Heat transfer in HTS transformer and current limiter windings

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Design of cryogenic systems for HTS transformers and fault current limiters (FCL) must provide for fault conditions as well as normal operation. In the course of a fault the HTS windings may be heated rapidly to a temperature of 300 K or higher. The ability of the device to return to normal operation after a fault current depends critically on the efficiency of heat transfer from the hot windings to the cooling system. The engineering of the interface of the winding with the cryogen, generally liquid nitrogen in the case of HTS transformers and FCL, can properly be considered a crucial component of cooling system design.

We report measurements of heat transfer from short metal and superconductor tape samples immersed in liquid nitrogen in conditions which approximate those in an HTS transformer winding. Samples were subjected to current pulses of several hundred A/mm^2 for time intervals up to 2 seconds. The average sample temperature was estimated from the resistance. The current density during cool down was varied over the range corresponding to HTS transformer operation. Heat transfer was measured on samples with UV-cured polymer coatings as well as on bare samples. Somewhat paradoxically, by thermally insulating the metal surface from the liquid nitrogen the coating can drastically improve heat transfer. It does this by avoiding film boiling - the formation of a gas sheath on the surface - and extending the range of efficient cooling by nucleate boiling where the liquid is able to continuously wet the hot surface.

We find that heat transfer during conductor cool down

- Is highest in subcooled operation e.g. at 65 K at atmospheric pressure compared to operation at the boiling point e.g. 77.3 K at atmospheric pressure
- Is significantly increased by a thermally insulating coating of optimised thickness applied to the conductor compared to bare conductor, and reduced by wrapped-paper electrical insulation