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CONSTRUCTION AND TEST OF 1.8 m DIPOLE DSS011

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October 13, 1988

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SUMMARY.

The principal construction features of this 1.8m SSC R and D magnet were: shims between the collars and yoke, stainless steel collars assembled with tapered keys, welded shell, preloaded coil ends, 1.5"-thick end plates, bonded yoke modules, and an improved design of the ramp-splice. The cable used in the inner layer had 20 micron NbTi filaments, with a 1.6:1 copper-to-superconductor ratio. Also, the magnet had a much higher level of diagnostic instrumentation than previous magnets (57 voltage taps).

In its initial test at 4.35K, the magnet reached the limit of the conductor at a current of 6.7kA (about 6.8T central field) after one training quench at 6.37kA. At 3.8K, the magnet needed one additional training quench before reaching a plateau in the range 7.2kA - 7.3kA. At 3.3K, quenches were in the range 7.5kA - 7.7kA. After a thermal cycle, the magnet did not retrain at 4.35K. At 3.3K, there was one retraining quench at 7.1kA.

QUENCH HISTORY AND LOCATION.

The quench history of the magnet is shown in Fig. 1. In the figure, the conductor-limited quenches (as identified from quench location and current) are indicated by solid symbols. The conductor-limited quenches at 4.35K and 3.8K were at currents about 4% above the current calculated from short-sample measurements. This is in agreement with the performance of DSS10, which was made from the same reels of inner and outer cable [1].

This was the first magnet tested at BNL to have many more than the standard five taps on the coil. The 57 taps were read by a PC-based system, which controlled a LeCroy data logger of the same type used in testing 17m magnets at Fermilab. G. Ganetis and T. Wild brought the system on in a timely manner.

The added voltage taps were all in the inner coil, concentrated near the pole turns. Each turn had four taps so that the straight-sections could be isolated from the ends. The tap locations are given in blueprint 21E-00.08-4. Detailed information about each of the quenches is given in Table I.

Quenches which occur when the conductor is at its current-carrying limit are expected to occur at the peak field point, the pole turn (turn 16) of the inner coil, in the straight section. Quenches which did originate in this area also had very consistent quench currents, typically in a 20A range (e.g., quenches 2-6, 25-29).

Briefly summarized, the locations of the training quenches were as follows: ten quenches in turn seven straight section, five quenches in turns 13 and 14 straight section, one in the splice, and one in the return end of turn 16. Turn seven lies against the wedge in the outer coil, turns 13 and 14 are adjacent to the largest wedge in the inner coil, and turn 16 is the pole turn. Inspection of the magnet following the test revealed no obvious defects in these areas.

The remainder of this section is a more detailed discussion of quench location, currents, and temperatures. Of the training quenches, the two which occurred at the lowest currents were quench 1 (6.4kA) and quench 7 (6.9kA). These both occurred in the right-hand-side of the straight section of turn 13 of the upper inner coil. One was in the axial center of the straight section and the other very near the voltage tap, which was about 13" from the end of the straight section. Turn 13 is on the midplane side of the largest wedge in the inner coil. Quenches originating in this turn limited the performance of magnet DD10. (In DSS11, an additional three quenches at higher currents originated in the turns adjacent to this wedge.)

Most of the "training" quenches occurred when the helium temperature was lowered sufficiently (3.3K) so that the mechanical limit of the magnet's performance could be determined. Typical quench currents were 7.5kA - 7.7kA. The coil region which was the source of the largest number of these quenches was turn 7 of the lower inner coil. Seven quenches originated very nearly at the same spot, the transition from the straight section to the end on the left hand side. Two originated very near the lead end - straight section transition in this same turn. In the upper inner coil, one quench also originated in turn 7, at the return end - straight section transition.

In addition to the above, one quench originated at the splice and one in the pole turn, at the return end. By location, these could have been conductor-limited quenches, but they were at lower currents than they should have been.

MULTIPOLES AND B/I.

