Title
INSTRUCTIONS FOR THE USE OF SCMAG1, SCMAG2, SCMAG3, AND SCMAG4

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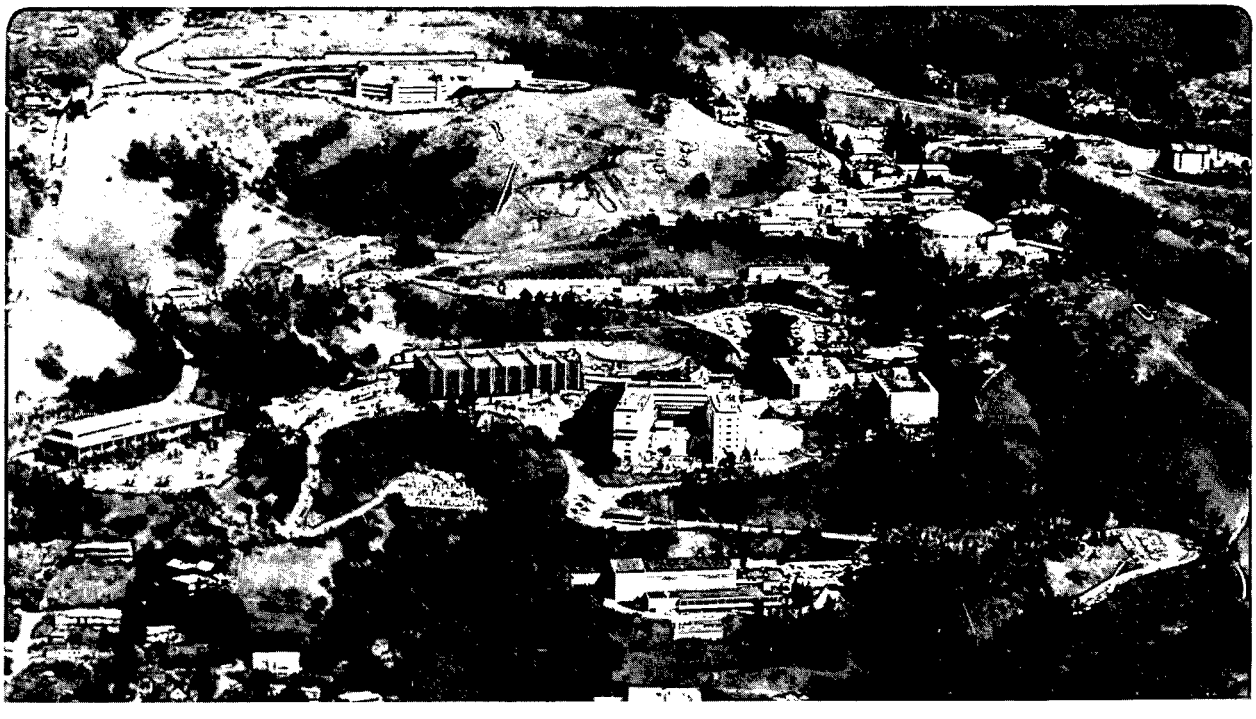

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ENGINEERING NOTE

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PROGRAM — PROJECT — JOB
GENERAL

MAGNETIC FIELD PROGRAMS

TITLE

INSTRUCTIONS FOR THE USE OF SCMAG1, SCMAG2, SCMAG3, AND SCMAG4

There exist four computer programs for calculating superconducting dipole and quadrupole magnets. The SCMAG series of programs were developed at the Lawrence Berkeley Laboratory and the Institute fur Experimentelle Kernphysik, Kernforschungszentrum, Karlsruhe, W. Germany. The development of the programs started in 1970 here at LBL. The programs were developed further in 1971 and 1972 while I was at the Kernforschungszentrum. The capability of the programs was extended further in late 1973 and 1974. The programs are capable of calculating magnets with a wide variety of conductor configurations with an infinitely permeable circular iron shell.

The first four SCMAG programs (SCMAG1 through SCMAG4) are designed to calculate symmetric dipoles, quadrupoles, sextupoles, and so on. The magnetic fields are expanded in a power series. In most applications, one wants the field to be a pure dipole, quadruple, sextupole, or so on. The coils may have a wide variety of coil shapes. However, the infinitely permeable iron shell may only be a circular cylinder with it's axis coincident with the axis of the coil.

A general description of the four programs is as follows:

SCMAG1 This program designs superconducting dipole and quadrupole coils. The program uses a point algorithm. The program will design a coil with any desired two-dimensional multipole structure which is consistent with the coil geometric constraints. After the two-dimensional design is complete, the program goes on to design coils which produce the desired infinite integrated field. The magnet coil configuration produced will have both the two-dimensional field and integrated field properties which are desired.

SCMAG2 This program uses a point algorithm to calculate the field related properties in a magnet with a given two-dimensional coil and end design. The program calculates the two-dimensional field multiple structure and the field multipole structure. A two-dimensional field plot inside the useful aperture is generated. The field is calculated along the inner coil boundary and the inner iron boundary. A point by point magnetic field and magnetic force plot is generated for points inside the magnet coil. A magnetic force table is created for major magnet components. Other magnet parameters such as the magnet inductance and the magnet stored energy are calculated. The program calculates all of the above when there is no iron or when there is a circular iron shell ($\mu = \infty$) of a given radius.

SCMAG3 This program uses a point algorithm to calculate the effect of various types of random tolerance errors on the multipole field structure and the $\Delta B/B$ inside given aperture radii. The tolerance limits are applied to: 1) individual conductors; 2) coil sectors; 3) coil parts; 4) the whole coil with respect to the iron; and 5) errors in magnetic measuring coil placement. The sum of the first four types of errors is calculated and analyzed.

SCMAG4 This program uses a point algorithm to calculate the two-dimensional residual field. Round superconducting filaments are assumed. The program considers the effect of multiple flux penetrations of the superconductor and the variable J_c vs. H characteristic of a real type two superconductor. The effect of Meisner state behavior in type two conductors is considered. The results of this calculation seem to agree with measured data.

The programs can handle a number of two-dimensional coil configurations. The point algorithm programs can calculate: 1) sector coils (cases 1 and 2 in Figure 1); 2) modified sector coils (cases 3 and 4 in Figure 1); 3) rectangular block coils (cases 5 and 6 in Figure 1); and 4) current points (cases 7 and 8 in Figure 1). The coil configurations may be used as shown in Figure 1 or they may be shifted with respect to the x and y axis as shown in Figure 2. The point algorithm programs may calculate or check every coil configuration currently being used to generate a dipole or quadrupole fields in a conductor dominated magnets with circular iron. For example, case 1 with no shift in axis may be used to model Rutherford's AC-4 magnet; case 4 with no shift in axis may be used for Karlsruhe's dipole D-2a; case 5 with no shift in axis can be used to describe Karlsruhe's dipole D-1 or Saclay's Moby dipole; and case 1 with axis shift can be used to describe the NAL doubler magnets. Various combinations of the eight cases can be used to describe a wide variety of magnet coil shapes.

The A1, A2, R1, and R2 variables along with the current density of the block XJ (the point current A_3 in cases 7 and 8) may be used iteratively to calculate the basic two-dimensional geometry of the magnet. The length of various two-dimensional blocks may be varied to produce the desired integrated field. SCMAG1 performs these functions for cases 1 through 8 with or without an axis shift. The SCMAG2 may be used with coils designed using all eight cases. SCMAG3 and SCMAG4 are currently restricted to cases 1 through 4. Eventually SCMAG1 through SCMAG4 will have a common deck of cards which describes the basic magnet parameters and the basic coil shape. SCMAG3 and 4 have no provision for X Shift and Y Shift. Eventually these codes will have this provision.

