Thermal Analysis on Module Level in an Automotive Battery Package

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Thermal Analysis on Module Level in an Automotive Battery Package

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Thermal Analysis on Module Level in an Automotive Battery Package

Motivation

- Individual batteries have their own operational temperature ranges
- Many Li-Ion cells do not function well above 60 °C
- A good understanding of the thermal behavior of the batteries has its significance during designing safe and robust battery packages

AHR18700M1Ultra graphite/LiFePO4 cell from A123 Systems

[Source: photo, ebaracus.com]

[Source: Linden's Handbook of Batteries]
Thermal Analysis on Module Level in an Automotive Battery Package

- Ground Model - Battery Module

- 48 V battery module with a least number of cells

- 15 identical cells High capacity power cell from K2 Energy - K218650P01

[Source: K2 ENERGY]
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Ground Model - Load Profile

- Load profile is derived from the technical data
- Charging at 2 C-rate
- Discharging at 8 C-rate
- Cell Heating: $\dot{Q}_{cell} = I^2 \cdot R$
- Simulation duration: $20 \cdot 10^3 \text{ second}$

<table>
<thead>
<tr>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Capacity @ C/5 (Ah)</td>
</tr>
<tr>
<td>Average Operating Voltage @ C/5 (V)</td>
</tr>
<tr>
<td>Internal Impedance @ 1kHz, AC (mΩ)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RECOMMENDED OPERATING CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Discharge (A)</td>
</tr>
<tr>
<td>Charge Current (A)</td>
</tr>
<tr>
<td>High Operating Temp (°C)</td>
</tr>
<tr>
<td>Low Operating Temp (°C)</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th>MAXIMUM OPERATING CONDITIONS</th>
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<td>Continuous Discharge (A)</td>
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<tr>
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<td>Low Operating Temp (°C)</td>
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</tbody>
</table>

[Source: K2 ENERGY]
Temperature - $T_{ext} = T_0 = 20 \, ^\circ\text{C}$

Convective Heat Flux - $q_0 = \dot{h} \cdot (T_{ext} - T)$

Constant $\dot{h}c = 20 \, \text{W/(m}^2\cdot\text{K)}$

Objective 1: $T_{Cell} \leq T_{recommended \, operation}$

Objective 2: $T_{Cell_{Max}} - T_{Cell_{Min}} \leq 3 \, \text{K}$
Thermal Analysis on Module Level in an Automotive Battery Package

Internal Cooling Fin - Concept

- Temperature: $T_{ext} = T_0 = 20 \, ^\circ C$
- Convective Heat Flux: $q_0 = h \cdot (T_{ext} - T)$
- Constant $htc = 20 \, W/(m^2\cdot K)$
- **Objective 1**: $T_{Cell} \leq T_{recommended \, operation}$
- **Objective 2**: $T_{Cell_{Max}} - T_{Cell_{Min}} < 3 \, K$

<table>
<thead>
<tr>
<th>Internal Cooling Fin (ICF) Concepts</th>
<th>ICF_1</th>
<th>ICF_2</th>
<th>ICF_3</th>
<th>ICF_4</th>
<th>ICF_5</th>
<th>ICF_6</th>
</tr>
</thead>
<tbody>
<tr>
<td>XY-Cross Section (mm$^2$)</td>
<td>11.95</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.00</td>
<td>12.01</td>
</tr>
<tr>
<td>Circumference (mm)</td>
<td>12.25</td>
<td>25.13</td>
<td>16.00</td>
<td>19.00</td>
<td>26.00</td>
<td>23.50</td>
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</tbody>
</table>
Internal Cooling Fin - Results

Temperature Gain of Hottest Cell

ΔT between Hottest and Coldest Cell
Thermal Analysis on Module Level in an Automotive Battery Package

Internal Cooling Fin - Results

8 * Internal Cooling Fin

ΔT between Hottest and Coldest Cell

Temperature Gain of Hottest Cell

XY-Cross Section

ICF_4_2 @ 20000 s (K)

Temperature Gain of Hottest Cell

ICF_0
ICF_1_1
ICF_3_1
ICF_4_1
ICF_5_1
ICF_6_1
ICF_1_2
ICF_3_2
ICF_4_2
ICF_5_2
ICF_6_2
ICF_2_1

8 * Internal Cooling Fin
Thermal Analysis on Module Level in an Automotive Battery Package

Internal Cooling Fin - Results

**ΔT** between Hottest and Coldest Cell

**Temperature Gain of Hottest Cell**
Thermal Analysis on Module Level in an Automotive Battery Package

ICF & External Water Cooling

- External Water Cooling
  - 8 * ICF_2
  - Temperature:
    \[ T_{\text{ext}} = T_0 = 20 \, ^\circ C \]
  - Velocity: \( U_W = 1 \, m/s \)

**Temperature Gain of Hottest Cell**

**\( \Delta T \) between Hottest and Coldest Cell**

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>0</th>
<th>4000</th>
<th>8000</th>
<th>12000</th>
<th>16000</th>
<th>20000</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta T ) (K)</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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<tr>
<th>Time (s)</th>
<th>0</th>
<th>4000</th>
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<th>20000</th>
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</thead>
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<tr>
<td>( \Delta T ) (K)</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
</tbody>
</table>

ICF_2_2

ICF_2_2 - 3
Thermal Analysis on Module Level in an Automotive Battery Package
ICF & External Water Cooling

- External Water Cooling
  - 8 * ICF_2
  - Temperature:
    \[ T_{\text{ext}} = T_0 = 20 \, ^\circ C \]
  - Velocity: \( U_W = 1 \, m/s \)

\[ \Delta T \text{ (K)} \]

\[ \Delta T \text{ (K)} \]

\[ \text{ICF}_2-2 \]
\[ \text{ICF}_2-2-3 \]
\[ \text{ICF}_2-2-5 \]

\[ \text{Temperature Gain of Hottest Cell} \]

\[ \text{0 4000 8000 12000 16000 20000} \]
\[ \text{0 4000 8000 12000 16000 20000} \]

\[ \text{Time (s)} \]
\[ \text{Time (s)} \]
Thermal Analysis on Module Level in an Automotive Battery Package

Summary

- Simulative thermal analysis contributes in gaining knowledge of the cell heating during operational conditions
  → a helpful step before conducting actual tests
- The simulation results show, the temperature distribution in the ground model of the battery module is greatly uneven
  → differences in cell cycle life within the same battery module
  → a shortened cycle life of the entire module
- Cooling systems for the battery module shall be considered as an indispensable component in battery systems for automotive applications
- Combine systems with different cooling principle shall be involved for large battery module
  → a homogenous temperature distribution
  → ensure the function of all cells
Thank you!

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