EGVI Expert Workshop on Testing of Electric Vehicle Performance and Safety

Battery Safety and Electric Vehicle Benchmarking

Brussels, 03 July 2014

Roland Wohlecker, Michael Funcke

Forschungsgesellschaft Kraftfahrwesen mbH Aachen

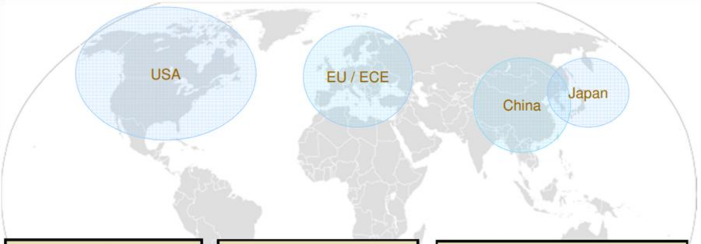
Agenda

- 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

Legal Requirements High-Voltage-Safety



Electric Safety (in use)	
USA	-
EU/ECE	ECE-R100
China	GB/T 18384
Japan	Attachement 10

Electric Safety (post crash)	
USA	FMVSS 305
EU/ECE	ECE-R94/95
China	GB/T 19751 (only hybrid vehicles)
Japan	Attachement 111

Battery Safety	
USA	- (only SAE-standard J2929)
EU/ECE	- (in progress)
China	QC/T 743
Japan	Kokujigi 178
ISO	(Draft ISO 12405)

Source: EU project MATISSE

- High number of different concepts and development status of EVs

- Which performance have EVs in different disciplines?
- Standardised functional benchmarking of EVs necessary?

Agenda

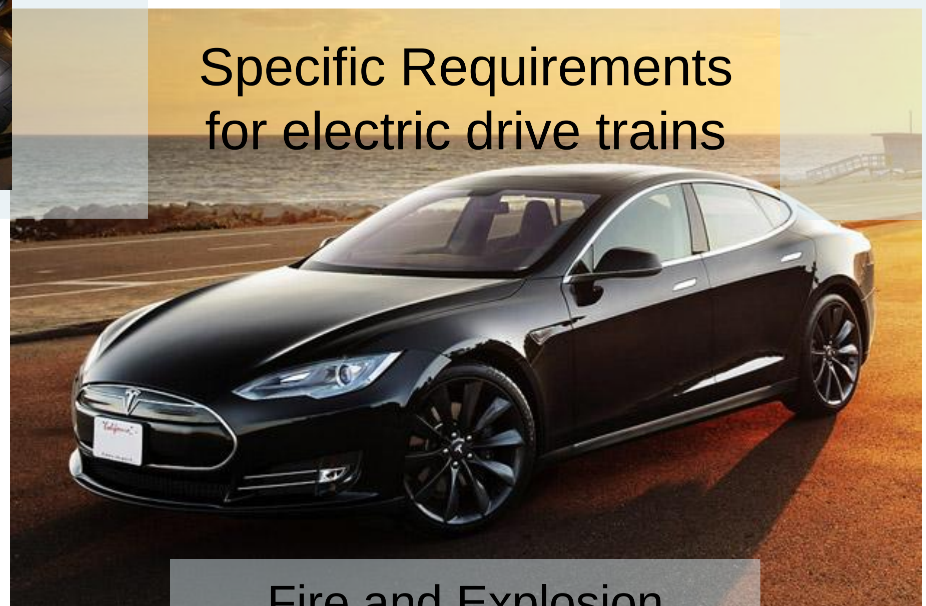
- Introduction
- Battery Safety
  - Requirements
  - Testing
  - Simulation
- Electric Vehicle Benchmarking
- Summary

Battery Safety Requirements

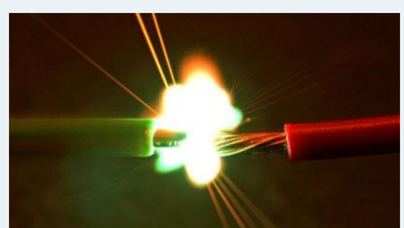
Structural Safety
(new components)

