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HELIX - AN INPUT GENERATOR FOR EFFI

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Abstract

The EFFI-code allows the calculation of electromagnetic fields, forces and inductances for ironless magnetic systems of geometries consisting of complete circles (LOOP) and/or circular arcs (ARC) and/or straight sections (GCE = general current element). So, even modestly complex coils give rise to very long EFFI input files. To ease life for the family of helical coils, the HELIX input generator writes the input file for EFFI. The method is described and examples illustrate the use of the input generator.

Zusammenfassung

HELIX - Ein Input-Generator für EFFI

Das EFFI-Programm erlaubt die Berechnung elektromagnetischer Felder, Kräfte und Induktivitäten eisenloser Magnetsysteme für Geometrien, die aus vollständigen Kreisen (LOOP) und/oder Kreisbogenstücken (ARC) und/oder geraden Stücken (GCE) bestehen. Daher geben bereits relativ einfache Spulen Veranlassung zu länglicher Eingabe. Zur Erleichterung erzeugt der HELIX-Eingabe-Generator den Eingabe-File für die Familie der helikalen Spulen. Die Methode wird beschrieben, und Beispiele illustrieren den Gebrauch des Input-Generators.

Contents

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1. Problem

EFFI [1,2] calculates electromagnetic fields, forces and inductances for magnetic systems of arbitrary geometry without iron. Any current carrying coils which are input to EFFI consist of complete circles (LOOP), circular arcs (ARC) and/or general current elements (GCE). Therefore, even simple coils may require longish input data. To avoid complex input for magnetic systems input generators write in general the input for EFFI.

There exist already in KfK two input generators for EFFI:

1. EIG [3] for solenoids, Bitter coils, race-track coils, window frame coils, Yin-Yangs, C-shaped coils, IOFFE bars, saddle coils, cone related coils, box coils, bow coils and special other forms.

2. TOKEF [4] for the coils of a Tokamak System, i.e. for poloidal field solenoids and toroidal field D-shaped coils.

These input generators require only few data to describe the coil geometry and the current or current density in the winding of coils.

A simple solenoid for example requires only five data, which might be entered also without the use of an input generator. But for more complex problems like a helical coil system, which must be defined as sets of many GCEs, an input without using an input generator is nearly impossible and needs at least a great time expenditure. Therefore an input generator for a helical coil system has been written.

2. Definition of a helical coil

As mentioned before, a helical coil must be defined as a set of GCEs. EFFI has two different specifications for "General Current Elements". For this problem the following has been chosen :

```
GCE
          6.00000000          0.00000000          0.00000000
          6.75000000          0.00000000          0.00000000
          6.00000000          0.00000000         -0.75000000
       4000.00000000
          5.89388508          1.03925096          0.17364818
          6.62126981          1.16750851          0.30388431
          6.02214263          1.06186623         -0.56495764
$
```

The example above shows the definition of one GCE. The keyword GCE indicates that the GCE definition above will follow. The next three triplets of data are describing the first end-plane. The first triplet (P_1) contains the 3-D coordinates for the centroid. The second and third triplets (P_2, P_3) contain the 3-D cross section coordinates for the first end-plane. The next data is the current density in the element, followed by the three triplets (P_1, P_2, P_3) for the succeeding end-plane. The $ terminator indicates the end of this GCE definition (see Figure 1).

This description of a helical coil by sets is advantageous for EFFI. The user himself must define the helical coil by only very few data.

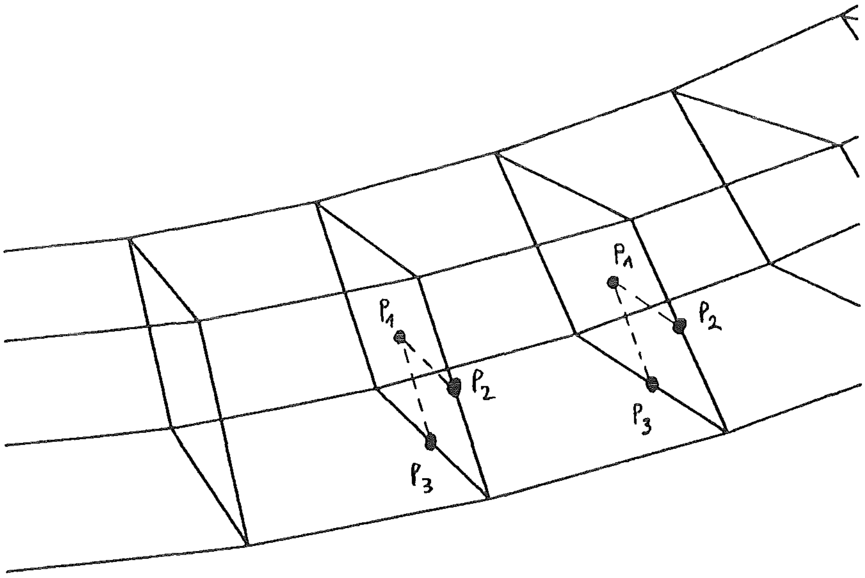

Figure 1. Definition of a General Current Element GCE

3. Mathematics

The main problem was the calculation of the coordinates defining a GCE. The mathematic necessary to solve this problem will be described next.
The variables are fixed as (see Figure 2) :

R = major radius
r = minor radius
r_a = sum of r and half of DR
DR = radial thickness of helical coil
DA = axial width of helical coil
P_1 = GCE central point
P_2 = GCE cross section coordinate 1
P_3 = GCE cross section coordinate 2
θ = first rotation angle (radius R)
ϕ = second rotation angle (radius r)

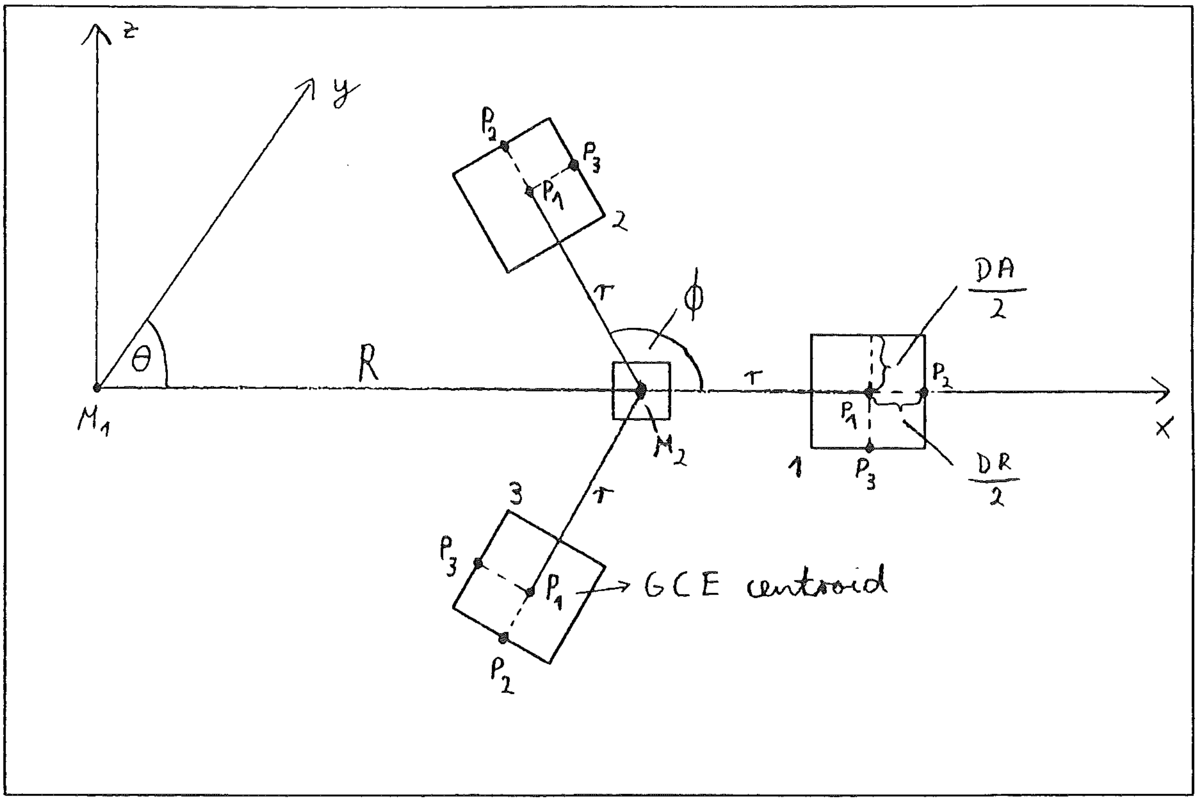

Figure 2. Explanations of the parameters. Three helical coils (1,2,3), one solenoid (plasma simulation).

Figure 3 on page 4 and Figure 4 on page 4 show the meaning of the angles. The GCE centroid is a point rotating around M_1 while rotating around M_2. The GCE centroid coordinates (P_1) depend only on the rotation angles, as well as P_2 and P_3.

