LAWRENCE BERKELEY LABORATORY · UNIVERSITY OF CALIFORNIA

# ENGINEERING NOTE

| CODE | SERIAL | PAGE |
|---|---|---|
| AA0100 | M6670 | 1 of 31 |


| AUTHOR | DEPARTMENT | LOCATION | DATE |
|---|---|---|---|
| M. A. Green | Mechanical Engineering | Berkeley | August 1987 |


PROGRAM — PROJECT — JOB

Superconducting Super Collider

Superconducting Dipole Magnet

TITLE

Aberrations Due to Asymmetries in Current, Filaments and Critical Current

ABS


This report examines the effects of asymmetric currents and filament diameters on the quality of the magnetic field in an SSC dipole generated by the transport current and the magnetization currents. Three types of magnets are used as examples which permit one to look at the effects of the asymmetries. These magnets include: 1) the simple sixty-degree dipole, 2) a six-block cosine theta dipole, and 3) the LBL SSC dipole NC-7.

The sixty-degree dipole with normal magnet symmetry is shown in Figure 1. The magnet has a constant $J_c$ in the right half, and it has a constant $-J_c$ in the left half. This magnet develops a normal dipole (N = 1) component; a small normal N = 5 (decapole) component; a small normal N = 7 component; and very small N = 11, 13, 17, 19, 23, . . .; and so on. The normal sextupole (N=3), the N = 9, the N = 15, and N = 21, and so on, are specifically zero by virtue of a sixty-degree angle. The normal N = 2 (quadrupole); N = 4 (octupole); N = 6, 8, 10, . . .; and so on, are zero by symmetry. All of the skew terms are zero by symmetry as well. Case 0 shown in Figure 1 has all of the odd normal terms (N = 1, 3, 5, 7, 9, . . ., and so on) in the magnetization field.[1,2] Table 1 shows the magnetization field components and multipole ratio at R = 10 mm for the magnet shown in Figure 1. Table 1 also presents the transport current field and multipole ratio at R = 10 mm. The filament diameter in Case 0 is 5 microns.

Case 1 with the sixty-degree dipole shown in Figure 2 has a current density in the top coils which is 10 percent higher than the current densities in Case 0. The current density in the bottom coils is ten percent lower than the current densities in Case 0. The filament diameter is 5 microns as in Case 0. Table 2 shows the magnetization and transport current field generated by Case 1. The transport current field has normal dipole; N = 5; N = 7; and N = 11, 13, 17, 19, 23, 25, . . .; and so on. In addition, there are skew N = 2 (quadrupole); N = 4, 6, 8, . . .; and so on. The magnetization field contains normal N = 1, 3, 5, 7, . . .; and skew N = 2, 4, 6, 8, . . . (see Table 2). The dominant terms in the magnetization are normal dipole, skew quadrupole and normal sextupole. Case 4 has a fully symmetric distribution of current density as in Case 0. The filament diameter is 5.5 microns in the upper coils in Case 2. The filament diameter in the lower coils is 4.5 microns. The transport current field multipoles are identical to Case 0. The magnetization field contains normal N = 1, 3, 5, 7, . . .; and skew N = 2, 4, 6, 8, . . .; and so on (see Table 5 and Figure 5).


*This work was supported by the U.S. Department of Energy under Contract DE-AC03-76SF00098.

Case 2 shown in Figure 3 is a sixty dipole with a left-right asymmetry. The current density is 10 percent higher in the right coil and 10 percent lower in the left coil. Case 2 has no transport current skew terms (see Table 3). All of the normal terms are present except for N = 3, 9, 15, 21, and so on. The magnetization field has all of the normal terms and none of the skew terms. Case 5, shown in Figure 6 and Table 6, has fully symmetric current densities, but the right side filaments are 5.5 microns in diameter, and the left side filaments are 4.5 microns in diameter. The transport current field is identical to Case 0. The magnetization field has all of the normal terms (imaginary part) and no skew terms (real part). (See Table 6)

Case 3 (see Table 4 and Figure 4) has completely asymmetric current densities. The upper right is 10 percent higher than Case 0, the upper left is 20 percent higher than Case 0, the lower left is 20 percent lower than Case 0, and the lower right is 10 percent lower than Case 0. This case generates all multipoles (both normal and skew) in the magnetization field. The transport current field contains all of the skew terms and only the normal terms of N = 1, 5, 7, 11, and so on. Case 6 (see Table 6 and Figure 6) has symmetric current densities to generate a normal dipole field as in Case 0. The filament diameters are 5.5 microns in the upper right quadrant, 6.0 microns in the upper left quadrant, 4.0 microns in the lower left quadrant, and 4.5 microns in the lower right quadrant. The transport current field is the same as Case 0, which contains only normal N = 1, 5, 7, 11, 13, and so on (the skew terms are zero). The magnetization field (see Table 6) contains all normal and skew terms which are similar to Case 5.

The studies done in cases 0 through 6 show that the transport current fields are governed by the symmetries of the currents. The magnetization field will contain all of the same terms as the transport field, plus terms which are excluded by angular geometric factors in the transport current pattern. In reality, cases 2, 3, 5 and 6 do not usually exist in real buildable dipole magnets, but these cases do show the effect of various types of asymmetries.

Cases 7 and 8 use a six-block cosine theta current distribution (see Figure 8). Table 8 shows the distribution of currents which will generate a normal dipole field which has all skew terms zero and normal terms N = 3, 5, 7, 9, 11 and 13 equal to zero. The N = 15, 17, and so on, are small by virtue of the fact that the useful aperture radius ($R_0$ = 10 mm) is half the inside radius of the coil ($R_c$ = 20 mm). Case 7 has 5 micron filaments - top and bottom, left and right. The magnetization field contains only normal N = 1, 3, 5, 7, and so on (see Table 9). All other terms are zero. Case 8 has 5.5 micron filaments in the top half and 4.5 micron filaments in the bottom half. The transport field has the same quality as in Case 7. The magnetization field has normal N = 1, 3, 5, 7, . . ., and so on; and skew N = 2, 4, 6, 8, 10, . . ., and so on (see Table 10). The dominant magnetization terms are normal dipole, skew quadrupole and normal sextupole.

The last cases (cases 9, 10 and 11) which have been looked at are the effects of asymmetric filament diameters on the LBL SSC dipole cross-section NC-7 which is shown in Figure 9. If the filament diameter is 5 microns all over, one gets only the normal N = 1, 3, 5, 7, . . ., terms. Figure 10 shows the ratio of magnetization field components to transport current field as a

function of central induction. Figure 10 shows the normal N = 3 (sextupole) and normal N = 5 (decapole) terms. Table 11 shows the dipole component of the magnetization field plus the ratio of the magnetization field to the transport current field for the normal N = 3, N = 5, N = 7, N = 9 , N = 11, and N = 13 terms.

The effect of a 10-percent variation of the superconductor filament diameter is shown in figures 11 and 12 for the NC-7 coil cross-section with filament diameters of 5 ± 0.25 microns and 20 ± 1 micron. Table 12 shows the basic properties of the NC-7 coil which was put into the SCMAG04 code. Table 13 shows the superconductor parameters used to calculate the case shown in Figure 11. Table 14 shows the dipole component of the magnetization field plus the ratio of magnetization to transport current field for normal and skew N = 2 (quadrupole), N = 3 (sextupole), and N = 4 (octupole). Table 14 applies when the filament diameter in the upper coil half is 5.25 microns and the filament diameter in the lower coil half is 4.75 microns. (Table 14 can be compared directly with Figure 11.) Table 15 applies when the upper half coil filament diameter is 21 microns and the lower half coil filament diameter is 19 microns. (Table 15 can be compared directly with Figure 12.)

An up-down asymmetry in filament diameter will generate skew N = 2, 4, 6, 8, etc. A 10-percent variation in up-down filament diameter will produce about 1 unit skew quadrupole at an injection field of 0.33 T when the basic filament diameter is set to 5 microns. Filament diameter is not the only factor which affects the magnetization. Up-down variation in critical current density will affect the magnetic field in the same way as filament diameter. Small up-down variations of filament spacing can also affect the magnetization of injection if the filament spacing is less than 0.8 microns. At 0.8 microns spacings, proximity coupling begins to rear its ugly head.[3]

The superconductor for the Fermilab Tevetron showed critical current density variations of the order of 10 percent (including the conductor in the first magnets). The bulk of the Tevetron conductor showed only a 5- or 6-percent variation in critical current density at 5 T. (The low field $J_c$ varies as the $J_c$ at 5 Tesla.) The SSC superconductor should be made as uniform as possible so that the product of critical current density and filament diameter varies less than 3 percent. The conductor uniformity can be greatly enhanced by shuffling the strands in the cable in the same way that iron is shuffled in accelerator magnets in order to minimize the magnet-to-magnet variation of the field.[4]

## Acknowledgments

The author acknowledges discussions he has had with J. M. Peterson of the SSC Central Design Group and C. E. Taylor of LBL.

## References

1. M. A. Green, "Fields Generated Within the SSC Magnets Due to Persistent Currents in the Superconductor", Proceedings of the Ann Arbor Workshop on SSC issues, LBL-17249, December 1983.

2. 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.

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

4. M. A. Green "Gesss Machine Design Committee Reports", GESSS-MD/28 on Conductor Shuffling, p. 58-60, Kernforschungszentrum Karlsruhe Report KfK 1764, June 1973.

