E-DRIVE: HIGHLY INTEGRATED AND HIGH EFFICIENT

Korea EV Engineering & Testing Exhibition
KEY ASPECTS FOR BATTERY ELECTRIC VEHICLES (BEVs)

E-DRIVE: AFFORDABLE - FURTHER - FASTER

Cost
must be acceptable
(and is directly related to range)

Range
is the key item for EV success

Time
to re-charge a BEV must be short

Cost must be acceptable (and is directly related to range)
Range is the key item for EV success
Time to re-charge a BEV must be short

km ➔插头
KEY ASPECTS FOR BEVs

- Powertrain
- Environment
- Vehicle

RANGE

km →
### Reference vehicle

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Vehicle</td>
<td>C - Segment</td>
</tr>
<tr>
<td>Max. vehicle speed</td>
<td>230 km/h</td>
</tr>
<tr>
<td>Acceleration (0-100km/h)</td>
<td>&lt; 6 sec.</td>
</tr>
</tbody>
</table>
E-AXLE
THE KEY E-AXLE COMPONENTS

Maximization of BEV range @ affordable cost

Highly efficient
Highly integrated

Mechanically
Thermal
Electrically
Highly efficient
Highly integrated

High Efficiency Areas

Torque

PSM
ASM
SRM

Speed

PSM efficiency is at least as good as ASM & SRM

Highly efficient
Highly integrated

PSM is selected – power density and efficiency

<table>
<thead>
<tr>
<th></th>
<th>PSM</th>
<th>ASM</th>
<th>SRM</th>
</tr>
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<tbody>
<tr>
<td>Power density</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Overload capacity</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Max speed</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Dynamics</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Development cost</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Production cost</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Efficiency</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>NVH</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>System robustness</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Controllability</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
<tr>
<td>Reliability</td>
<td>☀⃝</td>
<td>☀⃝</td>
<td>☀⃝</td>
</tr>
</tbody>
</table>

Very good ☀⃝ Average ☀⃝ Very poor ☀⃝
E-MACHINE SPEED AND TORQUE SELECTION CRITERIA

Highly efficient
Highly integrated

Maximum speed:
Bearing and sealing's for standard automotive application up to 20.000 rpm for E-machines are feasible for upcoming designs.

→ 20.000 rpm is selected for the E-machine

➢ The max. rotor surface velocity defines the max. rotor diameter

➢ The max. torque/power is defined by the rotor length

➢ Power density very depending on cooling design

E-machine requirements base on vehicle targets

<p>| | |</p>
<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Max. torque</td>
<td>360Nm</td>
</tr>
<tr>
<td>Max. power</td>
<td>230kW</td>
</tr>
</tbody>
</table>
E-MACHINE COOLING AS ENABLER FOR POWER DENSITY

Highly efficient
Highly integrated

Better cooling higher power density

Better cooling \(\rightarrow\) higher power density / efficiency

1. End windings flooded with coolant (oil)
2. Additional heat transfer at slot openings
3. Additional cooling paths through the yoke
4. Sleeve in air gap to avoid drag losses of the rotor in the coolant (oil)

- Efficiency
- Cooling
- Enabler

Direct oil
Oil spray
WATER JACKET
FORCED AIR

AVL decided to implement direct cooling of stator and stator winding. Cooling at the source, actively cooling also winding heads. The sleeve design avoids any splash loss.
E-MACHINE
FINAL DESIGN

Highly efficient
Highly integrated

**E-machine key figures**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. speed</td>
<td>20,000 rpm</td>
</tr>
<tr>
<td>Diameter</td>
<td>Ø 220 mm</td>
</tr>
<tr>
<td>Power (const./peak)</td>
<td>150 kW/230 kW</td>
</tr>
<tr>
<td>Torque (const./peak)</td>
<td>240 Nm/360 Nm</td>
</tr>
<tr>
<td>Length</td>
<td>402 mm</td>
</tr>
<tr>
<td>Weight (active parts)*</td>
<td>&lt;45 kg</td>
</tr>
<tr>
<td>Power density</td>
<td>&gt;5.1 kW/kg</td>
</tr>
<tr>
<td>Torque density</td>
<td>&gt;8 Nm/kg</td>
</tr>
<tr>
<td>Efficiency (best point)</td>
<td>98%</td>
</tr>
</tbody>
</table>

* Saving up to 35% in weight compared to typical E-machine application
**TRANSMISSION TOPOLOGY SELECTION CRITERIA**

![Highly efficient](image)

Highly efficient

<table>
<thead>
<tr>
<th>Package</th>
<th>Lay shaft</th>
<th>Double planetary gear set</th>
<th>Planetary gear set with lay shaft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity</td>
<td>⚫</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Reliability</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Efficiency</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>NVH</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Cost</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Development effort</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Production capability</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Lubrication complexity</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
</tbody>
</table>

Lay shaft design selected → efficiency, ..
Target is to guarantee lubrication without additional pump:

High speed at input shaft major challenge!