SCMAG1 and SCMAG2 will calculate the two-dimensional field and the integrated field along the magnet axis from minus infinity to plus infinity. SCMAG3 and SCMAG4 are two-dimensional programs only. The types of ends which can be calculated are limited to four basic types. The SCMAG1 and SCMAG2 programs are by necessity fairly general computer codes. Other end types are possible but we leave it to the user of the codes to develop end types which will fill his needs.

The end types which are available for use in SCMAG1 and SCMAG2 are as follows:

Equal Length Round Ends - This type of end is developed round. The conductor assumes a shape in the end region consistent with the law of continuity.

Lambertson Ends - This type of end results in an integrated field which has the same structure as the two-dimensional field. Any bend angle may be used. The most practical angle from a construction point of view is 30 degrees.

Turned Up Ends - The end of the coil is turned up 90 degrees. The program takes into consideration the real physical behavior of the conductor bundle during the process.

Bent Ends - The round end is bent up at any desired angle. It is like a turned up end in this respect.

A developed view (the ends are unbent and unfolded) of various end types are shown in Figure 3.

The SCMAG codes were originally written in a sector algorithem but were converted to point algorithm in 1972. The theory behind SCMAG1 and SCMAG2 is given in references 1, 2, 4, and 7. (The first three references are given in sector algorithm.

The last reference is given in point algorithm.) The sector and point algorithm versions of SCMAG2 are compared in reference 10. In 1974 the sector version of SCMAG1 and SCMAG2 was done away with. The study of residual fields in superconducting dipoles and quadrupoles in 1970 and 1971 led to the development of the SCMAG4 code which uses a Taylor expansion of point doublet currents as the basis for calculating residual fields. Residual field theory is discussed in references 3, 5, 7, 8 and 11. The SCMAG3 program development was started in 1971 and 1972. The basic theory of coil errors and its application in the SCMAG3 code is given in references 6, 8, 9, and 11. No computer code development has occurred on SCMAG1 through 4 since 1975. There was an effort to integrate the SCMAG codes into a single set of calculations which simulate an accelerator magnet at various currents. This simulation is described in reference 11.

The author would like to point out that other dipole and quadrupole computer codes exist at the Lawrence Berkeley Laboratory and at other laboratories. The SCMAG codes are not unique or original. The only thing they really have going for them is the fact they use a common set of input data cards that describe the magnet and coil parameters. A description of the data input decks for each of the four SCMAG dipole and quadrupole programs is given in the Appendix.

Acknowledgement

The author would like to thank J. M. DeOlivares for putting the four SCMAG dipole and quadrupole codes back into operation. Thanks to Juan these codes are available to other users at the Lawrence Berkeley Laboratory.

References

1. K. Halbach, "Fields and First Order Perturbation Effects in Two-Dimensional Conductor Dominated Magnets," UCRL-18947, July 1969.

2. M. A. Green, "The Elimination of Higher Multipoles in Air Core Dipoles and Quadrupoles," LBL Engineering Note M4299, December 1979.

3. M. A. Green, "The Theory of Residual Fields in Two Dimensional Dipoles and Quadrupoles without Iron Shields," UCID 3508, January 1971.

4. M. A. Green, "The Elimination of Higher Multipoles in the Two Dimensional and Integrated Fields of Conductor-Dominated Dipole and Quadrupole Magnets with Iron Shells," LBL Engineering Note M4373, UCID-3493, January 1971.

5. M. A. Green, "Residual Field in Superconducting Dipole and Quadrupole Magnets," IEEE Transaction on Nuclear Science NS-18, No. 3, UCRL 20171, June 1971.

6. M. A. Green, "Field Aberrations in Superconducting Dipole and Quadrupole Magnets for a Superconducting Synchrotron," KFK, Ext. Ber. IEKP 3/71-7.

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8. M. A. Green, "GESSS Machine Design Committee Reports for 1972," KFK 1764, June 1973.

9. M. A. Green, "Superconducting Dipoles and Quadrupoles for the PEP Accelerating-Storage Proton Ring," PEP Note-70, 1973 PEP Summer Study, November 1973.

10. M. A. Green, "Comparison Between the Sector and Point Version of the Computer Program SCMAG," UCID 3655, April 1974.

11. M. A. Green, "Computer Simulation of the Interaction of a Superconducting Synchrotron Magnet Good Field Region with a Particle Beam," IEEE Transactions, NS-22, No. 3, June 1975, LBL 3373.

Table 1. Input data which describes the magnet coils in the SCMAG programs. The dimension of each of the parameters is shown.

	Coil Type	Coil R Parameters		Coil A Parameters		Coil Straight Sect. Leng.	Coil Current Density	Cond. spacing in A direct. or cond. cur.	Assembly Number
	NT	R_1	R_2	A_1	A_2	XLEN	XJ	A_3	MK
Case 1	1	cm	cm	deg	deg	cm	A cm^{-2}	cm	N.D.
Case 2	2	cm	cm	deg	deg	cm	A cm^{-2}	cm	N.D.
Case 3	3	cm	cm	deg	deg	cm	A cm^{-2}	cm	N.D.
Case 4	4	cm	cm	deg	cm	cm	A cm^{-2}	cm	N.D.
Case 5	5	cm	cm	cm	cm	cm	A cm^{-2}	cm	N.D.
Case 6	6	cm	cm	cm	cm	cm	A cm^{-2}	cm	N.D.
Case 7	7	cm	cm	cm	cm	cm	A cm^{-2}	A	N.D.
Case 8	8	cm	cm	deg	deg	cm	A cm^{-2}	A	N.D.

cm = Dimensions are given in centimeters.

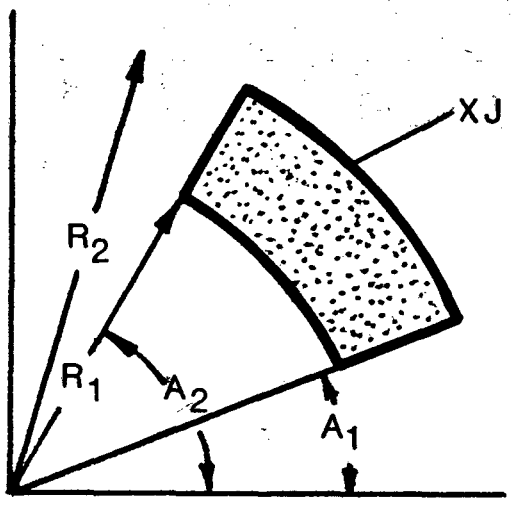
deg = Angles are given in degrees.

A cm^{-2} = Coil current densities are given in amps per square centimeter.

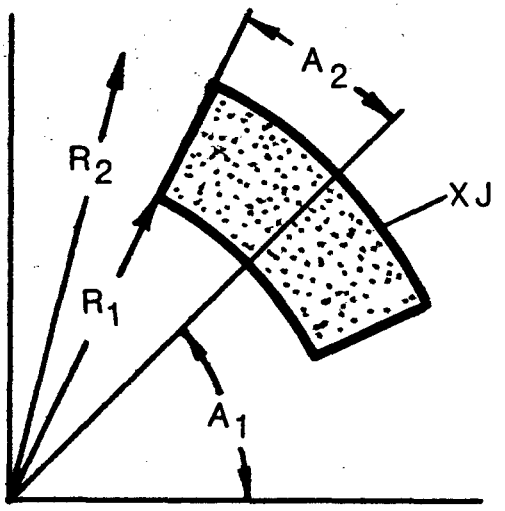
A = Conductor currents given in amperes.

