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CONSTRUCTION AND TEST OF 1.8M DIPOLE DSS013

C. Goodzeit, J. F. Muratore, P. Wanderer

June 24, 1989

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SUMMARY.

This magnet was the first to be assembled with "line-to-line" fit of the yoke-collar assembly. The tapered keys were inserted in the collars using both vertical and horizontal force, as is standard. The magnet quench performance was good. At 4.35K, it reached a plateau at 6.9T after two training quenches. After a thermal cycle the magnet's only quench below plateau was within 1% of the plateau current. The magnet reached 8T with little additional training. (Erratic performance at 8T was traced to the magnet's hookup to the test stand.) The multipoles were very good. The strain gauge data indicated that the coils were not unloaded at 7.4 kA. The results have been summarized in a conference paper (Appendix A). This note adds quench location and strain gauge data to that presented in the paper, and updates the multipole analysis.

QUENCH HISTORY AND LOCATION

With DSS013, as with previous 1.8 m SSC dipole magnets, the quench test procedure consisted of training by ramping up the magnet current at a rate of 16A/s until a quench was generated, and repeating this until the quench currents achieved had reached a four-quench plateau, within an allowable range of 30A. Since it was shown to have no apparent effect on the plateau quench currents in the DSS012 tests, the time between quenches was reduced to 1/2 hour. Training was performed at the SSC operating temperature of 4.35K (nominal), where the central magnetic field is 6.9T, then again at the subcooled temperatures of 3.85K and 3.35K, where the central field is about 7.6T and 8.1T, respectively. This schedule was then repeated after a warm-up to room temperature and recooling (thermal cycle). The training at subcooled temperatures is done to test the magnet to the limits of its mechanical performance under the stress of the higher magnetic fields possible at the lower temperatures. In addition, at the end of each set of plateau quenches, strain gauge measurements were made every 500A until the magnet quenched.

Figure 1 gives the quench history of the magnet and shows each of the training and conductor-limited (plateau) quenches by symbols which distinguish between upper and lower coil quenches. As in DSS011, DSS012, and DSS014, all quenches in DSS013 occurred in the inner coils, as expected. The training quenches were located mostly in the ramp-splice region of the upper or lower inner coils. All conductor-limited plateau quenches started in the upper inner coil except for one quench

after a strain gauge run. As seen in Fig. 1, the quench currents are all very consistent (except in the 8.1T test after the thermal cycle, as will be discussed later). However, on studying the quench location details in Table 1, it is noticed that the quench locations are not quite as consistent as in DSS014. Most plateau quenches at 6.9T were closer to the ramp-splice and were in the same location as the training quenches; whereas, in DSS014, the plateau quenches were all in a long middle straight section of the pole turn (T16SS). At 7.6T and 8.1T, however, the plateau quenches in DSS013 were mostly in T16SS, as in DSS014.

Details of each quench as to temperature, current, and location, are given in Table 1. As can be seen, the conductor-limited quenches at 4.35K, 3.85K, and 3.35K were at average plateau values of 6919 A, 7570 A, and 8095 A, respectively; the corresponding calculated short sample limits at each temperature were exceeded by 1%, 3%, and 4%, respectively. It should also be noted that the average quench currents at each test temperature after the thermal cycle were slightly lower, by about 0.4%, than they were before the thermal cycle. This can be accounted for by a 0.02K increase in the magnet temperature.

As can be seen from Fig. 1, there were eight training quenches during the testing schedule. Four of these originated in the short straight section adjacent to the ramp-splice region, close to the tap 16G (tap 16G is about 1/2 inch into the G10 box which houses the ramp-splice itself). Three were in the lower inner coil and one in the upper inner, where all the plateau quenches occcurred. This differs from DSS014, where three out of the four ramp-splice training quenches were in the upper coil like the plateau quenches. Calculation of the approximate quench origin locations for the ramp-splice training quenches places the start point about 1 - 2 inches from the tap 16G on the straight section side of the G10 box. The first three such quenches started outside but near the G10 box while the last one happened inside the box. These quenches were essentially the same as for DSS014.

The magnet initially quenched, at 6.9T, in the upper coil in the left hand straight section of turn 13, which is adjacent to the thick copper wedge on the midplane side. Its location can be placed about 1 inch behind the ramp and this puts it in the same axial region as the ramp.

The next training quench started in the lower coil pole turn return end section (T16RE), but in the left hand straight section part about 1 1/2 inches from spot heater 4. The other quench which occurred in the T16RE was at 8.1T (before the thermal cycle) and was located at the position of spot heater 4, about 11 inches from the tap 16C. Since the quench propagation times for these are similar to those for a quench triggered by the spot heater 4 itself, it is inferred that the T16RE training quenches might be related to the presence of

that device on the cable.

As can be seen by studying Fig. 1, the second T16RE training quench was the second training quench which occurred at 8.1T (before the thermal cycle) and was separated from the first quench (a ramp-splice quench in the lower coil) by an apparent plateau quench. This behavior indicates that at 8T the magnet first trained in the lower coil and then had to train again in the upper coil. Similar behavior was seen in DSS014 at 8.1T.

The only aberrant behavior exhibited by DSS013 appeared at 8.1T after the thermal cycle, where, after apparently showing one training quench (data for locating this quench origin was lost), the magnet quenched at abnormally low currents. The start locations for these quenches,denoted "L" in Fig. 1, were placed at lead connections outside the magnet and the quenches were therefore not due to any problem with the magnet itself.

Voltage tap data indicate that these aberrant quenches originated in a section of magnet lead which passes from very low field to very high field. From the plots of magnet voltage versus time in Fig. 2 it can be seen that the development of a typical conductor-limited quench (top) is much faster than the development of the abnormal quenches (bottom), indicating that the quench originated at a current far below the conductor limit. (Note that the vertical and horizontal scales of the plots are quite different.) Data from the abnormal quenches were compared with data at the same temperature and current generated by a spot heater located in the high field region of the magnet midplane. These data indicated that the abnormal quenches originated in a low-field region. The lead region of the magnet was inspected after testing and a G10 piece was found touching the lead at the location of the quenches. (The design of this piece was changed to prevent this from happening again.)

The plateau quenches all occurred in the pole turn of the upper inner coil as expected and as was also seen in DSS014. All were in the left hand straight section of that turn (T16), but, unlike DSS014, where all were located in the middle straight section, the 6.6T plateau quenches in DSS013 originated in the ramp splice region straight section, closer to tap 16G than to tap 16A. In the other cases, the quenches were on the other side of tap 16A.

