LBL-28853
UC-414

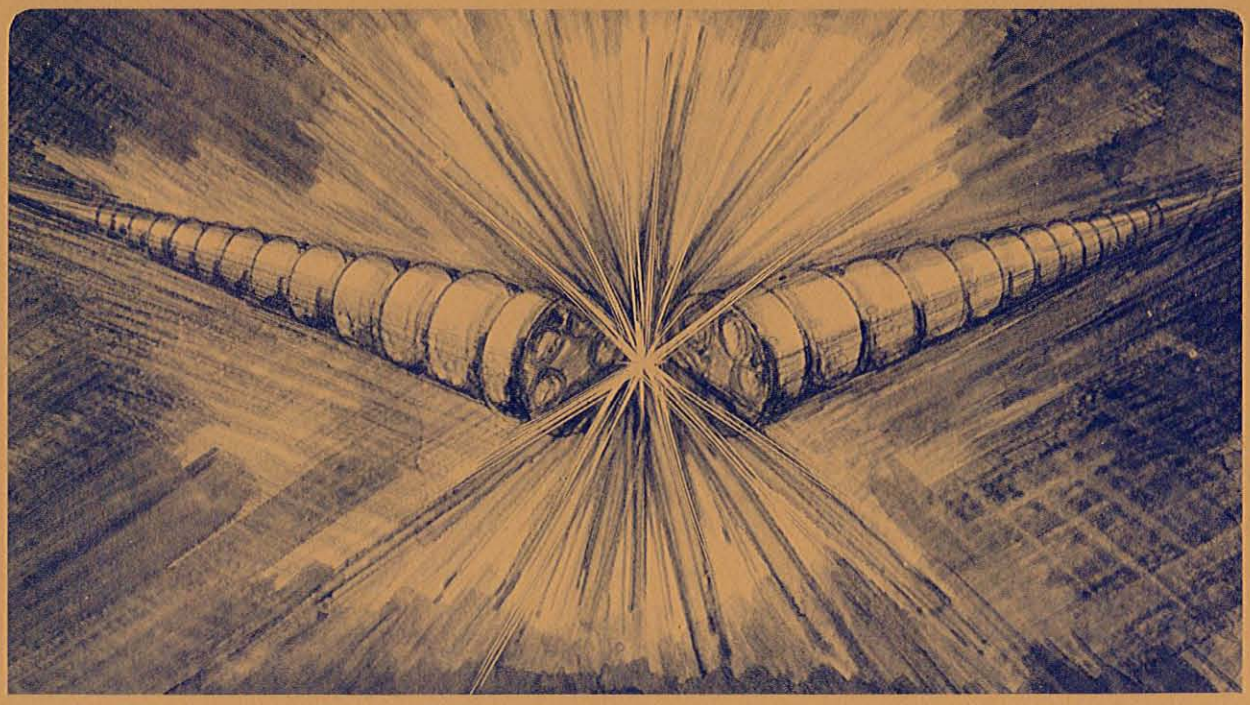
Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Accelerator & Fusion
Research Division

A 5-cm Dipole for the SSC - DE-1

S. Caspi

April 1990



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

DISCLAIMER

Available to DOE and DOE Contractors from the
Office of Scientific and Technical Information
P.O. Box 62, Oak Ridge, TN 37831
Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, VA 22161
Price: Printed Copy A04, Microfiche A01

SC-MAG-283
LBL-28853

A 5cm Dipole for the SSC - DE-1*

S. Caspi

Lawrence Berkeley Laboratory
Accelerator & Fusion Research Division
1 Cyclotron Road
Berkeley, CA 94720

April 30, 1990

*This was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U. S. Department of Energy, under Contract No. DE-AC03-76SF00098.

Abstract

A 5cm SSC superconducting dipole that develops 6.6 tesla at 5790 A is proposed. The two layer magnet has 12% more transfer function than the present design as a result of using thin collars and "close in" iron. The thin collars provide precise positioning of the coils ; they also provide minimum prestress (perhaps 2000 psi) as aid for magnet assembly. A welded skin around the iron provides the final prestress and shapes the coil geometry. A prestressed aluminum bar placed between the vertically split iron yokes provides precise control of the gap between yokes halves and is designed to allow the gap to close tightly during cooldown so that there is no decrease of prestress[1].