The magnet was assembled with inner (outer) coil shims which were 7 (8) mils smaller than the design size to achieve optimum prestress. To facilitate comparison with other magnets, this note reports the difference between the calculated values (which include corrections for non-design shims) and the measured values [2]. The allowed multipoles (averaged from 2 to 3 kA, including up-ramp and down-ramp) are given in Table II. Also given is the transfer function, B/I, measured at 1.8 kA. The unallowed terms (Table III) were obtained by choosing currents where feeddown effects can be made negligible [3].

In the Tables results from this magnet are compared to results from three other magnets with the C358 coil cross section and assembled with shims between the yoke and collars. It is hazardous to compare multipoles from a group as small as four magnets with the SSC tolerances, particularly when the last three were made with cable from the same spool. With these limitations in mind, the comparison is a useful exercise. Only the mean value of the skew sextupole a2 and the rms variation of the normal quadrupole b1 are larger than the tolerances [5]. (The variation of b1 is line with expectations for magnets built without a mechanism for centering the collared coil in the yoke.)

Measurements of sextupole versus time are plotted in Figs. 2 and 3. Details of the history of the measurement appear on the figures. One measurement was made using 8 A/s ramps; the other was made with the new default value, 16 A/sec [4].

ADDITIONAL DATA

A summary of prestress data is given in Table II of Ref. 5. Data from the spot heater quenches are presented in a separate report [6].

FOOTNOTES.

1. Direct comparison with the quench currents of DSS10

can't be made because DSS10 was tested at a nominal 4.5K. Also, beginning with DSS11, a slightly different curve of temperature vs. quench current has been adopted (see G. Morgan and W. B. Sampson, "New Coefficients for a Jc(B,T) Analytic Form," SSC-N-519, June 10, 1988).

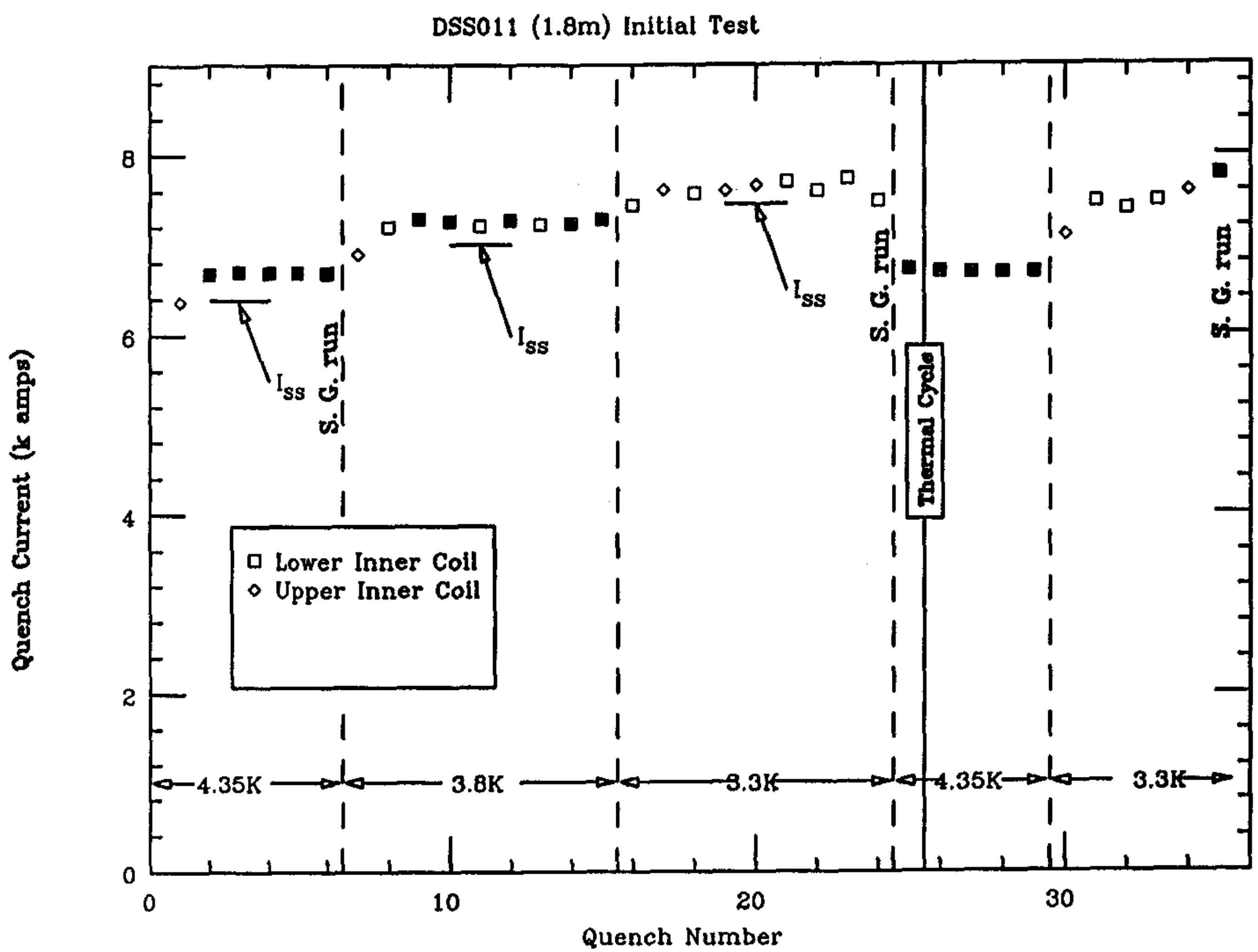
2. Measured values are given in internal report TMG 382.

