SSCL-N-694

SSC-CDG, LBL

FINITE ELEMENT ANALYSIS OF THE MAGNETIC FIELD OF AN OVERLAPPING CYLINDER DIPOLE COIL

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Note: This originally appeared as a letter from Chapman to Bob Schermer, May 22, 1989.

The attached summarizes the ANSYS calculation of the pure magnetic dipole field that you requested. A pure magnetic dipole field is formed in the region of intersection of two overlapping cylinders with opposite current densities +**J** and -**J**. For this calculation, the radii of the cylinders is 2.5 cm and the centers of the cylinders are off-set by 0.96 cm. The current density **J** is 4.2×10^4 amps/cm^2. Eleven different boundary conditions were considered: Neumann B.C. ($d\mathbf{A}/dn=0$) at radii of 4, 6, and 10 cm and Dirichlet B.C.($\mathbf{A} = 0$) at radii of 4, 5, 6, 7, 8, 9, 10 and 100 cm. The Neumann boundary condition models $\mu = \infty$ iron, while the Dirichlet boundary condition models a perfect superconductor with $\mu = 0$.

The model uses the 2-D multi-field STIF13 element, which in this case has only one d.o.f., scalar magnetic potential. The element mesh is shown in the attached figures. Symmetry permits consideration of just one quadrant of the problem. The mesh is very refined in the center of the model with a average element side length of 0.5 mm, and the air mesh extends out to 100 cm. The total number of nodes and elements in the model are 6496 and 9569, respectively.

The Dirichlet boundary conditions in the model are specified explicitly by setting the magnetic d.o.f. to 0 on the desired boundary. The Neumann boundary conditions cannot be specified explititly in ANSYS. Instead, they are automatically specified by the program for all boundaries of the model on which no Dirichlet boundary conditions are specified. Therefore, it is necessary to create explicit boundaries at the desired radii in order to model the infinite iron. This is done simply by selecting only the desired subset of nodes and elements for $0<r<$(radius of infinite iron) of the full model prior to the solution phase of the analysis.

The attached table lists the calculated field B_y at the center and at a radius of 1 cm. The attached graph shows the calculated field B_y at a radius of 1 cm. In the graph and table, the calculations with Dirichlet boundary conditions are assigned a negative value of $1/r^2$.

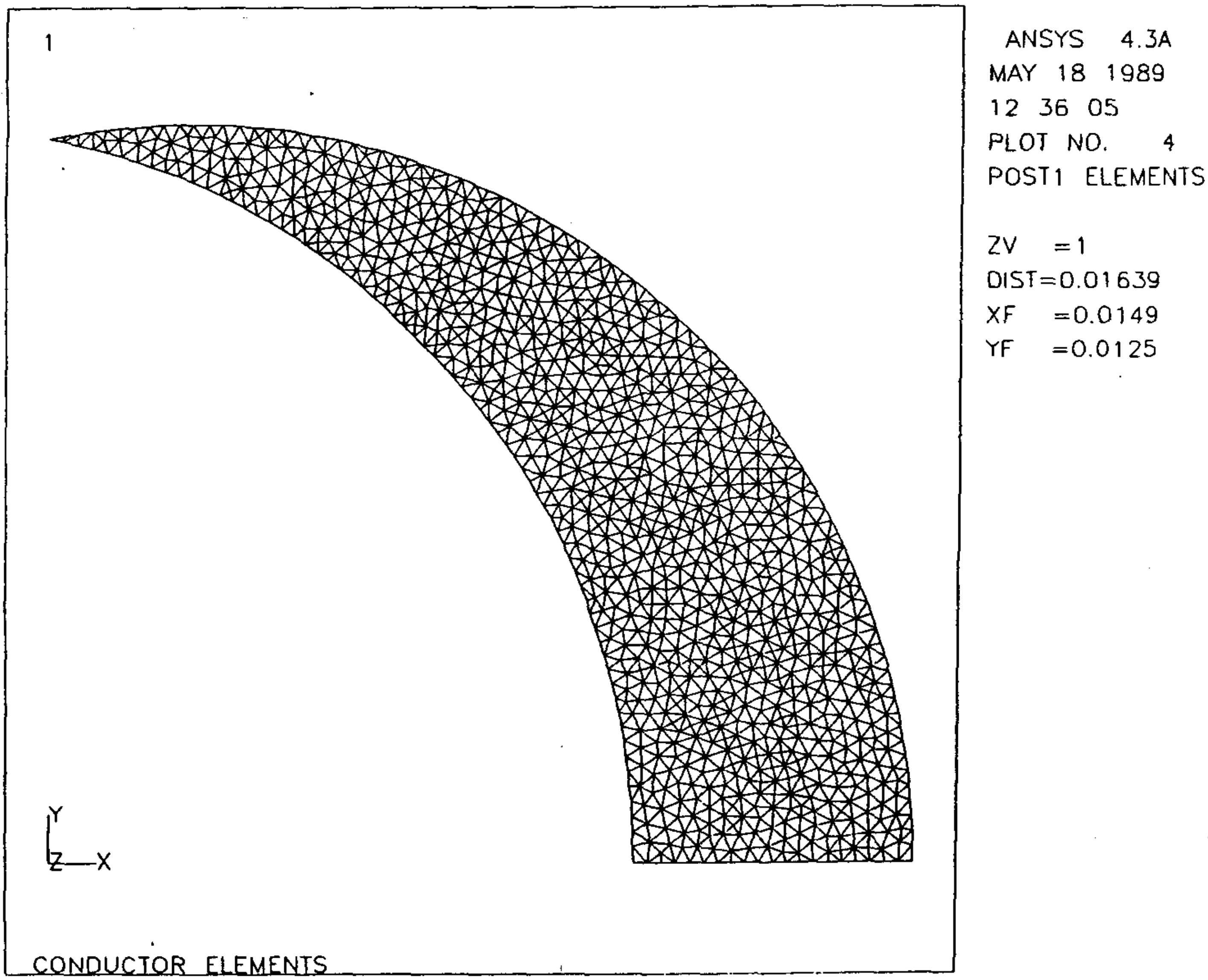
The closed-form solution of the field in the region of the cylinder overlap (bore) with the boundary at infinity is given by

