EGVI Expert Workshop on Testing of Electric Vehicle Performance and Safety

Battery Safety and Electric Vehicle Benchmarking

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Agenda

• Introduction
• Battery Safety
  • Requirements
  • Testing
  • Simulation
• Electric Vehicle Benchmarking
• Summary
Introduction

- Growing share of EVs on the market
- Consideration of new risks like mechanical, thermal, electrical and chemical hazards
- Hence, suitable requirements are necessary
- Testing methods of batteries and corresponding simulation methods have to be created

- High number of different concepts and development status of EVs
- Which performance have EVs in different disciplines?
- Standardised functional benchmarking of EVs necessary?
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Battery Safety Requirements

Specific Requirements for electric drive trains

Structural Safety
(new components)

High Voltage Safety

Fire and Explosion Protection
# Battery Safety

## Legal regulations (post crash)

<table>
<thead>
<tr>
<th>Market</th>
<th>Regulation</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE</td>
<td>ECE R94/12</td>
<td>Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision</td>
</tr>
<tr>
<td></td>
<td>ECE R95</td>
<td>Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral impact</td>
</tr>
<tr>
<td>USA</td>
<td>FMVSS 305</td>
<td>Electric powered vehicles: electrolyte spillage and electrical shock protection</td>
</tr>
<tr>
<td>Japan</td>
<td>Trias 67-3</td>
<td>Test procedure for protection of occupants against high voltage in electric and hybrid vehicles after collision</td>
</tr>
<tr>
<td></td>
<td>Art 17-2 Attach. 111</td>
<td>Technical standard for protection of occupants against high voltage after collision in electric vehicles and hybrid electric vehicles</td>
</tr>
<tr>
<td>China</td>
<td>GB/T 18384</td>
<td>Electric vehicles – safety specifications</td>
</tr>
<tr>
<td></td>
<td>GB/T 19751</td>
<td>Hybrid electric vehicles – safety specification</td>
</tr>
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</table>
### Battery Safety

#### Legal regulations (post crash)

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<th>Test</th>
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</table>
| ECE    | ECE-R12; ECE-R33 | Protection against electrical shock  
- El. isolation > 100/500 Ω/V d.c/a.c  
- Physical protection  
- Absence of high voltage (HV cut-off < 60 V in 5 sec)  
- Low electrical energy < 0.2 J in 5 secs  

| ECE-R94; 96/79/EC | 40% - 56 km/h | Rechargeable energy storages:  
- The RESS shall stay in their original locations with their components inside and no intrusion into the passenger compartment allowed  
- No electrolyte spillage into passenger compartment within 30 min after impact (outside < 7 % or < 5 l)  
- No explosion or fire of RESS  

| ECE-R95; 96/27/EC | 50 km/h; 950 kg |
| ECE-R32 / ECE-R34 | 35 - 38 km/h; 1100 kg |
Battery Safety
Reasons for Battery Testing

• Difference between test standards and reality

Test Conditions:
- Impact Speed: 56 km/h
- Overlap: 100 %
- Rigid barrier
- Zero degree impact

Criteria for Crashworthiness Assessment:
- Deceleration max 50 - 80 g
- Structural energy management (qualitatively, based on expert judgement)
- Intrusion into battery compartments

Test Conditions:
- Impact Speed: 64 km/h
- Overlap: 40%
- Offset deformable barrier
- Zero degree impact

Criteria for Crashworthiness Assessment:
- Deceleration max 50 - 80 g
- Structural energy management (qualitatively, based on expert judgement)
- Intrusion into battery compartments

Test Conditions:
- Impact Speed: 80 km/h
- Overlap: 70 %
- Deformable moving barrier
- Barrier weight: 1,368 kg

Criteria for Crashworthiness Assessment:
- Small deformation in region of the fuel tank / battery (qualitatively)
- Structural energy management (qualitatively, based on expert judgement)
- Intrusion into battery compartments

UN Transportation
Real loading depending on vehicle structure and system architecture

