MASTER

DIVERT

A Divertor Magnetic Field Line Following Code

by

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ABSTRACT

The computer code DIVERT has been written to trace magnetic field lines in the presence of a diverter. Its purpose is to allow a user to estimate the thickness of the plasma scrapeoff region and to provide a visual mapping of the magnetic field lines near the diverter. Included in the code is the capability to provide auxiliary graphics and compute the field ripple. The code can handle a diverter made up of any arrangement of straight line coil segments and will provide a graph of the field line configuration or output.

Introduction

The DIVERT computer code will allow a user to plot out the magnetic field line configuration near a bundle divertor. The user submits the major parameters of the tokamak and the line segment construction of the divertor along with the currents. Also included is a capability of drawing auxiliary lines on the graph. This graphic capability may be used to include various other nearby devices (pumps, magnets, neutral beam injectors, etc.) and so provide a means of determining "fit", since everything is drawn to scale.

The output is a graph of a selection of magnetic field lines, an outline of the torus, divertor, and any other auxiliary graphics.

Theory

The DIVERT code integrates the following equations for the field lines;

$$\frac{dx}{B} = \frac{dy}{B_x} = \frac{dz}{B_y} = \frac{dz}{B_z}$$

The magnetic field at point $\vec{X}$ from any given straight line coil segment between $\vec{X}_1$ and $\vec{X}_2$ is

$$\vec{B} = \frac{\mu_0 I_{\text{coil}}}{4\pi} \frac{\vec{X}_3 \times \vec{X}_1}{|\vec{X}_3 \times \vec{X}_1|^2} \left[\frac{\vec{X}_3 \cdot \vec{X}_1}{|\vec{X}_1|} - \frac{\vec{X}_3 \cdot \vec{X}_2}{|\vec{X}_2|} \right]$$

$$\text{where } \vec{X}_1 = \vec{X}_1 - \vec{X} \quad \vec{X}_2 = \vec{X}_2 - \vec{X} \quad \vec{X}_3 = \vec{X}_2 - \vec{X}_1$$

and ICOIL is the current from $\vec{X}_1$ to $\vec{X}_2$

See figure 1. This is added to the toroidal magnetic field

$$\vec{B}_T = \frac{BZA}{R}$$

The poloidal magnetic field is not incorporated at present, but it is a simple matter to add it in MAGFLD.

The computer program uses the differential equation solving subroutine DREBS from the computer library IMSLIB. Several other subroutines for solving the differential equations were tried, but DREBS provided the higher accuracy results for this type of problem. Other types of library subroutines are used in this computer code: The plotting routines from CALCOMP and the author's own library, RNMLIB, are used throughout the code. Please note that the submit file DSUB and some of the particulars of the input are local to the Georgia Tech computer

system (as of April 1980).

Input data

The input consists of three namelists and several lines of alpha numeric data. See table 1 for a list of the major Fortran variables.

The first portion of the input is the namelist PRAM. PRAM contains,

RADIUS

ASPECT

SCALE

CURRENT

The second namelist to be entered is IN. IN contains,

NLINE

XS(20)

YS(20)

NCOIL

V(7,20)

TOL

BPA

BZA

The only item to note is that the V7's should contain only the relative current so that scaling the current can be done by means of CURRENT. TOL is the integrator tolerance and can be varied for accuracy on different runs. For first "roughing" runs, it should be about $1.E-3$ to $1.E-4$.

The third namelist is GRAPH. G is an array which contains the coordinates of points to be plotted on the output graph. There are two graphing commands $1.E3$ and $1.E4$. $G(n,1)$ is the x coordinate and $G(n,2)$ is the z coordinate. Normally a line is drawn from $G(n-1,1)$, $G(n-1,2)$ to $G(n,1), G(n,2)$. If $G(n,1) = 1.E3$, the per is lifted for the move from $G(n-1,1), G(n-1,2)$ to $G(n+1,1), G(n+1,2)$. If $G(n,1) = 1.E4$ the graphing is terminated.

The final input data is the alpha numeric data. The first line is the run number, which is a line of alpha numeric data (20 characters max). The following line is a switch input and must contain either a YES or a NO. If it contains a NO, this is the end of the input data. If it contains a YES, the next three lines can contain any alpha numeric data which will be printed on the output graph. Note that three lines must be filled - pad with blanks if necessary.

This completes the input data.

Results

The following figures (2-4) show the results of several runs with three types of bundle diverters.

Acknowledgement

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TABLE 1

Fortran variables

BR(1)	X Coordinate
BR(2)	Y Coordinate
BR(3)	Z Coordinate
XS(20)	Initial set of x values (radial of desired starting point of a field line)
YS(20)	Initial set of y values (height off midplane)
RADIUS	Major radius of the device in meters
ASPECT	The aspect ratio of the plasma
SCALE	The graph scaling. Equals 1.0 for 1.0" on graph to equal 1.0 meter on device.
NLINE	Number of field lines to be traced. Maximum is 20.
NCOIL	The number of current segments in the divertor. Maximum is 20.
CURRENT	The current in the divertor. All V7'S are multiplied by this number.
TOL	Integrator tolerance
BPA	A variable to be used in MAGFLD. Currently unused.
BZA	A variable to be used in the subr MAGFLD. Currently it is the toroidal field in tesla.