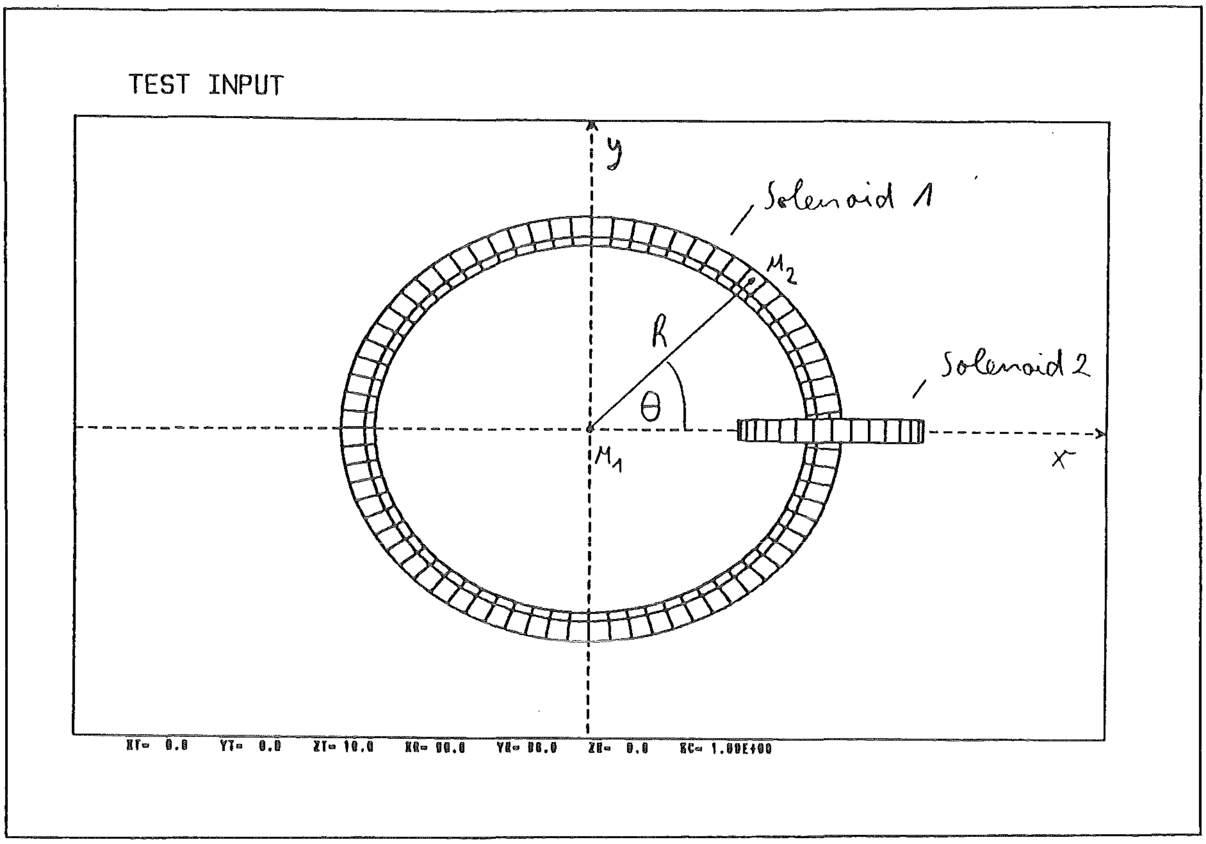

Figure 3. Theta angle

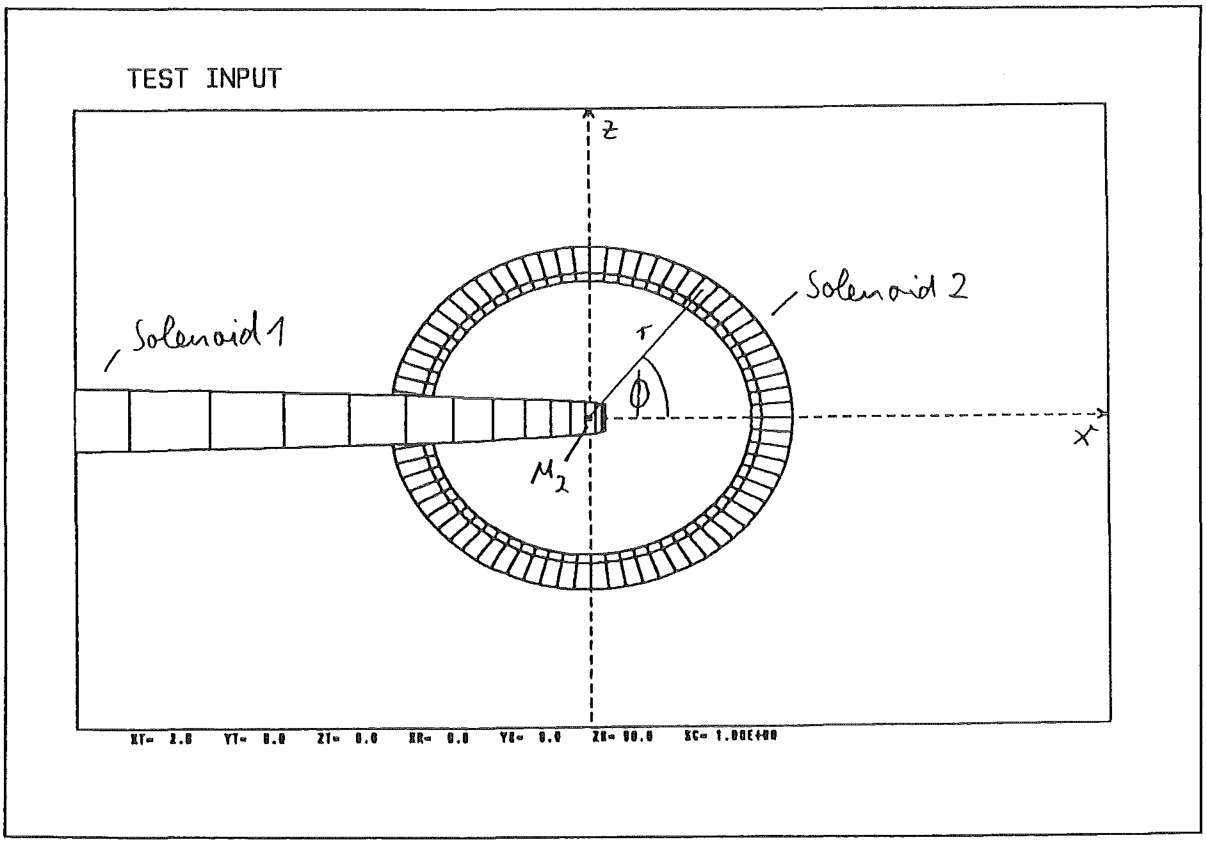

Figure 4. Phi angle. (Figure 3 rotated by 90 ° around the x-axis)

All formulas have been developed for a helical coil with z as main axis.

All coordinates of the GCE defining points depend on the angles θ and ϕ. Every calculation starts at $\theta = 0°$, $\phi = 0°$, $z = 0$. The ϕ value depends only on the first angle. This will be explained later in more detail. The considerations of a formula yielding the needed coordinates for the point P_1 resulted in the formulas (1) :

$$\begin{aligned} x(P_1) &= \cos(\theta)(R + r\cos(\phi)) \\ y(P_1) &= \sin(\theta)(R + r\cos(\phi)) \\ z(P_1) &= r\sin(\phi) \end{aligned} \tag{1}$$

The coordinates for P_2 have been evaluated in a similar way as for P_1. It was only necessary to use r_a instead of r. This results in (2) :

$$\begin{aligned} x(P_2) &= \cos(\theta)(R + r_a\cos(\phi)) \\ y(P_2) &= \sin(\theta)(R + r_a\cos(\phi)) \\ z(P_2) &= r_a\sin(\phi) \end{aligned} \tag{2}$$

For the last triplet of coordinates there are two ways of evaluation. Depending on the input option, the point P_3 is rotated by 90° around the P_1 - P_2 - axis. In case of a helical coil the coordinates may be calculated by (3) :

$$\begin{aligned} r_4 &= \sqrt{r^2 + \left(\frac{DA}{2}\right)^2} \\ \delta &= arcsin(\frac{DA}{2r_4}) \\ x(P_3) &= \cos(\theta)(R + r_4\cos(\phi - \delta)) \\ y(P_3) &= \sin(\theta)(R + r_4\cos(\phi - \delta)) \\ z(P_3) &= r_4\sin(\phi - \delta) \end{aligned} \tag{3}$$

This way needs more steps. Therefore an alternative formula (4) is used.

$$\begin{aligned} x(P_3) &= x(P_1) + \frac{DA}{2}\sin(\phi)\cos(\theta) \\ y(P_3) &= y(P_1) + \frac{DA}{2}\sin(\phi)\cos(\theta) \\ z(P_3) &= z(P_1) - \frac{DA}{2}\cos(\phi) \end{aligned} \tag{4}$$

The identity of (3) and (4) results from (only for x-coordinate) :

$$\begin{aligned}
(4) &= (3) \\
R\cos(\theta) + r\cos(\theta)\cos(\phi) + \frac{DA}{2}\sin(\phi)\cos(\theta) &= R\cos(\theta) + r_4\cos(\theta)\cos(\phi-\delta) \\
r\cos(\theta)\cos(\phi) + \frac{DA}{2}\sin(\phi)\cos(\theta) &= r_4\cos(\theta)\cos(\phi-\delta) \\
r\cos(\phi) + \frac{DA}{2}\sin(\phi) &= r_4\cos(\phi-\delta) \\
\frac{r}{r_4}\cos(\phi) + \sin(\phi)\sin(\delta) &= \cos(\phi-\delta) \\
\frac{r}{r_4}\cos(\phi) + \sin(\phi)\sin(\delta) &= \cos(\phi)\cos(\delta) + \sin(\phi)\sin(\delta) \\
\frac{r}{r_4}\cos(\phi) &= \cos(\phi)\cos(\delta) \\
\frac{r}{r_4} &= \cos(\delta)
\end{aligned}$$

For this proof, an addition theorem has been used. In case of a solenoidal form of the coil the formulas (5) yield :

$$\begin{aligned}
x(P_3) &= x(P_1) - \frac{DA}{2}\sin(\theta) \\
y(P_3) &= y(P_1) + \frac{DA}{2}\cos(\theta) \qquad (5) \\
z(P_3) &= z(P_1)
\end{aligned}$$

The formulas finally used to evaluate the points P_2 and P_3 are developed with respect to P_1.