N.D. = Not dimensionalized (this is an integer number).

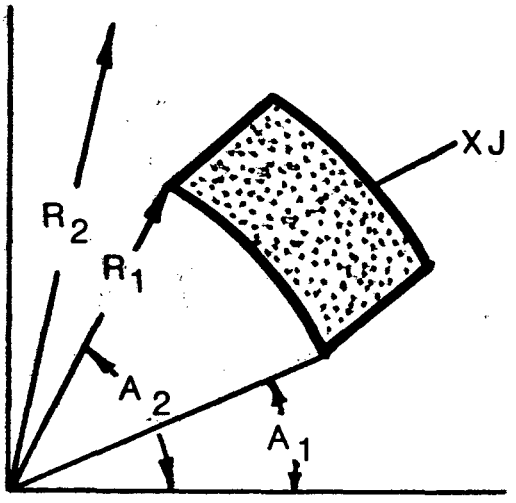
Figure 1 - Various dipole coil configurations case calculated by the programs. (Note: for quadrupoles these configurations would be confined to an angle between 0 and 45 degrees. Symmetry is used in these codes.)



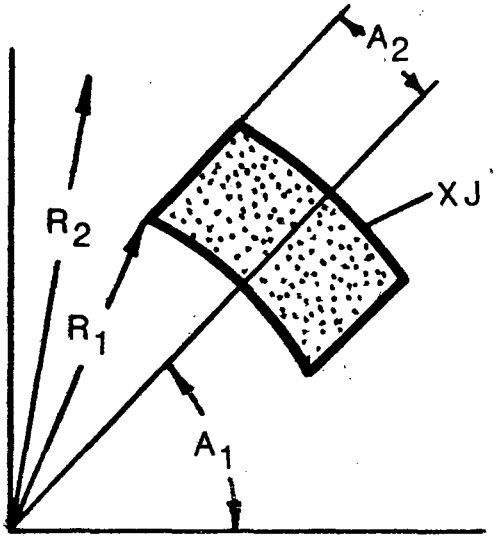
Case 1 - Sector Coils



Case 2 - Sector Coils

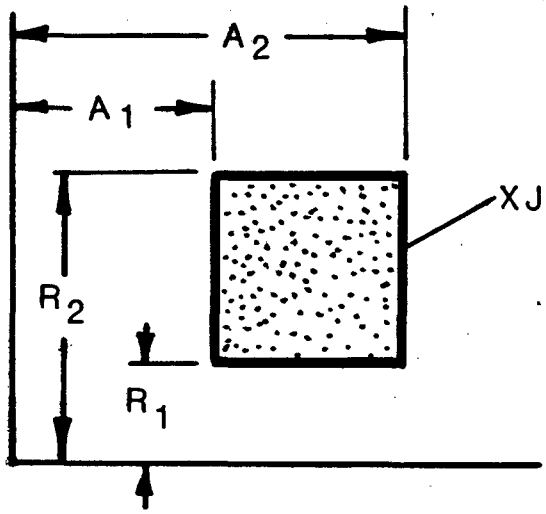


Case 3 - Modified Sector Coils

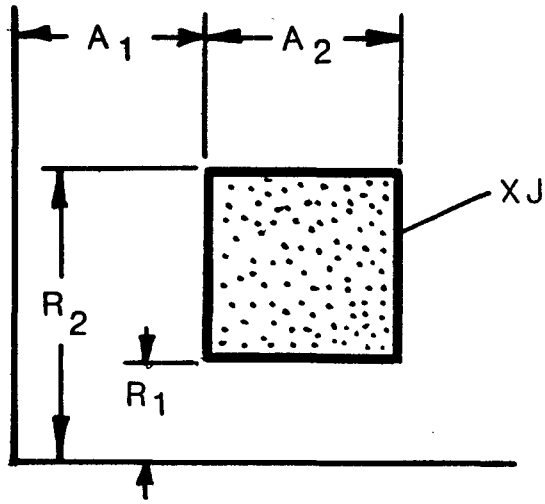


Case 4 - Modified Sector Coils

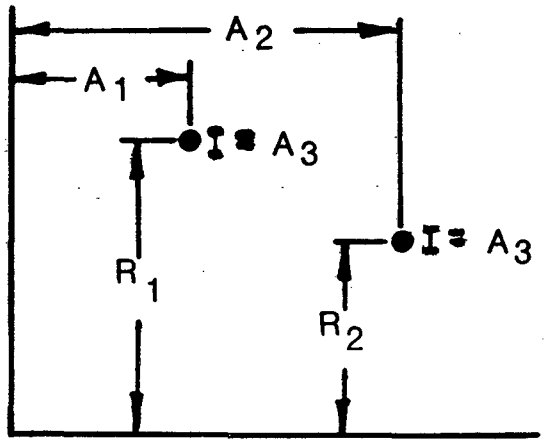
Figure 1 - continued



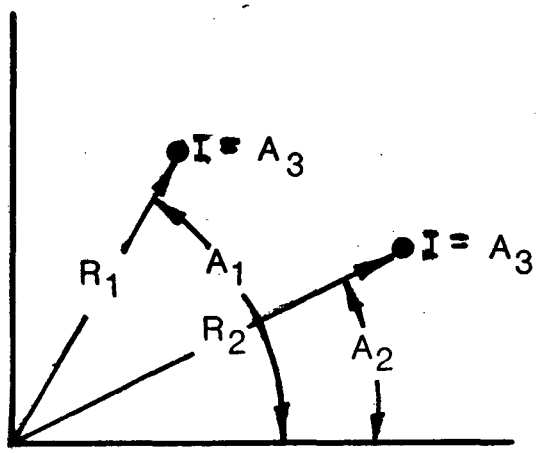
Case 5 - Rectangular Block Coils



Case 6 - Rectangular Block Coils