STRAIN GAUGE DATA

The coil stress data at significant points in the history of the magnet are given in Table 2 and in Fig. 3. A plot of the coil stress versus current squared up to 7.4kA is contained in Appendix A.

FIELD QUALITY DATA

A summary of the geometric multipole coefficients of the central 76cm of the magnet straight section is given in Table 3 for both cold and warm measurements. The results are given in the standard "units" (10**4/Bo at 1 cm radius). For the cold measurements, the geometric terms are obtained by averaging up-ramp and down-ramp data from 2 to 3 kA to eliminate the effect of magnetization currents. For the warm measurements, the geometric terms are obtained by averaging data at +10A and -10A to remove the effect of residual iron magnetization. For both cold and warm data, the unallowed 16-pole and 18-pole terms have been used to obtain the location of the measuring coil with respect to the magnet. (Thus, the values for b7, a7, b9, and a9 given in Table 4 are not meaningful. Upper limits for these terms can be obtained from the data before centering and are at most 0.02 units at 2.5 T.)

A plot of the sextupole versus current, which demonstrates the small effect of saturation, is given in Appendix A. More complete presentations of the multipole data are given in internal "prompt reports," TMG 395 (uncentered data) and TMG 398 (centered data). At 1.8kA, the NMR measurement of the transfer function gave the result 1.04596 T/kA.

TIME-DEPENDENT EFFECTS

A measurement of the change in sextupole with time at injection current is given in Fig. 4. The setup for this measurement was the same as for the last several magnets: spontaneous quench, AC cycle to 5.3kA, 8 minute wait at 25A idle current, ramp to 300A (3A overshoot), hold constant current, measure. Ramps were 16A/sec. The time dependence is larger than that observed in DSS6 and DSS11. Curiously, DSS13 has smaller filaments in both inner and outer coils than DSS6 and DSS11.

DSS 13

Quench #	I_Q (A)	$\dot{I}$	Temp (K)	start coil	date	File #	Comments
1	6666	16	4.344	UI	12/16/88	4	T13 SS (1' behind ramp) or LE on same side
2	6806		4.351	LI		5	T16RE but very prob. in SS very near heater
3	6938		4.35	UI		6	Ramp splice, probably in AG segment, near tap G
4	6936		4.35			7	same as Q #3
5	6925		4.36		12/19	9	"
6	6931		4.36			10	"
7	6956	0/16	4.36			11	T16 SS, ramp side, about 1" from SS tap (near spot heater)
8	7437	16	3.85	LI	12/21	23	SS of Ramp-Splice (AG segment) 2" ±1" from tap "G"
9	7587			UI		24	same as Q #7
10	7587			U		25	FAST DATA LOST
11	7578			U		26	FAST DATA LOST
12	7594			UI		27	same as Q #7
13	7596	0/16		UI		28	same as Q #7
14	7995	16	3.35	UI	12/22	29	same as Q #3
15	8115			UI		30	same origin as Q #7 (but large mechanical motion)
16	8005			LI		31	same as Q #7
17	8104			UI		32	Same as Q #15
18	8103	0/16		UI		33	same as Q #15
				THERMAL			CYCLE

B=UI

$\dot{I}$ = 0/16 ⇒ strain gauge run to quench.

QUENCH DATA SUMMARY - MAGNET DSS013
BY PW DATE 12/21/88 PAGE 1

TABLE I (page 1 of 2)

DSS013

QUENCH DATA SUMMARY - MAGNET DSS013
BY PW DATE ~~[illegible]~~ 1/5/89 PAGE 2

TABLE I (page 2 of 2)

Quench #	I_Q (A)	I	Temp (K)	start coil	date	File #	Comments (A=LI)
19	6847	16	4.35	LI	12/27	36	same as Q#8
20	6907			UI		37	AH ramp SS (similar to Q#8, only other half)
21	6905					38	same as Q#20
22	6909					39	"
23	6911					40	"
24	6905	0/16				41	S.G. Run - same as Q#7 (check t(Ac) → t(HA) for these
26	7339	16	3.85	LI	12/29	52	Ramp (GH) - but very near origin of Q#8, 19
27	7570			UI		53	AC Right SS - same as Q#7
28	7560					54	same as Q#7
29	7569					55	same as Q#20
30	7571					56	same as Q#7
31	7595	0/16		LI		57	S.G. Run - same as Q#8
32	7932	16	3.35	UI		58	No data
33	6208			LI		59	T1 Just outside of magnet (low field region)
34	8080			UI		60	same as Q#7
35	7252			LI		61	same as Q#33
36	6210	0		LI		62	Spot heater #3
37	7005	0/16		LI		63	S.G. Run same as Q#33
							END OF TEST
25	6940	16	4.35	UI	12/28	47	Same as Q#20

TABLE II
DSS013 & DSS014 COIL STRESS SUMMARIES
February 24, 1989

1. DSS013 SUMMARY

DATE	PACK1 - Straight Section Near Lead End	AVG. INNER	AVG. OUTER*	DELTA INNER	DELTA OUTER
10/ 5/88	After Collaring	7386	4777		
10/10/88	Before Shell Welding	6534	4373	-852	-404
10/18/88	After Shell Welding	6691	5601	158	1228
10/20/88	On Ass'y Floor	6619	5545	-72	-56
12/16/88	In Dewar at 4.3 deg K	4220	5143	-2399	-402
12/26/88	In Dewar at 298 deg K	6072	5360	1853	217
12/27/88	In Dewar at 4.3 deg K	3853	4950	-2219	-411

* - Average of Gauge #5&6

	PACK2 - Transition Section at Return end				
10/ 5/88	After Collaring	N/A	N/A		
10/10/88	Before Shell Welding	8144	4390	N/A	N/A
10/18/88	After Shell Welding	8202	5639	58	1248
10/20/88	On Ass'y Floor	8111	5601	-91	-38
12/16/88	In Dewar at 4.3 deg K	3508	3238	-4604	-2363
12/26/88	In Dewar at 298 deg K	7360	5543	3853	2305
12/27/88	In Dewar at 4.3 deg K	3319	3280	-4041	-2264

2.DSS014 SUMMARY

	Pack1 - Straight Section				
10/19/88	After Collaring	9390	6787		
1/19/89	On Ass'y Floor w/ Shell	9048	7927	-342	1139
1/25/89	In Dewar at 4.3 deg K	4820	4809	-4228	-3117