• Crucial loads depending on battery type, chemistry,…

18650 cell
pouch cell
prismatic cell
Battery Safety
Test Benches for Batteries

Requirements:
• Enclosed environment or open-air testing
• Gas leakage detection and warning
• Vacuum device
• Extinguishing system
Battery Safety Simulation - State of Art

Chemical and thermal simulation (3D)

Pros and Cons

+ realistic by high resolution
- time step to small for full vehicle simulation

Chemical and thermal simulation (2D)

Pros and Cons

+ low simulation time by simplifying
- not possible to map 3-dimensional mechanical behavior in 2D

Structural behavior of single cells

Pros and Cons

+ detailed view on each cell component possible
- time step to small for full vehicle simulation
- load cases not oriented to full vehicle simulation

Source: Journal of Power Sources
Battery Safety
Simulation - Approach OSTLER Project

Design Battery System
- Relevant load cases
- Cell tests
- FE Model (cell)
- Design validation

Design
- Cover (plastic)
- Closing panel (AL)
- Side walls (AL)
- Reinforcement (AL)

Battery Safety

Relevant full vehicle load cases

Creating a cell simulation model

Electrification and positioning

Deformation of the system
- Deformed battery pack
- Plastic strain battery cells

Identification relevant load cases

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- Intrusion into battery compartments

Test Conditions:
- Impact Speed: 29 km/h (CoG Driver's head)
- 50 km/h (varied position)
- Varying pole position along vehicle longitudinal axis

Criteria for Crashworthiness Assessment:
- Intrusion into battery compartments

- Plastic strain battery cells
- Deformed battery pack

- 50% of all wh, (2.4%)
- View from above

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- View from above
Battery Safety
Deformable Battery Pack

Deformable Battery Pack

- Purpose design approach
- Battery package making full use of the deformable concept

Current Concept in the Project “e performance”
- Conversion design approach
- Indirect force transmission via seat

Adapted Battery Package of SpeedE
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Electric Vehicle Benchmarking

Intention

- Functional analyses are executed in order to investigate and compare the performance status of EVs
- Several disciplines of important EVs are analysed
- Past analysed vehicles were Mitsubishi i-MiEV and Nissan Leaf
- Currently BMW i3 is under investigation
- Mainly the EV specific components (e.g. drivetrain, electronics) are analysed for their functions
- But also body and suspension are considered
- Benchmarking is completed by weight and dimension analyses of all parts
# Electric Vehicle Benchmarking

## Subjects of the Benchmarking Analysis

### Subjects DBM and FBM for Electric Vehicles

<table>
<thead>
<tr>
<th>Chassis</th>
<th>Electric/Electronics</th>
<th>Drivetrain</th>
<th>Body</th>
<th>Overall Vehicle</th>
</tr>
</thead>
</table>
| • Inertia parameters  
  • k&c-parameters  
  • Road tests  
  • Determination of the damper characteristics  
  • Objective assessment of the driving performance  
  • Analysis of handling errors | • 12V main power supply:  
  • Design analysis  
  • Stability and functions main power supply  
  • Standby current measurement  
  • HV main power supply:  
  • Design analysis  
  • Analysis charging and discharging process  
  • Main power supply functions | • Driving resistances  
  • Energy consumption and range measurement (NEDC and Hyzem)  
  • Temperature-dependent range measurement  
  • Efficiency electric drive  
  • Efficiency high voltage components  
  • Analysis of the maximum performance curve of the drivetrain | • Static bending and torsion stiffness  
  • Cutting of the body-in-white along the x-axis  
  • Disassembly of the left body half (driver's side)  
  • Detailed analysis of the body components:  
    • Weight  
    • Dimensions  
    • Fitting positions  
    • Joining techniques  
    • Photo documentation | • Vehicle disassembly  
  • Component analysis:  
    • Weight  
    • Dimensions  
    • Fitting positions  
    • Joining techniques  
    • Photo documentation |

### FBM

- Destructive benchmarking
- Non-destructive benchmarking

### DBM

- Body
  - Static bending and torsion stiffness
  - Cutting of the body-in-white along the x-axis
  - Disassembly of the left body half (driver's side)
  - Detailed analysis of the body components:
    - Weight
    - Dimensions
    - Fitting positions
    - Joining techniques
    - Photo documentation

