AXISYS: A System of Computer Programs for Calculation of Magnetic Fields, Forces, Inductances, and Flux Lines for Collections of Coaxial Solenoid Elements

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ABSTRACT

A system of Fortran programs for calculation of magnetic fields, forces, inductances, and flux lines from collections of coaxial solenoid elements is described. The user starts with a coil data file that serves as input to a program that prepares the data in the correct format for input to the various coaxial field, force, and inductance programs, or, if desired, to EFFI, the Livermore magnetics code. The field and inductance programs exist both in VAX and Cray versions.

INTRODUCTION

The system of programs described in this memorandum has evolved from a set of programs written by the author while at Oak Ridge. The solenoid routines are based on adaptive Gaussian integration in radial depth of analytical expressions for ideal (infinitesimally thin) solenoid elements.[1] For calculation of magnetic fields in or near windings, the windings are divided up relative to the field point location to ensure accuracy and to avoid singularities due to coincidence of the field point with a solenoid element. Inductance and force calculations require double Gaussian quadrature. The routines are generally faster and more accurate than EFFI, but provision has been made in the system to allow preparation of input for EFFI if needed (for example, if nonaxisymmetric coils are to be added to the coil system). At present, graphics output is not available for the VAX field program BCOAX. However, the Cray version of BCOAX, BAXIAL, has a flux line plotting routine using DISSPLA. Double precision is used in the VAX versions of the field and inductance routines (BCOAX and LFCOAX). Units are MKS except where otherwise noted.

OVERALL SYSTEM DESIGN

The overall system is shown schematically in Fig. 1. In the schematic, programs are denoted by ovals and data files by rectangles. Detailed descriptions of the above programs and data files are given in the following sections.

All of the magnet system information (coil dimensions and locations, current densities, and numbers of turns) is contained in the VAX file MAGDAT.DAT. The content of this file is independent of which field or inductance program is to be used. The additional data specifying field points, flux lines, coil grouping for inductance calculations, etc., specific to each of the various field and inductance programs, is contained in the VAX file AUXFIL.DAT. Input data files for the VAX coaxial solenoid programs and their corresponding Cray versions are identical, except for the added lines for graphics output from BAXIAL. AUXFIL.DAT takes on three distinctly different forms, depending upon whether input data files are being prepared for BCOAX (or its Cray version), LCOAX (or its Cray version), EFFI, or EIG. The above files, MAGDAT.DAT and AUXFIL.DAT, are input to the array generating program ARAGEN, which combines the data from MAGDAT.DAT with the information in AUXFIL.DAT to produce an output file named ARRAY.DAT. ARRAY.DAT must then be appropriately renamed for input to the various programs (see Fig. 1). During execution of ARAGEN, the user inputs a single number from the keyboard in order to specify the type of output required (1 for BCOAX or BAXIAL, 2 for LCOAX or LFAXYL, 3 for EFFI, 4 for EIG).

For access to the programs, at present the user must copy the entire directory [WALSTROM.AXISYS] to his own directory. Included also in [WALSTROM.AXISYS] are the sample data files COILDAT.DAT, BCOAX.DAT, LCOAX.DAT,

