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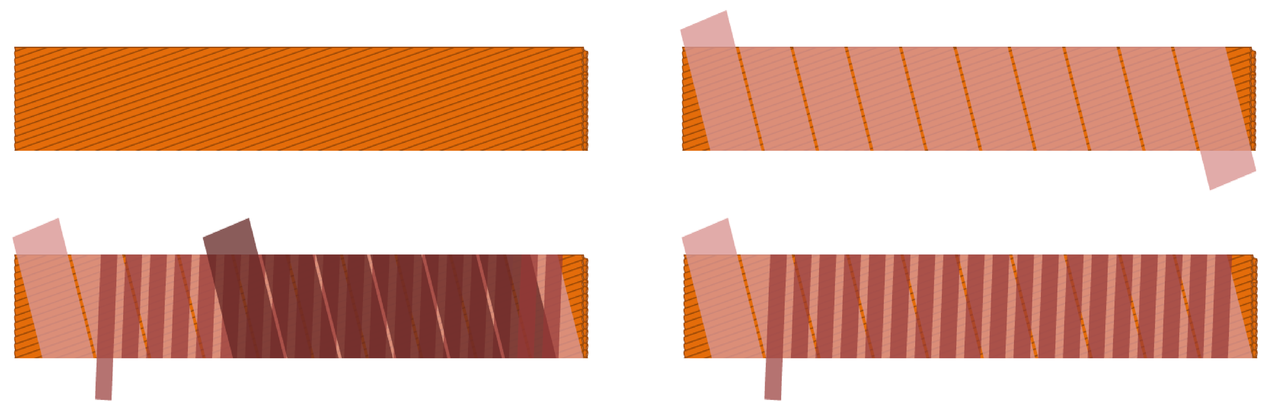
A structured approach to analyze the influence of channel dimensions on heat extraction via superfluid helium

E.R. Bielert*#, A.P. Verweij* and H.H.J. ten Kate*#
*CERN, Geneva, Switzerland # University of Twente, Enschede, the Netherlands

Introduction

For luminosity upgrades of the LHC at CERN, the final focusing quadrupole magnets will receive an increased energy deposition in their coil windings. To have a higher heat transfer rate between cable and superfluid helium bath, the cable insulation has been subject of many studies. Improved cable insulation designs, making use of several layers of Kapton tape wound around Nb-Ti Rutherford type cables, allow helium to penetrate via micro-channels, which are left open between the Kapton tape. To better understand the thermal behaviour at operating temperatures below and some degrees above the helium lambda transition, besides experimental work, several numerical models have been developed to study the influence of the cable insulation. Here we present a new numerical model, based on an earlier presented FEM model, which makes use of coupling variables such that the user can easily and quickly change the parameters of interest, giving the possibility to analyse new ideas effectively.

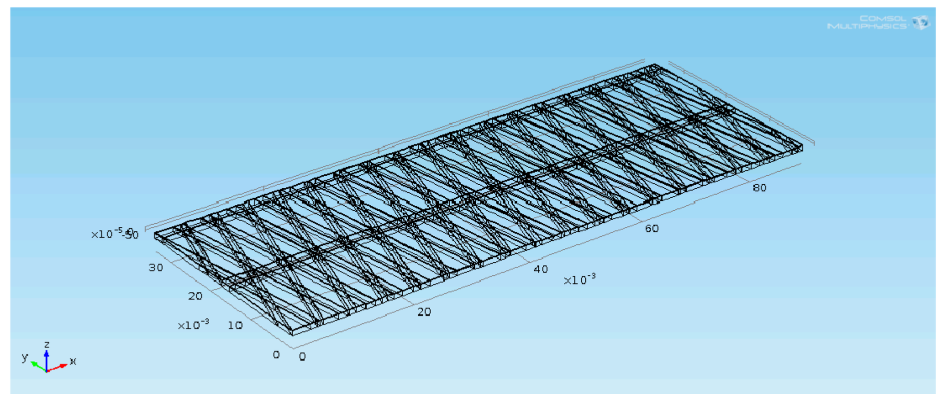
Cable insulation



To show the effect of changes in diameter of the micro-channels, which are embedded in the polyimide (Kapton) cable insulation, a model is required with which parametric sweeps of the geometry can easily be made. As a basis for all possible designs, the previously proposed Enhanced Insulation [1-2] is used. It consists of three layers, where each of the layers incorporates channels left open for (superfluid) helium to penetrate from the static helium bath to the cable strands.