In order to reduce the effect of iron saturation on the field multipoles the iron ID has been optimised to an elliptical shape. The coil inner layer is a 30 strand cable with 1.3:1 cu/sc. The outer layer is a 36 strand cable with 1.8:1 cu/sc. At the operating field of 6.6 tesla the current density in the copper is 666 A/mm^2 and 760 A/mm^2 in the inner and outer layers respectivly.

The magnet short sample performance is limited by the inner layer. Operating at 4.35 K the maximum current and central field are 6896 A and 7.95 tesla. The calculated operating short sample temperature at 6.6 tesla and 5798 A is 5.17 K (0.82 K temperature margin). The magnet stored energy is 100.0 (KJ/m) at the 5790 A operating current.

A mechanically similar 5cm bore two layer dipole for the cable test facility (D-16B-1) has been recently built and tested[2]. The magnet had no collars and the iron was placed directly on the coil OD. The magnet's first quench was at 7 tesla with 6000 A and it reached 7.6 tesla at 6600 A.

Following are tables and Figures associated with the design.

---

[1] "Design of Coil Containment Structure for Cable Test Facility Dipole Magnet" — C.Peters,, SC-MAG-265, November 15, 1989.

[2] "Design and Construction of a 5-cm Bore , 7.5 T Dipole for SSC Short Sample Testing", SC-MAG-269; LBL-28086a, March 1990.

