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PROGRAM — PROJECT — JOB

Superconducting Super Collider

Superconducting Dipole Magnets

TITLE

The Reduction of Magnetization Sextupole at Injection by Setting the Minimum Current in the Magnets

MAG

The studies which have been done on magnetization in the SSC dipoles has been done assuming that the magnetic field in the dipole drops from 6.6 Tesla to zero then up to the injection field of 0.33 Tesla.[1,2] By the time the field reaches 0.33 Tesla at the magnet center most of the superconducting filaments have been fully penetrated by the field rising in the filaments. The magnetization induced field is at its maximum at injection.

In the process of changing the transport current generated central induction from zero to 0.33 Tesla, the magnetic induction generated by circulating currents in the filaments will change sign. If one chooses the minimum field properly, the sextupole component of the magnetization can be made zero at an injection field of 0.33 Tesla. It is argued that the required beam aperture is largest during the process of injection and stacking of beams into the SSC ring. During the acceleration phase, the aperture is reduced even at fields as low as 0.34 Tesla. As the field increases, the beam size is decreased even more.

The idea of using penetration effects to get a zero sextupole component of magnetization at injection is not new,[3,4] but the central design group beam dynamics people feel that there is merit in making the sextupole zero at injection even though it will rise up to 4 units at a central induction of the order of 0.4 to 0.45 Tesla.

Figure 1 shows the SSC Dipole NC-7 used to calculate the magnetic field due to the transport current and the magnetization currents. Figure 1 is symmetric in the way that dipoles normally are. The transport current field generated by the cross section shown in Figure 1 will have a normal dipole component; normal N = 3, 5, 7 and 9 are small by design; normal N = 2, 4, 6, 8 are zero by symmetry; and all of the skew terms are zero by symmetry. The magnetization field generated by the coil shown in Figure 1 will have only normal N = 1, 3, 5, 7 and so on. Table 1 and 2 present the dipole and superconductor parameters.

Figures 2 and 3 are plots of the ratio of magnetization field multipole components to the transport current central field as a function of central induction and path. The central field path in Figures 2 and 3 is from 5.5 Tesla to zero then back up. Table 3 shows the dipole component of the magnetization field and the ratio of the normal N = 3, 5, 7, 9, 11 and 13 components to the transport current central induction. From Table 3 and Figures 2 and 3 one can see that the normal sextupole (N = 3) component at an injection induction of 0.33 Tesla is 6.52 units (1 unit is 1 part in 10000). The normal decapole (N = 5) at injection is 0.56 units (at a radius of 10 mm with 5 micron filaments in the superconductor).

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Figures 4 and 5 show the ratio of magnetization field multipole components to transport current field as a function of central induction and path. The central induction path in Figure 4 and 5 goes from 5.5 Tesla down to 0.308 Tesla then back up. Table 4 shows the dipole component of the magnetization field and the ratio of the normal N = 3, 5, 7, 9, 11 and 13 components to the transport current central induction. From Table 4 and Figures 4 and 5 one can see that the sextupole component at an injection induction of 0.33 Tesla is nearly zero. The dipole component at injection is substantially reduced, and the decapole (N = 5) component ratio is reduced to 0.30 units. From Table 4, one can see that each component follows a different path. The superconductor in various parts of the magnet sees different magnetic field levels; therefore, the conductor in each region becomes fully penetrated by a different flux change.

Figure 6 shows the full NC-7 superconducting dipole cross section with 5.25 micron filaments in the upper half and 4.75 micron filaments in the lower half.[5] The magnetization field has both normal and skew terms. The normal terms are N = 1, 3, 5 and so on. The skew terms are N = 2, 4, 6 and so on. All other terms are zero. Figures 7 and 8 show the skew quadrupole (N = 2) and normal sextupole (N = 3) magnetization ratios or transport current central field as a function of transport current central induction. The path shown in Figures 7 and 8 goes from 5.5 Tesla down to 0.308 Tesla then back up. Table 5 shows the coil parameters. Table 6 shows the superconductor parameters for the superconductors top and bottom in the inner and outer coils. Table 7 shows the normal dipole component of magnetization and the ratios of the following magnetization terms to the transport current induction. They are: skew quadrupole (N = 2), normal quadrupole (N = 2), skew sextupole (N = 3), normal sextupole (N = 3), skew octupole (N = 4) and normal octupole (N = 4). The dominant terms are: skew quadrupole (1.04 units at injection), normal sextupole (zero at injection but a peak of 4.12 units at 0.4 Tesla), skew octupole (0.07 units at injection), and normal decapole (0.30 units at injection). From Table 7 and Figures 7 and 8, one can see that the zero sextupole at injection is not changed by up-down asymmetry due to different filament diameters or superconductor critical current density. The skew quadrupole does not go to zero when the normal sextupole goes to zero. It is clear that it is desirable to minimize variation in superconductor properties between the upper and lower coils in the magnet.

Acknowledgments

The author would like to thank J.M. Peterson of the SSC Central Design Group for many useful suggestions. W.S. Gilbert of the Superconducting Magnet Group at LBL has been pushing the concept of not taking the dipole current down to zero in the SSC dipoles.

References

1. M.A. Green, "Control of the Field Due to Superconductor Magnetization in the SSC Magnets", IEEE Transactions on Magnetics MAG-23, No. 2, March 1987.

2. M.A. Green, "Modeling of Proximity Coupling Between Filaments in Superconducting Dipole Magnets", to be published in Advances in Cryogenic Engineering 33 (1987).

3. M.A. Green, "GESSS Machine Design Committee Reports", GESS-MD/28 on bringing the central field below the injection field in order to make the sextupole component zero at injection, Kernforschungszentrum Karlsruhe report KFK 1764, June 1973.

4. M.A. Green, Field Generated Within the SSC Magnets Due to Persistent Currents in the Superconductor, Proceedings of the Ann Arbor Workshop on SSC Issues, December 1983, LBL-17249.

5. M.A. Green, "Aberrations Due to Asymmetries in Current, Filaments and Critical Current", LBL Engineering Note M6670 August 1987.

Figure 1 The SCMAG04 version of the LBL-SSC Dipole NC-7 which has full dipole symmetry