3. This procedure is discussed in detail in SSC-N-416.

4. These data are compared with those from DSS6 in BNL Magnet Division Note 296-11.

5. A more exhaustive comparison between these four magnets is given in: P. Wanderer et al., "Test Results from Recent 1.8m SSC Model Dipoles," submitted to the 1988 Applied Superconductivity Conference (San Francisco) and BNL Report number BNL-41975.

6. A. Prodell, "Results from Spot Heater Quenches on DSS-011 and DSS-012," BNL Magnet Division Report 309-11 (SSC-MD-217), December, 1988.



solid symbols denote conductor-limited quenches
open symbols denote quenches at currents less than the conductor limit

FIG. 1

DSS11 Sextupole Vs. Time (Run 45)

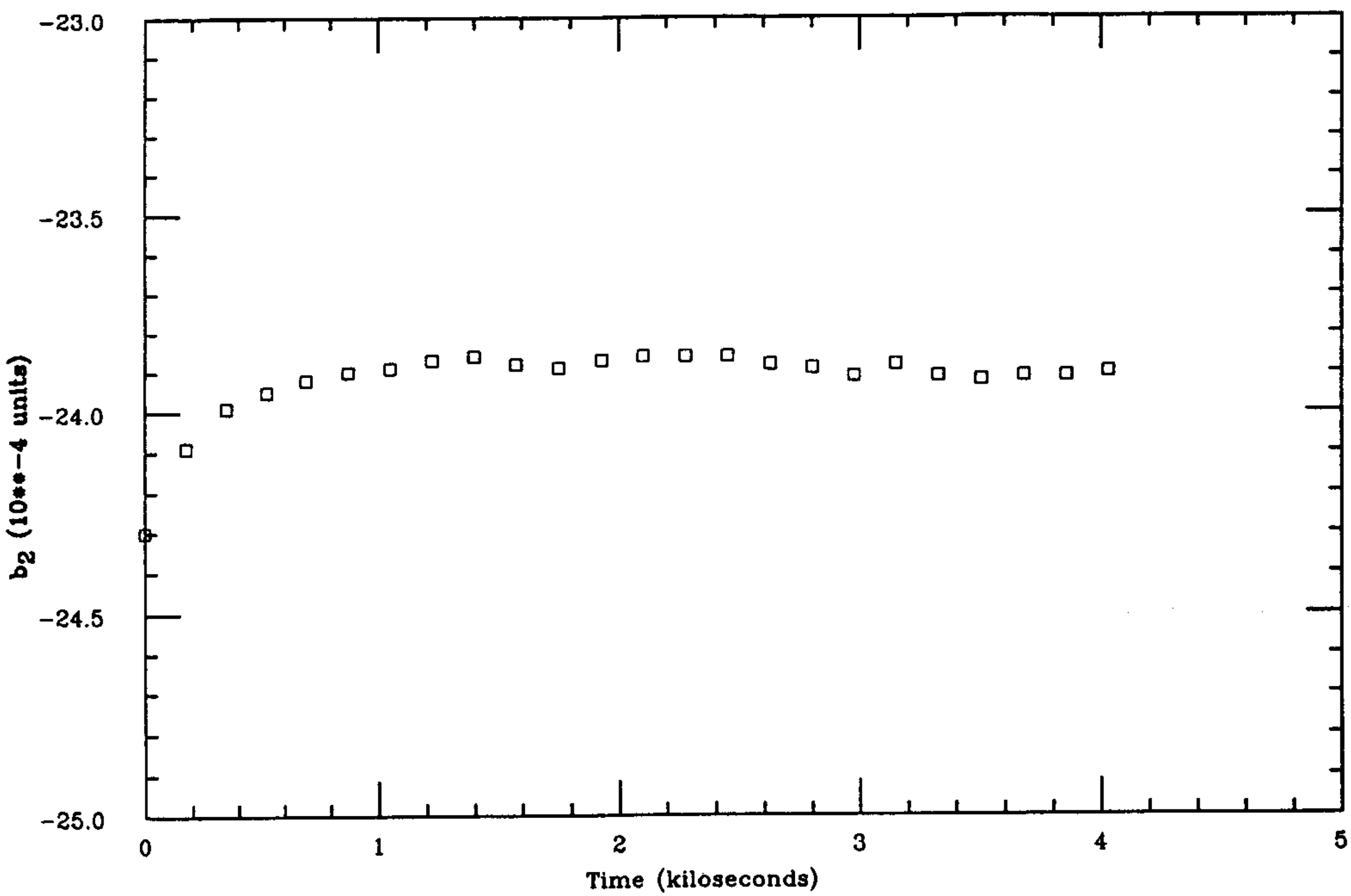


FIG 2

History: Quench (6.7kA), cycle to 5.3kA, wait 8 min. at 25A idle current, ramp to 300A, hold constant current, measure. (4.35K, 16A/sec ramps, 20 micron filaments in inner cable)