4. HELIX-Input and -Output

The input of HELIX has the following structure :

```
I.   Title card , unit data , parameter data
***
II.  Coil and current definitions (HELIX input)
***
III. Output data
***
```

Note : Start position of the three stars must be column 1 !

I.
Data needed by EFFI (see EFFI User's Manual [2], Chapter 3.1 and 3.2).

II.
This is the HELIX input. It will be transformed to a code understandable to EFFI (see EFFI User's Manual [2], Chapter 3.3).

III.
Data needed by EFFI (see EFFI User's Manual [2], Chapter 3.4).

Structure of a valid HELIX input :

COIL=name_of_coil
L R r DA DR d M NDIV J ϕ_{rot}

with

L = option for the choice of coil types
R = major radius
r = minor radius
DA = helical coil axial width
DR = helical coil radial thickness
d = measure of non-planarity, maximum diplacement of a modular coil to the central planar plane (see Figure 9 on page 15)
M = number of periods for one rotation ($\phi = M\theta$)
NDIV = number of GCEs for one coil for one rotation
J = overall current density in the GCE set
ϕ_{rot} = parameter for the definition of single coils

Note : L,M,NDIV are INTEGER parameters !!!

With this input generator it is possible to define :

1. Helical coils
2. Solenoids
3. Modular coils

To choose the **type of coil** you want, use the L option.

$L > 0$:
The value of L is the number of helical coils. The first coil always starts at $\phi = 0°$. If L would have the value 4, the second coil would start at $\phi = 90°$, the third at $\phi = 180°$, and the last at $\phi = 270°$.

$L < 0$:
This is nearly analogous. Now L defines the number of solenoids. The first solenoid always starts at $\theta = 0°$. Their positions depend only on θ. In case of this option, θ has L fixed values over one period, too. A solenoid might be imagined as a special case of a helical coil. If you want to define a modular coil, the M (for a solenoid = 0) parameter defines the number of periods and d the maximum displacement of the modular coil to its central plane.

$L = 0$:
This option allows the definition of a single helical coil, a single solenoid or a single modular coil. If $\phi_{rot} < 0$, a single solenoid or a single modular coil is defined at $\theta = |\phi_{rot}|$. If $\phi_{rot} \geq 0$, a single helical coil is defined with a ϕ start angle of ϕ_{rot}. The parameter ϕ_{rot} must be entered in degree.

Note : To define a single solenoid with L=0 at $\theta = 0°$, ϕ_{rot} must have a value of $-360°$.

The best method to understand the meaning of the input data is to study the following examples.

5. Examples

I. One helical coil and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=HELI15
  1 5.   1.5  0.5  0.5 .5  5  72  4000.  0.
COIL=SOLPL
  1 5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.    1.    10.
 -10.    1.    10.
  0.     0     $
***
```

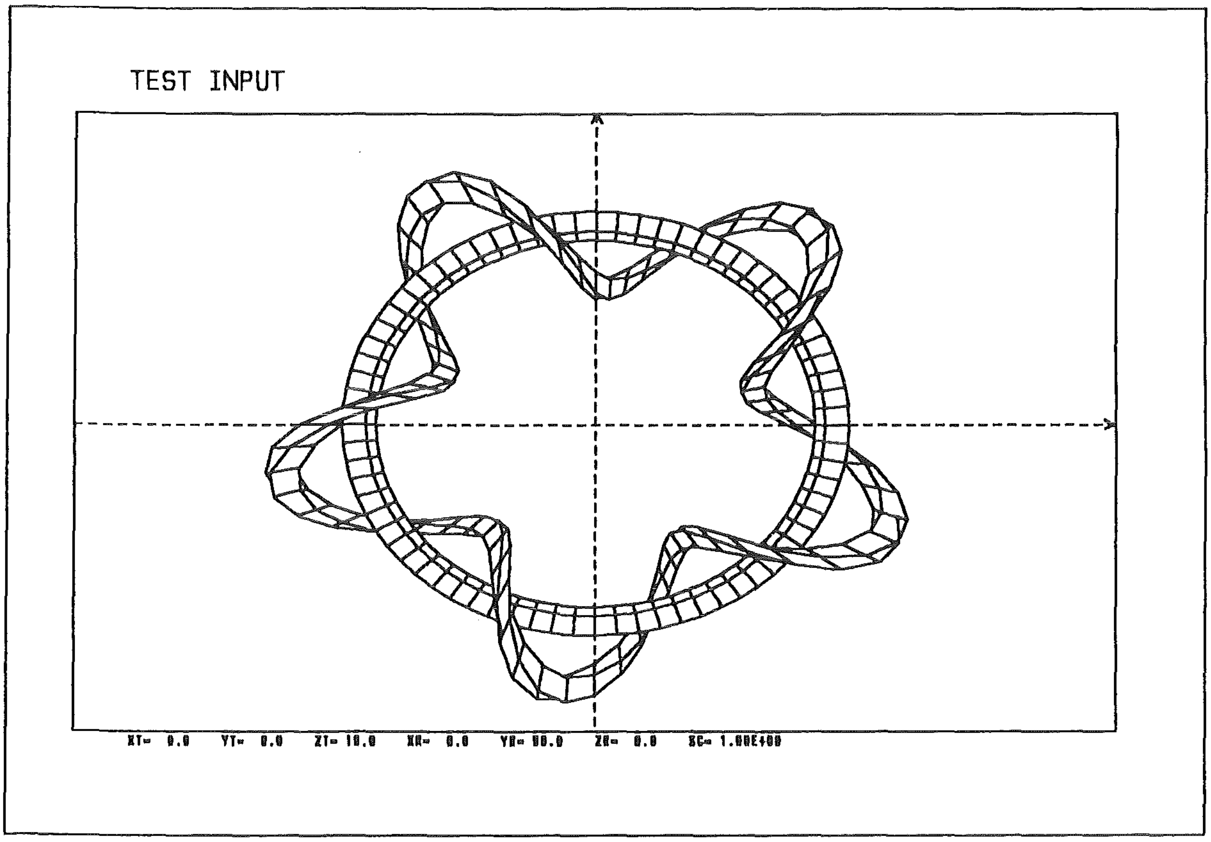

Figure 5. One helical coil and one solenoid in the X-Y-plane

For this input HELIX generates an EFFI-Input with 1310 rows. The next two pages give an impression, how the EFFI-Input looks like; however only a few of the first rows and the last rows are shown as example.

EFFI-Input :

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
 $
COIL=HELI15
 $
 GCE
        6.50000000       0.00000000      -0.00000188
        6.75000000       0.00000000      -0.00000220
        6.49999905       0.00000000      -0.25000185
     4000.00000000
        6.33526230       0.55426341       0.63392490
        6.56097698       0.57401085       0.73957902
        6.44051361       0.56347173       0.40734780
 $
 GCE
        6.33526230       0.55426341       0.63392490
        6.56097698       0.57401085       0.73957902
        6.44051361       0.56347173       0.40734780
     4000.00000000
        5.87357426       1.03566837       1.14906406
        6.03182983       1.06357288       1.34057426
        6.06217480       1.06892300       0.98836672
 $
 GCE
        5.87357426       1.03566837       1.14906406
        6.03182983       1.06357288       1.34057426
        6.06217480       1.06892300       0.98836672
     4000.00000000
        5.20463181       1.39457607       1.44888783
        5.26713181       1.41132259       1.69036865
        5.43788433       1.45707512       1.38418198
 $
                          .
                          .
                          .
                          .
                          .
                          .
                          .
                          .
```

```
                         .
                         .
                         .
                         .
                         .
                         .
                         .
                         .
                         .
 GCE
      4.82962513     -1.29410744      0.00000000
      5.07110691     -1.35881329     -0.00000031
      4.82962418     -1.29410648     -0.25000000
    4000.00000000
      4.92403603     -0.86825162      0.00000000
      5.17023849     -0.91166419     -0.00000031
      4.92403507     -0.86825156     -0.25000000
 $
 GCE
      4.92403603     -0.86825162      0.00000000
      5.17023849     -0.91166419     -0.00000031
      4.92403507     -0.86825156     -0.25000000
    4000.00000000
      4.98097229     -0.43578714      0.00000000
      5.23002052     -0.45757645     -0.00000031
      4.98097134     -0.43578708     -0.25000000
 $
 GCE
      4.98097229     -0.43578714      0.00000000
      5.23002052     -0.45757645     -0.00000031
      4.98097134     -0.43578708     -0.25000000
    4000.00000000
      5.00000000      0.00000000      0.00000000
      5.25000000      0.00000000     -0.00000031
      4.99999905      0.00000000     -0.25000000
 $
 $
XYZ
 -10.    1.    10.
 -10.    1.    10.
  0.    0     $
 $
```

