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EXPERIMENTS WITH ALL-KAPTON INSULATION AND AXIAL PRESTRESS IN 1.8 M-LONG SSC R&D MAGNETS*

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Abstract

Several 1.8 m-long magnets have been built to evaluate possible variations in the design of the SSC collider dipoles. Except for length and the parameters being tested, these models have the features of 40 mm aperture collider dipoles, which are based on a two-layer cosine theta coil. In these magnets, we have tested all-Kapton cable insulation and the effects of changes in the axial coil prestress. Construction details and test results for quenching, field harmonics, and coil loading are reported.

I. INTRODUCTION.

The magnets reported here have a two-layer coil, with 40 mm aperture and 80 mm outer diameter (Fig. 1). The coil cross-section (designated C358D) is a four-wedge, non-radial block design[1]. The standard cable insulation is a combination of the DuPont polyimide material "Kapton"[2] and epoxy-impregnated fiberglass. This paper reports test results from magnets made with the standard insulation and with an alternate, all-Kapton insulation.

Other construction features included collars that are "anti-ovalized" such that the vertical dimension of the collars with prestressed coils is reduced by about 0.010" over that which would be achieved with the nominal geometry. A yoke surrounds the collared coil; the inner radius of the yoke laminations was chosen to achieve line-to-line contact with unstressed collars at room temperature. Stainless steel shells were welded around the yoke and a single end plate made of 38.1 mm thickness stainless steel was secured to the shell at each end of the magnet. Finally, end preload was applied to the coils via instrumented screws set into the end plate. This paper reports results due to the variation of the end preload in one magnet. The magnet is designed to operate at 6.6 T central field in 4.35 K helium with a current of 6.5 kA. Details of the magnet design not discussed here are described elsewhere[3].

II. EXPERIENCE WITH ALL-KAPTON INSULATION

The magnets with all-Kapton insulation test a new system of cable insulation which is presently being developed through a joint effort between BNL and DuPont. The system consists of two wraps of improved polyimide film coated with a polyimide adhesive. It replaces the present cable insulation system of one wrap of polyimide film, overwrapped with (B-staged) epoxy-impregnated fiberglass. The polyimide adhesive of the new insulation system is activated immediately upon reaching a temperature of 217 C. For comparison, the epoxy in the present system requires a cure cycle of 90 minutes at 135 C. The target for applied coil pressure during molding has been increased from 7000 psi for the present system to 10,000 psi for the improved system, to increase bond strength between cable turns.

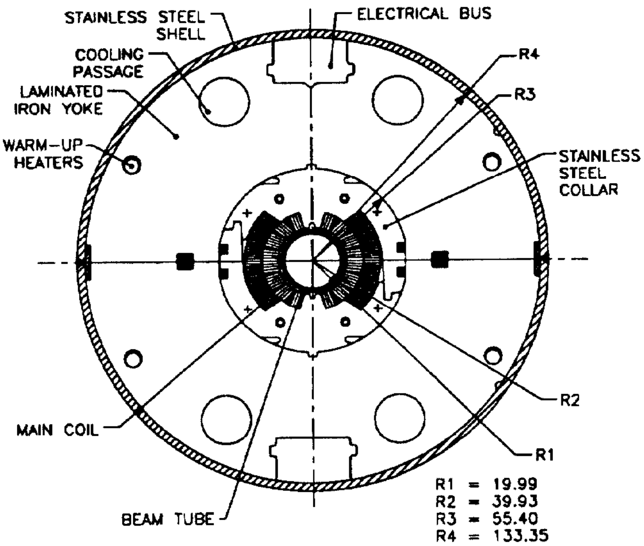

Figure 1. Drawing of the baseline, 40 mm aperture, collider dipole cold mass.

The principal goal of the new system is to achieve greater resistance to electrical breakdown between cable turns under compressive load by increasing the strength, or "punch-through resistance" of the cable insulation. This has been demonstrated through extensive testing (see Fig. 2). A second important goal is to improve the radiation resistance of the cable insulation system; this has been verified through independent materials testing. Secondary goals, which are

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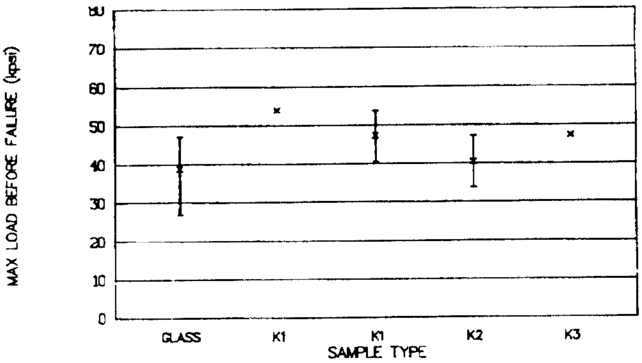

Figure 2. Punch through resistance of standard insulation (glass) and various types of all-Kapton insulation (k) in a test fixture. Each point represents the average of many tests; the error bars show the range of test results.

expected improvements but have not yet been verified, are improved conductor position uniformity and improved creep resistance. Finally, an unexpected benefit of the new insulation system which has been realized is an improved method for maintaining coil size repeatability, as indicated by initial testing.