	Pack2 - Return End Transition				
10/19/88	After Collaring	11816	8005		
1/19/89	On Ass'y Floor w/ Shell	10345	8207	-1471	202
1/25/89	In Dewar at 4.3 deg K	7128	6054	-3217	-2153

Results of warm-cold comparison for magnet dss013 by program WARM run 5-JUN-89 at 13:28:43 16p/18p

dss013.264co is warm dsf
dss013.2455n is up ramp dsf
dss013.2465n is down ramp dsf

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Normal terms															
cold	1.00	-0.44	-2.88	-0.18	-0.57	0.00	0.02	0.00	0.05	0.00	0.07	0.00	-0.01	0.00	0.00
warm	1.00	-0.83	-2.10	-0.16	-0.65	-0.01	0.04	0.01	0.06	0.00	0.07	0.00	-0.01	0.00	0.01
c-w	0.00	0.39	-0.77	-0.02	0.08	0.02	-0.02	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00
Skew terms															
cold	~~-0.36~~	-0.69	-0.65	0.03	-0.12	-0.02	-0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
warm	~~-1.17~~	-0.37	-0.59	0.03	-0.07	-0.02	-0.01	0.00	0.00	-0.01	0.01	0.00	0.00	0.00	0.00
c-w	~~0.81~~	-0.33	-0.06	0.00	-0.05	0.00	-0.01	0.00	-0.01	0.01	0.00	0.00	0.00	0.00	0.00

