Holistic Method of Thermal Management Development
Illustrated by the Example of the Traction Battery for an Electric Vehicle

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Agenda

- Motivation
  - Holistic Method (modelling principle)
  - Exemplary applications
    - Thermal behaviour of different battery design approaches
    - Control strategies for battery preheating
  - Summary
„Current chaos of technologies has to be well managed“

20th Aachen Colloquium „Automobile and Engine Technology“
Introduction

Motivation

Increasing efficiency by substitution of the combustion engine

Higher number of new components

Challenge between climatisation and range

Alternative climatisation strategies (heat pump)

Different operating temperatures (heat recovery)

20 °C 120 °C

Decentralised package

Higher overall system complexity

Alternative technologies

Holistic development / simulation tool is necessary
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- Summary
Modelling principle
1. vehicle level

- Combines all vehicle submodels
- Definition of global boundary conditions
  - driving cycle
  - route profile
  - ambient conditions, initial conditions
### Modelling principle

#### 2. energy flow level

- Combines all component models
- Definition of circuit respectively control loops
  - mechanics (power train, longitudinal dynamics)
  - thermal (AC, heat pump, cooling circuits)
  - electrics (high voltage and low voltage power supply)
Modelling principle
2. energy flow level – simulation example

2. energy flow level
Modelling principle
3. component level

- Combines all component sub-models
  - mechanics (e.g. power loss calculation)
  - thermal (heat flows via a 3D-discret volume model)
  - electrics (e.g. cell characteristics)
  - signals (component internal control units)
Modelling principle
4. physical base level

- Describes all physical laws
  - differential energy and mass balance
  - differential linear force and torque balance
  - material properties
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- Holistic Method (modelling principle)

Exemplary applications

- Thermal behaviour of different battery design approaches
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- Summary
Exemplary applications
Vehicle information

1. Thermal behavior of different battery design approaches.
2. Control strategies for battery preheating.

<table>
<thead>
<tr>
<th>vehicle information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>vehicle class</td>
</tr>
<tr>
<td>two seated sports car</td>
</tr>
<tr>
<td>vehicle mass</td>
</tr>
<tr>
<td>1400 kg</td>
</tr>
<tr>
<td>electric machine</td>
</tr>
<tr>
<td>1 x ASM: 45 kW, 172 Nm (peak performance)</td>
</tr>
<tr>
<td>2 x PMSM: 45 kW, 150 Nm (peak performance)</td>
</tr>
<tr>
<td>battery system</td>
</tr>
<tr>
<td>type of cells</td>
</tr>
<tr>
<td>18650 Li-Ion-Cell</td>
</tr>
<tr>
<td>number of cells</td>
</tr>
<tr>
<td>2080 cells (tunnel battery) / 3120 cells (rear battery)</td>
</tr>
<tr>
<td>performance</td>
</tr>
<tr>
<td>appr. 220 kW</td>
</tr>
<tr>
<td>energy content</td>
</tr>
<tr>
<td>appr. 42 kWh</td>
</tr>
<tr>
<td>mass</td>
</tr>
<tr>
<td>appr. 310 kg</td>
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</table>
Exemplary applications
Requirements and limits

requirements
- deformable and energy absorbing battery system
- low overall system weight
- low installation space

thermal requirements / limits
- maximum operating temperatures: < 40 °C
- maximum axial cell temperature gradient: < 4 K
- maximum temperature difference between two cells: < 4 K
- minimum cell temperature for charging: 5 °C
Exemplary application I
Influences of different design approaches

Variations:
- material of the cell reinforcement to improve battery crash safety (foam, aluminum, copper)
- thickness of the reinforcement (0,5 mm up to 2,5 mm)

Assumptions:
- thermal equilibrium at the beginning
- starting temperature is 25°C
- adiabatic battery system behavior
- thermal contact of the cells only via the cooling plate
Influence of different design approaches
Maximum temperatures & temperature differences

- speed
- foam 2 mm
- aluminium 2 mm

- foam $\Delta T$ axial
- foam $\Delta T$ cell
- aluminium $\Delta T$ axial
- aluminium $\Delta T$ cell
Influence of different design approaches
Multi-criteria analysis
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Exemplary application II
Battery preheating strategies / opposite effects

1. Could a realistic drive cycle be driven without preheating?
2. If not which preheat temperature should be chosen to get a good compromise between
   - potential start time
   - vehicle performance
   - overall energy demand

<table>
<thead>
<tr>
<th>criteria</th>
<th>low (preheat) temperature</th>
<th>high (preheat) temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>battery / vehicle performance</td>
<td>▼</td>
<td>▼</td>
</tr>
<tr>
<td>internal cell resistance / battery losses</td>
<td>▲</td>
<td>▼</td>
</tr>
<tr>
<td>recuperation potential</td>
<td>▼</td>
<td>▼</td>
</tr>
<tr>
<td>energy demand for heating period</td>
<td>▼</td>
<td>▼</td>
</tr>
<tr>
<td>potential start time</td>
<td>▼</td>
<td>▼</td>
</tr>
</tbody>
</table>
Exemplary application II
Battery preheating strategies

energy flow level

Variations:
- switch off temperature of the coolant heater (from -15°C up to +25°C)

Assumptions:
- strong winter scenario, starting temperature is -20°C
- thermal equilibrium at the beginning
- adiabatic battery system behavior (form is used for the reinforcement)
Without battery preheating

\[ T_{\text{start}} = -20^\circ \text{C} \]
Battery preheating

$T_{heater,off} = -5^\circ C$
Battery preheating

$T_{\text{heater,off}} = 20^\circ\text{C}$

- tunnel max
- tunnel min
- rear max
- rear min
- coolant at heater

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Driving cycle finished

Average surplus power
Battery preheating
Multi-criteria analysis
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Summary
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- Increasing overall system complexity
- Holistic simulation tool is necessary
  - Simulation of mechanical, electrical and thermal energy flows
  - Support the design process (e.g. functional or structural development)
- Flexible holistic support tool is been developed at ika/fka
- Exemplary applications demonstrate the benefit of the holistic approach
Thank you for your attention.

Many thanks also to all team members of the project eperformance
Contact

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