ShowerPower®
Turbulator keeps
IGBTs Cool

FloEFD™ Efficiently Cools IGBT Power Modules

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The ShowerPower® liquid cooling heat exchange turbulator (Figure 1) was designed in 2005 by Danfoss GmbH engineers to efficiently cool IGBT power modules. The driver at the time was the fact that every electronic circuit generates heat during normal operation (except perhaps for superconductivity scenarios which are rare in industrial situations).

This heat generation is due to conductive and switching losses in active devices as well as ohmic losses in conductor tracks. And since every new generation of power semiconductors becomes smaller than the preceding one, and the market expects smaller and more compact solutions, the demands to be met by the thermal design engineer kept growing. Sufficient cooling of power electronics is therefore crucial for good operational performance. The dominant failure mechanisms in power semiconductor components are related not only to high absolute temperatures but to changes in temperature during cycling; temperature swings produce thermo-mechanically induced stresses and strains in the material interfaces of the components (that have mismatches in coefficients of thermal expansion) which in turn lead to fatigue failures.

Liquid cooling of power electronics has been around for many years, primarily because of the ever-increasing power densities demanded, and due to the availability of liquids in certain applications. Liquid cooling outperforms air cooling by producing heat transfer coefficients several orders of magnitude higher, thus enabling much higher power densities and more compact module and inverter solutions. The acceptance of liquid cooling varies from business segment to business segment. The automotive industry for example has been using liquid cooling for internal combustion engines for more than a century, so the idea of liquid cooling of power electronics in an automotive application is considered a non-issue. In other industries the idea of having fluids flowing through power electronic assemblies often finds resistance and concerns. The term "turbulator" for the ShowerPower is a little misleading: under normal flow conditions, liquid flow in the flow channels
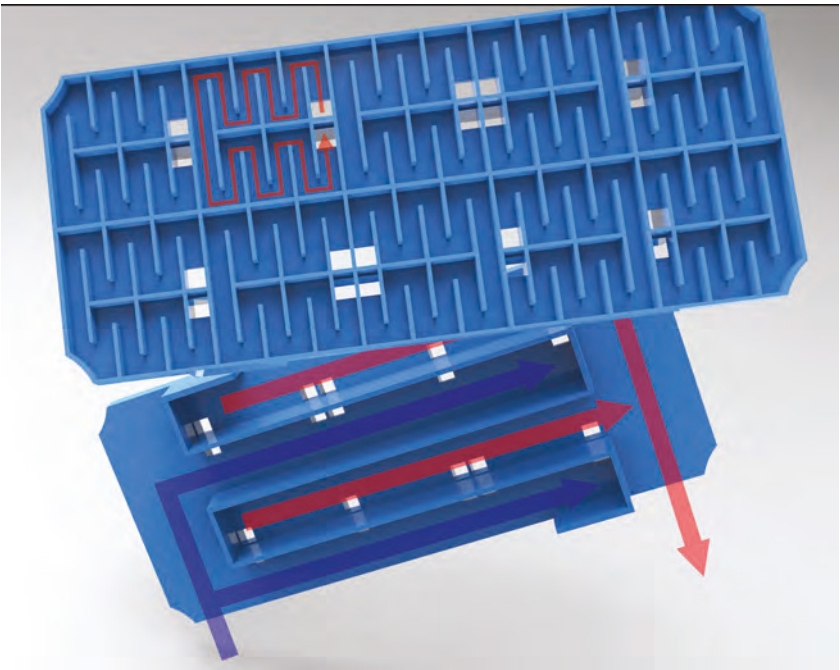