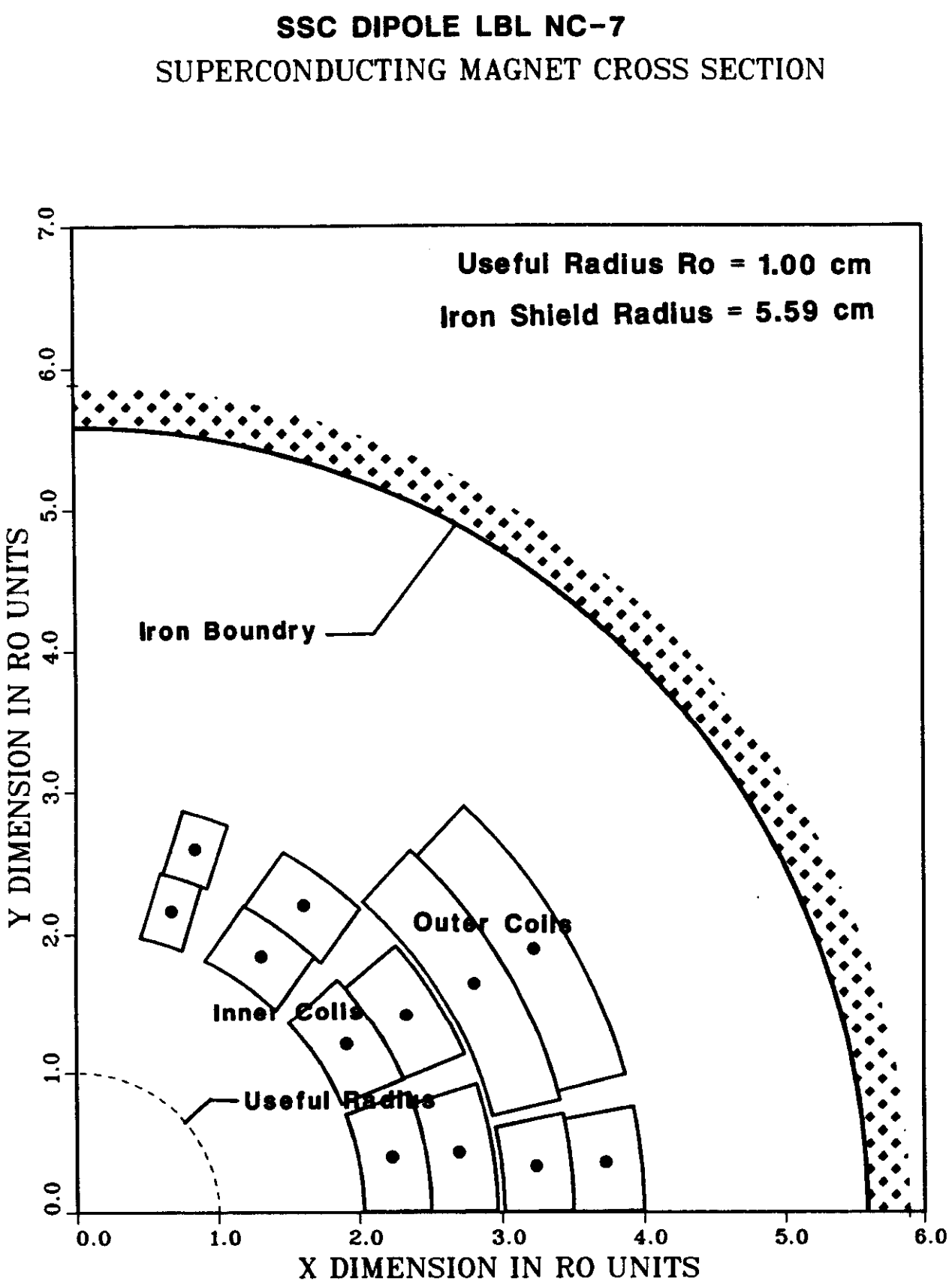


Table 1 Coil Parameters for a Symmetrical Version of LBL-SSC Dipole NC-7

SSC DIPOLE CONFIGURATION NC-7, 0.81 MM STRANDS INNER, 0.65 MM STRANDS OUTER

MAGNET SYMETRY NUMBER (NN)	1
NUMBER OF COIL PARTS (KL)	12
NUMBER OF MULTIPOLES (NX)	13
NUMBER OF R DIVISIONS (MX)	1
NUMBER OF CONDUCTOR TYPES (NSC)	2
NUMBER OF IRON PIECE TYPES (NFE)	0
NUMBER OF MAGNETIZED PIECES (NPM)	0
NUMBER OF MAGNETIZATION LOOPS (NMG)	0
NUMBER OF MAGNET CASES (JA)	32
NUMBER OF CONDUCTOR JC STEPS (LT)	12

IRTYP = 1, THIS MAGNET HAS CIRCULAR IRON.

IRON INNER RADIUS (RIIRON)	5.590 cm
USEFULL APERATURE RADIUS (RO)	1.000 cm
COIL APERTURE RADIUS (RC)	2.030 cm
MEASUREMENT RADIUS (RA)	1.250 cm
OPERATING TEMPERATURE (TOP)	4.20 deg K
FIELD CHANGE RATE (BDOT)	0.0066 T per sec

NT	R1	R2	A1	A2	YANG	XJ	A3	MK
1	2.0300	2.4980	0.2600	20.1100	1700.0000	41999.	0.1539	1
1	2.4980	2.9650	0.2200	18.0900	1700.0000	42907.	0.1675	1
1	2.0300	2.4980	22.4200	42.2600	1700.0000	41810.	0.1539	1
1	2.4980	2.9650	22.5700	40.4200	1700.0000	42958.	0.1675	1
4	2.0300	2.4980	54.7000	0.3078	1700.0000	42847.	0.1539	1
4	2.4980	2.9650	53.8500	0.3350	1700.0000	42847.	0.1675	1
4	2.0300	2.4980	72.8300	0.1539	1700.0000	42847.	0.1539	1
4	2.4980	2.9650	72.0900	0.1675	1700.0000	42847.	0.1675	1
1	3.0140	3.5040	0.1800	11.6400	1700.0000	48883.	0.1293	2
1	3.5040	3.9940	0.1600	10.9200	1700.0000	48951.	0.1398	2
1	3.0140	3.5040	13.2800	47.6800	1700.0000	48853.	0.1293	2
1	3.5040	3.9940	14.3200	46.6400	1700.0000	48888.	0.1398	2

Table 2 Superconductor Parameters of the Superconductor Used in the Symmetrical Version of LBL-SSC Dipole NC-7 Calculations of Magnetization Field

COIL AND SUPERCONDUCTOR MATRIX PROPERTIES

COIL NUMBER	1	2
S/C TO NORMAL METAL RATIO	1.400	1.800
S/C NUMBER OF FILAMENTS	10882	5999
S/C FILAMENT DIAMETER (micr)	5.000	5.000
S/C LAYER THICKNESS (micr)	2.500	2.500
S/C INTERFILAMENT DISTANCE (micr)	1.200	1.200
S/C INTERFILAMENT RHO (ohm-m)	0.150E-09	0.150E-09
S/C COIL PACKING FACTOR	0.760	0.720
S/C STRAND DIAMETER (mm)	0.808	0.648
S/C EFFECTIVE STRAND DIAMETER (mm)	0.727	0.583
S/C FILAMENT REGION THICKNESS (mm)	0.234	0.145
S/C STRAND OUTSIDE RHO (ohm-m)	0.150E-09	0.150E-09
S/C TWIST RATE (twists/cm)	0.500	0.500
S/C COUPLED MAGNETIZATION FACTOR	1.000	1.000

BASIC SUPERCONDUCTING MATERIAL PROPERTIES

CONDUCTOR NUMBER	1	2
HC1 at 0 K (tesla)	0.014	0.014
HC2 at 0 K (tesla)	14.100	14.100
TC at 0 T (deg K)	9.500	9.500
COHERENCE DIST. (ang.)	100.000	100.000
PENETRATIAN DIST. (ang.)	2500.000	2500.000

SUPERCONDUCTING MATERIAL PROPERTIES AT 4.20 K

CONDUCTOR NUMBER	1	2
HC1 (tesla)	0.011	0.011
HC2 (tesla)	10.858	10.858

SUPERCONDUCTOR JC VERSES B PROPERTIES AT A TEMPERATURE OF 4.20deg K

CONDUCTOR NUMBER	1	2
B (tesla)	CRITICAL CURRENT DENSITY (A/cm**2)	
0.00	2690000.	2690000.
0.05	2290000.	2290000.
0.10	1880000.	1880000.
0.30	1430000.	1430000.
0.50	1110000.	1110000.
1.00	764000.	764000.
2.00	492000.	492000.
3.00	393000.	393000.
5.00	242000.	242000.
7.00	147000.	147000.
9.00	52000.	52000.
10.00	4300.	4300.

Table 3 Magnetization Dipole and Mutipole Ratios with the Transport Current Field as a Function of the Magnet Charge and Discharge Cycle

