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# MIG: MCNP INPUT GENERATOR FOR EFFI MAGNET GEOMETRIES

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## ABSTRACT

A computer code, MIG, has been developed to interface the magnet design and the three dimensional Monte Carlo code MCNP to perform neutronics design analyses. MIG prepares all the required MCNP cells and surfaces to simulate the magnets described in EFFI input. Extra zones with different materials could be added to envelop or divide the winding packs of the magnets. Examples of the input and output of MIG used by MCNP are given to illustrate the different capabilities of MIG.

## INTRODUCTION

In all of the magnetic fusion reactor designs, data transfer is required between different subsystem design codes. This process requires a great deal of effort and errors could occur in transferring data from one or more codes to another. To avoid these difficulties and to make the design process consistent and accurate, an interface computer code(s) should control these processes. The main functions of the interface(s) are to prepare input, interpret output, and make output available as input for other code(s) which needs the data. Thus, it appears that the initial step in developing this capability is to interface input/output of the different codes involved in the design process. Once these interfaces are established, the construction of one design code to control the reactor design process and drive the subsystem design codes would be possible.

This design code can be used in an iterative scheme to perform a parametric survey or design study but it would be too expensive and impractical. Thus, the existence of such a code would not eliminate the need for systems codes such as the Tokamak Systems Code or the Tandem Mirror Reactor System Code developed at the national laboratories. Usually these systems codes contain simplified models for plasma physics, magnets, etc. which allow an inexpensive parametric survey to choose initial design parameters. The design point resulting from the system code should then be examined and verified by the design code.

As a first step, two computer codes were developed which provide interfaces between magnet, neutronics, and stress analysis codes. The first one is NIG[1] (Nastran Input Generator), which establishes the interface between the magnet design code EFFI[2] and the stress analysis code NASTRAN.[3] The second code, the subject of this paper, is MIG (MCNP Input Generator). MIG provides the interface between the conductor geometries used by the EFFI code, the structure requirements as defined by the NASTRAN analyses, and the magnet geometrical models used by MCNP.[4]

Figure 1 shows the data transfer process between magnetics structure analyses and neutronics established by NIG and MIG. The EFFI input describes the conductor specifications for the magnets which are used by MIG to generate the MCNP input modeling the magnets. Other components of the magnets (case, insulator zone, dewar, etc.) calculated or specified as input data are modeled explicitly by MIG for MCNP calculations.

A magnet is defined in EFFI to be a group of conductor elements. These elements could be circular arcs and/or straight segments with rectangular cross sections. MIG uses all pertinent element quantities as defined for EFFI to generate the surface equations of each elements. Then, MIG sorts these surfaces, forms one cell for each conductor element according to the MCNP rules, and combines the different cells of each coil in one cell describing the winding pack. Also, MIG can add envelopes or divide the winding pack for each coil to simulate the coil case, thermal insulator gap, and coil dewar if desired. Material number and density can be assigned for each envelope as well as for the winding material. This procedure produces a complete geometrical model for MCNP to use. Details of this procedure are given below, followed by a few examples for illustration purposes.

