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MAGNETOSTATIC COMPUTER PROGRAM TRIM OPERATIONS MANUAL

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OPERATIONS MANUAL

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ABSTRACT

This paper describes the capabilities and limitations of the magnetostatic computer program TRIM, with particular emphasis on the usage of this program, preparation of input data, and general utilization. The program is a general two-dimensional magnetostatic code capable of solving mathematical models of two-dimensional magnets.

I. INTRODUCTION

This paper describes in detail the information required to operate TRIM, a magnetostatic computer program. The program is written in machine language "FAP" and it is operational for the IBM 7094 computer system, under the 7094 monitor system.

Our purpose is to furnish detailed information on the capabilities and limitations of this program, on preparation of input data, and on operating characteristics that will ensure the proper use of this versatile code. Parts of this paper have been taken from an unpublished paper by F. Andrews of LRL, Livermore with his permission.

II. PROGRAM CAPABILITIES

TRIM is a general two-dimensional magnetostatic code capable of solving mathematical models of two-dimensional magnets.

It uses a mesh composed of irregular triangles in which the mesh lines may be distorted to conform to irregular interfaces and boundaries. Additional features include

(a) Variable triangular mesh of about 1600 points is used; may have many regions.

(b) Conductor sides and all points at the interface lie on mesh lines.

(c) No geometrical restriction is imposed. Any shape of magnet may be considered.

(d) Symmetry about the median plane is not required. Therefore both symmetric and asymmetric magnets may be investigated.

(e) Any current distribution may be considered.

(f) Several different kinds of iron may be used in the same magnet; voids or currents within the iron may be used.

III. PROGRAM DESCRIPTION

The program is divided into two major parts, the mesh generator, GENMON, and the proper trim code, TRIMON. Both these parts will be examined with sufficient detail to ensure proper understanding.

A. GENMON

The purpose of the generator is to construct the irregular triangle mesh.[1,2] It does this by interpolating on specified (by input) boundary points, locating the internal mesh points of each region by a pseudo-equipotential method, and by assigning regional properties to each triangle.

The generator performs these functions by using four subroutines--INPT, HSTAR, SETTLE, and GENOR--in a manner described in Ref. 1. This part of the code has been written in machine language, and it is operational under the IBM 7094 monitor system.

B. TRIMON

Once the irregular triangular mesh has been generated, TRIMON[3] takes over and calculates the vector potentials and magnetic induction in any plane arrangement of iron, air, and conductors. From these quantities the gradient, flux density, and energy are derived and printed.

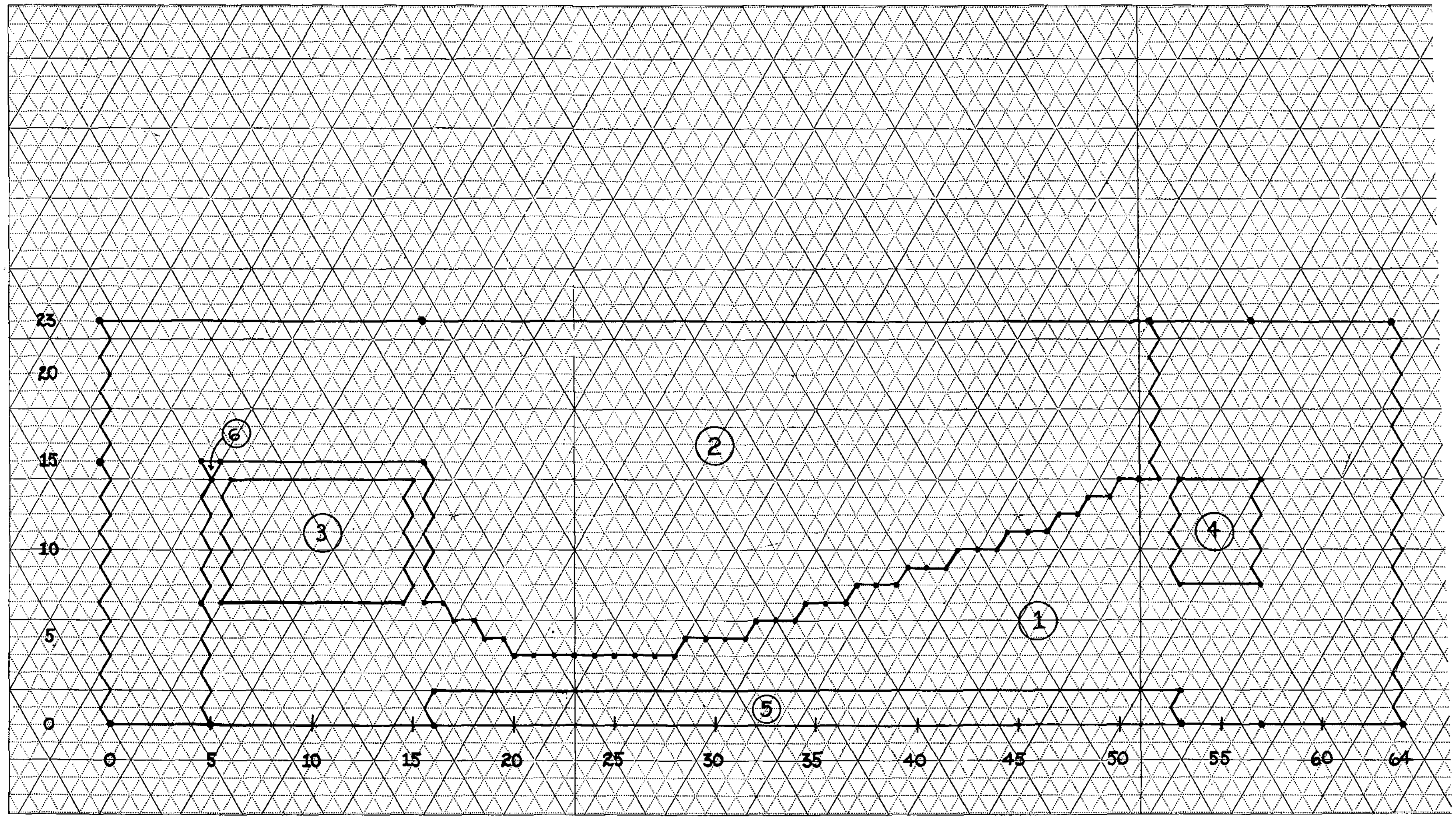
TRIMON has been written in machine language and is operated under the IBM 7094 monitor system. Instructions for operation are given in Appendix II.[4]

IV. PREPARATION OF INPUT DATA

The preparation of data requires considerable effort and attention. It is suggested that the instructions given below, as well as the sample input data included, be studied carefully before any attempt is made to prepare input data.

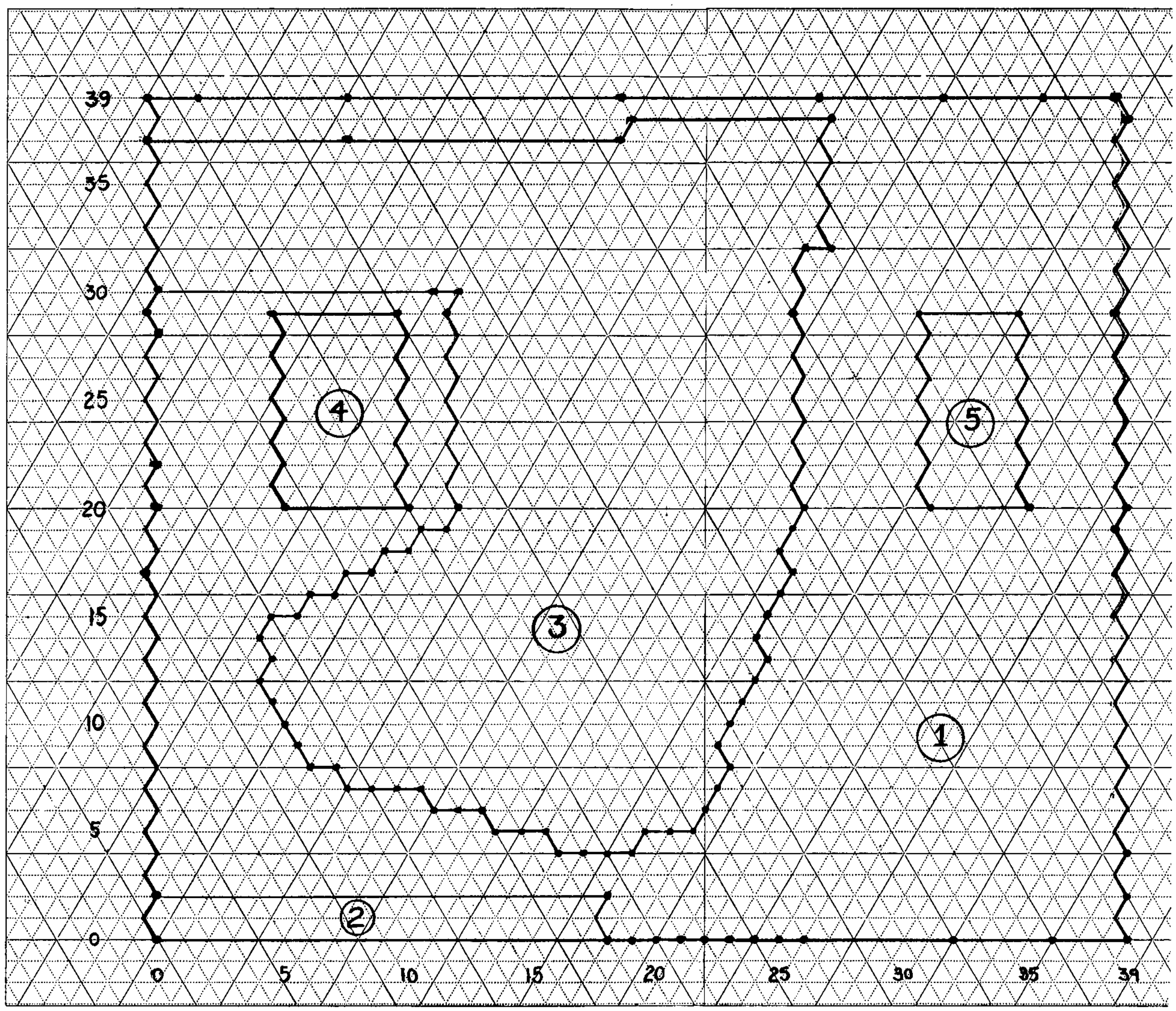
As a first step, draw a diagram which shows the problem as pictured in terms of mesh coordinates. We call this a "logical diagram" because the rows are those followed by the program in performing the relaxation process. Figures 1, 2, 3, and 4 show such logical diagrams for various magnet configurations. The physical dimensions for these magnets are shown in Figs. 5, 6, 7, and 8. For purposes of illustation, Fig. 1 will be used as an example to show the process required in accurately recording input data.