Induction 5.5 $\rightarrow$ 0 $\dashrightarrow$ B_0

RATIO OF RESIDUAL MULTIPOLES TO NN FIELD
NN = 1, NORMAL DIPOLE MAGNET, N=1,3,5,7-----

CASE	BSTART (T)	BINTER (T)	BFINAL (T)	BR(NN) (T)	N = 3 RATIO	N = 5 RATIO	N = 7 RATIO	N = 9 RATIO	N =11 RATIO	N =13 RATIO
1	0.000	5.500	2.500	0.000093	0.000018	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.000	5.500	2.000	0.000114	0.000028	-0.000001	0.000000	0.000000	0.000000	0.000000
3	0.000	5.500	1.500	0.000142	0.000046	-0.000002	0.000001	0.000000	0.000000	0.000000
4	0.000	5.500	1.000	0.000182	0.000090	-0.000004	0.000001	0.000000	0.000000	0.000000
5	0.000	5.500	0.750	0.000216	0.000141	-0.000007	0.000002	0.000000	0.000000	0.000000
6	0.000	5.500	0.600	0.000241	0.000197	-0.000010	0.000003	-0.000001	0.000000	0.000000
7	0.000	5.500	0.500	0.000261	0.000256	-0.000014	0.000004	-0.000001	0.000000	0.000000
8	0.000	5.500	0.250	0.000345	0.000665	-0.000046	0.000011	-0.000002	0.000000	0.000000
9	0.000	5.500	0.100	0.000413	0.001987	-0.000144	0.000034	-0.000007	0.000000	0.000000
10	0.000	5.500	0.000	0.000666	0.473748	-0.041242	0.008542	-0.001760	-0.000098	0.000000
11	5.500	0.000	0.050	-0.000191	-0.001469	0.000409	-0.000050	0.000012	0.000000	0.000000
12	5.500	0.000	0.100	-0.000456	-0.002108	0.000317	-0.000045	0.000010	0.000001	0.000000
13	5.500	0.000	0.150	-0.000477	-0.001556	0.000186	-0.000029	0.000007	0.000000	0.000000
14	5.500	0.000	0.200	-0.000470	-0.001164	0.000122	-0.000021	0.000005	0.000000	0.000000
15	5.500	0.000	0.250	-0.000459	-0.000913	0.000087	-0.000016	0.000004	0.000000	0.000000
16	5.500	0.000	0.300	-0.000442	-0.000735	0.000065	-0.000013	0.000003	0.000000	0.000000
17	5.500	0.000	0.330	-0.000431	-0.000652	0.000056	-0.000011	0.000002	0.000000	0.000000
18	5.500	0.000	0.350	-0.000426	-0.000606	0.000051	-0.000010	0.000002	0.000000	0.000000
19	5.500	0.000	0.400	-0.000412	-0.000513	0.000041	-0.000009	0.000002	0.000000	0.000000
20	5.500	0.000	0.500	-0.000387	-0.000384	0.000027	-0.000006	0.000001	0.000000	0.000000
21	5.500	0.000	0.600	-0.000371	-0.000303	0.000020	-0.000005	0.000001	0.000000	0.000000
22	5.500	0.000	0.700	-0.000353	-0.000246	0.000015	-0.000004	0.000001	0.000000	0.000000
23	5.500	0.000	0.800	-0.000338	-0.000205	0.000012	-0.000003	0.000001	0.000000	0.000000
24	5.500	0.000	0.900	-0.000323	-0.000175	0.000010	-0.000003	0.000001	0.000000	0.000000
25	5.500	0.000	1.000	-0.000307	-0.000150	0.000008	-0.000002	0.000000	0.000000	0.000000
26	5.500	0.000	1.200	-0.000282	-0.000114	0.000006	-0.000002	0.000000	0.000000	0.000000
27	5.500	0.000	1.400	-0.000260	-0.000090	0.000005	-0.000001	0.000000	0.000000	0.000000
28	5.500	0.000	1.600	-0.000243	-0.000073	0.000004	-0.000001	0.000000	0.000000	0.000000
29	5.500	0.000	1.800	-0.000228	-0.000061	0.000003	-0.000001	0.000000	0.000000	0.000000
30	5.500	0.000	2.000	-0.000212	-0.000052	0.000002	-0.000001	0.000000	0.000000	0.000000
31	5.500	0.000	2.250	-0.000195	-0.000042	0.000002	-0.000001	0.000000	0.000000	0.000000
32	5.500	0.000	2.500	-0.000182	-0.000035	0.000001	-0.000001	0.000000	0.000000	0.000000

END OF RESIDUAL FIELD FOR THE DIPOLE

All of the terms given in the table are normal terms.