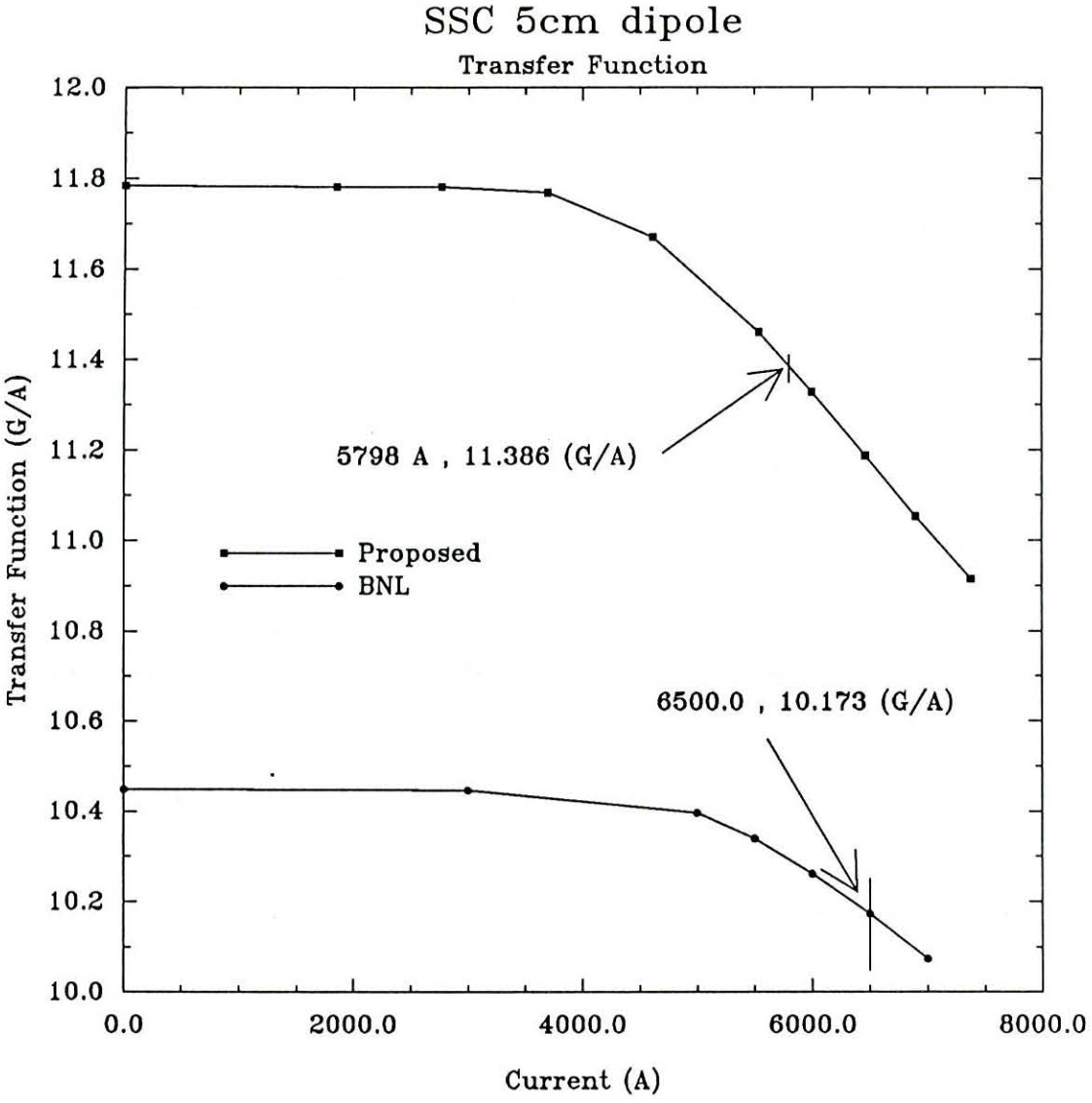


Figure 1 Transfer function.

	Cu/SC	Bo(T)	Io (A)	Jcu(Io) A/mm^2	Bc(T)	To(K) F=1.0	To(K) F=0.95	Iss(A) F=1.0	Iss(A) F=0.95	Bc_ss(T) F=1.0	Bc_ss(T) F=0.95	Tss(K)
DE-1	1.0:1	6.6	5790	753	6.86	5.29	5.24	7111	7034	8.16	8.09	4.35
DE-1	1.3:1	6.6	5790	666	6.86	5.17	5.12	6896	6814	7.956	7.87	4.35
BNL		6.6	6500	748	6.91	5.03	5.03	7460	-	7.8	-	4.35
DE-1	1.5:1	6.6	5790	628	6.86	5.09	5.04	6762	6677	7.82	7.74	4.35
BNL		6.6	6500	705	6.91	4.94	4.94	7300	-	7.65	-	4.35

Table 1 Operating and short sample values for the 30 strand inner layer (see nomenclature in Fig. 2).

	Cu/SC	DT(K)	DT/Tss%	DI(A)	DI/Io%	DB(T)	DB/Bo%
DE-1	1.0:1	0.94	21.6	1321	22.8	1.30	18.95
DE-1	1.3:1	0.82	18.9	1106	19.1	1.10	16.0
BNL		0.68	15.6	960	14.8	0.89	12.9
DE-1	1.5:1	0.74	17.0	972	16.8	0.96	14.0
BNL		0.59	13.6	800	12.3	0.74	10.7

Table 2 Temperature , Current and Field Margins for the 30 strand inner layer (F=1.0).

DT=To — Tss DI = Iss — Io

DB = Bc_ss — Bc ; F=1.0 (no degradation = 2750 (A/mm^2) at 5 T, 4.2K) ; F=0.95 corresponds to a 5% degradation.

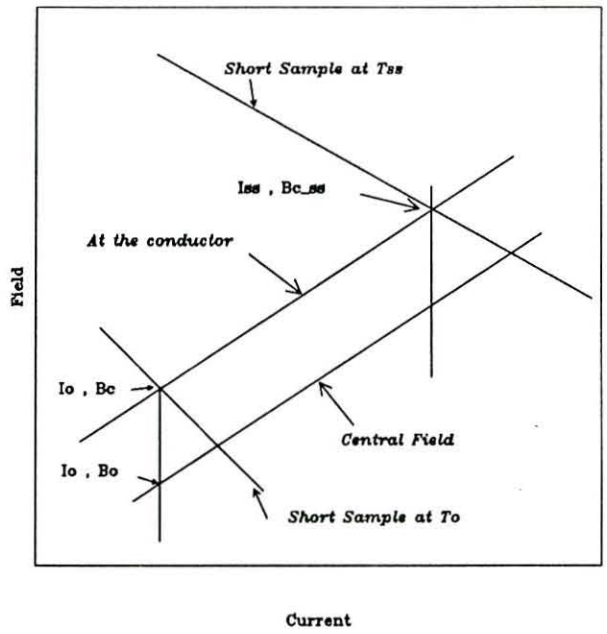


Figure 2 Nomenclature

LAYER	N strands	Diameter inch	CU:SC	Asc/turn (mm^2)	Acu/turn (mm^2)	Jc(4.2K,5T) (A/mm^2)
INNER	30	0.0318	1.3:1	6.684	8.689	2750
OUTER	36	0.0255	1.8:1	4.236	7.625	2750

Table 3 Cable parameters for the two layer dipole.

