AMAP Colloquium

Re-defining Driving Experience – Competences & Concepts Behind the Research Vehicle SpeedE

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Agenda

- Introduction of the SpeedE Research Vehicle
- Functionally Adapted Physical Vehicle Architecture
- Body Structure
- Crash Deformable Battery System
- Electric Powertrain and Vehicle Electrical System
- Wheel-Individual Steer-by-Wire
- Sidesticks for Lateral Vehicle Guidance
- Synopsis and Outlook
Introduction of the SpeedE Research Vehicle
Open research and innovation platform

- Driving pleasure despite intervention of DAS
- DRIVING EXPERIENCE
- ingess and door concept

- More safety with less weight
- SAFETY
- safe battery systems

- Minimal energy consumption
- EFFICIENCY
- 2 electric drives at rear axle

- Innovative structure

- Active sidesticks + vehicle control

- Innovative steering (wheel-individual steer-by-wire)
Introduction of the SpeedE Research Vehicle

Timeline

- Oct. 2011
- Oct. 2013
- Oct. 2014
- Oct. 2015
- March 2016
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Functionally Adapted Physical Vehicle Architecture
Prospects of purpose design

Conversion Design
- Based on existing concept
- Efficient design approach
- Low risk regarding feasibility and invest
- Limited innovation potential for technical and creative design
- Evolutionary development

Purpose Design
- New Basic Vehicle Concept
- Comply with unique requirements and functions
- Innovative dimensional concepts possible
- Less compromises and improved setting of components
- Revolutionary development

Targets, Requirements and Functions

Definition of Concept Framework
- Vehicle Type
- Dimensional Concept
- Basic Technologies

Basic Vehicle Concept Development
(Harmonization of Concept Framework)

Existing Basic Vehicle Concepts

Targets assessed plausible?

Feasible Vehicle Concept

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Functionally Adapted Physical Vehicle Architecture
Ingress strategy for sportscar with central driver position

Challenges
- Huge lateral distance from sill to seat
- No continuous seat row
- Torso movement limited by roofrail
- Leg movement limited by steering wheel

Concept Development
1. Provide large lateral door opening
2. Enter in upright body posture (1,2)
3. Move next to the seat (3)
4. Sit down compared to conventional seat ingress strategies (4,5,6)

Testing and Prototyping

[Source: Fifth Gear]
Body Structure
Development approach

Component simulation
- Pre-dimensioning of components
- Determination of loads, section loads and load application

Global sucesive topology optimisation
- Design space evaluation
- Design space determination
- Design inspiration

Simplified models
- Fast CAD and FEM modelling
- Assessment of alternatives
- Quasi static optimisation
- Transfer of simplified model to feasible design
- Detailed analysis and design iteration

Detailed design
- Design space determination
- Design inspiration
- Fast CAD and FEM modelling
- Assessment of alternatives
- Quasi static optimisation
- Transfer of simplified model to feasible design
- Detailed analysis and design iteration
### Unique Solutions Design Features of Functional Prototype

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Torsional stiffness</td>
<td>49000 Nm/°</td>
</tr>
<tr>
<td>Bending stiffness</td>
<td>33700 N/mm</td>
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<tr>
<td>1st Eigenfrequency</td>
<td>70.3 Hz</td>
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<tr>
<td>2nd Eigenfrequency</td>
<td>71.4 Hz</td>
</tr>
<tr>
<td>Weight Body-in-white</td>
<td>256 kg</td>
</tr>
<tr>
<td>Material Mix</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Al</td>
</tr>
<tr>
<td></td>
<td>GFRP</td>
</tr>
<tr>
<td></td>
<td>St-CFRP</td>
</tr>
<tr>
<td></td>
<td>Sandwich</td>
</tr>
</tbody>
</table>

- **Narrow crash structure**
- **V-shaped passenger cell front**
- **Large door opening**
- **Structurally integrated battery housing**
Body Structure
Numerical Analysis of Functional Prototype

Example: Front crash 40% offset deformable barrier

Example: Front crash small overlap 25% offset
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Crash Deformable Battery System

Approach

Crash Element

Marco Cell

Force
Battery cells have to be protected from high deformations to avoid thermal runaway.
Crash Deformable Battery System
Physical Tests

18650 Cell
Quasi-static

Macro Cell
Quasi-static

Battery System
Dynamic
Crash Deformable Battery System
Physical Tests
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Electric Powertrain and Vehicle Electrical System