Case 7 - Current Points



Case 8 - Current Points

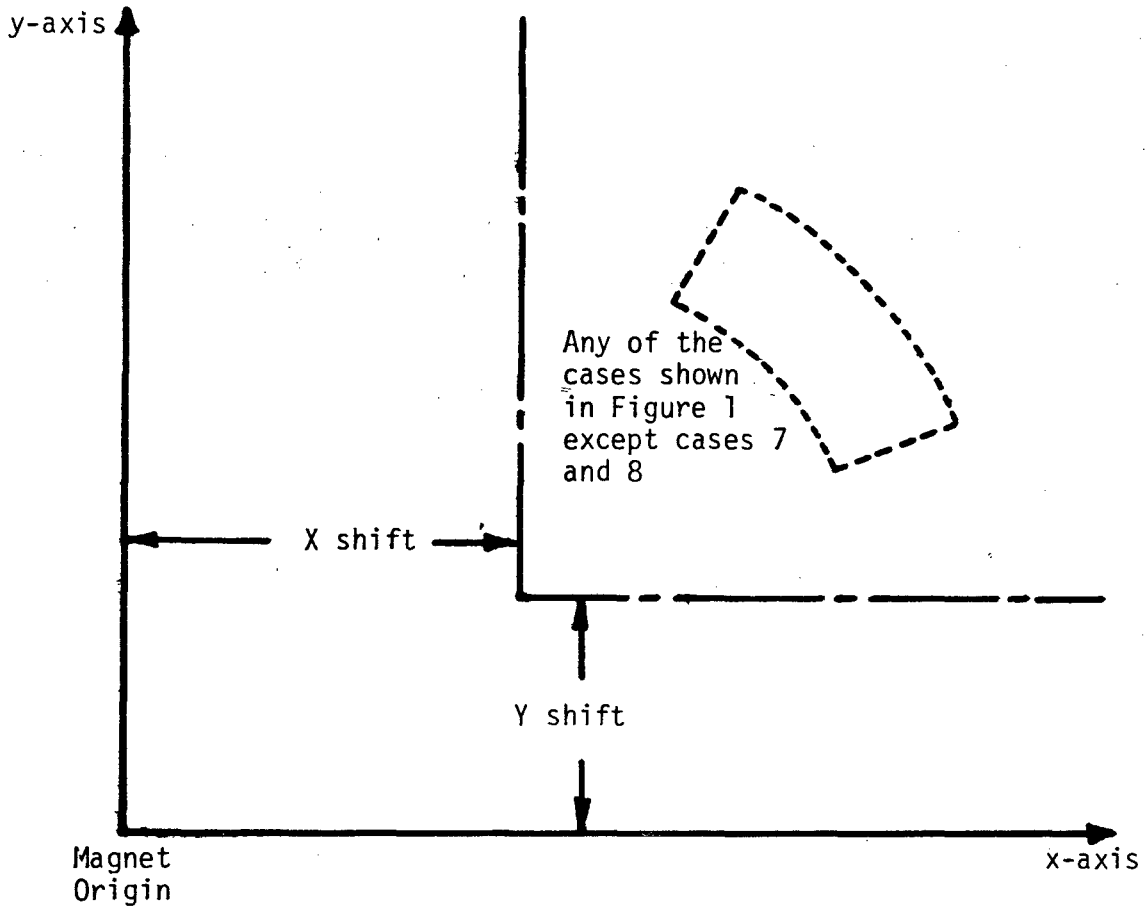
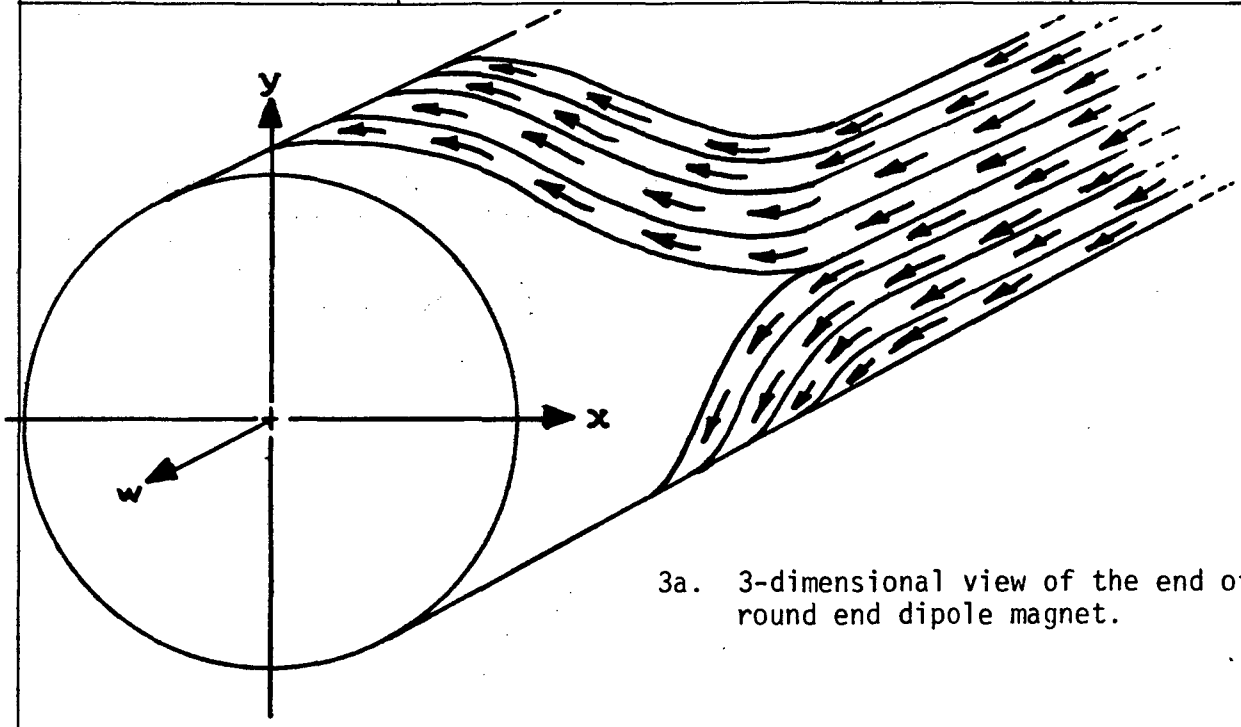


Figure 2 - The axis shift permitted in programs SCMAG1 and SCMAG2. The first six cases shown in Figure 1 can be shifted with respect to the x and y axis as shown.*

* For example, the old Fermi Lab dipole consisted of four sector coils. Case 1 was used to model each coil. All four coils were shifted along the x-axis about a half an inch. There was no shift of the y-axis. The result was a coil with an elliptical coil bore.



3a. 3-dimensional view of the end of a round end dipole magnet.

3b. Flattened section of a round end showing the method of integrated current calculation.

