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Data-Driven Modeling of Quenches in Superconducting Accelerator Magnets

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Current research in magnet technology focuses on superconductors and technologies to achieve dipole fields in the 12-16 T range using Nb_3Sn wire. With their anisotropic and stress-dependent material properties, these materials require multiphysics simulations right from the start of the magnet-design process, particularly for stress management and magnet protection. Owing to the many empirical parameters to be specified in multiphysics simulations, an essential part of the design work is the validation of the model to obtain a match between simulations and measurements.

Magnet protection in case of a quench relies on quench heaters (QH), extraction resistors, and coupling-loss induced resistance (CLIQ) to speed up and homogenize the energy dissipation and thus avoid conductor degradation due to overheating. The efficiency of the measures is estimated using multi-physics simulations based on numerical solutions of ordinary and partial differential equations (network models, finite element, and boundary element methods, among others). Unfortunately, both simulations and measurements are affected by uncertainty and biased by ignorance. Mitigation measures exist for most sources of uncertainty, such as oversampling, signal compensation, calibration, convergence studies, and maxwellification by imposing the regularity conditions of magnetic fields. However, ignorance, in the sense of unrecognized systematic effects of the underlying physics, can only be addressed by merging simulations and measurements.

In this paper, we first study the sensitivity of the observable quantities (such as voltages and current decay curves) to the material parameters and loss mechanisms implemented in the CERN field computation program ROXIE. The test data from the 11T dipole program and MQXF quadrupoles for the LHC upgrade is analyzed, and statistical models are developed to compensate for the ignorance in the numerical model.

The updated models allow the extrapolation of performance parameters to the next generation of magnets.

Primary authors: PAUDEL, Deepak; RUSSENSCHUCK, Stephan (CERN); Dr MANGIAROTTI JULIO, Franco; Dr BONORA, Matthias

Presenter: PAUDEL, Deepak

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