Table III

DSS013 (1.8m) Initial Test and training quench locations

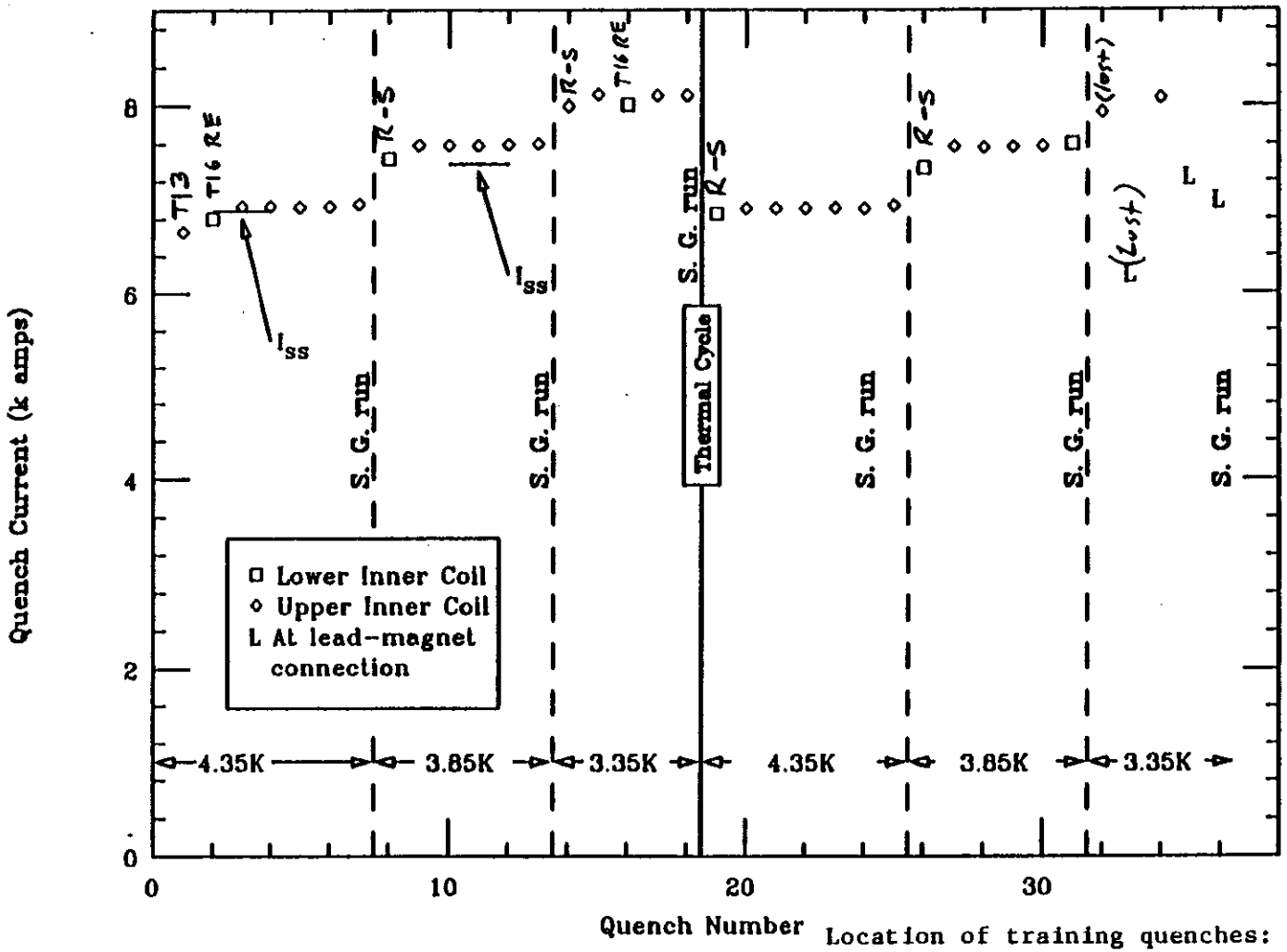


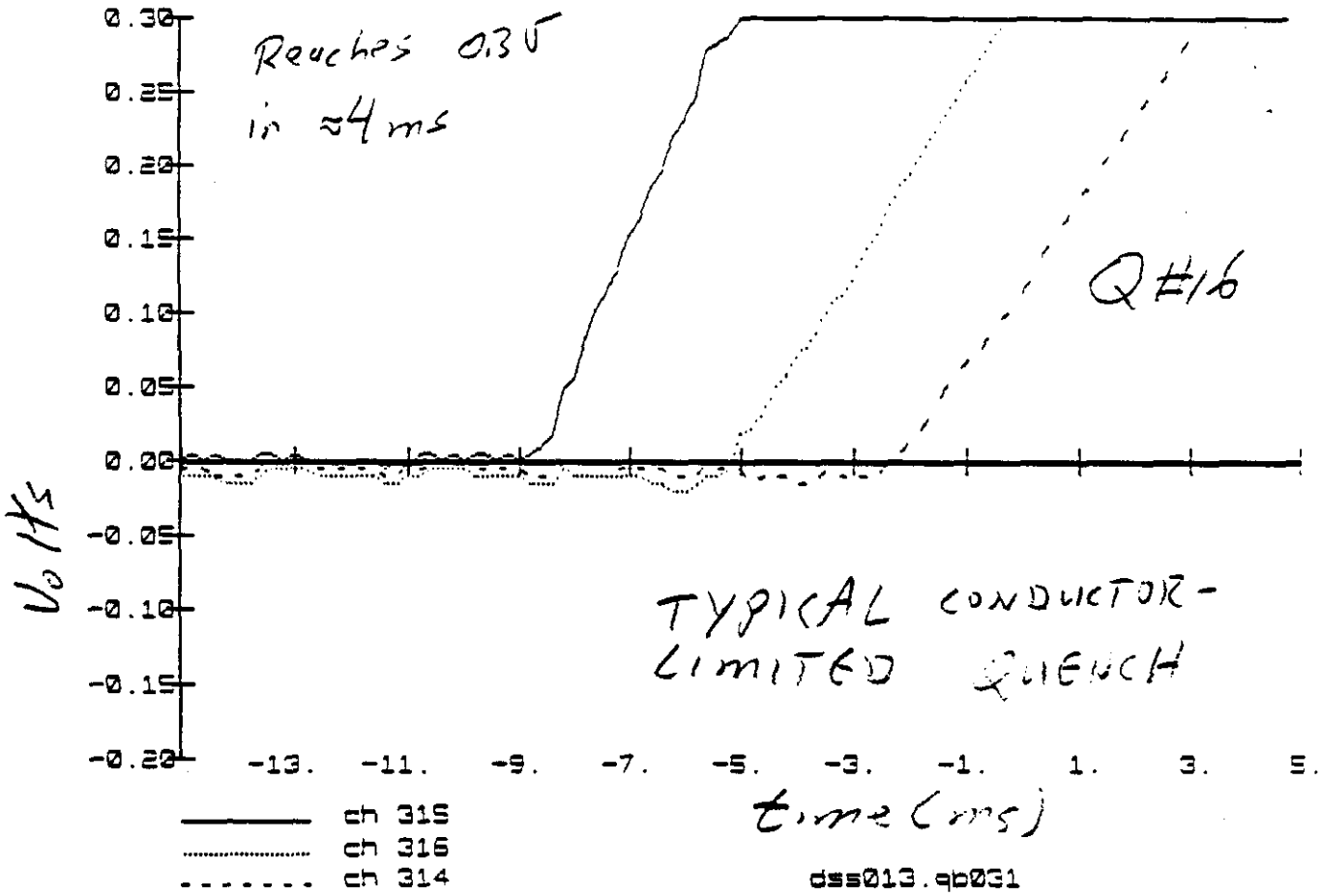
Figure 1

Location of training quenches:

1 quench turn 13 (T13) left-hand side, same axial region as ramp-splice. (Turn 13 is on midplane side of thick wedge.)

3 quenches in ramp-splice (R-S) region, 2"±1" past G10 piece in straight section (Tap 16G). Both coils.

2 quenches in pole turn return end (T16RE).


Reaches 0.3 V
in ≈4 ms
Q #16
TYPICAL CONDUCTOR-
LIMITED QUENCH
Volts
time (ms)
ch 315
ch 316
ch 314
dss013.qb031

