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CONSTRUCTION AND TEST OF 1.8 m DIPOLE DSS012

P. Wanderer

November 1, 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, high Mn 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 about 60 voltage taps.

In its initial test at 4.35K, the magnet reached the limit of the conductor, 6.7kA (about 6.8T central field), after two training quenches. With two additional training quenches, the magnet reached the conductor limit of 7.7kA at 3.35K. After a thermal cycle, the magnet quenched at 6.1kA before reaching the 4.35K conductor limit. After two additional thermal cycles of the magnet, no further retraining was found. At 2.6K, the magnet quenched at currents in the range 7.7kA - 8.1kA.

QUENCH HISTORY AND LOCATION.

The quench history of the magnet is shown in Figs. 1 and 2. In the figures, 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. (At 3.35K, the quench currents exceeded the calculation by 2%.) This is in agreement with the performance of DSS10 and DSS11 which were made

The voltage taps were concentrated in the pole turns of the inner coil. Each of these turns had four taps so that the straight-sections could be isolated from the ends. The tap locations are given in blueprint 21E-00.09-4. 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 30A range (e.g., quenches 3-7, 10-14, 16-20). There were 35 quenches at the conductor limit, 20 in a straight section of turn 16 and 14 in the ramp-splice. (Data from one were lost.) Thus, there was no training due to the ramp-splice, even at the 8T level.

An additional study was done with "plateau" quenches. The time between quenches was reduced from the standard 1 hour to 1/2 hour. At temperatures from 4.35K to 3.35K, a total of eight such quenches were made. It was found that the quench currents were not affected by the reduction of time between quenches.

A total of 18 training quenches occurred during the testing. The testing included quenches at temperatures as low as 2.6K to study quench performance in the 8T range. The origin of the two initial training quenches was unusual (outer coil near the splice and turn 15 of the inner coil). Five quenches started in the straight section or end of inner coil turn 13. (This turn is adjacent to the thick wedge.) Ten quenches originated in the ten turns nearest the midplane. (The arrangement of taps grouped these turns together.) The data from one quench were lost.

At currents of 7.7kA and above, the quench performance of the magnet was limited by quenches occurring in the ten turns nearest the midplane. In order to extract as much information as possible from the existing data, a detailed study of the propagation of these quenches has been made. It is of particular interest to know whether these quenches originated in turn 7, since this turn was found to be the source of many quenches in DSS11. As discussed in the following paragraphs, it is not possible to answer this question unambiguously. The most plausible answer is that about half the quenches started near the return end of turn

7 in DSS12, and the others did not.

The beginning point was the characterization of those quenches in DSS11 which are known to have originated in turn 7, using taps which also appear in DSS12. Azimuthal propagation is characterized by the time to reach the nearest tapped turn, 12, and the the last tapped turn, 16, at the end where the quench originated. (The voltage difference between the upper and lower inner coils was used to indicate the quench starting time.)

DSS11 had seven identical quenches originating at the return end of turn 7 (T7 RE). They took an average of 24 +/- 2 ms to reach T12 RE, but reached T16 RE/SS within +/- 3ms of the same time they reached T12 RE. (One set of taps covered turn 16 return end and both straight sections in DSS11; hence the notation T16 RE/SS.) This indicates that by the time the quench reaches T12, the remaining turns in the RE being to quench about the same time, rather than in succession. The two quenches which originated at the lead end of turn 7 took substantially the same time to reach T11/12 LE (27 and 31 ms), but appear in T15/16 LE 9 and 11 ms <u>before</u> they appear in T11/12 LE.

Although the azimuthal data from DSS11 turn 7 quenches do not display a well-defined quench progression, the longitudinal data do. Of the seven quenches which originate in T7 RE, five are seen in T15/16 LE 5-6 ms after they are seen in T16 RE. (The other two appear only 1-2ms later.)

The two quenches which start in T7 LE appear in T16 RE/SS 6 and 7 ms after they appear in T 15/16 LE.

The study of DSS12 begins with four quenches which originate in the UI coil. These quenches appear in T12 RE 23-29 ms after they appear initially but are seen in T16 RE 4-5 ms before they are seen in T12 RE. Thus, the azimuthal development is similar to that of DSS11. Longitudinally, they appear in T 15/16 LE 8-12 ms after they appear in T16 RE, indicating a RE origin, again using DSS11 as a model.