# CASE 0

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

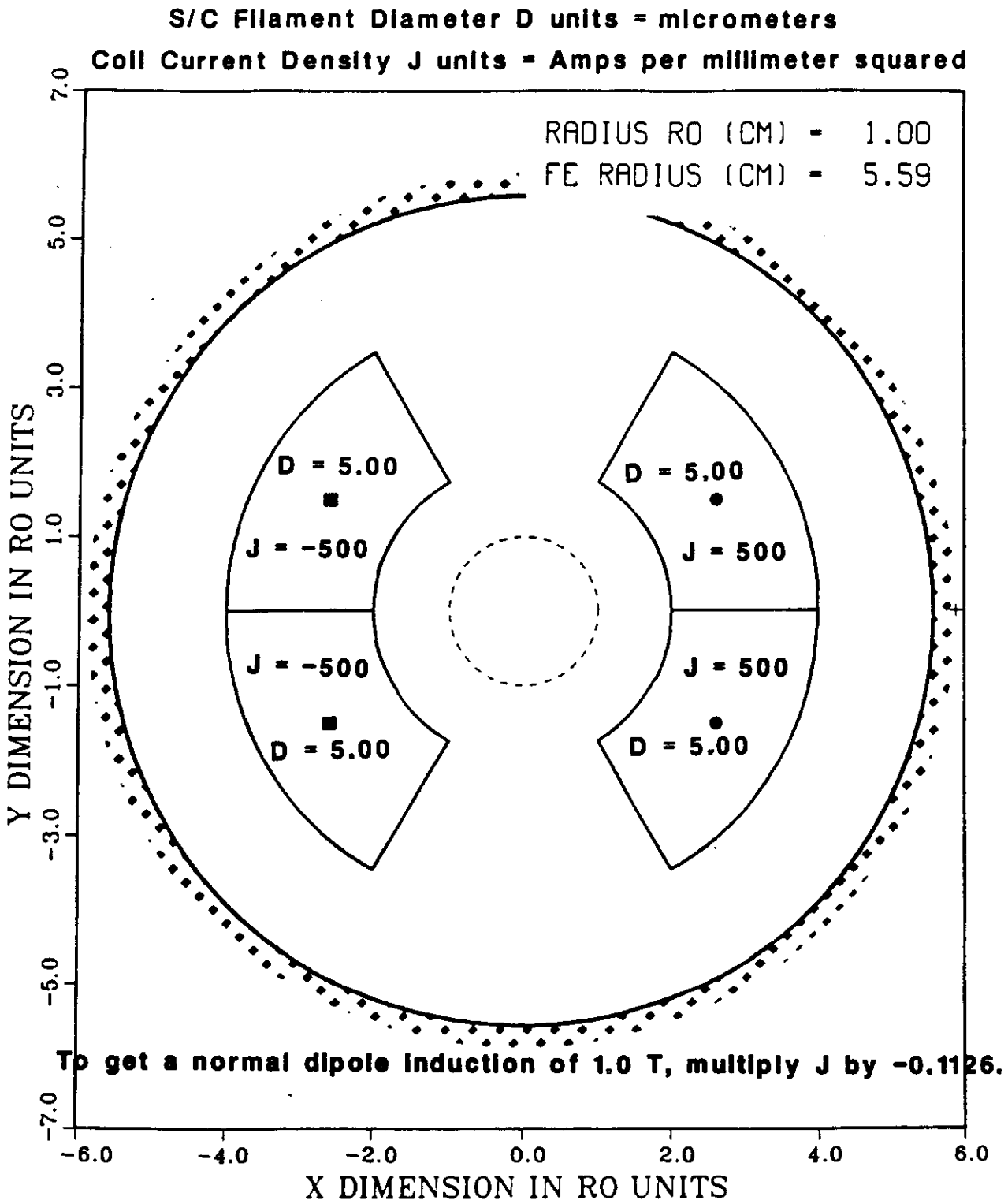


Figure 1. The sixty-degree dipole with normal magnet symmetry. The filament diameters are 5 microns.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 1
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.000368 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | -0.000272 | 0.000000 | 0.737642 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.000001 | 0.000000 | 0.003189 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000004 | 0.000000 | -0.010843 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | -0.000001 | 0.000000 | 0.002591 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | -0.000058 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.002806 | 0.000000 | -0.002806 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000331 | 0.000000 | 0.000331 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | -0.000007 | 0.000000 | -0.000007 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Skew Term | Normal Term | Skew Term | Normal Term |

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 1. Multipoles and multipole ratios for Case 0, the sixty-degree dipole with no asymmetries present.

# CASE 1

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

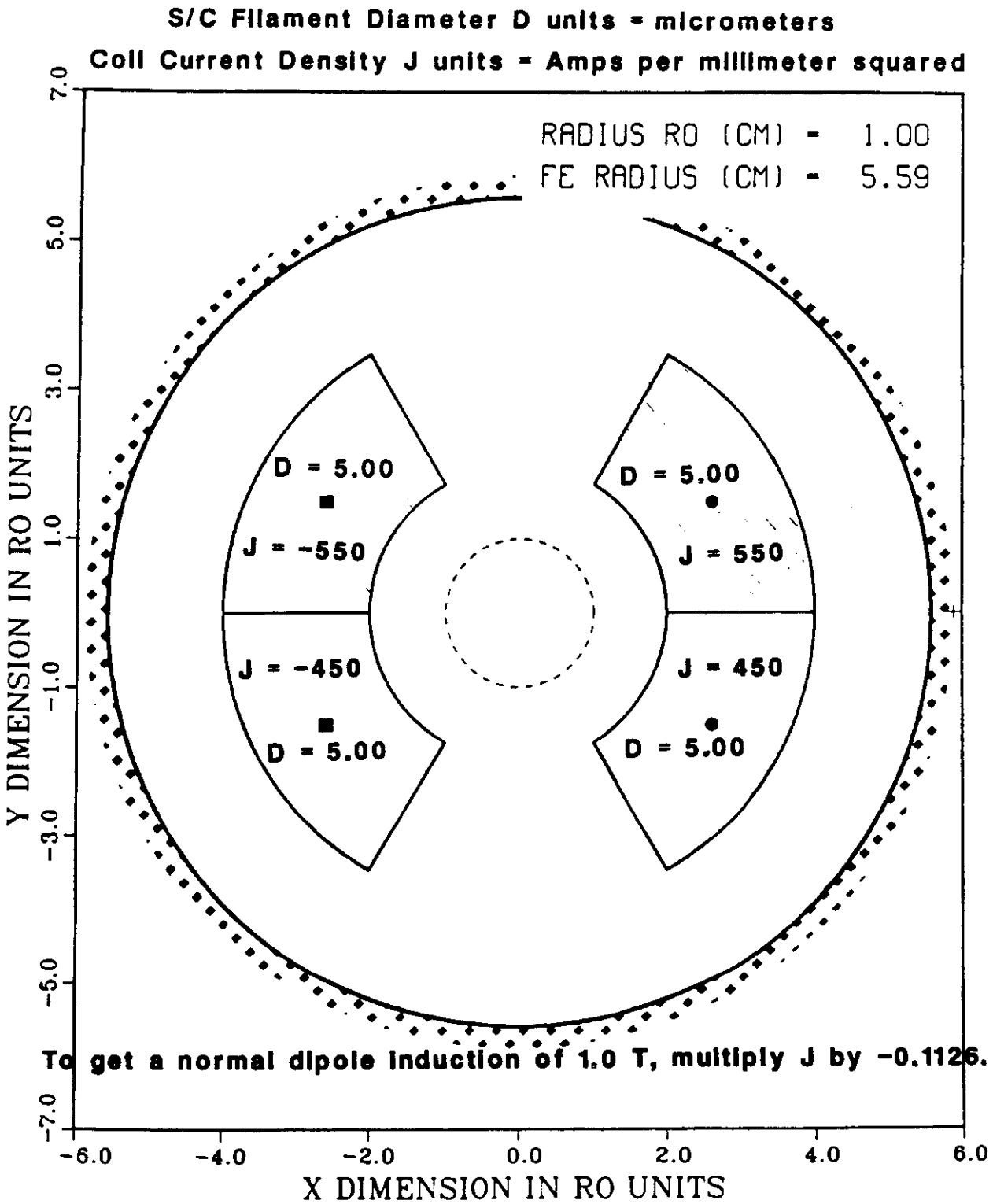


Figure 2. The sixty-degree dipole with unbalanced current top and bottom. Filament diameters are 5 microns.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 1
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.000371 | 0.000001 | 1.000000 |
| 2 | -0.000112 | 0.000000 | 0.301598 | 0.000000 |
| 3 | 0.000000 | -0.000272 | 0.000000 | 0.734499 |
| 4 | -0.000010 | 0.000000 | 0.026344 | 0.000000 |
| 5 | 0.000000 | -0.000001 | 0.000000 | 0.002700 |
| 6 | -0.000001 | 0.000000 | 0.003116 | 0.000000 |
| 7 | 0.000000 | 0.000004 | 0.000000 | -0.010846 |
| 8 | 0.000000 | 0.000000 | 0.000560 | 0.000000 |
| 9 | 0.000000 | -0.000001 | 0.000000 | 0.002597 |
| 10 | 0.000000 | 0.000000 | 0.000018 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | -0.000055 |
| 12 | 0.000000 | 0.000000 | 0.000004 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.025159 | 0.000000 | 0.025159 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.001573 | 0.000000 | 0.001573 | 0.000000 |
| 5 | 0.000000 | -0.002806 | 0.000000 | -0.002806 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000331 | 0.000000 | 0.000331 |
| 8 | 0.000021 | 0.000000 | 0.000021 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000003 | 0.000000 | 0.000003 | 0.000000 |
| 11 | 0.000000 | -0.000007 | 0.000000 | -0.000007 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Skew Term | Normal Term | Skew Term | Normal Term

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 2. Multipoles and multipole ratios for Case 1, the sixty-degree dipole with top-bottom current asymmetry, but filament diameter is consistent.