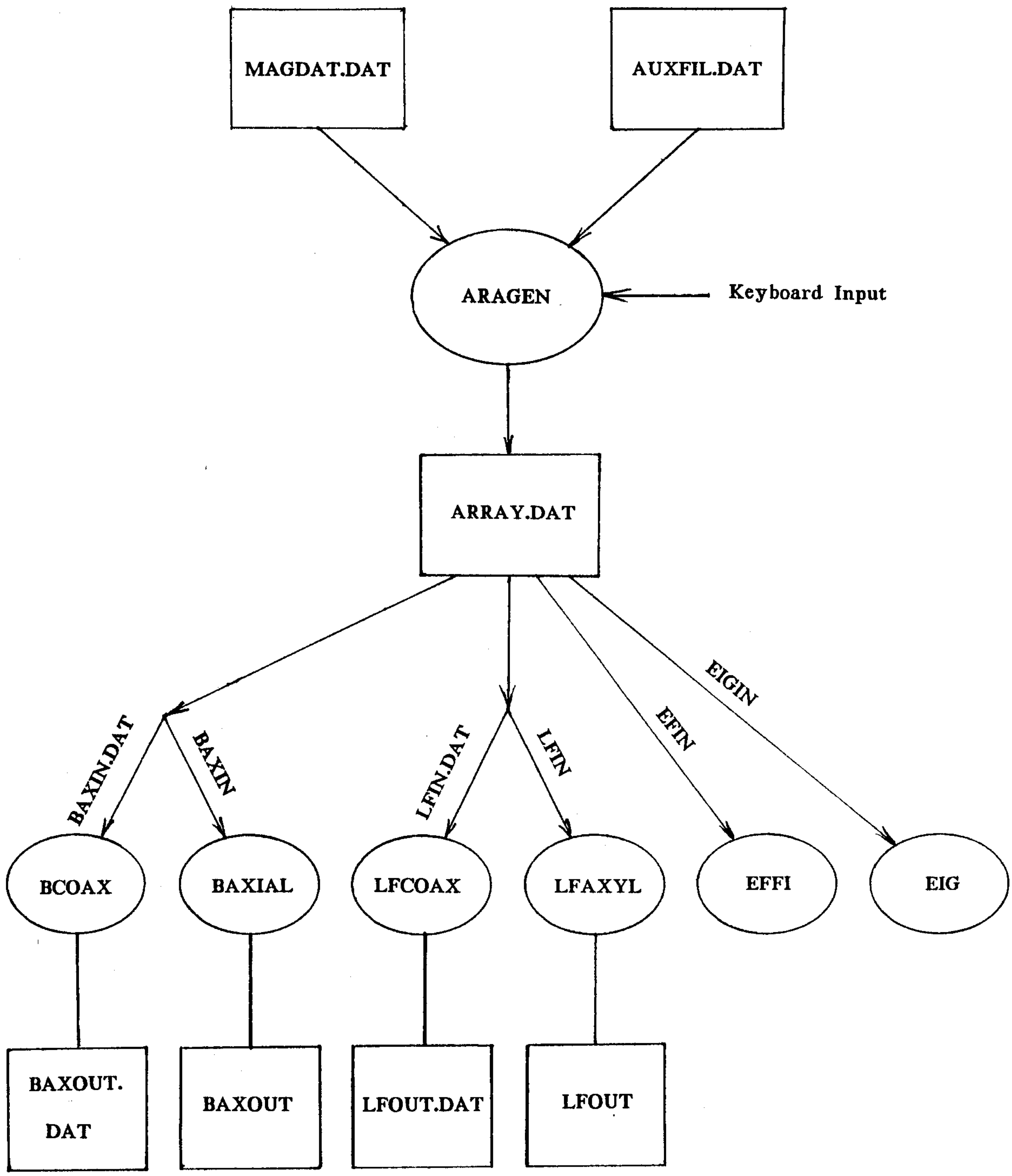

Figure 1. AXISYS schematic.

EFFI.DAT, and EIG.DAT. The file COILDAT.DAT is a set of sample coil data that can be copied over into the file MAGDAT.DAT for test runs. The remaining sample data files are versions of AUXFIL.DAT appropriate to BCOAX, LCOAX, EFFI, and EIG, respectively. For test runs, they must be copied over to AUXFIL.DAT.

In the following sections the various programs in AXISYS are described in detail.

ARAGEN

The VAX program ARAGEN accepts as input the two files MAGDAT.DAT and AUXFIL.DAT. These files must be present along with the executable file ARAGEN.EXE in the current directory. ARAGEN takes groups of coils specified in MAGDAT.DAT and repeats them, and if desired, reflects them about z = 0, according to coding in MAGDAT.DAT. The first line of MAGDAT.DAT is read in with A format and can contain any title information that the user wants. This title will appear in all of the program outputs. The line is limited to 80 characters, including blanks.

After the title line, the coil data in MAGDAT.DAT is given in blocks. Except for the title line, all of the MAGDAT.DAT data is read in free format, so that the column location of the numbers is not critical. Numbers can be separated by blanks or commas. Blanks are generally preferable for legibility. Each block represents a group of solenoid elements that may be repeated and/or reflected. A block begins with a line containing a single 0 (zero). A line containing data for a solenoid element comes next. The numbers in the line represent, in order, A1, the inner radius, A2, the outer radius, ZL, the Z coordinate of the left hand side of the windings, ZR, the right hand side coordinate, CD, the current density, and XNT, the number of turns. Note that the number of turns XNT is a real variable and need not be an integer.

Also, it should be noted that ZL and ZR represent the coordinates relative to an arbitrary local coordinate system for the group, not the final locations.

If there are more solenoid elements in the first group, similar lines containing data for them follow. A line containing a 1, -1, 2, or -2 which is read into the variable KODE follows the coil data lines for the group, to signify the end of the group. If the absolute value of KODE is 1, there are more coil groups to follow. If the absolute value of KODE is 2, the above group is the last group and only one more line of data will be present in MAGDAT.DAT. The numbers in the next line represent ZSTART, the initial Z value for the origin of the local coordinate system for the group, DELZ, the Z increment for the group origin, and NRPEAT, the number of times the group is repeated. If NRPEAT is 0, it is set equal to 1 by the program. If KODE is negative, the repeated group is reflected in mirror image fashion about $z = 0$ and therefore occurs two times the absolute value of NRPEAT times in the output file.

A sample data set (called COIL.DAT in [WALSTROM.AXISYS]), to be renamed MAGDAT.DAT for execution of ARAGEN, is shown in Example 1. This data set is the basis for all of the following examples. This particular example contains two groups of coils. The first group of coils contains three solenoid elements that are to occur twice without reflection. The second group contains a single solenoid element that is to occur once without reflection, and once with reflection. Before reading in MAGDAT.DAT, the program will write on the screen, "type in 1 for BAXIAL, 2 for LFAXYL, 3 for EFFI, 4 for EIG". The user must then type in a 1 if an input file for BCOAX or BAXIAL is desired, a 2 for LFCOAX or LFAXYL, a 3 for EFFI, and a 4 for EIG, followed by a carriage return.

The final section of ARAGEN reads in the data file AUXFIL.DAT. AUXFIL.DAT contains data specific to the particular program for which ARAGEN is creating an input file. Each line of AUXFIL.DAT is read in according to the format I1,20A4. The first number is an end code and is a zero except the last line, in which case it is a one.

BCOAX

The coaxial solenoid magnetic field programs BCOAX (VAX version) and BAXIAL (Cray version) calculate the radial and axial magnetic field components, magnetic flux, jBr stresses inside windings, and also follow flux lines, for arbitrary collections of coaxial solenoid elements. The program can calculate magnetic fields anywhere, inside or outside the windings. At present, only the Cray version, BAXIAL, has graphics output for flux line plots, using DISSPLA. When compiling BAXIAL, the DISSPLA library must be invoked. A sample version of AUXFIL.DAT, named BCOAX.DAT, is contained in the [WALSTROM.AXISYS] directory (see Example 2).

When intended for BCOAX input, the first line of AUXFIL.DAT contains the end code 0, and then the two nonnegative integers NG and NDOG. NG specifies the order of Gaussian integration for points away from the windings and NDOG the increment in Gaussian order for points inside or near the windings. The sum of NG and NDOG must be less than or equal to 16; NG should be 4 or greater. For greatest accuracy, NG = 16 and NDOG = 0.

The remaining lines specify either arrays of points at which the field is to be calculated, or flux lines, and, for the Cray version, flux line plots. The first point in the line is the end code (0 if more lines follow, 1 if it is the last line in AUXFIL.DAT). For field point arrays, after one end code, the variables are, in order, ZFO, DZF, RHO, DRH, NSTP, and KEND. The variable ZFO is the starting Z coordinate, DZF the increment in Z, RHO the starting radial coordinate, DRH the increment in r, and NSTP the number of points. Field data will be printed out for NSTP equally spaced points along a line with a slope given by the Z and r increments.