Several variations of the improved system have been used in different magnets. In most cases each wrap of polyimide is made with 50% overlap onto itself, with the first wrap being coated with a polyimide adhesive on its outside surface, and the second wrap being coated with the same adhesive on both surfaces (K1). In some instances, a more porous wrap style was used for increased helium circulation around the cable. In this case, the first layer is made with 50% overlap onto itself but is uncoated, and the second layer is made as a non-overlap wrap with polyimide adhesive coated onto its outside surface only (K2). This variation of the cable insulation system most closely models the present Kapton/fiberglass cable insulation system. Recently, interest has subsided somewhat in the porous wrap variation, based on 1) the lack of evidence of Kapton disruption after testing (due to helium pressures after quench) found during inspection of a magnet made with the less porous insulation, and 2) testing subsequently completed on molded, compressed cable samples which demonstrated substantial, albeit reduced, helium flow through the polyimide cable insulation at modest pressures.

Based on test results of an early magnet, where coil stress losses due to thermal contraction effects (after cooldown to 4 K) where measured to be greater than those for similar Kapton/fiberglass magnets, another variation of the improved cable insulation system has been tried. This version features a mineral filler added to the second wrap of polyimide film around the cable, to reduce the integrated thermal contraction of the film upon cooldown (K3). A comparison of the stress loss for various insulation types can be seen in Figure 3. The filled polyimide should also aid in greater creep resistance.

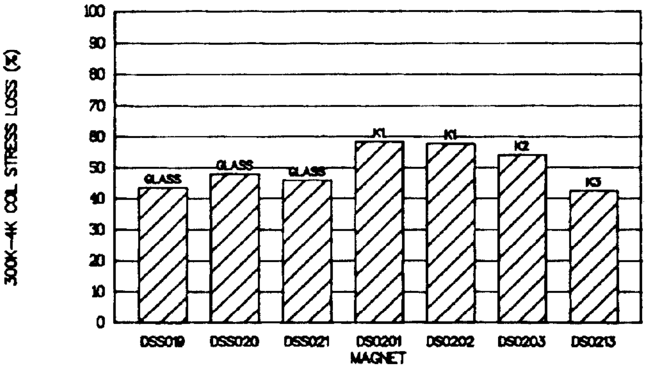

Figure 3. Cooldown coil azimuthal stress loss for various types of cable insulation.

III. MAGNET END LOADING STUDY

It was found that the end preload as measured by strain gauges[4] at one end of a magnet (DS0213) at room temperature (1200 lbs./end) was lost during cooldown. As a test, the end preload on one magnet was increased to 2000 lbs./end and the magnet retested. Although the strain gauges still showed a loss of preload upon cooldown (Fig. 4), the quench performance was substantially improved (see below). Lastly, the end preload at room temperature was entirely removed, and the magnet quench-tested a third time. The quench performance (discussed in Section IV) was not as good as with the 2000 lb. end preload.

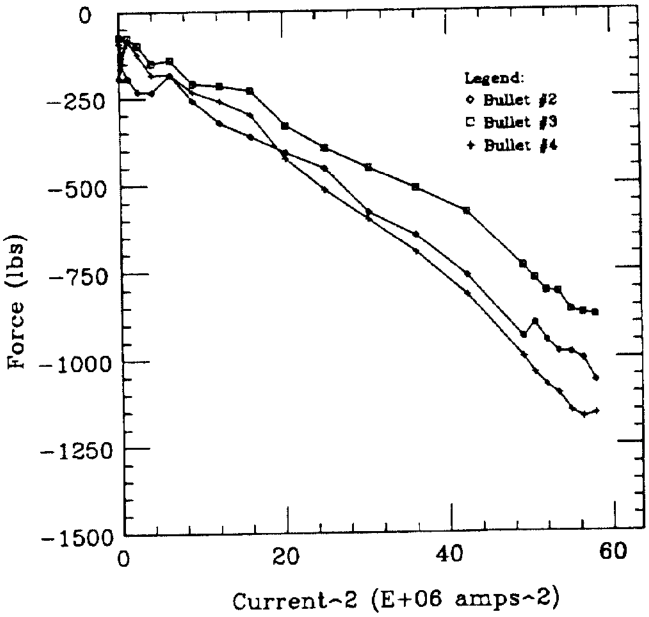

Figure 4. End force measured at one end of a magnet by 3 of 4 strain gauges (the 4th was non-functional).