# CASE 2

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

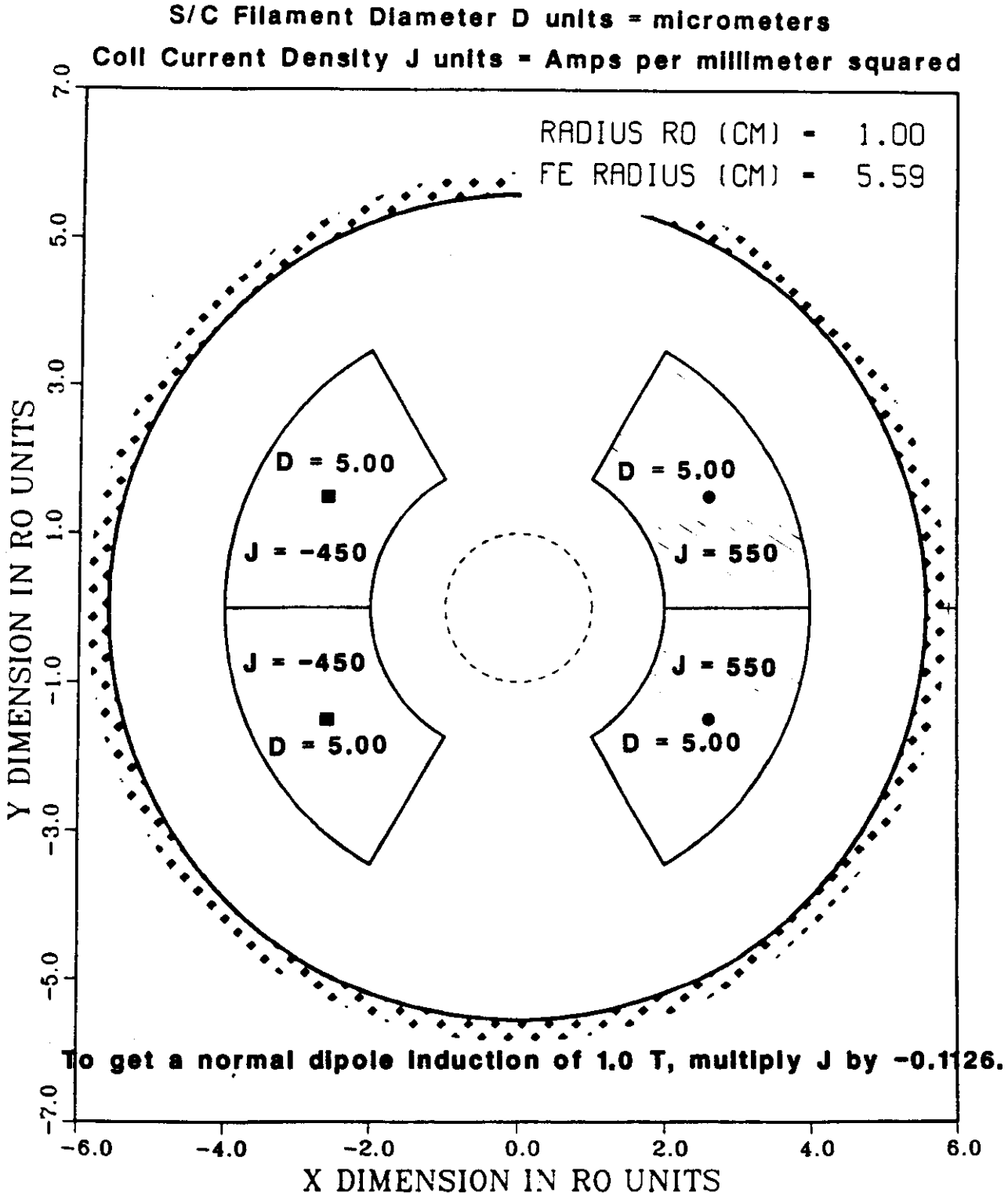


Figure 3. The sixty-degree dipole with unbalanced current left and right. Filament diameters are 5 microns.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 1
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.000357 | 0.000000 | 1.000000 |
| 2 | 0.000000 | -0.000059 | 0.000000 | 0.165913 |
| 3 | 0.000000 | -0.000270 | 0.000000 | 0.755421 |
| 4 | 0.000000 | -0.000001 | 0.000000 | 0.002377 |
| 5 | 0.000000 | -0.000001 | 0.000000 | 0.003360 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.001038 |
| 7 | 0.000000 | 0.000004 | 0.000000 | -0.011179 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000284 |
| 9 | 0.000000 | -0.000001 | 0.000000 | 0.002680 |
| 10 | 0.000000 | 0.000000 | 0.000000 | -0.000042 |
| 11 | 0.000000 | 0.000000 | 0.000000 | -0.000058 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.014526 | 0.000000 | 0.014526 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | -0.000908 | 0.000000 | -0.000908 |
| 5 | 0.000000 | -0.002806 | 0.000000 | -0.002806 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000331 | 0.000000 | 0.000331 |
| 8 | 0.000000 | 0.000012 | 0.000000 | 0.000012 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | -0.000002 | 0.000000 | -0.000002 |
| 11 | 0.000000 | -0.000007 | 0.000000 | -0.000007 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Skew Term | Normal Term | Skew Term | Normal Term

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 3. Multipoles and multipole ratios for Case 2, the sixty-degree dipole with left-right current asymmetry, but filament diameter is constant.

# CASE 3

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

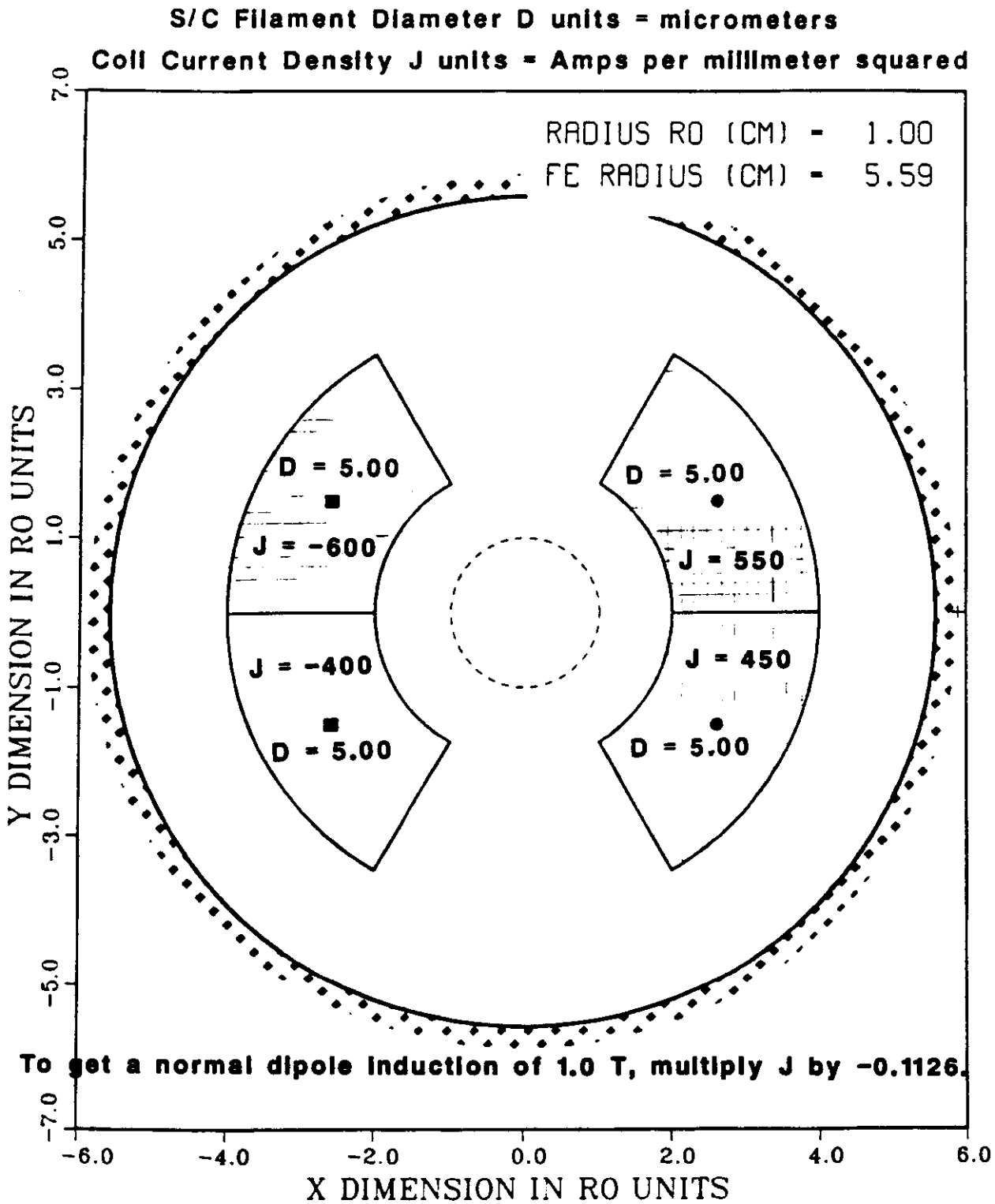


Figure 4. The sixty-degree dipole with different current densities in the four quadrants. Filament diameters are 5 microns.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 2
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

| | |
|---|---|
| STARTING CENTRAL INDUCTION | 5.5000 TESLA |
| INDUCTION AFTER FIRST FLUX CHANGE | 0.0000 TESLA |
| INDUCTION AFTER SECOND FLUX CHANGE | 1.0000 TESLA |

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000124 | -0.000355 | -0.348830 | 1.000000 |
| 2 | -0.000185 | 0.000021 | 0.521922 | -0.058956 |
| 3 | 0.000011 | -0.000249 | -0.031055 | 0.700892 |
| 4 | -0.000019 | 0.000003 | 0.052824 | -0.008486 |
| 5 | 0.000001 | -0.000001 | -0.002318 | 0.001667 |
| 6 | -0.000002 | 0.000000 | 0.006680 | -0.000840 |
| 7 | 0.000000 | 0.000001 | -0.000276 | -0.003080 |
| 8 | 0.000000 | 0.000000 | 0.000780 | -0.000090 |
| 9 | 0.000000 | 0.000000 | -0.000001 | 0.000810 |
| 10 | 0.000000 | 0.000000 | 0.000053 | -0.000010 |
| 11 | 0.000000 | 0.000000 | 0.000003 | -0.000008 |
| 12 | 0.000000 | 0.000000 | 0.000006 | -0.000001 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | -0.028867 | 1.000000 | -0.028867 | 1.000000 |
| 2 | 0.036437 | 0.000000 | 0.036437 | 0.000000 |
| 3 | -0.003407 | 0.000000 | -0.003407 | 0.000000 |
| 4 | 0.001888 | 0.000000 | 0.001888 | 0.000000 |
| 5 | -0.000056 | -0.001933 | -0.000056 | -0.001933 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | -0.000004 | 0.000154 | -0.000004 | 0.000154 |
| 8 | 0.000012 | 0.000000 | 0.000012 | 0.000000 |
| 9 | -0.000002 | 0.000000 | -0.000002 | 0.000000 |
| 10 | 0.000001 | 0.000000 | 0.000001 | 0.000000 |
| 11 | 0.000000 | -0.000001 | 0.000000 | -0.000001 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Skew Term | Normal Term | Skew Term | Normal Term

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 4. Multipoles and multipole ratios for Case 3, the sixty-degree dipole with each quadrant a different current density, but filament diameter is constant.