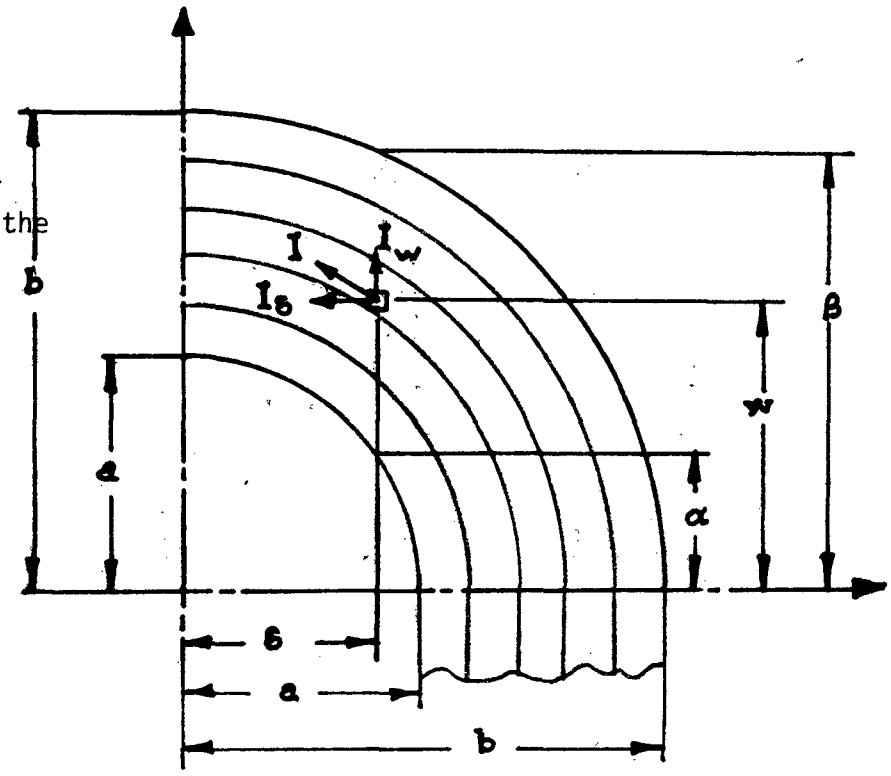
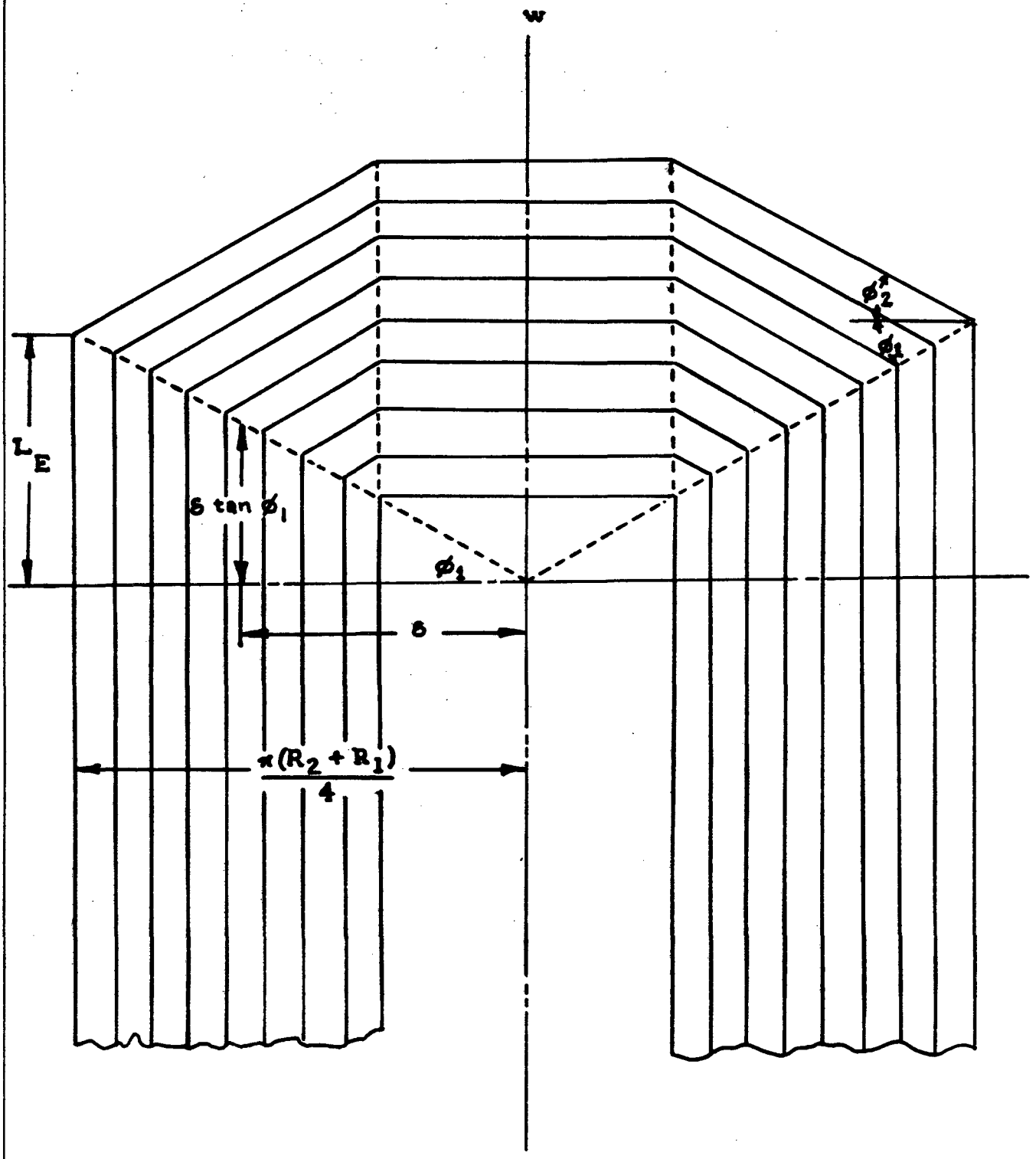


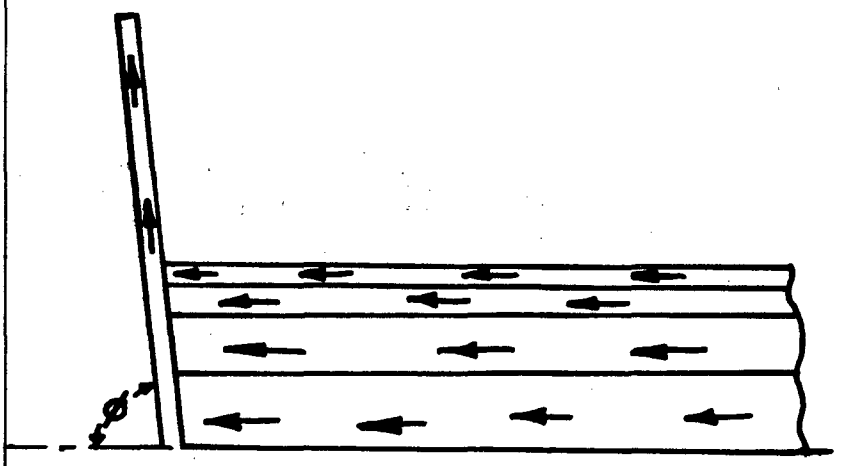
Figure 3 End configurations used in the SCMAG 1 and SCMAG2 programs

Figure 3 - Continued

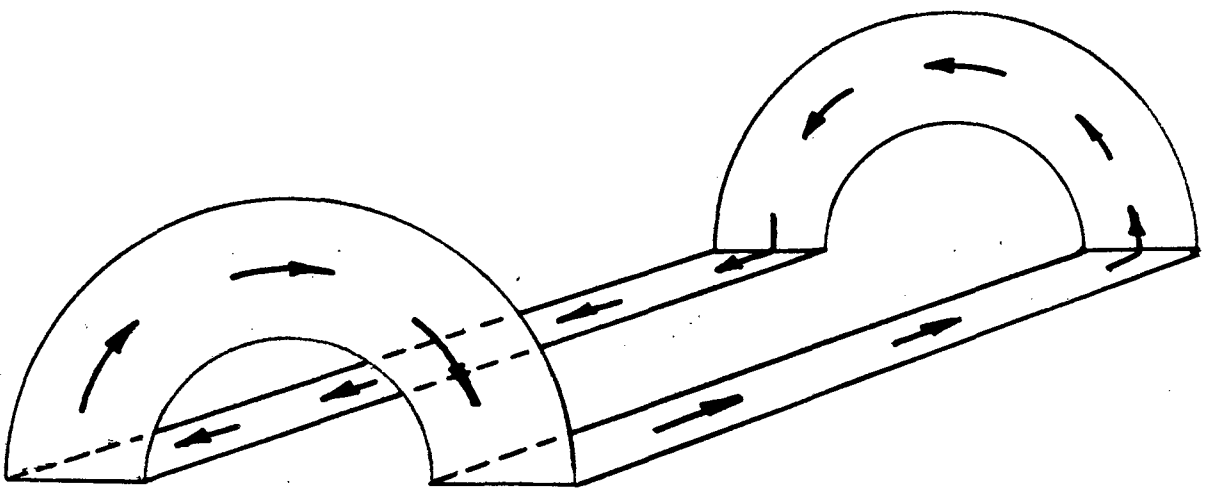


3c Lambertson Type Dipole end which has the same current distribution as the two-dimensional layer.

Figure 3 - Continued



3d The bent end, the angle Ø is the bend angle. When Ø = 90 degrees the end becomes a a bent up end



3e The bent up end with flat coils

APPENDIX

Data Deck for SCMAG1

The SCMAG1 data cards consist of one card which is a statement of the number of cases to be run and packets of cards for each of the cases. The first data card is always a card which states the number of cases. (We shall call this card a blue card.) Each case consists of four groups of cards (yellow, green, pink, and orange which corresponds to the way LBL arranges these cards).