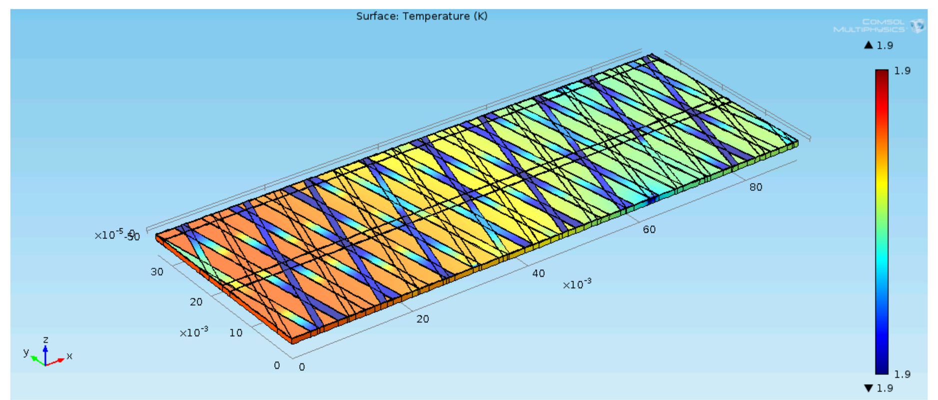
Numerical heat transfer model

Model implementation



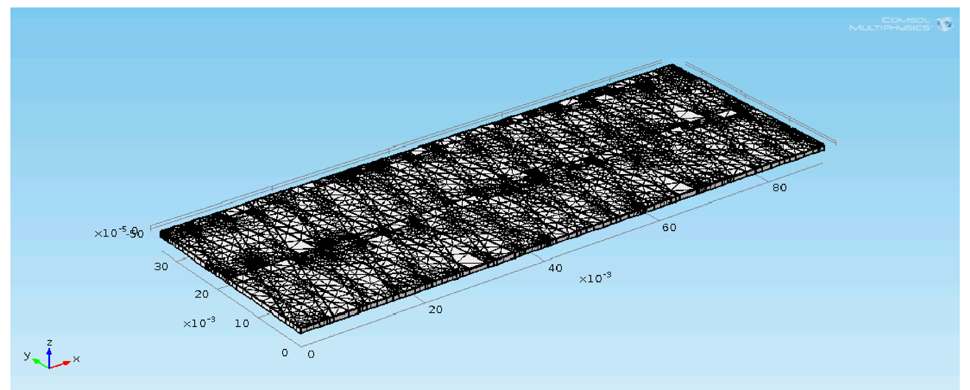
To effectively mesh the complete geometry, the following steps are followed:

1) A distributed mesh is applied to the thickness of the insulation layers on a corner edge.
2) 2) A mapped mesh is applied to the neighboring boundary.
3) 3) A swept mesh is applied in the direction of the insulation thickness. This results in 31804 mesh elements with a prism shape.

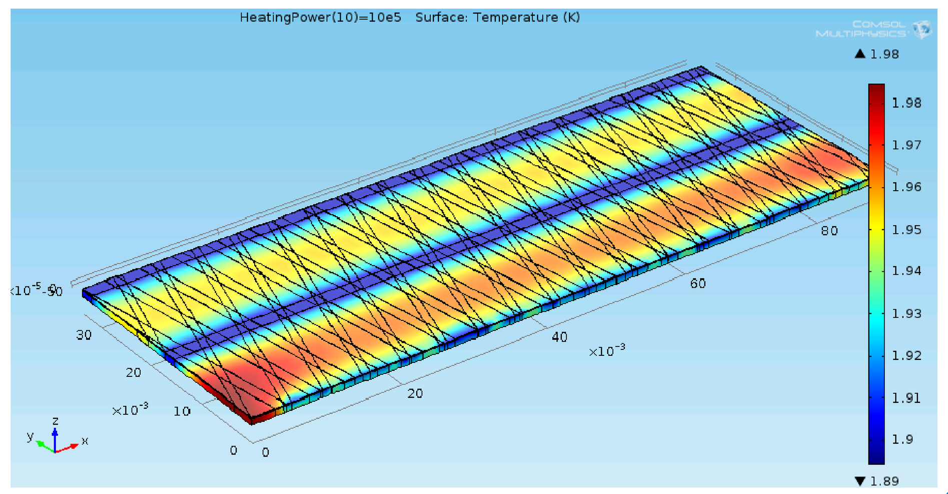


If Kapton is also considered, the temperature distribution changes quite a bit. The temperature over the width of the cable is much more homogeneous and the edges of the cable are cooled via conduction via the small side of the cable.