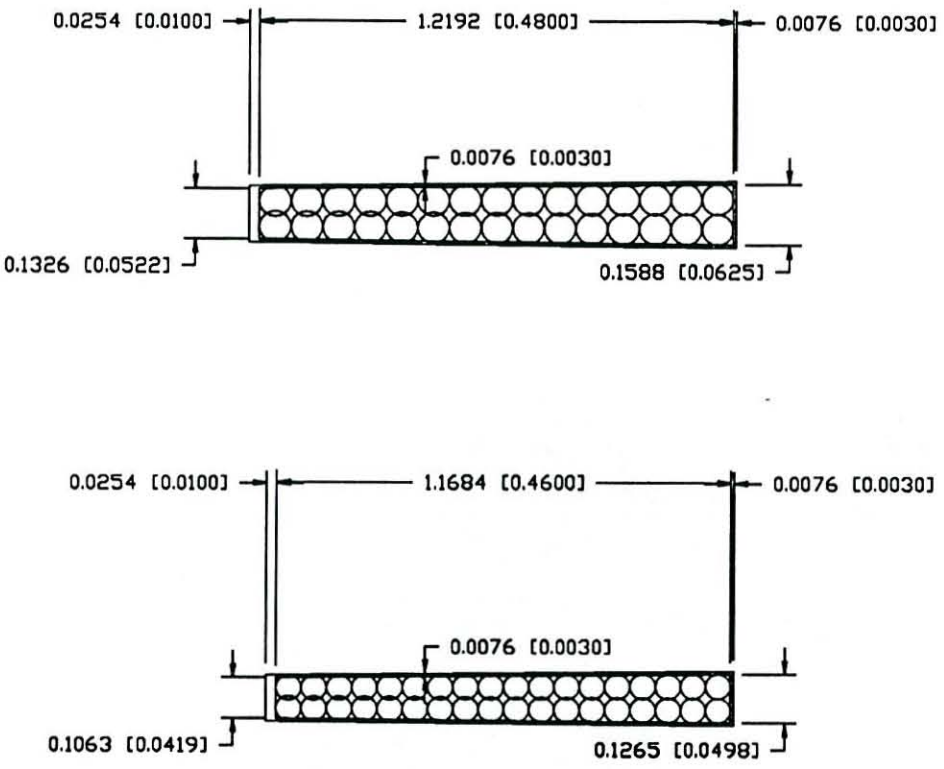


Figure 3 Top – 30 strand inner layer cable and bottom – 36 strand outer layer cable .