- V(7,20) The array that contains the current segment information.
- V(1,N) The X coordinate of the starting point of current segment N.
- V(2,N) The Y coordinate of the starting point of current segment N.
- V(3,N) The Z coordinate of the starting point of current segment N.
- V(4,N) The X coordinate of the ending point of current segment N.
- V(5,N) The Y coordinate of the ending point of current segment N.
- V(6,N) The Z coordinate of the ending point of current segment N.
- V(7,N) The Relative current in coil segment N that flows from start to end.
- G(100,2) Contains the auxiliary graphing coordinates.
- G(N,1) X coordinate.
- G(N,2) Z coordinate.

Figure 1

```

/JO3
/NCSE0
FOLLOW,T1000.
USER.
G,DIVERT,FNMLIB/UN=NE101CS.
AT,CALCCMP,IMSLIB/UN=LIBRARY.
NCEKIT.
FTN,I=DIVERT,L=0,SR,BEW,T,PMD.
LOSET(LIB=CALCCMP/IMSLIB/FNMLIB).
LGC,OF=F.
R,CLT.
C,CLT,OUTFUT.
PLOTGV,TAF3.
/EOF
$FRAM
RADIUS=5.0,
ASPECT=3.2,
SCALE=0.62,
CURRENT=5.0,
$
$IK
TCL=1.E-4,
NCCIL=7,
V(1,1)=7.1, -.4, 0., 7.1, .4, 0., 2.,
V(1,2)=7.1, .4, 0., 6.4, .4, -.8, 1.,
V(1,3)=6.4, .4, -.8, 6.4, -.4, -.8, 1.,
V(1,4)=6.4, -.4, -.8, 7.1, -.4, .0, 1.,
V(1,5)=7.1, .4, .8, 6.4, .4, .8, 1.,
V(1,6)=6.4, .4, .8, 6.4, -.4, .8, 1.,
V(1,7)=6.4, -.4, .8, 7.1, -.4, .0, 1.,
NLINE=11,
$
$GRAPH
G(1,1)=4.89, 5.86, 8.59, 7.29, 7.28, 6.59, 6.22, 6.94, 7.84,
3.1, 5.59, 5.37, 6.22, 5.82, 1.E3, 5.48, 6.54,
7.13, 8.02, 8.02, 7.03, 1.E4,
G(1,2)=4.48, 3.31, 1.6, 1.6, -1.6, -1.6, -1.38, -3.14, -2.60,
-4.57, -4.66, -3.99, -3.58, -2.87, 1.E3, 4.93, 3.54,
2.20, 2.20, -2.20, 1.E4,
$
APRIL 1980 TEST
YES
ANGLE BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION
TEST CASE
PLASMA WITH TOROIDAL FIELD ONLY

```

NOTES

ANGLE BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION

APRIL 1980 TEST

TEST CASE

PLASMA WITH TOROIDAL FIELD ONLY

RADIUS = 5.000E+00, ASPECT = 3.800E+00

CURRENT = 5.000E+00, BZA = 5.000E+00, COIL SEGMENTS = 7

METER

BUNDLE DIVERTER FIELD LINES

SIDE VIEW
OF COILS

RIPPLE ON AXIS POS 7.762E-01% NEG -1.095E-01%

Figure 2

```

/JOB
/NOSEQ
FOLLOW,T1000.
USER.
G,DIVERT,RNMLI3/UN=NE101G3.
AT,CALCOMP,IMSLI3/UN=LIBRARY.
NOEXIT.
FIN,I=DIVERT,L=0,ER,REW,T,PMD.
LOSET(LI3=CALCOMP/IMSLI3/RNMLI3).
LGO,OP=F.
R,OUT.
C,OUT,OUTPUT.
PLOT,TAPE3.
/EOB
$PRAM
RADIUS=5.0,
ASPECT=3.8,
SCALE=0.62,
CURRENT=5.0,
$
$IN
TOL=1.E-4,
NCOIL=7,
V(1,1)=6.8, -.4, 0., 6.8, .4, 0., 2.,
V(1,2)=6.8, .4, 0., 6.8, .4, -.8, 1.,
V(1,3)=6.8, .4, -.8, 6.8, -.4, -.8, 1.,
V(1,4)=5.8, -.4, -.8, 6.8, -.4, .0, 1.,
V(1,5)=6.8, .4, .0, 6.8, .4, .8, 1.,
V(1,6)=6.8, .4, .8, 6.8, -.4, .8, 1.,
V(1,7)=6.8, -.4, .8, 6.8, -.4, .0, 1.,
NLINE=11,
$
$GRAPH
G(1,1)=4.89, 5.85, 6.59, 7.28, 7.28, 6.59, 5.22, 6.94, 7.84,
9.0, 5.59, 5.37, 6.22, 5.32, 1.E3, 5.46, 6.54,
7.03, 8.02, 8.02, 7.03, 1.E4,
G(1,2)=4.48, 3.31, 1.6, 1.6, -1.6, -1.6, -1.88, -3.14, -2.60,
-4.57, -4.66, -3.99, -3.58, -2.87, 1.E3, 4.93, 3.54,
2.20, 2.20, -2.20, -2.20, 1.E4,
$
APRIL 1930 TEST
YES
PLANAR BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION
TEST CASE
PLASMA WITH TOROIDAL FIELD ONLY