Topography

48 V-Battery

Steering actuator

48 V-PDU

48 V-DC/DC

Steering actuator

HV-Battery

E_{Battery} Capacity: 16 kWh

U_N: 400 V

P_{discharge,max}: 160 kW (400 A)

PDU

DC/AC & EM1

P_{\text{max}} (each): 100 kW

T_{q_{\text{max}}}(each): 220 Nm

n_{\text{max}}: 12 000 rpm

i_{\text{ratio}}: 5.5

DC/AC & EM2

Charger
Electric Powertrain and Vehicle Electrical System
Drive-by-Wire & Brake-by-Wire

Driver Inputs

Functional Software

Component Outputs

two wheel-individual electric motors lead to high torque vectoring capability

four wheel-individual electro-hydraulic brake actuators allow for any wanted brake force distribution

Driver Inputs:
- Input Signals
- Signal Rebuilding
- Signal Mapping

Functional Software:
- Vehicle Manager
  - Start-Up / Shut-Down
  - Gear Choice
  - Lights
  - Charging
- Diagnostics
  - Detection of Faults and Derivation of Safe States

Component Outputs:
- Lateral Dynamics Controller
  - Steer-By-Wire
  - Torque Vectoring
- Longitudinal Dynamics Controller
  - Drive-By-Wire
  - Control of HV Components
  - Recuperation
  - Brake-By-Wire

Output Signals:
- Signal Rebuilding
- Signal Mapping

Component Outputs:
- Data Logging

Technical Details:
- Two wheel-individual electric motors lead to high torque vectoring capability.
- Four wheel-individual electro-hydraulic brake actuators allow for any wanted brake force distribution.
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Historical Review
Steer-by-Wire system and large wheel steering angles

Steer-by-Wire System

Research vehicle at ika 1991 with electro-hydraulic Steer-by-wire system

Large Wheel Steering Angles

Sidestick with potentiometer and rotary magnet

California United States. Date: 1933.
Steer-by-Wire System of the Research Vehicle SpeedE

Fields of research

Innovative front axle suspension Concept

Vehicle guidance via active sidesticks

Steer-by-Wire System

Functional safety concept

Innovative vehicle dynamics functionality

Faulty steering intervention on both wheels (FLT_ST_AXLE)

Faulty steering intervention on left wheel (FLT_ST_LE)

Faulty steering intervention on right wheel (FLT_ST_RI)
Steer-by-Wire System
Innovative front axle suspension concept

Design

Implementation

Validation
Steer-by-Wire System of the Research Vehicle SpeedE

Innovative vehicle dynamics functionality

- **Parking brake/ Emergency brake**
- **Optimization of lateral force**
  - Torque [Nm]
  - Time [s]
  - Lateral force [N]

- **Modified ackermann design**
  - $\delta_{FA,\text{inner}} > \delta_{FA,\text{outer}}$
  - $\delta_{FA,\text{inner}} < \delta_{FA,\text{outer}}$

- **Improvement of $\mu$-split braking**

- Torque about steering axis
- Pneumatic Trail
- Lateral Force

Vehicle Speed increased
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SpeedE
Vehicle Guidance

Control element

- Recuperation switch
- Additional board
- Strain gauge
- Rotary encoder
- Switch unit
- Sidestick handle bar
- Mainboard
- Motor and strain wave gear
- Lock disc

Control loop

\[ \Sigma T_{\text{Hand, Left}} \quad \Sigma T_{\text{Hand, Right}} \quad f(x) \quad \delta_{\text{Desired, Left}} \quad \delta_{\text{Desired, Right}} \]

\[ \Phi_{\text{Desired, Left}} \quad \Phi_{\text{Desired, Right}} \]

Driving condition

Feedforward
Feedback
Safety and reliability are the main concerns when it comes to Steer-By-Wire Systems

1. Solution
   Mechanical fallback layers or component redundancy
   “If one component fails, I need another one to replace it”

2. Solution
   Keep the solution space as wide as possible
   “If one component fails, I still have to be able to bring the vehicle to a safe standstill”

⇒ Steering angle failures are compensated by other vehicle systems (counter steering, torque-vectoring and braking)
SpeedE
Functional Safety
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Synopsis and Outlook

- SpeedE resembles a unique and innovative research platform to investigate on future mobility
- Complete X-by-Wire platform

Outlook:
- Further refinement of vehicle functions – i.e. feed-forward and feed-back behaviour of the Steer-by-Wire system
- Development and implementation of a sensor concept for automated driving
- Implementation of functions for automated driving
Thank you for your attention

Thanks to the Hans Hermann Voss foundation for their support in developing SpeedE

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