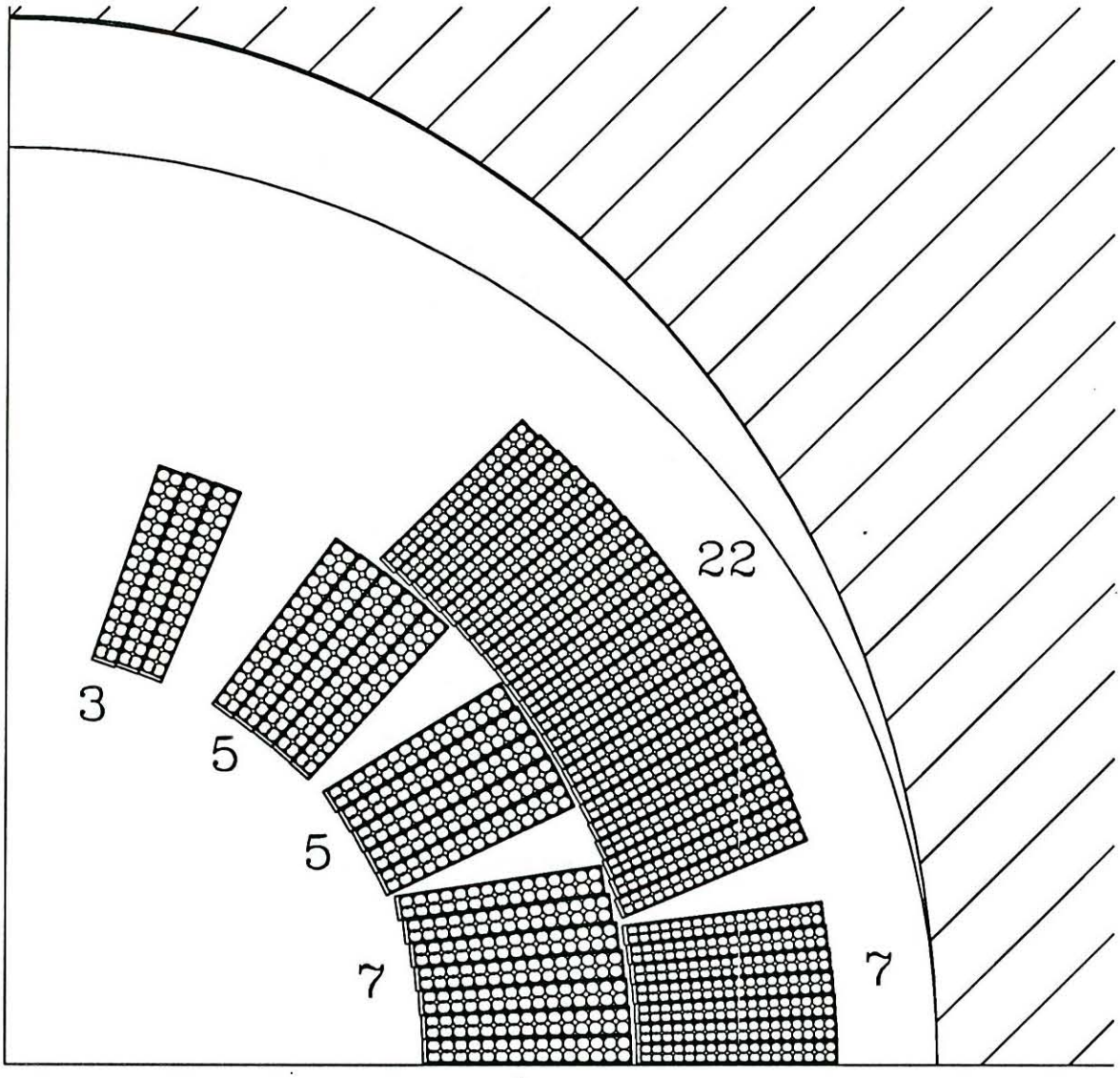


Figure 4 Coil closeup.