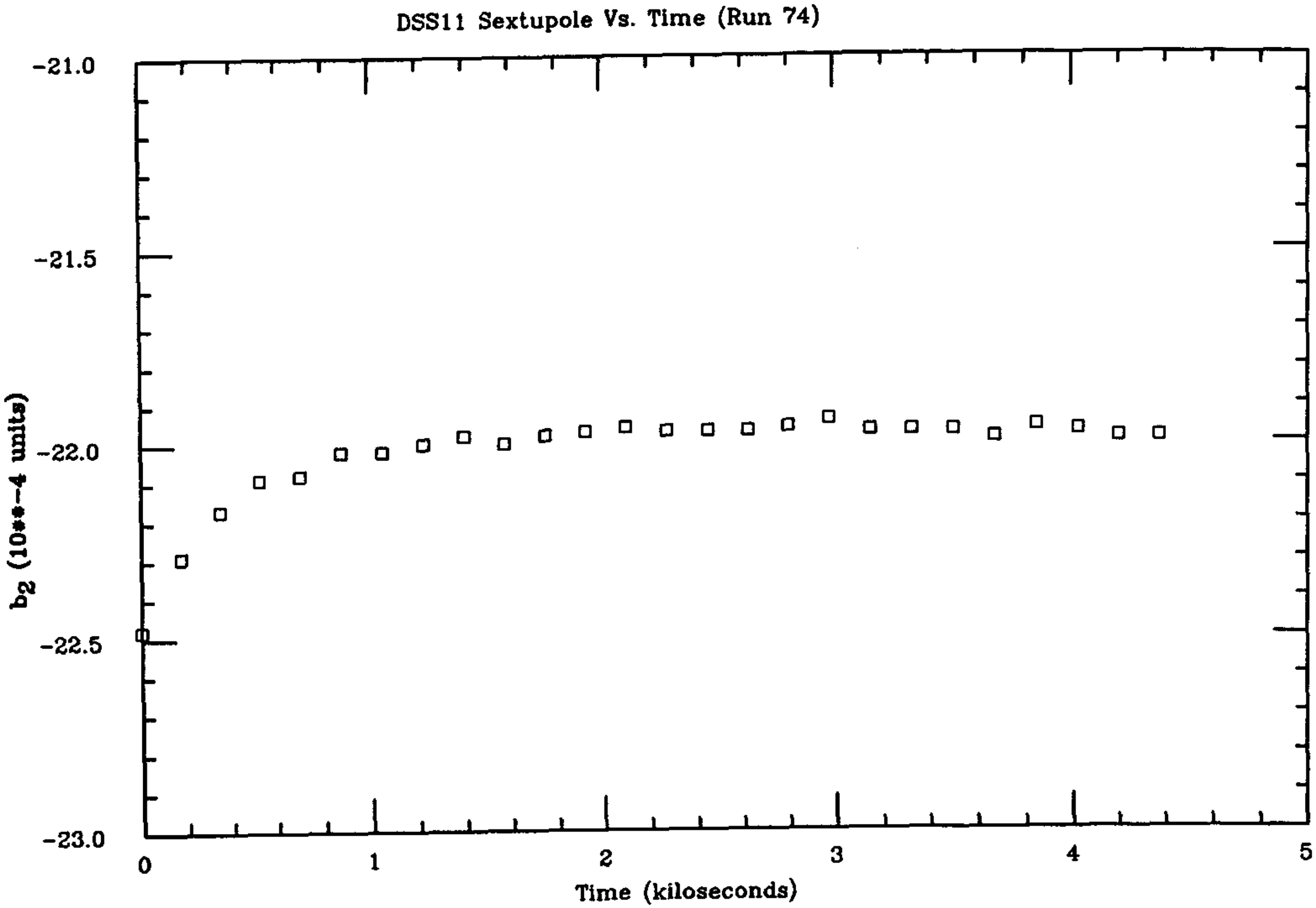


FIG. 3

History: Quench (6.5kA), cycle to 5.3kA, wait 8 min. at 25A idle current, ramp to 320A, hold constant current, measure. (4.5K, 8A/sec ramps, 20 micron filaments in inner cable.) Same run sequence as DSS6 measurement.

QUENCH DATA SUMMARY - MAGNET DSS 11

BY RW DATE 5/17/88 PAGE 1

FOR UI quenches, LHS & RHS refer to magnet assembled -- opposite of voltage tap blue print.

