AVL E-DRIVE
SOLUTIONS AND TECHNOLOGY FOR LOW & HIGH VOLTAGE COMPONENTS

AVL Services
Technology Consulting
Design Optimization
Component Integration
DVP Testing
EMC Simulation
Benchmark
SOP Development
Prototyping A-Sample
Calibration
Component Validation

Electrified Engine Components
Micro & Mild Hybrid
Full Hybrid
Plug-In Hybrid
Range Extended
Pure Battery
Fuel Cell

BMS From Cell to Battery System
E-Motor From Laminate to Machine
48-1000V Inverter From Silicon to Power Electronics
DCDC converter
Charging

BCU
ON board
MCU
OFF board

AVL E-DRIVE SOLUTIONS AND TECHNOLOGY FOR LOW & HIGH VOLTAGE COMPONENTS
AVL E-DRIVE TECHNOLOGY TIMELINE

2010
1st Gen DIYLE – Combined Motor & Inverter incl. Software

2012
Re-design 2nd Gen PI 800 incl. Software 800V/150kW

2014
1st Gen PI 450 450V/150kW

2015
6-phase Hub Inverter 450V/85 kW

2016
3rd Gen PI 850 Incl. Software-Update 800V/200kW

2017
4th Gen PI850e 800V/250kW

2011
2nd Gen PI 800 – stand alone Inverter incl. Software 150kW

2013
Torque-Vectoring Inverter 450V/10kW

2014
48V Powerstage 48V/18kW

2016
Air cooled Inverter 48V/12kW
AVL E-DRIVE
DEVELOPMENT OF E-DRIVE SYSTEM

Target system requirements for performance and fuel economy of vehicle are given

E-motor development tasks:
• Selection of technology and topology
• Performance and efficiency simulations
• Thermal behavior
• Mechanical design
• Electromagnetic design

Power inverter development tasks:
• Concept and topology definition
• Inverter loss and efficiency simulations

E-Drive System Efficiency Calculation
E-Machine & Inverter Design
AVL E-Drive E-Machine Design
E-MOTOR DESIGN
DEVELOPMENT LOOP

- Performance, Efficiency
- Saturation, Back-EMF, Demagnetization
- Harmonics content
- Cogging torque, Torque ripple
- Short circuit
- Losses
- Cooling
- Hotspots
- Drive cycle
- Package
- Structural strength
- Reliability, Robustness
- Design to Manufacturing
- Design to Cost
- Flow rate
- Flow resistance in cooling circuit
- Minimization of flow stagnation regions
- Evaluation of heat flux into the coolant
- Torque ripple, Forces in air gap
- Natural frequencies
- Rattling, hammering in driveline
- Tonal noise from e-motor

During one development phase AVL will calculate and simulate all critical features of an e-motor in Frontloading reducing by this the effort in hardware development and prototype testing in later development and also shortening this verification and validation phases.
E-MOTOR DESIGN
ELECTROMAGNETIC DESIGN – SIZING OF THE E-MOTOR

E-motor parameter study to reach required extreme operating points within the boundaries conditions of electrical supply, cooling and packaging

Specify:
- outer diameters of stator,
- inner diameter of rotor
- active iron length,
- lamination design

→ input for CAD design

The first step is the initial sizing of the e-motor.

Based on the most critical operation points: peak torque, maximum power and maximum speed AVL will specify the outer dimension of the active parts giving the basis of the packaging study and ensuring that this required extreme operation points are covered within the constraints.
E-MOTOR DESIGN
AVL TOOLCHAIN – THERMAL DESIGN  CFD – TOOLS AND TASKS

TOOLS:
AVL FIRE, FLOWMASTER

CFD / FEM
Detailed thermal design

CAD model
Velocity distribution
Pressure drop
Heat transfer coefficient (HTC) distribution
Temperature distribution

TASK:
- Loss input
- Cooling layout and boundaries
- Velocity distribution
- Pressure drop
- Calculation of Heat Transfer Coefficient
- Adjusting of analytical thermal resistances
- Temperature distribution
E-MOTOR DESIGN
AVL TOOLCHAIN – MECHANICAL DESIGN – TOOLS AND TASKS

TASK:
- 3D CAD
- Package
- Structural strength
- Reliability, Robustness
- Design to Manufacturing
- Design to Cost

TOOLS: AVL EXCITE, PRO E, MECHANICA

CAD and FEM based mechanical design

- Mechanical design
- Structural simulation → Strength
- Packaging
E-MOTOR DESIGN
AVL TOOLCHAIN – NVH – TOOLS AND TASKS

TASK:
- Modal analysis of e-motor and housing
- Mapping of forces in airgap to stator
- Torque and torque ripple to driveline
- Multibody dynamic simulation
- Noise

CAD and FEM based mechanical design

TOOLS:
- AVL EXCITE
- NASTRAN
- ABAQUS
- FEMFAT

Modal Analysis
Mapping forces to stator
Mechanical excitation and tonal noise
AVL E-Drive Power Electronics Design
AVL E-DRIVE
INVERTER AND POWER MODULE CHARACTERIZATION

- Simulation of Power modules
  - spice-modelling of high-current structures and the parasitic elements based on the mechanical shape and material properties.