# CASE 4

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

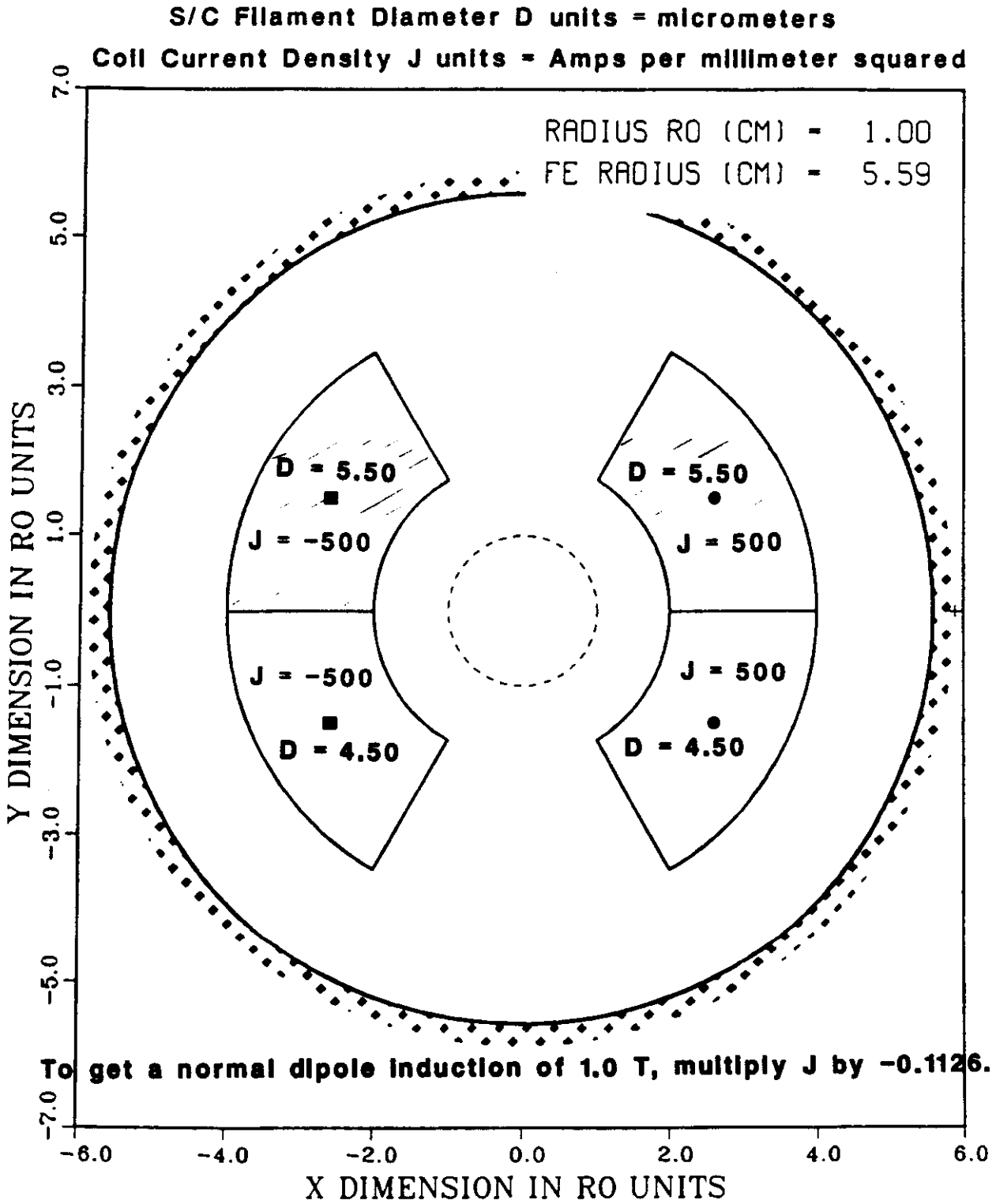


Figure 5. The sixty-degree dipole with normal dipole symmetry in the transport currents. The filament diameter has a top-bottom asymmetry.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 1
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.000368 | 0.000000 | 1.000000 |
| 2 | 0.000075 | 0.000000 | -0.202599 | 0.000000 |
| 3 | 0.000000 | -0.000272 | 0.000000 | 0.737687 |
| 4 | 0.000002 | 0.000000 | -0.005602 | 0.000000 |
| 5 | 0.000000 | -0.000001 | 0.000000 | 0.003173 |
| 6 | 0.000001 | 0.000000 | -0.001978 | 0.000000 |
| 7 | 0.000000 | 0.000004 | 0.000000 | -0.010848 |
| 8 | 0.000000 | 0.000000 | -0.001104 | 0.000000 |
| 9 | 0.000000 | -0.000001 | 0.000000 | 0.002591 |
| 10 | 0.000000 | 0.000000 | -0.000064 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | -0.000058 |
| 12 | 0.000000 | 0.000000 | -0.000017 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.002806 | 0.000000 | -0.002806 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000331 | 0.000000 | 0.000331 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | -0.000007 | 0.000000 | -0.000007 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Skew Term — Normal Term — Skew Term — Normal Term

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 5. Multipoles and multipole ratios for Case 4, the sixty-degree dipole with top-bottom asymmetry in filament diameter, but the current density is constant.

# CASE 5

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

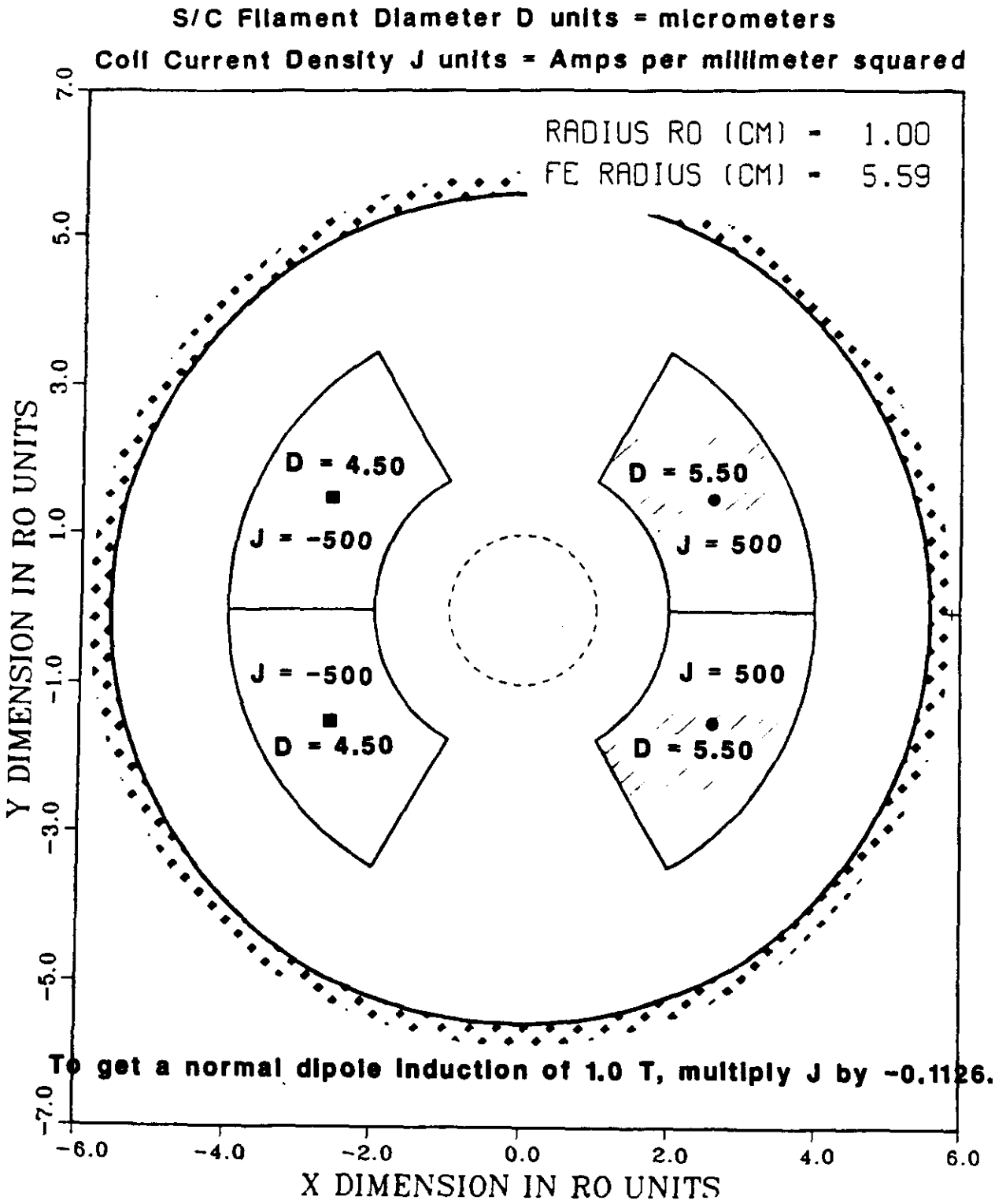


Figure 6. The sixty-degree dipole with normal dipole symmetry in the transport currents. The filament diameter has a left-right asymmetry.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 1
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.000368 | 0.000001 | 1.000000 |
| 2 | 0.000000 | -0.000038 | -0.000001 | 0.102096 |
| 3 | 0.000000 | -0.000272 | 0.000000 | 0.737688 |
| 4 | 0.000000 | -0.000006 | 0.000000 | 0.017600 |
| 5 | 0.000000 | -0.000001 | 0.000000 | 0.003173 |
| 6 | 0.000000 | 0.000001 | 0.000000 | -0.002282 |
| 7 | 0.000000 | 0.000004 | 0.000000 | -0.010848 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000061 |
| 9 | 0.000000 | -0.000001 | 0.000000 | 0.002591 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000079 |
| 11 | 0.000000 | 0.000000 | 0.000000 | -0.000058 |
| 12 | 0.000000 | 0.000000 | 0.000000 | -0.000018 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.002806 | 0.000000 | -0.002806 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000331 | 0.000000 | 0.000331 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | -0.000007 | 0.000000 | -0.000007 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

Skew Term | Normal Term | Skew Term | Normal Term

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 6. Multipoles and multipole ratios for Case 5, the sixty-degree dipole with left-right asymmetry in filament diameter, but the current density is constant.

