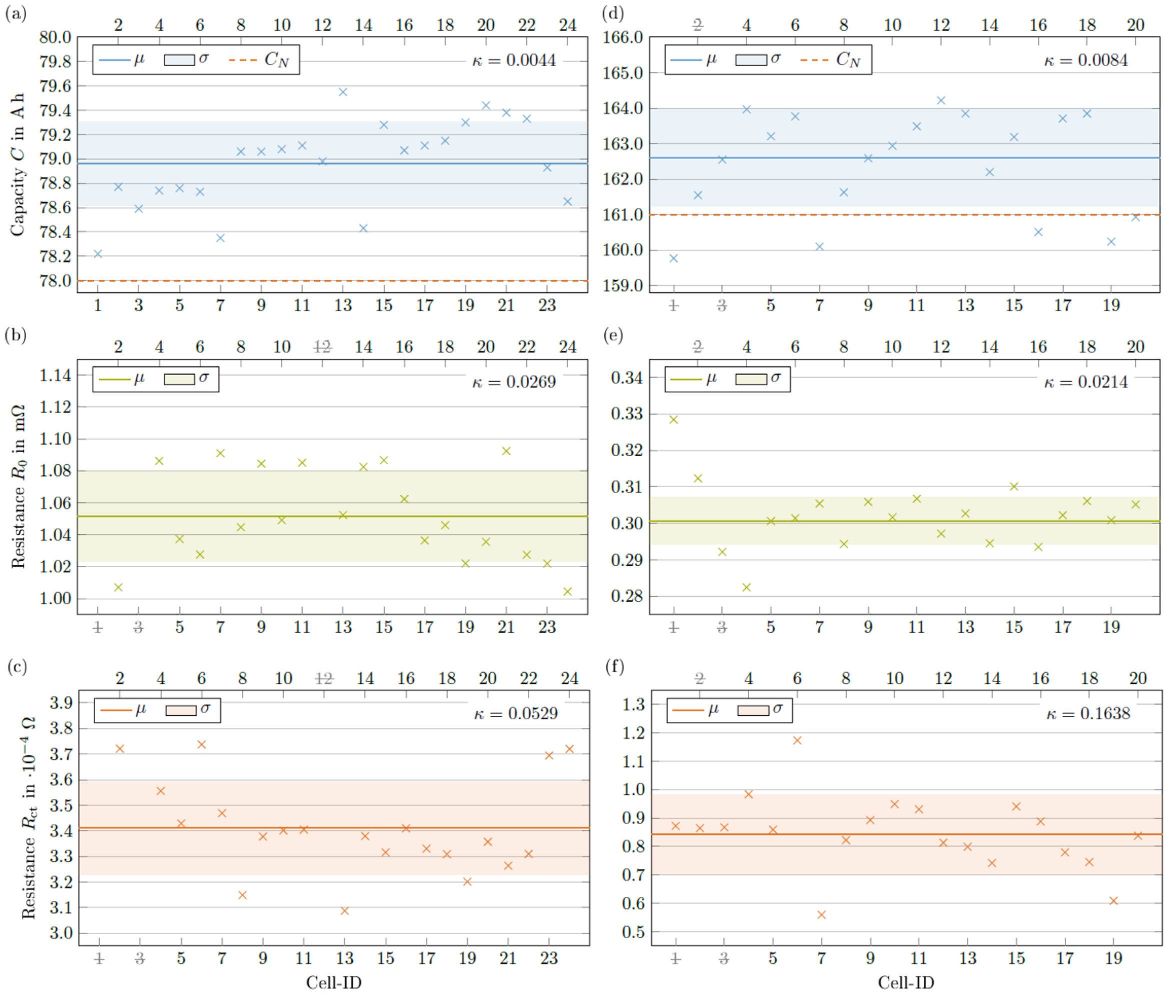

Figure 2: Parameter scattering of the battery modules of vehicles ① and ② . (a)/(d) Capacity C, (b)/(e) impedance R_o, and (c)/(f) charge transfer resistance R_{ct} determined with C/3 CCCV discharge procedures between 2.5 V and 4.2 V and EIS measurements between 0.01 Hz and 5000 Hz at 20° ± 0.2 °C ambient temperature, plotted over the cell-ID. In plots (b)-(c), the coefficient of variation κ is calculated without the measured data of cells 1, 3, and 12 because these cells had already undergone extended aging as a result of previous experiments. However, in a pre-test, we were able to validate that these cells are also within the scatter range of the cells shown. For (d)-(f), κ is calculated without the measured data of cells 1–3 because these cells have suffered slight deformation on the casing during the previous module disassembly. For vehicle ②, five cells (Cell-ID 21 to 25) were excluded from this study.

PUBLICATION

[1] Nikolaos Wassiliadis et al., Quantifying the state of the art of electric powertrains in battery electric vehicles: Range, efficiency, and lifetime from component to system level of the Volkswagen ID.3, eTransportation, 2022 https://doi.org/10.1016/j.etran.2022.100167

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