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PERSISTENT-CURRENT MULTIPOLES IN THE SSC DIPOLES

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Summary

The measured persistent-current multipoles in the BNL and LBL short dipole models are surveyed and scaled to the critical-current density and filament size anticipated for the superconducting cable in the SSC dipoles.

Survey of Measured Multipoles

Table 1 lists the values of the normal persistent-current multipole coefficients b_2, b_4, and b_6 at the SSC 1 Tev injection field (0.331 T) measured[1] in nine BNL 1.8-meter dipole models in the series DSS002, -12. Each entry is the difference between the value at 0.331 T and the extreme value at high field (about 5.8 T) where persistent-current effects are presumably quite small but before yoke-saturation effects are evident. The BNL procedure in these magnetic measurements has been to ramp the dipole once up to high field at 16 amperes/second and back to low field immediately before each measurement cycle. The excitation cycle without measurement takes about 15 minutes, the measurement cycle about two hours.

Also listed in Table 1 are the cable and strand identification numbers and physical characteristics[2] for both the inner and outer coil layers that were available to us. Double entries are listed in Table 1 in a few cases where the various sources disagreed. The only serious disagreement is for DSS007, where the inner-coil filament diameter is listed both as 5 and as 23 microns. Because of the relatively large values of all the persistent-current multipoles, the 23-micron value is undoubtedly the correct one.

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[1] From BNL Testing and Measuring Group internal reports TMG-359, -361, -365, -369, -370, -373, -376, -382, -386; May 1987 – September 1988.

[2] Sources (provided by R. Scanlan and R. Leedy) were:

(a) BNL internal memo, "Revised Flow Chart – DSS Magnet Project," A. Bertshe, February 22, 1988.

(b) Magnetization Table, A. K. Ghosh, June 3, 1988, unpublished.

(c) Summary SSC Magnet Report, DSSXX, from the SSC/LBL database.

(d) CBREVO and CBELEC2 BNL Database Reports.

Table 1 shows the range of variation of the parameters of the superconducting cables used in the nine BNL 1.8-meter models. The SSC production magnets are anticipated to use 6-micron filaments with a minimum critical current density (J_c) of 2750 amperes/mm^2 at 5 T and 4.2 K. Since the multipole strengths are expected to scale as the product of J_c and filament diameter, the multipole values to be expected in the production dipoles can be estimated using this simple scaling law, as listed in the last three columns of Table 1 for the five models with 5-micron filaments. In this scaling, the simple average of the J_c values of the inner and outer layer cables was used.

The persistent-current pattern at injection depends not only on the magnet excitation cycle, but also on the superconductor dependence of critical current density on magnetic field. The ratio of J_c (0.33 T) to J_c (5 T) may vary from manufacturer to manufacturer, and this effect must be studied.

Table 2 similarly lists the persistent-current multipoles in LBL 1-meter dipole models[3] and also the available cable and strand data.[2] The LBL procedure in these magnetic measurements has been to cycle the magnet three times between high field (typically 6.6 T) and low field (typically 0.05 T) at a ramp rate of 16 amperes/second in each direction before the measurement cycle. The time required for the three non-measurement cycles totals about 45 minutes. The time for the measurement cycle involving about 30 points takes about two hours. The measurement sweep begins at about 0.05 T, takes data up to about 6.6 T, then down to 0.05 T, and then back up to 0.33 T (SSC injection field).

There are two sets of multipole data for magnet D15A-5, one for the original model and one for the rebuilt version D15A-5R1, which used the same coils. The differences between the two sets of data are not understood. In scaling the multipole strengths to the values corresponding to the production parameters (6-micron filaments, 2750 A/mm^2 J_c), the simple averages of the D15A-5 and D15A-5R1 multipole strengths were used.