The first card of each data case is an alphanumeric card which is a title which describes that case. Then there are three cards which describe basic parameters of the magnet coils to be analyzed. (The first four cards make up the yellow set.) The next card in the data set is a card which describes the multipoles which are to be set to desired values. (This is a green card.) The next set of cards inputs the first guess for the magnet coil configuration. There can be from one to fifty of these cards in this set. (The number of cards is equal to the value of KL which is on the second yellow data card. We call this data set the pink data set). The next set of cards tells which parameters which can be varied to produce the desired structure of the two-dimensional or integrated magnetic induction. (There are KL of these cards. This is called the orange data set.)

DATA CARDS

Program symbols used on the data cards are as follows: (See the program listing for the formats to be used.)

Blue Card	IA
Yellow Cards	
1st Card	Alphanumeric title (up to 80 characters)
2nd Card	NN, KL, NX, MX, RC, RO, RA
3rd Card	RIIRON, ROIRON, XLIRON, TURNS, LT, XSHIFT, YSHIFT
4th Card	NEND(1), PH(1), NEND(2), PH(2), NEND(3), PH(3), NEND(4), PH(4)
Green Card	NP, DNOP(1), DNOP(2), DNOP(3), DNOP(4), DNOP(5)
Pink Cards	(a set of KL of these cards) NT, R1, R2, A1, A2, YLEN, XJ, A3, MK
Orange Cards	(a set of KL of these cards) NT, R1, R2, A1, A2, YLEN, XJ, A3, MK

The sequence of yellow, green, pink, and orange cards is repeated for each case.

Meaning of Symbols used in the SCMAG1 data cards:

Blue data card: IA = Number of cases.

Yellow data cards: NN = Magnet Principle Multipole Number
NN = 1 dipole
NN = 2 quadrupole
NN = 3 sextupole

KL = Number of coil blocks to make up the completed magnet.

NX = Number of multipoles calculated (usually 20)

MX = Number of divisions of the coil block in the direction between R1 and R2 which is found on the pink data cards.

RC = The innermost radius of a coil part from the origin (radius of convergence of the power series) (Dimensions in cm)

RO = Useful operture radius (typically 70-80% of RC) (dimensions in cm)

RA = The magnetic measurement radius (always less than RC) (dimension in cm)

RIIRON = Inner iron radius (always greater than the intermost radius of the coil) (dimension in cm).

ROIRON = Outer iron radius (not fully necessary. Make this greater than RIIRON) (dimension in cm).

XLIRON = The iron length (not necessary) (dimension in cm).

TURNS = Number of turns in the coil parts (dimensionless).

LT = Number of points in the superconductor JC vs. B table set this equal to zero in SCMAG1.

XSHIFT = The coil shift in the X direction (dimension in cm).

YSHIFT = The coil shift in the Y direction (dimension in cm).

NEND(I) = End type within a coil classification.

PH(I) = End parameter (generally and angle within a coil classification) (dimension in rads).

The meaning of NEND(I) and PH(I): I = 1, 4

NEND(1) and PH(1) apply for coils where NT = 1 and 2.
NEND(2) and PH(2) apply for coils where NT = 3 and 4.
NEND(3) and PH(3) apply for coils where NT = 5 and 6.
NEND(4) and PH(4) apply for coils where NT = 7 and 8.

When NEND(1) or NEND(2) equals 0 or 1, one has equal length saddle round ends where the region of XSHIFT is perpendicular to the Z axis. Set PH(1) or PH(2) equal to zero (leave blank).

When NEND(1) or NEND(2) equals 2, one has equal length saddle round ends where the ends are round even in the region of XSHIFT. Set PH(1) or PH(2) equal to zero (leave blank).

When NEND(1) or NEND(2) equals 3, one has a Lambertson type and where the integrated field structure is the same as the two-dimensional field structure. Set PH(1) or PH(2) to the Lambertson end angle. The best value for PH(1) or PH(2) is $\pi/6$ (30 degrees).

When NEND(1) or NEND(2) equals 4 or more, one has a turned up end with a 90 degree angle set PH(1) or PH(2) equal to zero (leave blank).

When NEND(3) equals 0 or 1, one has a flat race track end. Set PH(3) equal to zero (leave blank).

When NEND(3) equals 2, one has a race track end bent up at an angle of PH(3) set PH(3) to any desired angle from 0 to π.

When NEND(3) equals 3 or more, one has a turned up end bent up at 90 degrees (equivalent to the previous case with PH(3) = $\pi/2$) set PH(3) equal to zero (leave blank).

When NEND(4) has any value, one has a turned up end with a 90 degree angle. Set PH(4) equal to zero (leave blank).

Green data cards: NP = Start of selected multipole (dimensionless)

DNOP = Value of selected multipoles (the first 5) first selected multipole NS = NN (2 *NP + 1)

Example: NN = 1 dipole
NP = 0 then NS = 1
NP = 1 then NS = 3
NP = 2 then NS = 5
and so on

Example NN = 2 quadrupole

NP = 0 then NS = 2
NP = 1 then NS = 6
NP = 2 then NS = 10
and so on

If the card has an integer number (say 1) and is blank then the first five symmetric multipoles starting with NS will be set to zero (if there are enough variables to permit it). If the number of variables is less than five, then the number of multipoles sit equal to zero is equal to the number of variables starting with symmetric multipole NS. Multipoles beyond the five shown on this card are set to zero automatically if there is enough variables.

Pink Data Cards

NT = coil block type (see the engineering note for the definition).

R1, R2, A1, A2 — See Figure 1 and Table 1 for the definition of these values depending on the number given to NT.

YLEN = coil straight section length before the ends (dimension in cm).

XJ = coil block current density when NT = 1, 2, 3, 4, 5, or 6 (dimension in A cm^{-2}).

A3 = spacing of points in the direction A when NT = 1 through 6 (dimension in cm).

A3 = Coil point current in amps when NT = 7 or 8 applies to both points (dimension A).

MK = Coil half group number (leave blank).

Orange Data Cards

Set NT = 0 or leave blank
Set A3 = 0 or leave blank
Set MK = 0 or leave blank

Insert a 1 in any A1, A2, A1, A2 or XJ which can be varied in order to produce the desired multipole structure in the two-dimensional field. Insert a zero or leave blank unfilled R1, R2, A1, A2, or XJ (unless one plans to vary those parameters for the integrated field case).

Insert a 2 in any R1, R2, A1, A2, YLEN or XJ which can be varied in order to produce the desired multipole structure in the integrated field. Other values of R1, R2, A1, A2, YLEN, and XJ will be blank, zero or one.

Example: If one wants the two-dimensional and integrated field to have zero higher multipole insert a 1 for NP in the green card (leave the rest of the green card blank). Then insert a 1 in the desired R1, R2, A1, A2, and/or XJ. Insert a 2 only in values of YLEN.

Data Deck for SCMAG2

The SCMAG2 data cards consist of one card which is a statement of the number of cases to be run and the packets of cards for each of the cases. The first data card is always a card which states the number of cases to be run. (We shall call this card a blue card. Note, if only one case is to be run, there is a number 1 in column 5.) Each of the cases consists of two groups of cards. (There is a yellow group and the pink group which corresponds to the way LBL arranges these cards.)