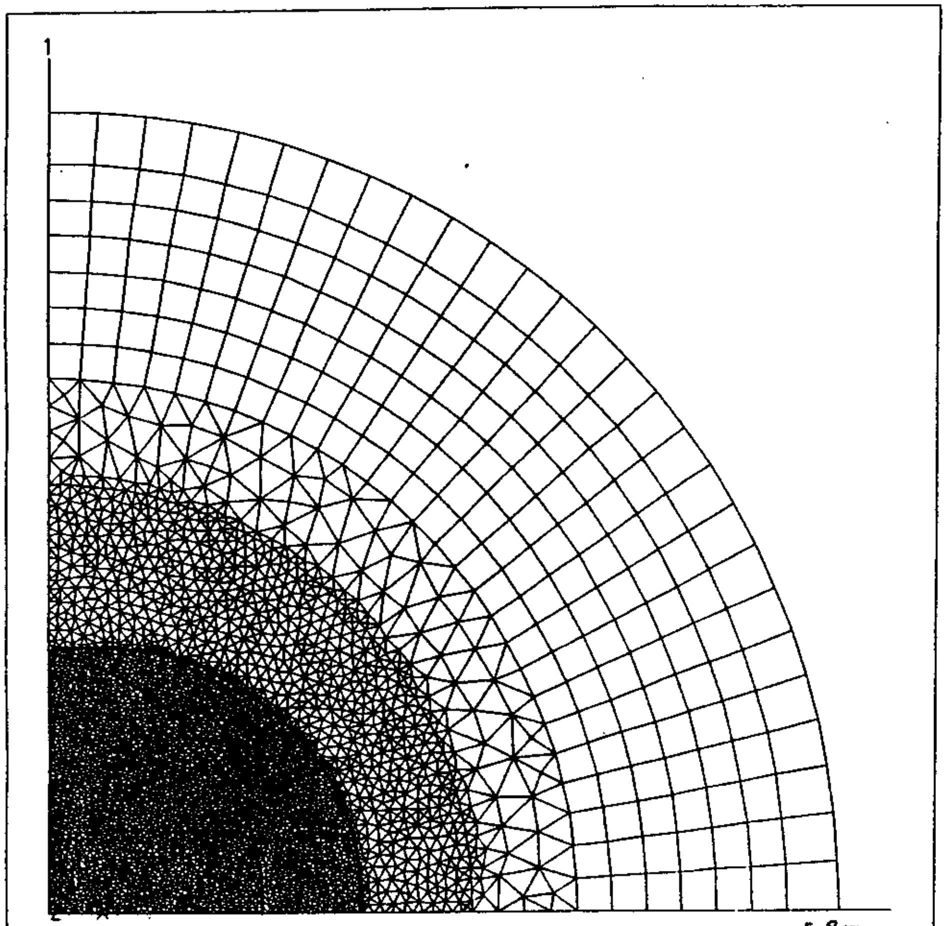
$$B_y = \mu_0 Js/2 = 2.53338 \text{ T}$$

$$B_x = 0$$

where s is the amount the cylinders are offset. The ANSYS solution for a *Dirichlet boundary condition at 100 cm* is $B_y = 2.53072$ T and $B_x = 2.0 \times 10^{-6}$ T at r = 1 cm. The difference in B_y is 0.0027 T or 0.15%.