If flux lines are to be specified, the data line has the same format, but NSTP is negative. In this case, the starting coordinates for the field line are ZFO and RHO, and the arc length increment is given by DZF. For flux lines, DRH should be set equal to 0.0, as in the example. If no graphics output is desired, the array data lines and/or flux line data lines are followed by a line containing the word "NOPLOT". If a plot is desired the line contains the word "PLOT", followed by a line with values for ZMIN, ZMAX, RMIN, RMAX, and STEP. These real variables specify the plot boundary and spacing of tic marks on the axes.

In BCOAX, the axial symmetry of the problem is exploited in calculating flux lines. The axial symmetry implies that a unique flux function, representing the flux through a coaxial disk with axial coordinate Z and radius r, can be defined for every Z and nonnegative r. Constant flux surfaces are surfaces of revolution of flux lines. This means that flux lines need not be determined by integration of the differential equations $dx/B_x = dy/B_y = dz/B_z$, as in the general 3-D problem, but by the condition ϕ = const. This means that flux lines can be followed in the axisymmetric case with no cumulative integration errors, and with coarse arc length increments. The equation $\phi(z,r) = \phi(z_0,r_0)$ is solved by Newton's method, using the equation

$$\frac{d\phi}{dy} = 2\pi\rho|\vec{B}|$$

where y is the distance in the direction locally perpendicular to the field line, and r the radial coordinate. The resultant algorithm is very fast compared to the integration scheme in EFFI, especially if only coarse spacing is needed.

After ARAGEN is run and the output file from ARAGEN, ARRAY.DAT, has been created, ARRAY.DAT must be renamed BAXIN.DAT for the VAX version of BCOAX, and BAXIN for input to the Cray version. A sample version of BAXIN is given in Example 3.

A sample output from BAXIAL, BAXOUT, is given in Example 6. The first set of 21 output data lines in the example, after END INPUT DATA, is a field scan at constant radius $\rho = 0.2$. As can be seen, in addition to axial and radial components of $\vec{B}$ in tesla, the modulus of $\vec{B}$, the two derivatives $dB_z/d\rho$ and dB_r/dz, the jBr stress (zero in this scan because all of the points lie outside the windings) and the flux function in webers are given. The flux function, as mentioned previously, is the flux through a disk at axial coordinate z with radius r.

The second two blocks of output lines in the example represent flux lines, and it should be noted that the flux function is constant, as it should be, along the line. The quantities Zav, rhoav, are the average z and r values between two successive points along the line (they are set equal to zero for the first point). The adiabaticity parameter is the quantity $\Delta|\vec{B}|/\Delta S/B^2$, calculated for two successive points along the line, and is used to determine when charged particles are tied to field lines.

BCOAX is based on the subroutine BFIELD, which calculates the magnetic field from a thick rectangular solenoid of rectangular cross-section and constant current density by radial Gaussian integration of analytic expressions containing elliptic integrals of the first, second, and third kind.[1] BFIELD, in turn, uses the subroutine ELLIPT, which calculates the elliptic integrals, and a BLOCK DATA subroutine, which contains the Gaussian coefficients up to order 16. Fig. 2 is a flux line plot produced by BAXIAL using the sample data BCOAX.DAT.

LFCOAX

The programs LFCOAX (VAX version) and LFAXYL (Cray version) calculate inductances and forces between coaxial solenoid elements using the methods of Ref. 1. The force calculation gives the total resultant axial force on a solenoid element due to other specified coils. These forces are the resultants of axial volume forces. The radial volume forces, of course, cancel when summed due to axial symmetry.

For the inductance calculation, the grouping defined by MAGDAT.DAT is used. The entire inductance matrix for all solenoid elements is first calculated and printed out, and then inductances between groups as defined by MAGDAT.DAT coding are calculated by summation. For large arrays of coils, the higher speed of the Crays is preferable, and the Cray version LFAXYL should be used.

For force calculations, coils are specified according to their coil indices, independently of group affiliation. The coil index is given by the

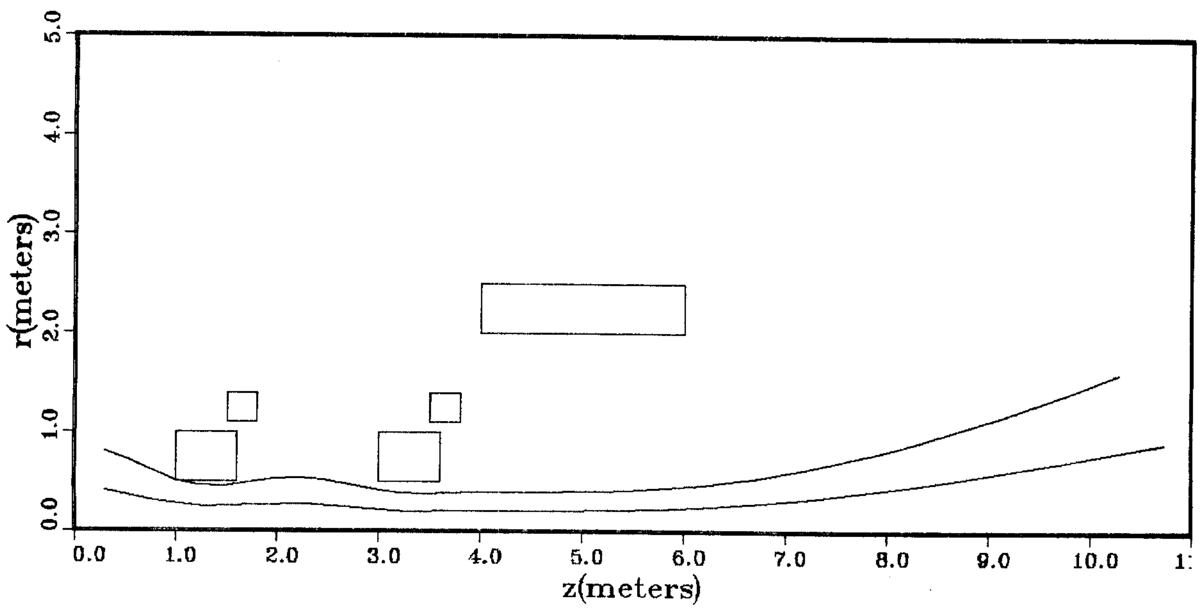

Figure 2. BAXIAL graphics output.

order in which the individual coil elements occur in ARRAY.DAT, to be renamed LFIN.DAT for VAX execution, and LFIN for Cray execution (see Example 5).