High Voltage Safety

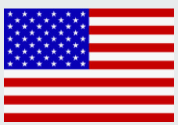
Specific Requirements for electric drive trains



Fire and Explosion Protection

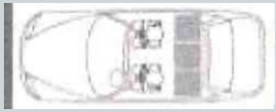
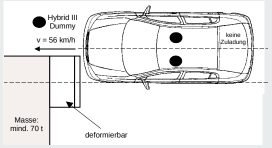
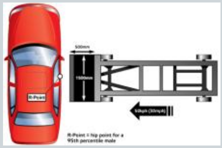


Battery Safety
Legal regulations (post crash)

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

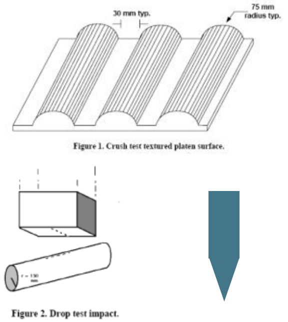
Battery Safety
Legal regulations (post crash)

Market	Regulation	Titel
ECE	ECE R94/12	Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision
	ECE R95	Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a lateral impact
USA	FMVSS 305	Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection
Japan	Trias 67-3	Test procedure for protection of occupants against high voltage in electric and hybrid vehicles after collision
	Art 17-2 Attach. 111	Technical standard for Protection of Occupants against high voltage after collision in electric vehicles and hybrid electric vehicles
China	GB/T 18384	Electric Vehicles – Safety Specifications
	GB/T 19751	Hybrid Electric Vehicles – Safety Specification

Regulation	Test	Requirements
ECE-R12; ECE-R33 48.3 - 53.1 km/h		**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 **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-R94; 96/79/EC 40% - 56 km/h		
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

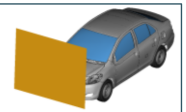
- Difference between test standards and reality



≠

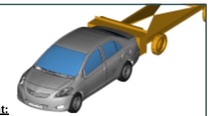
Test Conditions:
- Impact Speed: 56 km/h
- Overlap: 100 %
- Rigid barrier
- Zero degree impact

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



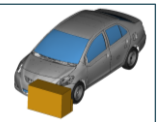
Test Conditions:
- Impact Speed: 80 km/h
- Overlap: 70 %
- Deformable moving barrier
- Barrier weight: 1,368 kg

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



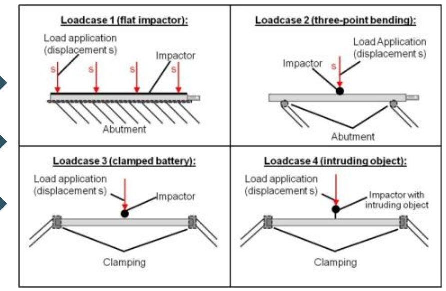
Test Conditions:
- Impact Speed: 64 km/h
- Overlap: 40%
- Offset deformable barrier
- Zero degree impact

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

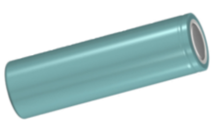
Criteria for Crashworthiness Assessment:
- Intrusion into battery compartments

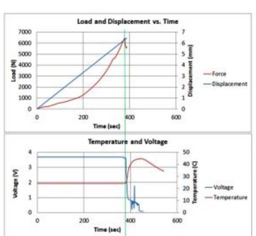


UN Transportation

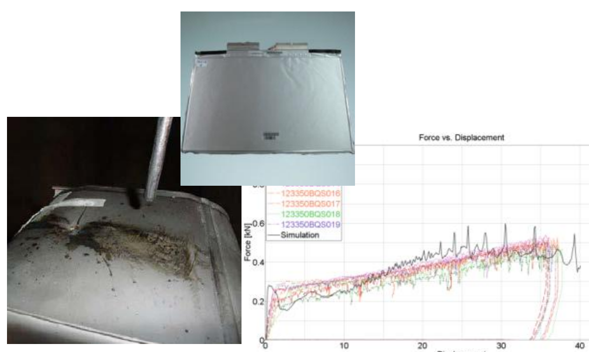
Real loading depending on vehicle structure and system architecture