I have attached flux plots for the **A** = 0 at 10 cm and the dA/dn = 0 at 10 cm runs, which are typical for each type of boundary condition. I have also included a graph of B_y versus r for the **A** = 0 at 10 cm run, which shows the uniformity of the field in the bore region. Finally, I have attached the input file for the Neumann boundary condition runs for reference.





ELEMENTS FOR 0 < R < 8 CM

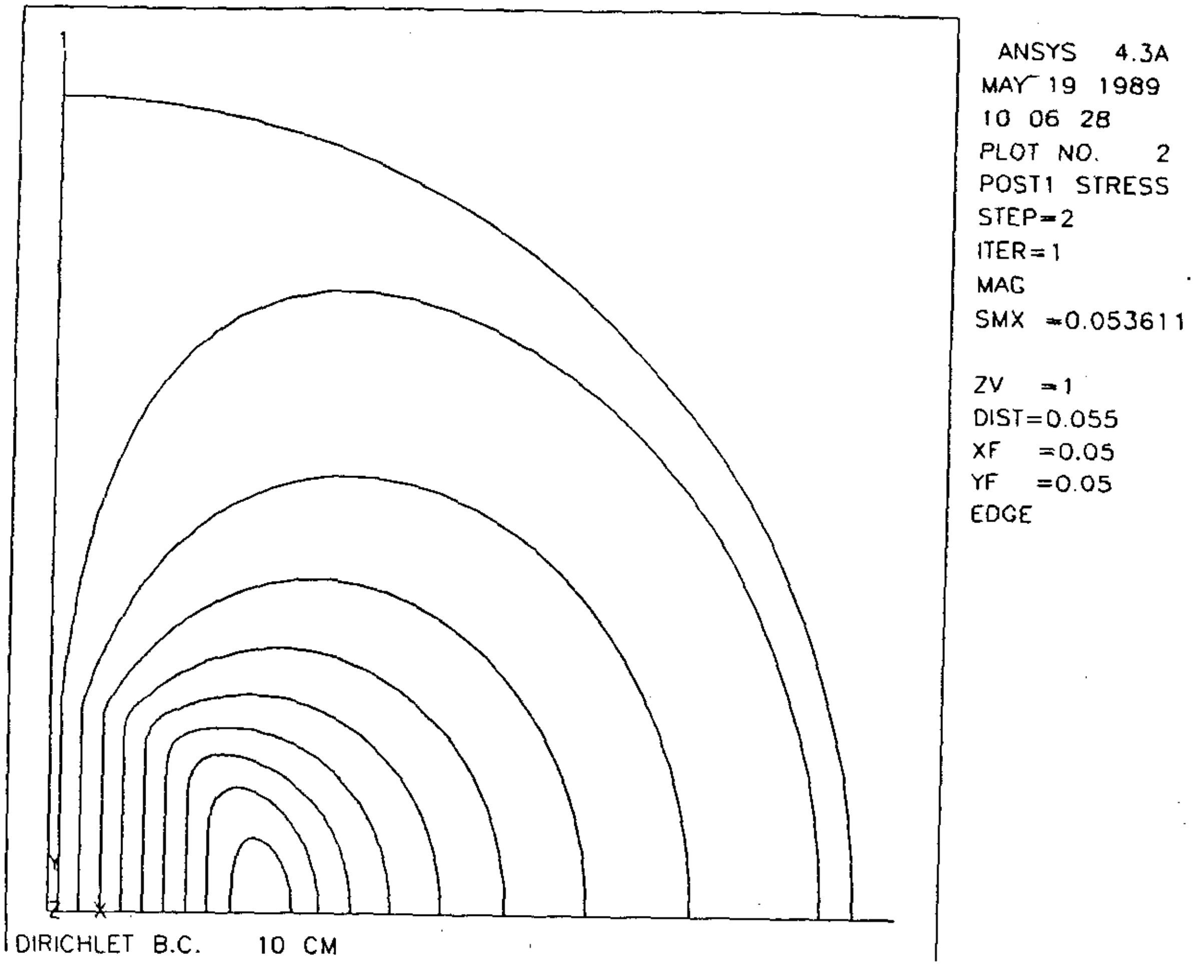
ANSYS 4.3A
MAY 18 1989
12 35 44
PLOT NO. 3
POST1 ELEMENTS