Of the seven quenches in DSS12 which originate in the LI coil, two are at 3.35K. Both show the same azimuthal characteristics as DSS11 quenches. One shows the same longitudinal development; in the other, the quench appears in both T15/16 LE and T16 RE at the same time. Thus, one looks like a T7 RE origin, but the other does not.

The five quenches in DSS12 LI coil at 2.6K look rather different than the DSS11 quenches. They take from 9 to 17 ms to reach T12 RE (cp. 24ms for DSS11) and reach T16 RE 1-6 ms later. Longitudinally, they reach T15/16 LE from 8 to 11 ms after they appear in T16 RE (cp. 1-7 ms for DSS11). These data are consistent with a quench originating near the RE, about halfway between T7 and T12.

MULTIPOLES AND B/I.

The magnet was assembled with inner (outer) coil shims which were 10 (2) 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 [4]. (The variation of b1 is line with expectations for magnets built without a mechanism for centering the collared coil in the yoke.)

ADDITIONAL DATA

A summary of prestress data is given in Table II of Ref. 4. Data from the spot heater quenches are presented in a separate report [5].

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).

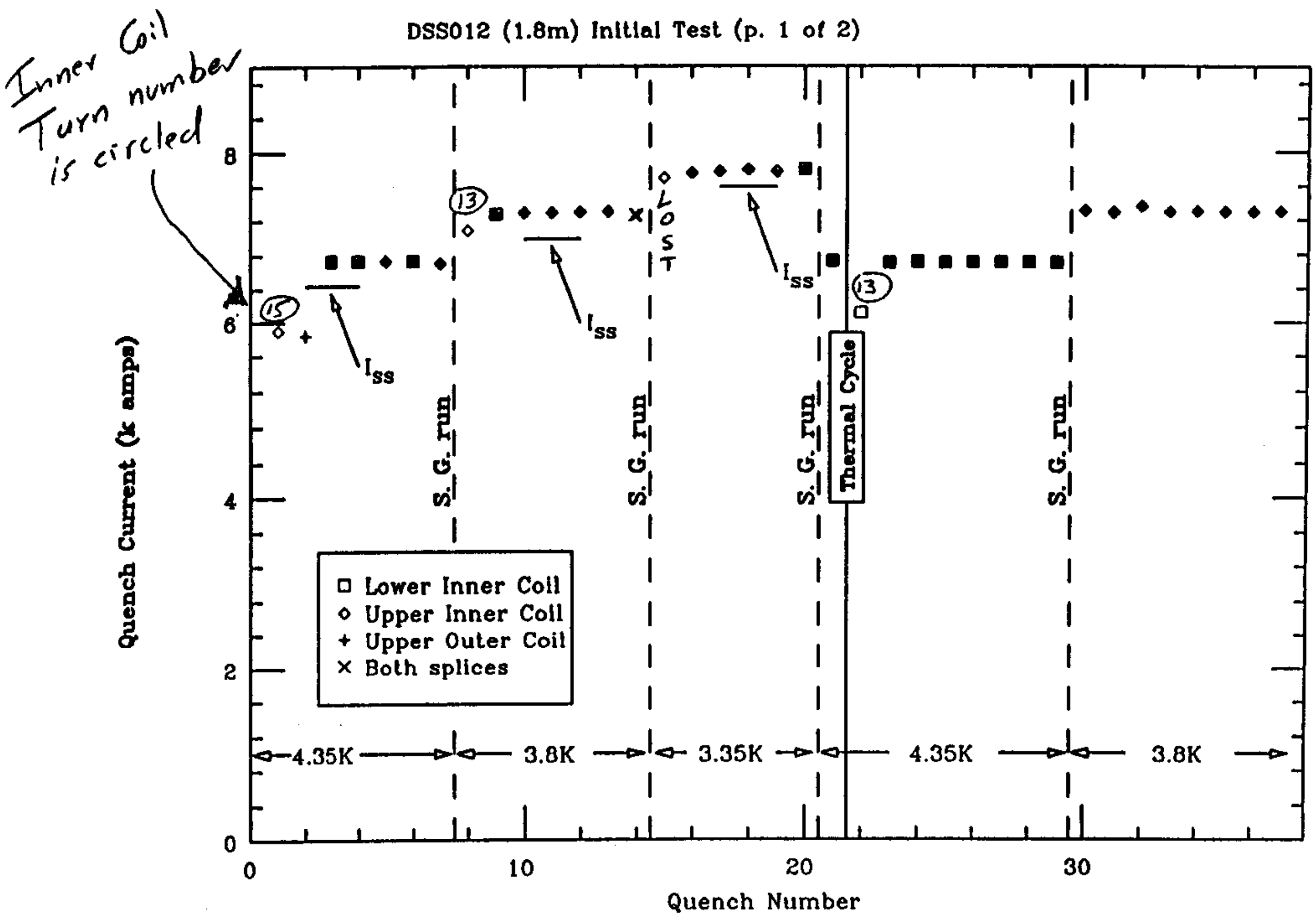
2. Measured values are given in internal report TMG 382.