II. Two helical coils and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=HELI25
  2 5.   1.5  0.5  0.5 .5  5  72  4000.  0.
COIL=SOLPL
  1 5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

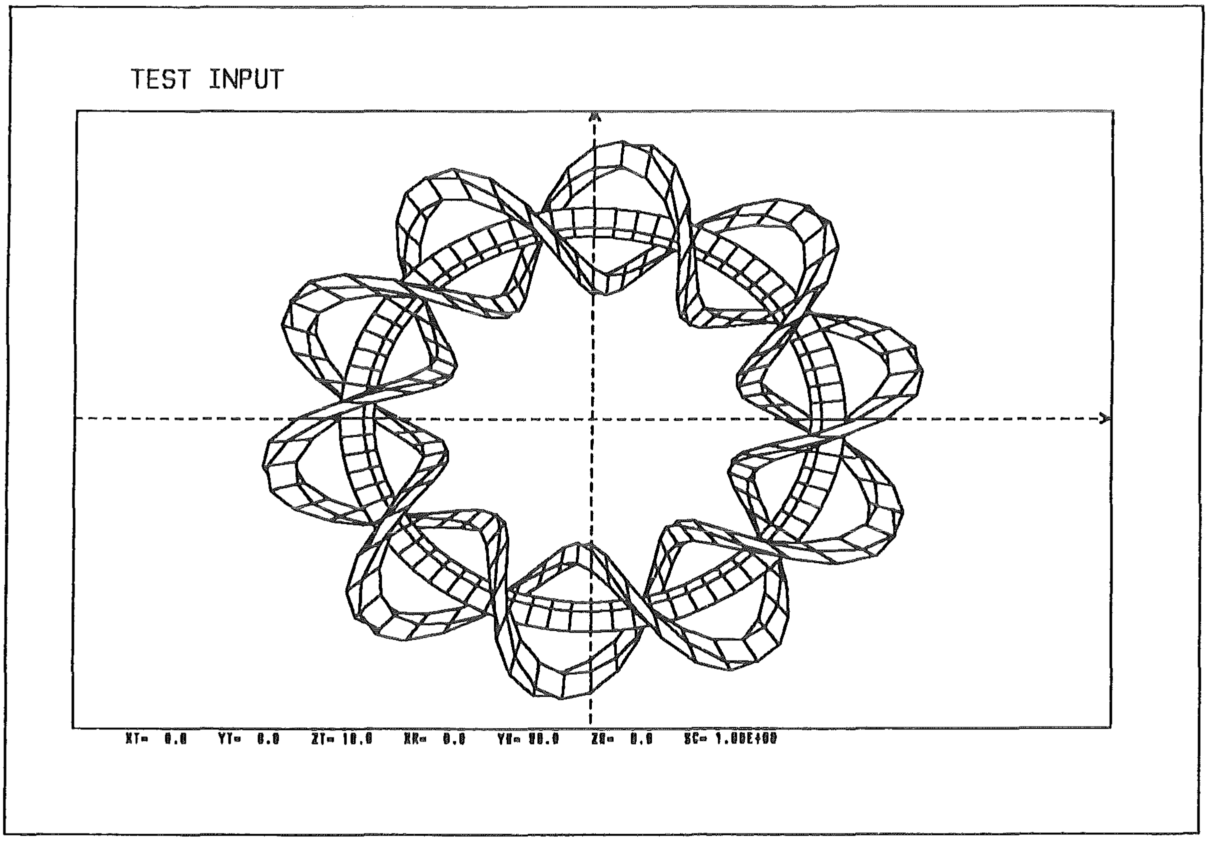

Figure 6. Two helical coils and one solenoid in the X-Y-plane

III. Four helical coils and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=HELI45
  4  5.   1.5  0.5  0.5 .5  5  72  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

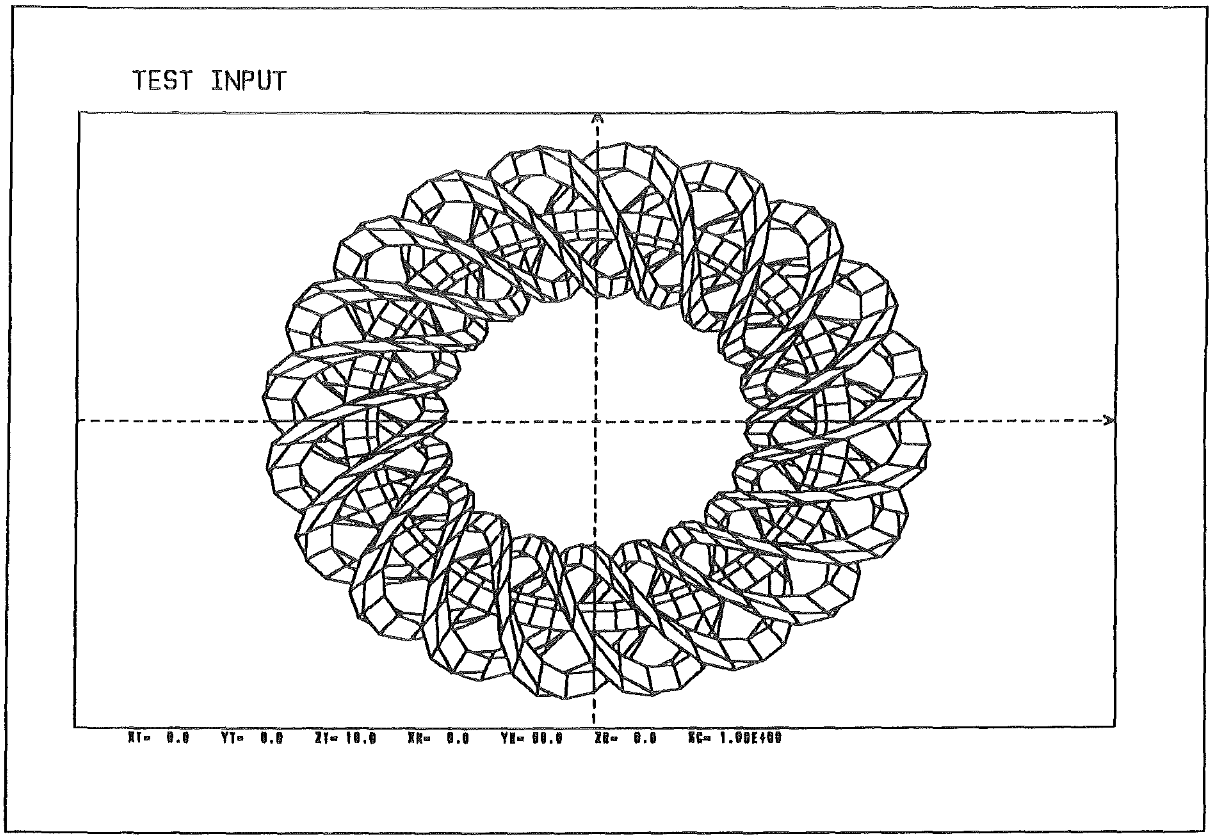

Figure 7. Four helical coils and one solenoid in the X-Y-plane

IV. Four solenoids and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=SOL40
 -4  5.   1.5  0.5  0.5 .5  0  72  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