The AUXFIL.DAT input file for ARAGEN needed to prepare the input file for LFCOAX (or LFAXYL) is as follows: The first line contains the end code 0 and NG, the Gaussian order. NG must be less than or equal to 16. The second line contains the end code followed by a code number that is equal to 1 if inductance calculations only are wanted, equal to 2 for both inductance and force calculations, and equal to 3 for force calculation only. The end code of this line is 1 if no force calculations are wanted since there are no more data lines in the file. If force calculations are desired, there are additional lines with coding to specify the grouping of coils for the force calculations. These need not coincide with the grouping for inductance calculations. This coding is as follows: each line contains the end code for ARAGEN, followed by a pair of coil indices. The first number is the lower coil index of a set of successive coils, the second the upper index of the set. The last set of successive coils in the first group for the first force calculation is signified by a negative second index. (This seemingly complicated scheme was adopted to allow arbitrary groups of coils to be formed for force calculations.) The second group of coils for the first force calculation is similarly specified. As many pairs of groups as desired, each pair for another force calculation, follow. The last coil pair of the second group of the last force calculation has an end code of 1, and both indices are negative.

A sample data file of AUXFIL.DAT (stored as LFCOAX.DAT in [WALSTROM. AXISYS]), for preparing input to LFCOAX, is given in Example 4. It should be noted that the force coding could have been shortened by combining the fifth and sixth lines into an equivalent line with the integers 0 2 -5, since the two lines contained successive coil indices.

A sample output of ARAGEN for the above sample files is given in Example 6. The resultant output from LFAXYL is given in Example 7. The output is fairly self-explanatory. The indices above the numbers in the printouts of the self and mutual inductances are the coil indices given in the coil winding data above. The inductances between groups of coils similarly refer to the group indices in the coil winding data. The indices in the force printout refer, as in the input file coding, to coil indices, not group indices (i.e., these are different coil groupings from those of the inductance calculations).

EFFI AND EIG

The Livermore program EFFI for nonaxisymmetric systems (axisymmetric systems are a special case) is described in Ref. 2. The AUXFIL.DAT file is the same for EFFI and for EIG, the input generating program for EFFI.

When executed for preparation of EFFI input, ARAGEN first produces coil data according to EFFI input format, followed by a $ terminator. AUXFIL.DAT, which contains all of the remaining EFFI input data (flux line, contour, force, etc. specification) is then written out, minus the end code at the beginning of each line.

AUXFIL.DAT, when intended for EFFI input, consists of lines beginning with the end code (0 in the first column except for the last line, which has a 1 in the first column). The remainder of the lines is as required by Ref. 2. An example of AUXFIL.DAT for EFFI input is given in Example 8. The resultant

ARAGEN output is given in Example 9. Finally, the flux line drawn in the example is shown in Fig. 3.

ACKNOWLEDGEMENT

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REFERENCES

1. M.W. Garrett, "Calculation of Fields, Forces, and Mutual Inductances of Current Systems by Elliptic Integrals," J. Appl. Phys., vol. 34, no. 9, pp. 2567-2573, Sept. 1963.
2. S.J. Sackett, "User's Manual for EFFI - A Code for Calculating the Electromagnetic Field, Force, and Inductance in Coil Systems of Arbitrary Geometry", Lawrence Livermore National Laboratory, UCID-17621 REV. 1 (1981).

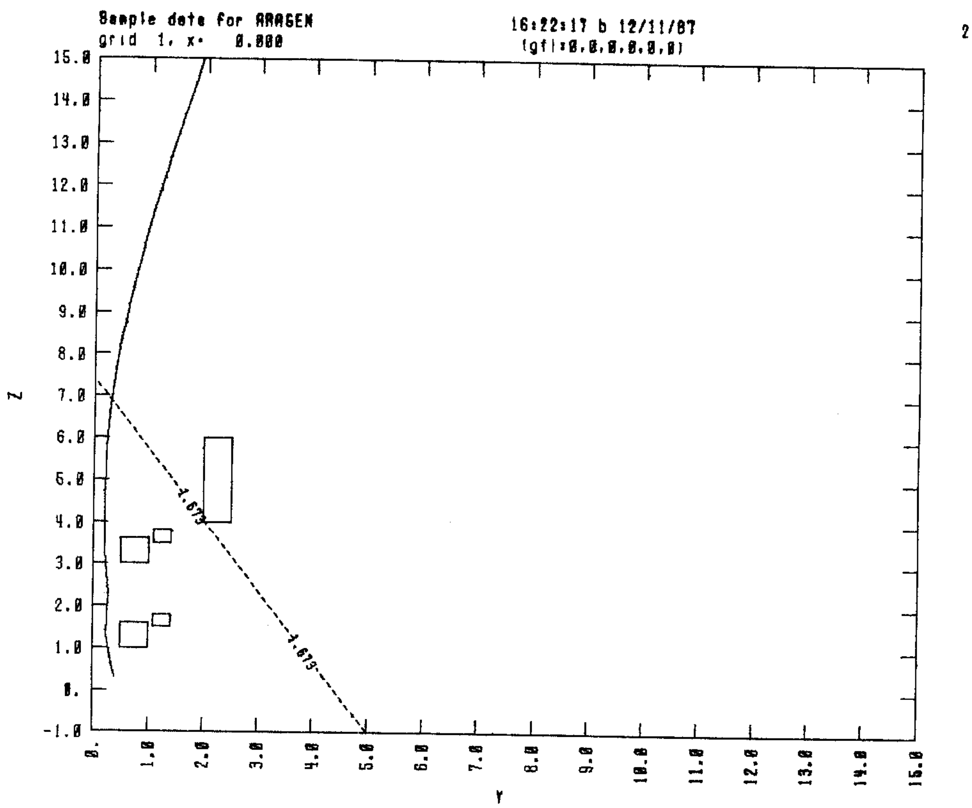

Figure 3. EFFI graphics output.

```
Sample data for ARAGEN
0
0.5 1.0 0. 0.6 3.e7 400.
0.7 1.3 -0.8 -0.3 3.e7 50.
1.1 1.4 0.5 0.8 3.5e7 40.
1
1. 2. 2
0
2. 2.5 -1. 1. 6.e7 500.
-2
5. 0  1
```