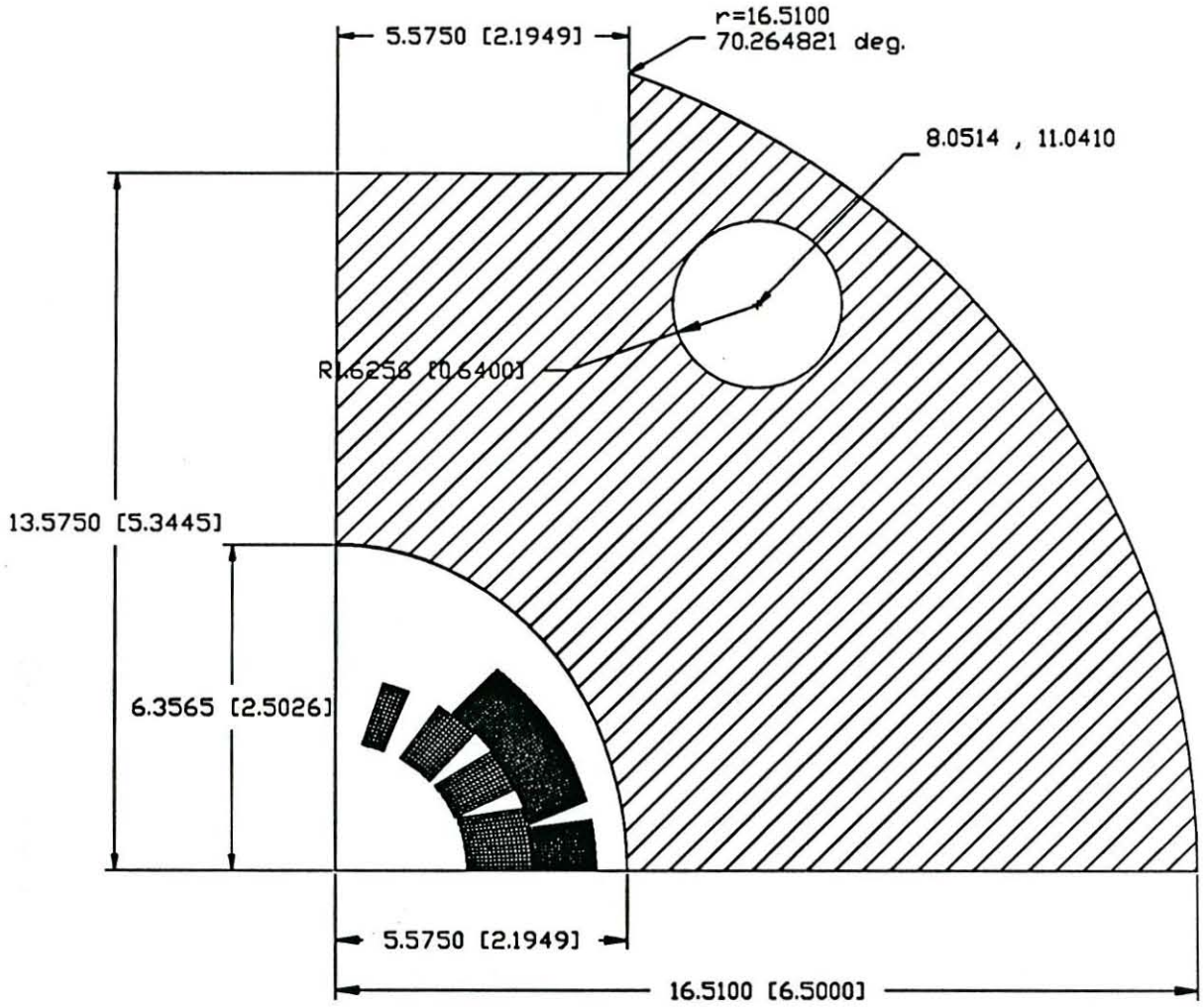


Figure 5 Magnet cross section

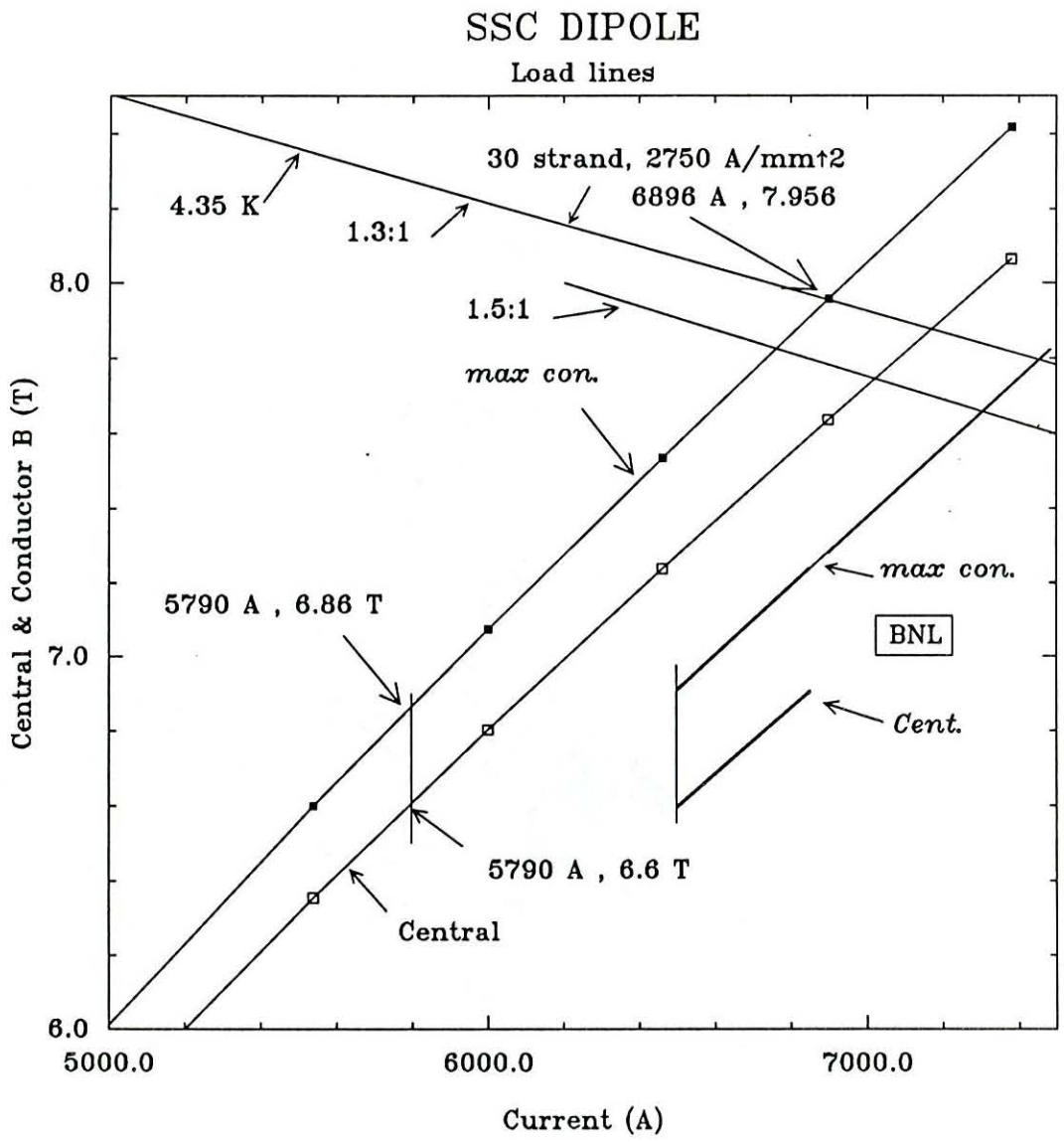


