

Development of a CLIQ-Varistor Quench Protection Scheme for the LPF3-U Superconducting Dipole Magnet

For the pre-study of the Super Proton-Proton Collider (SPPC) project, the Institute of High Energy Physics (IHEP) has developed the LPF3-U, designed to achieve a 16 T dipole field within a 30 mm aperture. The LPF3-U magnet integrates six Nb3Sn coils in a Common-Coil configuration, accompanied by an HTS insert that utilizes seven YBCO tapes wound in parallel with a stainless-steel tape in a racetrack coil structure. The HTS enables turn-to-turn current sharing for self-protection, while the stored energy of the LTS magnet exceeds 2.1 MJ at the designed current, posing a strong requirement for a robust quench protection system. A numerical simulation analysis of electro-magnetic-thermal coupling was conducted, considering the trade-off between CLIQ protection efficiency and helium boil-off, resulting in the development of an optimal quench protection scheme. During the simulation, the analysis incorporates the actual parameters of LPF3-U, accurately captures electro-magnetic-thermal coupling, including LTS-HTS interactions, turn-to-turn heat transfer, and magnet-helium thermal exchange. The numerical analysis also revealed that the strong LTS-HTS inductive coupling impacts quench dynamics, with LTS quenching transferring energy to HTS coils. Additionally, the induced current and strong electromagnetic forces in the HTS magnet, which could potentially cause severe damage, urgently requires decoupling strategies such as copper plates or auxiliary coils. Numerical analysis confirms that with the optimal quench protection system, the peak coil temperature and ground voltage remain within safe limits during quenching. The CLIQ-derived quantities, magnetic field distribution, and other physical variables align with expectations. This quench protection scheme has been successfully validated in LPF3-U tests, ensuring safe and reliable magnet protection.

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