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Thermal design of power transformers via CFD

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1 Introduction

The life time of power transformers is substantially influenced by chemical degradation in the electrical insulation. Since the speed of degradation depends on temperature, the prediction of component temperatures during transformer operation is a crucial part of the design process. There are several heat sources in transformers. If a time varying voltage is applied, in the core, magnetic hysteresis effects and eddy currents lead to no-load losses. In addition, during normal operation the electrical currents cause Ohmic and stray load losses. To keep the temperatures within acceptable limits, cooling is essential. It is normally accomplished via natural or forced convection of air or oil.

At Siemens, an in-house CFD (Computational Fluid Dynamics) code UniFlow is used to investigate fluid flow and heat transfer in oil-immersed and dry-type transformers, as well as components like windings, cores, tank walls, and radiators. This abstract sketches its physical models and numerical solution methods. Moreover, it shows an application to a winding in a locomotive transformer.

2 Physical models and numerical methods

Our physical model simulates flows of incompressible, Newtonian gases or liquids. Structural materials are considered as hydrodynamic obstacles and heat structures. The hydrodynamics is described by the continuity and the Navier-Stokes equation. To simulate turbulence the Baldwin-Lomax eddy viscosity model is available. Transitions between laminar and turbulent flow are covered by algebraic transition models of Drela and Mayle.

At temperature dependent density or viscosity the hydrodynamics is coupled to thermodynamics. For this reason, heat transfer by convection and conduction and heat generation by sources are modelled via a heat transport equation. To simulate phase transitions it is in enthalpy formulation. Radiant heat transfer is simulated at structural material surfaces. Material properties depend on temperature. Solids may have orthotropic heat conductivity.

For the numerical solution we developed a finite volume method with boundary fitted, curvilinear, non-orthogonal, block-structured grids. The blocks can be connected by 1-to-1 or patched couplings. The arrangement of dynamic variables in the control volumes is collocated at the node centre. The dynamic equations on momentum, pressure-correction, and heat transport are solved sequentially via implicit schemes. The system of continuity and momentum equation is solved by a SIMPLE [1], SIMPLEC [2], or PISO [3] algorithm.

To speed up the code execution and to estimate discretisation errors a FAS multi-grid algorithm is used. It is a geometric approach with standard coarsening applied to the outer iterations. At steady-state problems it operates as full multi-grid algorithm (FMG), for transient problems it starts at the finest grid.

Sparse linear equations of the parabolic momentum and heat transport equations may be solved with modified SIP solvers that handle block couplings via the residual vector [1]. For the elliptic pressure-correction equation an aggregation-based algebraic multi-grid algorithm [4] is available.

3 Application to high voltage winding of synthetic ester cooled locomotive transformer

The goal of this steady state application is to find the maximum temperature in the electrical insulation, to allow for the selection of materials that withstand the thermal load. Structural materials in this simulation are copper, Nomex insulation, and pressboard. To account for thin Nomex sheets in the inner windings, we use orthotropic heat conductivity. Load losses are calculated by a Maxwell-solver and subsequently mapped to the CFD grid.

The figure shows the temperature of ester and structural materials. The temperature steps of the ester at the ester side are caused by axial pressboard flow barriers. In the spacers the maximum temperature is 384 K. For Nomex this does not lead to long term stability issues while it may be critical for the pressboard at overload conditions.

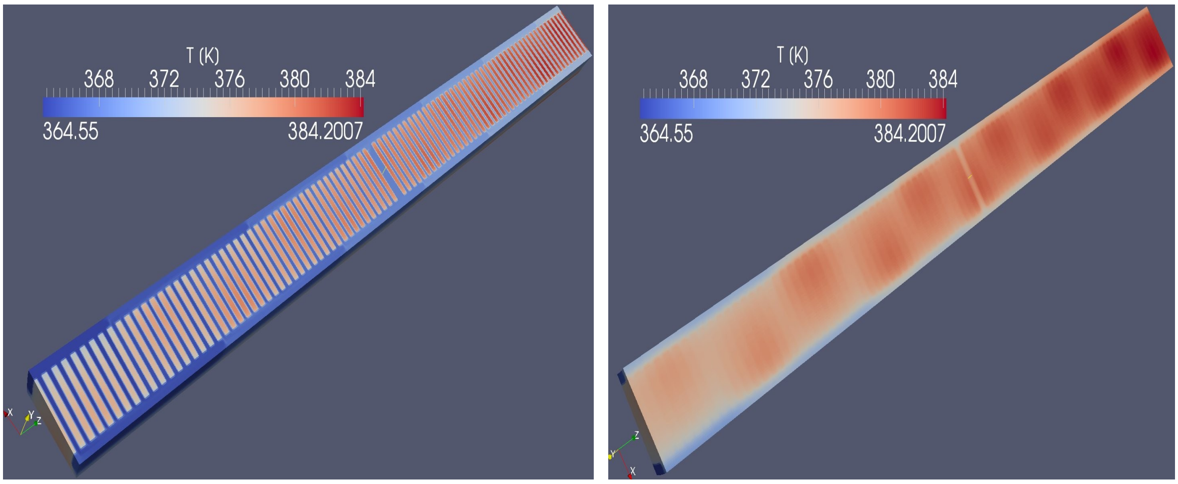

Figure a) Temperature on the ester side b) Temperature on the spacer side

4 Summary and conclusions

UniFlow is useful for the thermal design of oil-immersed and dry-type transformers. It can be used to investigate advantages and disadvantages of design features as well as to perform design optimisation.

In addition to the result shown here, the pressure loss encountered in a device as a result of the fluid flow may be a major result of a simulation. Other applications are related to detailed analyses on segments of disc windings with respect to, e.g., material composition or size of oil channels. Moreover, combined oil and air flows are analysed in the context of fin type distribution transformers and radiators.

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