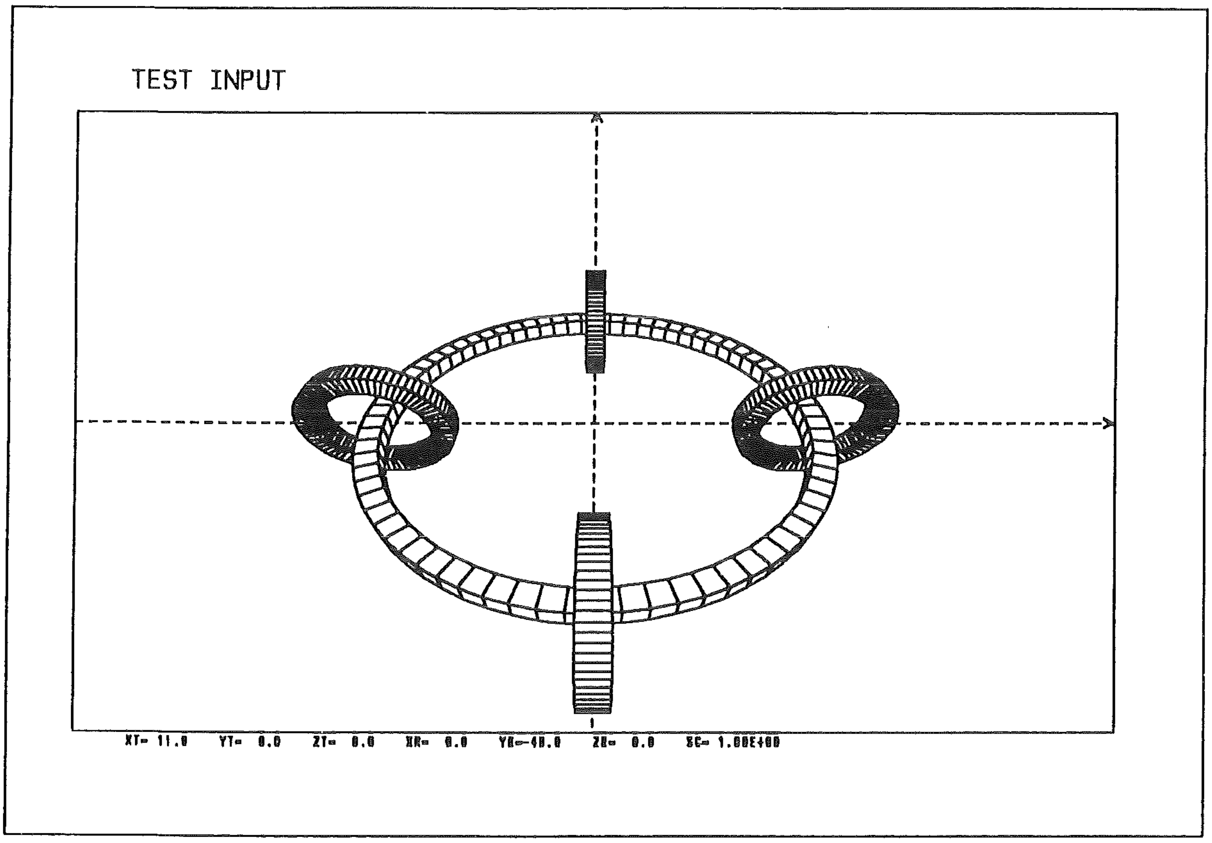

Figure 8. Four solenoids and one solenoid in the X-Y-plane

V. One modular coil (2 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOIL
 -1  5.   1.5  0.5  0.5 .5  2  36  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

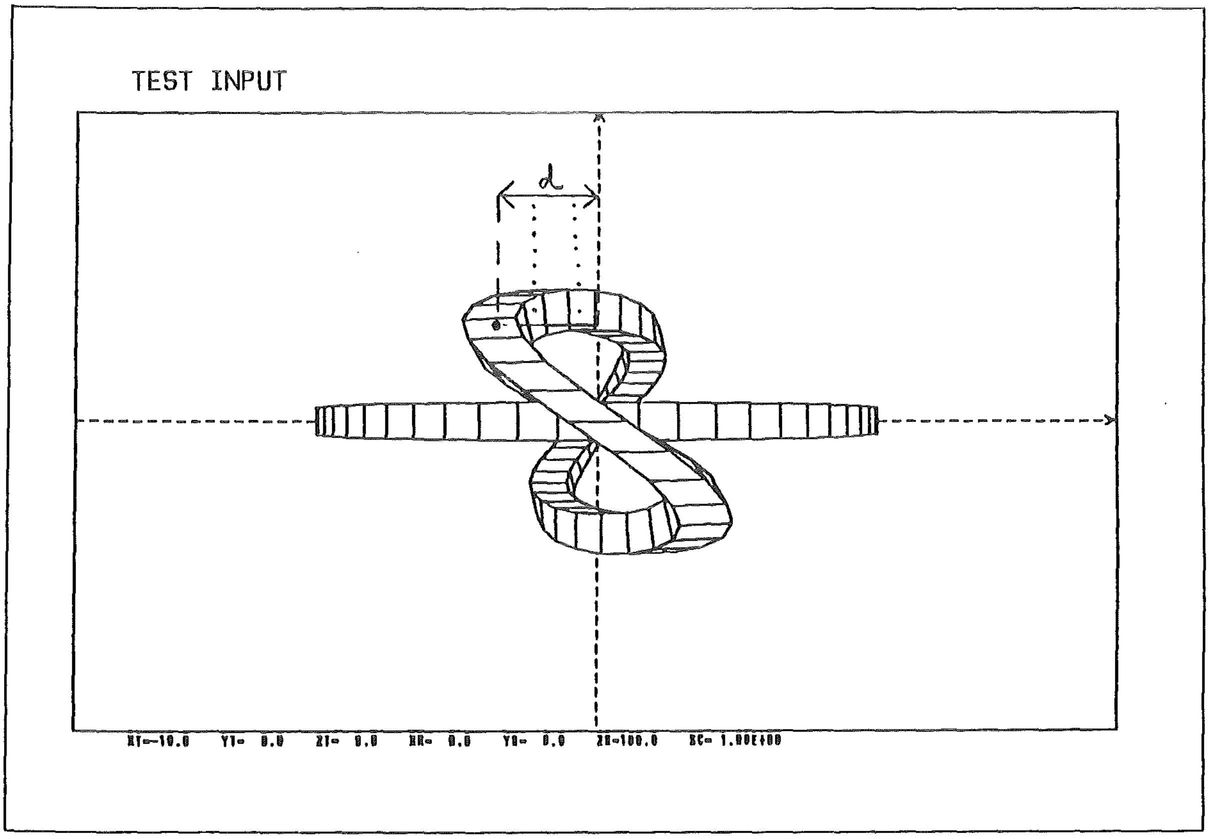

Figure 9. One modular coil (2 periods) and one solenoid in the X-Y-plane.

VI. One modular coil (3 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOIL
 -1  5.   1.5  0.5  0.5 .5  3  36  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