Figure 1. The general Danfoss ShowerPower® turbulator concept (cooling liquid in blue; warmed up liquid in red)
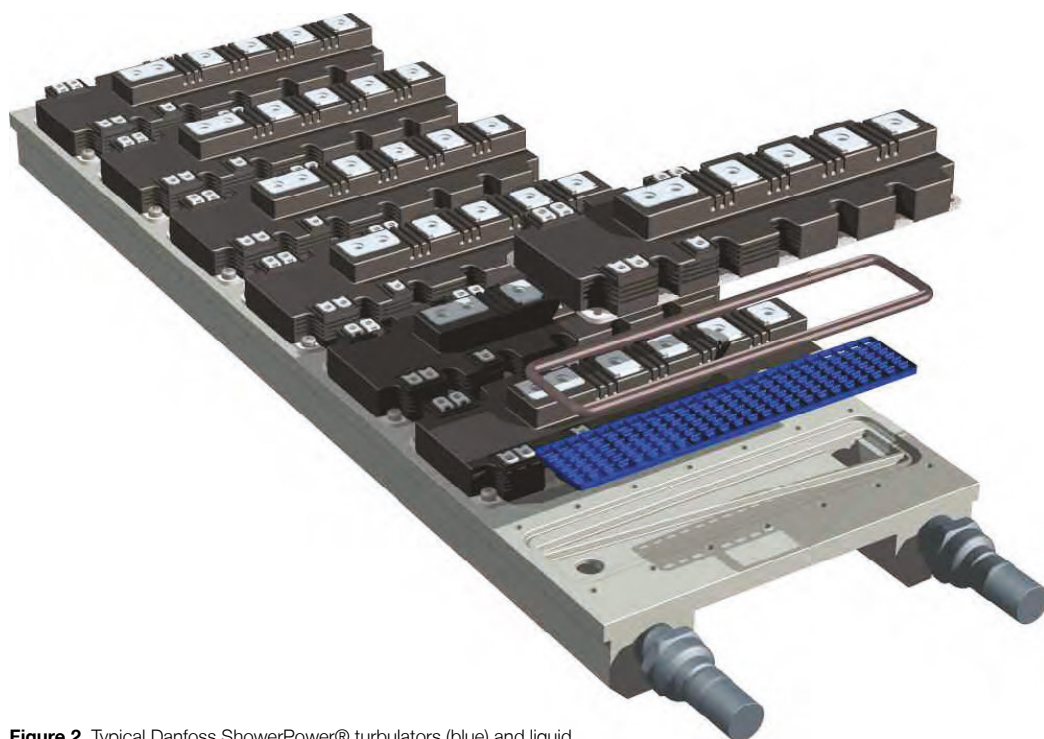
Figure 2. Typical Danfoss ShowerPower® turbulators (blue) and liquid cooling base plate for seven P3 power electronics modules in parallel

is laminar; typical Reynolds numbers range around 500 and the transition into the turbulence regime occurs at a Reynolds number around 2,400.

Liquid cooling solutions may be divided into two groups - indirect and direct liquid cooling. Indirect cooling means that the power module is assembled on a closed cooler, e.g. a cold plate. Cold plates may be manufactured by for example gun drilling holes in aluminum plates or by pressed-in copper tubes in aluminum extrusions. When dealing with cold plates it is necessary to apply a layer of TIM (Thermal Interface Material) between the power module and the cold plate. Direct liquid cooling on the other hand means that the coolant is in direct contact with the surface to be cooled. Here the cooling efficiency is improved by increasing the surface area and this is commonly done by various pin fin designs. Direct liquid cooling (Figure 2) eliminates the otherwise required layer of TIM. Because the TIM layer accounts for 30%-50% of the Rth, junction-coolant, this TIM-elimination results in an improved thermal environment for the power module. Since dominant failure mechanisms are temperature-driven, this will lead to higher reliability of the power module.

The ShowerPower cooler assembly in Figure 2 is for a wind turbine application featuring seven P3 IGBT modules, turbulators, sealings and a manifold. The design ensures that all chips in all modules are cooled

equally efficiently. The concept enables tailored cooling if hot spots need extra attention; this is simply done by designing the cooling channels individually.
For further information on the principles of ShowerPower please refer to References 1 and 2. The general ShowerPower plastic part (in blue) has several cooling cells in the X and Y directions and needs a manifold structure on the backside of the plastic part; this ensures that each cooling cell receives water at the same temperature. Since the P3 module is relatively long and narrow only one cell is necessary across the module; this makes the plastic part much simpler since the manifold structure on the backside becomes obsolete.