Now since the logical diagram is nothing but a transformation between the mesh indices and physical space, the next logical step is to transform the mesh indices to the corresponding geometrical coordinates of the magnet and record them as input. However, since the magnet consists of



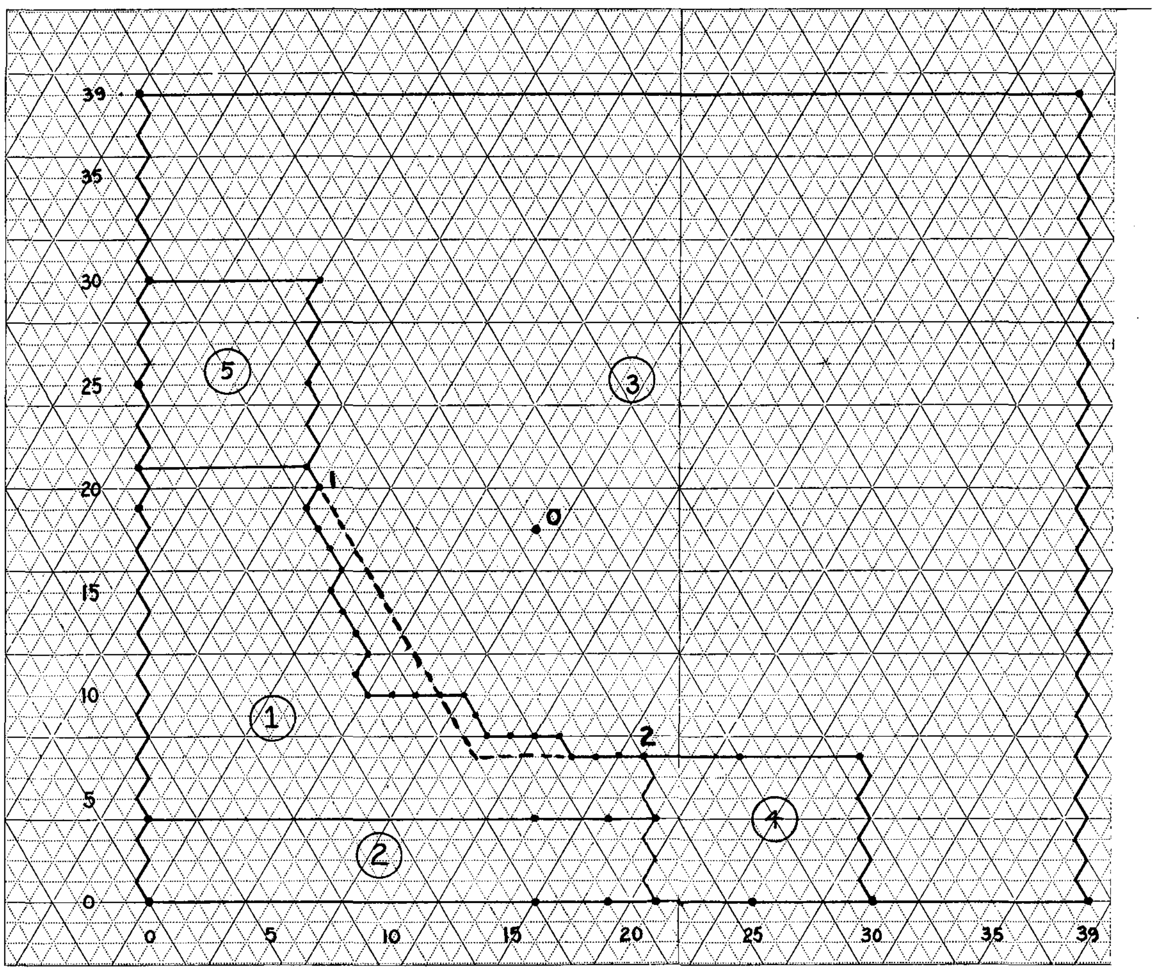
MUB-11612

Fig. 1. Logical diagram for CERN C magnet.



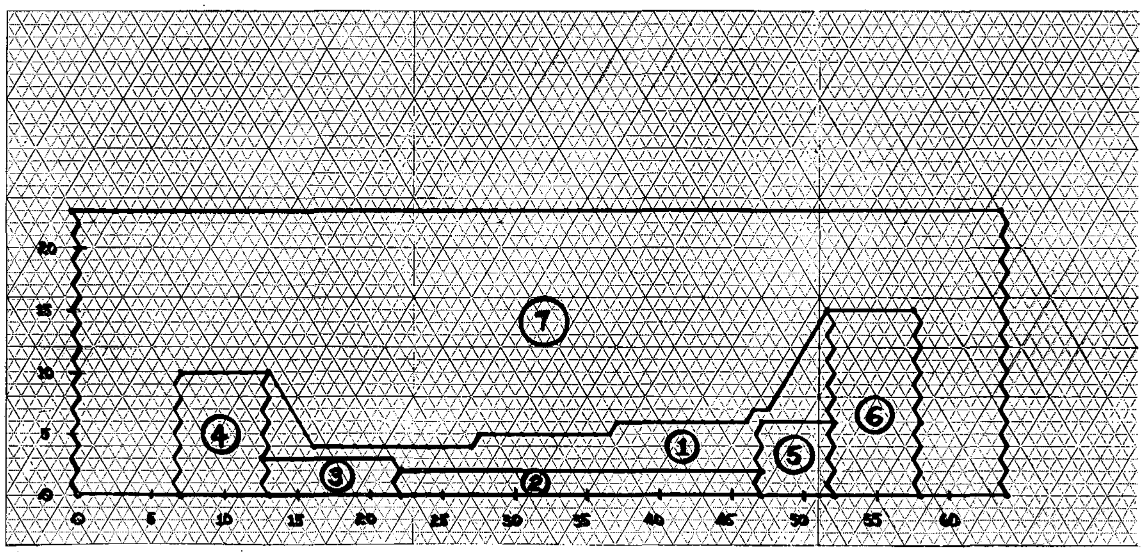
MUB-11613

Fig. 2. Logical diagram for COLLINS quadrupole.



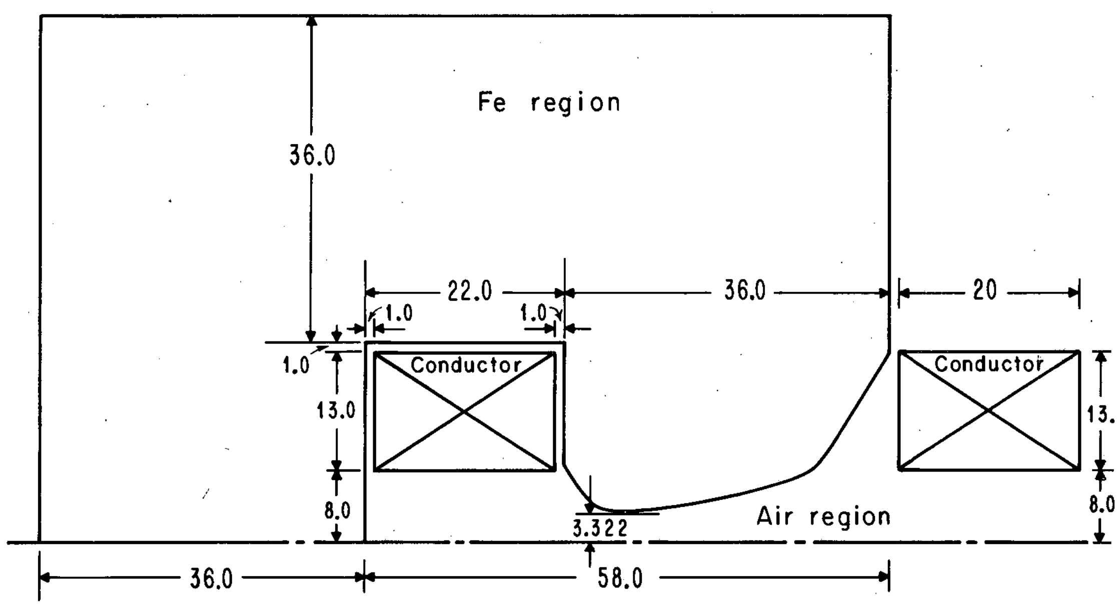
MUB 11533

Fig. 3. Logical diagram for quadrupole magnet.



MUB-11534

Fig. 4. Logical diagram for a conformal "H" magnet.



MUB 11921

Fig. 5. CERN PS magnet. Dimensions are in centimeters.