ZV =1
DIST=0.044
XF =0.04
YF =0.04

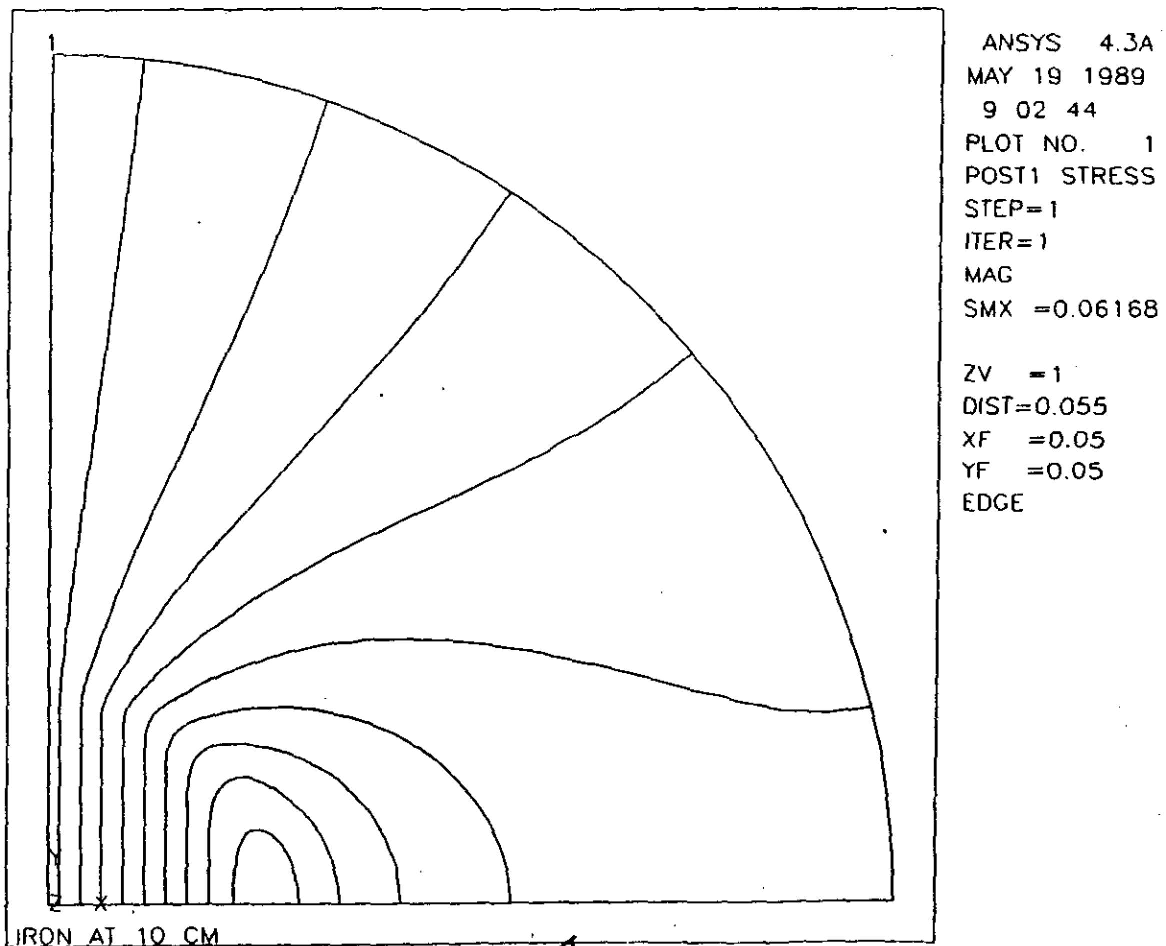
pure dipole.data

Fri, May 19, 1989

	radius (cm)	1	1/r	1/(r^2)	BY @ 0 cm	BY @ 1 cm	
1	-4.000	1.000	-0.250	-6.2500e-2	1.5434712	1.5426019	
2	-5.000	1.000	-0.200	-4.0000e-2	1.8989488	1.8987234	
3	-6.000	1.000	-0.167	-2.7778e-2	2.0924561	2.0923844	
4	-7.000	1.000	-0.143	-2.0408e-2	2.2091450	2.2091195	
5	-8.000	1.000	-0.125	-1.5625e-2	2.2848691	2.2848602	
6	-9.000	1.000	-0.111	-1.2346e-2	2.3367897	2.3367874	Dir.
7	-10.000	1.000	-0.100	-1.0000e-2	2.3739304	2.3739310	
8	100.000	1.000	0.010	1.0000e-4	2.5307132	2.5307166	
9	10.000	1.000	0.100	1.0000e-2	2.6907669	2.6907732	
10	6.000	1.000	0.167	2.7778e-2	2.9725575	2.9726377	Neu.
11	4.000	1.000	0.250	6.2500e-2	3.5227875	3.5236859	