Example 1. COIL.DAT

```
0 8 6
0 0.2 0.5 0.2 0.0 21 0
0 0.3 0.25  0.8 0. -41 0
0 0.3 0.5 0.4 0. -21 1
0plot
1 0. 11. 0. 5. 1.
```

Example 2. BCOAX.DAT

```
Sample data for ARAGEN
 2.00000E+00  2.50000E+00 -6.00000E+00 -4.00000E+00  6.00000E+07  5.00000E+02  1
 5.00000E-01  1.00000E+00  1.00000E+00  1.60000E+00  3.00000E+07  4.00000E+02  0
 1.10000E+00  1.40000E+00  1.50000E+00  1.80000E+00  3.50000E+07  4.00000E+01  1
 5.00000E-01  1.00000E+00  3.00000E+00  3.60000E+00  3.00000E+07  4.00000E+02  0
 1.10000E+00  1.40000E+00  3.50000E+00  3.80000E+00  3.50000E+07  4.00000E+01  1
 2.00000E+00  2.50000E+00  4.00000E+00  6.00000E+00  6.00000E+07  5.00000E+02  2
 8 6
 0.2 0.5 0.2 0.0 21 0
 0.3 0.25  0.8 0. -41 0
 0.3 0.5 0.4 0. -21 1
plot
 0. 11. 0. 5. 1.
```

Example 3. BAXIN.DAT

```
0 8
0 2
0 1 -1
0 2 -3
0 2 3
0 4 -5
1 -6 -6
```

Example 4. LFCOAX.DAT

```
Sample data for ARAGEN
 2.00000E+00  2.50000E+00 -6.00000E+00 -4.00000E+00  6.00000E+07  5.00000E+02  1
 5.00000E-01  1.00000E+00  1.00000E+00  1.60000E+00  3.00000E+07  4.00000E+02  0
 1.10000E+00  1.40000E+00  1.50000E+00  1.80000E+00  3.50000E+07  4.00000E+01  1
 5.00000E-01  1.00000E+00  3.00000E+00  3.60000E+00  3.00000E+07  4.00000E+02  0
 1.10000E+00  1.40000E+00  3.50000E+00  3.80000E+00  3.50000E+07  4.00000E+01  1
 2.00000E+00  2.50000E+00  4.00000E+00  6.00000E+00  6.00000E+07  5.00000E+02  2
 8
 2
 1 -1
 2 -3
 2 3
 4 -5
 -6 -6
```

Example 5. LFIN.DAT

Example 6. BAXOUT.DAT

Sample data for ARAGEN

INPUT COIL DATA

A1	A2	ZL	ZR	CD	nt
2.00000e+00	2.50000e+00	-6.00000e+00	-4.00000e+00	6.00000e+07	5.00000e+02
5.00000e-01	1.00000e+00	1.00000e+00	1.60000e+00	3.00000e+07	4.00000e+02
1.10000e+00	1.40000e+00	1.50000e+00	1.80000e+00	3.50000e+07	4.00000e+01
5.00000e-01	1.00000e+00	3.00000e+00	3.60000e+00	3.00000e+07	4.00000e+02
1.10000e+00	1.40000e+00	3.50000e+00	3.80000e+00	3.50000e+07	4.00000e+01
2.00000e+00	2.50000e+00	4.00000e+00	6.00000e+00	6.00000e+07	5.00000e+02

GAUSSIAN ORDER= 8 INCREMENT= 6

STARTING VALUES AND INCREMENTS FOR FIELD POINTS

ZF0= 2.0000e-01 DZF= 5.0000e-01
RH0= 2.0000e-01 DR= 0. NUMBER OF FIELD POINTS= 21

ZF0= 3.0000e-01 DZF= 2.5000e-01
RH0= 8.0000e-01 DR= 0. NUMBER OF FIELD POINTS= -41

ZF0= 3.0000e-01 DZF= 5.0000e-01
RH0= 4.0000e-01 DR= 0. NUMBER OF FIELD POINTS= -21

Data for plot: zmin= 0. zmax= 1.10000e+01 rmin= 0. rmax= 5.00000e+00 tic spacing= 1.00000e+00