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

4. 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 Fransicso) and BNL Report number BNL-41975.

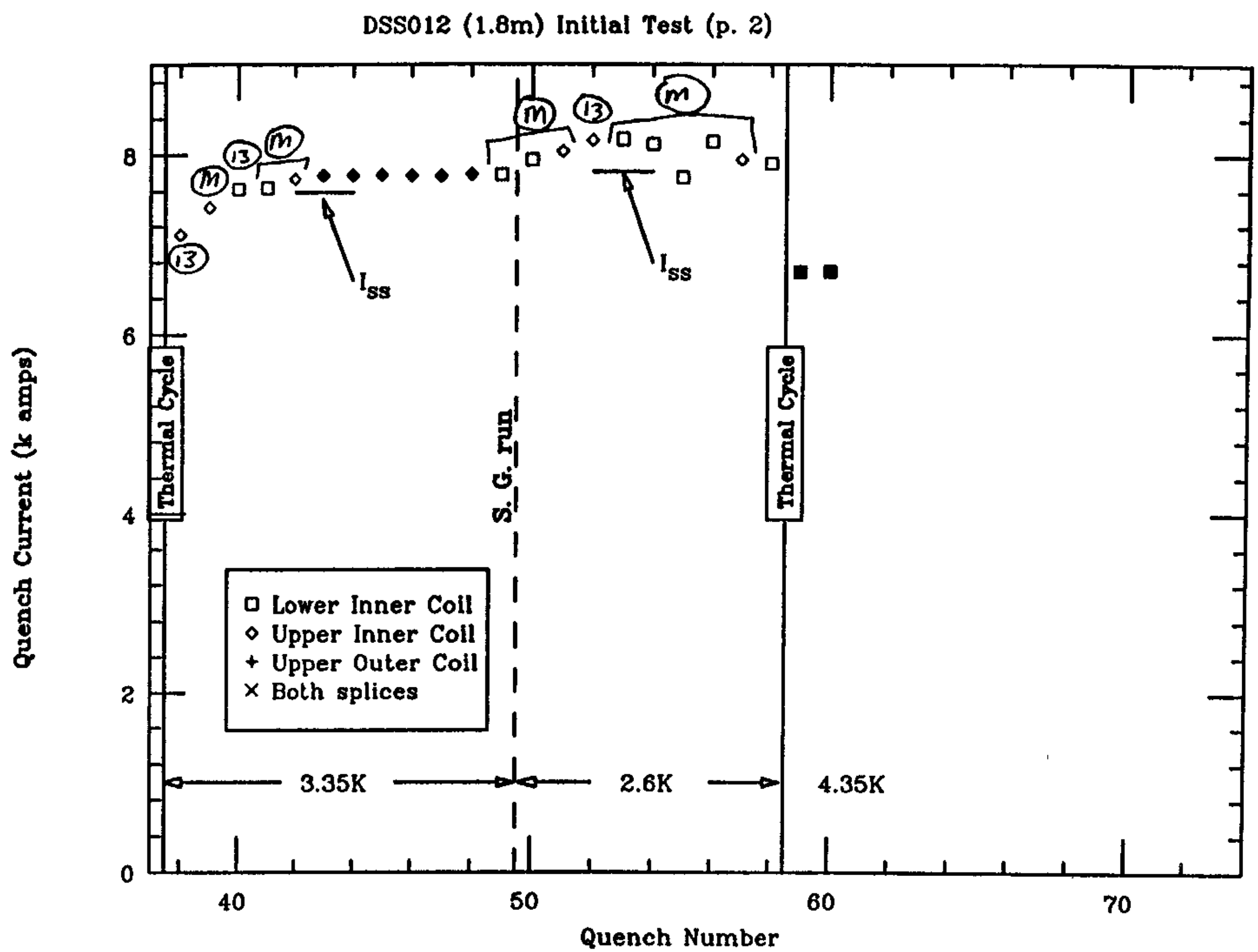
5. A. Prodell, "Results from Spot Heater Quenches on DSS-011 and DSS-012," BNL Magnet Division Report 309-11 (SSC-MD-217), December, 1988.

