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Towards to Quench Limit Determination of Superconducting Magnet with use of Thermal-Electrical Analogy

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The superconducting magnets are an essential part of large particle accelerators. The superconductors used in winding the coils of these magnets are characterized by the critical surface determined by three parameters: the critical temperature (Tc), the critical current density (Jc) and the critical magnetic field (Bc). The energy deposited in the superconductors by the particles lost from the beam or coming from the experiment collision debris may heat up the conductor in the magnet coil and provoke the magnet to quench. The modern design of the superconducting accelerator magnets requires the thermal optimization at cryogenic conditions in terms of heat transfer from magnet coils to heat reservoir. The main challenge of the accelerators operating with the superconducting magnets is their protection against the energy deposits to the coils from the particles lost from the beam and determination of the energy limits at which beam should be dump from the accelerators in order to avoid the magnets quench.

The thermo-electrical analogy was used to develop a model of the superconducting magnets which has been used to study the thermal behavior of magnet and to determine the limits of quench of the magnets for expected beam loss profiles. The developed Network Model was used for thermal analysis of LHC Nb-Ti magnets and for optimization of Nb3Sn quadrupole magnets developed for use in the LHC luminosity upgrade. The analysis focuses on the heat transfer from the superconductor to the heat exchanger through a multilayer structure of magnet made of solid elements and channels occupied by the normal fluid or the superfluid helium. The results of the simulation by means of the Network Model were validated with measurements. A different sources of heat were implemented (magnet quench heaters, Inner Heating Apparatus) in different configurations. All simulations showed a very good agreemnt with measurements and with expected accuracy. The sources of discrepancy between the results of the simulations and measurements were related to the thermal properties of materials used in simulatiions. The developed model was successfully implemented to study of the thermal behavior of the newly developed enhanced insulation and newly designed Nb3Sn magnets. The future development of the model is foreseen by the design of a dedicated module which will introduce the energy deposits compatibile with the LHC beam pattern as well as module to study the transient mode.

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