******************END INPUT DATA*****************

Z	RHO	BZ	BRHO	MODB	DBZDRHO	DBRHODZ	SIGMA(PSI)	FLUX
2.00000e-01	2.00000e-01	4.38867e+00	-3.34315e-01	4.40139e+00	-7.11278e-01	-7.11278e-01	0.	5.55990e-01
7.00000e-01	2.00000e-01	7.24074e+00	-8.74301e-01	7.29333e+00	-1.29010e+00	-1.29010e+00	0.	9.17701e-01
1.20000e+00	2.00000e-01	1.21439e+01	-5.94462e-01	1.21584e+01	3.01378e+00	3.01378e+00	0.	1.50763e+00
1.70000e+00	2.00000e-01	1.13793e+01	5.56676e-01	1.13929e+01	-6.88264e-02	-6.88264e-02	0.	1.43005e+00
2.20000e+00	2.00000e-01	9.82355e+00	-7.40390e-02	9.82383e+00	-1.62360e+00	-1.62360e+00	0.	1.24467e+00
2.70000e+00	2.00000e-01	1.23339e+01	-9.51658e-01	1.23706e+01	-1.75671e+00	-1.75671e+00	0.	1.56067e+00
3.20000e+00	2.00000e-01	1.80831e+01	-8.21039e-01	1.81017e+01	2.88427e+00	2.88427e+00	0.	2.25479e+00
3.70000e+00	2.00000e-01	1.84668e+01	3.71968e-01	1.84706e+01	2.68966e-01	2.68966e-01	0.	2.31856e+00
4.20000e+00	2.00000e-01	1.71609e+01	9.40315e-02	1.71612e+01	-4.77339e-01	-4.77339e-01	0.	2.15949e+00
4.70000e+00	2.00000e-01	1.69871e+01	4.83762e-02	1.69872e+01	2.23461e-01	2.23461e-01	0.	2.13328e+00
5.20000e+00	2.00000e-01	1.63321e+01	2.38408e-01	1.63339e+01	4.65062e-01	4.65062e-01	0.	2.04945e+00
5.70000e+00	2.00000e-01	1.45714e+01	4.53802e-01	1.45785e+01	3.50428e-01	3.50428e-01	0.	1.82890e+00
6.20000e+00	2.00000e-01	1.19620e+01	5.60460e-01	1.19751e+01	6.79879e-02	6.79879e-02	0.	1.50276e+00
6.70000e+00	2.00000e-01	9.17199e+00	5.32055e-01	9.18740e+00	-1.58237e-01	-1.58237e-01	0.	1.15357e+00
7.20000e+00	2.00000e-01	6.75183e+00	4.28320e-01	6.76541e+00	-2.33495e-01	-2.33495e-01	0.	8.49923e-01
7.70000e+00	2.00000e-01	4.89982e+00	3.14980e-01	4.90993e+00	-2.10251e-01	-2.10251e-01	0.	6.17050e-01
8.20000e+00	2.00000e-01	3.56936e+00	2.22611e-01	3.57630e+00	-1.58290e-01	-1.58290e-01	0.	4.49534e-01

8.70000e+00	2.00000e-01	2.63559e+00	1.55814e-01	2.64020e+00	-1.10767e-01	-1.10767e-01	0.	3.31895e-01
9.20000e+00	2.00000e-01	1.98079e+00	1.09743e-01	1.98382e+00	-7.55872e-02	-7.55872e-02	0.	2.49388e-01
9.70000e+00	2.00000e-01	1.51671e+00	7.83742e-02	1.51873e+00	-5.14797e-02	-5.14797e-02	0.	1.90919e-01
1.02000e+01	2.00000e-01	1.18260e+00	5.69307e-02	1.18397e+00	-3.53870e-02	-3.53870e-02	0.	1.48832e-01