Figure 6 Load lines and short sample curves

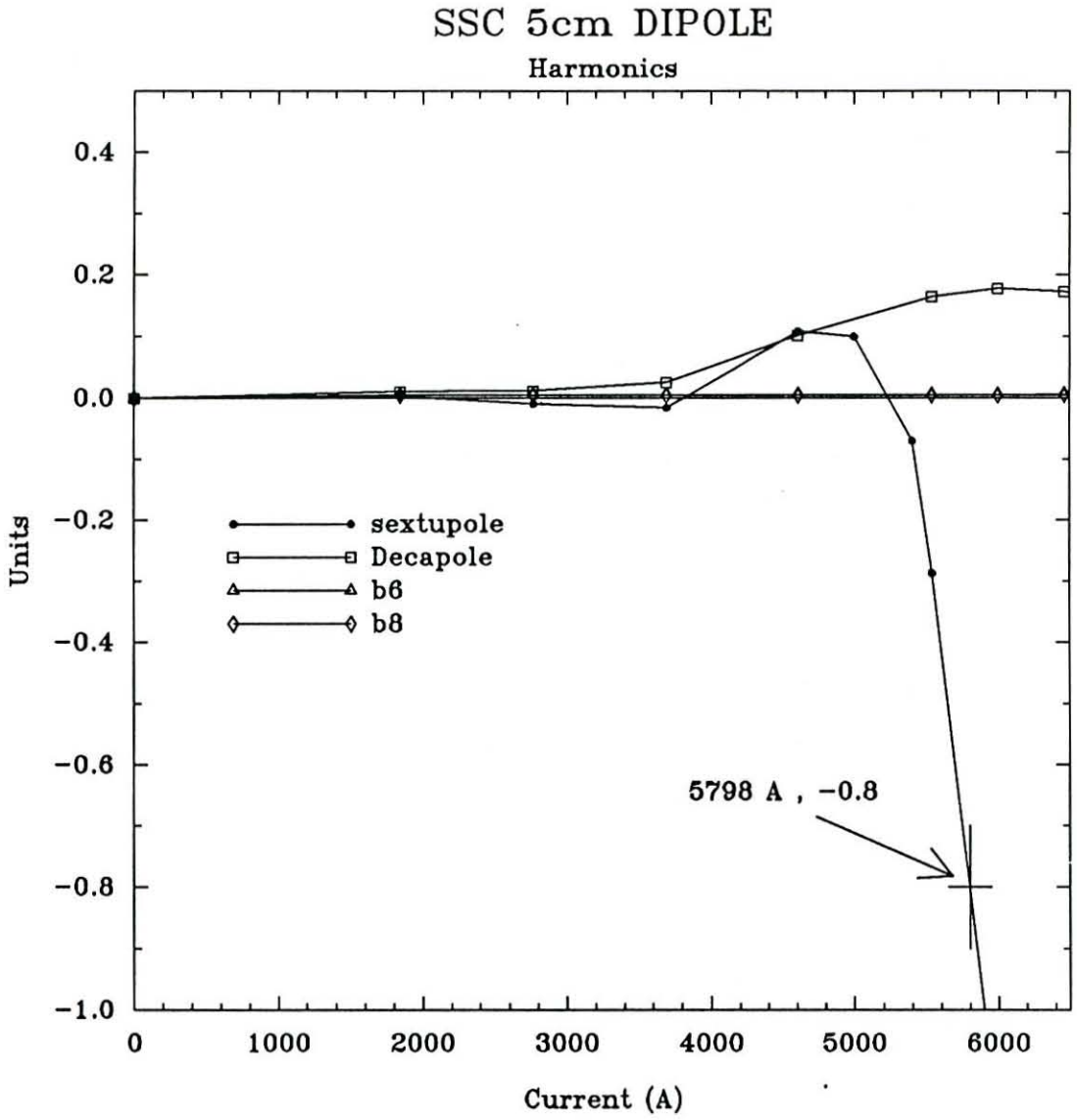