To correctly describe the heat transfer mechanisms in a complex geometry, a 3D model is required. By folding the insulation open and connecting the ends with coupling variables, a slightly simplified geometry can be implemented in the software. By drawing all channels in all layers of the insulation, difficulties occurring during the meshing step are strongly reduced.

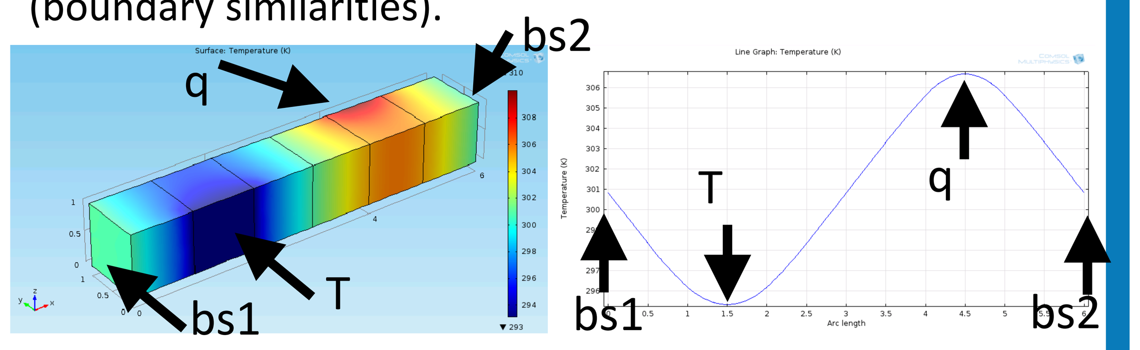


If only the helium channels are implemented, without taking into consideration Kapton at all, the temperature gradient occurs as expected over the length of channels, as was also seen with a previous less sophisticated model [3].



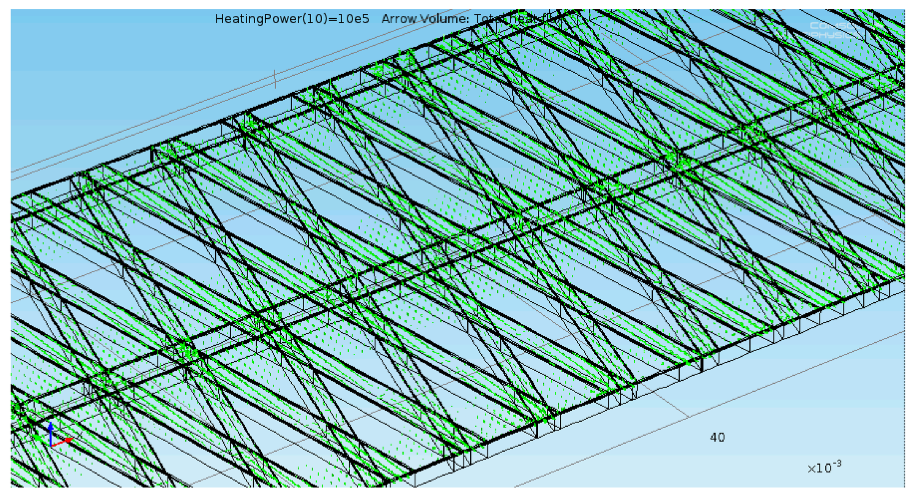
Model details

Via coupling variables, the boundaries which are artificially created by folding the geometry open, are connected with each other. Since these boundaries have the same shape, a direct mapping can be applied (boundary similarities).