```

NOTES
 PLANAR BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION
 TEST CASE
 PLASMA WITH TOROIDAL FIELD ONLY
 RADIUS = 5.000E+00, ASPECT = 3.800E+00
 CURRENT = 5.000E+00, GJA = 5.000E+00, COIL SEGMENTS = 7
 APRIL 1930 TEST
 METER

BUNDLE DIVERTER FIELD LINES

SIDE VIEW
 OF COILS

RIPPLE ON AXIS POS 2.920E-01% NEG -1.309E+00%

Figure 3

```

/JO8
/NOSEQ
FOLLOW-T1000.
USER.
G, DIVER, RANLIB/UN=NE10100.
AT, CALCCMP, IMSLIB/AN=LIFARY.
NCEXIT.
FTN, I=DIVER, L=0, EP, REW-T, FPO.
LDSET (LIB=CALCCMP/IMSLIB/RANLIB).
LGO, OF=F.
R, CLT.
C, CLT, OUTFLT.
PLCTCV, TAFE3.
/EOB
$FRAM
RADIUS=5.0.
ASPECT=3.0.
SCALE=0.62.
CURRENT=5.0.
$
$IN
TCL=1.E-4.
NCOIL=7.
V(1,1)=6.4, -.4, 0., 6.4, .4, 0., 2.,
V(1,2)=6.4, .4, 0., 7.1, .4, -.8, 1.,
V(1,3)=7.1, .4, -.8, 7.1, -.4, -.8, 1.,
V(1,4)=7.1, -.4, -.8, 6.4, -.4, .0, 1.,
V(1,5)=6.4, .4, .0, 7.1, .4, .8, 1.,
V(1,6)=7.1, .4, .8, 7.1, -.4, .8, 1.,
V(1,7)=7.1, -.4, .8, 6.4, -.4, .0, 1.,
NLINE=11,
$
$GRAPH
G(1,1)=4.89, 5.86, 6.59, 7.28, 7.22, 6.59, 6.22, 6.94, 7.84,
9.0, 5.59, 5.37, 6.22, 5.82, 1.E3, 5.46, 6.54,
7.03, 8.02, 8.02, 7.03, 1.E4,
G(1,2)=4.48, 3.31, 1.6, 1.6, -1.6, -1.6, -1.88, -3.14, -2.60,
-4.57, -4.66, -3.99, -3.58, -2.87, 1.E3, 4.93, 3.54,
2.20, 2.20, -2.20, -2.20, 1.E4,
$
APRIL 1980 TEST
YES
ANGLE BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION
TEST CASE
PLASMA WITH TOROIDAL FIELD ONLY

```

NOTES
 ANGLE BUNDLE DIVERTOR - TWO LOOPS WITH RECTANGULAR CROSS SECTION
 TEST CASE
 PLASMA WITH TOROIDAL FIELD ONLY
 RADIUS = 5.000E+00, ASPECT = 3.800E+00
 CURRENT = 5.000E+00, BZA = 5.000E+00, COIL SEGMENTS = 7

APRIL 1980 TEST

METER

BUNDLE DIVERTER FIELD LINES

SIDE VIEW
OF COILS

RIPPLE ON AXIS POS 5.375E-01% NEG -3.957E+00%

Figure 4

APPENDIX

Computer Program DIVERT

```

1  PROGRAM DIVERT (INFLT,OUTFLT,CUT
   & TAPE5=INFLT,TAPE6=CUT,TAPE7=OUT,TAPE8=INFLT)
C
C *** PROGRAM DIVERT BY R. N. MORRIS AND G. BATEMAN. APRIL 1980 ***
C *** GEORGIA TECH, ATLANTA GEORGIA ***
C
C *****
C* THIS PROGRAM TRACES MAGNETIC FIELD LINES THROUGH
C* A DIVERTOR. THE MAGNETIC FIELD EQUATIONS ARE
C* IN SUBR MAGFLD. SUBMIT USING FILE CSUB
C *****
C  BF(1) IS X
C  BF(2) IS Y
C  BF(3) IS Z
C  SUBR MAGFLD CONTAINS THE EQUATIONS FOR THE MAGNETIC
C  FIELD. THIS SUBR IS TO BE MODIFIED BY THE USER FOR THE
C  SPECIFIC PROBLEM ENCOUNTERED. IT CURRENTLY IS SET UP TO
C  HANDLE A MAGNETIC CONFIGURATION MADE OF UP TO 20 STRAIGHT
C  LINE SEGMENTS.
C *****
C
C          INPUTS
C
C  XS(20) IS THE INITIAL SET OF X VALUES (RADIUS IF DESIRED
C  STARTING POINT OF FIELD LINE)
C  YS(20) IS THE INITIAL SET OF Y VALUES (HEIGHT OFF MIDPLANE)
C  BOTH ARRAYS HAVE DEFAULT VALUES WITHIN THE PROGRAM
C  -- 11 FIELD LINES WITH DECREASING SPACING WITH INCREASING
C  RADIUS
C  --MAGNETIC AXIS  XS(-) = RADIUS, YS(-) = 0.0
C  RADIUS IS THE MAJOR RADIUS OF THE DEVICE (IN METERS)
C  ASPECT IS THE ASPECT RATIO OF THE PLASMA
C  SCALE IS THE GRAPH SCALING. = 1 FOR 1" ON PLOT TO EQUAL
C  1 METER IN DEVICE.
C  NLINE IS THE NUMBER OF FIELD LINES TO BE TRACED. MUST
C  BE LESS THAN 21
C  NCCIL IS THE NUMBER OF CURRENT SEGMENTS IN THE DIVERTOR
C  CCIL. MUST BE LESS THAN 21.
C  V(1,N),V(2,N),V(3,N) V(4,N),V(5,N),V(6,N) VERTEX
C  COORDINATES FOR THE END POINTS OF EACH STRAIGHT CCIL
C  LEG IN THE BUNDLE DIVERTOR.
C  -STARTING POINT OF LINE SEGMENT N. (CURRENT FLOWS TOWARD
C  THE END POINT)
C  V(1,N) IS X
C  V(2,N) IS Y
C  V(3,N) IS Z
C  -ENDING POINT OF LINE SEGMENT N.
C  V(4,N) IS X
C  V(5,N) IS Y
C  V(6,N) IS Z
C  V(7,N) IS THE RELATIVE CURRENT IN CCIL SEGMENT N.
C  CURRENT IS THE NOMINAL CURRENT IN THE DIVERTOR. ALL V7'S ARE
C  MULTIPLIED BY THIS NUMBER. CURRENT IS IN MEGAMPS.
C  TCL IS THE INTEGRATOR TOLERANCE.
C  BZA AND EPA ARE FREE VARIABLES TO BE USED IN SUBR MAGFLD
C  FOR THE TCKAPAK MAGNETIC FIELDS.
C
C  ALL THE ABOVE VALUES HAVE DEFAULT VALUES..
C *****