Figure 2

RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL

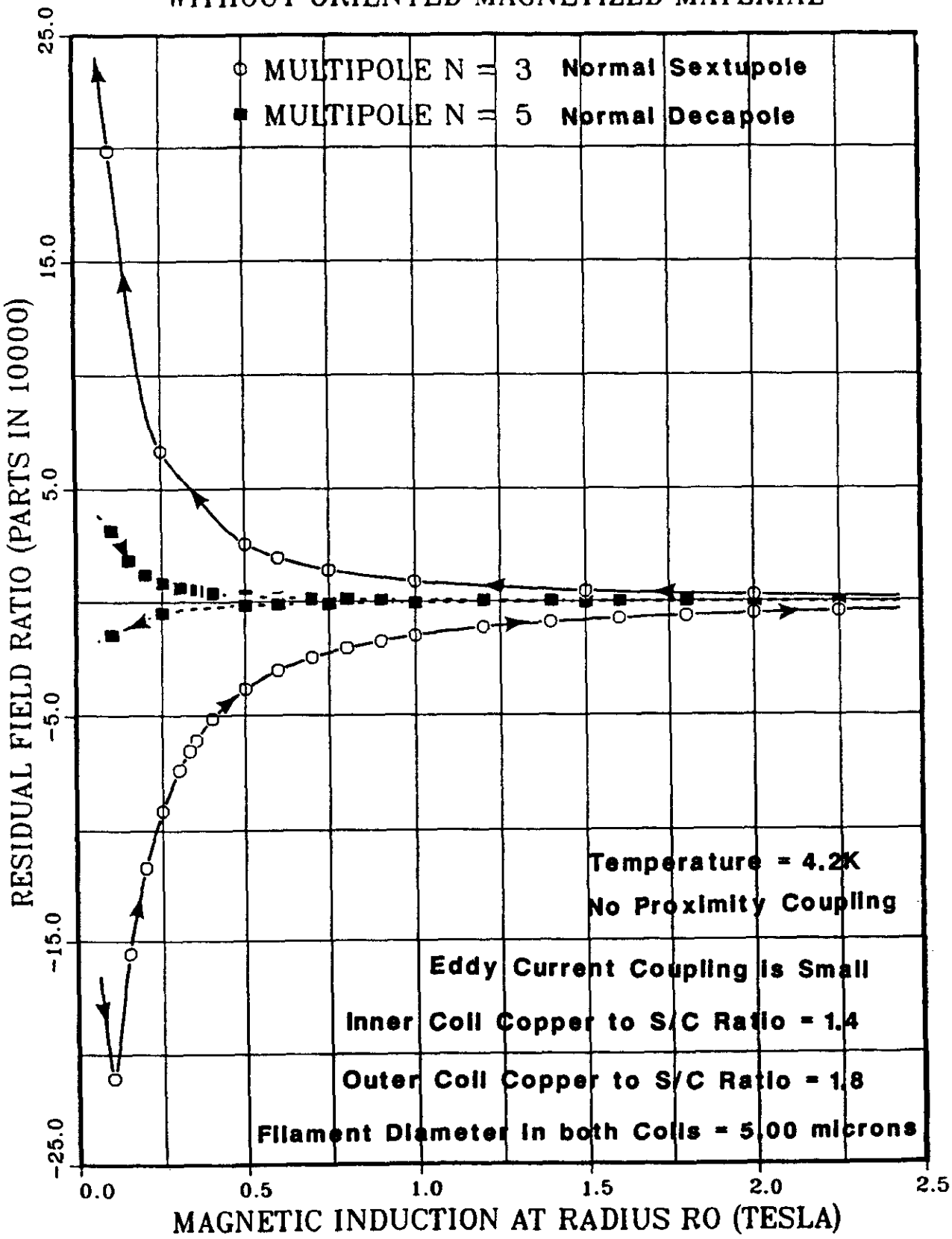


Figure 3

RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL

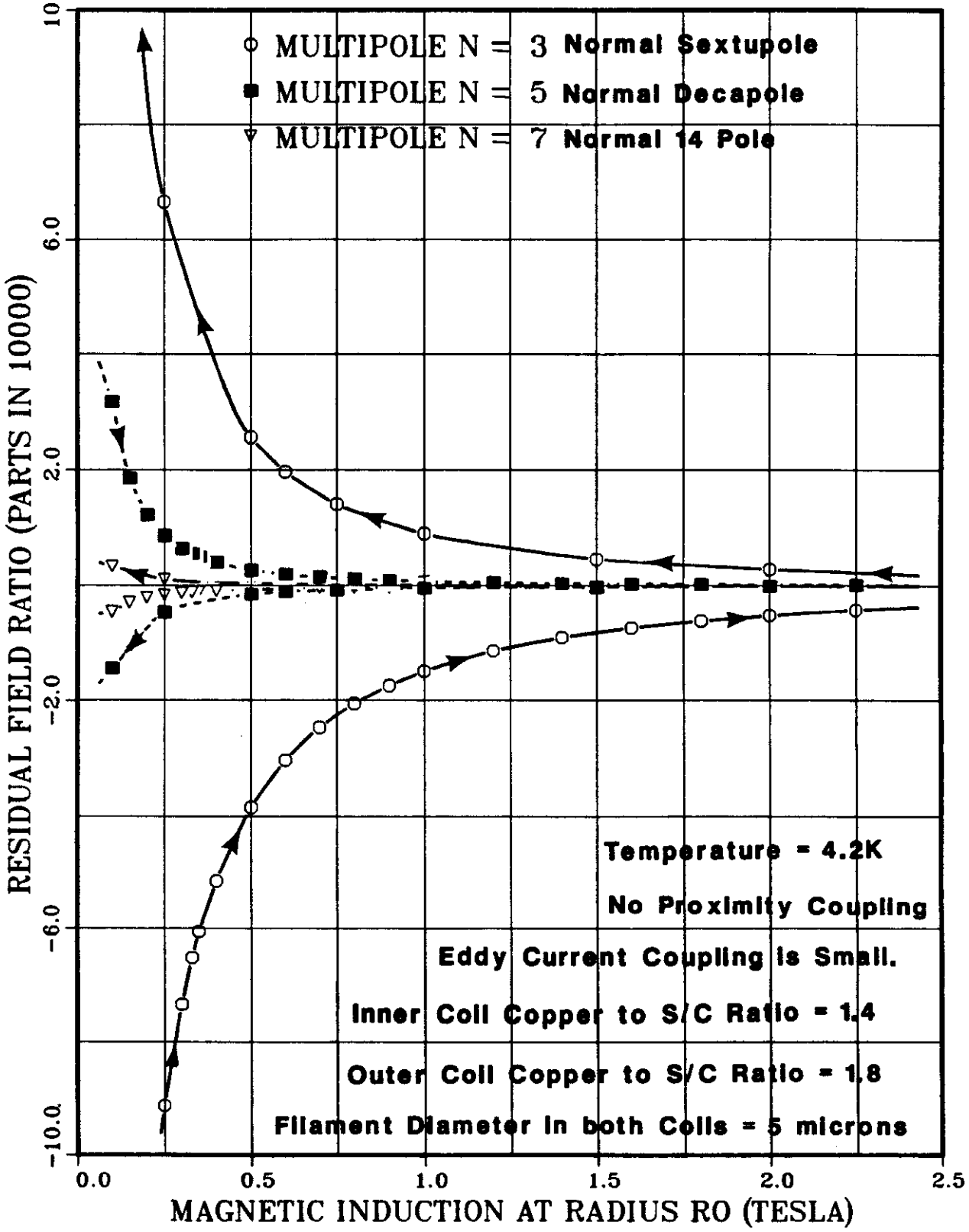


Table 4 Magnetization Dipole and Multipole Ratios with Transport Current Field as a Function of the Magnet Charge and Discharge Cycle, Induction 5.5T ---→ 0.308T ---→ B_0

RATIO OF RESIDUAL MULTIPOLES TO NN FIELD
NN = 1, NORMAL DIPOLE MAGNET, N=1,3,5,7-----

CASE	BSTART (T)	BINTER (T)	BFINAL (T)	BR(NN) (T)	N = 3 RATIO	N = 5 RATIO	N = 7 RATIO	N = 9 RATIO	N =11 RATIO	N =13 RATIO
1	0.000	5.500	2.500	0.000093	0.000018	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.000	5.500	2.000	0.000114	0.000028	-0.000001	0.000000	0.000000	0.000000	0.000000
3	0.000	5.500	1.500	0.000142	0.000046	-0.000002	0.000001	0.000000	0.000000	0.000000
4	0.000	5.500	1.000	0.000182	0.000090	-0.000004	0.000001	0.000000	0.000000	0.000000
5	0.000	5.500	0.750	0.000216	0.000141	-0.000007	0.000002	0.000000	0.000000	0.000000
6	0.000	5.500	0.600	0.000241	0.000197	-0.000010	0.000003	-0.000001	0.000000	0.000000
7	0.000	5.500	0.500	0.000261	0.000258	-0.000014	0.000004	-0.000001	0.000000	0.000000
8	0.000	5.500	0.400	0.000292	0.000355	-0.000022	0.000006	-0.000001	0.000000	0.000000
9	0.000	5.500	0.350	0.000308	0.000427	-0.000027	0.000007	-0.000001	0.000000	0.000000
10	0.000	5.500	0.308	0.000322	0.000506	-0.000033	0.000008	-0.000002	0.000000	0.000000
11	5.500	0.308	0.310	0.000243	0.000549	0.000036	0.000017	0.000002	0.000001	0.000000
12	5.500	0.308	0.315	0.000104	0.000207	-0.000021	0.000003	-0.000001	0.000000	0.000000
13	5.500	0.308	0.320	0.000089	0.000164	0.000000	0.000001	0.000000	0.000000	0.000000
14	5.500	0.308	0.325	0.000042	0.000097	0.000019	-0.000001	0.000000	0.000000	0.000000
15	5.500	0.308	0.330	-0.000021	0.000007	0.000030	-0.000002	0.000001	0.000000	0.000000
16	5.500	0.308	0.335	-0.000077	-0.000071	0.000038	-0.000004	0.000001	0.000000	0.000000
17	5.500	0.308	0.340	-0.000125	-0.000138	0.000045	-0.000005	0.000001	0.000000	0.000000
18	5.500	0.308	0.350	-0.000203	-0.000244	0.000055	-0.000007	0.000002	0.000000	0.000000
19	5.500	0.308	0.400	-0.000334	-0.000412	0.000054	-0.000008	0.000002	0.000000	0.000000
20	5.500	0.308	0.500	-0.000342	-0.000349	0.000032	-0.000006	0.000001	0.000000	0.000000
21	5.500	0.308	0.600	-0.000337	-0.000283	0.000022	-0.000005	0.000001	0.000000	0.000000
22	5.500	0.308	0.700	-0.000328	-0.000233	0.000017	-0.000004	0.000001	0.000000	0.000000
23	5.500	0.308	0.800	-0.000321	-0.000198	0.000013	-0.000003	0.000001	0.000000	0.000000
24	5.500	0.308	0.900	-0.000313	-0.000171	0.000010	-0.000003	0.000001	0.000000	0.000000
25	5.500	0.308	1.000	-0.000300	-0.000147	0.000008	-0.000002	0.000000	0.000000	0.000000
26	5.500	0.308	1.200	-0.000280	-0.000113	0.000006	-0.000002	0.000000	0.000000	0.000000
27	5.500	0.308	1.400	-0.000260	-0.000090	0.000005	-0.000001	0.000000	0.000000	0.000000
28	5.500	0.308	1.600	-0.000243	-0.000073	0.000004	-0.000001	0.000000	0.000000	0.000000
29	5.500	0.308	1.800	-0.000228	-0.000061	0.000003	-0.000001	0.000000	0.000000	0.000000
30	5.500	0.308	2.000	-0.000212	-0.000052	0.000002	-0.000001	0.000000	0.000000	0.000000
31	5.500	0.308	2.250	-0.000195	-0.000042	0.000002	-0.000001	0.000000	0.000000	0.000000
32	5.500	0.308	2.500	-0.000182	-0.000035	0.000001	-0.000001	0.000000	0.000000	0.000000

END OF RESIDUAL FIELD FOR THE DIPOLE

All of the terms given in the table are normal terms.