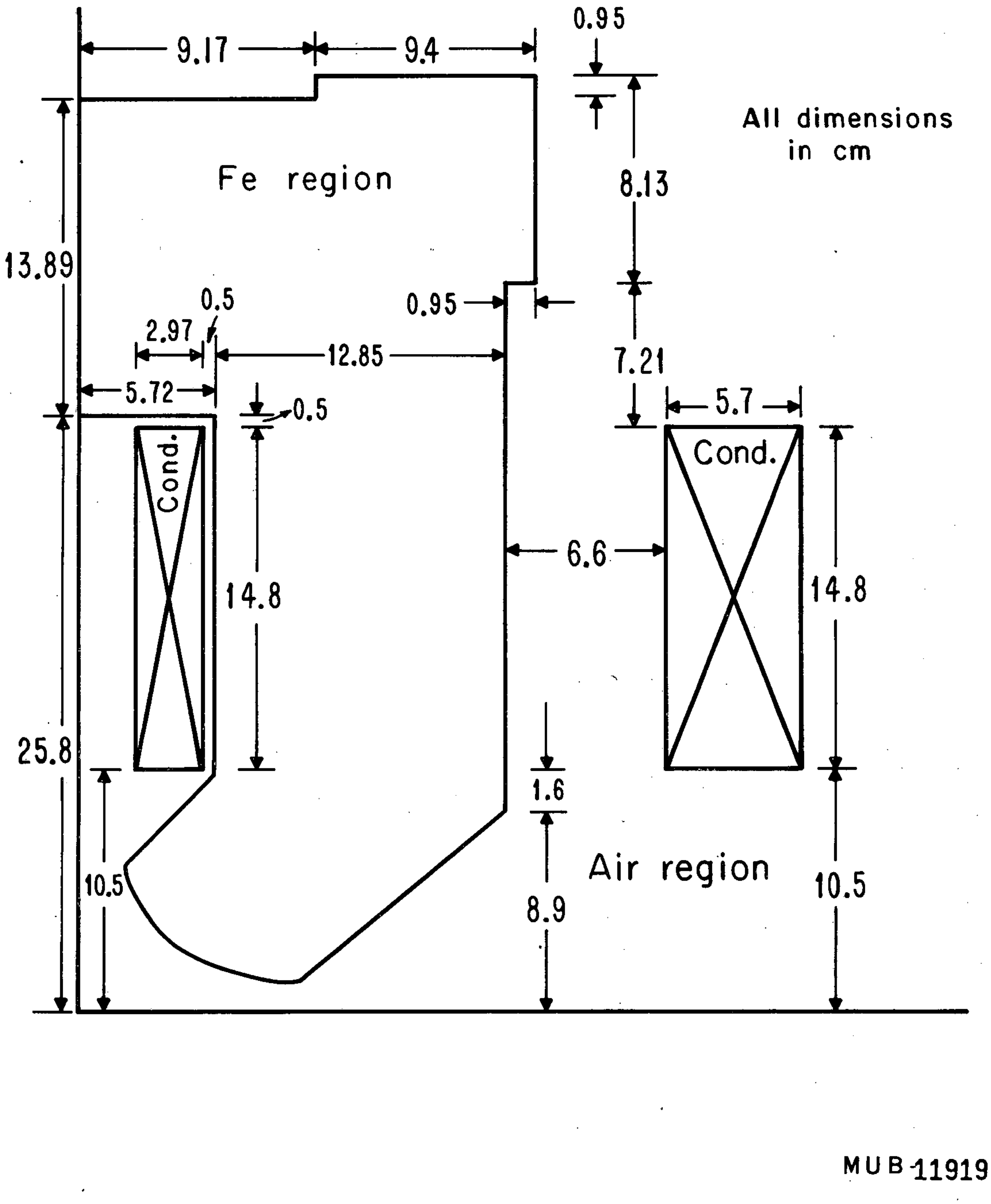
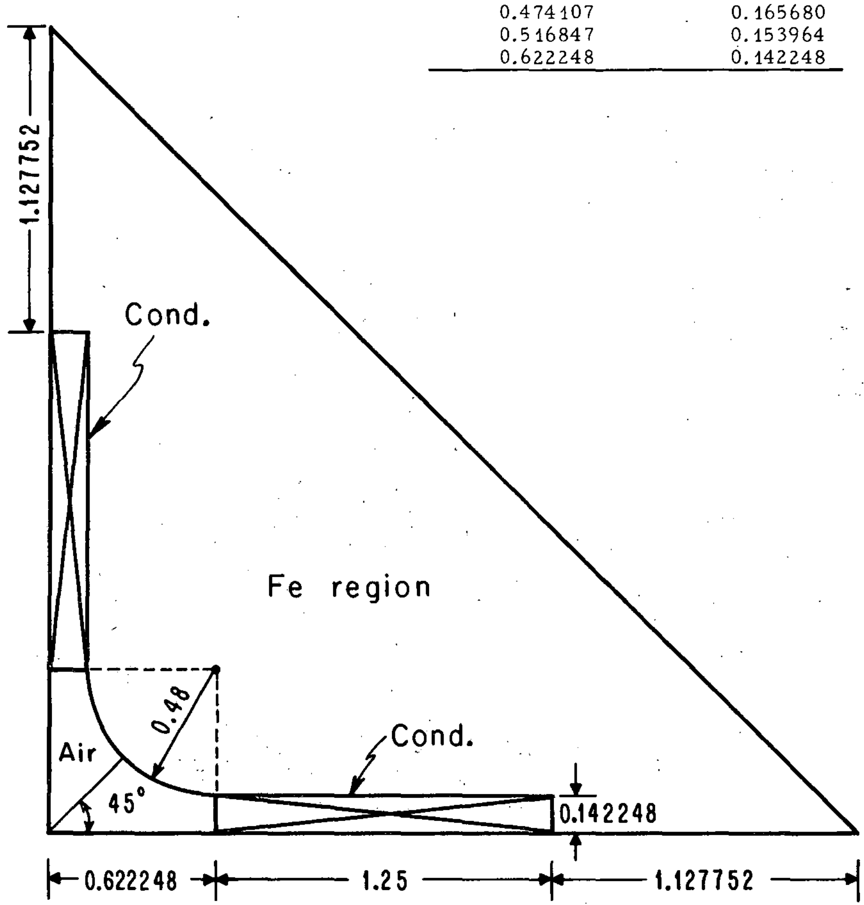


Fig. 6 "COLLINS" quadrupole profile. Dimensions in centimeters.

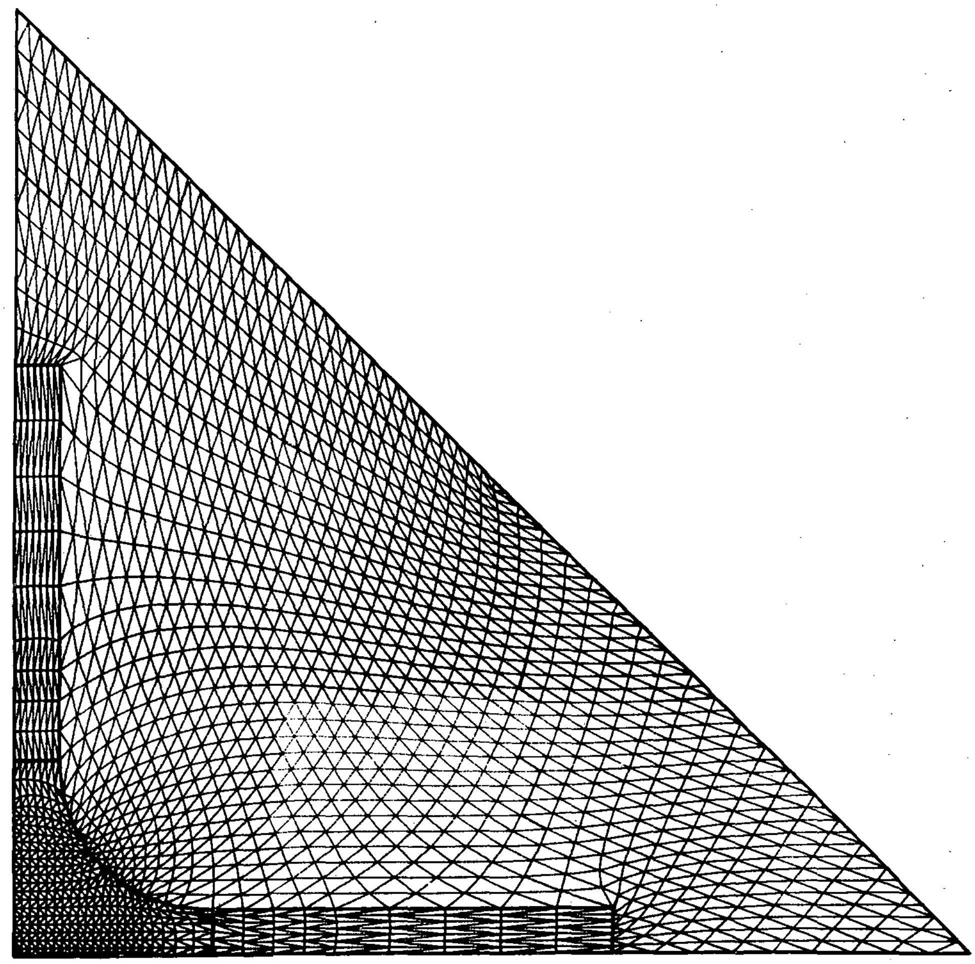
Pole face coordinates

X (inches)	Y (inches)	X (inches)	Y (inches)
0.142248	0.622248	0.259408	0.308006
0.153964	0.516847	0.282843	0.282843
0.165680	0.474107	0.294968	0.271124
0.177396	0.441950	0.308006	0.259408
0.189112	0.415386	0.322068	0.247692
0.200828	0.392451	0.337302	0.235976
0.212544	0.372165	0.353911	0.224260
0.224260	0.353911	0.372165	0.212544
0.235976	0.337302	0.392451	0.200828
0.247692	0.322068	0.415386	0.189112
		0.441950	0.177396
		0.474107	0.165680
		0.516847	0.153964
		0.622248	0.142248



MUB-11920

Fig. 7(a) Quadrupole magnet layout. Dimensions are in inches.



MUB-11958

Fig. 7(b) Generated mesh of the quadrupole magnet shown in Fig. 7.

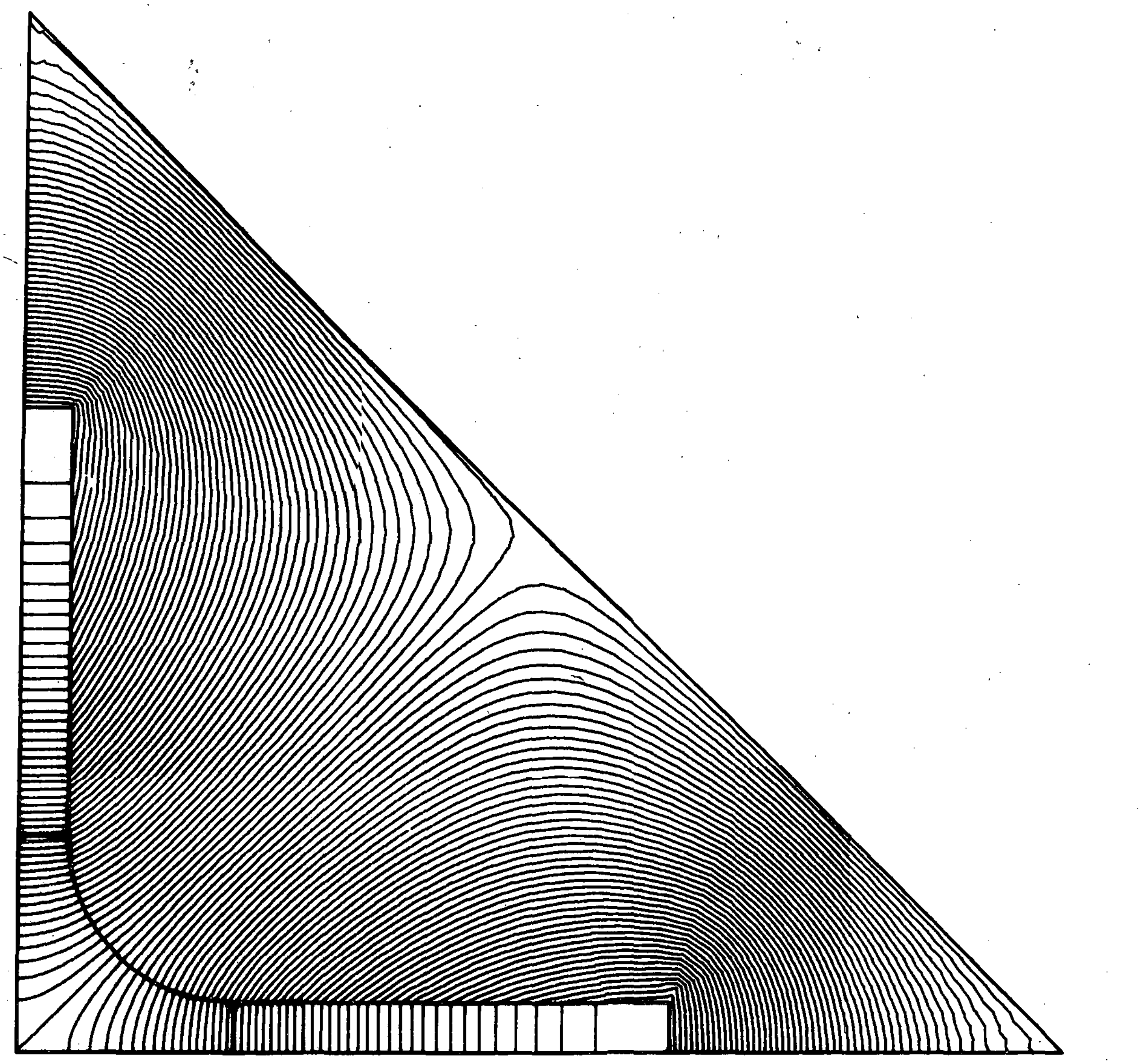
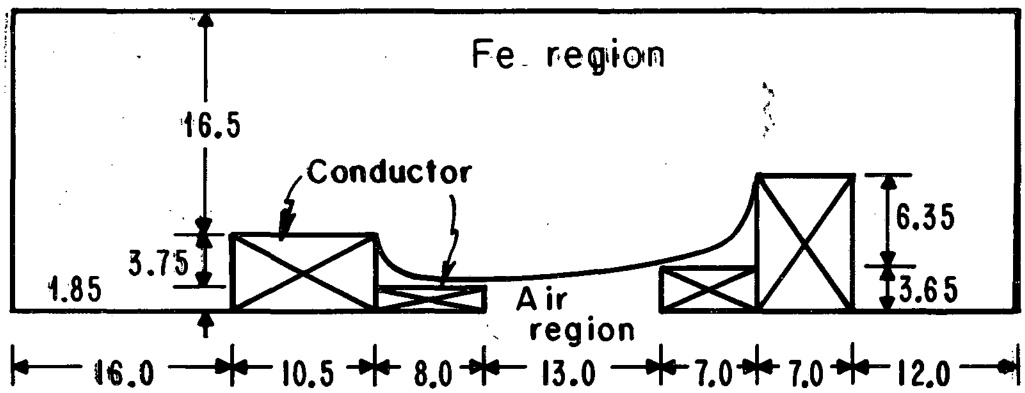