```

```

C
C          NAMELISTS
C
C          IN
C *****
C  NLINE, XS(20), YS(20), ACCIL, V(7,20), TOL, BFA, EZA
C
C          PRAM
C *****
C  RADIUS, ASPECT, SCALE, CURRENT
C
C          GRAPH
C *****
C  G
C *****
C
C          NOTES AND GRAPHICS
C
C  TO USE THE GRAPHING. G(-,1) IS THE X VALUE, G(-,2) IS THE
C  Z VALUE. THE G ARRAY CAN HAVE A MAXIMUM OF 100 VALUES G(100,2).
C  THE TWO IMPORTANT CONTROL VALUES ARE 1.E3 AND 1.E4. IF G(-,1)
C  IS EQUAL TO 1.E4 THE GRAPHING IS TERMINATED. IF G(N,1) IS EQUAL
C  TO 1.E3 THE PEN IS LIFTED FOR THE MOVE FROM G(N-1,1) TO
C  G(N+1,1). OTHERWISE A LINE IS DRAWN FROM G(N,1) , G(N,2) TO
C  G(N+1,1) , G(N+1,2).
C
C  TO USE THE NOTE CAPABILITY. AFTER ALL THE NAMELISTS
C  HAVE BEEN ENTERED, THE NEXT ITEM TO BE READ IS THE RUN NUMBER
C  THIS ALPHANUMERIC INPUT CAN BE UP TO 20 CHARACTERS LONG AND
C  MUST BE ENTERED (IT CAN BE ALL BLANKS). AFTER THIS THE FOLLOWING
C  LINE SHOULD CONTAIN EITHER A YES OR NO. IF A NO IS ENTERED, THE
C  DATA INPUT IS COMPLETE. IF A YES IS ENTERED, THE NEXT THREE
C  LINES CONTAIN ANY ALPHANUMERIC DATA (UP TO 65 CHARACTERS EACH). PAD
C  WITH BLANK LINES IF NECESSARY TO COMPLETE ALL THREE LINES.
C  IF YOU ARE HAVING THE COMPUTER PROMPT THE TERMINAL, JUST
C  FOLLOW THOSE INSTRUCTIONS.
C *****
C  DIMENSION BF(3), SPATCH(8)
C  COMMON /PAR/ PI
C  COMMON /FIELD/ NLINE, XS(20), YS(20)
C  & ,BMAX,XBMAX,YBMAX,ZBMAX ,BMIN,XBMIN,YBMIN,ZBMIN
C  & ,NCCIL, V(7,20), CURRENT
C  & ,TCL,RADIUS,ASPECT,SCALE,XREF,YREF,BFA,BZA
C
C  COMMON /INT/ XVALUE
C
C  DATA PI/3.14159265359/ , IN/6/
C
C  SET UP DATA
C
C  CALL DATIN
C
C  SETUP GRAPH AND INITIALIZE VALUES
C
C  CALL STARTP(2)
C
C  CALL SETUP
C
C  DETERMINE FIELD LINE STEPS