- Crucial loads depending on battery type, chemistry,…





18650 cell



pouch cell

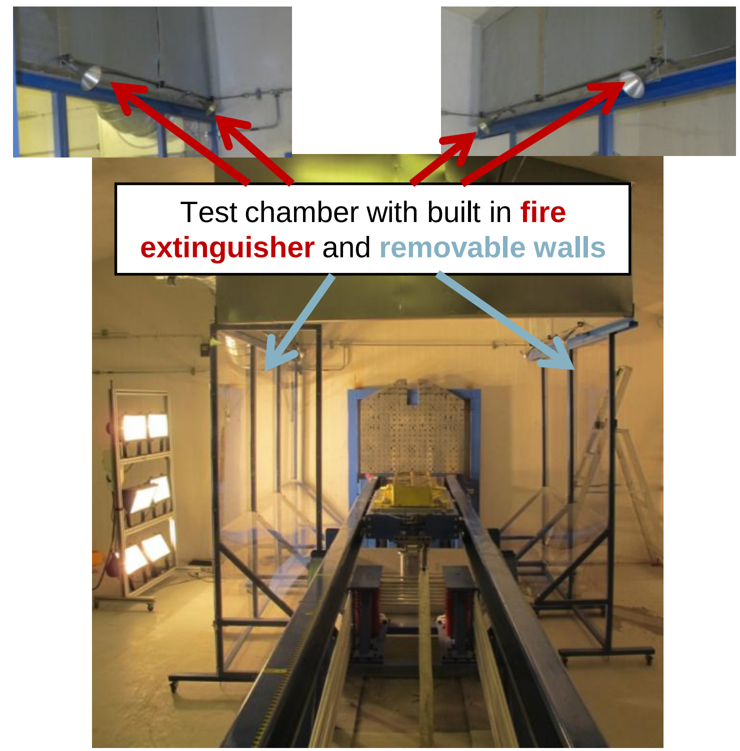
prismatic cell

Battery Safety
Test Benches for Batteries

Requirements:

- Enclosed environment or open-air testing
- Gas leakage detection and warning
- Vacuum device
- Extinguishing system

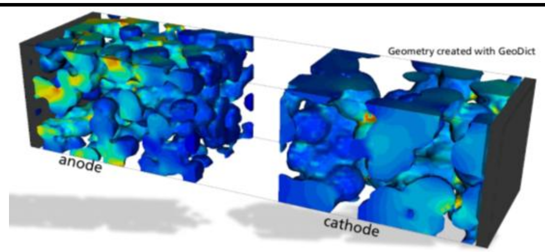
Source: fka



Source: Autoliv

Battery Safety
Simulation - State of Art

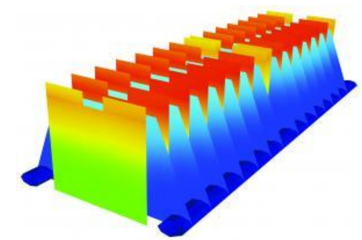
Chemical and thermal simulation (3D)



Pros and Cons

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

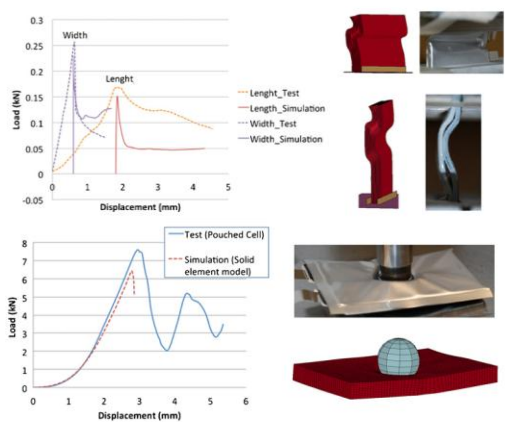
Chemical and thermal simulation (2D)



Pros and Cons

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

Structural behavior of single cells



Source: Journal of Power Sources

Pros and Cons

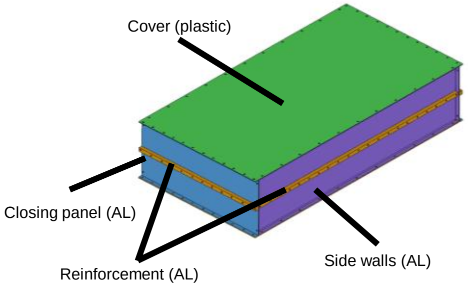
+ detailed view on each cell component possible