Fig. 7(c) CRT plot of flux distribution for the quadrupole magnet shown in Fig. 7.



Pole face coordinates

X (cm)	Y (cm)	X (cm)	Y (cm)	X (cm)	Y (cm)
26.5	5.5	37.0	2.47637	44.5	3.23410
26.72	4.36	37.5	2.51567	45.0	3.30029
27.02	3.76	38.0	2.55622	45.5	3.37166
27.32	3.36	38.5	2.59811	46.0	3.444916
27.72	2.95	39.0	2.6414	46.5	3.52143
28.72	2.33	39.5	2.68615	47.0	3.60142
29.22	2.07	40.0	2.73245	48.0	3.77283
30.42	2.055	40.5	2.78037	49.0	3.96136
31.00	2.08548	41.0	2.83	50.0	4.16973
32.0	2.14183	41.5	2.88143	51.42	4.54
33.0	2.20130	42.0	2.93477	52.42	5.06
34.5	2.29698	42.25	2.96298	53.12	5.77
35.0	2.33075	42.5	2.99012	53.57	6.56
35.5	2.36553	43.0	3.04759	54.03	8.28
36.0	2.4136	43.5	3.10732	54.4	10.00
36.5	2.43829	44.0	3.16944		

MUB 11922

Fig. 8. Conformal "H" magnet. Dimensions are in cm.

different materials (i. e., iron, conductors, and air), the concept of "regions" is introduced, which besides its usefulness in separating various materials, also serves as an agent in forcing regular or otherwise special zoning in any part of the problem. Figures 1 and 2 show these distinct regions.

GENMON superposes the regions in the order they are given in the input. Thus, all or part of a region which has once been specified may be respecified later in the input. This can save a great deal of writing in the input. It can also lead to trouble, since one may easily force mesh lines to cross one another in impossible ways, producing triangles of negative area. Such crossing can be avoided by twice recording points that belong in the boundary of two regions with a common border. This will become more obvious as the input data for the test problems are analyzed.

To recapitulate the procedure involved in preparing input data:

1. Draw a logical diagram of the problem.
2. Separate it into regions.
3. Record geometrical coordinates to correspond with each mesh line specified.

Note that the limited number of points available necessitates the careful distribution of mesh lines throughout the mesh. Namely, the experimenter should decide <u>a priori</u> which regions are most important and where the most accuracy is desired, and disperse the available points accordingly.

In magnet calculations for accelerator design, one is interested in the magnetic field and its gradient on the median plane, particularly within the limits of the vacuum chamber; therefore, one expects that the zoning in this region is very important. With this in mind, Figs. 1, 2, 3, and 4 were zoned.

Now we may proceed to the actual recording of the mesh coordinates and their corresponding physical dimensions.

For each geometrical point the data are recorded in the following sequence:

a. IY - index for vertical mesh line
b. IX - index for horizontal mesh line
c. Y - coordinate of physical dimension for this point
d. X - coordinate of physical dimension for this point.

Therefore, referring to Fig. 1 for the logical diagram and to Fig. 5 for the actual dimensions, we see that the coordinates of the four points of region 3 are:

Point	IY-mesh	IX-mesh	Y-dimension (cm)	X-dimension (cm)
1st	7	6	8	37
2nd	14	6	21	37
3rd	14	15	21	57
4th	7	15	8	57

Here it was assumed that the points were taken clockwise; however, the direction is immaterial. Also notice that in closing the region the first point need not be specified again.

The points shown above are entered in a data sheet as shown below:

```
LOD 7A 6+ 8+37
  D 7A15+ 8+57
  D14A15+21+57
  D14A 6+21+37
```

where LO = Indicator that this is the first point in this region. As used here, A and D are peculiar to the card-reading routine on the IBM 7094 and indicate numbers to be placed in the address and decrement parts of words, respectively.

After the region points have been specified, they are accompanied by two more cards--one having region constants, as will be shown, and one having -OM, which is a sentinel indicating the end of the region boundary points.

Information necessary for the region card is the following:

1. Region number
2. Flag describing the material of the region as follows:
   - 1 = air
   - 2 = iron

     or
   - 3 = iron of specified permeability, different from the preceding
3. Region current in ampere-turns (NI)
4. Region current density in ampere-turns/cm^2
5. Sentinel indicating the type of triangles into which the region should be zoned, as follows:
   - 1 = equilateral triangles
   - 2 = right triangles

Note: If region NI is specified, insert zero for NI/CM^2, and vice versa. The region information is recorded in the following manner.

LOA3D1-40250+OA2

(1) (2) (3) (4) (5)

Circled numbers identify the region constants as shown above. LO is the same indicator specifying the beginning of a new region. The completed region, therefore, will appear as shown below.

LOA3D1-40250+OA2	Region Card
LOD 7A 6+ 8+37	
D14A 6+21+37	Region boundary points
D14A15+21+57	
D 7A15+ 8+57	
-OM	Region termination card

In the same fashion all regions are recorded and punched on IBM cards. Any column may be used from 1 to 72. The X and Y dimension coordinates need not be integers; they may be entered as floating point numbers (i. e., 3.0, 4.375, etc.) or with exponents (i. e., 3. E10, 4.6E-3 etc.).

In problems where the pole face is described by circular arc, use may be made of the special arc routine incorporated in the program. This routine allows the user to specify only the end points and the center of the arc; the other points are interpolated equally in the program.

Use of this routine may be made as follows

1. Prepare the logical diagram as before for purposes of illustration, Fig. 3 may be used with the logical figure modified as shown by the dotted line. This modification is necessary since a circular arc must be described logically by two straight lines.
2. Next enter the data for arc as follows:

   For point 1 (Fig. 3) enter

   D20A7 + 0.622248+0.142248.

   For point 2

   D7A2ϕ+0.142248+0.622248.

   For point O (the logical center of the arc)

   D 18 A 16.

The last quantity necessary is the logical angle θ, which is the ratio of the triangle sides along logical slant to the sum of triangles of arc, or

$$\theta = \frac{\text{No. of triangles in slant line}}{\Sigma \text{ triangles in arc}}$$

For this example $\theta = \frac{13}{20} = 0.65$.

3. These data are recorded as follows:

⊙ 100000D20A7+0.622248+0.142248 D18A 16 + 0.65+D7A21+0.142248+0.622248

Flag	First point	Logical center	θ	second point
⊙ 100000	D20A7+0.622248+0.142248	D18A 16 +	0.65	+D7A21+0.142248+0.622248

The final assembled data deck will consist of the following cards:

1. Problem constants (for details see next paragraph)
2. Region card
3. Subsequent region boundary points (any number of cards)
4. End of region card
5. Region card (for next region)
6. Subsequent region boundary points, etc., until all regions have been exhausted (any number of cards).

Z

Z End of problem cards

Z

End of file card.

A complete listing for the sample problems shown in Figs. 1 and 2 appears in Appendices I. a and I. b.

V. DESCRIPTION OF PROGRAM CONSTANTS

It was mentioned in the previous paragraph that the first card of the assembled deck consists of program constants. A detailed description of these parameters is shown in Table I. These constants give the experimenter additional flexibility with which to process a variety of problems, including symmetric and asymmetric magnets.

Table I. Program constants (see also Ref. 5).

