Detecting quench in HTS magnets with LTS wires — a theoretical and numerical analysis

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Abstract

Using a co-wound and insulated NbTi low temperature superconducting (LTS) wire to detect quench in coils wound with ReBCO high temperature superconducting (HTS) tapes has recently been experimentally proved, yet a theoretical study is still needed to further develop this technique and make it prepared to be applied more generally in high field accelerator magnets. By theoretical and numerical analysis, we confirm a few important facts:

1. It is the significant difference in the $I_c(T)$ relation between LTS and HTS but not the normal zone propagation velocity (NZPV), that makes LTSs good quench detectors;
2. LTS quench detectors should have low matrix fraction, but a high matrix resistivity;
3. Heat conduction between cable and detector is important, but a poor condition is tolerable;
4. At field up to 15 T, Nb$_3$Sn, Nb$_3$Al and MgB$_2$ all show good potential as quench detectors, and some degradation in wire performance is also acceptable.

A theoretical explanation

➢ The variation of critical current as function of temperature and magnetic field is significantly different for ReBCO and several LTS materials.

➢ The resistance (per unit length) of LTS wires dramatically increases once $T_c$ is exceed. For ReBCO it’s much more gently.

Numerical analyses

• A classic 1-D numerical model

• An example at 5 T with NbTi quench detector

Outlook

➢ Voltages in NbTi detectors rise rapidly once its $T_c$ is exceed and normal zone occurs, regardless of its length.
➢ NTS with higher normal resistance has better sensitivity.
➢ Poor thermal conduction between ReBCO cable and NbTi wire can worsen the sensitivity, but quench can still be detected in ms.

• For high field application

Specifications of ReBCO cable and LTS quench detectors relevant to 15 T application

Outlook

➢ Detecting quench in HTS magnets with LTS wires seems a promising approach to release the challenge of quench protection of a HTS magnet. This is especially true for accelerator magnets with high conductor current density.
➢ Next, we will try to find or make proper LTS quench detectors and test this ideas at our HTS insert coil. Many technical problems are expected, like installation of reacted and insulated wires with good thermal conduction to the HTS coil.

➢ As expected, voltages in three LTS detectors all increase rapidly at Tc.
➢ Losing 80% Ic, NbSn can still work fine as quench detector.
➢ The voltages in Nb$_3$Al or MgB$_2$ wire should be much higher in real case, since their matrix are usually Nb or Monel, both of which have much higher resistivity than Cu. For Nb$_3$Sn, higher voltage can be achieved by removing Cu.