DSS012 (1.8m) Initial Test (p. 1 of 2)



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

FIG 1



(M) = Turns 1-10, tapped as 1 block. (Turn 1 = midplane)

FIG 2

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

DS 012

QUENCH DATA SUMMARY - MAGNET DSS012
BY P.W. DATE 7/21/88 PAGE 1

Quench #	File #	I_Q (A)	B/I [2]	B_Q (T)	$\dot{I}$ (A/s)	Temp [1] (K)	starting coil	Press. (psi) cntrl room	Press. (psi) W+T	Absol. T	Date	Comment
1	8	5895	—	—	16	4.348	UI	17.5	K.3	—	7/21	Turn 15 RE
2	9	5838			↓	4.345	UO	17.6			↓	seen in UI 20ms later
3	10	6731			↓	4.344	LI	17.5			↓	SPLICE
4	11	6725			↓	4.341	LI	17.5			↓	" - same as Q3
5	12	6730			↓	4.346	UI	17.5	16.5		7/22	Turn 16 SS LHS Toward RE
6	13	6727			↓	4.365	LI	17.6			↓	SPLICE - same as Q3
7	14	6705	STRAIN GAUGE	RUN	0/16	4.336	UI	17.8			↓	Turn 16 SS RHS near center
8	15	7089			16	3.814	UI	11.0			↓	Turn 13 SS LHS at top
9	16	7269			↓	3.814	LI	11.1	9.6		↓	SPLICE (but T13 goes 8ms later)
10	17	7289			↓	3.814	UI	10.8			↓	Turn 16 SS LHS (toward RE)
11	18	7293			↓	3.820	UI	11.0	9.5		7/25	"
12	19	7300			↓	3.826	UI	11.0			↓	"
13	20	7303			↓	3.809	UI	10.8			↓	"
14	21	7260	Strain run	gauge	0/16	3.824	see note	11.2			↓	starts in BOTH inner/outer splices at the same time!
15	22	7691			16	3.323	UI	6.9	5.3		↓	LeCroy data lost
16	23	7752			↓	3.334	UI	7.0			↓	Turn 16 SS LHS (toward RE) — Like Q10
17	24	7769			↓	3.338	UI	6.9			↓	"
18	25	7788			↓	3.340	UI	7.0			↓	"
19	26	7768			↓	3.326	UI	7.1			↓	"
20	27	7795	Strain run	gauge	0/16	3.309	LI				↓	SPLICE -
21	44	6723			16	4.351	LI	17.6	16.4		7/27	" - SAME AS Q20
		THERMAL CYCLE										

Plateau (4.35K) expected to be ≈ 6675A; 7280A @ 3.8K; 7730 A @ 3.35

[1] Temp from top thermometer [2] Morgan calc.

