RUHR-UNIVERSITÄT BOCHUM

RUB

Faculty of Electrical Engineering and Information Technology
Automotive Electronics Research Group
Institue of Electronic Circuits
Prof. Dr.-Ing. Thomas Musch

Advanced Thermal Analysis of Li-ion Cells - Test System and Accelerated Procedures

Haußmann, Peter; Moczynski, Pascal; Musch, Thomas

Introduction

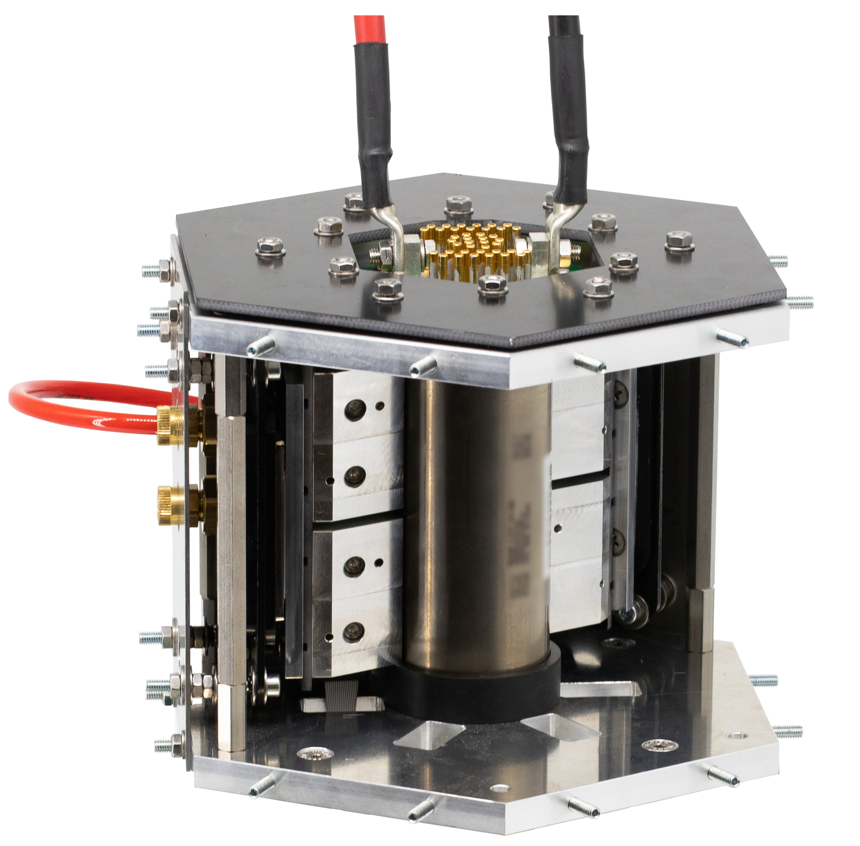

Figure 1: Photo of the presented system for advanced thermal control and analysis of cylindrical Li-ion battery cells.

Temperature is a crucial parameter of Li-ion cells regarding performance, lifetime and safety, especially for high energy cells of electric vehicles (EV). For battery cell tests, thermal boundary conditions are usually provided by a temperature chamber. Thus, achieving thermal cell equilibrium is time-consuming, cell heat generation is not measured, and thermal boundary conditions differ from those of an actual battery module of an EV.

In this poster, a high-power combined electrical and thermal cell test system is presented, enabling heat flow measurements, high-speed temperature variation and simulation.

