# Coupled A-H Field Formulation For HTS Magnets In COMSOL Multiphysics®

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## Abstract

Circular particle accelerators are powerful tools used in the field of high-energy physics to investigate the nature of the matter. They use strong magnetic fields to bend and focus the particle beams and generate collisions, which are thoroughly analyzed. New physical phenomena may be observed by pushing the collision energy beyond the limits of present-day particle colliders. This upgrade can be achieved by either increasing the machine radius or using stronger magnetic fields. In the case of the second option, circular accelerators can be possibly upgraded with magnets based on High Temperature Superconductors (HTS) to reach dipole fields of 20+ Tesla.

The HTS are manufactured as multi-layered tapes with a high aspect ratio on the transversal cross section. This causes the tapes to behave as anisotropic mono-filaments which properties depend on the angle of incidence of the magnetic field. Once the tape wide face is exposed to a time-varying field, large persistent currents are induced which results in hysteresis losses and effects the field quality of the magnets in a detrimental manner.

In this contribution, we illustrate how COMSOL Multiphysics® is used in understanding the complex behavior of magnetoquasistatic fields in HTS-based superconducting tapes and magnets. A domain decomposition technique is applied to overcome the numerical issues related to the vanishing resistivity in the superconductors. Thus, the field problem is described by a coupled A-H field formulation [1]. The magnetic field strength is used in the superconducting domain, whereas the remaining domains are treated with the magnetic vector potential. The field formulations are both implemented in the Weak Form PDE interface, together with the relevant interface and boundary conditions. The thermal dynamics of the superconducting coils is included in the formulation by using COMSOL Multiphysics® Heat Transfer Module.

The capabilities of the formulation are shown with dedicated 2D and 3D numerical examples. This formulation is useful for both the optimization of the magnetic field quality and the minimization of the thermal loss, thus assisting with the design of future HTS magnets.

[1] Bortot, Lorenzo, et al. "A Coupled A-H Formulation for Magneto-Thermal Transients in High-Temperature Superconducting Magnets." IEEE Transactions on Applied Superconductivity 30.5 (2020): 1-11.