- 3D CFD simulation mandatory in early development phase
- Design confirmation and validation over early plastic models
**TRANSMISSION FINAL DESIGN**

**Highly efficient**

**Highly integrated**

### Transmission key figures

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. speed input shaft E-machine*</td>
<td>20,000rpm</td>
</tr>
<tr>
<td>Max. torque input shaft E-machine</td>
<td>360Nm</td>
</tr>
<tr>
<td>Gear ratio</td>
<td>12</td>
</tr>
<tr>
<td>Weight (only transmission part)</td>
<td>36.5 kg</td>
</tr>
<tr>
<td>Lubrication type</td>
<td>passive</td>
</tr>
<tr>
<td>Cooling type</td>
<td>passive</td>
</tr>
<tr>
<td>Torque density</td>
<td>9.8 Nm/kg</td>
</tr>
<tr>
<td>Efficiency</td>
<td>97%</td>
</tr>
</tbody>
</table>

*Bearing / sealing = 1st gear on the rotor shaft
Checked with E-machine design and simulation
POWER INVERTER
OVERVIEW DEGREE OF INTEGRATION

Target: Maximization of Integration

→ Minimum package and weight, same housing, less connectors, less cables and pipes, less interfaces

→ Direct cooling of stator and power modules

→ Fully supports EMC requirements, less sources for radiation due to missing cables, etc.

Highly efficient
Highly integrated

Full integration selected
Design highlights:

- Shared housing and cooling with E-axle
- Supports all cooling concepts (oil, water or combined)
- Optimum arrangement of controller board and power modules / capacitor (low impedance)
- Compact arrangement of main components e.g. bus bar, ...
- Supports pretested subsystems (preassembled electronic as design requirement)
**POWER INVERTER FINAL DESIGN**

Highly efficient
Highly integrated

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### Power inverter key figures

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating voltage</td>
<td>800V</td>
</tr>
<tr>
<td>Max. current</td>
<td>450A&lt;sub&gt;ms&lt;/sub&gt;</td>
</tr>
<tr>
<td>Phases</td>
<td>3</td>
</tr>
<tr>
<td>Power inverter weight</td>
<td>5kg *</td>
</tr>
<tr>
<td>Power modules</td>
<td>IGBT *</td>
</tr>
<tr>
<td>Controller SW</td>
<td>FOC / variable frequency</td>
</tr>
</tbody>
</table>

**Special features:**
- Active short circuit
- Multicore
- Up to ASIL-D

* Further optimization by SiC technology not included
POWER INVERTER - OUTLOOK
NEW WIDE BAND GAP (SIC) TECHNOLOGY

Highly efficient
Highly integrated

SiC
Wide Band Gap

High Operation Temperature
higher power-density

200°C

Smaller Die-Size
size reduction of module

IGBT  DIODE  SiC

Lower Switching Losses
allows higher clocking

Reduction of DC-Link Capacitor
Reduction of EMC-filter structure

higher power
by same package

reimbursement of higher expenses on system-level

smaller package by same power

higher Drive Dynamic

High Operation Temperature
200°C

Highly integrated

Smaller Die-Size
size reduction of module

IGBT  DIODE  SiC

Lower Switching Losses
allows higher clocking

Reduction of DC-Link Capacitor
Reduction of EMC-filter structure

higher power
by same package

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higher Drive Dynamic
E-AXLE
EMC – THE CHALLENGE FOR THE FUTURE

Highly efficient
Highly integrated

Holistic EMC system development approach
EMC SIMULATION DURING DEVELOPMENT

Hybrid Filter:
Low frequency = active*
High frequency = passive

Integrated 3 Phase Filter

Integrated LV filter network

Shaft decoupling via Ferrite*

Highly integrated
Highly efficient

Appropriate measures to keep EMC under control!