# CASE 6

## SIXTY DEGREE NORMAL DIPOLE

## SUPERCONDUCTING MAGNET CROSS SECTION

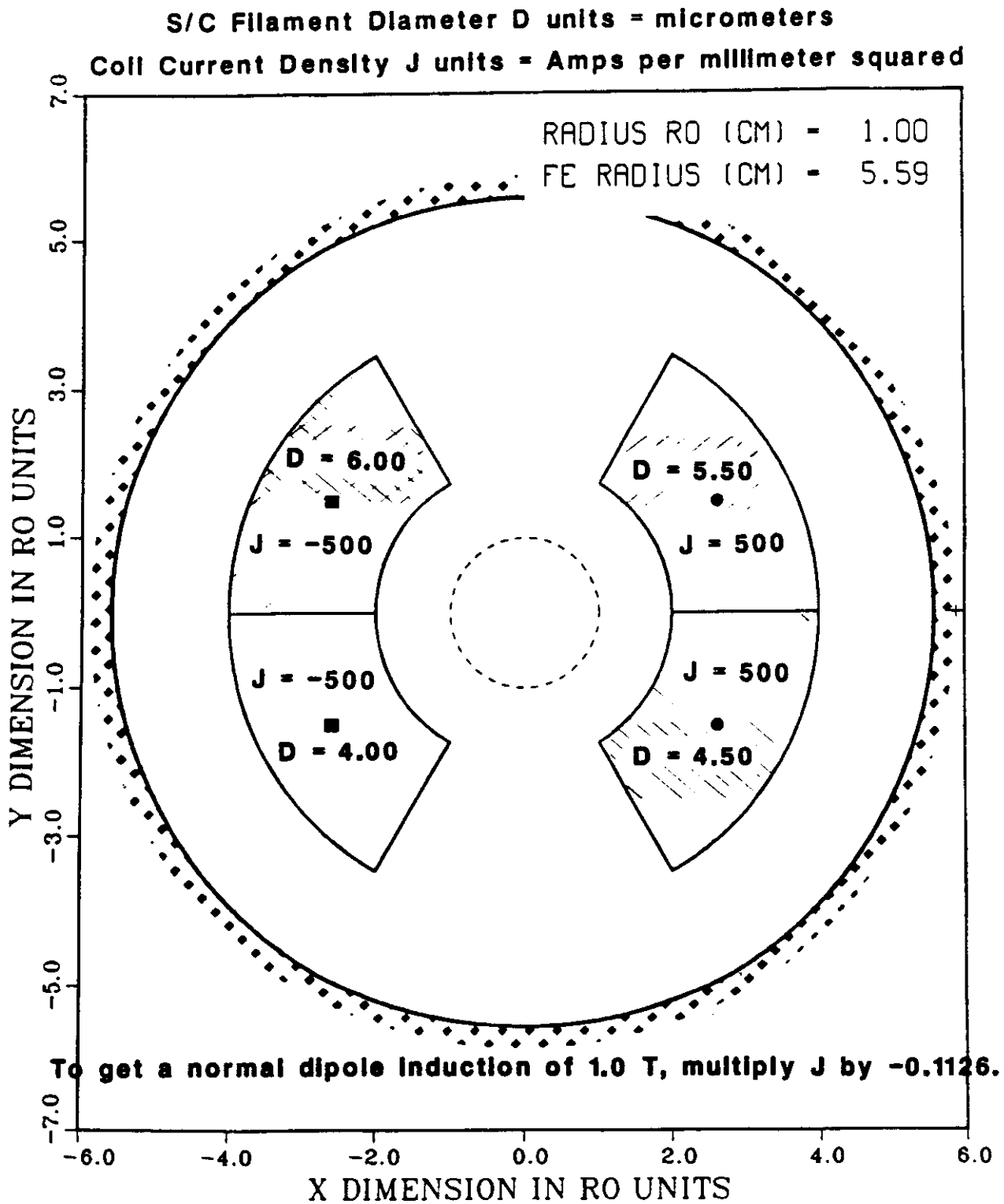


Figure 7. The sixty-degree dipole with normal dipole symmetry in the transport currents. The filament diameter is different in each quadrant.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 2
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | -0.000098 | -0.000296 | 0.330626 | 1.000000 |
| 2 | 0.000126 | 0.000000 | -0.425461 | -0.000238 |
| 3 | -0.000011 | -0.000228 | 0.035650 | 0.770630 |
| 4 | 0.000005 | 0.000000 | -0.015925 | -0.000034 |
| 5 | 0.000000 | 0.000002 | 0.001251 | -0.006890 |
| 6 | 0.000001 | 0.000000 | -0.003266 | 0.000003 |
| 7 | 0.000000 | 0.000001 | 0.000670 | -0.004685 |
| 8 | 0.000000 | 0.000000 | -0.000775 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000066 | 0.000856 |
| 10 | 0.000000 | 0.000000 | -0.000036 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000003 | -0.000023 |
| 12 | 0.000000 | 0.000000 | -0.000006 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.001933 | 0.000000 | -0.001933 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000154 | 0.000000 | 0.000154 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | -0.000001 | 0.000000 | -0.000001 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Skew Term | Normal Term | Skew Term | Normal Term |

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 7. Multipoles and multipole ratios for Case 6, the sixty-degree dipole with each quadrant having a different filament diameter, but the current density is constant.

**CASES 7 AND 8**

**SIX BLOCK COSINE THETA DIPOLE**
SUPERCONDUCTING MAGNET CROSS SECTION

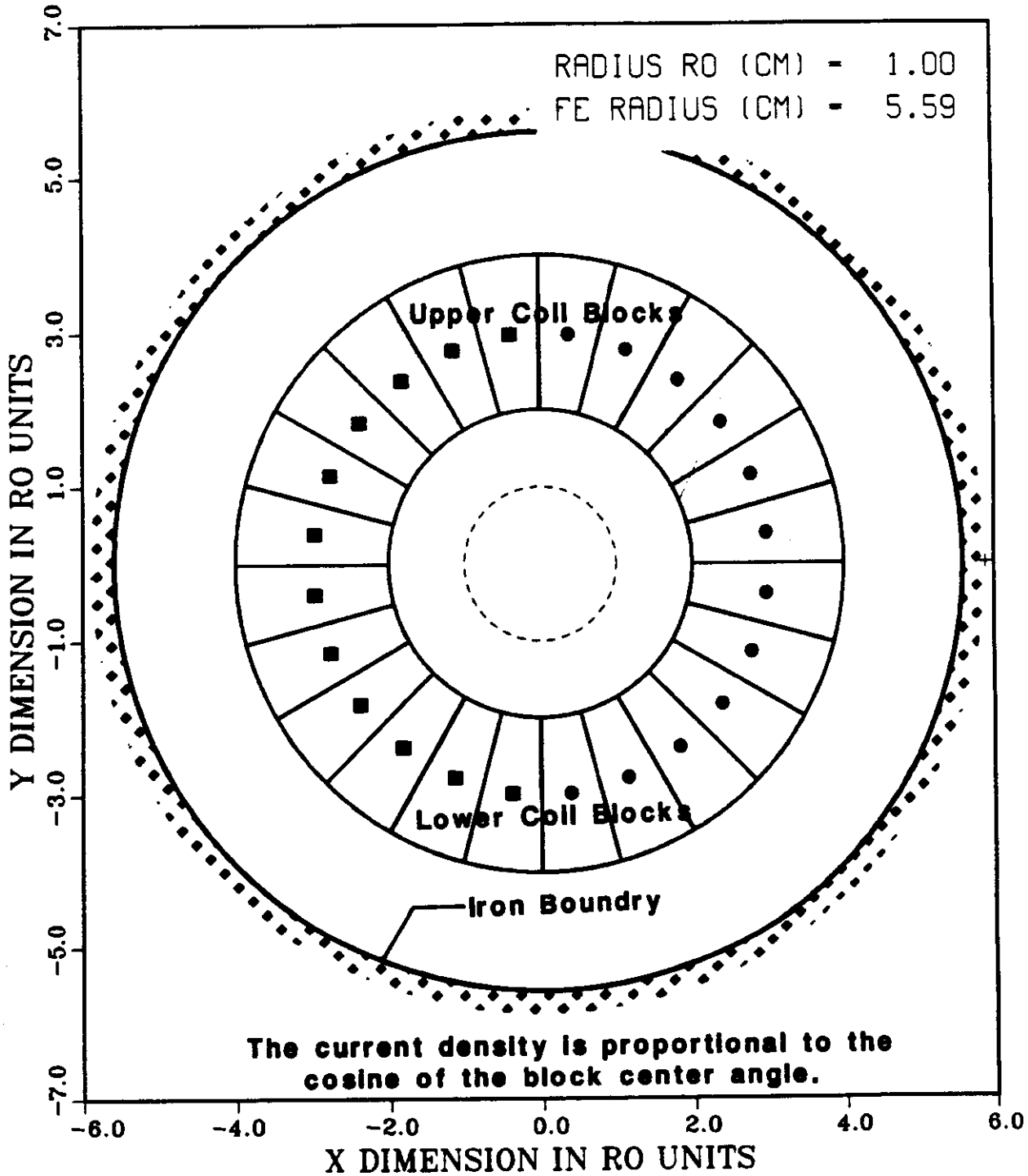


Figure 8. A six-block cosine theta dipole with a 10 mm useful aperture.

SSC DIPOLE CONFIGURATION COSINE THETA TYPE

| | |
|---|---|
| MAGNET SYMETRY NUMBER (NN) | 0 |
| NUMBER OF COIL PARTS (KL) | 24 |
| NUMBER OF MULTIPOLES (NX) | 13 |
| NUMBER OF R DIVISIONS (MX) | 4 |
| 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) | 2 |
| 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 | 2.0000 | 4.0000 | 0.0000 | 15.0000 | 1700.0000 | 50000. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 15.0000 | 30.0000 | 1700.0000 | 46593. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 30.0000 | 45.0000 | 1700.0000 | 40010. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 45.0000 | 60.0000 | 1700.0000 | 30701. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 60.0000 | 75.0000 | 1700.0000 | 19299. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 75.0000 | 90.0000 | 1700.0000 | 6583. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 165.0000 | 180.0000 | 1700.0000 | -50000. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 150.0000 | 165.0000 | 1700.0000 | -46593. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 135.0000 | 150.0000 | 1700.0000 | -40010. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 120.0000 | 135.0000 | 1700.0000 | -30701. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 105.0000 | 120.0000 | 1700.0000 | -19299. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 90.0000 | 105.0000 | 1700.0000 | -6583. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 180.0000 | 195.0000 | 1700.0000 | -50000. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 195.0000 | 210.0000 | 1700.0000 | -46593. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 210.0000 | 225.0000 | 1700.0000 | -40010. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 225.0000 | 240.0000 | 1700.0000 | -30701. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 240.0000 | 255.0000 | 1700.0000 | -19299. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 255.0000 | 270.0000 | 1700.0000 | -6583. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 345.0000 | 360.0000 | 1700.0000 | 50000. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 330.0000 | 345.0000 | 1700.0000 | 46593. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 315.0000 | 330.0000 | 1700.0000 | 40010. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 300.0000 | 315.0000 | 1700.0000 | 30701. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 285.0000 | 300.0000 | 1700.0000 | 19299. | 0.2000 | 1 |
| 1 | 2.0000 | 4.0000 | 270.0000 | 285.0000 | 1700.0000 | 6583. | 0.2000 | 1 |

To get a normal dipole field of 1.0 tesla, multiply XJ by -0.1228.