- time step to small for full vehicle simulation
- load cases not oriented to full vehicle simulation

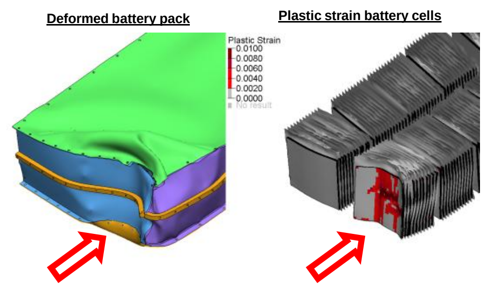
Battery Safety
Simulation - Approach OSTLER Project

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

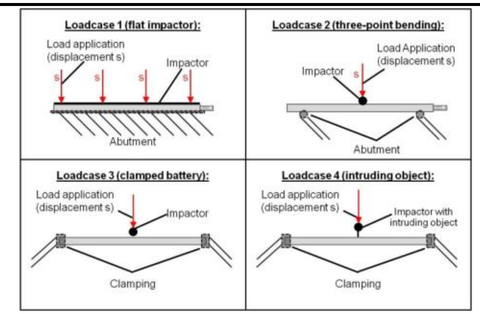
Design



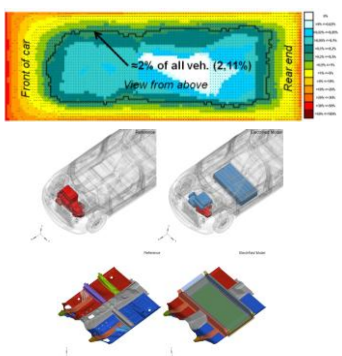
Deformation of the system



Identification relevant load cases

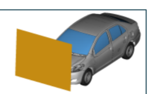


Electrification and positioning



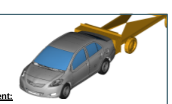
Relevant full vehicle load cases

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



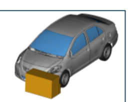
Criteria for Crashworthiness Assessment:
- Deceleration max 50 - 80 g
- Structural energy management (qualilatively, based on expert judgement)
- Intrusion into battery compartments

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 (qualilatively, based on expert judgement)
- Intrusion into battery compartments

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

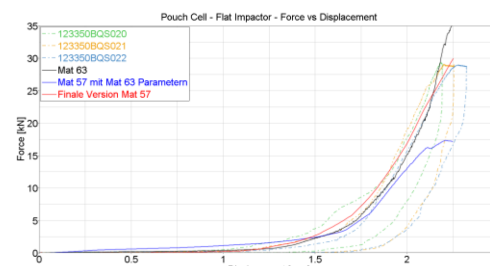


Criteria for Crashworthiness Assessment:
- Deceleration max 50 - 80 g
- Structural energy management (qualitatively, based on expert judgement)
- Intrusion into battery compartments

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

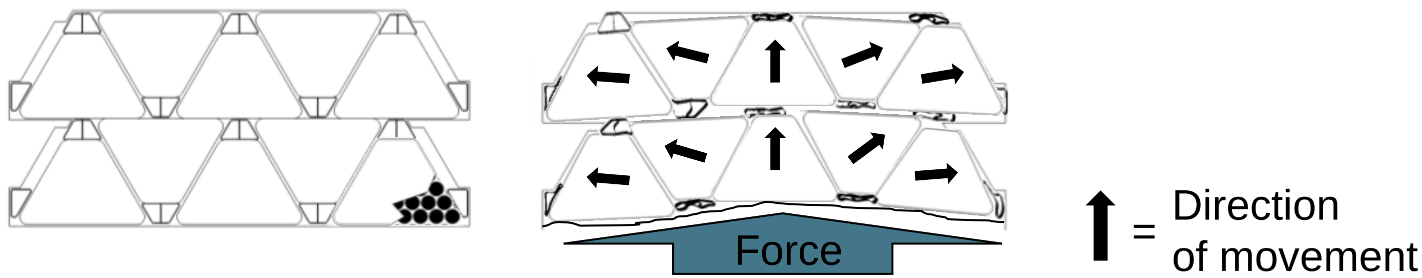
Criteria for Crashworthiness Assessment:
- Intrusion into battery compartments