z	rho	Bz	Brho	modB	zav	rhoav	adiab. param.	flux
Flux Line								
3.00000e-01	8.00000e-01	3.64518e+00	-1.16969e+00	3.82825e+00	0.	0.	0.	8.45413e+00
5.33922e-01	7.13848e-01	4.48692e+00	-1.85915e+00	4.85684e+00	4.16961e-01	7.56924e-01	0.	8.45413e+00
7.61802e-01	6.11716e-01	6.23539e+00	-2.93226e+00	6.89045e+00	6.47862e-01	6.62782e-01	0.	8.45413e+00
9.89403e-01	5.08814e-01	1.03796e+01	-4.15967e+00	1.11821e+01	8.75602e-01	5.60265e-01	0.	8.45413e+00
1.22529e+00	4.57430e-01	1.38463e+01	-1.36586e+00	1.39135e+01	1.10735e+00	4.83122e-01	0.	8.45413e+00
1.47262e+00	4.54337e-01	1.39208e+01	1.01566e+00	1.39578e+01	1.34896e+00	4.55884e-01	0.	8.45413e+00
1.71864e+00	4.92167e-01	1.07139e+01	1.96276e+00	1.08922e+01	1.59563e+00	4.73252e-01	0.	8.45413e+00
1.96550e+00	5.26739e-01	9.11866e+00	8.06673e-01	9.15427e+00	1.84207e+00	5.09453e-01	0.	8.45413e+00
2.21412e+00	5.34394e-01	8.86090e+00	-2.38364e-01	8.86410e+00	2.08981e+00	5.30566e-01	0.	8.45413e+00
2.46223e+00	5.14368e-01	9.58541e+00	-1.25557e+00	9.66730e+00	2.33818e+00	5.24381e-01	0.	8.45413e+00
2.70812e+00	4.72367e-01	1.14723e+01	-2.33720e+00	1.17080e+01	2.58518e+00	4.93368e-01	0.	8.45413e+00
2.95259e+00	4.20022e-01	1.51797e+01	-3.11072e+00	1.54951e+01	2.83035e+00	4.46195e-01	0.	8.45413e+00
3.19867e+00	3.83099e-01	1.89343e+01	-1.73998e+00	1.90141e+01	3.07563e+00	4.01561e-01	0.	8.45414e+00
3.44759e+00	3.72593e-01	1.99500e+01	7.31175e-02	1.99501e+01	3.32313e+00	3.77846e-01	0.	8.45413e+00
3.69718e+00	3.81570e-01	1.84704e+01	9.64605e-01	1.84956e+01	3.57239e+00	3.77081e-01	0.	8.45413e+00
3.94692e+00	3.92140e-01	1.73246e+01	5.04299e-01	1.73319e+01	3.82205e+00	3.86855e-01	0.	8.45413e+00
4.19683e+00	3.96505e-01	1.70215e+01	1.37503e-01	1.70221e+01	4.07187e+00	3.94323e-01	0.	8.45413e+00
4.44683e+00	3.97336e-01	1.70332e+01	1.16427e-02	1.70332e+01	4.32183e+00	3.96921e-01	0.	8.45413e+00
4.69682e+00	3.97734e-01	1.70579e+01	6.72408e-02	1.70581e+01	4.57183e+00	3.97535e-01	0.	8.45413e+00
4.94681e+00	3.99887e-01	1.69106e+01	2.40121e-01	1.69123e+01	4.82182e+00	3.98810e-01	0.	8.45413e+00
5.19673e+00	4.05204e-01	1.64877e+01	4.77520e-01	1.64946e+01	5.07177e+00	4.02545e-01	0.	8.45413e+00
5.44652e+00	4.14617e-01	1.57514e+01	7.38078e-01	1.57687e+01	5.32163e+00	4.09911e-01	0.	8.45413e+00
5.69608e+00	4.28799e-01	1.47183e+01	9.88466e-01	1.47514e+01	5.57130e+00	4.21708e-01	0.	8.45413e+00
5.94528e+00	4.48265e-01	1.34475e+01	1.20151e+00	1.35011e+01	5.82068e+00	4.38532e-01	0.	8.45413e+00
6.19397e+00	4.73387e-01	1.20274e+01	1.35743e+00	1.21037e+01	6.06962e+00	4.60826e-01	0.	8.45413e+00
6.44199e+00	5.04368e-01	1.05566e+01	1.44658e+00	1.06553e+01	6.31798e+00	4.88878e-01	0.	8.45413e+00
6.68921e+00	5.41234e-01	9.12491e+00	1.47063e+00	9.24266e+00	6.56560e+00	5.22801e-01	0.	8.45413e+00
6.93550e+00	5.83839e-01	7.79888e+00	1.44024e+00	7.93075e+00	6.81235e+00	5.62536e-01	0.	8.45413e+00
7.18079e+00	6.31914e-01	6.61710e+00	1.37059e+00	6.75755e+00	7.05815e+00	6.07877e-01	0.	8.45413e+00
7.42503e+00	6.85114e-01	5.59335e+00	1.27698e+00	5.73727e+00	7.30291e+00	6.58514e-01	0.	8.45413e+00
7.66819e+00	7.43063e-01	4.72380e+00	1.17205e+00	4.86703e+00	7.54661e+00	7.14088e-01	0.	8.45413e+00
7.91027e+00	8.05387e-01	3.99458e+00	1.06490e+00	4.13408e+00	7.78923e+00	7.74225e-01	0.	8.45413e+00
8.15128e+00	8.71734e-01	3.38752e+00	9.61380e-01	3.52130e+00	8.03077e+00	8.38561e-01	0.	8.45413e+00
8.39124e+00	9.41785e-01	2.88386e+00	8.64775e-01	3.01073e+00	8.27126e+00	9.06759e-01	0.	8.45413e+00
8.63019e+00	1.01525e+00	2.46621e+00	7.76614e-01	2.58559e+00	8.51072e+00	9.78518e-01	0.	8.45413e+00
8.86814e+00	1.09188e+00	2.11935e+00	6.97309e-01	2.23111e+00	8.74916e+00	1.05356e+00	0.	8.45413e+00
9.10513e+00	1.17144e+00	1.83046e+00	6.26611e-01	1.93474e+00	8.98663e+00	1.13166e+00	0.	8.45413e+00
9.34118e+00	1.25375e+00	1.58895e+00	5.63928e-01	1.68605e+00	9.22315e+00	1.21259e+00	0.	8.45413e+00
9.57632e+00	1.33862e+00	1.38617e+00	5.08513e-01	1.47650e+00	9.45875e+00	1.29618e+00	0.	8.45414e+00
9.81058e+00	1.42589e+00	1.21512e+00	4.59581e-01	1.29912e+00	9.69345e+00	1.38225e+00	0.	8.45414e+00
1.00440e+01	1.51545e+00	1.07014e+00	4.16370e-01	1.14829e+00	9.92728e+00	1.47067e+00	0.	8.45414e+00
1.02765e+01	1.60715e+00	9.46669e-01	3.78177e-01	1.01941e+00	1.01603e+01	1.56130e+00	0.	8.45413e+00

z	rho	Bz	Brho	modB	zav	rhoav	adiab. param.	flux

Example 6. BAXOUT.DAT (contd.)

Flux Line

3.00000e-01	4.00000e-01	4.50117e+00	-7.77086e-01	4.56776e+00	0.	0.	0.	2.34692e+00
7.90535e-01	3.04149e-01	7.94249e+00	-1.53877e+00	8.09018e+00	5.45267e-01	3.52075e-01	0.	2.34692e+00
1.28239e+00	2.44841e-01	1.27091e+01	-4.10460e-01	1.27157e+01	1.03646e+00	2.74495e-01	0.	2.34692e+00
1.78032e+00	2.61599e-01	1.08466e+01	7.13642e-01	1.08700e+01	1.53136e+00	2.53220e-01	0.	2.34692e+00
2.27863e+00	2.74136e-01	9.78521e+00	-2.75086e-01	9.78908e+00	2.02948e+00	2.67868e-01	0.	2.34692e+00
2.77605e+00	2.38246e-01	1.30552e+01	-1.29510e+00	1.31193e+01	2.52734e+00	2.56191e-01	0.	2.34692e+00
3.27398e+00	2.01116e-01	1.86278e+01	-5.97261e-01	1.86374e+01	3.02501e+00	2.19681e-01	0.	2.34692e+00
3.77339e+00	2.02735e-01	1.81634e+01	3.75092e-01	1.81673e+01	3.52368e+00	2.01925e-01	0.	2.34692e+00
4.27330e+00	2.08856e-01	1.71067e+01	6.56796e-02	1.71068e+01	4.02335e+00	2.05796e-01	0.	2.34692e+00
4.77330e+00	2.10027e-01	1.69512e+01	7.00759e-02	1.69513e+01	4.52330e+00	2.09442e-01	0.	2.34692e+00
5.27324e+00	2.15237e-01	1.61525e+01	2.93369e-01	1.61552e+01	5.02327e+00	2.12632e-01	0.	2.34692e+00
5.77297e+00	2.29216e-01	1.42393e+01	5.48835e-01	1.42499e+01	5.52311e+00	2.22226e-01	0.	2.34692e+00
6.27225e+00	2.54288e-01	1.15553e+01	7.19106e-01	1.15776e+01	6.02261e+00	2.41752e-01	0.	2.34692e+00
6.77077e+00	2.91404e-01	8.77842e+00	7.59936e-01	8.81126e+00	6.52151e+00	2.72846e-01	0.	2.34692e+00
7.26830e+00	3.40215e-01	6.42004e+00	7.01384e-01	6.45824e+00	7.01953e+00	3.15810e-01	0.	2.34692e+00
7.76470e+00	3.99517e-01	4.63950e+00	5.99453e-01	4.67806e+00	7.51650e+00	3.69866e-01	0.	2.34692e+00
8.25996e+00	4.67873e-01	3.37117e+00	4.93577e-01	3.40711e+00	8.01233e+00	4.33695e-01	0.	2.34692e+00
8.75410e+00	5.43976e-01	2.48562e+00	4.00844e-01	2.51774e+00	8.50703e+00	5.05925e-01	0.	2.34692e+00
9.24717e+00	6.26756e-01	1.86655e+00	3.25213e-01	1.89466e+00	9.00063e+00	5.85366e-01	0.	2.34692e+00
9.73923e+00	7.15366e-01	1.42857e+00	2.65297e-01	1.45300e+00	9.49320e+00	6.71061e-01	0.	2.34692e+00
1.02303e+01	8.09139e-01	1.11355e+00	2.18255e-01	1.13474e+00	9.98479e+00	7.62252e-01	0.	2.34692e+00
1.07205e+01	9.07542e-01	8.82854e-01	1.81282e-01	9.01274e-01	1.04754e+01	8.58340e-01	0.	2.34692e+00