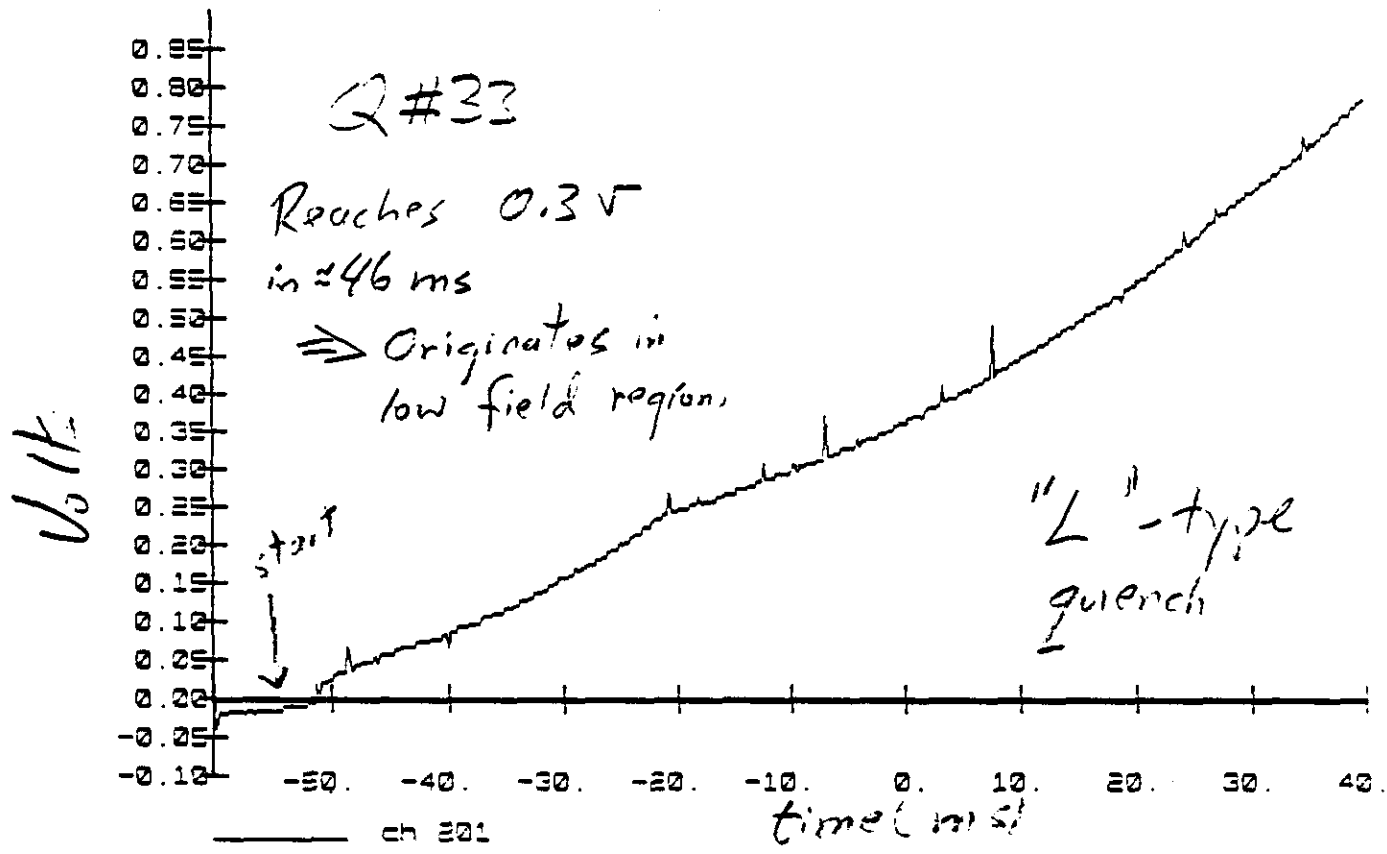
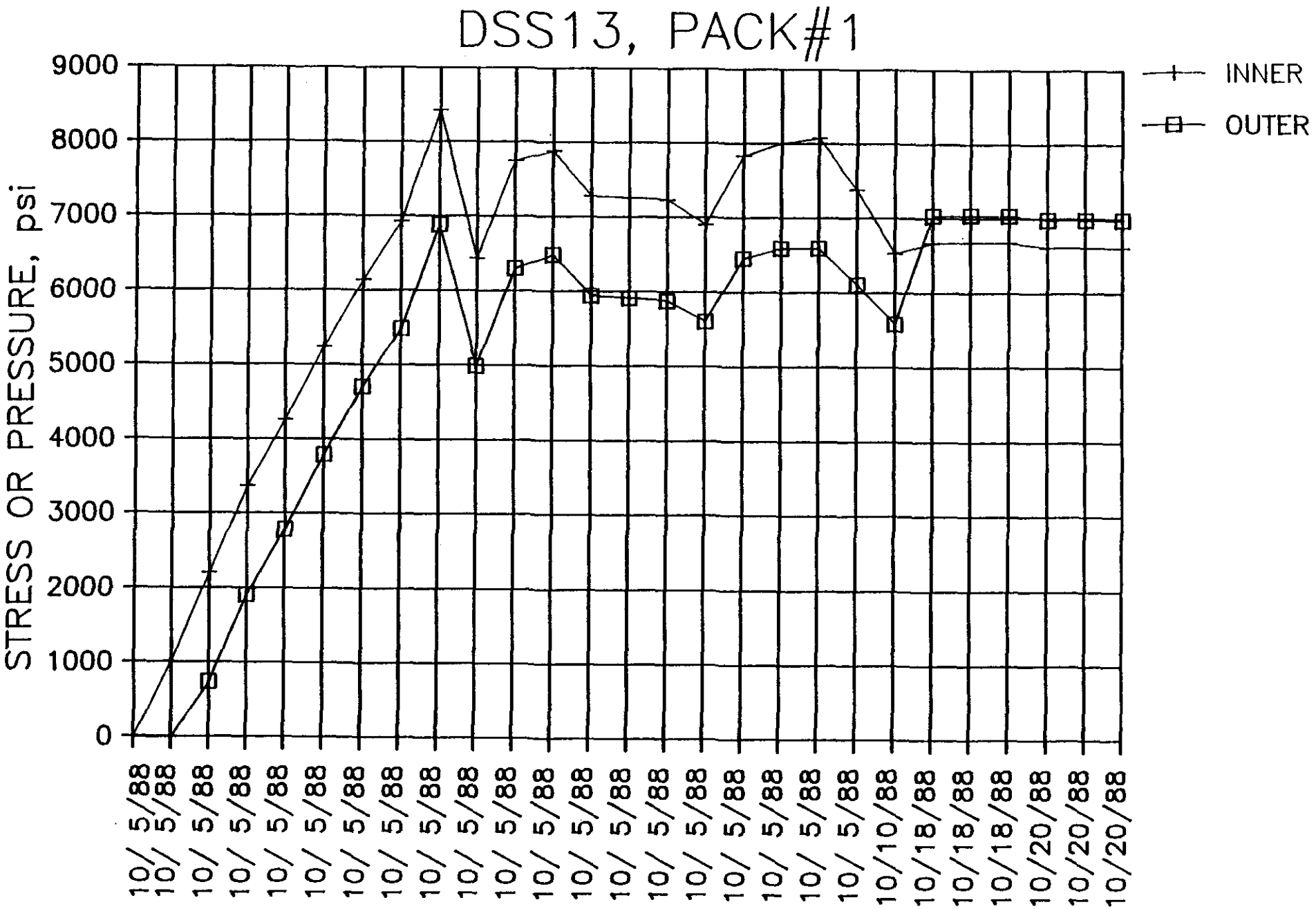

Q #33
Reaches 0.3 V
in ≈46 ms
⇒ Originates in
low field region
start
"L"-type
quench
Volts
time (ms)
ch 201
dss013.qb053

Figure 2


DSS13, PACK#1
STRESS OR PRESSURE, psi
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
INNER
OUTER
10/ 5/88
10/ 5/88
10/ 5/88
10/ 5/88
10/ 5/88
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10/20/88
10/20/88

