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Thermal Management & Crash-Resistance

of Lithium-Ion Batteries for Electro & Hybrid Vehicles

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Motivation

Depending on the specific application, thermal loads are caused by environmental conditions as well as by discharge currents which supply electrical consumer. Furthermore if fast battery charging is requested, the internal ohmic resistance also induces a significant increase of battery temperature.

To achieve sufficient operation for lithium-ion batteries (LIBs) – in terms of battery performance, reliability, safety and long-life cycle – a thermal management system is needed to adjust the working temperature of the corresponding LIB in an optimal way. In order to realize that, heating as well as cooling is needed.

The remaining questions are how to cool or heat a LIB in the right way? Where at the battery outer surface is the best place to do it and which is the best method to apply? For pre-design of battery systems it's important to know how far the operation range of a battery by a sufficient thermal management could be enlarged.

In addition to that, more and more safety aspects are a must. Especially in cases of car accidents, it has to be guaranteed that no additional risk in hurting people or polluting environment roots from the LIB.

The questions in this context are related to electrical safety aspect during and after a crash, exothermic heat release due to an external or internal short circuit of the battery and risks driven by toxic gases coming from the interior of the LIB in cases of a broken battery enclosure. Or more precisely how to prevent such hazards. Which active and/or passive safety precautions can be undertaken to minimize or even exclude the consequences following a crash of a battery driven vehicle?

Thermal Management

In literature a lot of models and methods can be found, where LIBs are thermally observed. The majority of this publications investigate the internal structure and the corresponding thermal behavior is concluded out of it. In some investigations even the electrochemical as well as the thermal principles are combined. These methods are quit detailed. Unfortunately, they all base on the information how the LIB is build-up internally. Therefore the thermal properties of each battery layer or component, respectively is required. Besides, it is rather difficult to calculate or even to assume the internal thermal contact resistances between the different layers as well as the quality of the internal heat release to the battery enclosure.

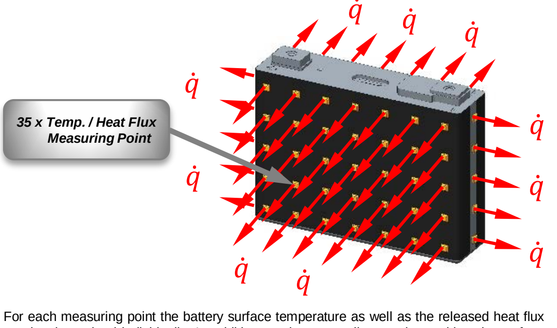
Therefore it was decided at NTB Interstate University of Applied Sciences of Technology, Buchs (SG) to do a reverse investigation. The LIB should be considered as a black box and the "real" released heat flux under different working conditions, i.e. charging and discharging, would be measured in situ.

NTB – Test Rigs

Currently two different test set-ups are under construction, one to test single battery cells and one for testing of modules up to 50 V.

CTR – Cell Test-Rig for single battery cells

The newly designed CTR is a test rig with unique thermal measurement performances under realistic working conditions. A single battery cell can be operated with discharge currents up to 400 A and max. charging current of 220 A. The test rig will be fully controlled by LabView, so that any electrical load pattern can be simulated. To record the corresponding heat release more than 80 measuring points – depending on the size of the battery cell – are available. These checkpoints can be distributed rectangular in all three directions by a 25x25 mm matrix.



For each measuring point the battery surface temperature as well as the released heat flux can be determined individually. In addition, each sensor allows to keep either the surface temperature constant by adjusting the heat flux accordingly or the other way round to keep the released heat flux constant by leaving the surface temperature finding its equilibrium.

Due to simultaneously measuring of battery current and battery surface temperature and/ or released heat flux two information can be obtained.

1) How fast the changes in battery current causes surface temperature variations
2) How will the released battery heat influence the overall temperature distribution

By answering these two questions, the definition of the best practice for cooling or heating for a LIB would be possible.

MTR – Module Test-Rig for battery modules

For testing of modules (max. 50 VDC) a new test rig is planned. Objective of the MTR experiments are to validate the thermal management system of battery modules. The different battery cooling and heating methods can be validated under operation and environmental conditions. Therefore the MTR consist of a thermal test chamber where battery modules can be placed and operated in. The thermal chamber allows to adjust the environmental temp. between -40 °C and +80 °C. The highest discharge and charge current for the MTR is 385 A at an max. electrical power of 20 kW.

Modelling

First duty of modeling is to calculate the material properties in an inverse way, i.e. from outside measured data to inside calculated material properties. Of course, it will not be possible to get the property of a single internal battery component neither any thermal contact resistance between different battery layers. In fact the result will be an overall or integral characterization of the thermal behavior in dependence on operational conditions. However this information is essential and sufficient to predict the optimal method of battery cooling/heating strategies.

Second duty of modeling will concern battery modules. With the information about a single battery cell, the performance of cell arrangements can be simulated. Furthermore the MTR experiments allow to verify the results of such simulations.

Out of that an extrapolation to a battery system can be done, to forecast the thermal behavior of a traction battery and to determine the interaction with the thermal management system of the corresponding vehicle.

Integration of Battery and Car Thermal Management

Electro or hybrid vehicle usually contain three independent cooling circuits: one for cooling of the engine or range expander, one for the power electronics and one for the traction battery. It would be beneficial to combine these three thermal management systems, especially due to synergies between them. In addition the overall efficiency can be improved and the number of parts needed reduced. Hence saving of weight and production costs are the result.

To evaluate the integration of battery and car thermal management system, detailed information of the above described CTR and MTR experiments as well as from simulations are needed.

Crash-Resistance

Concerning crash-resistance of LIBs following risks have to be consider:

- danger of non-protected high voltage at battery, cabling and car chassis
- exothermic heating-up of the battery – up to uncontrolled combustion and explosion
- release of toxic acrid gases and vapours in case of broken LIB enclosure

Actions to avoid these dangerous circumstances – safety elements for HV batteries:

- active components for electrical battery shut-off, e.g. particular emergency switches, which could be coupled to the airbag control unit (ACU)
- passive elements for additional electrical insulation, e.g. cable insulation with self-healing effect or insulation foam, which starts to grow immediately during and after an accident
- heat absorption by phase change material (PCM)
- application of methods to prevent or contain fire
- adsorption and neutralization of the accrued toxic acrid gases and vapours by suitable materials
- retention of toxic acrid gases and vapours at least, e.g. by a gas-tight bag which encloses the LIB