An efficient method to calculate the temperature distribution in the stator of an electrical machine using OpenFOAM

Nicolas Brossardt, Steffen Jahnke

BMW Group, 80788 München, 089 382 52341, Nicolas.Brossardt@bmw.de

The electrification of the automotive power train requires electrical machines with high energy densities. Only in this way it can be ensured that the requirements of future hybrid vehicles or electrical cars such as gross vehicle weight, package dimensions and capability of the engine will be met. Despite the high effectiveness of the deployed engines the necessary energy density leads to a significant power loss in the components of the electrical machine and heats up the system during operation. To avoid an overheating of the sensitive parts a suitable cooling system must be implemented.

State of the art cooling systems use the conduction in the solid components of the machine to transport heat into the surrounding cooling jacket. With the heat sink being outside the stator and high thermal resistances occurring inside the complex geometry the temperature distribution is strongly nonuniform. While the center of the stator is relatively cool, the temperatures in the end windings get close to the thermal limit of the used materials. To avoid damage, the overall power of the engine must be reduced. Hence, the effect of high temperatures in the end windings and the nonuniformity of the temperature field are directly related to the maximum capability of the electrical machine.

Especially in future machines with even higher energy densities, cooling systems that use nothing but conduction in their components will not be sufficient. Suitable cooling concepts must rather include additional mechanisms such as convection at the end winding surface to achieve a uniform temperature distribution and lower the overall temperature level. The development of these new approaches in electrical machine cooling, is strongly driven by simulation methods that allow an efficient and reliable prediction of the occurring temperatures in every solid of the machine. Current simulation models focus on either strong simplifications of the geometry and physics or are extremely detailed. When using the simple models the thermal conductivity in the end windings will be assumed to be uniform. Consequently the temperature distribution inside the end windings and thus the convectional heat transfer to the environment is subject to errors. The detailed approaches however imply a big manual effort for each setup, as the wires of the winding are individually modelled. For the application during the early stage of development both simulation methods are hence not suitable.

An adapted method to simulate the temperature distribution in electrical machines must instead be able to respect the strongly anisotropic character of heat conduction inside the windings without the need to model each single wire. This is achieved by the substitution of the windings with a composite that has anisotropic properties of thermal conductivity. Moreover the anisotropic character inside the composite is simplified by sections of constant anisotropic conductivity. The implementation of the method is primarily done in OpenFOAM, as the open structure of the code offers a powerful framework to generate an adapted solver for conjugate heat transfer in electrical machines. To achieve an independence in terms of simulation tools however, the approach is also implemented in ANSYS FLUENT. Simulations are conducted for an exemplary electrical machine with both tools. The results are evaluated and eventually compared with the results of the detailed modelling approach. In order to show the superior performance of the developed modelling method, a benchmark is performed and calculating times are compared.