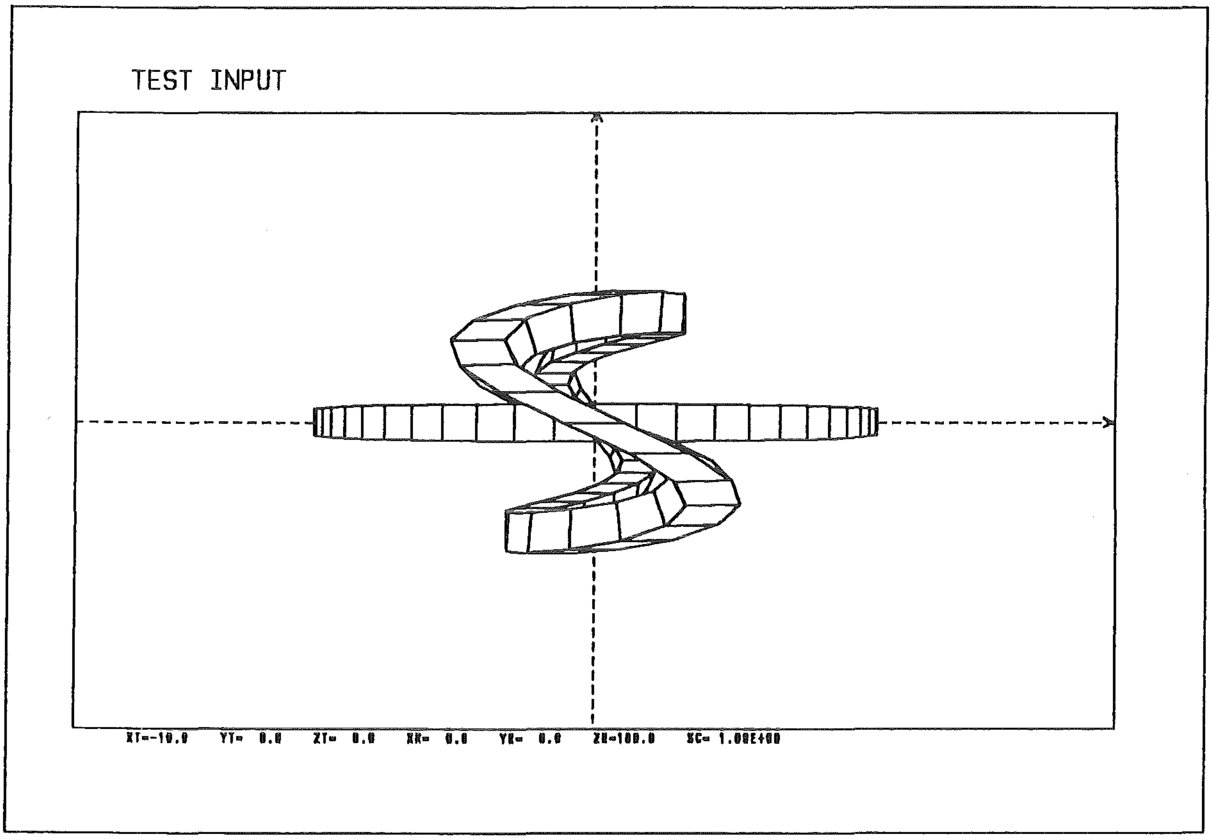

Figure 10. One modular coil (3 periods) and one solenoid in the X-Y-plane

VII. One modular coil (4 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOIL
 -1  5.   1.5  0.5  0.5 .5  4  36  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.      0     $
***
```

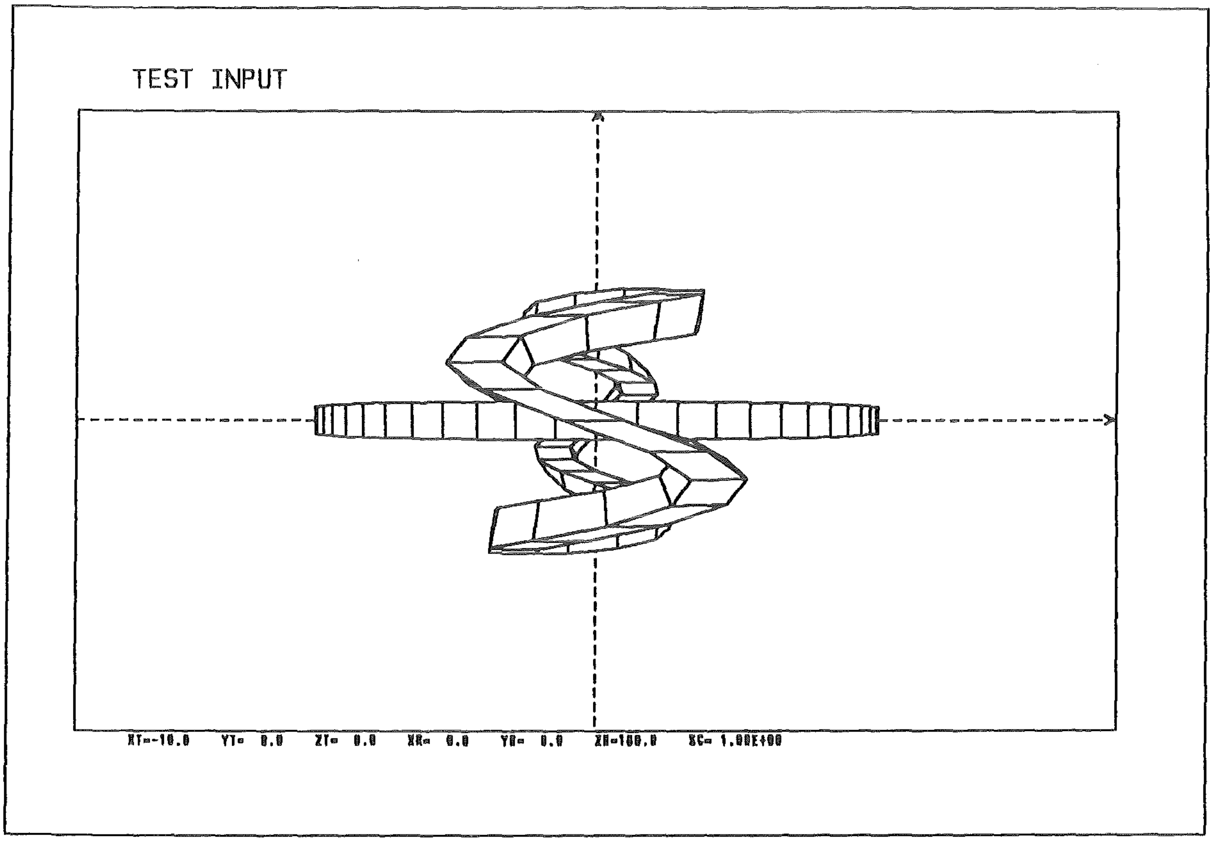

Figure 11. One modular coil (4 periods) and one solenoid in the X-Y-plane

VIII. Two modular coils (4 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOIL1
  0  5.   1.5  0.5  0.5 .5  4  36  4000.  45.
COIL=MODCOIL2
  0  5.   1.5  0.5  0.5 .5  4  36  4000.  315.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

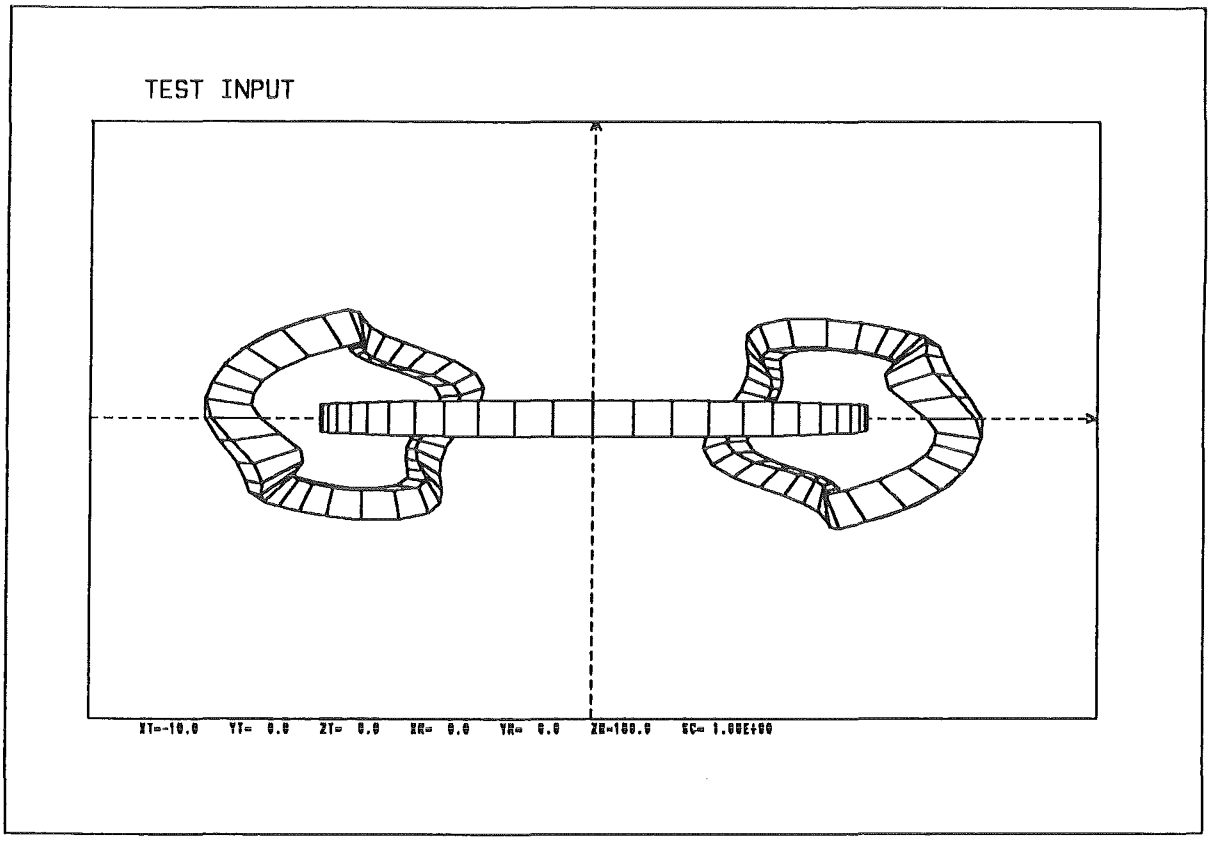

Figure 12. Two modular coils (4 periods) and one solenoid in the X-Y-plane

IX. 16 modular coils (2 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOILS
 -16  5.   1.5  0.5  0.5 .5  2  36  4000.  0.
COIL=SOLPL
  1  5.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.      0     $
***
```