```

```

      DS = .032 / SCALE
C
C SELECT STARTING POINTS AND INITIALIZE VALUES
C
      DC 50 M=1,NLINE
C
      BMAX = 0.
      BMIN = 100.
      ISWITCH = 0
      BF(1) = .707 * XS(M)
      BF(2) = YS(M)
      BF(3) = BF(1)
      ZEND = - BF(1)
      XF = (BF(1) - RADIUS) * SCALE
      YF = - BF(3) * SCALE
      CALL PLOT(XF,YF,3)
C
C INTEGRATE AROUND THROUGH THE INVERTER AND DRAW FIELD LINES
C
      BEGIN = 0.0
      DO 10 I=1,10000
        FINISH = DS - BEGIN
        CALL DSQ.VZ(BEGIN,FINISH,BF,TCL,ISWITCH,IN)
        XP = (BF(1) - RADIUS) * SCALE
        YP = - BF(3) * SCALE
        CALL PLOT(XP,YP,2)
        IF ((BF(3) .LT. 0.0) .AND. (ABS(BF(3)) .GT. ABS(BF(1)))) GO TO 20
        BEGIN = FINISH
      10  ISWITCH = 1
C
C WRITE OUT MAX AND MIN B FIELD ON THE GIVEN LINE
C
      20  WRITE (6,30) M,XS(M),YS(M),BMAX,BMIN
      30  FORMAT (1X,I3,1P7E13.5)
C
C COMPUTE RIPPLE ON AXIS AND WRITE OUT ON GRAPH.
C
      IF (M .NE. 1) GO TO 50
      RFLPCS = 100. * (BMAX-BZA) / BZA
      RFLNEG = 100. * (BMIN-BZA) / BZA
      XPLCT1 = 10.0 - XREF
      YPLCT1 = 1. - YREF
      ENCODE(20,40,SRATCH) RFLPCS, RFLNEG
      40  FORMAT("RIPPLE ON AXIS",5X,"POS",1X,1PE11.3
      & ",<#J".5X,">NEG",1X,1PE11.3,"<#J")
      CALL SYMBOL(XPLCT1,YPLCT1,.080,SRATCH,9,0,63)
C
      50  CONTINUE
C
      CALL ENCP
C
      STOP
      END
-----
      SUBROUTINE DATIN
C
      THIS SUBR HANDLES T-E DATA
C
      COMMON /PAR/ PI
C
      COMMON /TEXT/ NOTE1(7) , NOTE2(7) , NOTE3(7) , NRUN(2), G(100,2)
C
      COMMON /FIELD/ NLINE, XS(20), YS(20)
      & , BMAX,XBMAX,YBMAX,ZBMAX ,BMIN,XBMIN,YBMIN,ZBMIN

```

```

      & ,NCCIL, V(7,20), CURRENT
      & ,TCL,RADIUS,ASPECT,SCALE,XREF,YREF,BFA,BZA
C
      NAMLIST /IN/ NLINE, XS, YS, ACCIL, V, TOL, BPA, BZA
C
      NAMLIST /PRAM/ RADIUS, ASPECT, SCALE, CURRENT
C
      NAMLIST /GRAPH/ G
C
      DEFAULTS
C
      TCL = 1.E-7
      RADIUS = 3.
      ASPECT = 3.0
      BFA = 1.0
      BZA = 5.
      SCALE = 1.0
      NLINE = 1
      NCOIL = 1
      CURRENT = 5.0
      G(1,1) = 1.E4
C
      DO 10 I=1,11
      10  YS(I) = 0.0
C
      V(1,1) = 4.
      V(2,1) = -1.
      V(3,1) = 0.
      V(4,1) = 4.
      V(5,1) = 1.
      V(6,1) = 0.
      V(7,1) = 1.
C
      DO 30 I=1,7
      NOTE1(I) = "
      NOTE2(I) = "
      NOTE3(I) = "
      30  CONTINUE
C
      READ IN DATA AND COMPUTE FIELD LINE SPACING
C
      READ (5,PRAM)
C
      XS(1) = RADIUS
C
      SFACE = RADIUS/(ASPECT*3.0)
      XS(2) = RADIUS - 2.0*SFACE
      XS(3) = XS(2) + SFACE
C
      SFACE = RADIUS/(ASPECT*6.0)
      XS(4) = RADIUS + SFACE
      XS(5) = XS(4) + SFACE
      XS(6) = XS(5) + SFACE
C
      SFACE = RADIUS/(ASPECT*10.0)
      XS(7) = XS(6) + SFACE
      XS(8) = XS(7) + SFACE
      XS(9) = XS(8) + SFACE
      XS(10) = XS(9) + SFACE
      XS(11) = XS(10) + SFACE*0.75
C
      READ(5,IN)
      READ(5,GRAPH)
C

```

```

C READ RLN NUMBER
C
  WRITE(7,40)
  40  FORMAT(2X,"TYPE IN RLN ALMEER")
  READ(8,50) (NFK(I),I=1,2)
  50  FORMAT(2A10)
C
C READ NOTES
C
  WRITE(7,60)
  60  FORMAT(2X,"IF YOU WISH TO ADD NOTES, TYPE IN YES",/,
    & 2X,"OTHERWISE TYPE IN NO")
C
  READ(8,70) ANS
  70  FORMAT(A1)
C
  IF(ANS.NE."Y") GO TO 100
C
  WRITE(7,80)
  80  FORMAT(2X,"TYPE IN NOTES, 3 LINES MAX, 65 CHARACTERS",
    & /,2X,"PER LINE MAX. IF YOU INPUT LESS THAN 3 LINES",
    & /,2X,"TYPE A LINE OF BLANKS FOR THE REMAINING LINE(S)")
C
  READ(9,90) (NCTE1(I),I=1,7)
  90  FORMAT(7A10)
  READ(9,90) (NCTE2(I),I=1,7)
  READ(9,90) (NCTE3(I),I=1,7)
C
C WRITE OUT HEADER
C
  100 CALL STAR(1,6)
  WRITE(6,110)
  110  FORMAT(/,10X,"MORRIS AND BATEMAN FIELD LINE TRACING CODE",
    & /,15X,"GEORGIA TECH 1975",/)
  CALL STAR(1,6)
  CALL SKIP(2,6)
C
C WRITE OUT NOTES
C
  WRITE(6,120)
  120  FORMAT(2X,"NOTES:",/)
C
  WRITE(6,130) (NCTE1(I),I=1,7)
  WRITE(6,130) (NCTE2(I),I=1,7)
  WRITE(6,130) (NCTE3(I),I=1,7)
  130  FORMAT(2X,7A10)
  CALL SKIP(2,6)
C
C WRITE OUT NAMELISTS
C
  WRITE(6,PPAM)
  WRITE(6,IN)
  WRITE(6,GRAPH)
  CALL SKIP(2,6)
C
C WRITE OUT OTHER HEADER INFORMATION
C
  WRITE(6,140)
  140  FORMAT(/,3X,"M",6X,"XS(M)",8X,"YS(M)",8X
    & "EAMAX",6X,"EAMIN")
  RETURN
END
-----
SUBROUTINE DSCLVE(XSTART,XEND,BF,TOL,ISWITCH,IW)