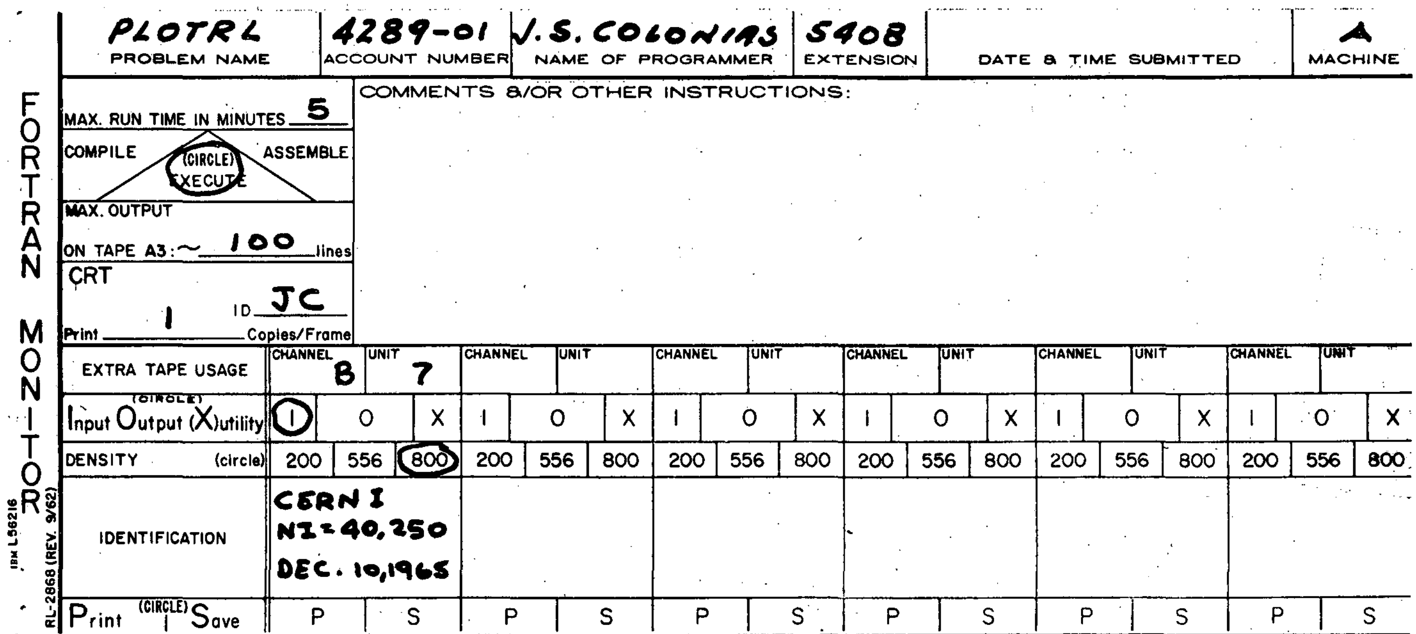
Code no.	Description	Standard values of program constants
L0	Mesh parity. Provisions have been made in the program so that rows can run in either the X or the Y direction. Here -1 parity indicates where the rows run in the X direction and +1 parity the Y direction.	
L1	N, number of regions to be specified in input (integer in address). Any number of regions may be specified.	
L2	L, maximum value of row index, i. e., number of rows of triangles (integer in address).	
L3	K, maximum value of "column" index (integer in address).	
L4	Mode: if L4 = -2, air solution only L4 = 0, all points L4 = -1, air solution followed by iron solution If set is equal to -1, it will be changed to zero after convergence in air and relaxation continued to converge over all points.	
L5	ρ_{air}: Over-convergence factor for points surrounded entirely by air (floating point).	1.94
L6	ρ_{Fe}: Fraction of new couplings to use in Fe (floating point).	0.0625
L7	Convergence criterion: value of residual at which the problem has converged sufficiently (floating point)	10^{-6}
L8	Dimension conversion factor. If dimension in cm, insert 0 or 1. If in inches, insert 2.54 cm/in. etc. (floating point)	0

Table 1 (cont.)

Code No.	Description	Standard values of program constants
L9	Interval between monitor prints (integer in address)	20
L10	Interval between dumps (integer in address)	10,000
L11, L12, L13	Not used	
L14 η_{max}	Constants having to do with recalculation of over-convergence factor	1
L15 β		0.5
L16 ω_0		0.005
L17 r_{max}		15
L18	Reciprocal of laminations stacking factor: Factor by which to multiply B in order to correct for presence of nonferrous material between laminations of magnet (floating point).	1
L19	Asymmetry sentinel; for problems without median plane symmetry, equals the value 1 which corresponds to the median plane (integer in address).	0
L20	Boundary condition sentinel for K=0, L=0. When L20 $\neq$ 0, the logical boundaries K = 0 and L = 0 will both be treated as reflecting surfaces. Note that this input has the effect opposite to that of L19.	

This completes the program constants that may be changed at the discretion of the experimenter. In the absence of specific input of any of the program constants specified above, the program will assume that the standard values prevail.

The complete listing of the input data for the logical diagrams appearing in Figs. 1 and 2 includes some of the program constants mentioned above (see Appendix I).



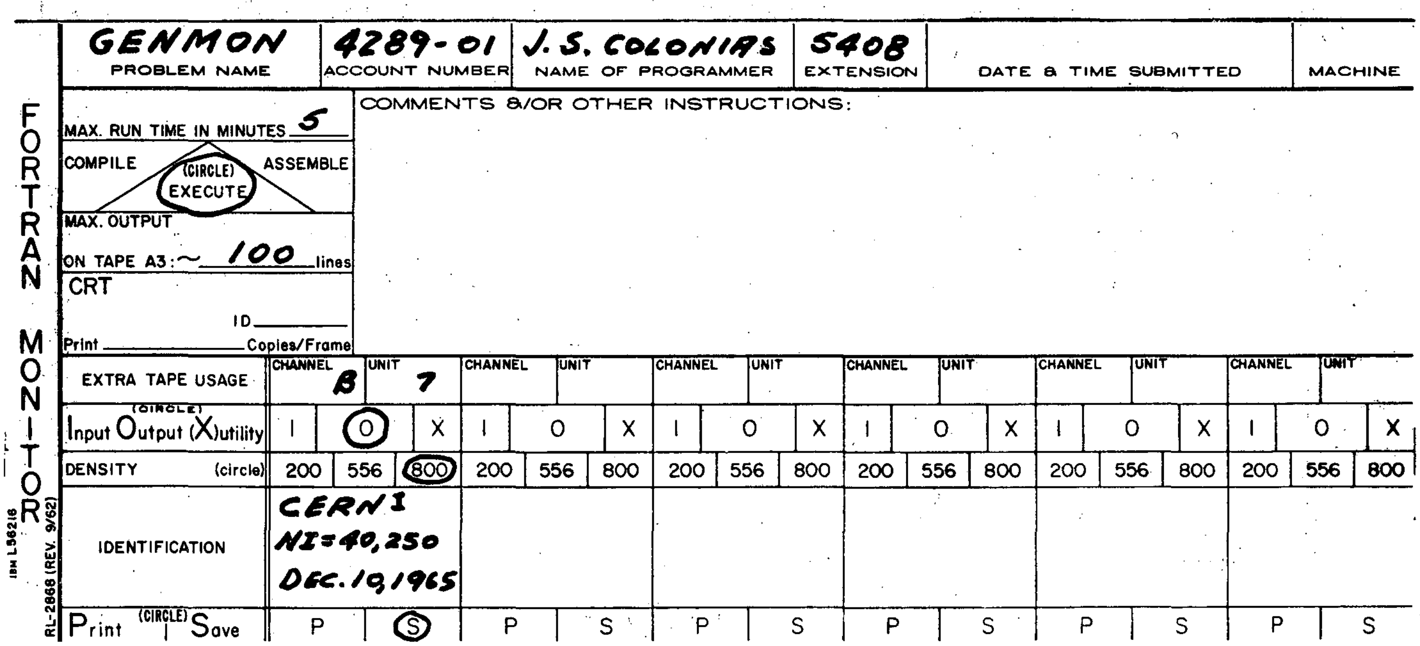
PROBLEM NAME	ACCOUNT NUMBER	NAME OF PROGRAMMER	EXTENSION	DATE & TIME SUBMITTED	MACHINE
PLOTRL	4289-01	J.S. COLONIAS	5408		A

FORTRAN MONITOR

MAX. RUN TIME IN MINUTES 5
COMPILE (CIRCLE) EXECUTE ASSEMBLE
MAX. OUTPUT ON TAPE A3: ~ 100 lines
CRT Print 1 Copies/Frame ID JC
COMMENTS &/OR OTHER INSTRUCTIONS:

EXTRA TAPE USAGE	CHANNEL B	UNIT 7		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT	
Input Output (X)utility (CIRCLE)	I	O	X	I	O	X	I	O	X	I	O	X	I	O	X	I	O	X
DENSITY (circle)	200	556	800	200	556	800	200	556	800	200	556	800	200	556	800	200	556	800
IDENTIFICATION	CERN I NI=40,250 DEC. 10,1965																	
Print (CIRCLE) Save	P	S		P	S		P	S		P	S		P	S		P	S	

IBM L56216 RL-2868 (REV. 9/62)



PROBLEM NAME	ACCOUNT NUMBER	NAME OF PROGRAMMER	EXTENSION	DATE & TIME SUBMITTED	MACHINE
GENMON	4289-01	J.S. COLONIAS	5408		

FORTRAN MONITOR

MAX. RUN TIME IN MINUTES 5
COMPILE (CIRCLE) EXECUTE ASSEMBLE
MAX. OUTPUT ON TAPE A3: ~ 100 lines
CRT Print Copies/Frame ID
COMMENTS &/OR OTHER INSTRUCTIONS:

EXTRA TAPE USAGE	CHANNEL B	UNIT 7		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT		CHANNEL	UNIT	
Input Output (X)utility (CIRCLE)	I	O	X	I	O	X	I	O	X	I	O	X	I	O	X	I	O	X
DENSITY (circle)	200	556	800	200	556	800	200	556	800	200	556	800	200	556	800	200	556	800
IDENTIFICATION	CERN I NI=40,250 DEC. 10,1965																	
Print (CIRCLE) Save	P	S		P	S		P	S		P	S		P	S		P	S	

IBM L56216 RL-2868 (REV. 9/62)

Fig. 9. Sample instruction card.

Fig. 10. Sample job card

VI. OPERATING INSTRUCTIONS

The versatility of this program in handling various types of problems is not simple. In this paragraph we list operating instructions for a variety of situations that might arise during the course of experimenting with this program.[4] Remember that there are two sets of distinct mesh sizes - one with dimensions 39 by 39 or less, and the other with dimensions 23 by 64 or less. The first number denotes the maximum Y-mesh size and the second the maximum X-mesh size. It is assumed that once the experimenter has chosen the proper mesh size, the following instructions are applicable:

a. Prepare input data as specified in the previous paragraphs.

b. Once all data cards have been punched, assemble the decks and submit them to computer room.

The final assembled deck should consist of the following:

1. Instruction card (see sample in Fig. 9)
2. ID card
3. GENMON deck (mesh generator program cards)
4. One card with * DATA
5. Data ID card (see sample in Fig. 10)
6. End of file card.

c. If the mesh generation was completed successfully, you will receive a tape B7 which constitutes the input to TRIMON. If generation was not successful, correct errors and resubmit.

d. Once you have received a B7 tape you may run TRIMON, following the instructions described in the attached supplementary note.[5] See also Appendix II.

One of the important features of TRIM is the ability of the program which causes the resulting triangular mesh to be displayed on a CRT, thus allowing the experimenter to observe the quality of the triangles and modify the distribution of mesh, if necessary.

To obtain a CRT plot, one must have generated the problem and obtained a B7 tape as described in Sec. V. The necessary information that the plot cards must contain and the order in which they appear on a data card are:

a. Y-axis scale

b. X-axis scale

c. Y origin

d. X origin (the lower left corner of the plot)

e. Zero (not used at this time)

f. The number of contours to plot (integer)

g. The number of dumps to skip

h. A flag to denote whether mesh lines are desired or not

If flag = 0, no mesh lines

If flag = 1, mesh lines

i. Flag indicating end of plot card

As an example,

```
L0 + 10 + 10 + 5 + 7 + 0A40A2A1Y
     (a)  (b)  (c) (d) (e)(f) (g)(h)(i)
```

Here the scale would be 10 cm in both directions; the Y origin would be 5 cm, the X origin would be 7 cm, 40 contour lines would be plotted, plotting will begin from dump No. 2, and mesh lines are desired. These data may be punched anywhere from columns 1 through 72 of a standard IBM card. (Blank spaces will be ignored.)

