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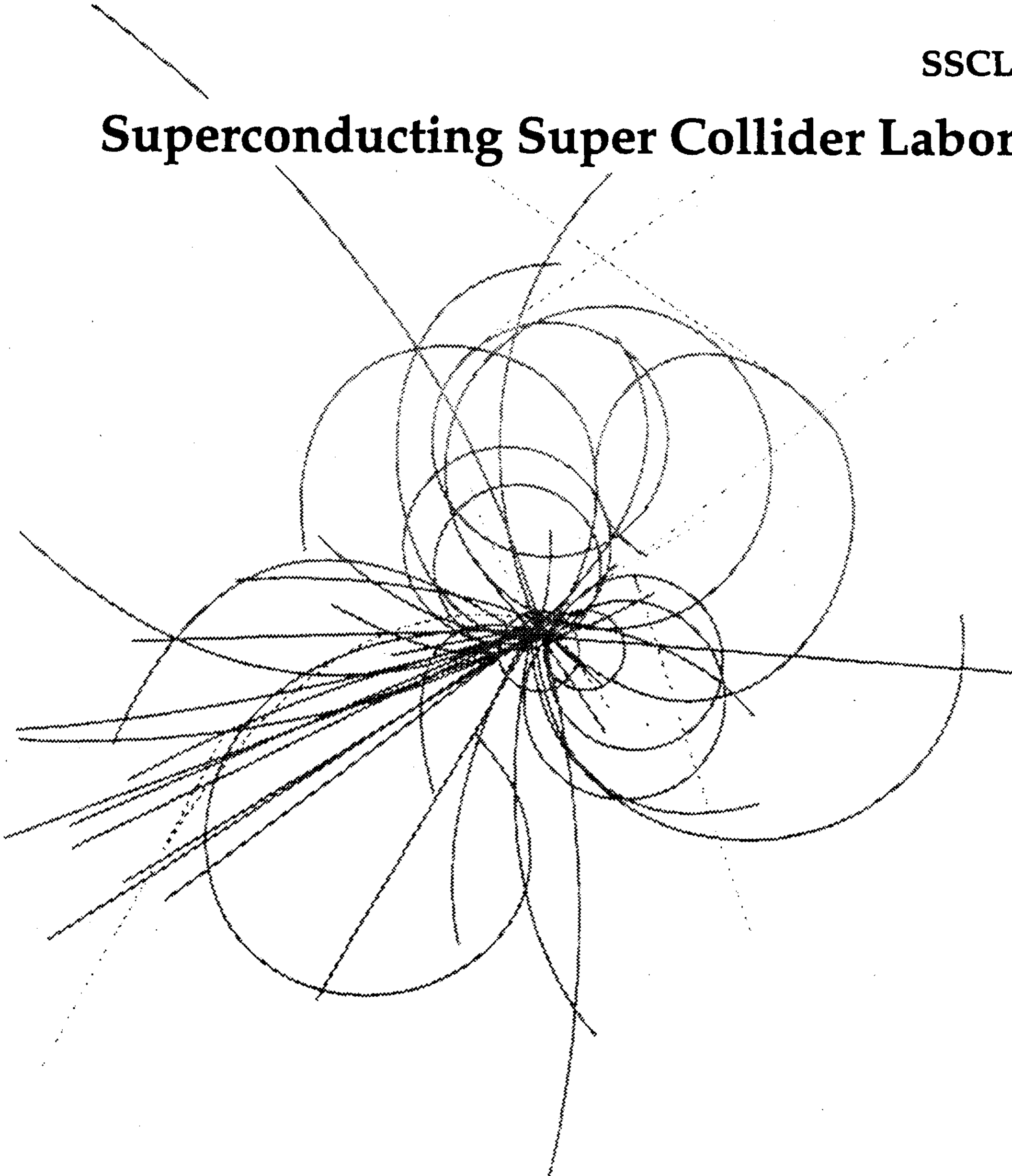

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†Operated by the Universities Research Association, Inc., for the U.S. Department of Energy under Contract No. DE-AC35-89ER40486.

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Abstract

The quench performance, ramp rate dependence, and mechanical behavior of ten full-length, 50-mm-aperture, SSC dipole magnets built at Fermilab are discussed. Cold testing of these magnets shows that the quench plateau established at 4.35 K exceeds the design value by more then 10%, virtually without training.