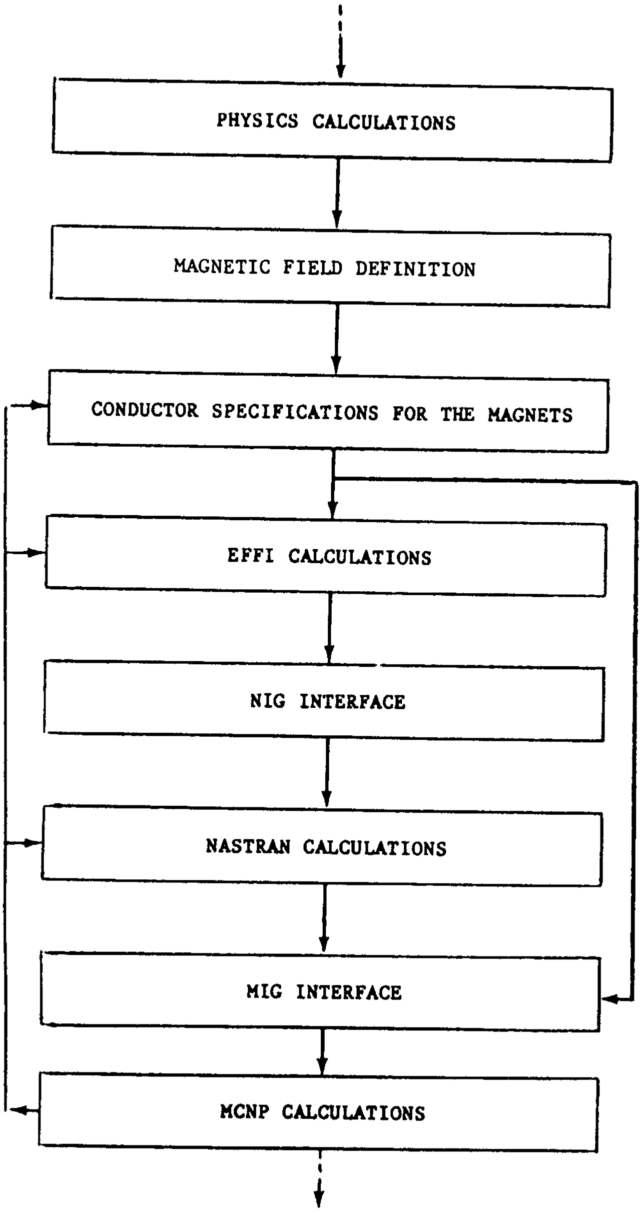

Fig. 1. Data transfer flow chart between magnetics, structure analyses, and neutronics established by NIG and MIG.

## GEOMETRY IN EFFI AND MCNP

To describe how MIG works, it is constructive to show how a coil could be presented in EFFI, and how geometries are described in MCNP. The readers should refer to references 2 and 4 for more details about EFFI and MCNP.

As mentioned before, a coil in EFFI consists of one or more elements. The different types of elements are loop, arc, and general current element (GCE). The loop is specified by its center $(x,y,z)$, the radius $(a)$, the Euler orientation angle $(\alpha,\beta)$, the axial, and the radial dimensions of the conductor cross section $(s1,s2)$.

The arc is described in the same way with the addition of the starting and the ending angles of the arc $(\phi_1,\phi_2)$. Figure 2 shows all the above variables necessary to describe a loop or arc element.

Figure 3 shows the variables used to describe a GCE. These are the centroid coordinates $(x,y,z)$, the Euler angle $(\alpha,\beta,\gamma)$, the width, the thickness, and the length of the element $(s1,s2,s3)$. There is another type of GCE in EFFI which is not considered in the present version of MIG, since most of the fusion magnets can be constructed by using the above elements. However, the inclusion of this GCE in MIG is simple.

Similar to EFFI elements, "cells" are used by MCNP to define any geometrical object. A cell is bounded by first- or second-degree surfaces and is defined by the intersections, the unions, and the complements of the regions bounded by these surfaces. Thus, the basic entities used in MCNP to describe an object are the surfaces bounding this object. In addition, the regions outside the objects or the regions between different objects should be defined in the same way. A complicated body can be defined by unions, intersections, and complements of cells within the body instead of defining the whole body as one complicated cell.

To model a coil given in EFFI input to MCNP, MIG generates all the surfaces bounding each EFFI element; each surface has an identification number. Next, MIG sorts these surfaces and checks if any of these surfaces had already been generated. In such a case, MIG disregards that surface(s) and uses the old one(s).

This step insures that no redundancy in surfaces could occur and the minimum number of surfaces is used to model the elements. A cell is formed for each element and the union of all cells is made to generate the coil.

## EXAMPLE OF ARC TRANSFORMATION

The arc shown in Fig. 2 is considered to describe the sequence of the process described above. There are two cylinders, and four planes bounding this arc. The first step is to set up the coordinate transformation matrix from the local arc coordinate system to the global one. Given the Euler angles $\alpha$, $\beta$, and $\gamma$, $(\gamma=0$ for arcs), the elements of this matrix are:

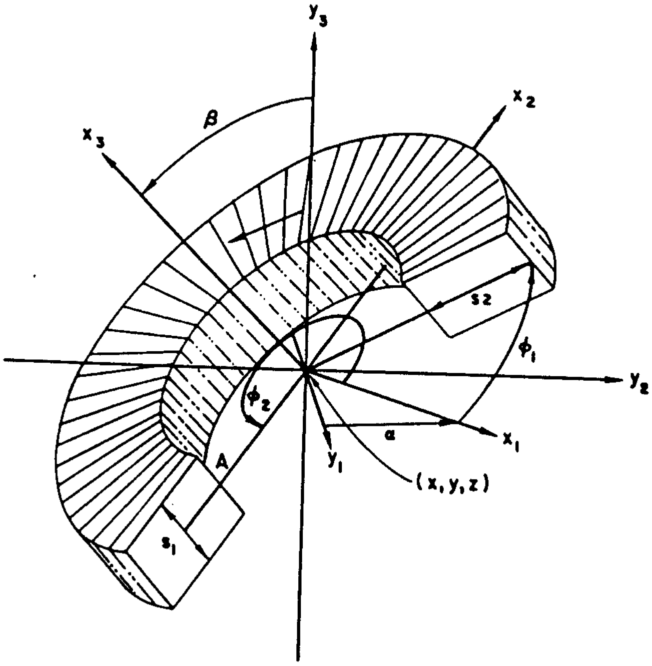

Fig. 2. Loop or arc variables from Ref. 2.

