

System Integrated Drive for Hybrid Traction in Automotive

The integration of the power electronic inverter with an electrical machine in the automotive powertrain is in the focus of the ECPE automotive Demonstrator Programme where the existing cooling circuit from the internal combustion engine is also used for the direct liquid cooling of the power electronics. The mechatronic integration of motor and power electronics leads to an ultra-high power density of 75kVA/l for the inverter. The high temperature of the cooling medium of up to 115°C in combination with this high power density poses a unique challenge. **Martin März, Fraunhofer Institute of Integrated Systems and Device Technology (IISB), Erlangen, Germany**

An optimised thermal design is necessary to master this thermal challenge. All temperature-sensitive components, passives and semiconductors, have to be thermally connected to the cooling system which provides a sufficient cooling capacity although working on a very high temperature level. On the module level, the optimised thermal design has to provide a homogeneous distribution of the chip temperature of the power semiconductors.

Towards an integrated inverter drive

For the latest generation hybrid drive there was a strong request for a solution that completely fits into the existing drive train of a passenger car. The clutch-box was designated as the housing, in which an electrical drive unit with a mechanical output power of 50kW and a maximum torque of 220Nm had to be integrated together with the complete inverter. But the conical, tuba-shaped housing with internal studs and ribs considerably complicated the integration challenges.

The basic internal arrangement of the components is shown in Figure 1. A permanent magnet excited synchronous machine (PM machine) provides a very high power density and a high efficiency even in the low speed range. By using a whole-coiled winding (single teeth coils), the winding overhang could be greatly reduced, resulting in an increased active motor length. The torque disadvantage, caused by the conical housing and the thereby restricted motor diameter, could be equalized this way. The electrical circuitry of the motor windings corresponds to that of a classical three-phase machine. Thus, only three power interconnections between motor and



Figure 1: Electric drive with the power electronics, both integrated into the clutch-box screwed at the gear-box

inverter are necessary. Multifunctional winding interconnections prevent a heat transfer out of the hot windings into the power electronics.

In order to achieve an optimum usage of the available package volume, a ring-shaped DC-link capacitor has been developed in cooperation with EPCOS AG. This capacitor provides a capacitance of 500µF (450V). Its concentric, nearly coaxial terminals form the DC-link bus-bar and allows for a very low parasitic DC-link. The ripple current rating of this capacitor is several hundred amperes and thus far beyond the actual ripple current load. The self-heating, caused by the inverter ripple current, is therefore negligible. However, in order to protect the capacitor against the high ambient temperature of up to 140°C, it is thermally coupled to the cooling jacket.

Thermally stressed power modules

As can be seen from Figure 2, three half-bridge power modules are placed at the periphery of the water cooling jacket that surrounds the whole electric machine. The remaining sections at the periphery are used for the control board, the current sensors and the EMC filter. Since the system is also intended as a test platform for different power module designs, special attention has been put on a modular and assembly friendly construction.

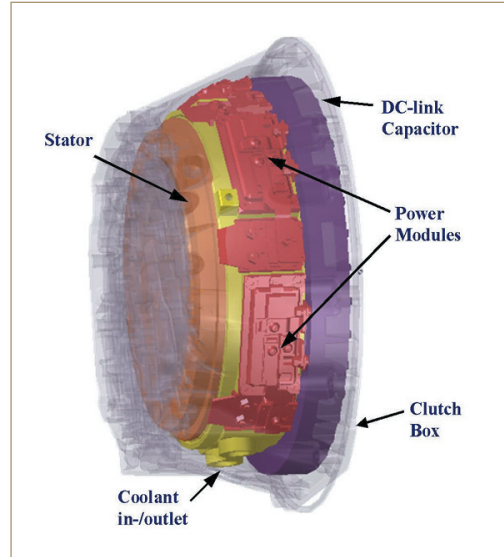
Special attention has been paid to an optimised thermal design of the power modules. The inverter drive is inserted in the existing coolant cycle of the ICE. The available coolant flow is about 8 litre/min and the maximum allowable total pressure drop 200mbar. An optimisation of the back-side structure of the modules

is necessary in order to minimise the thermal resistance between the power semiconductors and the coolant, but not to exceed the maximum allowable coolant pressure drop. The cooling efficiency of a finger-structure varies with its geometry - namely the finger thickness, shape, height and surface roughness - as well as the spacing and arrangement of the fingers. An important issue in this context is that the parameters of the coolant, especially the viscosity of the water-glycol mixture, greatly vary along with the temperature.

The realised power modules showed a specific thermal resistance junction-coolant ($R_{th,jc}$) of 0,45Kcm²/W at a coolant flow rate of 8 litre/min and a pressure drop of 60mbar, both of which were close to the predictions from simulation. With respect to the coolant flow, the three power modules are connected in series, thus the specification of a total pressure drop of 200 mbar was achieved.

The prototype was built on a machined Cu base plate. This, of course, is no solution for series production, partly because of cost issues, but mainly because of reliability issues of the DCB to base-plate solder joint. Due to the passive temperature cycles to be sustained (approximately 11.000 cycles with a mean temperature swing of 100K), an

Figure 2: X-ray view on the second generation inverter drive (50kW), integrated into the clutch-box



ALSiC base plate could be a choice to reduce the thermal mismatch between base-plate and DCB substrate to an acceptable low level at a small expense of thermal efficiency.

Outlook

Simultaneous engineering (electrical, mechanical, thermal) is an imperative prerequisite for a mechatronic integration of power electronics. Consistently following this way, an inverter drive for

hybrid traction could be integrated into the clutch-box of a passenger car, i.e. in an environment and package volume that had been considered as absolutely useless for high power electronics so far. 3D integration, new components and sophisticated thermal management solutions opened the way to a system with unique power density. The next steps aim on a further optimisation of the system reliability, manufacturability, and modularity.