1 Introduction

During the past year, substantial progress has been achieved in the design and manufacture of full-scale, 50-mm-aperture, SSC superconducting dipole magnets. At Fermilab, a series of thirteen such magnets, designed jointly by Fermilab, Brookhaven National Laboratory (BNL), and the SSC Laboratory, have been built using the Fermilab full-length tooling; ten have been successfully cold tested to date. Seven of these dipole magnets, designated for the Accelerator System String Test (ASST) being carried out in Dallas, were assembled at Fermilab by General Dynamics personnel. At BNL a similar program was carried out resulting in a series of seven full-length SSC dipole magnets built and cold tested, five of which were assembled by Westinghouse personnel. In this paper we present the cold performance of ten superconducting dipole magnets built and tested at Fermilab. The magnetic field quality of these magnets is discussed in another report to this conference [1].

2 Magnet Construction and Instrumentation

The design of the full-length, 50-mm-aperture SSC dipole magnets has been previously described [2-4]; here we note only the main features. The magnetic field is generated by a two layer, cos(θ) type coil clamped by stainless steel collars. The collars serve to position the conductor as specified by the magnetic design and to restrain conductor motion under excitation. As in the 40-mm-aperture dipoles, the upper and lower collars are locked together by tapered keys and left-right pairs of collars are spot welded to provide greater horizontal stiffness. No pole shims are used, and required prestress is achieved by controlling the molded coil size.

In the Fermilab design, a vertically split yoke is employed to provide mechanical support to the collars near the horizontal mid-plane and thus to limit deflections under Lorentz force. The 4.95 mm thick, 340 mm O.D. stainless steel shell, made from two half-cylinders welded at the vertical parting plane of the yoke, serves as a helium containment vessel and as a structure clamping together the two halves of the vertically split yoke. The coil ends have current blocks, defined by machined G10 spacers, that match those of the two-dimensional cross section. The inner-outer coil splices are made outside the coil at the lead end. The coil ends and splices are clamped by a collet assembly consisting of a 4-piece G10 insulator with a tapered outer surface and an aluminum outer cylinder. An aluminum end cap is welded over the out-board end of the collet assembly. To provide axial restraint under excitation, a 38-mm thick end plate is welded to each end of the cold mass shell and the collared coil is preloaded axially against these plates by means of four set screws at each end.

The cable is insulated with the conventional Kapton plus epoxy-impregnated fiberglass tape in magnets DCA311-319. In the last four magnets (DCA320-323) alternative insulation schemes were employed using all-Kapton or all-Apical insulation coated with 3M epoxy or Cryorad adhesive respectively (to increase resistance to conductor motion).

The inner coil of each magnet is instrumented with 53 voltage taps located in the six turns nearest the poles. These voltage taps allow for a quench origin determination with the resolution of a few cm for quenches occurring in the instrumented turns.

All magnets are equipped with two collar packs instrumented with beam-type strain gauge transducers for azimuthal coil stress measurements [5]. These packs are located at positions corresponding to the minimum and maximum of inner coil size. Because of the reproducibility achieved with the full-length curing/molding press, these locations were the same in all magnets. In addition, each

This work was supported by the U.S. Department of Energy.

magnet has one assembly of load cells, mounted on the non-lead end of the magnet to measure the forces between the coil and the end plate during excitation, and gauges on the cold mass shell.

3 Experimental Procedure

The magnet cold testing was carried out at the Fermilab Magnet Test Facility at nominal temperatures of 4.35 K, 3.85 K and 3.50 K. The mass flow of supercritical helium at 4 atm was ~50 g/s.

The generic test sequence calls for unrestricted cool down (i.e. without a restriction on the temperature difference between the helium inlet and outlet ends of the magnet) and includes two test cycles, separated by warm-up to room temperature. Both testing cycles started at T=4.35 K with a strain gauge run. In such a run the magnet was ramped up to 6500 A and down to 0 A at ramp rate of 16 A/s in roughly equal steps of I^2, and data were collected at each step. This was followed by a strain gauge run to quench. Because of the significant dependence of the current at quench on ramp rate (see Sect. 4.2), lower ramp rates were used for currents greater than 5900 A. Additional ramps to quench at 4.35 K followed to establish a quench current plateau. During the first testing cycle, investigations of the ramp rate (dI/dt) dependence of the quench current were then performed at 4.35 K. During the second testing cycle, after re-establishing a quench plateau at 4.35 K, additional tests at 3.85 K and 3.50 K were performed to determine quench performance at these temperatures. Strain gauge ramps to currents 100 A below $I_{plateau}$ were taken at each test temperature. In addition, AC loss measurements were performed at 4.35 K for most of the magnets.