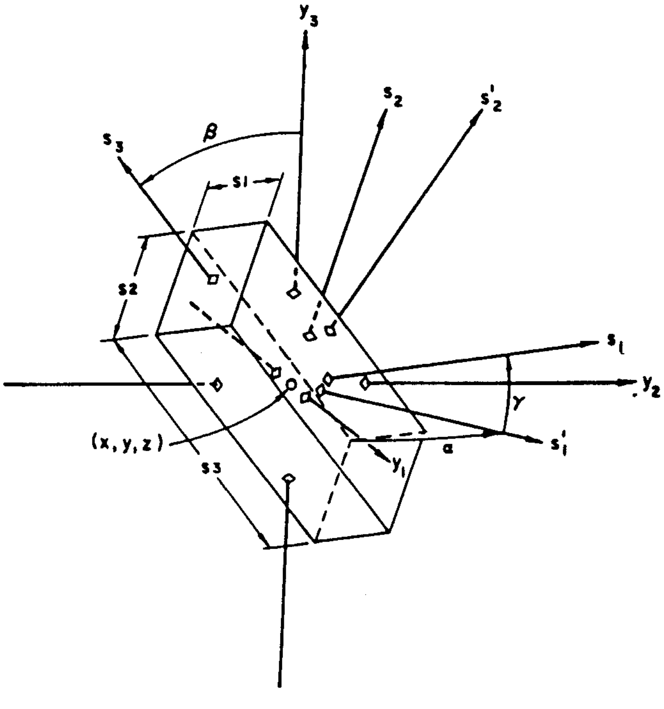

Fig. 3. GCE variables from Ref. 2.

$T(1,1)=\cos\gamma x\cos\alpha-\cos\beta x\sin\alpha x\sin\gamma$

$T(1,2)=-\sin\gamma x\cos\alpha-\cos\beta x\sin\alpha x\cos\gamma$

$T(1,3)=\sin\beta x\sin\alpha$

$T(2,1)=\cos\gamma x\sin\alpha+\cos\beta x\cos\alpha x\sin\gamma$

$T(2,2)=-\sin\gamma x\sin\alpha+\cos\beta x\cos\alpha x\cos\gamma$

$T(2,3)=-\sin\beta x\cos\alpha$

$T(3,1)=\sin\gamma x\sin\beta$

$T(3,2)=\cos\gamma x\sin\beta$

$T(3,3)=\cos\beta$

The direction cosines of the arc axis l,m,n (0,0,1 in the local coordinates) can be evaluated using the matrix T. The general equation of a cylindrical surface can be written as follows:

$$AX^2+BY^2+CZ^2+DXY+EYZ+FZX+GX+HY+KZ+L=0.$$

Given the direction cosines of the cylinder axis l,m,n and the coordinates x,y,z of a point on its axis, the coefficients of this equation can be evaluated as follows:

$A = n^2 + m^2$

$B = n^2 + l^2$

$C = m^2 + l^2$

$D = -2lm$

$E = -2nm$

$F = -2ln$

$G = -2(n^2+m^2)x + 2nlz + 2lmy$

$H = -2(n^2+l^2)y + 2mnz + 2lmx$

$K = -2(m^2+l^2)z + 2mny + 2nlx$

$L = x^2(m^2+n^2)+y^2(l^2+n^2)+z^2(l^2+m^2)-$
$-2mnyz-2nlzx-2lmxy-r^2$

where r is the radius of the cylinder. Only the last coefficient differs for cylinders of common axis. Thus, it is straightforward to evaluate the coefficients of the two cylindrical surfaces bounding the arc. If the cylinder axis is parallel to one of the principal axes, simpler forms recognized by MCNP are used.

The coefficients of the upper and the lower planes bounding the arc at a right angle with its axis can be evaluated by using the direction cosines (l,m,n) and the coordinates of a point on each. Similarly, the coefficients of the remaining bounding planes could be computed using the normals and the coordinates of a point on each plane.

