Schaeffler 4ePerformance – Test Bench On Wheels

Benedikt Locker
Technical Development Motorsport
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Introduction

Benedikt Locker

- Schaeffler Employee since 2012
  - Test Engineer Suspension Components
  - Vehicle Testing
  - System Testing Formula E
  - Project Leader of S4eP
- Former team member of Formula Student Team of FAU Erlangen-Nürnberg
Schaeffler at a glance

Schaeffler in facts – strong starting point

- Strong customer base with approx. **11,800** customers
- **1.1 m** tons of processed steel p.a.
- Approximately **EUR 14.2 bn** Sales in 2018
- More than **2,400** patents filed in 2018
- **73** plants
- **20** R&D centers
- **More than 170** locations in **50** countries
- Around **92,500** employees worldwide
- Far more than **10,000** different products

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1 Before one-off effects | 2 As at December 31, 2018
Agenda

1. Impressions
2. Base Ideas of S4eP
3. Vehicle Architecture
4. Technical Data
5. Project Goals
6. Difference to Competitors
7. Software AWD-TV
1 Impressions

Schaeffler 4ePerformance

VIDEO
Agenda

1 Impressions
2 Base Ideas of S4eP
3 Vehicle Architecture
4 Technical Data
5 Project Goals
6 Difference to Competitors
7 Software AWD-TV
1. **Formel E Technology Transfer**
   All four Motor-Generator-Units (MGUs) have been used for one complete season in our Formula E race cars. If we put our motorsport technology, Schaeffler components and our Know-how all together we have the ability to create a high performing supercar.

2. **Development Platform For All-Wheel-Drive Torque Vectoring Software**
   The drivetrain with its four individual powered wheels each connected to one MGU is the optimal architecture for wheel-individual drive torque distribution in order to improve driving dynamics and safety. The two horizontal degrees of freedom (yaw and longitudinal acceleration) are defined by four control actions; hence the optimization of secondary criteria like grip usage is possible.

3. **System Expertise In E-Mobility**
   The drivetrain with the Twin-Axle at the front and rear showcases motorsport applications, prototype potential and small series applications. With the concept car project the system expertise in electromobility gets in public focus and provides our pioneer spirit by convincing people of the mobility for tomorrow.
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3 Vehicle Architecture

**Drivetrain with four separate wheel driving engines and split battery**
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4 Technical Data

**Schaeffler 4ePerformance**

**Vehicle**

- Audi RS3 TCR platform (production chassis Audi A3)
- Maximum speed about 220 km/h
- Power to weight ratio about 1,5 kg/PS
- Total weight 1,850 kg (vo 50% / hi 50%)

- Max. power 880 kW (about 1,200 PS)
- Max. recuperation power 150 kW (about 204 PS)
- Max. torque 10,152 Nm at wheels

- Project owner and vehicle concept: Schaeffler AG
- Vehicle-Control-Unit: Schaeffler Engineering PROtroniC
- Software: Schaeffler Engineering / Schaeffler AG
4 Technical Data

**MGU**

- Max. power 220 kW
- Max. torque 320 Nm
- Max. rotation speed 13.700 U/min
- Voltage level 500-700 V DC
- Permanent-magnet synchronous machine
- SiC power electronics

- MGU used in Formula E season 2 race cars
- All engines used a whole season
- Technical base of Formula E Champion engines (3rd season)

- Efficiency of MGU including power electronic > 95%
- Weight of MGU including power electronic 25.5 kg

- Concept, design and manufacturing by Compact Dynamics GmbH (100% Schaeffler)
Gearbox

- Twin-Axle including two single speed gearboxes
- two step spur gear (straight toothed)
- Ratio $i = 7.93$
- Max. torque per wheel 2.538 Nm
- Weight per axle without MGUs ~54 kg (dry, without drive shafts)
- Casing of cast aluminum
- Dry sump lubrication
- Efficiency ~ 98 %

- Designed and manufactured by Schaeffler Engineering GmbH
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5. **Project Goals**
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Processes and flows

Usage Concept Car S4eP

Formel E Technology Transfer
Demonstration of the possibilities of Formula E motorsport technology for further applications

Prototypes And Small Series
Drivetrain containing electrical engines and gearbox for prototypes and small series applications.

Electrical Motorsport
Usage of motorsport technology in second life and further development for future motorsport applications.

All-Wheel-Drive Torque Vectoring
Development of all-wheel-drive torque vectoring software to improve driving dynamic and driving safety.

Development Platform
Showcase and demonstration of opportunities and possible upcoming development projects.