4 Test results and discussion

4.1 Spontaneous quenches

Figure 1 shows the spontaneous quench performance of the ten magnets tested to date - ordered in the sequence as they were tested. Magnets DCA313-DCA319, assembled by GD personnel, are those being used in the string test; DCA312 is the "technology transfer" magnet. Almost all quenches displayed in this plot occurred at a ramp rate ≤ 4 A/s except for the first five quenches observed in DCA311 (or as noted). The horizontal dashed line shows the design SSC operating current of 6600 A (corresponding to 6.7 T). All tested magnets exceeded the SSC operating current on the first or second quench and were within ~100 A of conductor limit on the subsequent quench. Fluctuations in the plateau current result from variation in the temperature at quench. There are four quenches below the SSC operating current (magnets DCA313, 314, 316, and 317). In three of the four cases (DCA313, 314, and 317) the quenches originated at the boundary of the collet end clamp and the collared part of coil, near the pole end key. This part, originally designed as a single piece, was made of two pieces to facilitate assembly. It is believed that the quenches resulted from movement of these pieces into a final stable location. This minor construction flaw was later corrected. The fourth low current quench (the first quench in DCA316) occurred in the uninstrumented portion of the coil (turn 0-13) at a ramp rate of 16 A/s. The cause of this quench is unknown but its location may indicate that both ramp rate dependence and training are involved.

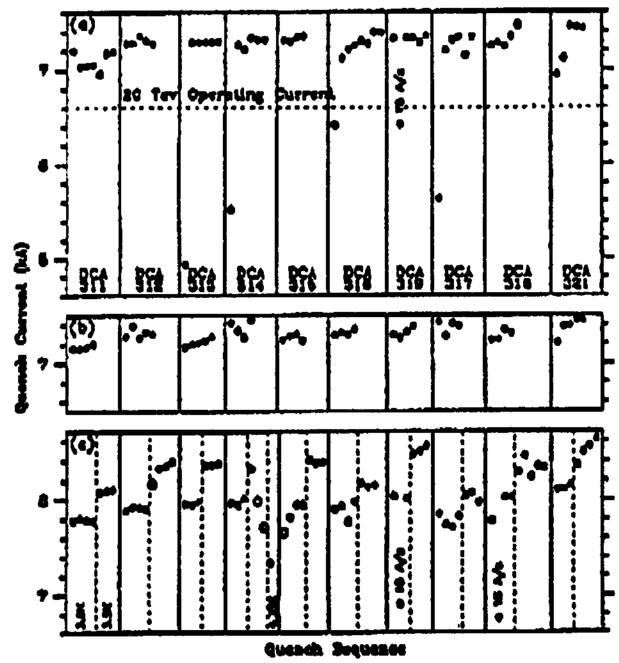

Figure 1. Spontaneous quench performance on the first (a) and second (b) cooldown at 4.35 K, and on the second cooldown at 3.85 K and 3.50 K (c). Closed (open) circles indicate quenches originating in the inner (outer coil).

During the second testing cycle no quenches below operating current were observed in any of the magnets. At the lower temperatures, a few magnets exhibited a mild training (one or two quenches) before reaching a plateau in quench current. At 3.50 K, DCA314 showed degradation in quench performance; it returned however to its previous plateau current when retested at 4.35 K.

4.2 Quenches at higher ramp rate

Early in the test program it was recognized that all magnets exhibit rather significant dependence of quench current on ramp rate. Figure 2 summarizes the quench current vs. ramp rate data for the tested magnets. Despite magnet to magnet variations, a distinctive behavior is apparent: the curves displaying ramp rate dependence for magnets DCA311, 316, 317, 318, 319, and 321 have a concave shape, in contrast to the convex curves for magnets DCA312-315. The cause of differences in ramp rate dependence between the two groups is not currently known, but may be related to differences in strand-to-strand resistance within the cable. It is worthwhile to note that magnets DCA312-315 were all made using superconducting wire supplied by IGC. All other magnets were made using wire either from Supercon (DCA311, 321) or Oxford (DCA316, 318, and 319). The only exception is DCA317, which uses IGC wire but whose slope of quench current vs. ramp rate is dramatically smaller than in the other magnets. The cable of DCA317 is from the same billet and would appear to differ from the others made with IGC cable only in that the cured coils of this magnet were awaiting magnet reassembly for more than 6 weeks.