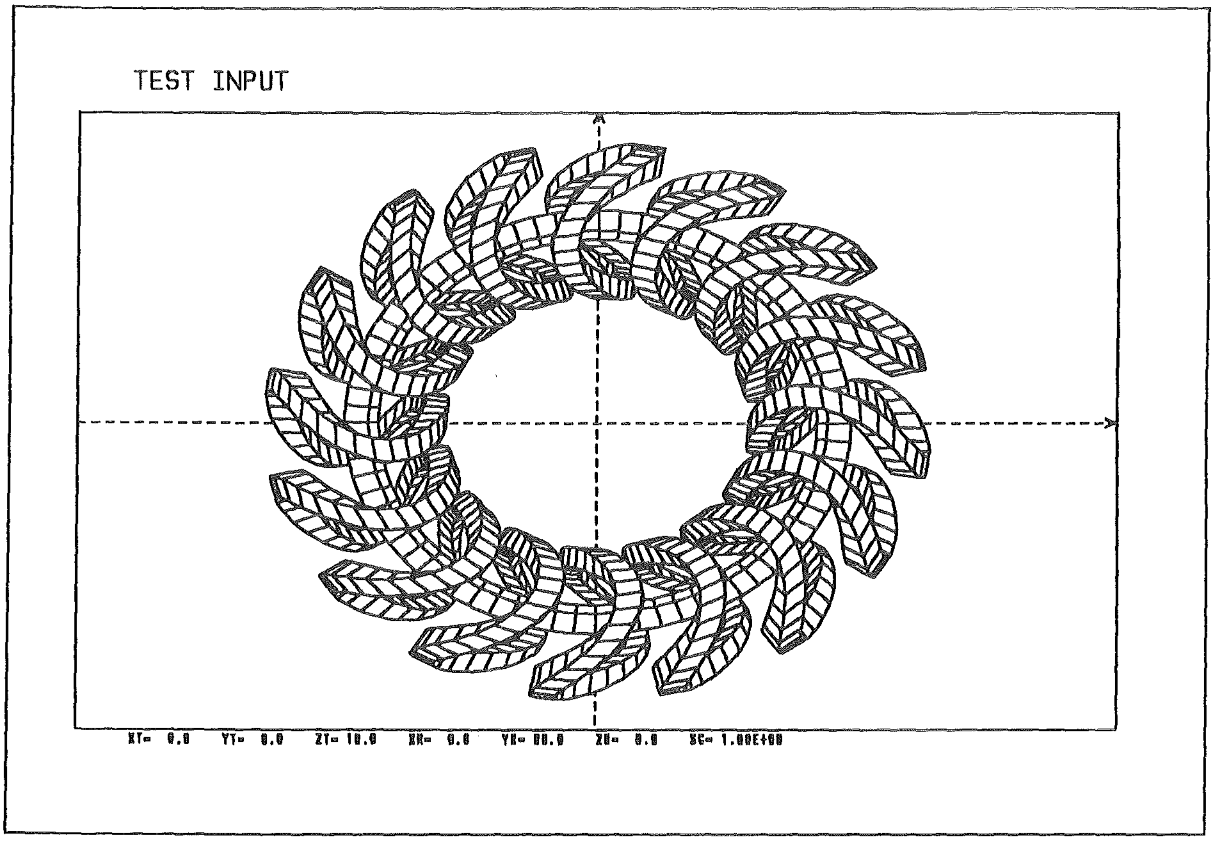

Figure 13. 16 modular coils (2 periods) and one solenoid in the X-Y-plane

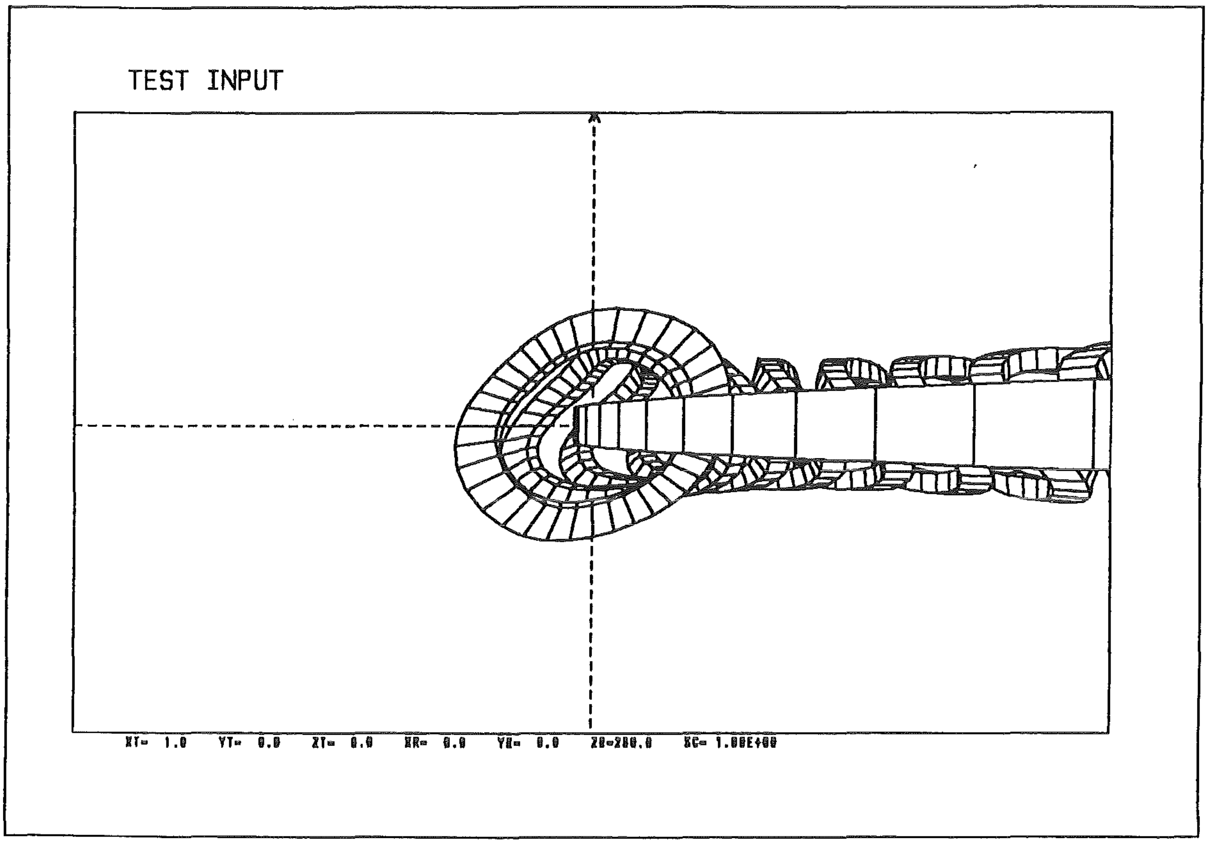

Figure 14. 16 modular coils (2 periods) rotated by 90 ° around the x-axis

X. 16 modular coils (3 periods) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=MODCOILS
 -16 10.   1.5  0.5  0.5 .5  3  36  4000.  0.
COIL=SOLPL
  1  10.   0.   0.5  0.5 .5  0  72  4000.  0.
***
XYZ
 -10.     1.    10.
 -10.     1.    10.
  0.     0      $
***
```

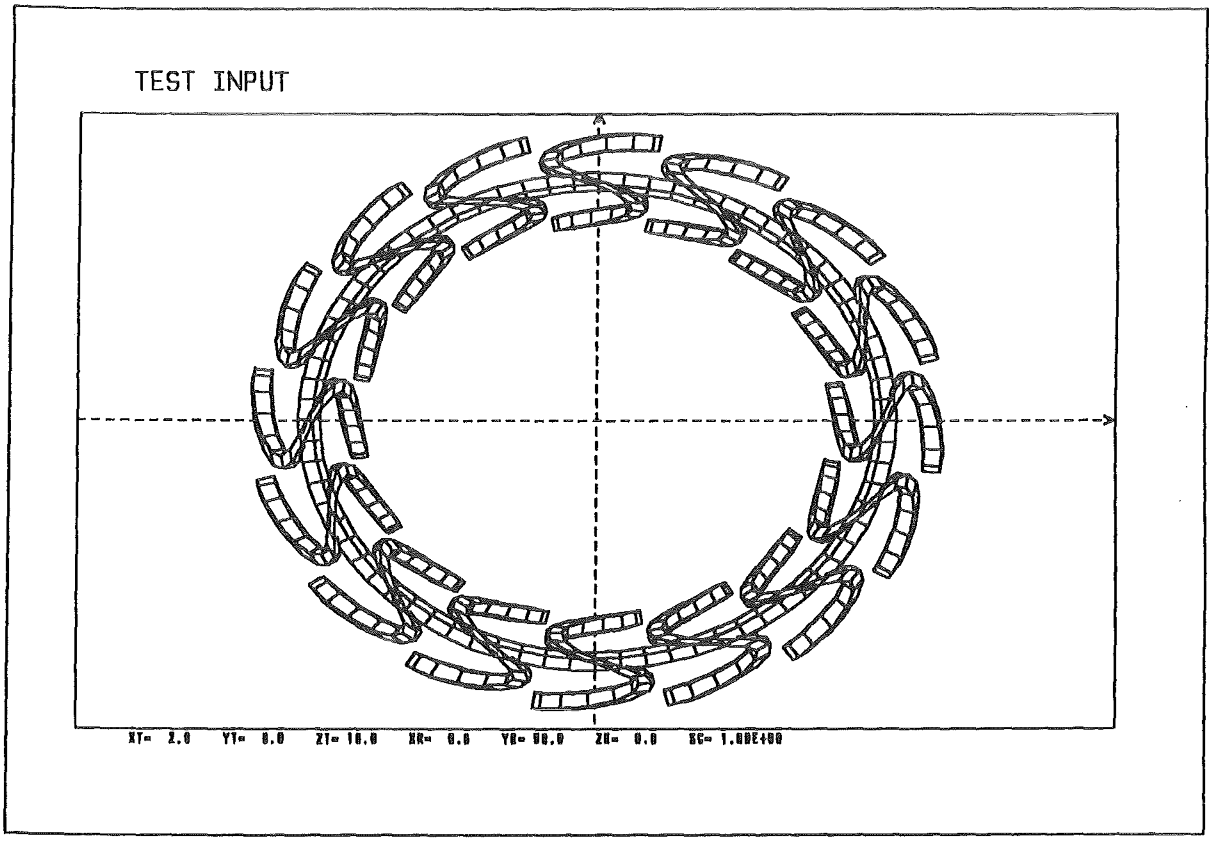

Figure 15. 16 modular coils (3 periods) and one solenoid in the X-Y-plane

XI. 100 solenoids (Energy Storage Unit) and one solenoid in the X-Y-plane.

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=SOL1000
 -100  50.   2.  .5  .5 .5  0  36  4000.  0.
COIL=SOLPL
  1    50.   0.  .5  .5 .5  0  36  4000.  0.
***
XYZ
 -60.     10.    60.
 -60.     10.    60.
  0.     0      $
***
```