There is no limit to the number of plot cards that may be used. All cards will be read and plotted sequentially. The deck of plot cards must be ended with a card containing a Z.

Once the cards have been prepared, the final deck to be submitted to the computer must include the following:

1. Job card (see sample on Fig. 11)
2. Monitor CRT deck (binary deck). Be careful to choose the proper deck with your choice depending on whether the maximum dimensions of your problem are 39 by 39 or 23 by 64.
   This deck will begin with *PLEASE HANG. Continue by specifying the name of the problem tape, i.e., *PLEASE HANG CERN1.
3. One card with *DATA
4. CRT plot cards (as specified in the preceding paragraph)
5. End-of-file card.
6. Submit this deck for execution accompanied with the B7 input tape (obtained from GENMON).

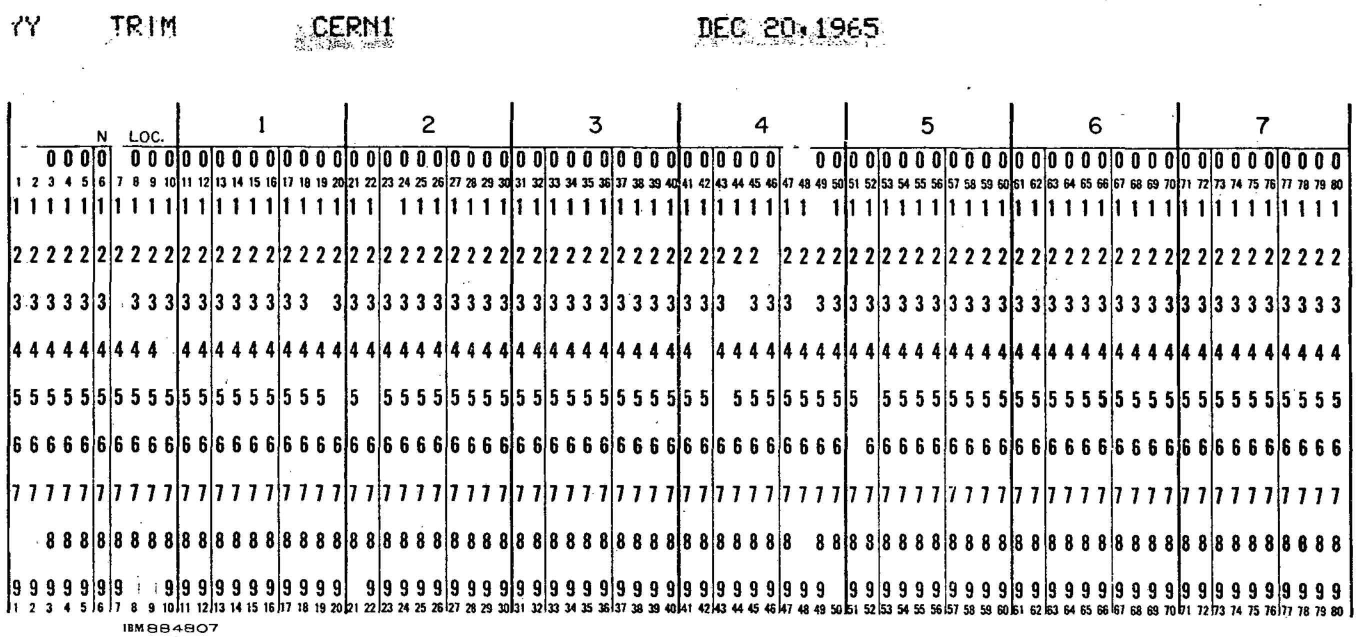


Fig. 11. Sample job card for CRT plot.

VII. OUTPUT DESCRIPTION

A. GENMON

A sample of a successful GENMON output is shown in Appendix IV. a. It is self explanatory in the sense that it describes all regions as they are processed, the material, and the type of triangles.

The QF and PF show respectively the number of iterations and the times that they converged in sequence. Five sequential convergences constitute successful generation, which is indicated by GENERATION COMPLETED.

Appendix IV. b shows an unsuccessful generation. Even though it ends with GENERATION COMPLETED, the appearance of negative triangles necessitates checking the input data at the location specified and correcting the error. However, if input data seem to be correct, obtain CRT plots which will reveal the error.

B. TRIMON

All printing is done OFF LINE. Observe that both GENMON and TRIMON use numbers which are in excess -50 exponential notation (i. e., 52.15 = 2.15, 54.3765 = 3,765. 49.3 = 0.03). A sample of this output is shown in Appendix V.

The four-line monitoring printout consists of:

1. ρ_{air} (under the word TRIM)
2. The cycle count (under the problem name)
3. The minimum and maximum values of the vector potential "A" in the mesh, and the maximum change that has occurred in A on the last cycle.
4. The maximum value of B in the iron
5. The "length" of the vector
6. The ratio of residuals from the last two cycles
7. The residual from the last cycle
8. The residual divided by the length
9. The value of p of the couplings.

If the Fe points are being skipped, i. e., mode < 0, there will appear next to TRIM the word AIR, and likewise if AIR points are being skipped, the word FE will appear.

When the convergence criterion is satisfied, the cycle counter Q and the number of successive times it has been satisfied P are printed out. After P reaches 5, a dump is made onto the B7, the dump number is printed out, a current print and a monitor print are forced, and finally an edited version of the median plane quantities is printed. The five columns to this printout are:

1. (labelled XB) These are the average X positions of successive pairs of mesh points, viz., the location at which the first difference of A is evaluated.
2. (labelled B) The Y component of the magnetic flux density.
3. (labelled XBX) The X positions of the mesh points, at which A and its second difference are evaluated.
4. (labelled A) The value of A
5. (labelled BX) The second X derivate of A (gradient).

In the asymmetrical version of the code, a column between A and the second derivative gives the X component of the field, naturally evaluated at the mesh points.

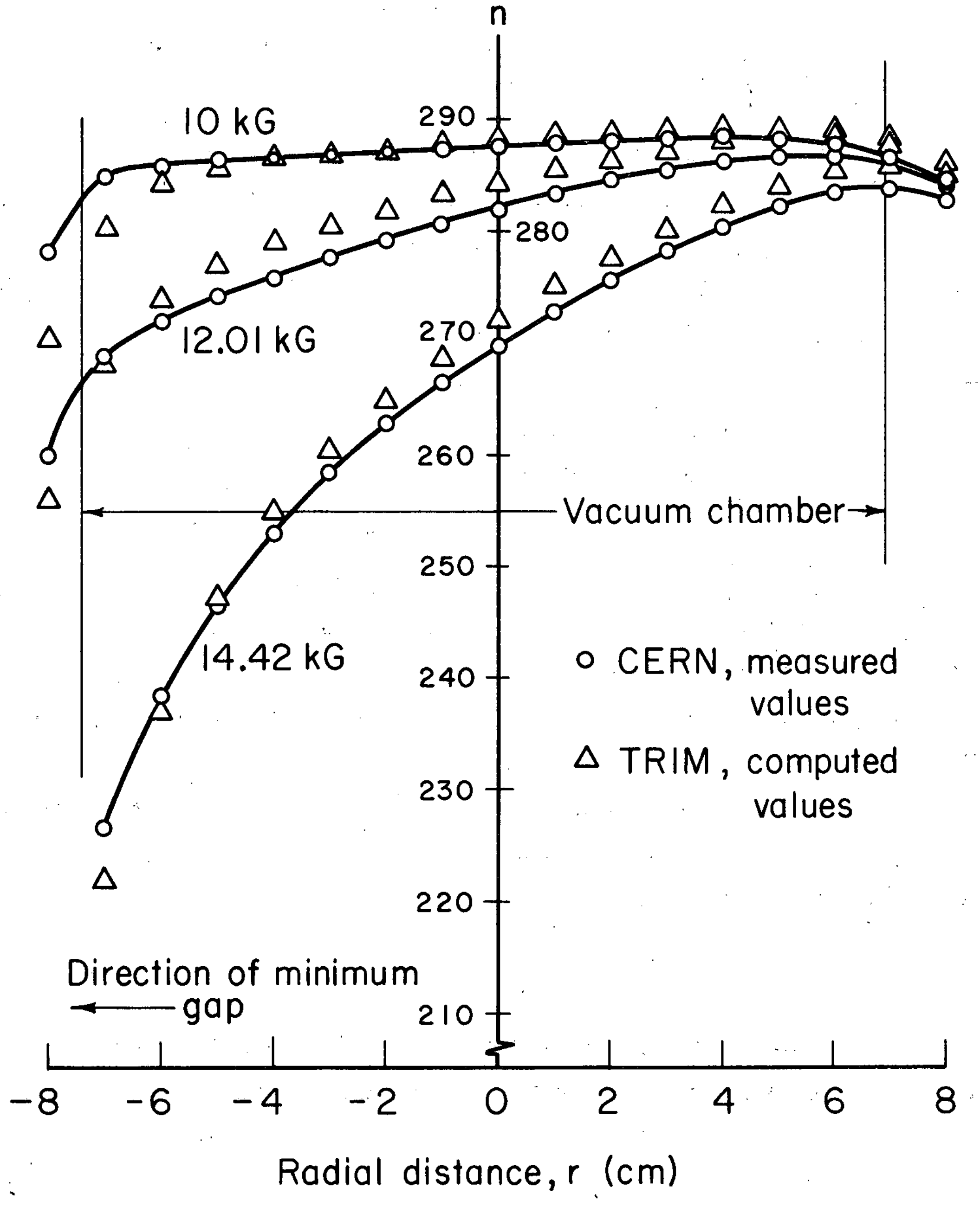
VIII. GENERAL REMARKS

The information presented in this paper should enable an experimenter to profitably exploit the potentialities of this program. Some experimentation with CRT plots of generated problems will convince the user that TRIM is definitely zone dependent, that is, zoning plays a very important role in the quality of the obtained results. The ability to predict a priori the quality of the generated mesh depends on the experience of the user.

Our experience[6] with this program has shown that, for most geometries, right triangles in air and equilateral triangles in iron give the best results. Also to obtain the best accuracy, it is essential to force regular zoning in the region of the median plane under the pole tip.

Finally, remember that the whole mesh consists of only 1,600 points, and do not expect to obtain results better than about 1% within the useful region of the vacuum chamber.

Figure 12 shows the percent deviation from measured data obtained from the CERN magnet which has been used as an example throughout this paper. As can be seen, the maximum error is ≈ 1% within the limits of the vacuum chamber.



MUB-7472

Fig. 12. Computed and measured gradients for the CERN PS magnet.

The approximate time required to run a problem utilizing the full mesh is about 30 minutes on the IBM 7094. This includes mesh generation, air, and iron solutions.