Overall, the ShowerPower concept has several inherent benefits:

1. The ability to homogeneously cool large flat baseplate power modules, and systems of modules, thereby eliminating temperature gradients thus improving life and facilitating paralleling of many power chips;
2. Eliminating the need for TIM - No TIM-related pump-out and dry-out effects;
3. A very low differential pressure drop,
4. Compact, low weight, high degree of design freedom enabling 3D designs; and
5. Low manufacturing costs: metal-to-plastic conversion into simple plastic
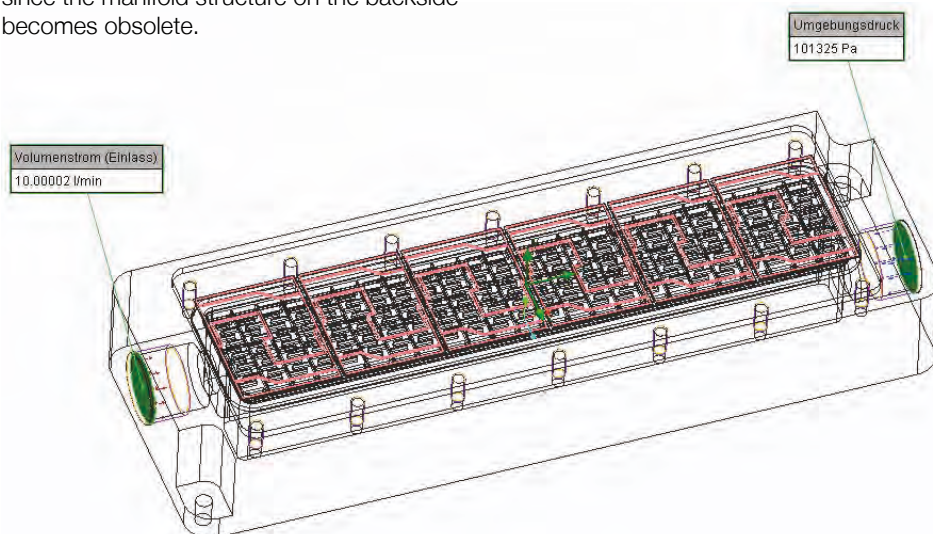

Figure 3. Typical Danfoss ShowerPower® liquid cooling CFD simulation of a Power Module geometry inside FloEFD for Creo
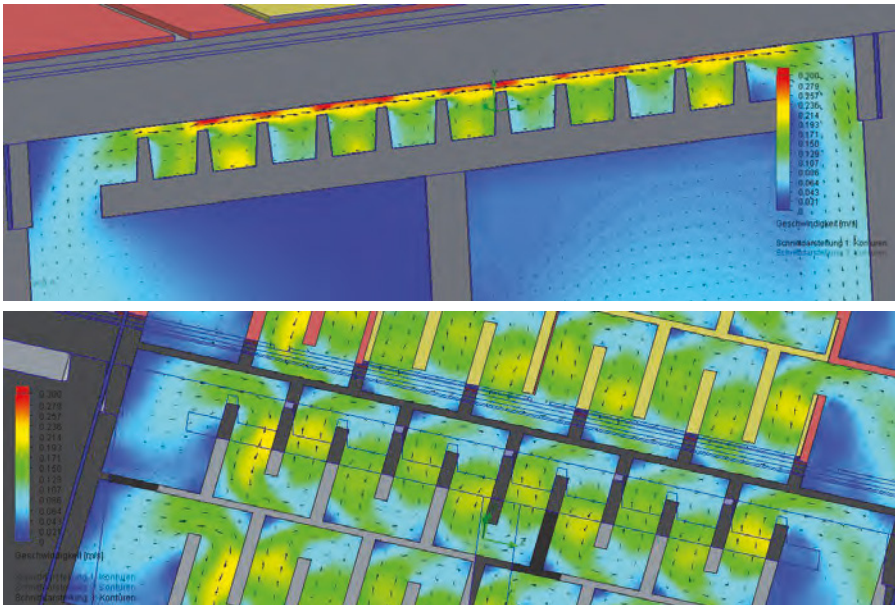
Figure 4. Typical Danfoss ShowerPower® liquid cooling CFD simulation of a Power Module geometry showing sectional views of flow vectors and velocity magnitude contours.

parts.