ANSYS 4.3A
MAY 19 1989
10 06 28
PLOT NO. 2
POST1 STRESS
STEP=2
ITER=1
MAG
SMX =0.053611
ZV =1
DIST=0.055
XF =0.05
YF =0.05
EDGE
DIRICHLET B.C. 10 CM



ANSYS 4.3A
MAY 19 1989
9 02 44
PLOT NO. 1
POST1 STRESS
STEP=1
ITER=1
MAG
SMX =0.06168
ZV =1
DIST=0.055
XF =0.05
YF =0.05
EDGE
IRON AT 10 CM

```
c**********************
c**********************
/prep7
/tit,pure dipole
kan,0
c**********************
c********************** define element types
c**********************
et,1,13,               * air
et,2,13,               * inner coil
c********************** material properties
c**********************
knl,1
nl,1,57,1              * mks units
nl,2,55,1
nl,3,55,1
c**********************
k,1,
k,2,.48e-2
k,3,-.48e-2
k,4,4e-2
k,5,5e-2
k,6,6e-2
k,7,7e-2
k,8,8e-2
k,9,9e-2
k,10,10e-2
k,11,100e-2
k,12,,4e-2
k,13,,5e-2
k,14,,6e-2
k,15,,7e-2
k,16,,8e-2
k,17,,9e-2
k,20,,10e-2
k,21,,100e-2
k,22,1e-2
k,23,,1e-2
circ,2,2.5e-2
circ,3,2.5e-2
lint,2,5
lint,3,8
1,26,18
1,18,4
1,30,12
larc,22,23,1,1e-2
larc,4,12,1,4e-2
larc,5,13,1,5e-2
larc,6,14,1,6e-2
larc,7,15,1,7e-2
larc,8,16,1,8e-2
larc,9,17,1,9e-2
larc,10,20,1,10e-2
larc,11,21,1,100e-2
1,4,5,4
1,5,6,3
1,6,7,3
1,7,8,2
1,8,9,2
1,9,10,2
1,10,11,100,10
1,20,21,100,10
a,1,22,23,1
a,22,26,30,23
```



```
al,13,1,2,5
al,14,17,15,2,1
a,4,5,13,12
a,5,6,14,13
a,6,7,15,14
a,7,8,16,15
a,8,9,17,16
a,9,10,20,17
a,10,11,21,20
type,1
mat,1
elsiz,.5e-3,,1
save
amesh,1,2
type,2,
mat,2
amesh,3
type,1
mat,1
elsiz,1e-3,,1
amesh,4
elsiz,3e-3,,1
amesh,5
elsiz,20e-3
amesh,6,11
save
c*****          magnetic b.c.'s
csys,
nsel,x,0
nt,all,mag,0
csys,1
nsel,x,100e-2
nt,all,mag,0
nall
eall
nt,all,temp,0
c*****          magnetic load's
esel,type,2
te,all,,420e6
nall
eall
ktemp,-1
save
csys,1
wsort,y
c****** load step 1
/tit,iron at 100 cm
lwrite
c****** load step 2
csys,1
nsel,x,10e-2
nt,all,mag,0
nall
/tit,iron at 10 cm
lwrite
c****** load step 3
csys,1
nsel,x,9e-2
nt,all,mag,0
nall
/tit,iron at 9 cm
lwrite
c****** load step 4
csys,1
```

```
nsel,x,8e-2
nt,all,mag,0
nall
/tit,iron at 8 cm
lwrite
c******  load step 5
csys,1
nsel,x,7e-2
nt,all,mag,0
nall
/tit,iron at 7 cm
lwrite
c******  load step 6
csys,1
nsel,x,6e-2
nt,all,mag,0
nall
/tit,iron at 6 cm
lwrite
c******  load step 7
csys,1
nsel,x,5e-2
nt,all,mag,0
nall
/tit,iron at 5 cm
lwrite
c*******  load step 8
csys,1
nsel,x,4e-2
nt,all,mag,0
nall
/tit,iron at 4 cm
lwrite
afwrit
fini
/exe
/input,27
fini
/eof
fini
/eof
```