Measurement System

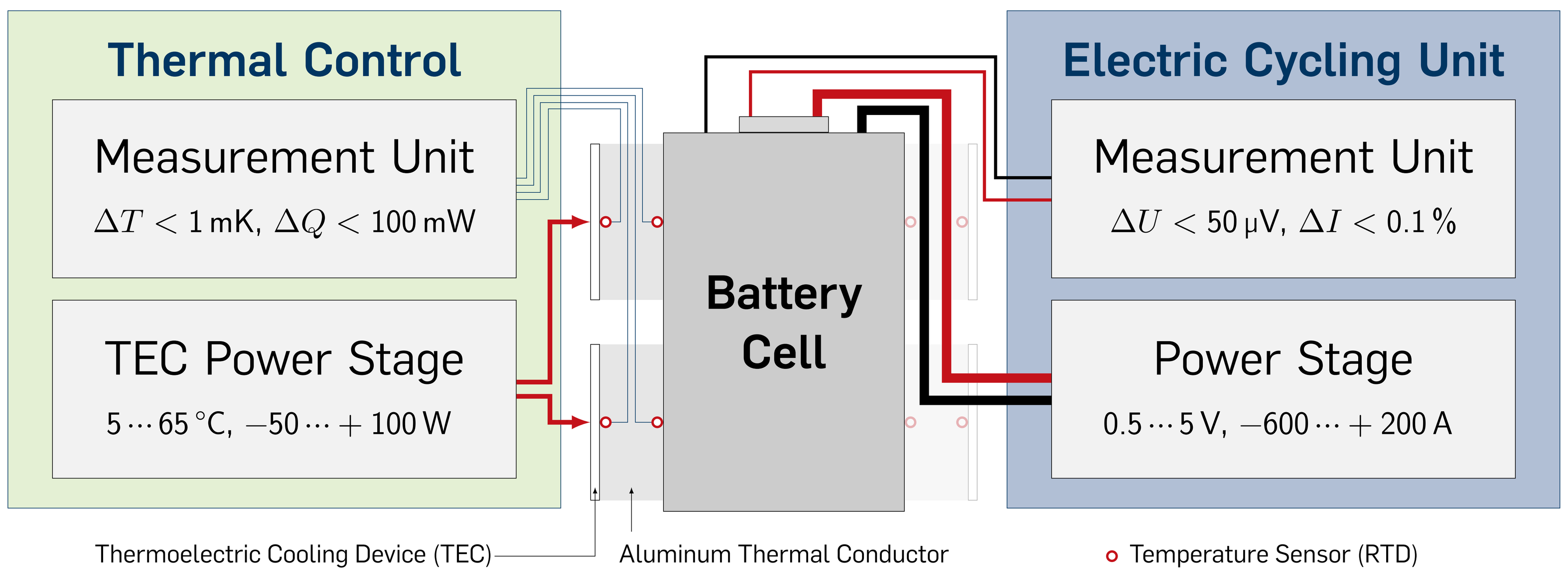

Figure 2: System structure block diagram.

The measurement system consists of 12 independent thermal source-measurement units (TSMU), each including a thermally conductive aluminum element, a thermoelectric cooling device with two precision temperature sensors. The heat flow through each element is calculated according its temperature differential. The conductive approach achieves fast response time.

Various thermal settings are available for cell testing:

- Isothermal (constant temperature, $\Delta T < 1$ mK)
- Adiabatic (thermal isolation)
- Finite thermal impedance (real time control)
- Complex cooling system behavior (real time control)

A precision electric cycling system provides electric cell stimulation [1]. Spring-loaded high-current contacts are used for fast cell switching. Contact losses are compensated for to enhance heat flow measurement accuracy.

Figure 3: Photo of one 60° thermal contact module with two TSMUs (vertical distribution).

Test Procedures

The system is suited for a wide variety of experiments in different stages of cell development. The following examples are presented in this work:

- **Entropy coefficient analysis:** Measurement of the cell entropy coefficient based on potentiostatic and calorimetric procedures.
- **Battery module evaluation:** Thermal response of a cell to heavy-duty driving cycles and fast charging profiles for realistic thermal boundary conditions of a battery module cooling system.

Entropy Coefficient Analysis

The entropy coefficient of Li-ion cells describes the impact of the charge/discharge reactions on the cell heat generation. It can be measured by calorimetric and potentiostatic procedures [2]. The presented system is capable of both concepts at reduced measurement duration compared to state of the art systems due to its fast response time.

Figure 4 presents a novel multi-rate-constant-current calorimetric procedure, by which the entropy coefficient is evaluated dependent on state-of-charge (SoC).

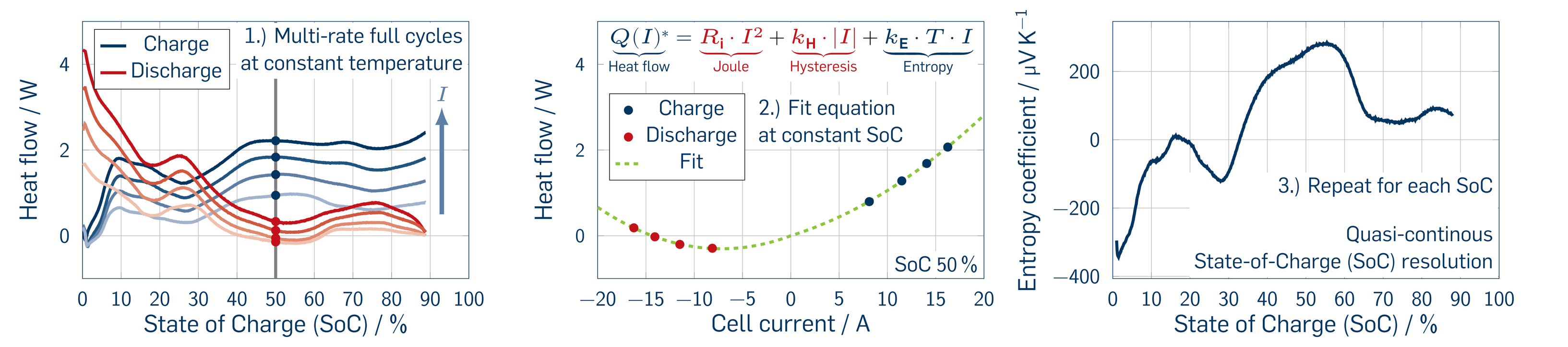

Figure 4: Calorimetric entropy coefficient determination based on multi-rate-constant-current cycles.