Typically, the two sets of the LBL data in the overlapping range (0.05 to 0.33 T) do not agree, the later data for the sextupole, for example, usually (but not always) being more positive than the earlier data, as would be expected due to the decay of persistent-current effects. The difference in the normal sextupole coefficient b_2 at the two 0.33-T points in the cases examined is typically [illegible] but varies considerably. Figure 1 is a plot of the sextupole data[4] during a measurement sweep of dipole D-15A3, which shows a disagreement between the two up-ramp points near 0.33 T (0.32 kA on the abscissa) of about 0.8 unit. This disagreement points up the need to standardize somehow the

[3] W. S. Gilbert and P. J. Barale, SSC-Mag-158, -169, -184, -186, -191, -196, -210, -211; June 1987 – September 1988.

[4] W. S. Gilbert and P. J. Barale, SSC-Mag-169; November 1987.

excitation cycle and the time sequence for the magnet measurements involving persistent-current effects.

The average scaled persistent-current multipole strengths of the five BNL model magnets in Table 1 are consistent with those of the eight LBL model magnets in Table 2. These two sets of scaled multipole strengths and their rms variations are repeated below, together with the averages and rms variations over all 13 of the small-filament model magnets.

	b_2	b_4	b_6
5 BNL models	-8.7 ± 1.3	0.85 ± 0.17	-0.22 ± 0.01 units
8 LBL models	-6.8 ± 1.6	0.74 ± 0.42	-0.23 ± 0.17
all 13 models	-7.6 ± 1.8	0.79 ± 0.33	-0.23 ± 0.14

I Inner Layer
O Outer Layer

TABLE 1 : COIL DATA AND PERSISTENT-CURRENT MULTIPOLES IN BNL 1.8-METER DIPOLE MODELS AT 0.33 TESLA

MAGNET	CABLE	STRAND BILLET	FIL. DIA.	Cu/SC	J_c(5T)	CABLE I_c(5T)	CABLE MAG	CABLE MAG B	MEASURED b_2	MEASURED b_4	MEASURED b_6	SCALED TO 6μ, 2750A/mm² b_2	SCALED b_4	SCALED b_6
			μ		A/mm²	kA	mT	mT						
DSS-002 I	SC 3[illegible]6	IGC 5940-22	5	1.31	2300	10.09 11.82	17.0	1.1	-7.3	0.68	-0.17	-10.0	0.93	-0.23
" O	SC 342	OST 1725-2,3	5	1.8	2550	8.06 8.58	13.7	0.9						
DSS-004 I	SC 352	OST 1738	5	1.55 1.6	2,507	11.27	15.1	1.1	-6.6	0.46	-0.16	-8.6	0.60	-0.21
" O	SC 348	OST 1725-1,2,3	5	1.8	2550	7.9 8.43	—	—						
DSS-005 I	SC 353	OST 1738	5	1.55 1.6	2,507	11.27	15.1	1.1	-6.55	0.79	—	-8.5	1.03	—
" O	SC 348	OST 1725-1,2,3	5	1.8	2,550	7.9 8.43	—	—						
DSS-006 I	SC 352	OST 1738	5	1.55 1.6	2,507	11.27	15.1	1.1	-7.5	0.71	-0.16	-9.8	0.93	-0.21
" O	SC 348	OST 1725-1,2,3	5	1.8	2,550	7.9 8.43	—	—						
DSS-007 I	SC 347A SC 344A	IGC 5440-22 5212	5 23,20	1.31 1.8	2,300 —	11.82 11.33	17.0 —	1.1 —	-17.5	2.70	-0.63			
" O	SC 348 SC 321	OST 1725-1,2,3 1579	5 —	1.8 —	2,550 —	8.43 8.84	— —	— —						
DSS-009 I	SC 347A	IGC 5940-22	5	1.31	2,300	10.09 11.82	17.0	1.1	-5.1	0.56	—	-6.7	0.74	—
" O	SC 346A	IGC 5948-1,2,3	5	1.7 1.8	2,687	8.72 9.23	—	—						
DSS-010 I	SC 363AB	SCN 362E	23 20	1.60 1.62	—	9.84 9.48 10.79	53.7	1.0	-19.1	2.70	-0.56			
" O	SC 370A	IGC 5934-3,4	6	1.65 1.75	—	9.84	18.9	1.5						
DSS-011 I	SC 363AB	SCN 362E 363B	23 20	1.60 1.62	—	10.79	53.6	1.0	-17.0	2.30	-0.49			
" O	SC 370B	IGC 5934-3,4	6	1.65 1.75	—	9.84	18.9	1.6						
DSS-012 I	SC 363B	SCN 362E 363B	23 20	1.60 1.62		10.79	53.6	1.0	-17.8	2.49	-0.51			
" O	SC 370B	IGC 5954-3,4	6	1.65 1.75		9.84	18.9	1.5						
											AVG ± σ	-8.7 ± 1.3	0.85 ± 0.17	-0.22 ± 0.01