Figure 4

RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL

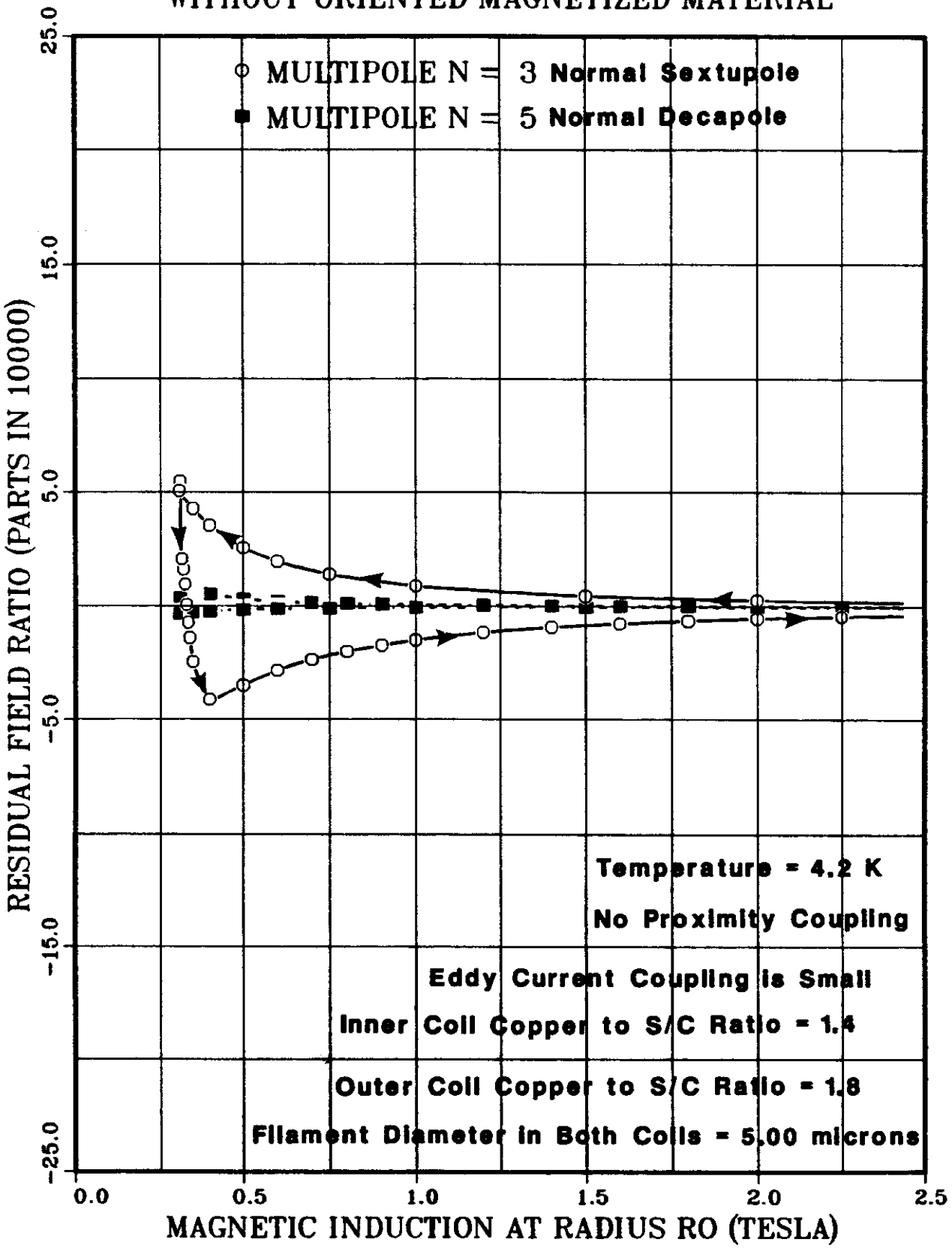


Figure 5

RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL

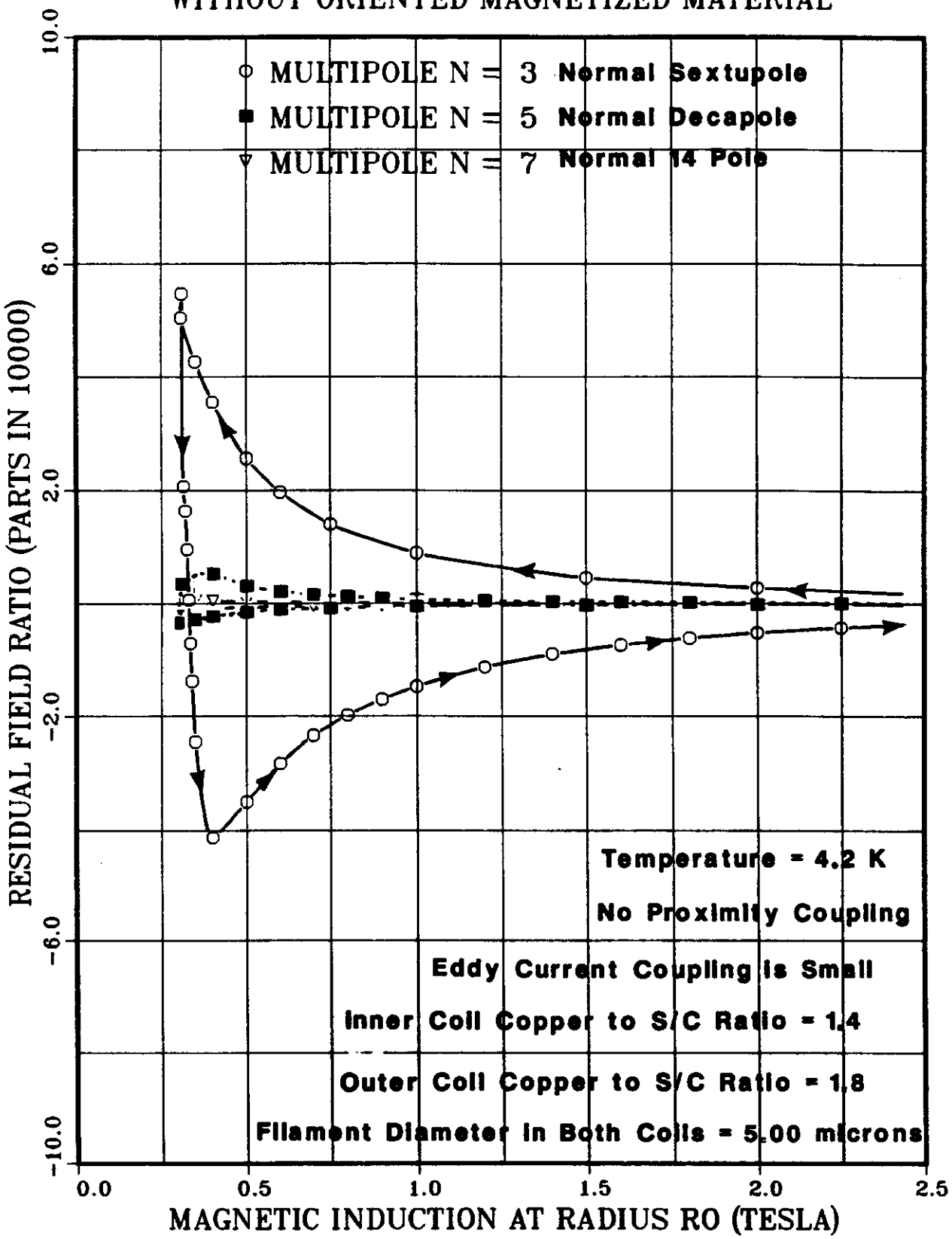


Figure 6 The SCMAGØ4 version of the LBL-SSC Dipole NC-7 which has Up-Down Asymmetry in the Filament Diameter