```

```

C
C THIS SUBR USES THE IMSL SUBR DREBS TO INTEGRATE
C BETWEEN XSTART AND XEND
C
C XSTART IS THE BEGINNING VALUE OF THE INTEGRATION
C XEND IS THE FINAL VALUE OF THE INTEGRATION LIMIT
C BF IS THE VALUE OF THE FUNCTION AT XEND
C TOL IS THE INTEGRATING TOLERANCE
C ISWITCH = 0 FOR FIRST CALL
C          = 1 FOR REMAINING CALLS
C IW IS THE LOGICAL UNIT ERRORS ARE WRITTEN ON
C
  EXTERNAL DFIELD
  DIMENSION BF(3), R(3), S(3), WK(87)
  COMMON /INT/ XVALUE
C
  IF(ISWITCH.NE.0) GO TO 10
C
C INITIALIZE VALUES
C
  JM = 6
  IND = 2
  JSTART = 0
  N = 3
  S(1) = BF(1)
  S(2) = BF(2)
  S(3) = BF(3)
  SAVE = XEND - XSTART
  HMIN = 1.E-9
  ERRCR = 0.5 * HMIN
  XVALUE = XSTART
C
  10 CONTINUE
C
  H = XEND - XVALUE
  IF(ABS(SAVE).LT.ABS(H)) H = SAVE
C
C INTEGRATE TO THE END POINT
C
  DO 30 I=1,1000
    CALL DREBS(DFIELD,BF,XVALUE,N,JM,IND,JSTART,H,HMIN,TOL,
      & R,S,WK,IER)
    IF(IER.NE.0) GO TO 40
    TEMP = XEND - XVALUE
    IF(ABS(TEMP).LT.ERRCR) RETURN
    SAVE = H
    IF(ABS(TEMP).GT.ABS(H)) GO TO 30
    H = TEMP
  30 CONTINUE
C
C ERROR EXIT
C
  40 CALL SYBCL(-2.0,-0.40,0.20,"ABORT",0.0,6)
  CALL ENCP
  CALL STAR(2,IW)
  WRITE(IW,50) XVALUE, H
  50  FORMAT(/,2X,"PROBLEM AT Z = ",1PE11.3,2X,
    & "STEP SIZE = ",1PE11.3,/,2X,
    & "*****SYSTEM ABORT*****",/)
C
  CALL STAR(2,IW)
C
  STOP

```

```

END
-----
SUBROUTINE SETUP
  DIMENSION TITLE(12)

  COMMON /TEXT/ NOTE1(7) , NOTE2(7) , NOTE3(7) , ARLN(2) , G(100,2)

  COMMON /FIELD/ NLINE , XS(20) , YS(20)
  & , XAPAX , YAPAX , ZAPAX , XAPIN , YAPIN , ZAPIN
  & , NCIL , V(7,20) , CURRENT
  & , TCL , RADIUS , ASFE (T,SCALE,XREF,YREF,8PA,BZA)

  THIS SUBR PREPARES THE GRAPH FORMAT
  IT DRAWS THE MARGINS AND LABELS THE GRAPHS

  DRAW MARGIN

  CALL MARGIN

  LOCATE AND DRAW LABEL

  CALL SYMBCL(2.30,1.85,-160,
  & , "BUNDLE DIVERGES FIELD LINES",90.0,28)

  WRITE OUT NOTES AND OTHER PARAMETERS ON GRAPH

  SCALE LINE

  CALL SYMBOL(1.50,6.00,-100,13,90.0,-1)
  XC1 = 6.00 + SCALE
  CALL SYMBOL(1.50,XC1,-100,13,90.0,-1)
  CALL PLOT(1.50,6.00,3)
  CALL PLOT(1.50,XC1,2)
  XC1 = 6.00 + SCALE/2.0 - .2
  CALL SYMBCL(1.72,XC1,.080,"1METER",90.0,6)

  NOTES

  CALL SYMBCL(0.75,1.00,.080,"NOTES",90.0,6)
  CALL PLOT(0.78,1.00,3)
  CALL PLOT(0.78,1.48,2)
  CALL SYMBCL(0.92,1.00,.080,NOTE1,90.0,55)
  CALL SYMBCL(1.06,1.00,.080,NOTE2,90.0,55)
  CALL SYMBCL(1.20,1.00,.080,NOTE3,90.0,55)
  ENCCOE(120,5,TITLE)RADIUS , ASPECT
  5  FORMAT("RADIUS =",1X,1PE10.3,"",1X,"ASPECT =",1X,1PE10.3)
  CALL SYMBOL(1.34,1.00,.080,TITLE,90.0,55)
  ENCCOE(120,30,TITLE)CURRENT , BZA , NCIL
  10  FORMAT("CURRENT =",1X,1PE10.3,"",1X,"BZA =",1X,1PE10.3
  & , " ",1X,"CCIL SEGMENTS =",1X,I2)
  CALL SYMBOL(1.48,1.00,.080,TITLE,90.0,55)
  CALL SYMBCL(6.44,1.00,0.080,"SIDE VIEW",90.0,9)
  CALL SYMBCL(6.56,1.00,0.080,"CF CCILS",90.0,8)

  RUN NUMBER

  CALL PLOT(0.75,5.98,1.60,0.16,0.0,3)
  ENCCOE(120,20,TITLE) ARLN(1),NRUN(2)
  20  FORMAT(24I0)
  CALL SYMBCL(3.87,6.02,.080,TITLE,90.0,18)

  DRAW CUT AXIS

  CALL AFOHD(2.75,4.25,3.50,4.25,0.15,0.05,12)