Table 8. The parameter for the six-block cosine theta dipole magnet for Case 7 and Case 8.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 2
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.001717 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | -0.000100 | 0.000000 | 0.058239 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | -0.000007 | 0.000000 | 0.003920 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000000 | 0.000000 | 0.000245 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000015 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | 0.000001 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Skew Term | Normal Term | Skew Term | Normal Term |

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 9. Multipoles and multipole ratios for Case 7, the six-block cosine theta dipole with no asymmetries.

MAGNET MULTIPOLE DATA FOR CASE NUMBER 2
RESIDUAL FIELDS WITH AN IRON SHELL, NORMAL NN = 1

STARTING CENTRAL INDUCTION 5.5000 TESLA
INDUCTION AFTER FIRST FLUX CHANGE 0.0000 TESLA
INDUCTION AFTER SECOND FLUX CHANGE 1.0000 TESLA

MAGNETIZATION CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | -0.001716 | 0.000000 | 1.000000 |
| 2 | 0.000030 | 0.000000 | -0.017838 | 0.000000 |
| 3 | 0.000000 | -0.000100 | 0.000000 | 0.058165 |
| 4 | 0.000006 | 0.000000 | -0.003255 | 0.000000 |
| 5 | 0.000000 | -0.000007 | 0.000000 | 0.003909 |
| 6 | 0.000001 | 0.000000 | -0.000612 | 0.000000 |
| 7 | 0.000000 | 0.000000 | 0.000000 | 0.000243 |
| 8 | 0.000000 | 0.000000 | -0.000117 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000015 |
| 10 | 0.000000 | 0.000000 | -0.000022 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | 0.000001 |
| 12 | 0.000000 | 0.000000 | -0.000004 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |

TRANSPORT CURRENT MULTIPOLE FIELDS AND MULTIPOLE RATIOS

| N | MULTIPOLE COMPONENT REAL PART | MULTIPOLE COMPONENT IMAGINARY PART | MULTIPOLE RATIO REAL PART | MULTIPOLE RATIO IMAGINARY PART |
|---|---|---|---|---|
| 1 | 0.000000 | 1.000000 | 0.000000 | 1.000000 |
| 2 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 3 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 4 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 5 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 6 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 7 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 8 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 9 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 10 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 11 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 12 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| 13 | 0.000000 | 0.000000 | 0.000000 | 0.000000 |
| | Skew Term | Normal Term | Skew Term | Normal Term |

The multipole reference radius is 10.0 mm. The coil inside radius is 20.0 mm. The coil outside radius is 40.0 mm. The iron shell inside radius is set at 55.9 mm.

Table 10. Multipoles and multipole ratios for Case 8, the six-block cosine theta dipole with top-bottom filament diameter asymmetry.

**CASES 9, 10 AND 11**

**SSC DIPOLE, LBL NC-7**

SUPERCONDUCTING MAGNET CROSS SECTION

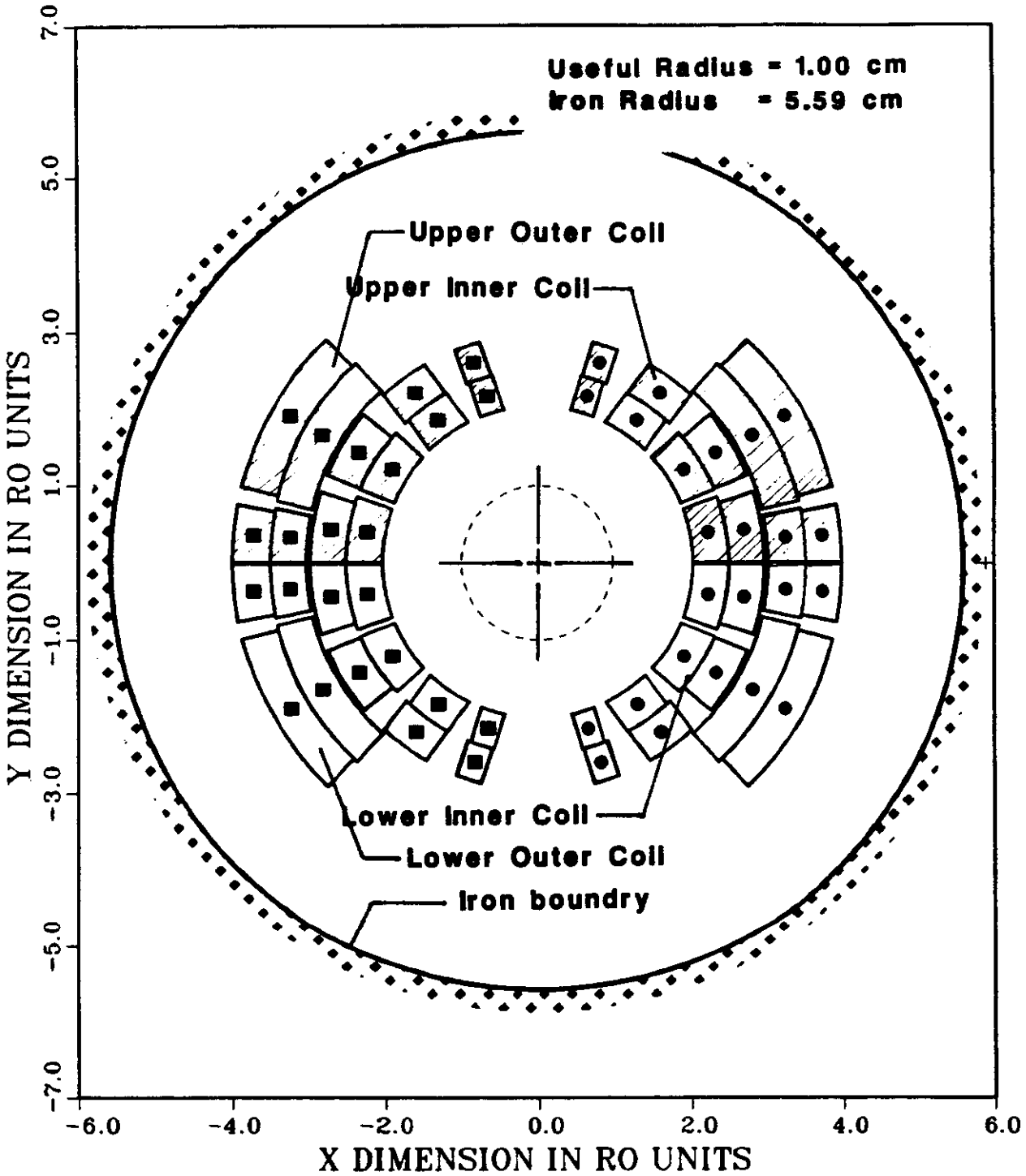


Figure 9. The LBL NC-7 SSC dipole cross-section (the shaded regions are regions of variable filament diameter for Case 10 and Case 11).

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.

Table 11. Dipole component of magnetization field and ratios of residual field multipoles with transport current central field for Case 9 in the NC-7 dipole with no asymmetry.

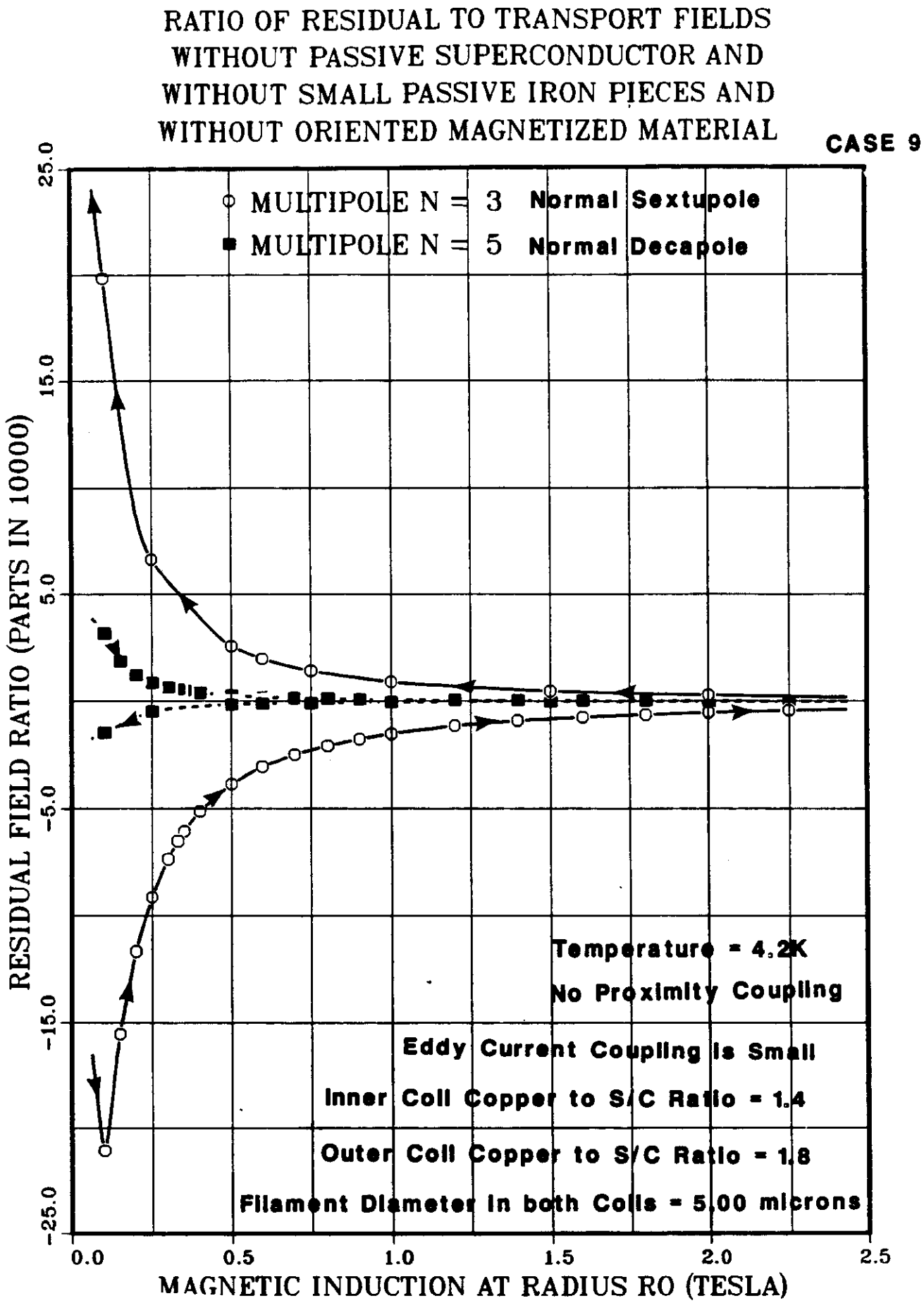


Figure 10. Magnetization field ratio versus field for a symmetric NC-7 dipole with 5 micron filaments.