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Table 1

I Inner Layer
O Outer Layer

TABLE 2: COIL DATA AND PERSISTENT-CURRENT MULTIPOLES IN LBL 1-METER DIPOLE MODELS AT 0.33 TESLA

MAGNET	CABLE	STRAND BILLET	FIL. DIA.	Cu/SC	J_c 5T	CABLE I_c(5T)	CABLE MAG	CABLE MAG β		MEASURED b_2	MEASURED b_4	MEASURED b_6	SCALED TO 6μ, 2750A/mm² b_2	SCALED b_4	SCALED b_6
			μ		A/mm²	kA	mT	mT							
D14B7 I	SC337	IGC 5940-22	5	1.27	2,285	11.85	17.2	4.0		-6.2	0.88	-0.16	-8.3	1.18	-0.21
" O	SC341	O 1725	5	1.8	2,550	8.34	13.6	1.0							
DSA-1 I	SC347A	IGC 5940-22	5	1.31	2,440	11.9	17.0	1.1		-6.4	0.50	-0.10	-8.2	0.64	-0.13
" O	SC346A	IGC 5948-1,2,3	5	1.7	2,687	9.23	—	—							
DSA-2 I	SC347A	IGC 5940-22	5	1.31	2,440	11.9	17.0	1.1		-5.4	0.67	-0.02	-7.0	0.86	-0.03
" O	SC346	IGC 5948-123	5	1.7	2,682	9.23	—	—							
DSA-3 I	SC351	IGC 5941-21	5	1.5	2,650	11.79	—	—		-5.4	—	—	-6.6	—	—
" O	SC346A	IGC 5949	5	1.7	2,750	9.31	15.6	1.6							
DSA-4 I	SC362B	IGC 5955-2	6	1.41	2,790	12.78	20.6	0.7		-6.8	0.63	-0.11	-6.6	0.62	-0.11
" O	SC361A	ISC 5954-3	6	1.8	2,844	9.91	18.3	1.2							
DSA-4F I	SG6215	FUR	4.8	1.28	2,674	13.6	—	—		-4.9	-0.01	-0.42	-6.2	-0.01	-0.53
" OA	SG6216	FUR	4.8	1.7	2,726	9.83	—	—							
" OB	SG6224	FUR	4.8	1.6	—	9.69	—	—							
DSA-5 I	SC368B	IGC 5955-1	6	1.22	2,740	14.77	21.4	1.3		(-7.8)	(0.88)	(-0.24)			
" O	SC369B	IGC 5954-3,4	6	1.7	2,861	9.93	—	—	AVG	-8.5	1.27	-0.35	-8.4	1.24	-0.34
DSA-5 R1	"	"	"	"	"	"	"	"		(-9.2)	(1.65)	(-0.45)			
DSA-6 I	SC356	SCN 355E1	5.3	1.4	2,700	11.25	16.2	3.7		-2.7	0.53	-0.23	-3.4	0.67	-0.29
" O	SC21-3352	SCN 355E1	4.3	1.4	2,700	9.15	—	—							
												AVG ± σ	-6.8 ±1.6	0.74 ±0.42	-0.23 ±0.17