Figure 3

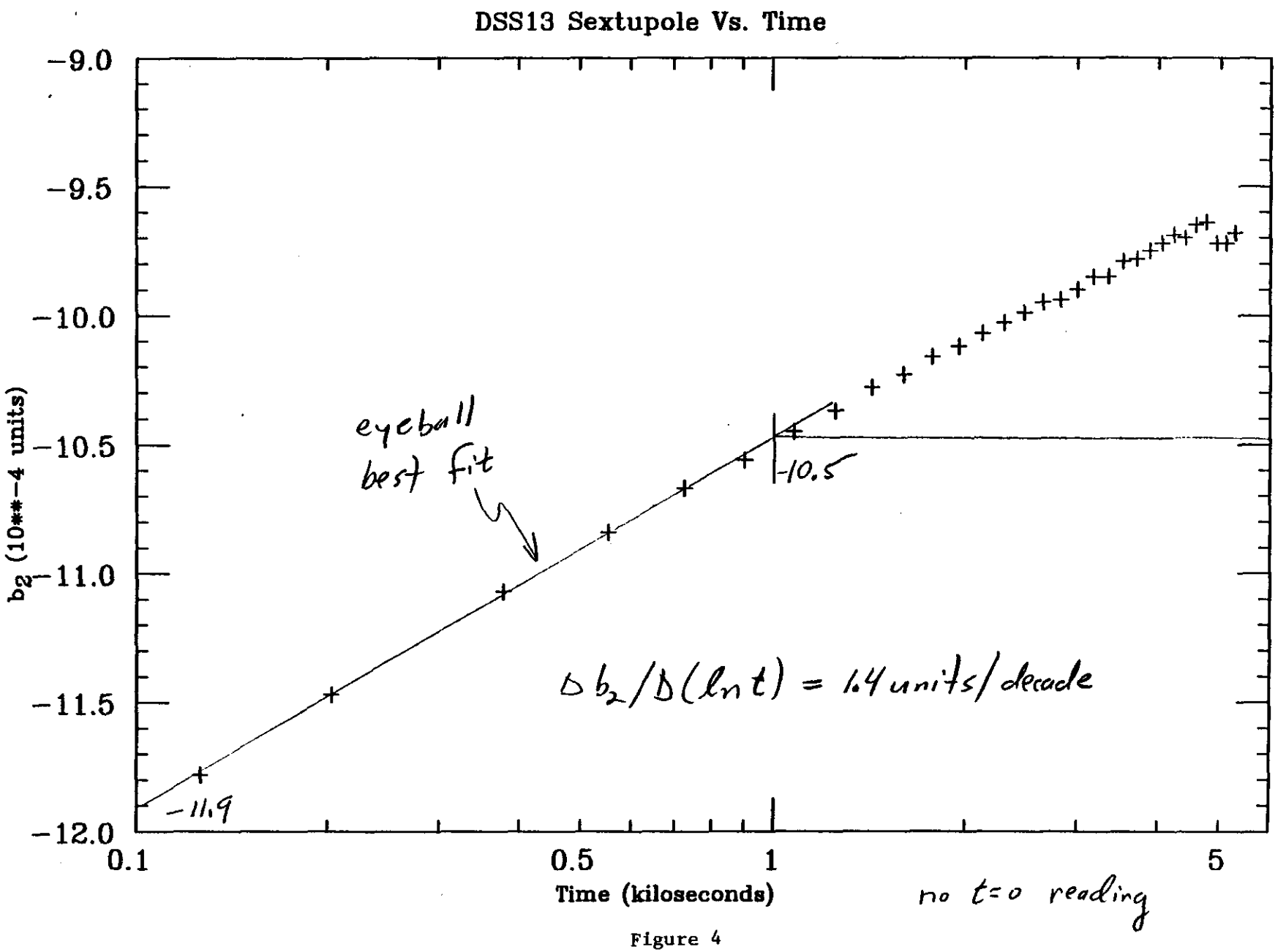
DSS13 Sextupole Vs. Time
-9.0
-9.5
-10.0
-10.5
-11.0
-11.5
-12.0
b2 (10**-4 units)
0.1
0.5
1
5
Time (kiloseconds)
eyeball
best fit
-10.5
-11.9
Δb2/Δ(ln t) = 1.4 units/decade
no t=0 reading

Figure 4

Submitted to the 1989 Particle Accelerator Conference, Hyatt Regency Hotel, Chicago, ILL - March 20-23, 1989

APPENDIX A

BNL-41898

TEST OF TWO 1.8 M SSC MODEL MAGNETS WITH ITERATED DESIGN*

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Abstract

We report results from two 1.8 m-long dipoles built as part of the Superconducting Super Collider (SSC) R&D program. These magnets contain design changes made on both the 1.8 m and the full-length 17 m dipoles to improve quench performance, magnetic field uniformity, and manufacturability. The magnets reach 8 T with little training.

Introduction

The good quench performance of two recent 17 m model dipoles [1] established the principles needed for producing magnets capable of reaching the conductor current-carrying limit with little training. Design changes have been made to implement these principles and other improvements in a more production-oriented way. Except for length, the 1.8 m magnet series [2,3] has the features of the SSC design, which is based on a two-layer cosine theta coil with 4 cm aperture. As compared to the 17 m design length SSC dipoles, these 1.8 m magnets are a faster and more economical way of testing design changes. To check magnet performance, these dipoles have been heavily instrumented with voltage taps, strain gauges and spot heaters. Existing tooling sets the magnet length at 1.8 m. The magnets are tested in liquid helium in a vertical dewar.

The design changes incorporated in these magnets are briefly summarized here. The coils were wound with a revised cross section which included asymmetric copper wedges and were molded in a single-cure procedure. In both magnets, the collars which compress the coils were locked with tapered keys. When one of the magnets was assembled, however, no pressure was applied to push the keys into the collars. The yoke inner diameter was reduced to obtain a line-to-line (zero clearance) fit to the collars. The yoke laminations were assembled to produce a monolithic yoke structure. The two yoke halves were keyed with respect to each other at the midplane.

Magnet Design and Construction

The coil aperture is 4 cm and the coil outer diameter is 8 cm. The yoke inner diameter is 11.1 cm; its outer diameter is 26.7 cm. The magnet is designed to operate at 6.6 T central field in 4.35 K helium with a current of 6.5 kA. Features of the magnet design which are not discussed in detail here are as described in the SSC Conceptual Design Report (CDR). [4]

Cable

The cable used in the inner (outer) quarter coils of both magnets came from a single reel. It had a critical current density of 2.77 (2.43) kA/mm^2 at 5 T, 4.22 K, a copper-to-superconductor ratio of 1.47 (1.74), a filament size of 6 (5)μm, and a relative resistance ratio between room temperature and 10 K of 63 (123).

Coil

A cross section of the collared coil in the yoke and helium vessel is shown in Fig. 1. The coil cross section (designated C358D) is a four-wedge non-radial block design. [5] The design differs only slightly from the previous design (C358A). The change was made to further reduce allowed multipoles.

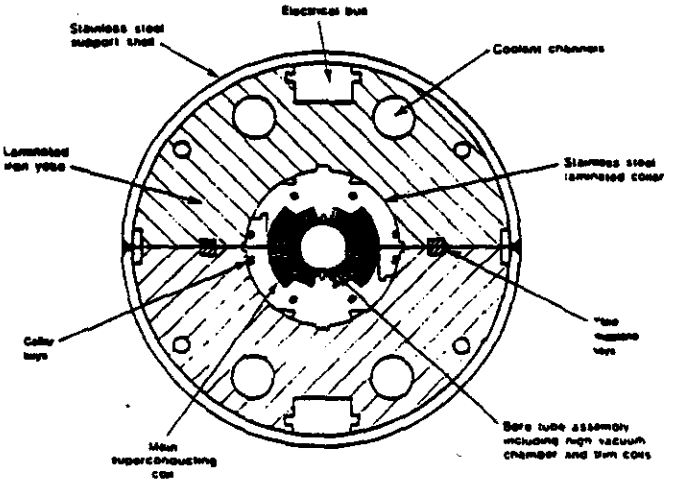

Fig. 1 Collared coil and yoke.