SSC DIPOLE, LBL NC-7

SUPERCONDUCTING MAGNET CROSS SECTION

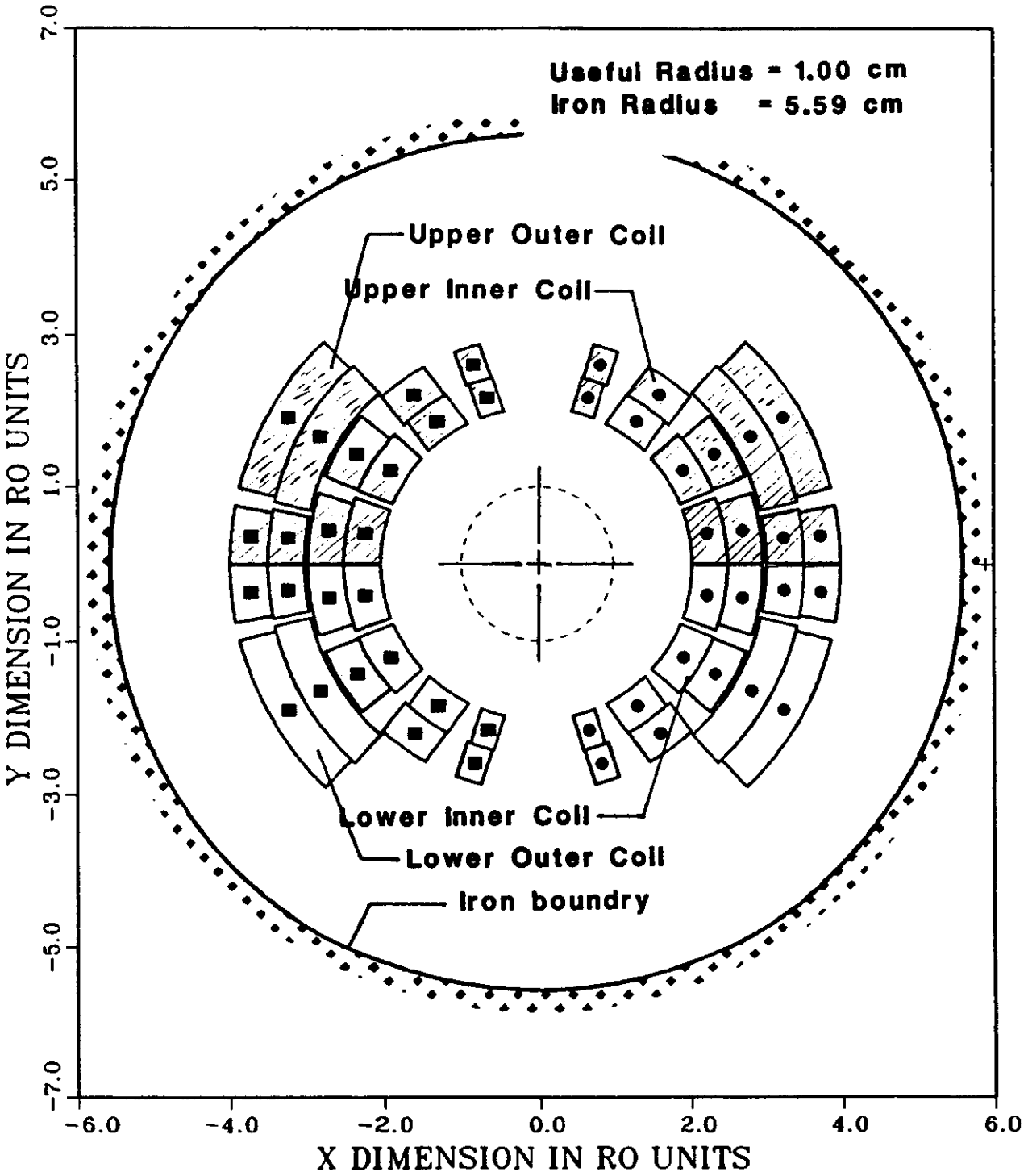


Table 5 Coil Parameters for an Asymmetric Version of LBL-SSC Dipole NC-7

SSC DIPOLE CONFIGURATION NC-7, 0.81 MM STRANDS INNER, 0.65 MM STRANDS OUTER

MAGNET SYMETRY NUMBER (NN)	0
NUMBER OF COIL PARTS (KL)	48
NUMBER OF MULTIPOLES (NX)	13
NUMBER OF R DIVISIONS (MX)	1
NUMBER OF CONDUCTOR TYPES (NSC)	4
NUMBER OF IRON PIECE TYPES (NFE)	0
NUMBER OF MAGNETIZED PIECES (NPM)	0
NUMBER OF MAGNETIZATION LOOPS (NMG)	0
NUMBER OF MAGNET CASES (JA)	32
NUMBER OF CONDUCTOR JC STEPS (LT)	12

IRTYP = 1, THIS MAGNET HAS CIRCULAR IRON.
IRON INNER RADIUS (RIIRON) 5.590 cm

USEFULL APERATURE RADIUS (RO)	1.000 cm
COIL APERTURE RADIUS (RC)	2.030 cm
MEASUREMENT RADIUS (RA)	1.250 cm
OPERATING TEMPERATURE (TOP)	4.20 deg K
FIELD CHANGE RATE (BDOT)	0.0066 T per sec

NT	R1	R2	A1	A2	YANG	XJ	A3	MK
1	2.0300	2.4980	0.2600	20.1100	1700.0000	41999.	0.1539	1
1	2.4980	2.9650	0.2200	18.0900	1700.0000	42907.	0.1675	1
1	2.0300	2.4980	22.4200	42.2600	1700.0000	41810.	0.1539	1
1	2.4980	2.9650	22.5700	40.4200	1700.0000	42958.	0.1675	1
4	2.0300	2.4980	54.7000	0.3078	1700.0000	42847.	0.1539	1
4	2.4980	2.9650	53.8500	0.3350	1700.0000	42847.	0.1675	1
4	2.0300	2.4980	72.8300	0.1539	1700.0000	42847.	0.1539	1
4	2.4980	2.9650	72.0900	0.1675	1700.0000	42847.	0.1675	1
1	3.0140	3.5040	0.1800	11.6400	1700.0000	48883.	0.1293	2
1	3.5040	3.9940	0.1600	10.9200	1700.0000	48951.	0.1398	2
1	3.0140	3.5040	13.2800	47.6800	1700.0000	48853.	0.1293	2
1	3.5040	3.9940	14.3200	46.6400	1700.0000	48888.	0.1398	2
1	2.0300	2.4980	159.8900	179.7400	1700.0000	-41999.	0.1539	1
1	2.4980	2.9650	161.9100	179.7800	1700.0000	-42907.	0.1675	1
1	2.0300	2.4980	137.7400	157.5800	1700.0000	-41810.	0.1539	1
1	2.4980	2.9650	139.5800	157.4300	1700.0000	-42958.	0.1675	1
4	2.0300	2.4980	125.3000	0.3078	1700.0000	-42847.	0.1539	1
4	2.4980	2.9650	126.1500	0.3350	1700.0000	-42847.	0.1675	1
4	2.0300	2.4980	107.1700	0.1539	1700.0000	-42847.	0.1539	1
4	2.4980	2.9650	107.9100	0.1675	1700.0000	-42847.	0.1675	1
1	3.0140	3.5040	168.3600	179.8200	1700.0000	-48883.	0.1293	2
1	3.5040	3.9940	169.0800	179.8400	1700.0000	-48951.	0.1398	2
1	3.0140	3.5040	132.3200	166.7200	1700.0000	-48853.	0.1293	2
1	3.5040	3.9940	133.3600	165.6800	1700.0000	-48888.	0.1398	2
1	2.0300	2.4980	180.2600	200.1100	1700.0000	-41999.	0.1539	3
1	2.4980	2.9650	180.2200	198.0900	1700.0000	-42907.	0.1675	3
1	2.0300	2.4980	202.4200	222.2600	1700.0000	-41810.	0.1539	3
1	2.4980	2.9650	202.5700	220.4200	1700.0000	-42958.	0.1675	3
4	2.0300	2.4980	234.7000	0.3078	1700.0000	-42847.	0.1539	3
4	2.4980	2.9650	233.8500	0.3350	1700.0000	-42847.	0.1675	3
4	2.0300	2.4980	252.8300	0.1539	1700.0000	-42847.	0.1539	3
4	2.4980	2.9650	252.0900	0.1675	1700.0000	-42847.	0.1675	3
1	3.0140	3.5040	190.1800	191.6400	1700.0000	-48883.	0.1293	4
1	3.5040	3.9940	190.1600	190.9200	1700.0000	-48951.	0.1398	4
1	3.0140	3.5040	193.2800	227.6800	1700.0000	-48853.	0.1293	4
1	3.5040	3.9940	194.3200	226.6400	1700.0000	-48888.	0.1398	4
1	2.0300	2.4980	-20.1100	-0.2600	1700.0000	41999.	0.1539	3
1	2.4980	2.9650	-18.0900	-0.2200	1700.0000	42907.	0.1675	3
1	2.0300	2.4980	-42.2600	-22.4200	1700.0000	41810.	0.1539	3
1	2.4980	2.9650	-40.4200	-22.5700	1700.0000	42958.	0.1675	3
4	2.0300	2.4980	-54.7000	0.3078	1700.0000	42847.	0.1539	3
4	2.4980	2.9650	-53.8500	0.3350	1700.0000	42847.	0.1675	3
4	2.0300	2.4980	-72.8300	0.1539	1700.0000	42847.	0.1539	3
4	2.4980	2.9650	-72.0900	0.1675	1700.0000	42847.	0.1675	3
1	3.0140	3.5040	-11.6400	-0.1800	1700.0000	48883.	0.1293	4
1	3.5040	3.9940	-10.9200	-0.1600	1700.0000	48951.	0.1398	4
1	3.0140	3.5040	-47.6800	-13.2800	1700.0000	48853.	0.1293	4
1	3.5040	3.9940	-46.6400	-14.3200	1700.0000	48888.	0.1398	4