System Expertise Electromobility
Support of electromobility marketing activities by high performance motorsport applications.
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6 Difference to Competitors

Unique Selling Point Of The S4eP

Unique Selling Points

• High performance car based on series production chassis (no monocoque or special developed chassis).
• Use of four victorious Formula E engines of 2nd season
• Sustainable vehicle concept with very high power in conjunction with efficient powertrain and low energy consumption at full load.
• Drive unit with two motors and two gearboxes can be used for numerous prototypes or electric racing series or adapted for a specific application, thus providing a basis for near-series applications.
• Demonstration of original Formula E technology in a close-to-production vehicle with high driving dynamics, taking advantage of wheel-selective drives.
• Lap records on race tracks are no project goal.

Drivetrain

• Electric engines front left/right (Lucas di Grassi)
  – 3x 1st Place (Putrajaya, Paris, Long Beach)
  – 2x 2nd Place (Peking, Punta del Este)
  – 2x 3rd Place (Berlin, Buenos Aires)

• Electric engines rear left/right (Daniel Abt)
  – 2x 2nd Place (Berlin, London)
  – 1x 3rd Place (Long Beach)
### Technical Data High-Performance E-Cars

<table>
<thead>
<tr>
<th></th>
<th>Schaeffler 4ePerformance</th>
<th>NIO EP9</th>
<th>Rimac Concept One</th>
<th>Rimac C Two</th>
<th>Tesla P100D</th>
<th>Vanda Dendrobium</th>
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<tr>
<td><strong>Chassis</strong></td>
<td>Series</td>
<td>Monocoque</td>
<td>Monocoque</td>
<td>Monocoque</td>
<td>Serie</td>
<td>Monocoque</td>
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<tr>
<td><strong>Number of Engines</strong></td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
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<tr>
<td><strong>Overall Power (kW)</strong></td>
<td>880</td>
<td>1.000</td>
<td>900</td>
<td>1.408</td>
<td>515</td>
<td>1.120</td>
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<tr>
<td><strong>Battery (kWh)</strong></td>
<td>64</td>
<td>91</td>
<td>120</td>
<td>100</td>
<td>30-50</td>
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<tr>
<td><strong>Number of Gears</strong></td>
<td>1</td>
<td>1</td>
<td>1 (v) / 2 (h)</td>
<td>1 (v) / 2 (h)</td>
<td>1</td>
<td>P</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>1.850</td>
<td>1.735</td>
<td>1.900</td>
<td>1.950</td>
<td>2.200</td>
<td>1.750</td>
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<tr>
<td><strong>Weight/ Power ratio (kg/kW)</strong></td>
<td>2.10</td>
<td>1.73</td>
<td>2.11</td>
<td>1.38</td>
<td>4.27</td>
<td>1.56</td>
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<td><strong>0-100 km/h, 0-62 miles (s)</strong></td>
<td>2.7</td>
<td>2.7</td>
<td>2.5</td>
<td>1.9</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>0-200 km/h , 0-124 miles (s)</strong></td>
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<td>7.1</td>
<td>6.2</td>
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<tr>
<td><strong>Max. Speed (km/h)</strong></td>
<td>220</td>
<td>355</td>
<td>412</td>
<td>250</td>
<td>320</td>
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<tr>
<td><strong>Range (km)</strong></td>
<td>426</td>
<td>500 (NEDC)</td>
<td>650 (NEDC)</td>
<td>613 (NEDC)</td>
<td>&gt;600</td>
<td></td>
</tr>
</tbody>
</table>
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Overview

- Development of a modular vehicle dynamics control system for four individual wheel drives
- Drive mode dependent model-based target vehicle motion generation
  - Drive mode dependent yaw rate or side slip angle reference
  - Combined pre-control / control approach to achieve desired vehicle motion
  - Limitation of the generated target motion to physically achievable states by additional stabilization criteria
- Control allocation methodology to allow for mathematically optimal drive torque distribution under given constraints
  - Minimization of energy consumption
  - Maximization of driving safety / acceleration potential
- Development and application of various control strategies
- Platform for testing and evaluating the different concepts
- Description and maximum utilization of the vehicle's limit area
- Development in cooperation with Schaeffler Engineering

Schaeffler 4ePerformance

- Three horizontal degrees of freedom of movement vs. six possibilities of intervention (four motors close to the wheel, steering, brake)
- In addition to actively influencing longitudinal, transverse and yaw behavior, it is possible to implement secondary goals
Software Structure

- Pre-Control
  - Target Vehicle Movement
  - Different Drive Modes
  - Target Vehicle Motion

- Feed Forward
  - Driver Input

- Chassis Control
  - Wheel Forces, Tyre Potentials

- Driving Dynamics Control
  - Torque Allocation
    - Optimal Distribution
  - Vehicle Control
    - Yaw Rate
    - Vehicle Side Slip

- Wheel Slip Control
  - Wheel Torque
  - Wheel Speeds

- Vehicle
  - Actual Vehicle Behaviour
  - Vehicle Model for SiL/Hil

Determination of Driving Condition
- Situational Awareness
- Controller Coordination

Control Manager
Because yesterday we already thought of tomorrow!