The first card of each data case is an alphanumeric card which is a title which describes that case. There are then three cards which describe the basic parameters of the magnet coils to be analyzed. (The first four cards make up a set of yellow cards.) The next set of cards inputs the magnet coil configuration. There can be from one to fifty of these cards in this set. (The number of cards is equal to the value of KL which is on the second yellow data card. We call this data set the pink data set.)

Using the set of data cards one calculates the multipole structure of the two-dimensional central field and the multipole structure of the integrated field. In addition, this program calculates the magnetic induction in the coil, at the inner boundary of the coil, at the inner boundary of the iron, and at a designated field map. The program calculates magnetic forces on the coil and the inductance per unit length of the two-dimensional magnet.

Data Cards

Program symbols used on the data cards are as follows: (see the program listing for the formats to be used).

Blue Card	IA
Yellow Cards	
1st Card	Alphanumeric title (up to 80 characters)
2nd Card	NN, KL, NX, MX, RC, RO, RA
3rd Card	RIIRON, ROIRON, XLIRON, TURNS, LT, XSHIFT, YSHIFT
4th Card	NEND(1), PH(1), NEND(2), PH(2), NEND(3), PH(3), NEND(4), PH(4)
Pink Cards	(a set of KL of these cards) NT, R1, R2, A1, A2, YLEN, XJ, A3, MK

The sequence of yellow and pink cards is repeated for each case.

The meaning of symbols used in SCMAG2 data cards:

Blue data card: IA = Number of cases.

Yellow data cards: NN = Magnet Principle Multipole Number
NN = 1 dipole
NN = 2 quadrupole
NN = 3 sextupole

KL = Number of coil blocks to make up the completed magnet.

NX = Number of multipoles calculated (usually 20)

MX = Number of divisions of the coil block in the direction between R1 and R2.

RC = The innermost radius of a coil part from the origin (radius of convergence of the power series) (dimensions in cm)

RO = Useful aperture radius (typically 70-80% of RC) (dimensions in cm)

RA = The magnetic measurement radius (always less than RC) (dimension in cm)

RIIRON = Inner iron radius (always greater than the innermost radius of the coil) (dimension in cm).

ROIRON = Outer iron radius (not fully necessary. Make this greater than RIIRON) (dimension in cm).

XLIRON = The iron length (not necessary) (dimension in cm).

TURNS = Number of turns in the coil parts.

LT = Number of points in the superconductor JC vs. B table (set this equal to zero in SCMAG2).

XSHIFT = The coil shift in the X direction, see the engineering note (use only in SCMAG1 and SCMAG2) (dimension in cm).

YSHIFT = The coil shift in the Y direction, see the engineering note (dimension in cm).

NEND(I) = End type within a coil classification.

PH(I) = End parameter (generally and angle within a coil classification) (dimension in radiuns).

The meaning of NEND(I) and PH(I): I = 1, 4

NEND(1) and PH(1) apply for coils where NT = 1 and 2.
NEND(2) and PH(2) apply for coils where NT = 3 and 4.
NEND(3) and PH(3) apply for coils where NT = 5 and 6.
NEND(4) and PH(4) apply for coils where NT = 7 and 8.

When NEND(1) or NEND(2) equal 0 or 1, one has equal length saddle round ends where the region of XSHIFT is perpendicular to the Z axis. Set PH(1) or PH(2) equal to zero (leave blank).

When NEND(1) or NEND(2) equals 2, one has equal length saddle round ends where the end are round even in the region of XSHIFT. Set PH(1) or PH(2) equal to zero (leave blank).

When NEND(1) or NEND(2) equals 3, one has a Lambertson type and where the integrated field structure is the same as the two-dimensional field structure. Set PH(1) or PH(2) to the Lambertson end angle. The best value for PH(1) or PH(2) is $\pi/6$ (30 degrees).

When NEND(1) or NEND(2) equals 4 or more, one has a turned up end with a 90 degree angle set PH(1) or PH(2) equal to zero (leave blank).

When NEND(3) equals 0 or 1, one has a flat race track end. Set PH(3) equal to zero (leave blank).

When NEND(3) equals 2, one has a race track end bent up at an angle of PH(3) set PH(3) to any desired angle from 0 to π.

When NEND(3) equals 3 or more, one has a turned up end bent up at 90 degrees (equivalent to the previous case with PH(3) = $\pi/2$) set PH(3) equal to zero (leave blank).

When NEND(4) has any value, one has a turned up end with a 90 degree angle. Set PH(4) equal to zero (leave blank).

Pink Data Cards

NT = Coil block type (see the engineering note for the definition).

R1, R2, A1, A2 — See Figure 1 and Table 1 for the definition of these values depending on the number given to NT.

YLEN = coil straight section length (used in SCMAG1 and SCMAG2) (dimension in cm).

XJ = coil block current density when NT = 1, 2, 3, 4, 5, or 6 (dimension in A cm^{-2}).

A3 = spacing of points in the direction A when NT = 1 through 6 (dimension in cm).

A3 = Coil point current in amps when NT = 7 or 8 applies to R2 and A2 (dimension A).

MK = Coil half group number (leave blank).

Data Deck for SCMAG3

The SCMAG3 data cards consist of one card which is a statement of the number of cases to run and packets of cards for each of the cases. The first data card is always a card which states the number of cases to be run. (We shall call this card a blue card. Note, if only one case is to be run, there is a number 1 on column 5.) Each of the cases consists of three groups of cards. (There is a yellow group, a pink group and a green card. This is the LBL arrangement of these cards.)

The first card of each data case is an alphanumeric card which is a title which describes that case. There are then two cards which describe the basic parameters of the magnet coils to be analyzed. (The first three cards of each case make up a set of yellow cards.) The next set of cards inputs the magnet coil configuration. There can be from one to fifty of these cards in this set. (The number of these cards is equal to the value of KL which is on the second yellow data card. We call this data set the pink data set.) There is one card (a green card) after the pink data set. This card gives tolerance for the placement of the conductor, coil sectors, coil halfparts, the iron shield with respect to the coil, and the magnetic measurement year with respect to the coil. (The tolerance refers to a ninety percent probability of the position of the component being within the tolerance band.)

Data Cards

Program symbols used on the data cards are as follows: (see the program listing for the formats to be used).

Blue Card IA

Yellow Cards
- 1st Card Alphanumeric title (up to 80 characters)
- 2nd Card NN, KL, NX, MX, RC, RO, RA
- 3rd Card NEND, RIIRON, ROIRON, XLIRON, LT, TURNS

Pink Cards: (a set of KL of these cards)
NT, R1, R2, A1, A2, YLEN, XJ, A3, MK

Green Card:
XCOND, XSEC, XHALF, XSHDI, XMEAS

The meaning of the symbols used in SCMAG3 data cards:

Blue Card:
IA - number of cases

Yellow Cards:
NN = Magnet principle multipole number
- NN = 1 dipole
- NN = 2 quadrupole
- NN = 3 sextupole

KL = Number of coil blocks to make up the completed magnet.

NX = Number of multipoles calculated (usually 20)

MX = Number of divisions of the coil block in the direction between R1 and R2.

RC = The innermost radius of a coil part from the origin (radius of convergence of the power series) (dimensions in cm)

RO = Useful aperture radius (typically 70-80% of RC) (dimensions in cm)

RA = The magnetic measurement radius (always less than RC) (dimension in cm)

NEND = End type (not used in SCMAG3 or in SCMAG4, so leave blank.

RIIRON = Inner iron radius (always greater than the innermost radius of the coil) (dimension in cm).

ROIRON = Outer iron radius (not fully necessary. Make this greater than RIIRON) (dimension in cm).

XLIRON = The iron length (not necessary) (dimension in cm).