The components of the normals to these planes in the local arc coordinate system are $\cos(\phi_1$ or $\phi_2)$, $\sin(\phi_1$ or $\phi_2)$, and 0. Using the transformation matrix T, the corresponding values of these components in the global coordinate system could be obtained. Similar steps could be done for the GCE with all the bounding surfaces being planes.

## ADDING LAYERS

The dimensions given in the EFFI input are the winding pack dimensions, i.e. the current carrying part. To include all the layers that could possibly envelop the winding pack in a real magnet, e.g. case, insulator, dewar, etc., a simple instruction could be added in front of the coil data in the EFFI input. These instructions control the number of layers to be added, the thickness, and the material of each.

Additional surfaces and cells are then generated by MIG to model these layers. The winding pack itself could be divided into more than one zone using the same procedure. This could be beneficial in determining a certain nuclear response (e.g. nuclear heating) in different parts of the winding pack.

## ILLUSTRATIVE EXAMPLES

Two examples are discussed to illustrate the use and the main features of the MIG interface. The first example has a simple solenoid with the following dimensions: a 150 cm inner radius, a 450 cm outer radius, and a 200 cm winding pack length. In this example, the solenoid axis is the z axis which simplifies the surface equations for MCNP. Table 1 gives the input and the output of the MIG interface for this solenoid. The MIG input consists of an EFFI input with a small addition to illustrate the material assignments and the layer option. Records 4 and 5 in the MIG input of Table 1 define the densities for the two materials used in this example. Material 1 is assigned to the winding pack by Record 6. The winding pack is assigned a zero zone number where positive and negative numbers are given to the zone outside and inside the winding pack, respectively. Record 7 defines a layer of 10 cm thickness of material 1 measured from the surface of the winding pack. The minus sign in front of the zone number indicates that this zone is contained inside the winding pack boundaries. Record 8 defines a vacuum gap (material 0) of 10 cm thickness measured from the surface of the winding pack. This gap is located outside the winding pack as indicated by the positive sign of the zone number. Record 9 defines a case for the winding of 10 cm thickness of material 2. The output from MIG is also shown in Table 1. Cells 1 and 2 are the winding pack dividing to two sections as defined in the MIG input. Cell 3 is the vacuum gap and Cell 4 is the case. Cells 5 and 6 are the inner and the outer space surrounding the solenoid. Figure 4 shows two cross sections in the coils as plotted by MCNP.

TABLE 1. MIG EXAMPLE FOR THE SOLENOID

```
 1                                       SAMPLE CASE
 2    P1=0 P2=1.0E-10
 3    $
 4    MATE 1 1.0
 5    MATE 2 1.0
 6    ZONE  0 1
 7    ZONE -1 1 10.0
 8    ZONE  1 0 10.0
 9    ZONE  2 2 10.0
10    (START OF SOL)
11    LOOP
12     0.0 0.0 0.0 3.0 0.0 0.0 2.0 3.0 1.0E+06 $
13    (END OF SOL)
14    $
15    B-LINE .001 .001 0. .05 58. $
16    $
```

MIG INPUT

```
 1   MESSAGE:    IP
 2
 3                                      SAMPLE CASE
 4   C        COIL=                  NO=   1   .NO   1   IN REG    1
 5          1   1      1.000    (       9      -10       -7        8)
 6          2   1      1.000   ((      13      -14      -11       12)
 7                              (      -9:      10:       7:      -8))
 8          3   0                  ((  17      -18      -15       16)
 9                              (     -13:      14:      11:     -12))
10          4   2      1.000   ((      19      -20       -5        6)
11                              (     -17:      18:      15:     -16))
12          5   0              ((     -19:      20:       5:      -6))
13                                  -1       6    -5
14          6   0                        1:      5:   -6
15
16          1  CZ      670
17          5  PZ                  120.0000
18          6  P.Z                -120.0000
19   C         COIL=                  NO=   1   .NO   1   IN REG    1
20          7  PZ                    90.0000
21          8  PZ                   -90.0000
22          9  CZ        160.0000
23         10  CZ        440.0000
24         11  PZ                   100.0000
25         12  PZ                  -100.0000
26         13  CZ        150.0000
27         14  CZ        450.0000
28         15  PZ                   110.0000
29         16  PZ                  -110.0000
30         17  CZ        140.0000
31         18  CZ        460.0000
32         19  CZ        130.0000
33         20  CZ        470.0000
34
35   MODE     0
36      IN    1      4R    0
37
```

MIG OUTPUT

The second example is the geometrical model of the end cell of the FPD-I (the Fusion Power Demonstration, the mirror ETR) developed for the neutronics analyses[5]. Figure 5 shows the six Cee coils of the end cell as defined in the EFFI input and the geometrical model generated by MIG and plotted by MCNP. In this model, a small layer in the winding pack, a vacuum gap, and a coil case are included for each coil. Also, a shielding zone was added to the MIG output between the coil and the plasma for the coil protection. In this model, one quarter of the geometry is modelled to take advantage of the symmetry as shown in Fig. 5; this is another feature of MIG. In fact, the user has the choice of utilizing the symmetry in the geometry around any of the main planes to save on the number of cells and surfaces used by MCNP to model the geometry.