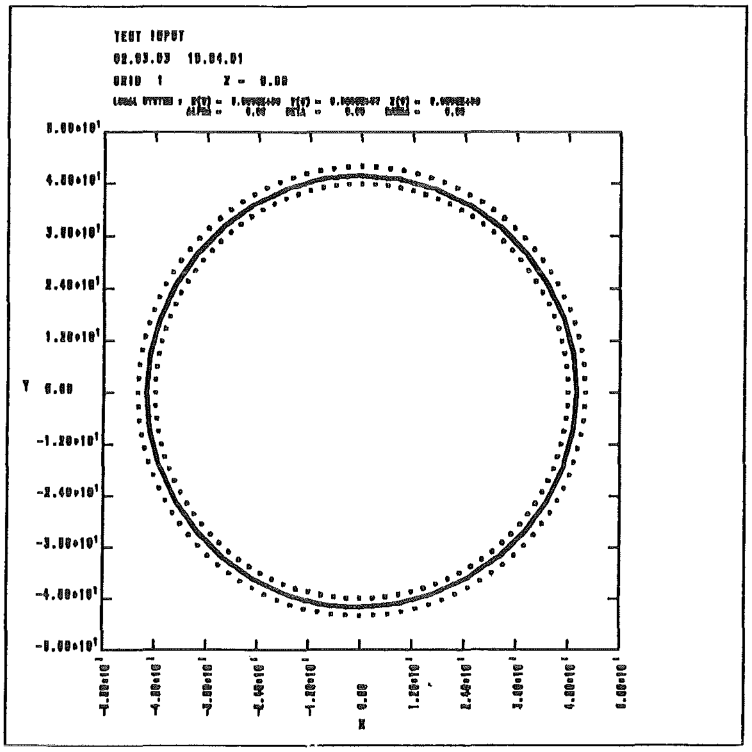

Figure 16. 100 solenoids (Energy Storage Unit) and one solenoid in the X-Y-plane. The HELIX Input Generator is advantageous for the calculation of very large toroidal energy storage units. This figure shows 100 storage solenoids grouped around a center line (= the 101st solenoid).

XII. Field contour plot of three helical coils (5 periods).

```
TEST INPUT
CURRENT=A/CM**2
LENGTH=CM
***
COIL=OU1
  1 5.   0.  .5   .5  .5  0  72  000000.  0.
COIL=OU1
  3 5.   2.  1.   1.  .5  5  72  170000.  0.
***
XZY
   2.     .1    8.
  -3.     .1    3.
  0.     0      $
  B-CON 1. 2. 3. 3.1 4. 5. 6. $
***
```

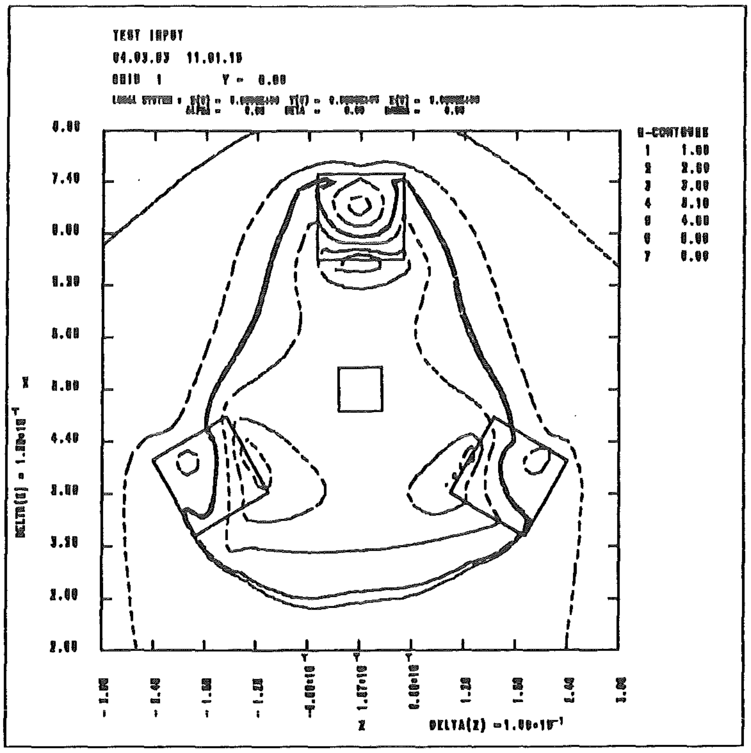

Figure 17. Field contour plot of three helical coils (5 periods). Field contour plot for the range of $2\ cm \leq x \leq 8\ cm$, $-3\ cm \leq z \leq 3\ cm$, $y = 0\ cm$. The double line for 3 T and 3.1 T eases the orientation for the identification of the B-contours.

6. Program

This program describes the input generator HELIX :

```
      PROGRAM HELIX
      CHARACTER*80 INP,F01
      F01 = '(A80)'
      OPEN(1,FILE='/MAT1M7.TAHEL.INP')
      OPEN(2,FILE='/MAT1M7.TAHEL.OUT')
   10 READ (1,F01) INP
      IF (INP(1:3).EQ.'***') GOTO 20
      WRITE (2,F01) INP
      GOTO 10
   20 WRITE(2,*) '$'
   25 READ (1,F01) INP
      IF (INP(1:3).EQ.'***') GOTO 30
      WRITE(2,F01) INP
      WRITE(2,*) '$'
      READ (1,*) L,RAD1,RAD2,RD4,RD3,RTRA,M,NTEIL,OACD,BETDREH
      IF (L.EQ.0) THEN
        BETDREH = BETDREH * ACOS(-1.) / 1.80E2
        CALL HEL(RAD1,RAD2,RD3,RD4,RTRA,M,NTEIL,OACD,BETDREH)
      ELSE
        DO I = 1,ABS(L)
          BETDREH = I * 2. * ACOS(-1.) / FLOAT(L)
          IF (L.GT.0) BETDREH = ABS(BETDREH)
          CALL HEL(RAD1,RAD2,RD3,RD4,RTRA,M,NTEIL,OACD,BETDREH)
        ENDDO
      ENDIF
      GOTO 25
   30 WRITE (2,*) '$'
   40 READ (1,F01) INP
      IF (INP(1:3).EQ.'***') GOTO 99
      WRITE (2,F01) INP
      GOTO 40
   99 WRITE (2,*) '$'
      CLOSE(1)
      CLOSE(2)
      END
```

```
      SUBROUTINE HEL(RAD1,RAD2,RD3,RD4,RTRA,N2,NTEIL,OACD,BETDREH)
      PARAMETER(NDIM=100000)
      REAL X(NDIM,3),Y(NDIM,3),Z(NDIM,3)
      RL3 = RD3 * .5
      RL4 = RD4 * .5
      PI = ACOS (-1.)
      NC = 0
      STEP = 360 / FLOAT (NTEIL)
      DO IALP = 0 , NTEIL
        NC = NC + 1
        ALPHA = IALP * STEP * PI / 1.80E2
        BETA  = ALPHA * N2 + BETDREH
        IF (BETDREH.LT.0) THEN
          BETA  = ALPHA
          ALPCO = RTRA * SIN ( BETA * N2 ) *
     +            ASIN ( RTRA / SQRT ( RTRA * RTRA + RAD2 * RAD2 ) )
          ALPHA = ABS ( BETDREH ) + ALPCO
        ENDIF
        X(NC,1) = COS(ALPHA) * ( RAD1 + COS(BETA) * RAD2 )
        Y(NC,1) = SIN(ALPHA) * ( RAD1 + COS(BETA) * RAD2 )
        Z(NC,1) = RAD2 * SIN(BETA)
        X(NC,2) = COS(ALPHA) * ( RAD1 + COS(BETA) * (RAD2+RL3) )
        Y(NC,2) = SIN(ALPHA) * ( RAD1 + COS(BETA) * (RAD2+RL3) )
        Z(NC,2) = (RAD2+RL3) * SIN(BETA)
        IF (BETDREH.LT.0) THEN
          X(NC,3) = X(NC,1) - SIN (ALPHA) * RL4
          Y(NC,3) = Y(NC,1) + COS (ALPHA) * RL4
          Z(NC,3) = Z(NC,1)
        ELSE
          X(NC,3) = X(NC,1) + SIN(BETA)  * RL4 * COS(ALPHA)
          Y(NC,3) = Y(NC,1) + SIN(ALPHA) * RL4 * SIN(BETA)
          Z(NC,3) = Z(NC,1) - COS(BETA)  * RL4
        ENDIF
      ENDDO
      DO I = 1,NTEIL
        WRITE (2,*) 'GCE'
        DO J = 1,3
          WRITE (2,'(3F20.8)') X(I,J),Y(I,J),Z(I,J)
        ENDDO
        WRITE (2,'(F20.8)') OACD
        DO J = 1,3
          I2 = I + 1
          IF (I2.GT.NTEIL) I2 = 1
          WRITE (2,'(3F20.8)') X(I2,J),Y(I2,J),Z(I2,J)
        ENDDO
        WRITE (2,*) '$'
      ENDDO
      END
```

REFERENCES

[1] S. J. Sackett, "EFFI - A Code for Calculating the Electromagnetic Field, Force, and Inductance in Coil Systems of Arbitrary Geometry", UCRL-52402, 1978.

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[3] B. M. Manes, W. Maurer, "EIG - An Input Generator for EFFI" Kernforschungszentrum Karlsruhe, KfK 3672, Januar 1984.

[4] B. M. Manes, "TOKEF : A Tokamak Input Generator for EFFI" Kernforschungszentrum Karlsruhe, KfK 3854, Dezember 1984.