Table 6 Superconductor Parameter of the Superconductor Used in the Asymmetrical Version of LBL-SSC Dipole NC-7 Calculations of Magnetization Field

COIL AND SUPERCONDUCTOR MATRIX PROPERTIES

COIL NUMBER	1	2	3	4
S/C TO NORMAL METAL RATIO	1.400	1.800	1.400	1.800
S/C NUMBER OF FILAMENTS	9870	5441	12057	6647
S/C FILAMENT DIAMETER (micr)	5.250	5.250	4.750	4.750
S/C LAYER THICKNESS (micr)	2.625	2.625	2.375	2.375
S/C INTERFILAMENT DISTANCE (micr)	1.200	1.200	1.200	1.200
S/C INTERFILAMENT RHO (ohm-m)	0.150E-09	0.150E-09	0.150E-09	0.150E-09
S/C COIL PACKING FACTOR	0.760	0.720	0.760	0.720
S/C STRAND DIAMETER (mm)	0.808	0.648	0.808	0.648
S/C EFFECTIVE STRAND DIAMETER (mm)	0.727	0.583	0.727	0.583
S/C FILAMENT REGION THICKNESS (mm)	0.226	0.141	0.243	0.150
S/C STRAND OUTSIDE RHO (ohm-m)	0.150E-09	0.150E-09	0.150E-09	0.150E-09
S/C TWIST RATE (twists/cm)	0.500	0.500	0.500	0.500
S/C COUPLED MAGNETIZATION FACTOR	1.000	1.000	1.000	1.000

BASIC SUPERCONDUCTING MATERIAL PROPERTIES

CONDUCTOR NUMBER	1	2	3	4
HC1 at 0 K (tesla)	0.014	0.014	0.014	0.014
HC2 at 0 K (tesla)	14.100	14.100	14.100	14.100
TC at 0 T (deg K)	9.500	9.500	9.500	9.500
COHERENCE DIST. (ang.)	100.000	100.000	100.000	100.000
PENETRATIAN DIST. (ang.)	2500.000	2500.000	2500.000	2500.000

SUPERCONDUCTING MATERIAL PROPERTIES AT 4.20 K

CONDUCTOR NUMBER	1	2	3	4
HC1 (tesla)	0.011	0.011	0.011	0.011
HC2 (tesla)	10.858	10.858	10.858	10.858

SUPERCONDUCTOR JC VERSES B PROPERTIES AT A TEMPERATURE OF 4.20deg K

CONDUCTOR NUMBER	1	2	3	4
B (tesla)	CRITICAL CURRENT DENSITY (A/cm**2)			
0.00	2690000.	2690000.	2690000.	2690000.
0.05	2290000.	2290000.	2290000.	2290000.
0.10	1880000.	1880000.	1880000.	1880000.
0.30	1430000.	1430000.	1430000.	1430000.
0.50	1110000.	1110000.	1110000.	1110000.
1.00	764000.	764000.	764000.	764000.
2.00	492000.	492000.	492000.	492000.
3.00	393000.	393000.	393000.	393000.
5.00	242000.	242000.	242000.	242000.
7.00	147000.	147000.	147000.	147000.
9.00	52000.	52000.	52000.	52000.
10.00	4300.	4300.	4300.	4300.

Table 7 Magnetization Dipole and Multipole Ratios with Transport Current Field as a Function of the Magnet Charge and Discharge Cycle, Induction 5.5T --→ 0.308T --→ B_0. There is an Up-Down Asymmetry in Filament Diameter

RATIO OF RESIDUAL MULTIPOLES TO NN FIELD
NN = 0, GENERAL MAGNET, NORMAL AND SKEW, N=1,2,3---

CASE	BSTART (T)	BINTER (T)	BFINAL (T)	BR(NN) (T)	N = 2 RATIO	N = 2 RATIO	N = 3 RATIO	N = 3 RATIO	N = 4 RATIO	N = 4 RATIO
1	0.000	5.500	2.500	0.000093	-0.000006	0.000000	0.000000	0.000018	0.000000	0.000000
2	0.000	5.500	2.000	0.000114	-0.000009	0.000000	0.000000	0.000028	0.000000	0.000000
3	0.000	5.500	1.500	0.000142	-0.000013	0.000000	0.000000	0.000046	-0.000001	0.000000
4	0.000	5.500	1.000	0.000182	-0.000025	0.000000	0.000000	0.000090	-0.000001	0.000000
5	0.000	5.500	0.750	0.000216	-0.000038	0.000000	0.000000	0.000141	-0.000002	0.000000
7	0.000	5.500	0.500	0.000261	-0.000067	0.000000	0.000000	0.000258	-0.000003	0.000000
8	0.000	5.500	0.400	0.000292	-0.000090	0.000000	0.000000	0.000355	-0.000004	0.000000
9	0.000	5.500	0.350	0.000308	-0.000107	0.000000	0.000000	0.000427	-0.000005	0.000000
10	0.000	5.500	0.308	0.000322	-0.000125	0.000000	0.000000	0.000505	-0.000006	0.000000
11	5.500	0.308	0.310	0.000236	-0.000125	-0.000026	0.000002	0.000534	0.000001	-0.000005
12	5.500	0.308	0.315	0.000104	-0.000104	0.000000	0.000000	0.000207	-0.000004	0.000000
13	5.500	0.308	0.320	0.000089	-0.000113	0.000000	0.000000	0.000164	-0.000006	0.000000
14	5.500	0.308	0.325	0.000042	-0.000111	0.000000	0.000000	0.000097	-0.000006	0.000000
15	5.500	0.308	0.330	-0.000021	-0.000104	0.000000	0.000000	0.000007	-0.000006	0.000000
16	5.500	0.308	0.335	-0.000076	-0.000097	0.000000	0.000000	-0.000071	-0.000006	0.000000
17	5.500	0.308	0.340	-0.000125	-0.000089	0.000000	0.000000	-0.000138	-0.000006	0.000000
18	5.500	0.308	0.350	-0.000203	-0.000071	0.000000	0.000000	-0.000244	-0.000006	0.000000
19	5.500	0.308	0.400	-0.000334	0.000014	0.000000	0.000000	-0.000412	-0.000003	0.000000
20	5.500	0.308	0.500	-0.000342	0.000047	0.000000	0.000000	-0.000349	0.000001	0.000000
21	5.500	0.308	0.600	-0.000337	0.000044	0.000000	0.000000	-0.000283	0.000002	0.000000
22	5.500	0.308	0.700	-0.000328	0.000039	0.000000	0.000000	-0.000233	0.000002	0.000000
23	5.500	0.308	0.800	-0.000321	0.000034	0.000000	0.000000	-0.000198	0.000002	0.000000
24	5.500	0.308	0.900	-0.000313	0.000029	0.000000	0.000000	-0.000171	0.000002	0.000000
25	5.500	0.308	1.000	-0.000300	0.000025	0.000000	0.000000	-0.000147	0.000001	0.000000
26	5.500	0.308	1.200	-0.000280	0.000019	0.000000	0.000000	-0.000113	0.000001	0.000000
27	5.500	0.308	1.400	-0.000260	0.000015	0.000000	0.000000	-0.000090	0.000001	0.000000
28	5.500	0.308	1.600	-0.000243	0.000012	0.000000	0.000000	-0.000073	0.000001	0.000000
29	5.500	0.308	1.800	-0.000228	0.000010	0.000000	0.000000	-0.000061	0.000001	0.000000
30	5.500	0.308	2.000	-0.000212	0.000008	0.000000	0.000000	-0.000052	0.000000	0.000000
31	5.500	0.308	2.250	-0.000195	0.000007	0.000000	0.000000	-0.000042	0.000000	0.000000
32	5.500	0.308	2.500	-0.000182	0.000006	0.000000	0.000000	-0.000035	0.000000	0.000000
					Skew Term	Normal Term	Skew Term	Normal Term	Skew Term	Normal Term