TABLE I (p1)

PRINT 21E - 00, 09-4 for taps
SDQUENCH_NEW Z P D
"MAGNET MAGNET"

QUENCH DATA SUMMARY - MAGNET DSS012
BY PW DATE 8/18 PAGE 2

DSS012

Quench #	File #	I_Q (A)	B/I [2]	B_Q (T)	$\dot{I}$ (A/s)	Temp [1] (K)	starting coil	Press. (psi) cntrl room	Press. (psi) W&T	Absol. T	Date	Comment
22	49	6108	—	—	16	4.352	LI	17.7	16.4	—	8/9	T13RE (≈ 3" into SS, RHS)
23	50	6700				4.354	LI	17.7			"	SPLICE - same as Q20
24	52	6712				4.340	LI	17.7			8/10	SPLICE - "
25	53	6709				4.339	LI	17.5				SPLICE - "
26	54	6706				4.343	LI	17.6				SPLICE - "
27	55	6706				4.332	LI	17.6				(½ hr.) SPLICE - same as Q20
28	56	6708				4.335	LI	17.8				" SPLICE - "
29	57	6705	Strain Gauge	Run	0/16	4.336	LI	17.5				" SPLICE - "
30	58	7307			16	3.802	U1	11.1	9.9		8/11	T16 SS LHS (2/3 of way from LE to RE)
31	59	7288				3.775	U1	11.5				" "
32	60	7364				3.779	U1	11.3				" "
33	61	7300				3.804	U1	11.0	9.7		8/12	no data
34	62	7301				3.802	U1	10.9				T16 SS LHS (same as Q30)
35	63	7297				3.804	U1	11.0				(½ hr) T16 SS RHS (≈ axial center)
36	64	7300				3.801	U1	11.0				(") T16 SS LHS (same as Q30)
37	65	7306	Strain gauge run		0/16	3.802	U1	11.0				(3") T16 SS RHS (2/3 of distance from LE to RE)
		THERMAL CYCLE (CRYO REPAIR)										
38	67	7109			16	3.348	U1	6.9	5.4		8/17	T13 SS RHS (toward LE)
39	68	7417				3.347	U1	6.8				In turns 1-10 somewhere,
40	69	7626				3.343	L1	6.8				T13 SS LHS (1/3 of way from LE to RE)
41	70	7639				3.346	L1	6.8				In turns 1-10 somewhere
42	71	7741				3.340	U1	6.8				Similar to Q39 (in turns 1-10)
43	72	7778				3.340	U1	6.8				T16 SS LHS (same as Q30)

TABLE I (p2)

"½ hr" - wait after previous quench (start of ramp to start of ramp)

[1] Temp from top thermometer [2] Morgan calc.

QUENCH DATA SUMMARY - MAGNET DSS012
BY P.W. DATE 8/18/88 PAGE 3

DSS012

Quench #	File #	I_Q (A)	B/I ②	B_Q (T)	$\dot{I}$ (A/s)	Temp ① (K)	starting coil	Press. (psi) cntrl voum	Press. (psi) W&T	Absol. T	Date	Comment
44	73	7775			16	3.336	U1	6.8			8/17	T16SSLIts (same as Q30)
45	74	7786				3.338	U1	6.8				LeCroy data lost
46	75	7780				3.335	U1	6.8				" "
47	76	7773				3.336	U1	6.7				" (similar to Q30) ½ hr
48	77	7787				3.334	U1	6.8				" (same as Q30) ½ hr
49	78	7785	strain gauge run		0/16	3.335	L1	6.8				Turns 1-10 (similar to Q41)
50	79	7950			16	2.605	L1	3.3	1.8		8/18	" "
51	80	8048				2.611	U1	3.2				"
52	81	8165				2.606	U1	3.2				T13RE (≈3" into SS from end, 4.4s)
53	82	8177				2.594	L1	3.2				T16RE in BOTH halves *
54	83	8121				2.617	L1	3.3	2.1		8/19	Turns 1-10 (similar to Q41)
55	84	7753				2.623	L1	3.2				" "
56	85	8146				2.611	L1	3.0				" " ½ hr
57	86	7950				2.612	U1	3.1				" ½ hr
58	87	7904	SG RUN TO 5KA	mell quench		2.619	L1	3.1				" "
				THERMAL CYCLE								
59	93	6692				4.344	L1	17.7	16.2		8/23	SPLICE
60	94	6694				4.334	L1	17.8				SPLICE
												end of spont. quenches

TABLE I (p3)

① Temp from top thermometer ② Morgan calc.

½ hr - as on previous page

* short file - analyzed printout.

max $\dot{I}$

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.