```

```

  CALL AFOHD(2.75,4.25,2.75,3.50,0.15,0.05,12)
  CALL SYMBCL(3.05,4.32,0.080,"X",90.0,1)
  CALL SYMBCL(2.95,3.50,0.080,"Z",90.0,1)

  DRAW CUT TOROID AND CCIL CONFIGURATION

  DRAW TOROID

  A = RADIUS/ASPECT
  RIN = RADILS - A
  RCUT = RADILS + A
  XREF = 3.25 + (SIN*0.293 + A) * SCALE
  YREF = 4.25
  CALL PLOT(XREF,YREF,-3)
  CALL SYMBCL(0.0,0.0,0.045,14,90.0,-1)
  XC1 = -A * SCALE
  RAD = RIN * SCALE
  CALL CIRCLE(XC1,0.0,0.0,45.0,RAD,RAD,0.5)
  CALL CIRCLE(XC1,0.0,0.0,-45.0,RAD,RAD,0.5)
  XC1 = -XC1
  RAD = ROLT * SCALE
  CALL CIRCLE(XC1,0.0,0.0,45.0,RAD,RAD,0.5)
  CALL CIRCLE(XC1,0.0,0.0,-45.0,RAD,RAD,0.5)

  DRAW CCILS (TCP VIEW)

  DO 40 I=1,NCIL
    XC1 = (V(1,I)-RADIUS)*SCALE
    YC1 = -V(3,I)*SCALE
    XC2 = (V(4,I)-RADIUS)*SCALE
    YC2 = -V(6,I)*SCALE
    IF((XC1.EQ.XC2).AND.(YC1.EQ.YC2)) GO TO 30
    CALL PLOT(XC1,YC1,3)
    CALL PLOT(XC2,YC2,2)
    CALL SYMBCL(XC1,YC1,0.080,11,0.0,-1)
    CALL SYMBCL(XC2,YC2,0.080,11,0.0,-1)
  30  CONTINUE
  40  CONTINUE

  DRAW CCILS (SIDE VIEW)

  DO 50 I=1,NCIL
    XC1 = -V(2,I) * SCALE - XREF + 2.50
    YC1 = -V(3,I) * SCALE
    XC2 = -V(5,I) * SCALE - XREF + 2.50
    YC2 = -V(6,I) * SCALE
    IF((XC1.EQ.XC2).AND.(YC1.EQ.YC2)) GO TO 45
    CALL PLOT(XC1,YC1,3)
    CALL PLOT(XC2,YC2,2)
    CALL SYMBCL(XC1,YC1,0.080,11,0.0,-1)
    CALL SYMBCL(XC2,YC2,0.080,11,0.0,-1)
  45  CONTINUE
  50  CONTINUE

  DRAW CUT THE HARDWARE AROUND THE INVERTOR

  J = 3
  DO 60 I=1,100
    IF(G(I,1).GT.9000.0) GO TO 70
    IF(G(I,1).GT.900.0) J = 3
    IF(G(I,1).GT.900.0) GO TO 60
    XC1 = (G(I,1) - RADIUS)*SCALE
    YC1 = -G(I,2)*SCALE
    CALL PLOT(XC1,YC1,J)
    J = 2
  60  CONTINUE
  70  PRTLN
  END

```

```

C-----
C SUBROUTINE CFIELD (N,S,F,FP)
C DIMENSION F(N), FP(N)
C
C THIS IS THE DIFF EQ SET FOR THE FIELD LINES
C IN A TOROID GIVEN ANY THREE COORDINATES (X,Y,Z)
C F(1) = X, F(2) = Y, F(3) = Z
C
C COMMON /FIELD/ NLINE, XS(20), YS(20)
C & ,BAPAX,XBAPAX,YBAPAX,ZBAPAX ,BAMIN,XBAMIN,YBAMIN,ZBAMIN
C & ,NCCIL, V(7,20), CURRENT
C & ,TCL,RADIUS,ASPECT,SCALE,XREF,YREF,BPA,BZA
C
C COMMON /PAR/ PI
C
C DETERMINE FIELD COMPONENTS
C
C CALL MAGFLD(F(1),F(2),F(3),EX,EY,EZ,B)
C
C DIFF ECLATION FOR FIELD LINE IN CYLINDER
C
C FP(1) = BX / B
C FP(2) = BY / B
C FP(3) = BZ / B
C
C RETURN
C END