- S-Parameter Measurements
  - Characterisation of IGBT-Modules by measurement of the S-parameters (scattering-matrix).
  - Enhancement of manufacturer-models by real measured data
  - Identification of module parasitic parameters
Double-Pulse Investigation of Power Modules
- Analysis of switching behavior by double-pulse tests in the laboratory
- Analysis of ringing-and overshoot behavior
- Test at maximum current and voltage can be carried out

Full Performance analysis of power modules & inverter modules
AVL E-DRIVE
INVERTER POWER MODULE SIMULATION

- Spice simulation of the entire Inverter Power-Stage
- Considering inductive and capacitiv parasitics
- Specific analysis by detailed sub-models
- conductive-and switching loss analysis
- semiconductor-models enhanced by real device measurement
- large model data base available
AVL E-Drive EMC Simulation and Functional safety
AVL E-DRIVE
EMC SIMULATION APPROACH

- Analog Simulation (circuitry diagram based)
  - Functional / thermal analysis
  - EMC analysis
  - Audible noise detection

- 2D/3D Simulation (CAD data based)
  - Analysis of U/I distribution in f/t domain
  - Analysis of E-field/H-field distribution
  - Various coupling analysis

- Augmented Simulation (combined analog & 3D)
  - Analysis of complex scenarios
  - Virtual assessment of radiated emission
  - Virtual assessment of ESD/pulse impact
What we need...

- Schematic diagram
- BOM, datasheets & real sample of single key component

What you get...

- Simulation result of Conducted Emission by "virtual" measurement long before sample built

What you save...

- Simulation result vs. real measurement result → saves time

- Only schematic diagram and eventually samples of unknown components needed
- Complete sample available with similar EMC behavior → months later
Identification of possible noise sources at component level (L, C, silicon)
- Add functional, physical, electrical effects and frequency behavior
- Perform virtual noise measurement of occurring frequencies and amplitudes
AVL E-DRIVE
FUNCTIONAL SAFETY DEVELOPMENT

PRODUCT DEVELOPMENT LIFECYCLE

FS - Project Management and Supporting activities

- Item Definition
  - H&R
    - Functional Safety Concept
    - Safety Requirement Specification
  - Technical Safety Concept
    - SW development
    - HW development
    - Integration
  - V&V
    - Release, Safety Case

Concept
System development
AVL E-DRIVE
TECHNOLOGY TRENDS

Integration
- Trend to full integrated E-Drive Systems & E-Axle development

New Material Technologies
- Trend SiC-Semiconductors: Increase switching frequency & reduce losses

Multiphase
- Increase of Motor Phases to 6 or more for increasing robustness to failure

High Speed & Torque
- Huge variety of E-Motors for all types of application

Voltage
- Higher Voltage Levels (up to 850 V) reduce package weight, costs & enables fast charge capability
AVL E-DRIVE
E-AXLE PROTOTYPE

Highlights
- Full integrated power inverter
- High efficient oil stator cooling
- Lay shaft with passive lubrication
- PSM – high speed concept with 20,000 rpm
- EMC optimized

Technical Specifications
- Operating Voltage: 800 V
- Power (cont./peak): 150 kW / 230 kW
- Torque (cont./peak): 240 Nm / 360 Nm
- Dimensions: 544 x 387 x 280 mm
- Weight overall (approx.): < 100 kg
- Power to weight ratio: > 2.3 kW/kg
- Cooling: Oil, water or combined
AVL E-DRIVE
E-AXLE FOR TRUCKS AND BUSES

AVL Contribution
- AVL high performance PMS motor with direct oil-cooling of windings
- high speed transmission
- fully integrated power electronics
- e-machine and transmission controls
- AVL system integration (functional, electrical, thermal)

Highlights
- Fully integrated electric axe (e-motor, inverter, transmission, differential, cooling, lubrication)
- Same fluid (oil) for cooling and lubrication
- Minimized number of connectors / interfaces: DC high voltage, controls and oil
- Transmission control integrated on power electronics

Technical Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Voltage</td>
<td>800 V</td>
</tr>
<tr>
<td>Power (cont./peak)</td>
<td>150 kW / 250 kW</td>
</tr>
<tr>
<td>Torque output</td>
<td>13.200 Nm</td>
</tr>
<tr>
<td>Cooling concept</td>
<td>Oil, water or combined</td>
</tr>
</tbody>
</table>
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