Creating a cell simulation model

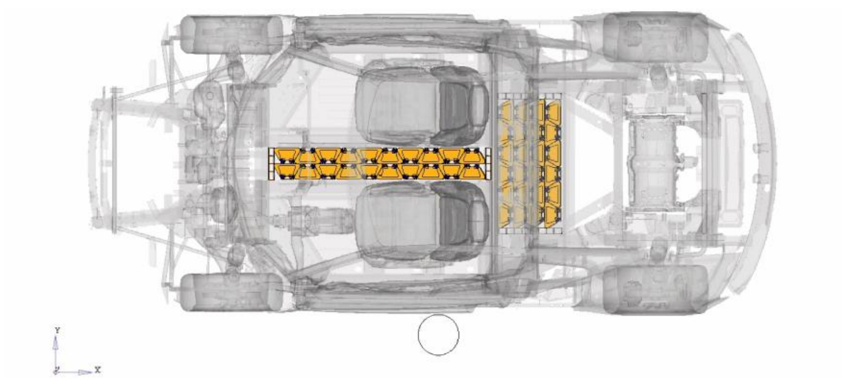


Battery Safety
Deformable Battery Pack

Deformable Battery Pack

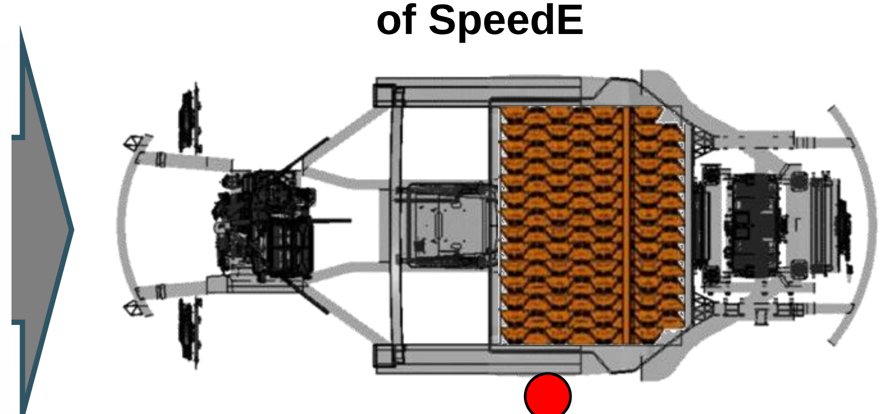


Current Concept in the Project "e performance"



- Conversion design approach
- Indirect force transmission via seat

Adapted Battery Package of SpeedE



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

Agenda

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

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

2011

2012

2014

Electric Vehicle Benchmarking
Subjects of the Benchmarking Analysis

Subjects DBM and FBM for Electric Vehicles

Chassis

- Inertia parameters
- k&c-parameters
- Road tests
- Determination of the damper characteristics
- Objective assessment of the driving performance
- Analysis of handling errors

FBM

DBM

Electric/ Electronics

- 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

Drivetrain

- 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
- Characterisation of the high voltage battery

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 position
  - Joining and manufacturing techniques
  - Sheet thicknesses
  - Photo documentation

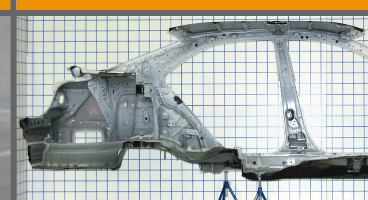
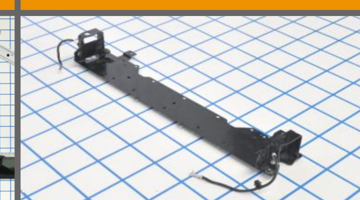
Overall Vehicle