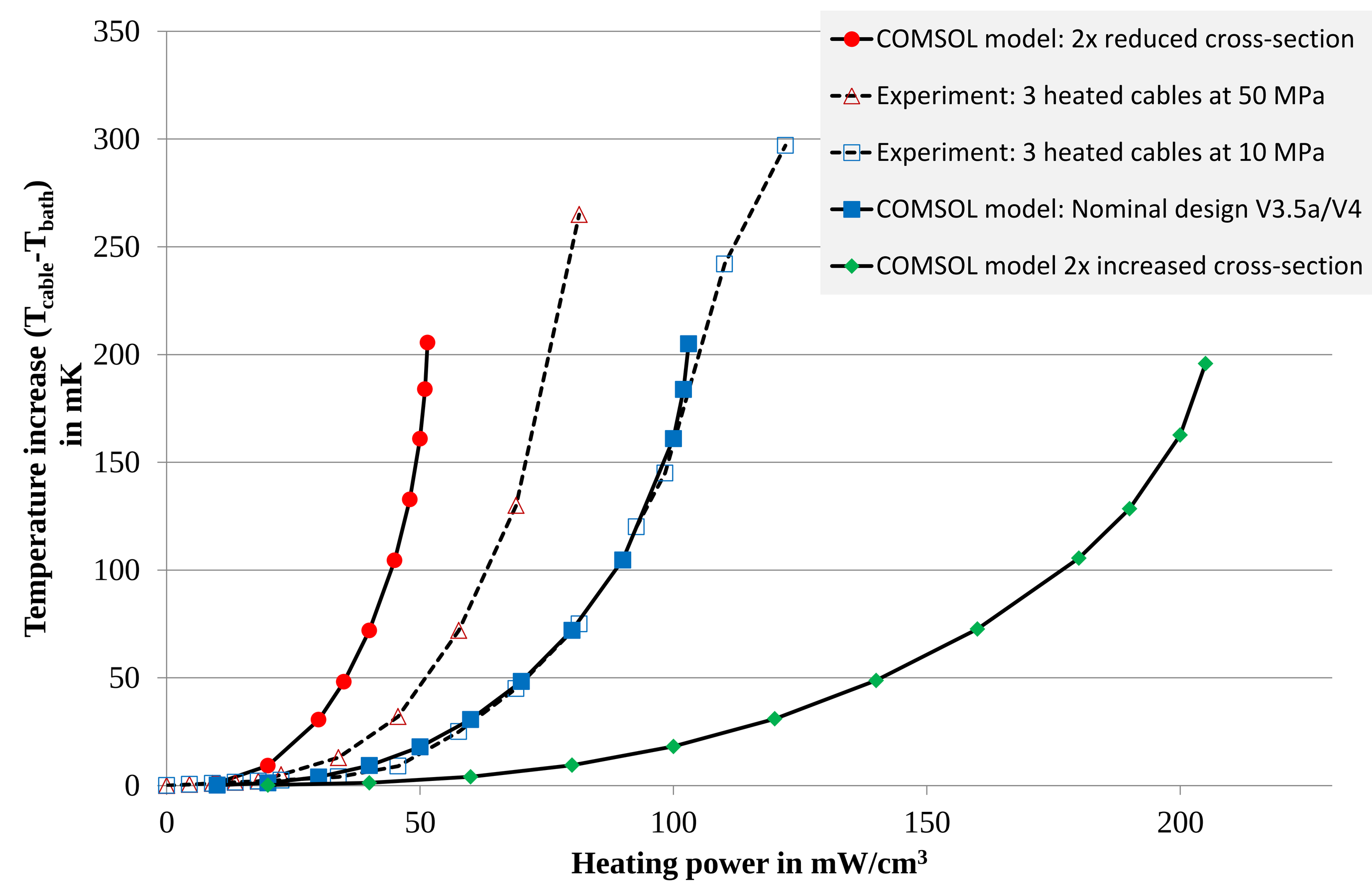


The total number of Degrees Of Freedom (DOF) for the model is about 200,000. This results in a calculation time of about 2 minutes per iteration, on a recent desktop computer.

Although the temperature distributions are different in case the Kapton insulation is considered or not, the direction of the heat flux is almost identical. The flux in the cable is directed in the direction of the helium channels on the wide side of the cable and in the direction of the bath on the small sides.



Comparison of results



Conclusion

It is demonstrated that complex 3D geometries can be modeled using COMSOL MultiPhysics V4.4. Through the use of coupling variables, simplifications to the geometry can be made, such that parametric sweeps of the geometrical parameters can be implemented in an effective way. Comparisons between different designs can be made fast once the original model is implemented. The model confirms that below the lambda transition temperature between He I and He II, most of the heat from the cable is transferred to the bath via the micro-channels filled with helium.

References

[1] M. La China, D. Tommasini, *IEEE Trans. Appl. Supercond.*, vol. 18, pp. 1285-1288
[2] P.P. Granieri, D. Richter, *Proc. 23rd Int. Cryo. Eng. Conf.*, Wroclaw, Poland, pp. 893-898
[3] E.R. Bielert et al, *IEEE Trans. Appl. Supercond.*, vol. 22, no3, June 2012

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