Battery Module Evaluation

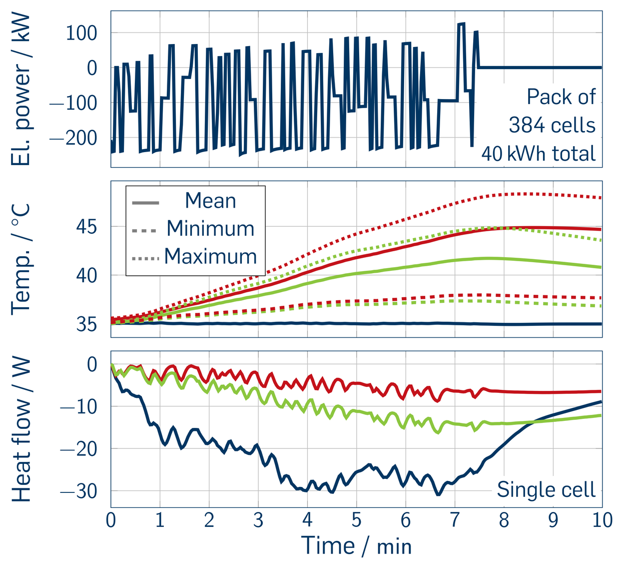

Figure 5: Driving cycle measurement.

The cooling system of an EV must provide sufficient thermal budget to safely handle high current load profiles. Figure 5 shows the measurement data of a **heavy-duty driving cycle** for three different cooling systems:

- Isothermal (35 °C)
- Single-sided cooling system
- Double-sided cooling system

The test system allows for designing battery pack cooling strategies by single-cell tests.

Fast charging performance is particularly dependent on temperature. Especially using a single-sided cooling system, thermal inhomogeneity must be considered to avoid local overheating and increased lithium plating in cold regions [3].

Figure 6 displays the thermal response to a 20-minute fast charging profile. The test system measures the inhomogeneous cell surface temperature distribution to identify hot and cold spots. Charging profiles can be modified accordingly for enhanced life time and safety.

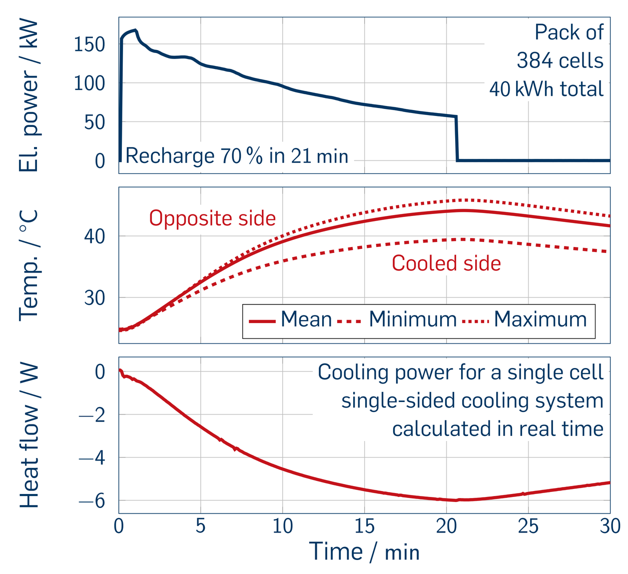

Figure 6: Fast charging measurement.

Conclusions

The presented system allows for fast and accurate temperature and heat flow measurement and control for cylindrical Li-ion cells. It can easily be adapted for alternative cell geometries due to its modular structure.

The system is suitable for a wide range of applications, including thermal cell modeling, calorimetry, electrochemical entropy analysis, and complex cooling system simulation with real-time control. It enhances all stages of battery cell and pack development by enabling accelerated and reproducible test procedures at high accuracy.

Literature

[1] Patrick Weßkamp et al. ``600-A Test System for Aging Analysis of Automotive Li-Ion Cells With High Resolution and Wide Bandwidth''. In: *IEEE Transactions on Instrumentation and Measurement* 65.7 (2016), pp. 1651–1660.

[2] Sun Woong Baek et al. ``Potentiometric entropy and operando calorimetric measurements reveal fast charging mechanisms in PNb9O25''. In: *Journal of Power Sources* 520 (2022), p. 230776.

[3] Alexander Adam et al. ``Fast-Charging of Automotive Lithium-Ion Cells: In-Situ Lithium-Plating Detection and Comparison of Different Cell Designs''. In: *Journal of The Electrochemical Society* 167.13 (Sept. 2020), p. 130503.