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

Destructive benchmarking

Non-destructive benchmarking



Electric Vehicle Benchmarking
Electric/Electronics (Extract)

HV Main Power Supply

Design 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:

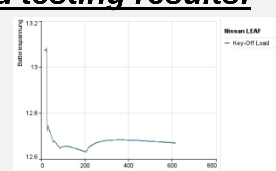
Name:	Elektromotor
Länge:	315 mm
Breite:	383 mm
Höhe:	272 mm
Gewicht:	43.39 kg

Charging Process

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:

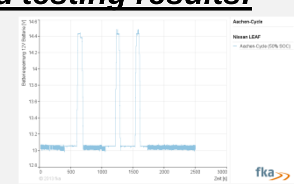


Main Power Supply Functions

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)

Analysis Driving Resistance

Overview:

- Performance of coast load tests
- Identification of driving resistance parameters (roll and air resistance)

Extract testing results:

Driving resist. parameters	
f_0 [N]	135
f_1 [N*h/km]	0.838
f_2 [N*h²/km²]	0.0406

Determination Energy Consumption

Overview:

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

Extract testing results:

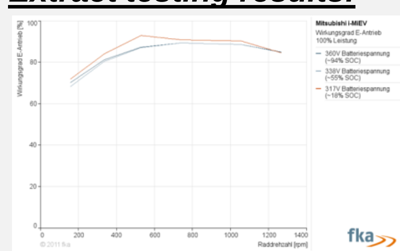
Energy consumption	
Manufacturer information [Wh/km]	135
Measured cycle consumption [Wh/km]	165

Efficiency Electric Drive

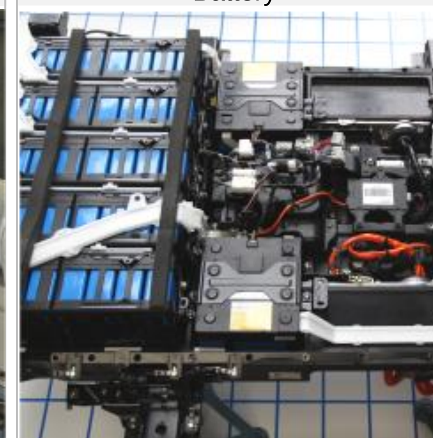
Overview:

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

Extract testing results:



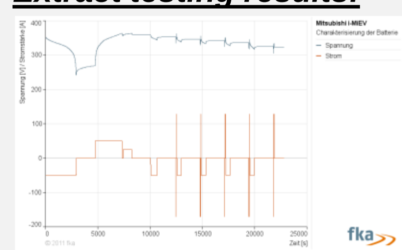
Characterisation High Voltage Battery



Overview:

- Capacities
- Internal resistance, open-circuit voltage, pulse/peak power, Energetic/Coulomb super-/discharging eff.

Extract testing results:



Electric Vehicle Benchmarking Drivetrain (2/2)

Efficiency HV Components

Overview:

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

Expected testing results:

Efficiencies	
$\eta_{DC/DC\ converter}$ [-]	0.97
$\eta_{Charge\ unit}$ [-]	0.90
$\eta_{Electric\ motor}$ [-]	0.94

Temperature-dependent range measurement (NEDC)

Overview:

- - 20 °C
- - 10 °C
- 0 °C
- 20 °C
- 40 °C

Expected testing results:

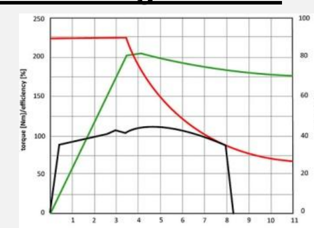
Range [km]	
$R_{-20°C}$	65
$R_{0°C}$	85
$R_{20°C}$	100

Analysis of the Maximum Performance Curve of the Drivetrain

Overview:

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

Expected testing results:



Agenda

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

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

Contact

Roland Wohlecker

Forschungsgesellschaft Kraftfahrwesen mbH Aachen
Steinbachstraße 7
52074 Aachen
Germany

Phone +49 241 8861 191
Fax +49 241 8861 110

Email wohlecker@fka.de
Internet www.fka.de