IX. AUXILIARY PROGRAMS

A. BEDIT

This program is used to print out the absolute value of flux density (B) at each upper and lower triangle of the generated mesh (B7 output tape).

Sample input data for the CERN magnet are shown in Appendix III. In Columns 1 and 2 of a standard IBM card, put the value of the beginning X-coordinate. In Columns 3 and 4, put the value of the beginning Y-coordinate.

The printout consists of a flux-density map. The flux-density signs in iron is indicated by negative signs.

B. TRED

This program was written with the intention of improving the quality of the existing edit routine.[7] It edits the last dump on a TRIM dump tape (B7); it obtains partial derivatives of vector potentials by a least-squares method, using harmonic polynomials through first, second, or third degree. It edits at vertices or at triangle centers.

The output consists of a tabular listing of all pertinent quantities (vector potential, field, and gradient) for either the median plane only, or throughout the mesh.

ACKNOWLEDGMENTS

I am grateful to Fred Andrews and Dr. Alan Winslow, who wrote the computer program, for their help and suggestions.

PROGRAMMER J. S. COLONIAS　　　　DATE DEC 10/65

PROBLEM CERN 1 EXT.　　　　PAGE 1 of 2

FORTRAN

APPENDIX I.a

Input data for CERN1 magnet

```
YY   TRIM      CERN1
L0-1A6A23A64 L4-1. L7+1.0E-7 L18+1.0416 Y
  L0A1D1+0+0A2
  L0D0A0+0+0
     D0A5+0+36 D0A16+0+58 D0A53+0+95 D0A57+0+115 D0A64+0+150
     D23A64+58+150 D23A57+58+115 D23A52+58+94 D23A16+58+58
     D23A0+58+0 D15A0+22+0
-0M
  L0A2D2+0+0A1
  L0D0A0+0+0
     D0A5+0+36 D7A5+7.4+36 D14A5+21.3+36 D15A5+22+36 D15A6+22+38
     D15A16+22+58 D7A16+8.526+58 D7A17+6.976+59 D6A17+6.2+59.5
     D6A18+4.94+60.5 D5A19+4.06+61.5 D5A20+3.769+62 D4A20+3.536+62.5
     D4A21+3.369+63 D4A22+3.322+64 D4A23+3.414+65 D4A24+3.522+66
     D4A25+3.639+67 D4A26+3.762+68 D4A27+3.882+69 D4A28+4.010+70
     D5A29+4.147+71 D5A30+4.293+72 D5A31+4.451+73 D5A32+4.620+74
     D6A32+4.709+74.5 D6A33+4.802+75 D6A34+5+76 D7A35+5.215+77
     D7A36+5.448+78 D7A37+5.704+79 D8A37+5.813+79.4 D8A38+5.985+80
     D8A39+6.295+81 D9A40+6.639+82 D9A41+7.023+83.0 D9A42+7.454+84
     D10A42+7.642+84.4 D10A43+7.941+85 D10A44+8.497+86 D11A45+10.028+87
     D11A46+11.596+88 D11A47+13.163+89 D12A47+13.9465+89.5
     D12A48+14.730+90 D13A49+16.298+91 D13A50+17.865+92 D
     D14A50+18.649+92.5 D14A51+19.433+93 D14A52+21.0+94 D23A52+58+94
     D23A16+58+58 D23A0+58+0 D15A0+22+0
-0M
  L0A3D1-40250+0A2
  L0D7A6+8+37
```

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PROGRAMMER ______________________ DATE ______________________

PROBLEM ______________ EXT. ________

FORTRAN

PAGE *2 of 2*

C ← FOR COMMENT | STATEMENT NUMBER | CONT | FORTRAN STATEMENT

```
    D14A6+21+37
    D14A15+21+57
    D7A15+8+57
-OM
  LOA4D1+40250+0A2
  LOD8A53+8+95
    D14A53+21+95
    D14A57+21+115
    D8A57+8+115
-OM
  LOA5D1+0+0A2
  LODoA16+0+58
    D2A16+2+58
    D2A53+2+95
    D0A53+0+95
-OM
  LOA6D1+0+0A2
  LOD14A5+21.3+36
    D15A5+22+36
    D15A6+22+38
-OM
Z
Z
Z
```

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PROGRAMMER J. S. COLONIAS

DATE DEC. 10/65

PROBLEM COLQB EXT.

FORTRAN

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APPENDIX I.b

Input data for Collins Quadrupole

FORTRAN STATEMENT

```
YY    TRIM        COLQB
L0-1A5A39A39 L4-1.L18+1.0526 L20+1 L7+1.0E-7  Y
L0A101+0+0A2
     L0D0A0+0+0
       D 0A18+ 0  + 9.0
       D 0A19+ 0  + 9.25
       D 0A20+ 0  +10.0
       D 0A21+ 0  +10.7
       D 0A22+ 0  +11.5
       D 0A23+ 0  +12.5
       D 0A24+ 0  +14.5
       D 0A25+ 0  +16.5
       D 0A26+ 0  +19.0
       D 0A32+ 0  +35.0
       D 0A36+ 0  +41.0
       D 0A39+ 0  +47.0
       D 2A39+ 1.0+47.0
       D 4A39+ 1.5+47.0
       D19A39+ 9.0+47.0
       D20A39+10.5+47.0
       D29A39+25.0+47.0
       D38A39+40.0+47.0
       D39A39+41.0+47.0
       D39A36+41.0+41.0
       D39A32+41.0+35.0
       D39A27+41.0+20.0
       D39A19+41.0+10.0
```

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PROGRAMMER ______ DATE ______

PROBLEM ______ EXT. ______

FORTRAN

PAGE 2 OF 3

FORTRAN STATEMENT

```
      D39A 8+41.0+ 5.7
      D39A 2+41.0+ 0.5
      D39A 0+41.0+ 0
      D37A 0+39.69+ 0
      D30A 0+25.8+ 0
      D29A 0+25.3+ 0
      D28A 0+24.0+ 0
      D22A 0+12.0+ 0
      D20A 0+10.0+ 0
      D17A 0+ 8.5+ 0
      D 2A 0+ 1.0+ 0
-OM
LOA2D1+0+0A2
      DOA0+0+0 DOA18+0+9 D2A18+1+9 D2A0+1+0
-OM
LOA3D2+0+0A1
    LOD30A0+25.8+0 D30A11+25.8+5.5 D30A12+25.8+5.72 D29A12+25.3+5.72
     D20A12+10.2+5.72 D19A12+10.1+5.6 D19A11+10.0+5.5 D18A10+9.5+5
     D18A9+9.25+4.75 D17A9+9.0+4.5 D17A8+8.5+4.0 D16A7+8.0+3.5
     D16A6+7.75+3.25 D15A6+7.5+3.0 D15A5+7.0+2.5 D14A4+6.48+1.905
     D13A5+6.097742+1.905 D12A4+5.8081+2.0 D11A5+5.162755+2.25
     D10A5+4.646480+2.5 D9A6+4.224072+2.75 D8A6+3.872066+3.0
     D8A7+3.318914+3.5 D7A8+2.904050+4.0 D7A9+2.581377+4.5
     D7A10+2.323240+5.0 D7A11+2.212609+5.25 D6A11+2.112036+5.5
     D6A12+1.936033+6.0 D6A13+1.787107+6.50 D5A14+1.659457+7.0
     D5A15+1.548826+7.5 D5A16+1.498864+7.75 D4A16+1.452025+8.0
     D4A17+1.366611+8.5 D4A18+1.290688+9.00 D4A19+1.290688+9.44882
```

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PROGRAMMER ___ DATE ___

PROBLEM ___ EXT. ___

FORTRAN

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FORTRAN STATEMENT

```
    D5A20+1.75+10.0 D5A21+2.18+10.5 D5A22+3.0+11.5 D6A22+3.41667+12.0
    D7A23+3.83334+12.5 D8A23+4.25+13.0 D9A23+4.66668+13.5
    D10A23+5.08335+14. D11A24+5.5+14.5 D12A24+5.91669+15.0
    D13A25+6.33336+15.5 D14A24+6.75+16.0 D15A25+7.1667+16.5
    D16A25+7.58337+17.0 D17A26+8.0+17.5 D18A25+8.4167+18.0
    D19A26+8.8334+18.55 D20A26+10.5+18.55 D29A26+25.3+18.55
    D32A26+31.6+18.55 D32A27+31.6+19.5 D38A27+40.64+19.5
    D38A19+40.64+10.1 D37A19+39.69+10.1 D37A8+39.69+5.7 D37A0+39.69+0
-OM
LOA4D1-15037+0AZ
  LOD20A5+10.5+2.23
    D20A10+10.5+5.22
    D29A10+25.3+5.22
    D29A 5+25.3+2.23
-OM
LOA5D1+15037+0AZ
  LOD20A31+10.5+25.15
    D20A35+10.5+30.85
    D29A35+25.3+30.85
    D29A31+25.3+25.25
-OM
Z
Z
Z
```

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II. TRIMON

(Supplementary writeup to TRIM Magnetostatic Program)

Identification: TRIMON (A modified version of the on-line code called "TRIM").

Author: Bobby Powell November 8, 1965

Machine language: Fortran II and FAP

Basic machine required: IBM 7090 or 7094

Purpose: To enable TRIM to run as an off-line operation (i. e., to run TRIM under the FORTRAN monitor system) and to include the asymmetric case.

Usage: (a) Start the problem

1. Obtain a source or object deck for the code TRIMON and a 'dump tape'. **

**Note: There are two versions of this code (1) KMAX = 39 and LMAX = 39, and (2) KMAX = 64 and LMAX = 24. To create versions other than those mentioned change KMAX to the derived value, under the condition that (KMAX)(LMAX) $\leq$ 1600 points.

(a) The object deck to be submitted should consist of the following:

(1) An '* ID' card

(2) '* XEQ' card

(3) The Fortran calling program

(4) A copy of the Fortran subroutine '$EXIT' (2 binary cards)

(5) A copy of the Fortran subroutine '$TES' (2 binary cards)

(6) The program called TRIMON

(7) '* DATA' card

(8) An end of file card

(b) The dump tape to be submitted is obtained from the code called GENMON (the monitor version of the mesh generator) and is used as input to TRIMON. *

* Note: The input (dump tape) tape is B7.

Termination:

(1) Automatic termination:
Automatic termination occurs if and only if the convergence criterion has been satisfied in both Air and Iron (see Note 2).

(2) Forced termination:
Forced termination is the procedure used to terminate a problem after a specified time limit (where time limit refers to the maximum run time on the computer).

(a) Sense switch #1 is used for forced termination.
(b) When sense switch #1 is down, the following sequence of events occurs:

1. The information necessary to restart the problem from the last iteration is written on the dump tape (B7).
2. An edit similar to the final one is obtained.
3. Transfer of control over the machine to the FORTRAN monitor system is executed (see Note 2).

Note 2: Tape B7 (the dump tape) should be saved.