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Table 2

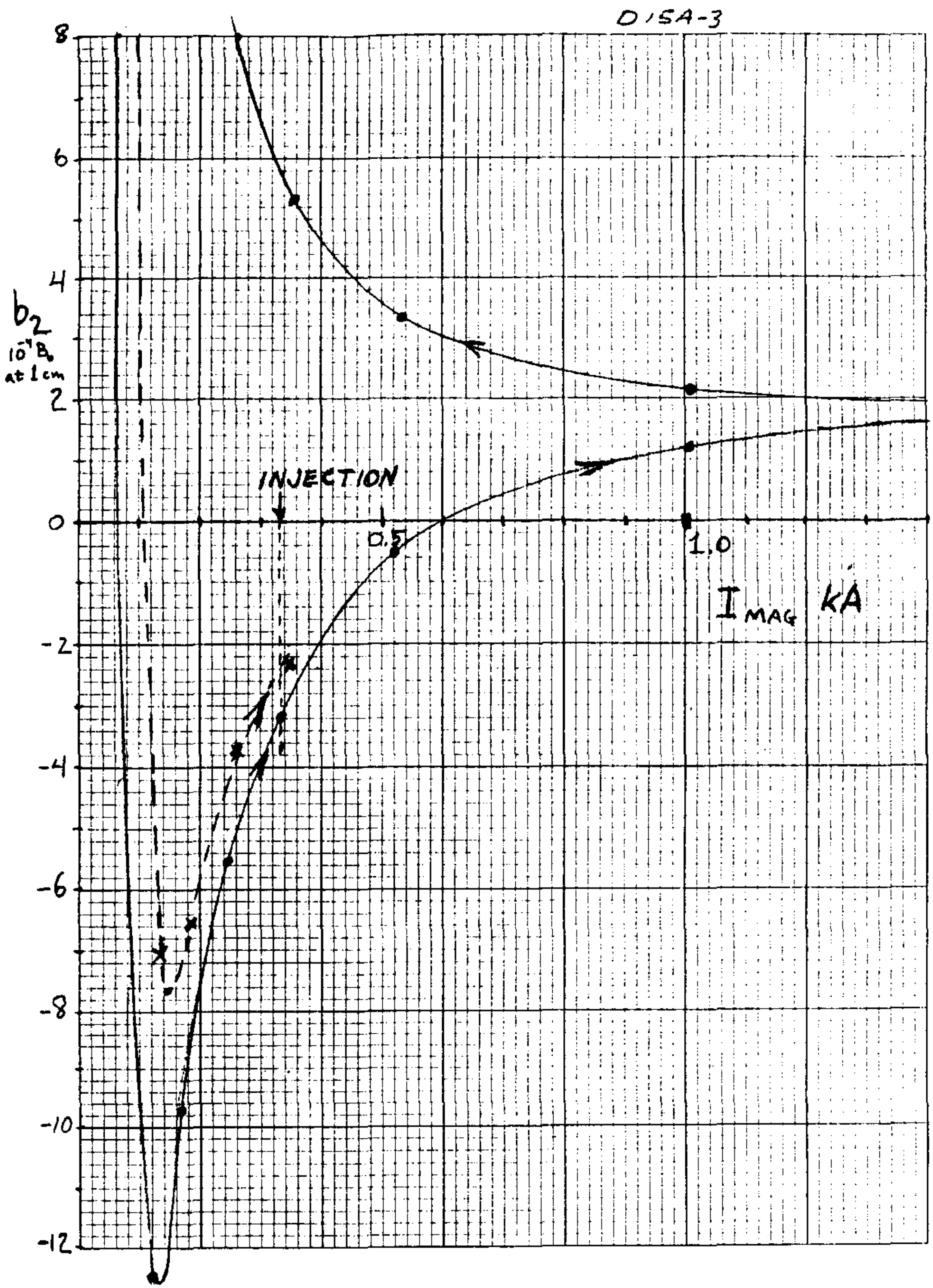

Figure 1. Data taken during the measurement cycle of LBL model magnet D15A-3, showing disagreement between early and late data in the overlapping region between 0.05 and 0.32 kA excitation current, du· possibly to decay effects in the persistent currents.