Numerous CFD simulations and test measurements have been done over the years on various Danfoss ShowerPower designs to validate the concept and to extend it to niche and custom applications. Engineering simulations, (thermal, fluid, mechanical, stress, vibrational etc.) are a crucial part in any Power Module product development project, the obvious reason being, to reduce the number of time-consuming and costly experimental tests necessary. Computational Fluid Dynamics, CFD, is the best way to simulate a ShowerPower liquid cooling system. CFD will predict fluid flow so that the correct heat transfer rates and pressure drop conditions are found and thus the relevant temperatures, e.g. semiconductor junction temperatures are calculated and maintained.

When designing a liquid cooled system in the FloEFD for Creo CFD package (Figure 3) we consider several issues in order to ensure a reliable solution that is capable of delivering the performance needed over the required lifetime of the system. We also consider other factors such as corrosion, "tightness", sedimentation (including bio growth) and anti-freezing issues for instance. The permutations in the turbulator geometry are quite large:
• Width of channel;
• Depth of channel;
• Height of bypass;
• Amount of channels per meander; and
• Channel cross section area to avoid the risk of blockage.

Figure 4 illustrates such a CFD prediction for a typical ShowerPower application.
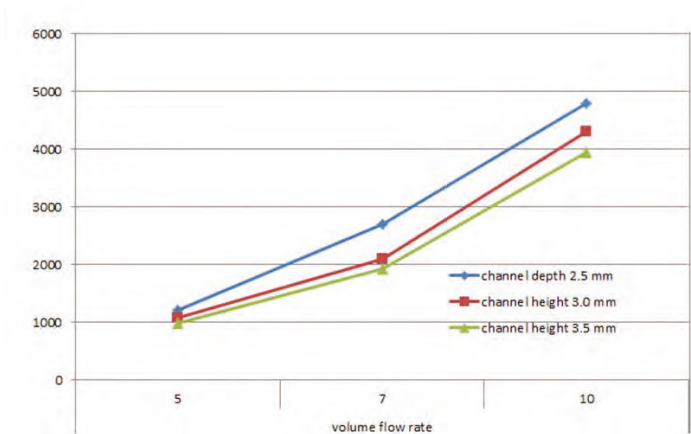With FloEFD we can easily create several

different simulation cases to allow the design engineer to make optimization judgements. Finding the best design out of many CFD cases is supported by effective parametric results comparison in the software. We are able to look at many different channel dimensions for a range of flowrates (Figure 5). FloEFD ultimately gives us predictions of the surface temperatures on the IGBT/ShowerPower system before we iterate to a final prototype and build and

test it (Figure 6).

Figure 5. FloEFD Pressure drop curves for different volume flow rates in the ShowerPower®

References:

1. K. Olesen et al.,"ShowerPower® New Cooling Concept", PCIM Conference Proceedings 2004, Nuremberg.
2. K. Olesen et al., "Designing for reliability, liquid cooled power stack for the wind industry", EWEA Conference Proceedings, Copenhagen, Denmark, 2012.
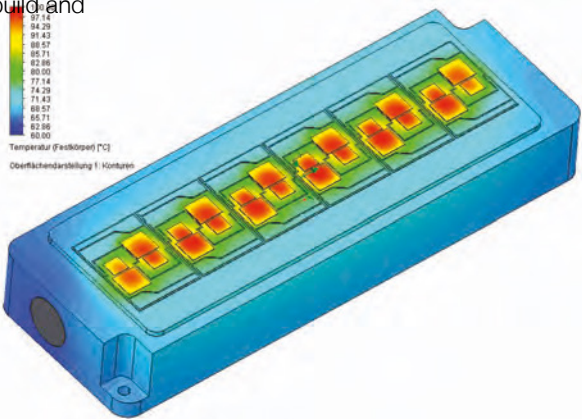
Figure 6. CFD temperature surface plot on a Danfoss Power module with an operating ShowerPower®