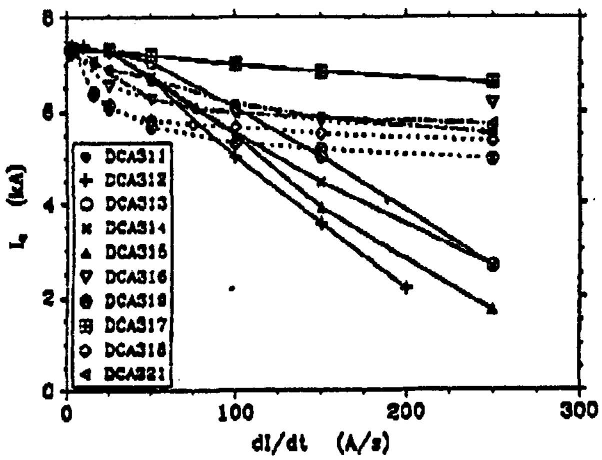

Figure 2. Ramp rate (dI/dt) dependance of quench current.

Though the overall ramp rate dependence does not affect the collider operation at 4 A/s, it is a potential problem for faster cycling synchrotrons such as the High Energy Booster.

4.3. Mechanical behavior

The azimuthal inner coil stress, averaged over the four quadrants, as a function of I^2, is shown in Figure 3 for all tested magnets.

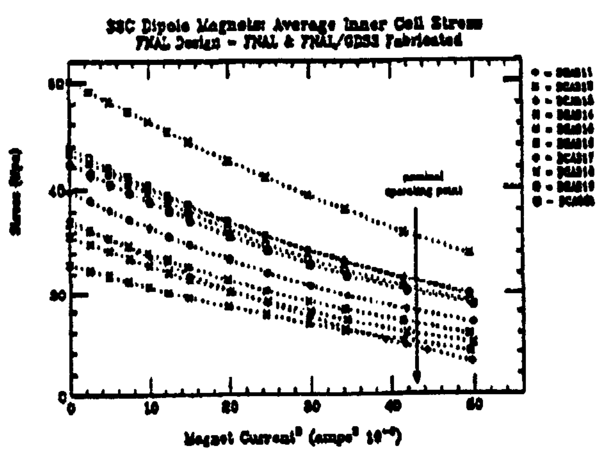

Figure 3. Azimuthal coil stress as a function of I^2 for all tested magnets. Data taken at 4.35 K during the first thermal cycle.

The average stress loss between 0 and 6500 A is about 20 MPa. The stress is essentially linear with I^2, (i.e. with force during excitation) and the prestress is still positive even at the highest current at which strain gauge data were taken (8100 A). In the all 50 mm magnets tested to date, there is no indication of inner coil unloading [6]. This is in contrast with 40-mm-aperture magnets of the DC series [7].

5 Summary and conclusions

Thirteen full size, 50-mm-aperture SSC R&D magnets have been built at Fermilab, following the baseline design. The spontaneous quench performance of all ten magnets tested to date is substantially better that in the previous 40 mm prototypes [8]. The quench current was above 95% of the conductor limit on the first or second quench in all magnets. The significant quench current dependence on ramp rate observed in these magnets is not well understood at present and is being investigated further.

6 Acknowledgements

We are grateful to the Fermilab and the SSC Laboratory design team and the Fermilab and General Dynamics production staff for their excellent work during this project. We also wish to thank the staff of the Fermilab Magnet Test Facility for their dedication and support of the test program there.

References

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[1] J. Strait et al., " Magnetic Field Measurements of Full-Length 50 mm Aperture SSC Dipole Magnets at Fermilab", presented at the XVth International Conference on High Energy Accelerators, Hamburg, Germany, July 20-24, 1992.

[2] J. Strait t al, "Mechanical Design of the 2D Cross-Section of the SSC Collider Dipole Magnets", Proceedings of the 1991 IEEE Particle Accelerator Conf.,1991, p 2127.

[3] S.W. Delchamps et al., SSC Collider Dipole Magnet End Mechanical Design, ibid, p.2185.

[4] J.S.Brandt et al., Coil end Design for the SSC Collider Dipole Magnet, ibid, p.2182.

[5] C. L. Goodzeit, M. D. Anarella, and G. L. Genetis, "Measurement of Internal Forces in Superconducting Accelerator Magnets with Strain gauge Transducers", *IEEE Trans. Mag.* 25, No. 2, 1989, pp 1455-1458.

[6] M. Wake et al., "Mechanical Behavior of Fermilab - General Dynamics Built 15-m SSC Collider Magnets", presented at the Fourth Annual International Industrial Symposium on the Supercollider, New Orleans, LA, USA March 4-6, 1992.

[7] A. Devred et al., "Status of 4-cm Aperture, 17-m Long SSC Dipole Magnet R&D Program at BNL, Part II", SSCL-487, 1991.

[8] J. Kuzminski et al., "Test Results of BNL Built 40-mm Aperture, 17-m-Long SSC Collider Dipole Magnets", *IEEE Trans. Mag.* 28, No. 1, 1992, pp 311-314.