To eliminate the abrasion of wedge insulation during coil molding, the outer radius of the wedges was made with the same curvature as the coil. The result, in this non-radial design, was an "asymmetric" wedge.

To improve coil molding time, a "single size of the shim used in the curing fixture was determined from a size measurement made in the same fixture when the B-stage epoxy had become just warm enough to liquify. Also, further changes were made to the coil ends to make them stronger and more uniform in size.

Coil Assembly and Collaring

The G10 "ramp-splice" assembly was modified to better support and prestress the cable. This piece encapsulates the inner coil cable as the cable moves to the outer coil radius; it also encapsulates the splice between the inner and outer coils.

As in earlier models [2], the collars were punched from Nitronic 40 stainless steel and spot welded in pairs, with the pairs then left-right alternated to prevent twist in the collared coil. Tapered keys were used in the collaring. For DSS013, the usual procedure for tapered key assembly was followed, whereby the overall prestress on the magnet during collaring is minimized by using both vertical and horizontal force to seat the keys. As an experiment to test differences between this procedure and assembly with rectangular keys, DSS014 was assembled with tapered keys but with no significant horizontal force.

Yoke and Shell

The inner radius of the yoke laminations was 0.63 mm smaller than on previous magnets so that there would be a line-to-line (zero clearance) fit of yoke and unstressed collars at room temperature.

For the portion of the yoke which covered the straight section of the magnet, 15 cm-long stacks of standard iron laminations were alternated with single stainless steel laminations punched to provide channels for radial helium flow during quenches. All the laminations were stacked on rods and then compressed to a predetermined length to obtain a "monolithic" axial structure. The yoke end (including the last 5.2 cm of the inner coil straight section) contained only stainless steel laminations, bonded together.

To assure correct relative positioning, the two yoke halves were keyed together at the midplane with iron keys, as shown in Fig. 1. The stainless steel half shells were then welded around the

*Work performed under the auspices of the U.S. Department of Energy

yoke. The welding was done by hand, by two welders. The rods used to stack the yoke were withdrawn after the welding was completed and the end plates installed. A modest preload (a few hundred pounds) was applied to the coil ends via the one-piece 38.1-cm thick end plates.

Test Results

Quench Data

The initial quench program was carried out at temperatures close to those of SSC operation, 4.35 K. The helium temperature was then lowered in two 0.5 K steps to determine the mechanical limits of magnet performance. After a cycle to room temperature, these steps were repeated. As seen in Figs. 2 and 3, both magnets reached the conductor limit at fields above 8 T with little training and the training was retained after a thermal cycle. The maximum quench current in DSS013 was 8.11 kA; in DSS014 it was 8.14 kA. The current required to reach 8.0 T is approximately 8.07 kA.

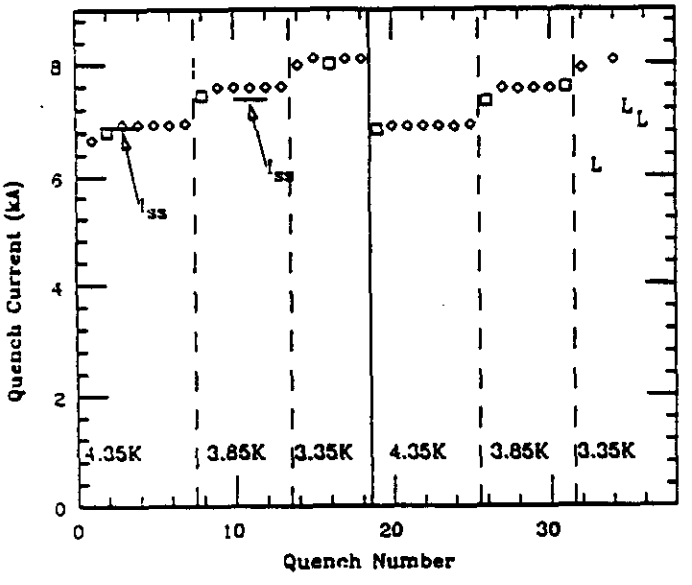

Fig. 2 Quench performance of DSS013. The solid line indicates a thermal cycle. Quenches originating in the lower (upper) inner coil are indicated by squares (diamonds). I_{SS} is the calculated quench current, based on measurements made on a short sample of the cable. Quenches designated L were due to a test stand fault.

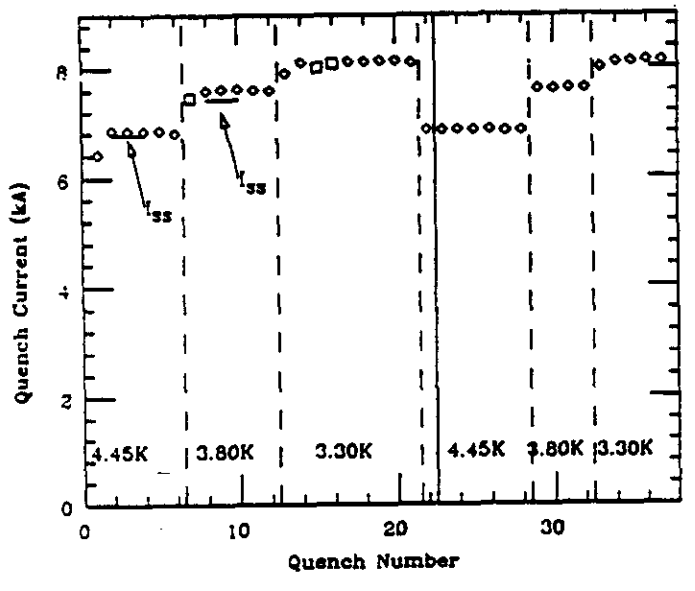

Fig. 3 Quench performance of DSS014. (Notation is the same as in the previous figure.)

Each magnet had more than 100 voltage taps, nearly all in the inner coils. Quenches which occurred when the magnet reached the current-carrying capacity of the conductor ("plateau" quenches) originated in the expected place, the pole turns of the inner coils. At 4.35 K, plateau quenches were at 6.93 kA, reproducible within about 0.01 kA.