Temp. range	Quench #	File #	I_Q (A)	Quench Type (T = training, P = plateau)		$\dot{I}$ (A/s)	Temp[1] (K)	starting coil	Press. (psi) cntrl room	Press. (psi) WxT	Absol. T	Date	Quench Origin Segment	Quench Origin (post = turn 16)	
4.36 K	1	6	6372	T		16	4.354	UI	17.8	16.3		5/17	7A-6B	turn 13 S.S. RHS	at axial center
	2	7	6677	P		↓	4.358	LI	17.9			↓	8B-9A	turn 16 SS RHS	
	3	8	6702	P		↓	4.354	LI	17.5			↓	"	↓	same as Q#2
	4	9	6689	P		↓	4.354	LI	17.6			↓	"	↓	"
	5	10	6693	P		↓	4.362	LI	17.8			↓	"	↓	"
	6	11	6686	?	S.G. Run	0/16	4.348	LI	17.7	16.4		5/18	9A-9B	splice	37" from top 9A
3.80 K	7	12	6896	T		16	3.809	UI	10.8	9.5		↓	7A-6B	turn 13 S.S. RHS	very near return end voltage tap.
	8	13	7202	T		↓	3.80	LI	10.6			↓	9A-9B	splice	same as Q#6 (9½" from 9A)
	9	14	7289	P		↓	3.803	LI	10.9			↓	9A-8B	turn 16 SS RHS	same as Q#2
	10	15	7266	P		↓	3.788	LI	11.1	9.9		5/19	9A-8B	"	"
	11	16	7217	T		↓	3.796	LI	11.1			↓	4D-4C	turn 7 RE	LHS at transition from SS to end (2" into SS.
	12	17	7276	P		↓	3.806	LI	10.8			↓	9A-8B	turn 16 SS RHS	same as Q#2
	13	18	7225	T		↓	3.788	LI	10.6			↓	7A-6B	turns 13+14	near tops 6A/7A complex
	14	19	7240	P		↓	3.801[2]	LI	10.8			↓	9A-8B	turn 16 SS RHS	same as Q#2
	15	20	7282	P		↓	3.808	LI	10.8			↓	9B-8B	"	"
3.30 K	16	21	7444	T		↓	3.321	LI	6.9	5.6		5/20	4D-4C	turn 7 RE	same as Q 11
	17	22	7619	T		↓	3.326	UI	6.9			↓	6A-6B	7" into SS turn 13 LHS	very near top 6B
	18	23	7581	T		↓	3.311	LI	6.8			↓	4A-4B	turn 7 LHS	at SS/LE transition (or very near)
	19	24	7610	T		↓	3.314	UI	6.7			↓	4A 4C 4C 4D	NOISY IN ORIGINATING TURNS turn 7 SS (RHS) or RE	
	20	25	7666	T		↓	3.326	UI	6.8			↓	9A-8B	turn 16 in or very near to RE	
	21	26	7708	T		↓	3.291	LI	6.4	4.9		5/23	4D-4C	LHS SS at or near turn 7 end	same as Q#11
	22	27	7603	T		↓	3.296	LI	6.7			↓	4D-4C	" "	"
