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

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INTRODUCTION

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 16*24 mm^2 aperture.

The LPF3-U magnet integrates six Nb_3Sn coils in a Common-Coil configuration, accompanied by an HTS insert that utilizes seven ReBCO tapes wound in parallel with a stainless-steel tape in a racetrack coil structure.

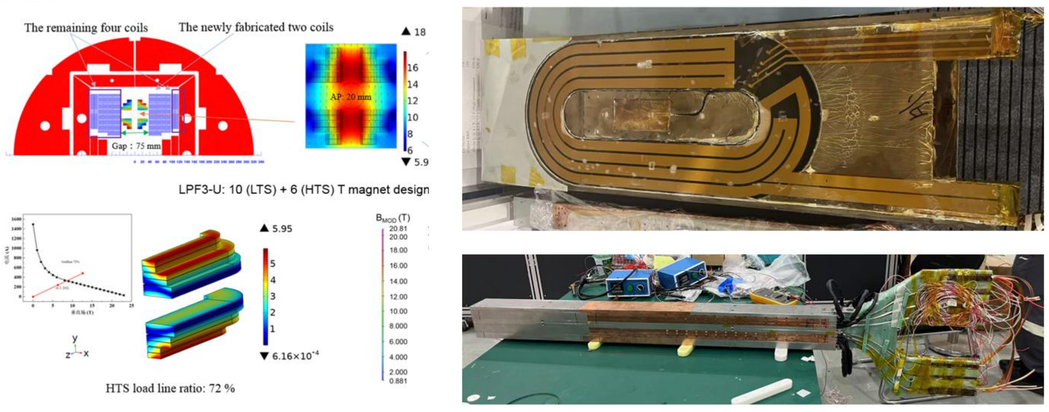


Fig.1. Electromagnetic Design and Physical Diagram of LPF3-U

LTS magnet stores 2.1 MJ at 7580 A, HTS insert magnet 0.166 MJ at 2180 A, and mutual inductance energy between them is 0.04 MJ.

CLIQ Quench Protection Scheme For the LPF3 LTS Magnet

Through calculations, the segmenting scheme that minimizes the equivalent inductance of the circuit is 1, 3, 2, 5-4, 6.

- **Circuit Model and the Optimal CLIQ Scheme**

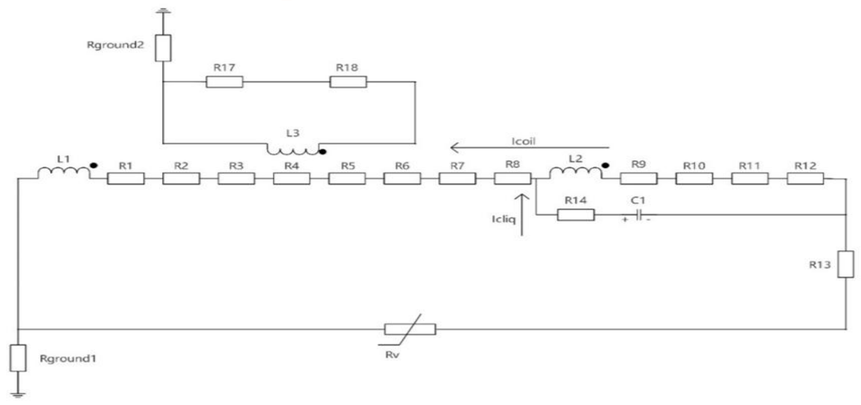


Fig.2. Quench Protection Circuit Model of LTS Magnet

In hybrid magnets, the mutual inductance coupling between magnets must be considered when analyzing the performance of CLIQ.

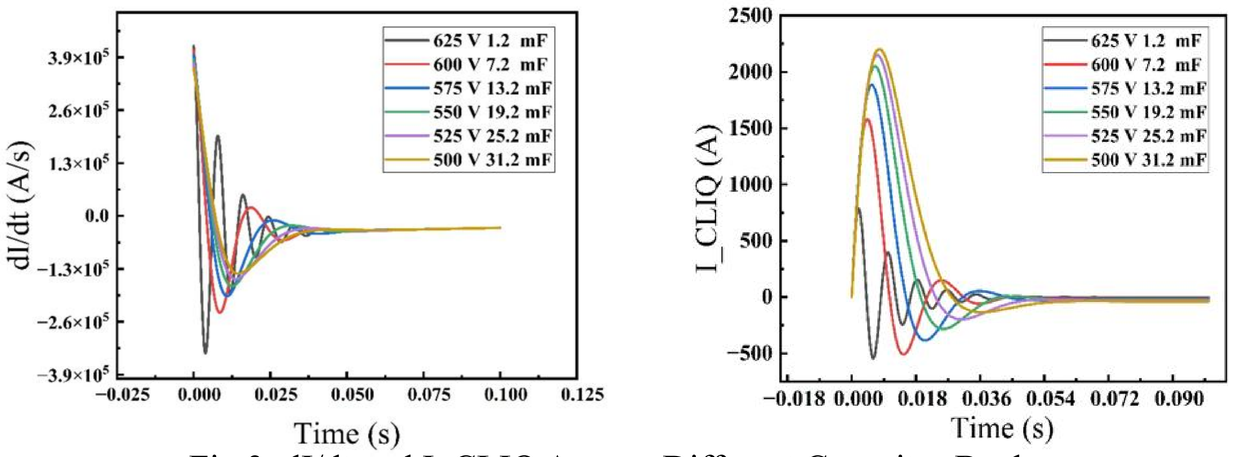


Fig.3. dI/dt and I_CLIQ Among Different Capacitor Banks

By comparing results such as CLIQ efficiency, action time, and heat transfer calculations, 7.2 mF@600 V is selected as the optimal CLIQ scheme

- **Simulation Results and Experiment**

Calculations indicate that the maximum voltage to ground is 918 V and the maximum hot-spot temperature is 318 K, both within the safe range. To date, 30 safe LTS quench protections have been achieved in the tests of three generations of LPF3-U magnets.

