Contribution ID: **13** Type: **not specified**

Quench Protection in Insulated REBCO Conductors: Design Optimization and Fast Detection via REBCO SQD

Within the French exploratory program SupraFusion, we investigate fast and reliable quench detection and protection strategies for insulated REBCO coated-conductor stacks intended for fusion-relevant, high-field magnet systems. Because these insulated windings show very slow normal-zone propagation and hold large magnetic energies, conventional voltage-tap detection often reacts too late, letting the hotspot temperature reach damaging levels. Our aim is to develop strategies that improve detectability and make insulated REBCO stacks protectable without adding integration constraints.

We focus on two complementary techniques. The first relies on stabilizer-based protection, where the copper cross-section is adjusted to balance Joule heating with the slower voltage rise. The second makes use of a co-wound Superconducting Quench Detector (SQD): a slightly stabilized REBCO tape, thermally coupled but electrically insulated from the conductor, designed to generate a stronger voltage response for the same disturbance. The SQD's behaviour is tuned by controlled deoxygenation through heat treatments, which reduce its critical properties (Tc and Ic) , allowing earlier detection while keeping the overall design simple.

To assess the reliability of these two approaches, we build one-dimensional electro-thermal models in THEA©. These simulations reproduce adiabatic quenches, examine the role of stabilizer content, and include an independent SQD circuit to capture its thermal and electrical evolution. The numerical results indicate that suitably thick stabilizer sections can keep the hotspot within acceptable limits, while the SQD—when given the right degradation level and operating current—detects the quench noticeably earlier than the main conductor, lowering the hotspot at detection. Overall, the modelling strongly supports the relevance of both protection techniques and provides clear guidance for the next test campaign.

Experimentally, calibration campaigns have confirmed that the deoxygenation process used to degrade the SQD tapes is both controllable and reproducible. The link between heat-treatment parameters and the reduction of Tc and Ic has been established, making it possible to fabricate SQDs with well-defined characteristics. In parallel, proof-of-concept experiments for both protection methods have already been carried out at liquid-nitrogen temperature on several stack-type conductors. These first results validate the enhanced sensitivity of degraded SQDs and show that conductors with optimized stabilizer content can be effectively protected. A new experimental campaign, covering variable temperatures and magnetic fields up to 3 T in the H0 facility at CEA-Saclay, is currently being prepared and is expected to be ready during the first semester of 2026.

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