Quench Performance of 50-mm Aperture, 15-m-Long SSCL Dipole Magnets Built at Fermilab


July 1992
Quench Performance of 50-mm Aperture, 15-m-Long SSCL Dipole Magnets
Built at Fermilab

J. Kuzminski, T. Bush, R. Coombes,
A. Devred, T. Ogitsu, et al.

Superconducting Super Collider Laboratory†
2550 Beckleymeade Ave.
Dallas, TX 75237

July 1992

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
Quench Performance of 50-mm Aperture, 15-m-Long SSC Dipole Magnets
Built at Fermilab

J. Kuzminski, T. Bush, R. Coombes, A. Devred, J. DiMarco, C. Goodzeit, M. Puglisi,
P. Sanger, R. Schermer, J. C. Tompkins, Y. Yu, and H. Zheng
SSC Laboratory, 2550 Becklismade Avenue, Dallas, TX 75237 USA

T. Ogitsu
SSC Laboratory and KEK, National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305, Japan
R. Bossert, J. Carson, S. W. Delchamps, S. Gourlay, R. Hanft, W. Koska, M. Kuchnir, M. J. Lamm,
Fermil National Accelerator Laboratory, Batavia, IL 60510 USA

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 4.5 K exceeds the design value by more than 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-outter 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-
load 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 \( \Delta I \), 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 (\( \frac{dI}{dt} \)) 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 \( I_{\text{plateau}} \) 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
\( \leq 4 \text{ A/s} \) except for the first five quenches observed in
DCA311 (as noted). The horizontal dashed line shows the
design SSC operating current of 6500 A (corresponding
to 6.7 T). All tested magnets exceeded the SSC operating
current on the first or second quench and were within \( \pm 100 \text{ A} \)
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 it's 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
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 (DCA31, 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) dependence of quench current.](image)

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.](image)

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