	23	28	7748	T		↓	3.290	LI	6.6			↓	7A-6B	turns 13 & 14	similar to Q#13
	24	29	7489	T	SG Run	0/16	3.295	LI	6.7			↓	4D 4C	LHS SS at or near turn 7 end	same as Q#11

(4) Some variation for 0 < I < 2kA (??? why)

(1) Temp from top thermometer (2) Morgan calc.

TABLE I, p. 1 of 2

"same as" - followed for 7-8 segments. - some sequence of coil sections going normal.

QUENCH DATA SUMMARY - MAGNET DSS 11

BY PW DATE 6/15/88 PAGE 2

Quench #	File #	I_Q (A)	Quench Type (T=Training) (P=Plateau)		$\dot{I}$ (A/s)	Temp ① (K)	starting coil	Press. (psi) cntrl room	Press. (psi) W+T	Absol T	Date	Quench Origin Segment	
25	43	6717	P		16	4.362	LI	17.5	16.4		6/10	8B-9A	turn 16 SSRHS same as q#2
			THERMAL CYCLE										
26	48	6688	P		16	4.355	LI	18.0	15.8		6/13	"	" "
27	49	6678	P		↓	4.356	LI	17.9			↓	"	" "
28	50	6674	P			4.356	LI	17.7				"	" "
29	51	6675	P			4.357	LI	17.9				"	" "
30	52	7100	T			3.321	UI	6.9	5.5		6/14	7A-6B	wedge turns (End wss)
31	53	7479	T			3.317	LI	6.9			↓	4A-4B	turn 7/8 LE — Q#11 same as
32	54	7396	T			3.315	LI	6.9				4C-4D	turn 7 RE LHS in SS
33	55	7474	T			3.316	LI	6.9				4C-4D	" "
34	56	7594	T		↓	3.319	UI	7.1				7A-6B	wedge turns - similar to Q30
35	57	7773	P	SC Run	0/16	3.314	LI	6.7				8B-9A	turn 16 LHS near/in RE
36	58	6030	SH #1	spot heaters	0	4.354	LI	17.9	16.6		6/15		5V③, 58ms
37	59	↓	SH #2	↓	↓	4.353	↓	17.8			↓		↓ ↓
38	60		SH #3			4.360		17.9					
39	61		SH #4			4.361		17.9					
40	62		SH #5			4.360		17.8					
41	63		SH #6			4.360		17.8					
42	64		"			4.358		17.8					25ms (13 ms chan't go)
43	65		SH#3			4.35		17.7	16.6		6/16		≈17ms (")
44	66	5360	"					17.7					58ms
45	67	4690	"					17.7					5.5
46	68	4020	"					17.6					
47	69	3350	"					17.7					
48	70	5025	"					17.7					
49	72	6522			16	4.5	LI	19.7	18.5		6/17	8B-9A	Set up by visit Turn 16 SSRHS toward RE