- Overall Vehicle
  - Vehicle disassembly
  - Component analysis:
    - Weight
    - Dimensions
    - Fitting positions
    - Joining techniques
    - Photo documentation

- Electric Vehicle Benchmarking

- Subjects of the Benchmarking Analysis
## Overview:
- Identification and photographic documentation of the main HV components (power electronics, HV battery, HV fuses, gates, boltings and plugs, consumer (if possible)) and of the wiring, creation of a topology documentation

### Expected testing results:
```
<table>
<thead>
<tr>
<th>Name</th>
<th>Electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion</td>
<td>315 Ah</td>
</tr>
<tr>
<td>Energy</td>
<td>180 kWh</td>
</tr>
<tr>
<td>Weight</td>
<td>272 kg</td>
</tr>
<tr>
<td>Weight</td>
<td>43.39 kg</td>
</tr>
</tbody>
</table>
```

## Overview:
- Recording of a complete charging process (ca. 50% to the end of the charging process and “vehicle denies to start” to the end of the charging process)
- View of the energy flow in the main power supply during the charging process

### Expected testing results:

## Overview:
- Recording of a discharging process of the HV battery during a drive with activated consumer loads (Monitoring of potential system shut-offs)
- Recording of a discharging process of the HV battery at 25% SoC in holdup mode

### Expected testing results:
Electric Vehicle Benchmarking Drivetrain (1/2)

Overview:
• Performance of coast load tests
• Identification of driving resistance parameters (roll and air resistance)

Extract testing results:
Driving resist. parameters

| f₀ [N] | 135 |
| f₁ [N·h/km] | 0.838 |
| f₂ [N·h²/km²] | 0.0406 |

Energy testing results:

- Manufacturer information [Wh/km]: 135
- Measured cycle consumption [Wh/km]: 165

Overview:
• Determination of the NEDC- and Hyzem-cycle consumption
• Analysis of the NEDC range
• Determination of the energy consumption according to UDDS and HWFET

Overview:
• Measuring of the efficiency in stationary adjusted operation points (op)
• Determination of the electr. and mech. power (per op)

Overview:
• Capacities
• Internal resistance, open-circuit voltage, pulse/peak power, Energetic/Coulomb super-/discharging eff.
Efficiency HV Components

Overview:
- DC/DC converter
- DC/AC converter
- Charge unit
- Electric motor
- HV battery

Expected testing results:

<table>
<thead>
<tr>
<th>Efficiencies</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_{\text{DC/DC converter}}$ [-]</td>
<td>0.97</td>
</tr>
<tr>
<td>$\eta_{\text{Charge unit}}$ [-]</td>
<td>0.90</td>
</tr>
<tr>
<td>$\eta_{\text{Electric motor}}$ [-]</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Temperature-dependent range measurement (NEDC)

Overview:
- - 20 °C
- - 10 °C
- 0 °C
- 20 °C
- 40 °C

Expected testing results:

<table>
<thead>
<tr>
<th>Range [km]</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{-20^\circ C}$</td>
<td>65</td>
</tr>
<tr>
<td>$R_{0^\circ C}$</td>
<td>85</td>
</tr>
<tr>
<td>$R_{20^\circ C}$</td>
<td>100</td>
</tr>
</tbody>
</table>

Analysis of the Maximum Performance Curve of the Drivetrain

Overview:
- Exemplary analysis of the derating behaviour for two different vehicle speeds

Expected testing results:
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Summary

• EU project OSTLER deals with research work about testing and simulation methods for EV batteries

• In general three different ways possible:
  • Protect battery pack completely from deformation
  • Allow certain deformation of the battery cells
  • Consider movement of cell modules with energy absorption elements (deformable battery pack)

• Different battery cell types have to be considered

• Functional benchmarking helps to understand and compare the performance of EVs (especially in relation to ICE vehicles)

• Standardised functional benchmarking of EVs necessary
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