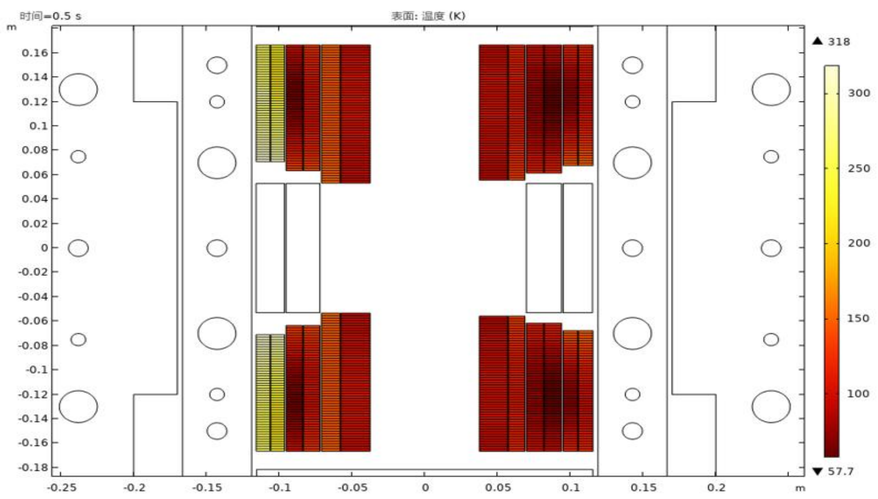


Fig.4. Temperature Distribution of Quenched Coils in LTS at 7580 A

Quench Damage Analysis and Self-Protection Scheme of HTS

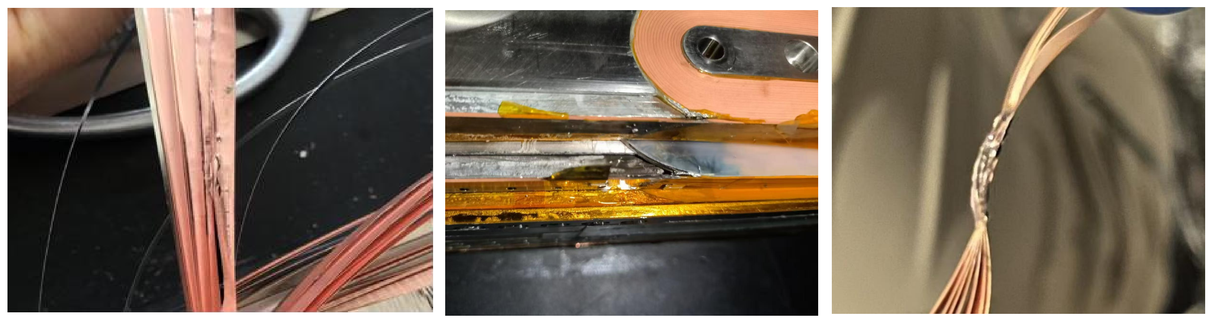
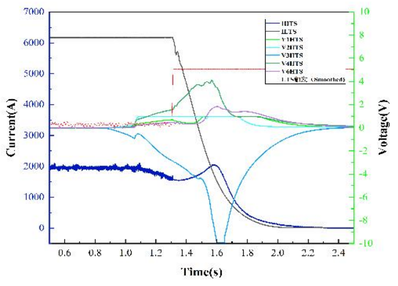


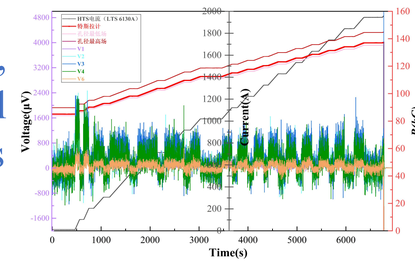
Fig.5. Typical damage Types of NI/MI HTS coils

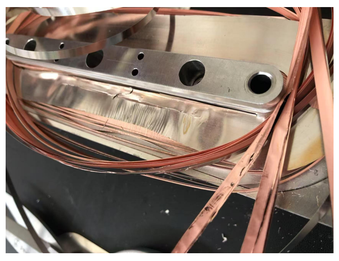
When the HTS insert magnet is subjected to the quench of the background magnet or its own high-current quench, there is a high risk of damages such as REBCO tape mechanical damage, voltage breakdown, and overheating burnout. NI/MI coils allow significant intra-turn and inter-turn shunting, which greatly improves the self-protection performance of the magnet; however, the extremely small inter-turn resistance also prevents effective energy release outside the magnet.

The shielding measure reduces the induced current from over 2000 A to 1300 A



The insulation design, together with additional parallel superconducting strips





Adjust the winding tension and assembly preload, and add mechanical buffers at key positions

In addition, the design and optimization of the HTS self-protection scheme have been carried out through solutions such as thermal conductivity design, joint technology, inter-turn resistance optimization, and the balance between loadline and copper plating thickness. Furthermore, a scientific hybrid magnet excitation scheme can also avoid HTS quench damage to a great extent.

Optimized self-protection design enables the HTS insert magnet to reach a 7.66 T bore center field at 2159 A, and assists the LPF3-U magnet in achieving 13.74 T (bore center) and 14.49 T (maximum bore) via combined excitation.

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