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) | 8 |
| 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 | 180.1800 | 191.6400 | 1700.0000 | -48883. | 0.1293 | 4 |
| 1 | 3.5040 | 3.9940 | 180.1600 | 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 12. The parameters for the SSC-LBL-NC-7 coil with unbalanced superconductor $T_0$ and bottom for Case 10 and Case 11.

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 13. The superconductor parameters for superconductor in the NC-7 dipole used in Case 10. Case 11 has the same parameters except the 5.25 micron filament diameter is 21 microns and the 4.75 micron filament diameter is 19 microns.

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 |
| 6 | 0.000 | 5.500 | 0.500 | 0.000261 | -0.000067 | 0.000000 | 0.000000 | 0.000256 | -0.000003 | 0.000000 |
| 7 | 0.000 | 5.500 | 0.300 | 0.000325 | -0.000129 | 0.000000 | 0.000000 | 0.000523 | -0.000006 | 0.000000 |
| 8 | 0.000 | 5.500 | 0.200 | 0.000387 | -0.000212 | 0.000000 | 0.000000 | 0.000878 | -0.000010 | 0.000000 |
| 9 | 0.000 | 5.500 | 0.100 | 0.000413 | -0.000467 | 0.000000 | 0.000000 | 0.001978 | -0.000021 | 0.000000 |
| 10 | 0.000 | 5.500 | 0.000 | 0.000666 | -0.085274 | 0.000000 | 0.000000 | 0.473747 | -0.003397 | 0.000000 |
| 11 | 5.500 | 0.000 | 0.050 | -0.000191 | -0.000871 | 0.000000 | 0.000000 | -0.001471 | -0.000050 | 0.000000 |
| 12 | 5.500 | 0.000 | 0.100 | -0.000455 | -0.000131 | 0.000000 | 0.000000 | -0.002113 | -0.000026 | 0.000000 |
| 13 | 5.500 | 0.000 | 0.150 | -0.000477 | 0.000105 | 0.000000 | 0.000000 | -0.001560 | -0.000007 | 0.000000 |
| 14 | 5.500 | 0.000 | 0.200 | -0.000470 | 0.000132 | 0.000000 | 0.000000 | -0.001166 | 0.000001 | 0.000000 |
| 15 | 5.500 | 0.000 | 0.250 | -0.000459 | 0.000123 | 0.000000 | 0.000000 | -0.000914 | 0.000003 | 0.000000 |
| 16 | 5.500 | 0.000 | 0.300 | -0.000442 | 0.000109 | 0.000000 | 0.000000 | -0.000736 | 0.000004 | 0.000000 |
| 17 | 5.500 | 0.000 | 0.325 | -0.000433 | 0.000102 | 0.000000 | 0.000000 | -0.000666 | 0.000004 | 0.000000 |
| 18 | 5.500 | 0.000 | 0.350 | -0.000426 | 0.000096 | 0.000000 | 0.000000 | -0.000607 | 0.000004 | 0.000000 |
| 19 | 5.500 | 0.000 | 0.400 | -0.000412 | 0.000084 | 0.000000 | 0.000000 | -0.000514 | 0.000004 | 0.000000 |
| 20 | 5.500 | 0.000 | 0.500 | -0.000387 | 0.000066 | 0.000000 | 0.000000 | -0,000385 | 0.000003 | 0.000000 |
| 21 | 5.500 | 0.000 | 0.600 | -0.000371 | 0.000051 | 0.000000 | 0.000000 | -0.000303 | 0.000003 | 0.000000 |
| 22 | 5.500 | 0.000 | 0.700 | -0.000353 | 0.000042 | 0.000000 | 0.000000 | -0.000246 | 0.000002 | 0.000000 |
| 23 | 5.500 | 0.000 | 0.800 | -0.000338 | 0.000035 | 0.000000 | 0.000000 | -0.000206 | 0.000002 | 0.000000 |
| 24 | 5.500 | 0.000 | 0.900 | -0.000323 | 0.000030 | 0.000000 | 0.000000 | -0.000175 | 0.000002 | 0.000000 |
| 25 | 5.500 | 0.000 | 1.000 | -0.000307 | 0.000025 | 0.000000 | 0.000000 | -0.000150 | 0.000001 | 0.000000 |
| 26 | 5.500 | 0.000 | 1.200 | -0.000282 | 0.000019 | 0.000000 | 0.000000 | -0.000114 | 0.000001 | 0.000000 |
| 27 | 5.500 | 0.000 | 1.400 | -0.000260 | 0.000015 | 0.000000 | 0.000000 | -0.000090 | 0.000001 | 0.000000 |
| 28 | 5.500 | 0.000 | 1.600 | -0.000243 | 0.000012 | 0.000000 | 0.000000 | -0.000073 | 0.000001 | 0.000000 |
| 29 | 5.500 | 0.000 | 1.800 | -0.000228 | 0.000010 | 0.000000 | 0.000000 | -0.000061 | 0.000001 | 0.000000 |
| 30 | 5.500 | 0.000 | 2.000 | -0.000212 | 0.000008 | 0.000000 | 0.000000 | -0.000052 | 0.000000 | 0.000000 |
| 31 | 5.500 | 0.000 | 2.250 | -0.000195 | 0.000007 | 0.000000 | 0.000000 | -0.000042 | 0.000000 | 0.000000 |
| 32 | 5.500 | 0.000 | 2.500 | -0.000182 | 0.000006 | 0.000000 | 0.000000 | -0.000035 | 0.000000 | 0.000000 |

END OF RESIDUAL FIELD FOR THE GENERAL MAGNET NN = 1

Skew Term | Normal Term | Skew Term | Normal Term | Skew Term | Normal Term

Table 14. Dipole component of magnetization field and ratios of residual field multipoles with transport current central field for Case 10 in the NC-7 dipole with up-down filament diameter asymmetry (nominal 5 micron filaments).

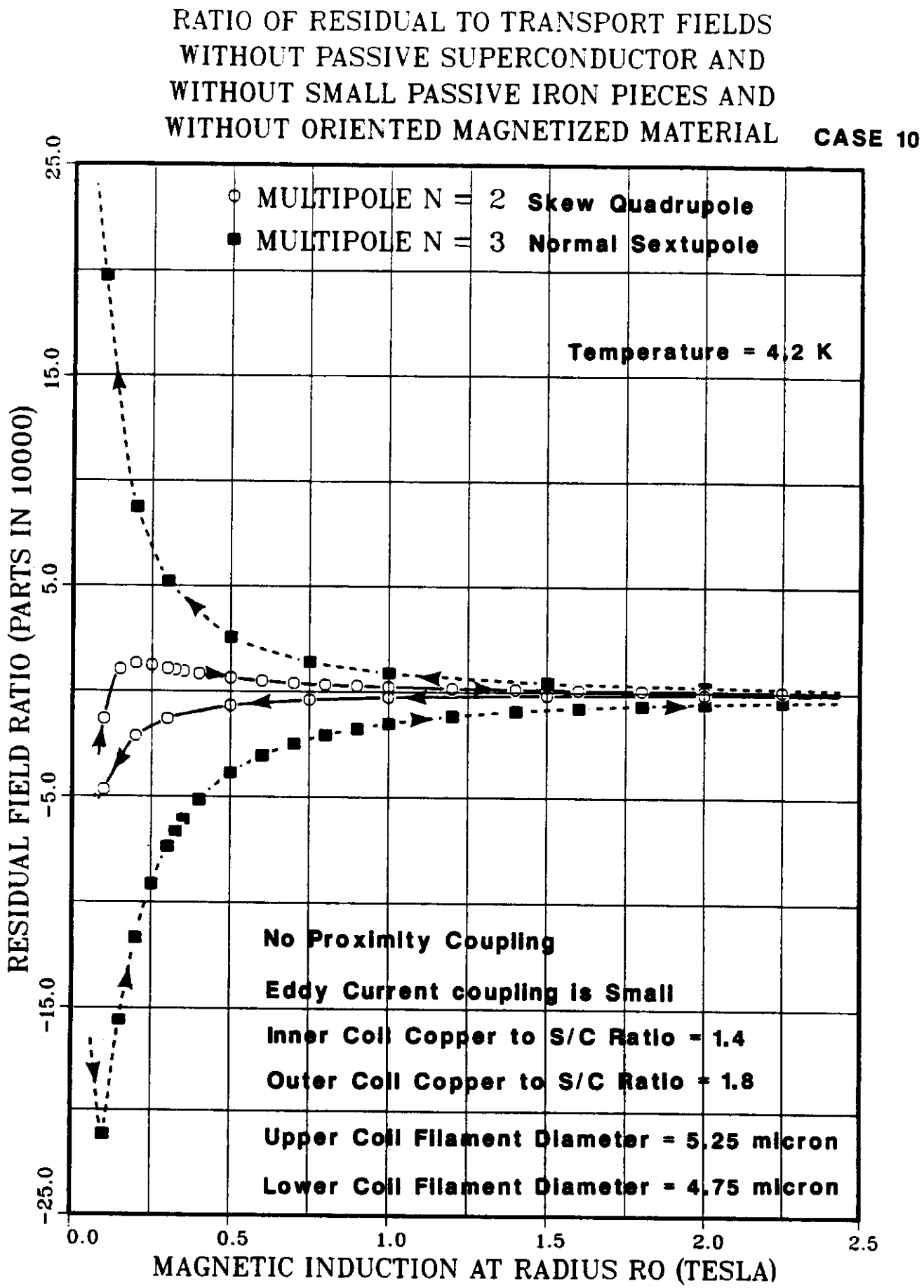


Figure 11. Magnetization field ratio versus field for up-down asymmetry with 5 ± 0.25 micron filaments.