Restart procedures:

(1) The restart procedure is the same as that used in starting the problem.
(2) The problem will restart from the last iteration or dump.

Space: The memory requirements for the two versions of TRIMON are:

(1) For the 39 by 39 generated mesh, the code TRIMON, the information from the input tape (dump tape), and the FORTRAN monitor programs use $31{,}680_{10}$ locations.
(2) For the 23 by 64 generated mesh, the code TRIMON and the FORTRAN monitor program use $30{,}597_{10}$ locations.

Format: The format of the printed output from TRIMON differs from the output described in the writeup (to which this paper is supplementary) in only two respects: (1) the decimal point between the excess fifty exponent and the fraction is omitted, and (2) zeros are represented by a dash (-).

Alterations:

Two procedures are suggested for changing the permeability tables. Both procedures require reassembling the program TRIMON.

(1) A direct replacement of the present table with new B^2 and gamma values.
(2) Obtain a listing of the program TRIMON and do the following:
(a) Find the subroutine PERM in the listing.
(b) Scan the listing of the subroutine PERM until you find

```
      TRA    PRE1
             PUT REGION NAMES HERE.  PZE ,,NAME
      PZE    ,,2          MATERIAL NO. 2.  CARBON STEEL.  CFE
PRE1  LAS    *,4
      TRA    *+2
      TRA    EUREKA
      TIX    *-3,4,1
      HTR    *            NONEXISTENT NAME
```

PUT CORRESPONDING TABLE SIZES HERE. PZE FWABSQ,,NMAX

PZE CFE,,CFEG-CFE MATERIAL NO. @. CARBON STEEL. CFE
EUREKA CLA *,4

(c) Make the above indicated changes and

(d) Assemble the program.

Timing: The time required for a complete solution in Air and Iron ranges from 15 to 25 minutes.

Program stops:

(a) A program stop will occur for the following reasons:

(1) Negative B squared

(2) Negative coupling sum.

(3) Zero material

(4) Nonexistent name

PROGRAMMER J. S. COLONIAS

PROBLEM BEDIT EXT.

FORTRAN

DATE DEC. 10/65

APPENDIX III

Input data for BEDIT program

FORTRAN STATEMENT

STATEMENT NUMBER (1–5)	CONT (6)	FORTRAN STATEMENT (7–72)
0000		
0010		
0020		
0030		
0040		
0050		
0060		
-999		
		END OF FILE CARD

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IV.a. Successful generation of GENMON

```
REGIONS      K MAX        L MAX
-00460       000047       000047
                   PARITY
             -51.10000000
 REGION NO.  000001       MATERIAL      NAME 001000       000001
                   CURRNT        DENSTY
              50.0          50.0
 REGION NO.  000002       MATERIAL      NAME 002000       000001
                   CURRNT        DENSTY
              50.0          50.0
 REGION NO.  000003       MATERIAL      NAME 001000       000002
                   CURRNT        DENSTY
              54.32000000  50.0
 REGION NO.  000004       MATERIAL      NAME 001000       000002
                   CURRNT        DENSTY
             -54.32000000  50.0
                   TL            RHO
              47.99999999  51.16000000
                   QF            PF
              53.10000000  51.10000000
                   QF            PF
              53.10100000  51.20000000
                   QF            PF
              53.10200000  51.30000000
                   QF            PF
              53.10300000  51.40000000
                   QF            PF
              52.47000000  51.10000000
                   QF            PF
              52.48000000  51.20000000
                   QF            PF
              52.49000000  51.30000000
                   QF            PF
              52.50000000  51.40000000
                   QF            PF
              52.51000000  51.50000000
GENERATION COMPLETED
```

IV.b. Unsuccessful generation of GENMON

```
                          TRIM   AIR  QUAD4
 -00460      000047      000047
                   PARITY
             -51.10000000
 REGION NO. 000001       MATERIAL      NAME 001000      000001
                   CURRNT       DENSTY
              50.0        50.0
 REGION NO. 000002       MATERIAL      NAME 002000      000001
                   CURRNT       DENSTY
              50.0        50.0
 REGION NO. 000003       MATERIAL      NAME 001000      000002
                   CURRNT       DENSTY
              54.32000000 50.0
 REGION NO. 000004       MATERIAL      NAME 001000      000002
                   CURRNT       DENSTY
             -54.32000000 50.0
                   TL           RHO
              47.99999999 51.16000000
                   QF           PF
              53.10000000 51.10000000
                   QF           PF
              53.10100000 51.20000000
                   QF           PF
              53.10200000 51.30000000
                   QF           PF
              53.10300000 51.40000000
                   QF           PF
              52.47000000 51.10000000
                   QF           PF
              52.48000000 51.20000000
                   QF           PF
              52.49000000 51.30000000
                   QF           PF
              52.50000000 51.40000000
                   QF           PF
              52.51000000 51.50000000

             NEG OR ZERO LW AREA.  K IS     000036L IS  000007
             NEG OR ZERO UP AREA. K IS      000036 L IS 000007
GENERATION COMPLETED
```

V. Iterative printout of TRIMON

```
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119399999     -               -               -            -         -        -
  RATIO        RESIDUAL      RES/LEN      RHOCP
    -              -             -        4962500000
  I PLUS        I MINUS      I SUM         NRG FE       NRG AIR
5540250011 -5540250011 -4748828125          -             -
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119399999  5220000000 -5565474912  5525864406  5420126250  -    5669557853
  RATIO        RESIDUAL      RES/LEN      RHOCP
5110223972  5537206688  4953490276  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119384729  5240000000 -5612457307  5526747009  5415895585  -    5715776629
  RATIO        RESIDUAL      RES/LEN      RHOCP
5110033442  5530891871  4919580780  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119460097  5260000000 -5617559189  5523733610  5413428046  -    5723297813
  RATIO        RESIDUAL      RES/LEN      RHOCP
5098810022  5526953381  4911569060  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119517474  5280000000 -5621735736  5519442696  5411014296  -    5729999208
  RATIO        RESIDUAL      RES/LEN      RHOCP
5099817655  5523736140  4879122557  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119517474  5310000000 -5625475889  5515327145  5399384960  -    5736012299
  RATIO        RESIDUAL      RES/LEN      RHOCP
5099101351  5520669813  4857396537  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119612130  5312000000 -5629154616  5511963970  5394950781  -    5741825999
  RATIO        RESIDUAL      RES/LEN      RHOCP
5099898398  5520430896  4848847359  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119645584  5314000000 -5632502700  5492204144  5385470703  -    5747216906
  RATIO        RESIDUAL      RES/LEN      RHOCP
5099147305  5517929261  4837972122  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119657685  5316000000 -5635331554  5472457852  5370697265  -    5751823378
  RATIO        RESIDUAL      RES/LEN      RHOCP
5098763851  5514693837  4828353685  4962500000
TRIM AIR  CERN1               AMIN           AMAX         DMAX     BMAX    LENGTH
5119661616  5318000000 -5637589313  5457775734  5357056250  -    5755506698
  RATIO        RESIDUAL      RES/LEN      RHOCP
```

VI. Final printout of TRIMON

XB	B	XBX	A	BX BX
5135999999	-5511671922	-	-	-5432422006
5210799999	-5511690867	5171999998	-5584037837	-5126313442
5217999999	-5511689028	5214399999	-5616821208	5025543212
5225199999	-5511617880	5221599999	-5625237309	5198817442
5232399999	-5511539818	5228799999	-5633602183	5210841945
5237000000	5314172265	5236000000	-5641910852	5425394653
5239000000	5344182226	5238000000	-5641882507	5315004980
5241000000	5375975195	5240000000	-5641794143	5315896484
5243000000	5411068750	5242000000	-5641642192	5317356152
5245000000	5414959765	5244000000	-5641420817	5319455078
5247000000	5419446582	5246000000	-5641121622	5322434082
5249000000	5424788417	5248000000	-5640732691	5326709179
5251000000	5431378457	5250000000	-5640236922	5332950195
5253000000	5439817949	5252000000	-5639609353	5342197460
5255000000	5451008085	5254000000	-5638812994	5355950683
5257000000	5466128535	5256000000	-5637792832	5375602246
5258500000	5481338007	5258000000	-5636470262	5410139648
5259500000	5492964687	5259000000	-5635656882	5411626679
5260500000	5510576515	5260000000	-5634727235	5412800468
5261500000	5511867554	5261000000	-5633669583	5412910390
5262500000	5512978429	5262000000	-5632482828	5411108750
5263500000	5513730832	5263000000	-5631184985	5375240234
5264500000	5514036140	5264000000	-5629811901	5330530859
5265500000	5513993878	5265000000	-5628408287	-5242261718
5266500000	5513748664	5266000000	-5627008900	-5324521484
5267500000	5513404589	5267000000	-5625634033	-5334407421
5268500000	5513019617	5268000000	-5624293574	-5338497265
5269500000	5512620169	5269000000	-5622991612	-5339944726
5270500000	5512215800	5270000000	-5621729595	-5340436914
5271500000	5511809144	5271000000	-5620508015	-5340665625
5272500000	5511401267	5272000000	-5619327101	-5340787695
5273500000	5510992945	5273000000	-5618186974	-5340832226
5274500000	5510584320	5274000000	-5617087680	-5340862500
5275500000	5510175037	5275000000	-5616029248	-5340928320
5276500000	5497653027	5276000000	-5615011744	-5340973437
5277500000	5493551796	5277000000	-5614035214	-5341012304
5278500000	5489447773	5278000000	-5613099696	-5341040234
5279500000	5485340361	5279000000	-5612205218	-5341074121
5280500000	5481229335	5280000000	-5611351814	-5341110253
5281500000	5477116289	5281000000	-5610539521	-5341130468
5282500000	5473005683	5282000000	-5597683584	-5341106054
5283500000	5468906699	5283000000	-5590383016	-5340989843
5284500000	5464836494	5284000000	-5583492346	-5340702050
5285500000	5460821806	5285000000	-5577008697	-5340146875
5286500000	5456899941	5286000000	-5570926516	-5339218652
5287500000	5453114580	5287000000	-5565236522	-5337853613
5288500000	5449508066	5288000000	-5559925064	-5336065136
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5314750000	-5169512414	5314500000	5234756207	-5049689879

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FOOTNOTES AND REFERENCES

1. Alan Winslow, An Irregular Triangle Mesh Generator UCRL-7880 (1964).
2. Alan Winslow, "Equipotential" Zoning of Two-Dimensional Meshes, UCRL-7312 (1963).
3. Alan Winslow, Numerical Calculation of Static Magnetic Fields in an Irregular Triangle Mesh, UCRL-7784 (1964).
4. Supplementary write-up for TRIM by Bobby Powell (attached).
5. Fred Andrews's paper on TRIM, unpublished.
6. J. S. Colonias and J. H. Dorst, Magnet Design Application of the Magnetostatic Program called TRIM, UCRL-16382 (1965).
7. This program was written by Alan Winslow of LRL, Livermore.