Plot requested—look for f* file

Example 6. BAXOUT.DAT (contd.)

```
Sample data for ARAGEN


                    COIL WINDING DATA

 INNER RADIUS OUTER RADIUS     ZL            ZR         CURR. DENS.  NO. OF TURNS.  GROUP INDEX   COIL INDEX
 2.00000e+00  2.50000e+00 -6.00000e+00 -4.00000e+00 6.00000e+07  5.00000e+02    1            1
 5.00000e-01  1.00000e+00  1.00000e+00  1.60000e+00 3.00000e+07  4.00000e+02    2            2
 1.10000e+00  1.40000e+00  1.50000e+00  1.80000e+00 3.50000e+07  4.00000e+01    2            3
 5.00000e-01  1.00000e+00  3.00000e+00  3.60000e+00 3.00000e+07  4.00000e+02    3            4
 1.10000e+00  1.40000e+00  3.50000e+00  3.80000e+00 3.50000e+07  4.00000e+01    3            5
 2.00000e+00  2.50000e+00  4.00000e+00  6.00000e+00 6.00000e+07  5.00000e+02    4            6
 GAUSSIAN ORDER =  8


              SELF-INDUCTANCES

     1           2           3           4           5           6
1.08336e+00 1.90808e-01 5.82470e-03 1.90808e-01 5.82470e-03 1.08336e+00

              MUTUAL INDUCTANCES

    2   1
3.98554e-03
    3   1       3   2
9.01350e-04 1.41789e-02
    4   1       4   2       4   3
1.86380e-03 9.53747e-03 2.92376e-03
    5   1       5   2       5   3       5   4
4.38452e-04 1.40904e-03 4.50524e-04 1.41789e-02
    6   1       6   2       6   3       6   4       6   5
1.14200e-02 1.49194e-02 4.68629e-03 5.35287e-02 1.75245e-02

         TOTAL INDUCTANCE IS 2.86388e+00 HENRIES
```

Example 7. LFOUT

```
INDUCTANCES BETWEEN GROUPS OF COILS

     1    1   1.0833596d+00
     1    2   4.8868943d-03
     1    3   2.3022509d-03
     1    4   1.1420021d-02
     2    1   4.8868943d-03
     2    2   2.2499009d-01
     2    3   1.4320797d-02
     2    4   1.9605719d-02
     3    1   2.3022509d-03
     3    2   1.4320797d-02
     3    3   2.2499009d-01
     3    4   7.1053144d-02
     4    1   1.1420021d-02
     4    2   1.9605719d-02
     4    3   7.1053144d-02
     4    4   1.0833596d+00


******************************
force run no. 1

group 1
  1-  1

group 2
  2-  3

force= 8.01724e+06newtons
******************************


******************************
force run no. 2

group 1
  2-  3
  4-  5

group 2
  6-  6

force= 2.41248e+08newtons
******************************
```

Example 7. LFOUT (contd.)

```
0 B-line 0. 0.4 0.3 0.5 15. $
0 zyx -1. 16. 15. 0. 10. 15. 1 1 2 $
1 $
```

Example 8. EFFI.DAT

```
Sample data for ARAGEN
 $
coil=solenoid $
loop .0 .0 -5.0000E+00  2.2500E+00 .0 .0  2.0000E+00  5.0000E-01  6.0000E+07 $
coil=solenoid $
loop .0 .0  1.3000E+00  7.5000E-01 .0 .0  6.0000E-01  5.0000E-01  3.0000E+07 $
coil=solenoid $
loop .0 .0  1.6500E+00  1.2500E+00 .0 .0  3.0000E-01  3.0000E-01  3.5000E+07 $
coil=solenoid $
loop .0 .0  3.3000E+00  7.5000E-01 .0 .0  6.0000E-01  5.0000E-01  3.0000E+07 $
coil=solenoid $
loop .0 .0  3.6500E+00  1.2500E+00 .0 .0  3.0000E-01  3.0000E-01  3.5000E+07 $
coil=solenoid $
loop .0 .0  5.0000E+00  2.2500E+00 .0 .0  2.0000E+00  5.0000E-01  6.0000E+07 $
$
 B-line 0. 0.4 0.3 0.5 15. $
 zyx -1. 16. 15. 0. 10. 15. 1 1 2 $
 $
```

Example 9. EFIN