IV. MAGNET QUENCH PERFORMANCE DATA

Magnets of both the standard Kapton glass cable insulation and the all-Kapton insulation reach the limit of the conductor at the three standard test temperatures (4.35 K, 3.85 K, 3.35 K). Three recent magnets (DSS019, DSS020, DSS021) have standard Kapton/glass insulation but otherwise similar construction to the all-Kapton magnets. The quench performance of DSS020 is typical (Fig. 5), with two outer coil quenches at 3.35 K. The all-Kapton magnets appear to have somewhat more outer coil quenches, four in DS0203 (Fig. 6). DS0213 had erratic quenching at 3.35 K but this was clearly improved by increasing the end loading of the magnet (Fig. 7). There is thus a suggestion that the all-Kapton magnets require a higher end preload to avoid outer coil quenches. Generally speaking, it is plausible that the outer coil of a magnet with all-Kapton insulation would be more sensitive to heat deposition. In a magnet, the inner coil presses against the inner edge of the outer coil, reducing its porosity to helium relative to that of the inner coil.

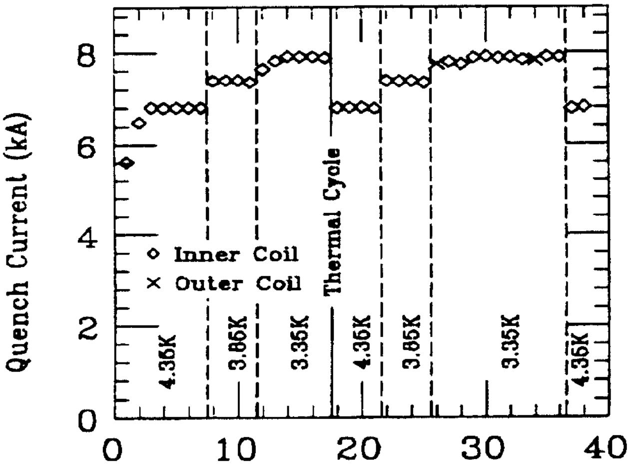

Figure 5. Quench performance of DSS020.

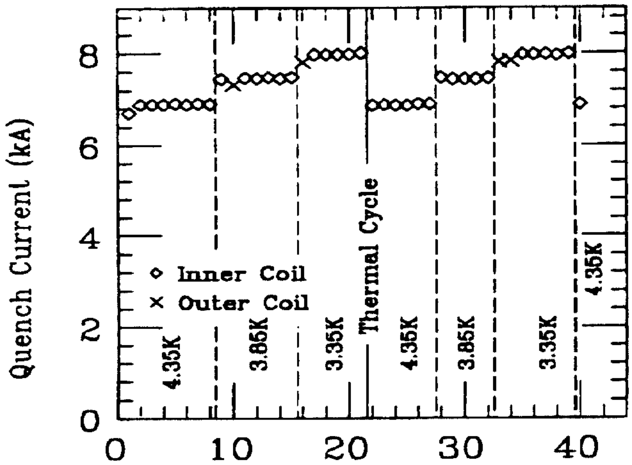

Figure 6. Quench performance of DS0203.

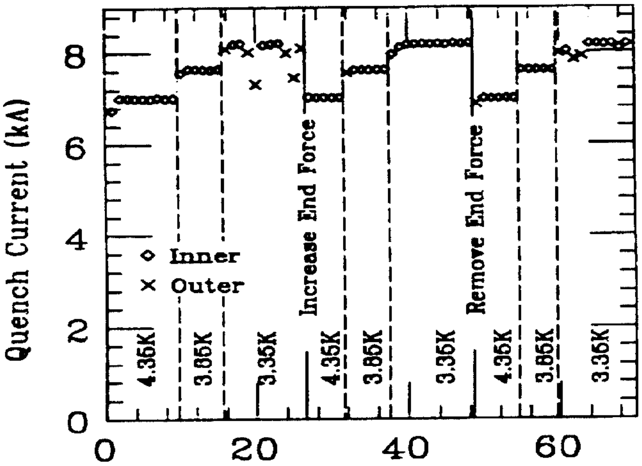

Figure 7. Quench performance of DS0213.

V. HARMONICS

The insulation used in these magnets varied in thickness so it is not useful to compare harmonics between magnets. However it is interesting that the lowest-order harmonic which is sensitive to left-right size differences in the same coil, the normal quadrupole, is better in the three all-Kapton insulation magnets (-0.04 ± 0.10 units) than in the three standard-insulation magnets (0.58 ± 0.30 units).[5]

VI. REFERENCES

1. G. Morgan, "C358D: A Revision of the SSC Coil Design C358A," Magnet Division Note 225-1 (SSC-MD-183), Brookhaven National Laboratory, Upton, NY 11973 (1988).

2. "Kapton" is a registered trademark of the DuPont Corporation.

3. C. Taylor and P. Dahl, "Dipole Magnets: A Brief Description," in "SSC Conceptual Design Report - Magnet Design Details," SSC-SR-2020B (1988).

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5. A "unit" is 10^{-4} of the dipole field at 10 mm radius.