Quench Protection of HTS Coils with Distributed Protection Heaters

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Introduction

High Temperature Superconductors (HTS) are being developed for a variety of applications including power transmission and magnet coils. Because of the high heat capacity of the conductor at high operating temperatures, or the high critical properties at low operating temperatures, the velocity of quench propagation is observed to be very low in comparison with Low Temperature Superconductors (LTS). Protection heaters are often used as part of the protection system for LTS coils, and serve the purpose of effectively increasing the quench propagation velocity in coils or sets of coils, even providing for an effective propagation velocity between thermally isolated coils. Here the possibility of protection of HTS coils with an extended distribution of protection heaters is examined as a way to compensate for the low propagation velocity. The use of a greatly extended distribution of protection heaters raises issues of complexity of design and fabrication. More fundamentally, it is possible to imagine that with a sufficiently large number of heaters, the protection of an HTS coil is assured. What is not assured, and what has not previously been determined, is whether the power and voltage requirements of a distribution of heaters that is sufficient to affect the protection of an HTS coil, are low enough to be compatible with practical quench protection systems.

Analysis and Discussion

An analysis is made of the protection of HTS coils in which the low quench propagation velocity is taken to the idealized limit of zero propagation velocity. The natural propagation velocity of LTS conductors is replaced by the action of a distribution of heaters. The spread in the initial hot spot region, essential for internal protection, is accomplished by the normal zones that are induced adjacent to the heaters. The analysis is described as applied to a tape wound solenoid magnet of pancake construction.

The internal protection of a superconducting coil, in which the stored energy is deposited within the windings, requires that a sufficiently large volume of the coil is normal so as to limit the dissipated energy density and associated temperature rise. The enthalpy, or thermal energy per unit volume, is determined by the selected maximum hotspot temperature. The energy to be absorbed by the windings is the stored magnetic energy. A comparison of the enthalpy with the energy that must be absorbed gives the volume fraction of the windings that must participate in the absorption of the energy, or equivalently the volume of the windings that must be driven normal by the heaters. As an example, the analysis is applied to a magnet constructed from 2G YBCO coated conductor in the form of tape wound disks or stacked pancakes. The heaters are imagined to occupy the space between the disks along with the disk insulators. The thickness of the heated zone is naturally the thickness of the disk, or the width of the tape. The volume of the required heated zone then determines the area of the disk that must be heated, or the area of the heater. In this way, the dimensions of the heater are determined. In order to be effective in protecting the coil and limiting the temperature of the hot spot normal zone, the heaters must operate quickly to drive the windings normal and initiate a discharge of the coil. Therefore the heaters must raise the temperature of the adjacent conductor well into the current sharing temperature in a time short compared to the required discharge time. This requirement, together with the volume windings being driven normal, defines the heater power requirements.

The analysis was applied to solenoid coils operating both at high temperature and relatively low field, and to coils operating at low temperature and very high field. In each case, the system of heaters was found to be practical in terms of required power and voltage.

Reference