*AVL Patent
EMC
SIC – INCREASING CHALLENGE

SiC technology opens system benefits while increasing the switching frequency from e.g. 10kHz to 50kHz

- EMC emission are drastically increasing compared to standard Si IGBT technology
- Precise filter design mandatory to overcome such problems and to stay within limits
E-AXLE
FINAL DESIGN

Highly efficient
Highly integrated

E-axle key figures

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>Power (cont./peak)</td>
<td>150kW/230kW</td>
</tr>
<tr>
<td>Torque (cont./peak)</td>
<td>240Nm/360Nm</td>
</tr>
<tr>
<td>Dimensions (lxwxh)</td>
<td>544x387x280</td>
</tr>
<tr>
<td>Weight overall (approx.)</td>
<td>&lt;100 kg</td>
</tr>
<tr>
<td>Power / weight total (peak)*</td>
<td>&gt;2,3 kW/kg</td>
</tr>
</tbody>
</table>

*approx. value
SUMMARY

Full integrated E-axle for best BEV range @ affordable cost

- PSM - high speed concept with 20,000 rpm
- Full integrated power inverter
- SiC - further potential for efficiency & integration
- Lay shaft with passive lubrication
- Full EMC optimized design
- High efficient oil stator cooling
- Full integrated power inverter
CHARGING THE BATTERY
ENABLER FOR SPEED & RANGE

Low / Medium Power

- "Always on" ➔ Whenever parked
- Effortless ➔ Inductive charging
- Cost efficient ➔ Simple devices

Standard Charging Method
if possible at home

Fast Charging / High Power

- "When in need" ➔ Mainly long dist.
- Highest power ➔ Dedicated devices
- Expensive ➔ Time is expensive

Necessary "Exception", a MUST
at premium price
mainly on highways
AVL CHARGING
CHARGING COMPETENCE

CUSTOMER REQUIREMENTS

• Quick charging of the fleet vehicle or machine in similar duration as Diesel refilling would take.
• Safe charging from different sources with the same fleet vehicle or machine worldwide.

AVL SOLUTION

• AVL development of charging systems and integration (AC/DC, CCS Powerline Communication) and fleet charging concepts
• AVL modular charging concept and software
• AVL Advanced high power charging competence up to 900V and 300kW
• AVL fast charging competence
• AVL DC Charging and Infrastructure interaction
• AVL on board charger system development up to 800 V

CUSTOMER BENEFITS

• Flexible adaption to specific customer charging system containing: on-board charger, off-board charger, connectors, battery interface, charging strategy and charging software.
• Improvement of charging speed and capacity.
• Individual integration of customer charging system in fully developed AVL charging solution.
AVL is cooperating with many research and development partners to build up an optimized solution for the Multi Range – Bidirectional Fast Charging station.

Nowadays EVs are not only a mobile transportation rather than a mobile energy storage. A bidirectional Charging Station supports the Grid Stability by refeeding some energy of EVs after the EVs Battery get 80% charged. This feature is an optional for the user, which offers him cost-effective charging and for the grid support for stability.
AVL CHARGING
800V COMBINED AC-DC CHARGING STATION

HIGHLIGHTS:

- Voltage level: 800 V (200V...1000V)
- Combination of DC and AC Charging
- Scalable power output: n * 32kW or n * 160 kW
- Advanced charging control, WiFi
- CCS communication protocol acc. IEC15118

→ To support development and fleet operation for high performance electric vehicles for ultrafast DC charging
MOTIVATION

- Research project to investigate high power AC charging without galvanic isolation (simulation, test bed, vehicle test)
- High power AC charging (> 44 kW(63 A AC)... 88 kW(125 A AC))
- Low weight due to reuse of traction inverter as charging devise
- Cost-efficient
- No galvanic isolation due to special handling of fault current

SYSTEM VEHICLE ARCHITECTURE
FAST CHARGING
LIMITED BY CHARGING INTERFACE

- Slow charging
- Fast Charging

800 V Vehicle systems and 1000 V Charging systems will come

Charge Power

- 350 kW
- 250 kW
- 150 kW
- 50 kW
- 44 kW
- 22 kW
- 11 kW
- 3.3 kW

- IC-CPD
- inductive Wallbox
- Type 2 32A IEC 61851
- Type 2 63A
- Combo 2 500V, 50kW IEC 15118 IEC 61851
- TESLA Super charger
- Combo 2 450V 350A
- Combo 2 800V 350A
- Combo 2 1000V 350A

*18 kWh/100km
THANK YOU