END OF RESIDUAL FIELD FOR THE GENERAL MAGNET NN = 1

Figure 7

RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL

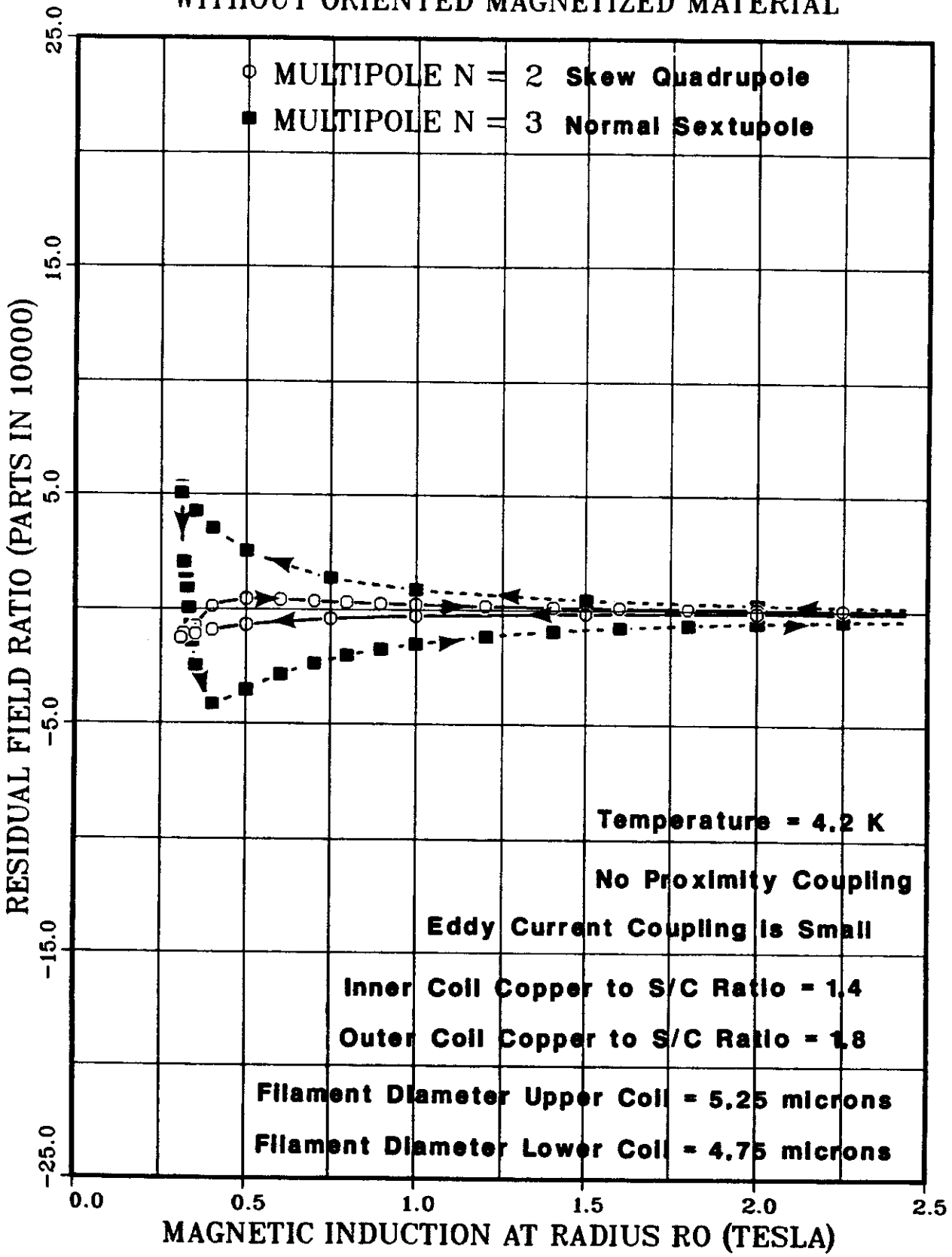
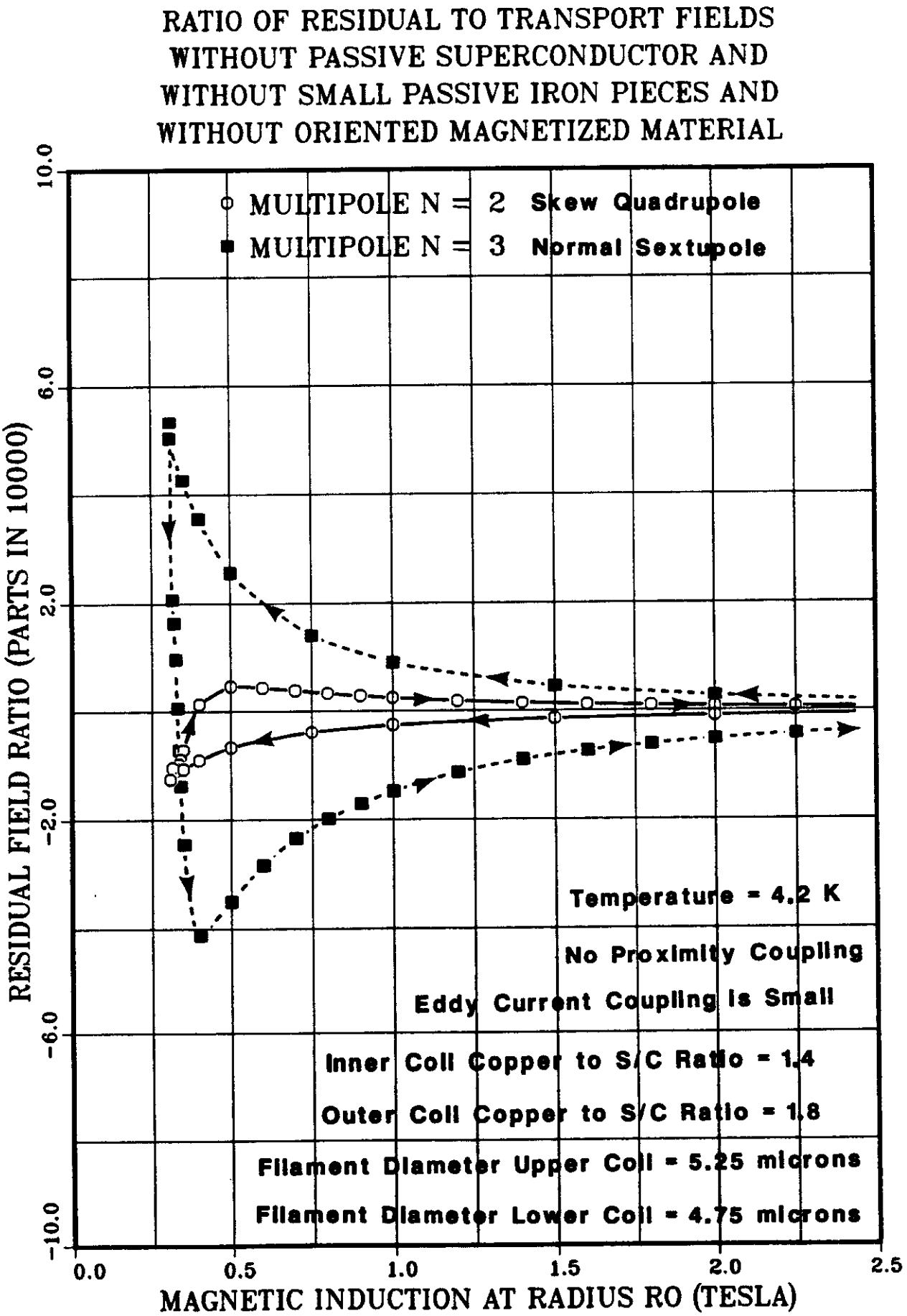


Figure 8


RATIO OF RESIDUAL TO TRANSPORT FIELDS
WITHOUT PASSIVE SUPERCONDUCTOR AND
WITHOUT SMALL PASSIVE IRON PIECES AND
WITHOUT ORIENTED MAGNETIZED MATERIAL
MULTIPOLE N = 2 Skew Quadrupole
MULTIPOLE N = 3 Normal Sextupole
Temperature = 4.2 K
No Proximity Coupling
Eddy Current Coupling is Small
Inner Coil Copper to S/C Ratio = 1.4
Outer Coil Copper to S/C Ratio = 1.8
Filament Diameter Upper Coil = 5.25 microns
Filament Diameter Lower Coil = 4.75 microns
RESIDUAL FIELD RATIO (PARTS IN 10000)
10.0
6.0
2.0
-2.0
-6.0
-10.0
0.0
0.5
1.0
1.5
2.0
2.5
MAGNETIC INDUCTION AT RADIUS RO (TESLA)