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Finite Element Thermal Thin Shell Approximation for Simulation of Transients in Accelerator Magnets

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Thermal transient responses of superconducting magnets are often simulated with the finite element (FE) method. Accelerator magnet geometries often consist of cables with a high dimensional aspect ratio of metal to insulation. The FE discretization of such geometries requires many mesh elements to resolve thin insulation layers and achieve an accurate solution. This increases computational time, particularly since non-linear material properties are involved.
To improve the computational efficiency for simulations of thermal transients in two dimensions, we propose to use the thermal thin-shell approximation (TSA) [1], which allows collapsing thin electrical or thermal layers into lines for representing the insulation. In this contribution, we present the TSA implementation in the open-source Finite Element Quench Simulation (FiQuS) tool [2], which is developed at CERN as part of the STEAM framework. To achieve this, modifications at the level of construction of geometry and mesh, as well as the FE formulation, are required when compared to classical FE simulations. FiQuS is capable of programmatically generating all components needed for the TSA. The thermal model allows for the Dirichlet (imposed temperature), Neumann (imposed heat flux), and Robin (imposed temperature-dependent heat flux) boundary conditions specified on the winding region with the help of the FiQuS input file.
The TSA is applied to simulate thermal transients in an LHC superconducting magnet including heat generation, thermal diffusion, and quench propagation. The method is verified against a solution obtained with a reference model comprising meshed insulation regions. The results demonstrate the advantages of the TSA, which enables faster simulations while preserving the accuracy of the solution.

***Index Terms* —quench simulation, finite element method, superconducting magnets, thin-shell approximation, FiQuS**

[1] Erik Schnaubelt, Mariusz Wozniak, Sebastian Schöps. Thermal Thin Shell Approximation for 3D Finite Element Quench Simulation of Insulated HTS Coils. 8th International Workshop on Numerical Modelling of High Temperature Superconductors (HTS 2022), Kévin Berger (Université de Lorraine - GREEN), Jun 2022, Nancy, France. ffhal-03791298

[2] FiQuS 2023.1.0. (2023) Finite Element Quench Simulation Tool.
[Online]. Available: cern.ch/fiqus

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