Taking the locations of the non-plateau quenches of the two magnets as a group, the most common origin was the section of inner coil cable 5–10 cm beyond the G10 ramp-splice assembly. Other quenches also originated in the pole turn, in and near the non-lead end, and in the turn next to the largest wedge.

The longitudinal quench velocities generally agree with those in 17 m SSC dipoles. [6] These velocities are substantially higher than those measured in 4.5 m SSC dipoles [7] and in 1 m SSC models built at LBL [8]. These velocities are also faster than would be calculated in the adiabatic approximation. [6] The reason for this discrepancy is not understood at this time. Azimuthal quench velocities are about the same for all these magnets.

Stress Measurements

Each of the magnets was instrumented with two "beam-type" strain gauge packs. [9] One pack was located in the straight section, near the lead end. The other was the last pack in the straight section at the non-lead end. Each pack had four gauges for each coil, plus temperature compensating gauges. Average data from the gauge pack in the straight section of DSS013 are presented in Fig. 4. Gauge-to-gauge variations in stress make the average stress somewhat uncertain; however, the linear variation with I^2 does indicate that the coils do not become unloaded at the highest current measured, 7.5 kA.

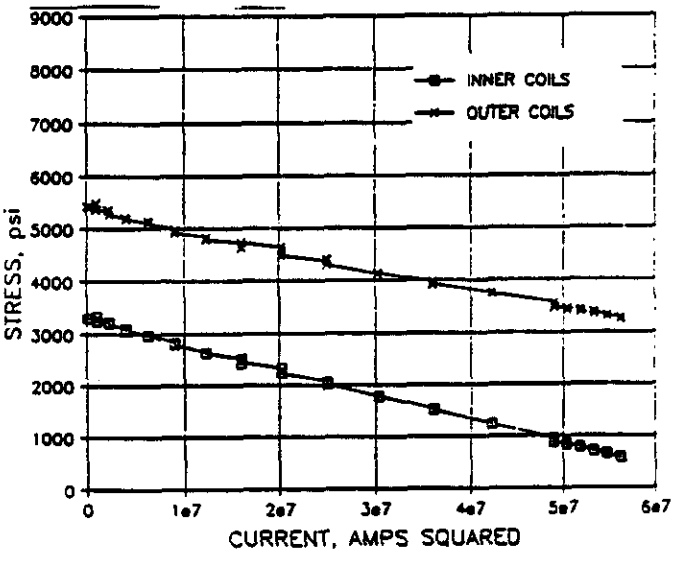

Fig. 4 Average inner coil stress vs. I^2, for strain gauge pack in DSS013 straight section.

Field Strength and Multipoles

The notation for multipoles is defined by the following equation:

$$B_y + iB_x = B_o \sum_{n=0}^{\infty} (b_n + ia_n)(x + iy)^n$$

where B_o is the dipole field, x and y are the horizontal and vertical coordinates measured from the magnet center. It is convenient to define a multipole "unit" as 10^{-4} of the dipole field, with the multipole evaluated at a radius of 1 cm.

Magnetic field measurements from the central section of the magnets are reported in Table I. The variation of the sextupole with current is shown in Fig. 5. The multipoles were measured with a

76-cm long rotating coil centered axially in the magnet. Measurements have been analyzed to remove feeddown and magnetization effects. [2]

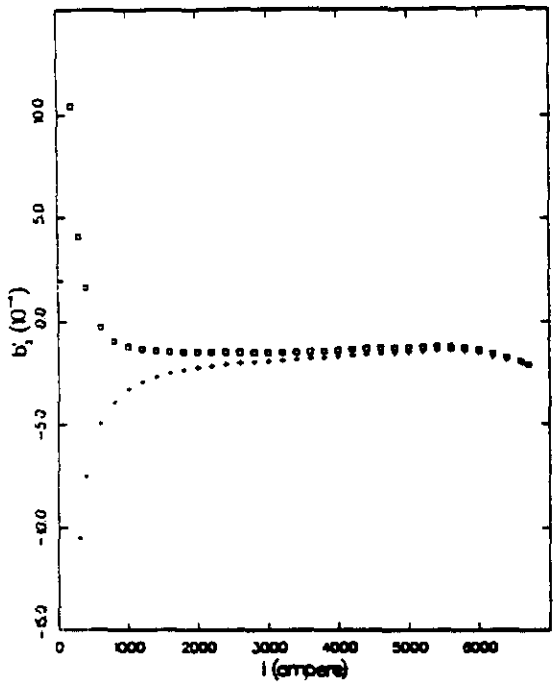

Fig. 5 Variation of sextupole with current in DSS014. The crosses are up-ramp data; the squares, down-ramp data.

Insofar as can be determined from two 1.8 m magnets, the higher order terms meet the SSC two-dimensional tolerances. [10] The low order terms deserve further comment. The quadrupole terms can be affected by the hand-welding involved in welding the shell around the yoke. Use of an automatic welding machine, to be introduced in the future, may reduce these terms. Allowed multipoles can be affected by changes in production procedures, such as the implementation of the line-to-line yoke-collar fit. It should be possible to compensate for these effects by making further small changes in the coil cross section.

Table 1
Multipole Coefficients (1 "unit" = 10^{-4} B_0, r = 1 cm)

	Measured		SSC Tolerances (body)	
Coefficient	DSS013	DSS014	Random (rms)	Systematic
a_1	−.55	−2.53	0.7	0.2
a_2	−.65	−.01	0.6	0.1
a_3	.43	−.12	0.7	0.2
a_4	−.12	−.01	0.2	0.2
a_5	−.02	−.03	0.2	—
a_6	−.02	.01	0.1	—
a_7	−.01	−.01	0.2	—
a_8	.00	.00	0.1	—
b_1	−.55	.42	0.7	0.2
b_2	−2.80	−1.86	2.0	1.0
b_3	−.19	.01	0.3	0.1
b_4	−.59	−.82	0.7	0.2
b_5	.00	−.01	0.1	0.04
b_6	.02	.04	0.2	0.07
b_7	−.01	.01	0.2	0.1
b_8	.05	.03	0.1	0.2

The field strength was measured with an NMR probe at 1.8 T. The measured transfer functions were 1.0460 T/kA for DSS013 and 1.0463 T/kA for DSS014. The calculated value is 1.0439 T/kA, with design shims.

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