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Integrated analysis of quench propagation in a system of magnetically coupled superconducting coils

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The design of the quench protection system for a superconducting solenoid for laboratory applications is a practical matter that has often been addressed by using simplified models based on analytical estimates for the quench propagation velocities in the longitudinal (along the conductor) and transverse (from turn to turn) directions. This approach can become cumbersome, especially for coil configurations such as segmented magnets or multiple coils with inductive coupling. We demonstrate in this paper how to use direct modeling of the heat transfer and circuital equations to produce a model suitable for such configurations, but producing results based on propagation velocities which are consistent with the physics of the phenomena.

To this aim we use an equivalent thermal 3-D model, based on a 1-D longitudinal model coupled with a simplified 2-D transversal model to solve the heat exchange among solids and coolant, and a circuital description of the coupled system of magnets. The building blocks are the CryoSoft suite of dedicated codes for the analysis of superconducting coils, i.e. THEA, POWER and SUPERMAGNET, integrated by "ad hoc" problem-related routines.

Our application example is a system of three, layer-wound and bath-cooled coils, all using a NbTi conductor. Following a quench initiation, we demonstrate the calculation of the time evolution of currents, voltages and temperatures in all coils. The sensitivity of these results to input parameters such as the thermal conductivity of the insulation between turns and layers, the heat transfer coefficient to helium bath and the heat perturbation, is investigated in a parametric study. The same model can be easily adapted to study coils with different topologies (e.g. pancake winding), geometry (e.g. non-circular shapes) and conductors (e.g. force-flow cooled).

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