LT = Number of points in the superconductor JC vs. B table (set this equal to zero in SCMAG2) (leave blank).

TURNS = Number of turns in the coil parts.

If NN = 1 (a dipole) TURNS should be half the number of TURNS in the magnet.

If NN = 2 (a quadrupole) TURNS should be one quarter of the number of TURNS in the magnet.
and so on

Pink Cards:

NT = Coil block type (see Figure 1 for the definition).

Note: in SCMAG3 only NT = 1, 2, 3, and 4 can be used.
NT = 5, 6, 7, and 8 are not operable in this code.

R1, R2, A1, A2 } See Figure 1 and Table 1 for the definition of these values depending on the number given to NT. Note: SCMAG3 allows only NT = 1, 2, 3, and 4.

YLEN = coil straight section length (not used in SCMAG3 so this can be left blank).

XJ = coil block current density (dimension in A cm^{-2}).

A3 = spacing of points in the direction A (dimension in cm).

MK = Coil half group number. All coil blocks or sectors which are part of the same assembly will have the same value of MK. In a dipole there is a minimum of two parts. In the minimum dipole all sectors will be marked with a 1 as MK (in column 80).

Note: Eventually SCMAG3 will be converted so that the same data set used in SCMAG1 and SCMAG2 can be used. The yellow and pink cards will then be the same as for SCMAG1 and SCMAG2.

Green Card:

XCOND = Conductor position tolerance (dimension in mm).

XSEC = Tolerance for the sector position (dimension in mm).

XHALF = Coil part assembly tolerance. (Note: each coil sector which has the same value of MK is part of the same coil part), (dimension in mm).

XSHDI = Coil to iron shell placement tolerance (displacement of the iron shield axis with respect to the coil axis) (dimension in mm).

XMEAS = Tolerance for the placement of magnetic measurement coils (rotating coils are assumed this is the tolerance for the placement of the axis of rotation tilt is not included) (dimension in mm).

The tolerances assume a 90 percent probability that the conductor, sector, part, shield axis, and measurement coil rotation axis will lie within the tolerance band. In other words, the tolerance bands are 1.95 standard deviations wide.

Data Deck for SCMAG4

The SCMAG4 data cards consist of one card which is a statement of the number of cases to run and packets of cards for each of the cases. The first data card is always a card which states the number of cases to be run. (We shall call this card a blue card. Note, if only one case is to be run, there is a number 1 on column 5.) Each of the cases consists of five groups of cards. (There is a yellow group, a pink group an orange group, a green card, and a group of white cards. This is the LBL arrangement of these cards.)

The first card of each data case is an alphanumeric card which is a title which describes that case. There are then two cards which describe the basic parameters of the magnet coils to be analyzed. (The first three cards of each case make up a set of yellow cards.) The next set of cards inputs the coil configuration. There can be from one to fifty of these cards in this set. (The number of cards is equal to KL which is on the second yellow data card. We call this data set the pink data set.) The next set of cards inputs the basic parameters of the superconductor in the magnet conductor. (This set is called the orange data set.) The next card (a green card) gives the coil packing factor, copper to superconductor ratio, filament and strand diameter, twist pitch and the magnet operating temperature. The final set of cards gives one the previous control induction history for a number of cases. (This is called the white data card set.)

Data Cards

Program symbols used on the data cards are as follows: (see the program listing for the formats to be used).

Blue Card IA

Yellow Cards
- 1st Card Alphanumeric title (up to 80 characters)
- 2nd Card NN, KL, NX, MX, RC, RO, RA
- 3rd Card NEND, RIIRON, ROIRON, XLIRON, LT, TURNS

Pink Cards: (a set of KL of these cards)
NT, R1, R2, A1, A2, YLEN, XJ, A3, MK

Orange Cards:
1st card, BC1, BC2, ZXI, TC, TCON

A set of card equal to LT/4 rounded up to the next integer number (for example if LT is blank LT=12 then there are three cards).

2nd card: H(J), YJC(J), J = 1, 4
3rd card: H(J), YJC(J), J = 5, 8
4th card: H(J), YJC(J), J = 9, 12

Green Card: JA, BETA, S, DFIL, DSTR, TWIST, TOP

White Cards: (a set of JA of these cards)
DH1, DH2, HSTART

The meaning of the symbols used in SCMAG4 are as follows:

Blue Card: IA = number of cases

Yellow Cards:

NN = Magnet principle multipole number.
NN = 1 dipole
NN = 2 quadrupole
NN = 3 sextupole

KL = Number of coil blocks to make up the completed magnet.

NX = Number of multipoles calculated (usually 20).

MX = Number of divisions of the coil block in the direction between R1 and R2.

RC = The innermost radius of a coil part from the origin (radius of convergence of the power series) (dimensions in cm)

RO = Useful aperture radius (typically 70-80 of RC) (dimensions in cm)

RA = The magnetic measurement radius (always less than RC) (dimension in cm)

NEND = End type (leave blank, not used).

RIIRON = Inner iron radius (always greater than the innermost radius of the coil).

ROIRON = Outer iron radius (not fully necessary. Make this greater than RIIRON).

XLIRON = The iron length (not necessary).

LT = Number of points in the superconductor JC vs. B table.

TURNS = Number of turns in the coil parts.

Pink Data Cards:

NT = Coil block type (see Figure 1 for the definition. Note: the current version of SCMAG4 has only NT=1 through 4 with no XSHIFT or YSHIFT.)

R1, R2, A1, A1 } Basic coil dimensions turns. See Table 1 and Figure 1 for the definition of these values depending on the number given for NT.

YLEN = Coil straight section length (not used in SCMAG4, leave blank).

XJ = Coil block current density (dimension in A cm^{-2}).

A3 = Spacing for points in the A direction when NT=1 through 4 (dimension cm).

MK = Coil block number.

Note: Eventually SCMAG4 will be converted so that the same data set used in SCMAG1 and SCMAG2 can be used. The yellow and pink cards will then be the same as for SCMAG1 and SCMAG2.

Orange Data Cards:

1st Card:

BC1 = lower critical field (type 1 superconductivity cases) (dimension tesla).

BC2 = Upper critical field (Type 2 superconductivity cases) (dimension tesla).

ZXI = Coherence distance (thickness of the current during type 1 superconductivity). Use 100 Angstroms (there is little dependence on ZXI) (dimension Angstroms).

TC = Superconductor critical temperature for type 2 superconductivity at zero induction (dimension Deg K).

TCON = The temperature at which the JC vs. H Table is created for. Usually TCON = 4.2K (dimension Deg K).

Rest of the cards (depends on LT)

H(J) = Magnetic induction in Tesla.

YJC(J) = Critical currents in superconductor in hundreds of thousands of Amps per square centimeter.

Green Data Cards:

JA = Number of cases of field changes in the coil (minimum JA=1) there are JA white cards.

BETA = The coil packing factor (fraction of the total coil area which is superconductor plus normal metal matrix).

S = Copper to superconductor ratio in the superconductor.

DFIL = Filament diameter (in microns).

DSTR = Superconductor matrix strand diameter (in millimeters).

TWIST = Number of twists per centimeter of conductor length.

TOP = Superconductor operating temperature (dimension Deg K).

White Data Cards: (there are JA of these cards).

DH1 = First central induction changes (first gradient change in a quadrupole).

DH2 = Second central induction change (2nd gradient change in a quadrupole).

HSTART = Starting central induction (starting gradient in a quadrupole).

DH1, DH2, and HSTART have the dimension of Tesla in a dipole magnet (NN=1) or a dimension of Tm^{-1} in a quadrupole magnet (NN=2).

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