Modeling of Electrodynamics in High Temperature Superconducting Magnets with COMSOL Multiphysics®

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Abstract

Future particle accelerators for high-energy physics could possibly rely on 20+ Tesla dipole magnetic fields in order to bend the beams in circular orbits. The advantage of increasing the magnetic field is twofold: particles collisions are obtained at higher energies, exploring new physics, while the orbits of the particle beams are kept unchanged. This would allow, in principle, to improve an existing accelerator without changing its infrastructure. At the moment, such an upgrade can be potentially achieved using bending magnets based on High Temperature Superconductors (HTS).

The HTS are manufactured as multi-layered tapes, with a high aspect ratio (10~50) 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 will be induced, widely contributing to the AC losses, and eventually putting limitations to the field quality of the dipole magnets. The dissipative phenomenon is enhanced by a smooth transition from superconducting to normal conducting state, which allows for overcritical currents. Furthermore, other loss mechanisms play a role (see Fig. 1), as eddy currents in the copper stabilizers (Q_eddy), hysteresis behavior in the magnetic substrate (Q_hyst), and coupling currents between the superconducting layers (Q_cc). Eventually, several HTS tapes can be combined in complex 3-D architectures (e.g. Roebel), in order to increase the nominal current of the cable.

Numerical simulations can help in understanding the aforementioned dynamic effects, investigating the HTS coil designs that would minimize the amount of AC losses and the magnetic field distortion in the magnets. Among the numerical methods, the Finite Element Method has proven to be flexible enough to consider complex geometries, nonlinear material properties and field-related dependencies. Nevertheless, the anisotropic nonlinear behavior of the HTS tapes enforces a rapid spatial and temporal variation of the distributed variables in the numerical solution, challenging the solver in terms of both, numerical stability and computational cost. In this work, we consider a 2-D model of a stack of HTS tapes implementing in COMSOL Multiphysics® three different formulations: the magnetic vector potential (A-V), the current vector potential (T-Omega) and the magnetic field (H). We compare the models in terms of stability and performance, scaling the most promising one to the size of an accelerator magnet of practical interest.

Figures used in the abstract

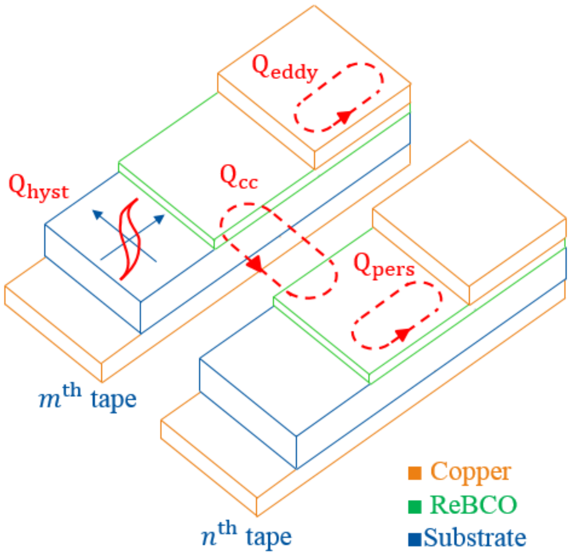

Figure 1: AC loss contributions.