① Temp from top thermometer ② Morgan calc. ③ .5 V steps

TABLE I, p.2 of 2

DSS M⁄ ⌡NETS
ALLOWED MULTIPOLES, MEASURED-CALCULATED
DSS6R, 10, 11, 12

	6R	10	11	12	MEAN	σ	TOLERANCES MEAN	TOLERANCES σ
b_2	2.56	-1.80	0.99	0.61	0.59	1.80	1.0	2.0
b_4	0.61	0.43	-0.27	-0.22	0.14	0.45	0.2	0.7
b_6	-0.07	-0.20	-0.09	-0.08	-0.11	0.06	0.04	0.2
b_8	0.04	0.04	0.08	0.03	0.05	0.02	0.1	0.1
b_{10}	-0.02	0.06	-0.01	-0.02	0.00	0.04	-	-
b_{12}	0	-0.01	0	0	0.00	0.01	-	-
B/I (G/A)	+.012	-.009	.012	-.001	.0035 G/A	.010 G/A		

NOTES:

1) Measurements with coil 33
2) Standard 10^{-4} units
3) Tolerances from Chao and Tigner, SSC-N-183
4) "Measured - Calculated" adjusts for non-design shims that are required for proper magnet assembly.

TABLE II

DSS MAGNETS
UNALLOWED MULTIPOLES
DSS6, 10, 11, 12

	6	10	11	12	MEAN	σ	TOLERANCES MEAN	TOLERANCES σ
a_1	0.95	0.29	-0.32	-0.69	0.06	0.72	0.2	3.3 (0.7)
a_2	0.41	0.11	-0.10	0.71	0.28	0.35	0.1	0.6
a_3	0.17	-0.44	0.15	0.28	0.04	0.33	0.2	0.7
a_4	0.02	-0.08	0.01	0.10	0.01	0.07	0.2	0.2
a_5	0.06	-0.05	0.06	0.03	0.025	0.05	-	0.2
a_6	0.00	-0.01	-0.01	0.03	0.003	0.02	-	0.1
a_7	<0.02	-0.01	0.01	<0.01	0	0.01	-	0.2
a_8	<0.02	-0.01	<0.01	0.01	0	0.01	-	0.1
b_1	-1.06	0.13	-0.07	1.76	0.19	1.17	0.2	1.6 (0.7)
b_3	-0.23	0.02	0.04	-0.09	-0.065	0.12	0.1	0.3
b_5	-0.05	-0.03	0.01	-0.01	-0.02	0.03	0.02	0.1
b_7	<0.02	-0.01	0.00	0.01	0	0.01	0.06	0.2

TABLE III

GENERAL NOTES:
1. Measurements with coil 33.
2. Standard 10^{-4} units.
3. Feed-down ≤ 0.02 units (interpolating between pos. and neg. values of allowed multipoles to get unallowed multipole where allowed term = 0).
4. Tolerances from Chao and Tigner (SSC-N-183) and (for quadrupole) SSC-7. The quadrupole values assume shimming of collared coil in yoke.