## CONCLUSIONS

The MIG code was developed to interface the magnetics and the neutronics analyses. It provides an accurate three-dimensional

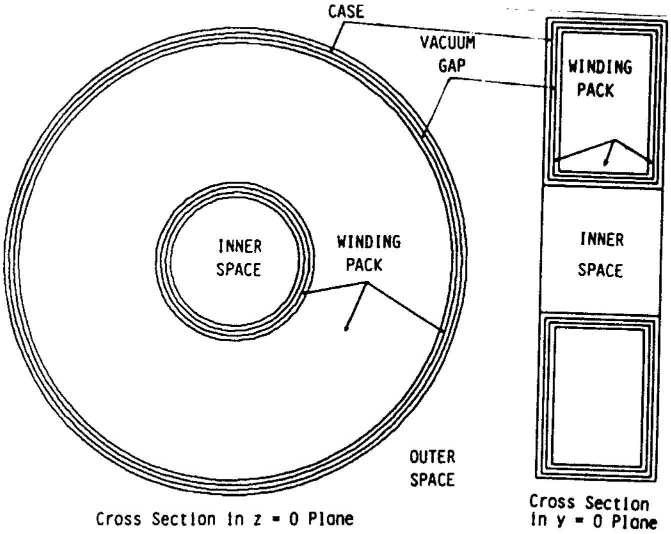

Fig. 4. MCNP plots resulted from the MIG geometrical model of the solenoid.

geometrical model of the magnets for the MCNP calculations. It was used successfully for the FPD-I design to analyze the difficult geometry of the end cell.[1]

## ACKNOWLEDGEMENTS

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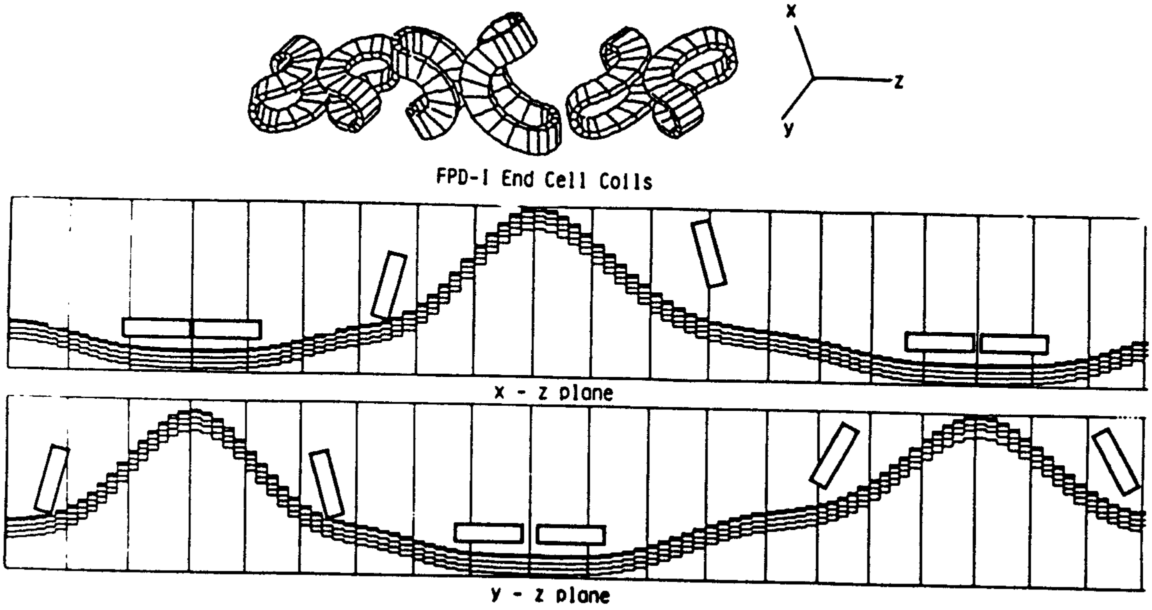

Fig. 5. FPD-I Cee coils and MCNP plots for the geometrical model generated by MIG.