AVL e-Drive

Air cooled Power electronic design

PDiM 2018 Sweden - Göteborg

F. Haag, S. Pruefling
AVL e-Drive
Development services and competences for advanced e-Drives

- Concepts
- Components
- Hardware
- Software
- Integration
- Benchmarking
- Technology consulting
- Industrialization support
- SOP development

Full solution offering from concept, components to fully integrated E-Drive systems
AVL e-Drive
How to select a cooling system for power electronics?

Module choice

Electrical design

Thermal design

Module choice

Topology

\( V_{CES} , I_{max} \)

Thermal management system

Cooling system

\( T_{j,max} , \Delta T_{max} \)

Requirements & Load profile

- Ambient air
- HTCs
- Vehicle parameters
- ...

Cooling of power electronics is a system topic

Source: Infineon
AVL e-Drive
Cooling solutions for power electronics in today’s use

Natural and forced convection air cooled head sinks

Jet impingement and direct contact liquid cooling of module base plates or DBC substrates

Single and double sided cooling with liquid cold plates

Two-phase liquid cold plates with boiling of dielectric refrigerant coolant

Micro-channel liquid coolers built into power module base plates or integrated with the DBC substrate
Natural or forced air cooling has several benefits such as...

- Lower system complexity by removing of water pumps, pipes, interfaces, etc.
- Cost benefit and reduction on system level
- No leakage compared to liquid cooling possible
- Good integration possibilities especially in (P)HEVs because of no interfacing of existing cooling system necessary

Today's vehicles are indirect air cooled (heat exchanger)

High potential of air cooling for lower system complexity and cost reduction
AVL e-Drive
What package of semiconductors for air cooling?

IPU Cooling Interface
@ WATER- and AIR-COOLING

IPU optimized for local interface to heatsink (water-cooler)

Discrete Semiconductors
@ AIR-COOLING application

discrete components to distributed thermal losses homogenously

Especially for air cooling discrete semiconductors supports better equal heat distribution
AVL e-Drive
Design options for power electronic boards for air cooling

Typical thermal connection

Alternative thermal connection

Thermal design also effects the PCB design and layout

Integration of busbars possible → cooling of busbars
What type of semiconductor technology? Advantages of SiC for air cooling

Visualization of conductive losses shows that SiC technology has big advantage especially in low and medium load area.

At a switching frequency similar to current IGBT inverter applications a SiC Converter shows:

- Lower losses -> less internal temperature increase **AND**
- Better thermal conductivity
- Accepts higher junction temperature up to 200°C

SiC has better thermal properties and therefore big advantages for air cooled applications.
AVL e-Drive

Air cooling example: 800V SiC Inverter for auxiliary applications

- Development of 800V SiC inverter for auxiliary components like e-charger, e-compressor
- Design to Cost
- Separated Control and Powerboard for better EMC-characteristics

**Key specifications**
- No. of phases: 3
- $V_{DC}$: 485-920V
- $V_{nom}$: 800V
- $P_{out, max}$: 22kW
- $I_{nom}$: 15A$_{rms}$
AVL e-Drive
Semiconductor loss calculation

- Loss simulation based on critical load points
- Mosfet model from supplier for simulation

Inverter conductive losses are defined as:

\[ P_{\text{loss,conductive}} = I^2 R_{DSon} + 2 \left( \frac{I}{2} \right)^2 R_{DSon} \]

Inverter switching losses are defined as:

\[ P_{\text{loss,switching}} = 6 f_{PWM} (E_{on} + E_{off}) \]

Total losses of Inverter:

\[ P_{\text{loss,total}} = I^2 R_{DSon} + 2 \left( \frac{I}{2} \right)^2 R_{DSon} + 6 f_{PWM} (E_{on} + E_{off}) \]

Mean value of losses per Mosfet:

\[ P_{\text{loss,Mosfet}} = \frac{1}{2} I^2 R_{DSon} + f_{PWM} (E_{on} + E_{off}) \]
AVL e-Drive
Thermal model of inverter

- Heat transfer coefficient of the housing: $HTC = 10 \frac{W}{m^2K}$ (free convection)
- Ambient temperature: $T_{ambient} = 20°C$
- Gappad (Kerafol U90 s=0,2mm): $d = 0.2mm, k = 6 \frac{W}{mK}$
- Housing (AlMg4.5Mn0.7 EN AW – 5083): $k = 125 \frac{W}{mK}$
- $R_{mosfet}$: 0.55 °C/W (junction-case resistance)

Gappad between Mosfet and housing is modelled as heat resistance

Heat transfer coefficient of the housing: $HTC = 10 \frac{W}{m^2K}$ (free convection)

- Ambient temperature: $T_{ambient} = 20°C$
- Gappad (Kerafol U90 s=0,2mm): $d = 0.2mm, k = 6 \frac{W}{mK}$
- Housing (AlMg4.5Mn0.7 EN AW – 5083): $k = 125 \frac{W}{mK}$
- $R_{mosfet}$: 0.55 °C/W (junction-case resistance)
AVL e-Drive
Results of the thermal simulation

- Max. power at 200°C junction temperature is 26.4kW based on the numerical simulation
- The Mosfet´s have a power losses of 270W
- Max. surface temperature of Gappad is 176 °C.
AVL e-Drive
Results of the thermal simulation and influence of module power

- Max. temperature at the Gappad is **79 °C and 138 °C** for **10 and 20 kW** module power
- The corresponding junction temperature is **88.2 °C at 10 kW** and **156 °C at 20 kW**
- The average surface temperature is for **10 and 20 kW** module power a surface temperature of **76 °C and 131 °C**.

For the planned operating performances, the power module is at a safe distance from its max. allowed limit temperature.
Investigation of different HTCs:
10 W/m²-K (free convection) 26.4 kW
50 W/m²-K (low air flow) 56.1 kW
150 W/m²-K (High air flow) 72.8 kW

Erhaltene Equations for module power and max. temperature of gappad:
\[ P_{\text{Module}} = 13.541 \cdot HTC^{0.341} \]
\[ T_{\text{Max}_if} = 222.841 \cdot HTC^{-0.103} \]

The air flow has the biggest impact for the max. possible power of the inverter
AVL e-Drive
Air cooled Example: 48V Crosscharger

- For the ideal vorticity (turbulent air flow) of the air the housing is designed as “pin fin”
- 4 parallel Mosfets per single switch
Thank You

www.avl.com