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 | 0.000497 | -0.000022 | 0.000000 | 0.000000 | 0.000098 | -0.000001 | 0.000000 |
| 2 | 0.000 | 5.500 | 2.000 | 0.000591 | -0.000033 | 0.000000 | 0.000000 | 0.000146 | -0.000002 | 0.000000 |
| 3 | 0.000 | 5.500 | 1.500 | 0.000719 | -0.000051 | 0.000000 | 0.000000 | 0.000233 | -0.000003 | 0.000000 |
| 4 | 0.000 | 5.500 | 1.000 | 0.000886 | -0.000094 | 0.000000 | 0.000000 | 0.000435 | -0.000005 | 0.000000 |
| 5 | 0.000 | 5.500 | 0.750 | 0.001034 | -0.000142 | 0.000000 | 0.000000 | 0.000669 | -0.000007 | 0.000000 |
| 6 | 0.000 | 5.500 | 0.500 | 0.001210 | -0.000243 | 0.000000 | 0.000000 | 0.001176 | -0.000012 | 0.000000 |
| 7 | 0.000 | 5.500 | 0.300 | 0.001457 | -0.000466 | 0.000000 | 0.000000 | 0.002335 | -0.000022 | 0.000000 |
| 8 | 0.000 | 5.500 | 0.200 | 0.001616 | -0.000749 | 0.000000 | 0.000000 | 0.003846 | -0.000033 | 0.000000 |
| 9 | 0.000 | 5.500 | 0.100 | 0.001795 | -0.001599 | 0.000000 | 0.000000 | 0.008419 | -0.000067 | 0.000000 |
| 10 | 0.000 | 5.500 | 0.000 | 0.002267 | -0.078133 | 0.000000 | 0.000000 | 0.473183 | -0.003108 | 0.000000 |
| 11 | 5.500 | 0.000 | 0.050 | 0.001225 | -0.003383 | 0.000000 | 0.000000 | 0.011894 | -0.000139 | 0.000000 |
| 12 | 5.500 | 0.000 | 0.100 | 0.000482 | -0.001613 | 0.000000 | 0.000000 | 0.002757 | -0.000074 | 0.000000 |
| 13 | 5.500 | 0.000 | 0.150 | -0.000109 | -0.000955 | 0.000000 | 0.000000 | 0.000036 | -0.000052 | 0.000000 |
| 14 | 5.500 | 0.000 | 0.200 | -0.000561 | -0.000593 | 0.000000 | 0.000000 | -0.001053 | -0.000041 | 0.000000 |
| 15 | 5.500 | 0.000 | 0.250 | -0.000871 | -0.000356 | 0.000000 | 0.000000 | -0.001481 | -0.000034 | 0.000000 |
| 16 | 5.500 | 0.000 | 0.300 | -0.001053 | -0.000187 | 0.000000 | 0.000000 | -0.001587 | -0.000028 | 0.000000 |
| 17 | 5.500 | 0.000 | 0.325 | -0.001103 | -0.000120 | 0.000000 | 0.000000 | -0.001571 | -0.000025 | 0.000000 |
| 18 | 5.500 | 0.000 | 0.350 | -0.001132 | -0.000083 | 0.000000 | 0.000000 | -0.001528 | -0.000022 | 0.000000 |
| 19 | 5.500 | 0.000 | 0.400 | -0.001143 | 0.000025 | 0.000000 | 0.000000 | -0.001400 | -0.000016 | 0.000000 |
| 20 | 5.500 | 0.000 | 0.500 | -0.001081 | 0.000101 | 0.000000 | 0.000000 | -0.001107 | -0.000004 | 0.000000 |
| 21 | 5.500 | 0.000 | 0.600 | -0.001017 | 0.000112 | 0.000000 | 0.000000 | -0.000877 | 0.000001 | 0.000000 |
| 22 | 5.500 | 0.000 | 0.700 | -0.000977 | 0.000107 | 0.000000 | 0.000000 | -0.000724 | 0.000003 | 0.000000 |
| 23 | 5.500 | 0.000 | 0.800 | -0.000941 | 0.000098 | 0.000000 | 0.000000 | -0.000609 | 0.000003 | 0.000000 |
| 24 | 5.500 | 0.000 | 0.900 | -0.000904 | 0.000089 | 0.000000 | 0.000000 | -0.000521 | 0.000003 | 0.000000 |
| 25 | 5.500 | 0.000 | 1.000 | -0.000860 | 0.000081 | 0.000000 | 0.000000 | -0.000449 | 0.000003 | 0.000000 |
| 26 | 5.500 | 0.000 | 1.200 | -0.000795 | 0.000066 | 0.000000 | 0.000000 | -0.000341 | 0.000003 | 0.000000 |
| 27 | 5.500 | 0.000 | 1.400 | -0.000748 | 0.000055 | 0.000000 | 0.000000 | -0.000273 | 0.000003 | 0.000000 |
| 28 | 5.500 | 0.000 | 1.600 | -0.000719 | 0.000046 | 0.000000 | 0.000000 | -0.000226 | 0.000003 | 0.000000 |
| 29 | 5.500 | 0.000 | 1.800 | -0.000691 | 0.000039 | 0.000000 | 0.000000 | -0.000192 | 0.000002 | 0.000000 |
| 30 | 5.500 | 0.000 | 2.000 | -0.000654 | 0.000033 | 0.000000 | 0.000000 | -0.000164 | 0.000002 | 0.000000 |
| 31 | 5.500 | 0.000 | 2.250 | -0.000611 | 0.000027 | 0.000000 | 0.000000 | -0.000134 | 0.000002 | 0.000000 |
| 32 | 5.500 | 0.000 | 2.500 | -0.000579 | 0.000023 | 0.000000 | 0.000000 | -0.000114 | 0.000001 | 0.000000 |

END OF RESIDUAL FIELD FOR THE GENERAL MAGNET NN = 1

Skew Term — Normal Term — Skew Term — Normal Term — Skew Term — Normal Term

Table 15. Dipole component of magnetization field and ratios of residual field multipoles with transport current central field for Case 11 in the NC-7 dipole with up-down filament diameter asymmetry (nominal 20 micron filaments).

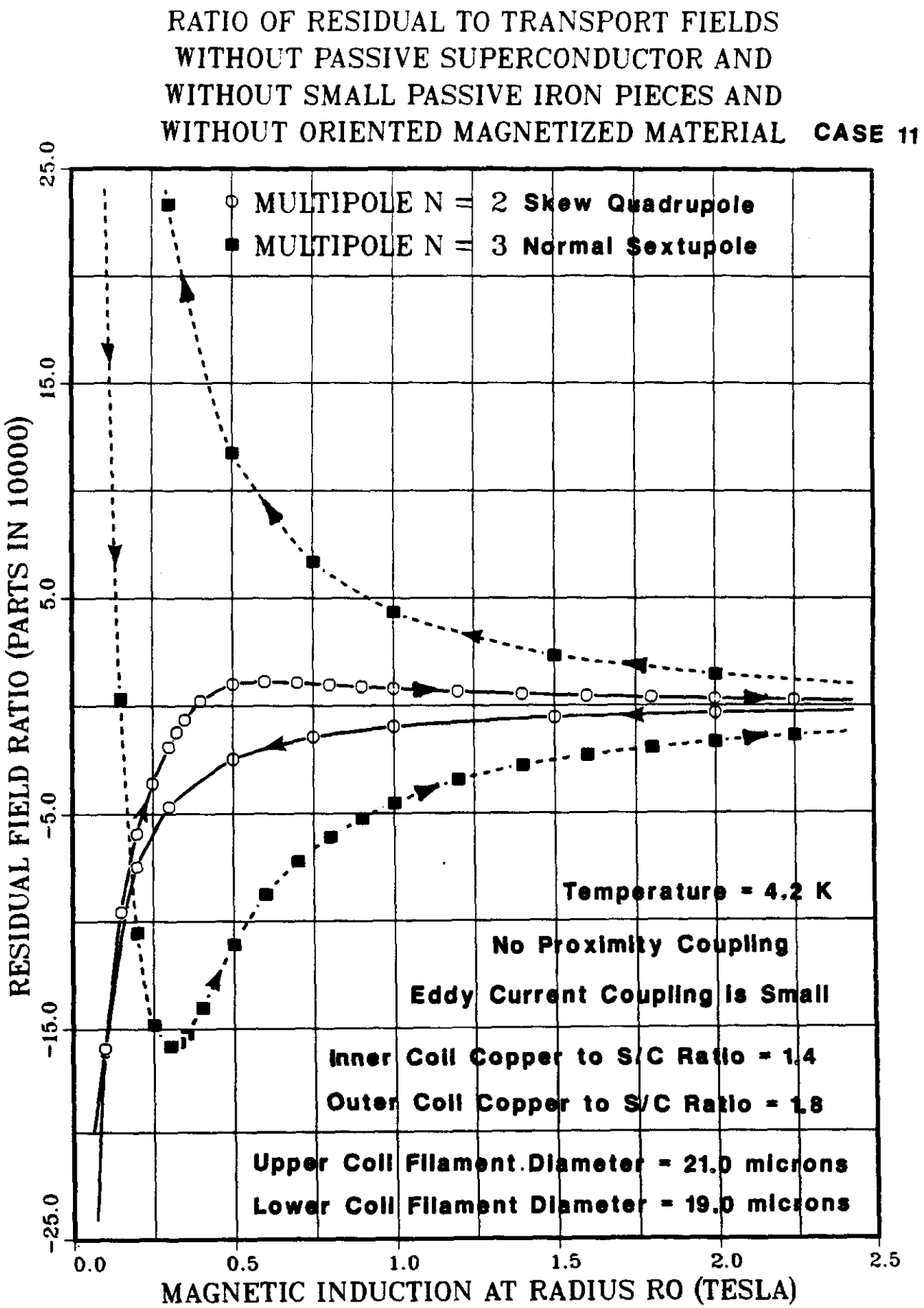


Figure 12. Magnetization field ratio versus field for up-down asymmetry with 20 ± 1 micron filaments.