```

```

C-----
C SUBROUTINE MAGFLD(X,Y,Z,EX,EY,EZ,B)
C
C THIS SUBR COMPUTE THE MAGNETIC FIELD COMPONENTS OF A TOROIDIAL
C FIELD WITH COMPONENTS IN THE X,Y AND Z DIRECTION
C
C COMMON /FIELD/ NLINE, XS(20), YS(20)
C & ,BAPAX,XBAPAX,YBAPAX,ZBAPAX ,BAMIN,XBAMIN,YBAMIN,ZBAMIN
C & ,NCCIL, V(7,20), CURRENT
C & ,TCL,RADIUS,ASPECT,SCALE,XREF,YREF,BPA,BZA
C
C COMPUTE TOROID FIELD
C
C DEM = (Z*Z + X*X)
C BX = BZA * Z * RADIUS / DEM
C BY = 0.0
C BZ = - BZA * X * RADIUS / DEM
C
C COMPUTE FIELD FROM DIVERTOR
C
C DO 20 N=1,NCCIL
C V1X = V(1,N) - X
C V1Y = V(2,N) - Y
C V1Z = V(3,N) - Z
C V1P = SQRT (V1X*V1X + V1Y*V1Y + V1Z*V1Z)
C
C V2X = V(4,N) - X
C V2Y = V(5,N) - Y
C V2Z = V(6,N) - Z
C V2A = SQRT (V2X*V2X + V2Y*V2Y + V2Z*V2Z)
C
C V3X = V(4,N) - V(1,N)
C V3Y = V(5,N) - V(2,N)
C V3Z = V(6,N) - V(3,N)
C
C CX = V3Y*V1Z - V3Z*V1Y
C CY = V3Z*V1X - V3X*V1Z

```

```

CZ = V3Y*V1Y - V3Y*V1Y
C CASO = CX*CX + CY*CY + CZ*CZ
C
C F = CURRENT * V(7,N) * ((V3X*V1X+V3Y*V1Y+V3Z*V1Z)
C & - ((V3X*V2X+V3Y*V2Y+V3Z*V2Z)/V2A)) / (CASO * 10
C
C BX = BX + CX*F
C BY = BY + CY*F
C BZ = BZ + CZ*F
C 20 CONTINUE
C
C KEEP TRACK OF FIELD RIFFLE. DETERMINE FIELD
C STRENGTH AND IF IT IS AN EXTREME, SAVE THE FIELD
C POSITIONS.
C
C B = SQRT (BX*BX + BY*BY + BZ*BZ)
C
C IF (B .LT. EAPAX) GO TO 40
C BAPAX = B
C XBAPAX = X
C YBAPAX = Y
C ZBAPAX = Z
C
C 40 CONTINUE
C IF (B .GT. BAMIN) RETURN
C BAMIN = B
C XBAMIN = X
C YBAMIN = Y
C ZBAMIN = Z
C
C RETURN
C END

```

```

C***   THESE SUBR ARE FROM RANLIB *****
C
C*****
C***
C***   LIBRARY
C***
C*****
C***
C***   GRAPHING
C***
C***   TO GRAPH, FIRST CALL STARTP WITH THE TOTAL NUMBER
C***   OF GRAPHS YOU PLAN TO MAKE. THEN CALL PLOTAP OR
C***   PLOTOM. AFTER THE PLOTTING IS DONE CALL ENDP.
C***   FINALLY SEND TAPE3 TO THE PLOTTING DEVICE.
C***
C*****
C   SUBROUTINE STARTP(N)
C   DIMENSION ISUFF(512)
C
C   THIS FUNCTION OPENS UP THE PLCT FILE ON UNIT 3
C   AND SETS THE PAPER LENGTH
C
C   N IS THE TOTAL NUMBER OF GRAPHS TO BE MADE
C
C   CALL PLGTS(ISUFF,512,3,0)
C   R = N * 15.
C   CALL PLOTMX(R)
C   END
C-----
C   SUBROUTINE ENDP
C
C   THIS FUNCTION CLOSES THE PLCT FILE
C
C   CALL PLOT(0.,0.,999)
C   RETURN
C   END
C*****
C***   FUNCTION FOUTINES
C***
C*****
C   SUBROUTINE SKIP(I,NOUT)
C
C   THIS SUBR SKIPS I LINES ON UNIT NOUT
C
C   DO 10 J=1,I
C   10  WRITE(NOUT,20)
C   20  FORMAT(/)
C   RETURN
C   END
C-----
C   SUBROUTINE STAR(I,NOUT)
C
C   THIS SUBR PRINTS I LINES OF STARS ON UNIT NOUT
C
C   DO 10 J=1,I
C   10  WRITE(NOUT,20)
C   20  FORMAT("*****")
C   30  WRITE(NOUT,20)
C   40  WRITE(NOUT,20)
C   50  WRITE(NOUT,20)
C   60  WRITE(NOUT,20)
C   70  WRITE(NOUT,20)
C   80  WRITE(NOUT,20)
C   90  WRITE(NOUT,20)
C   RETURN
C   END
C-----

```