Figure 7 Harmonics

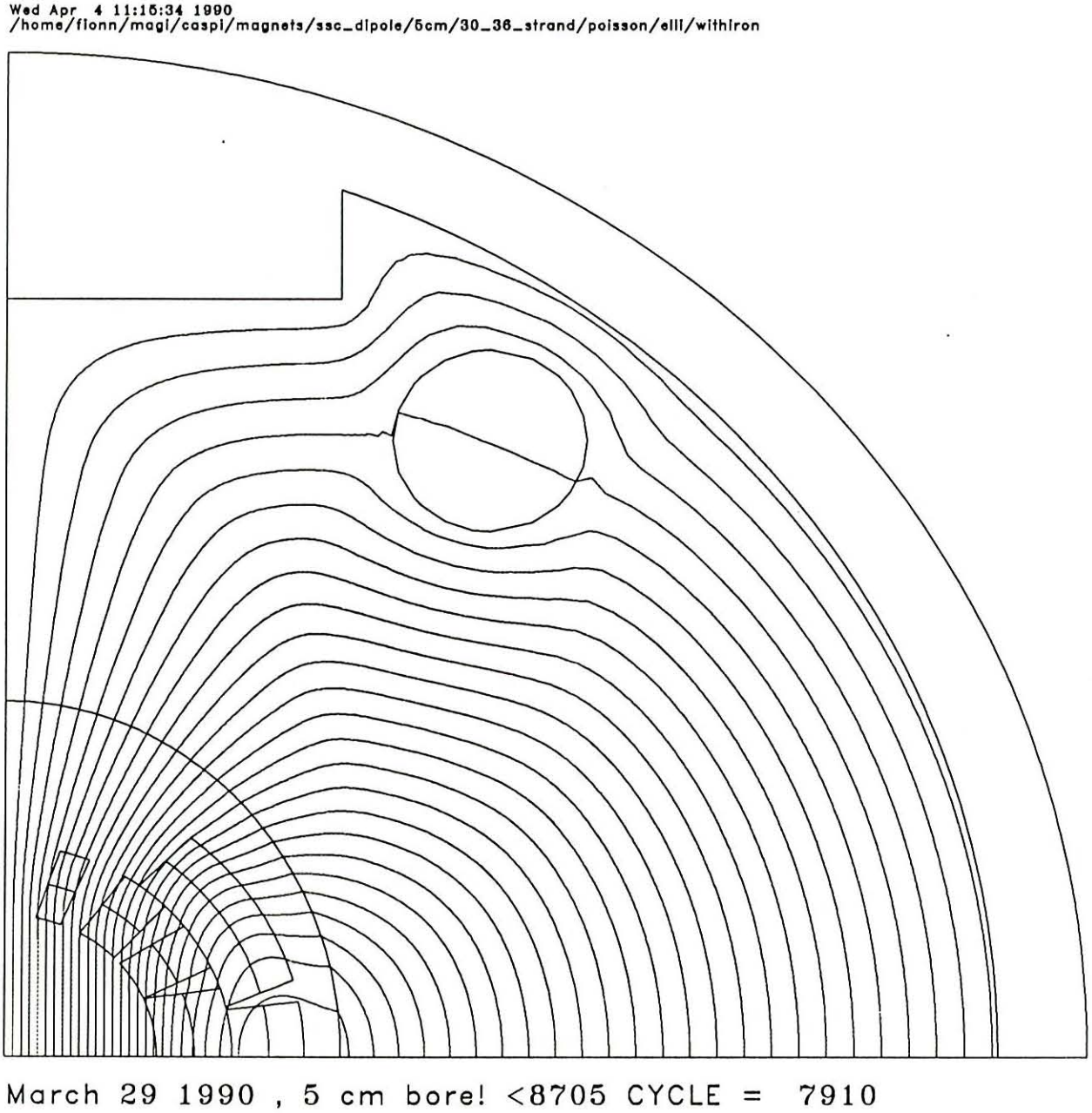


Figure 8 Flux plot at 6.6 tesla , from POISSON.

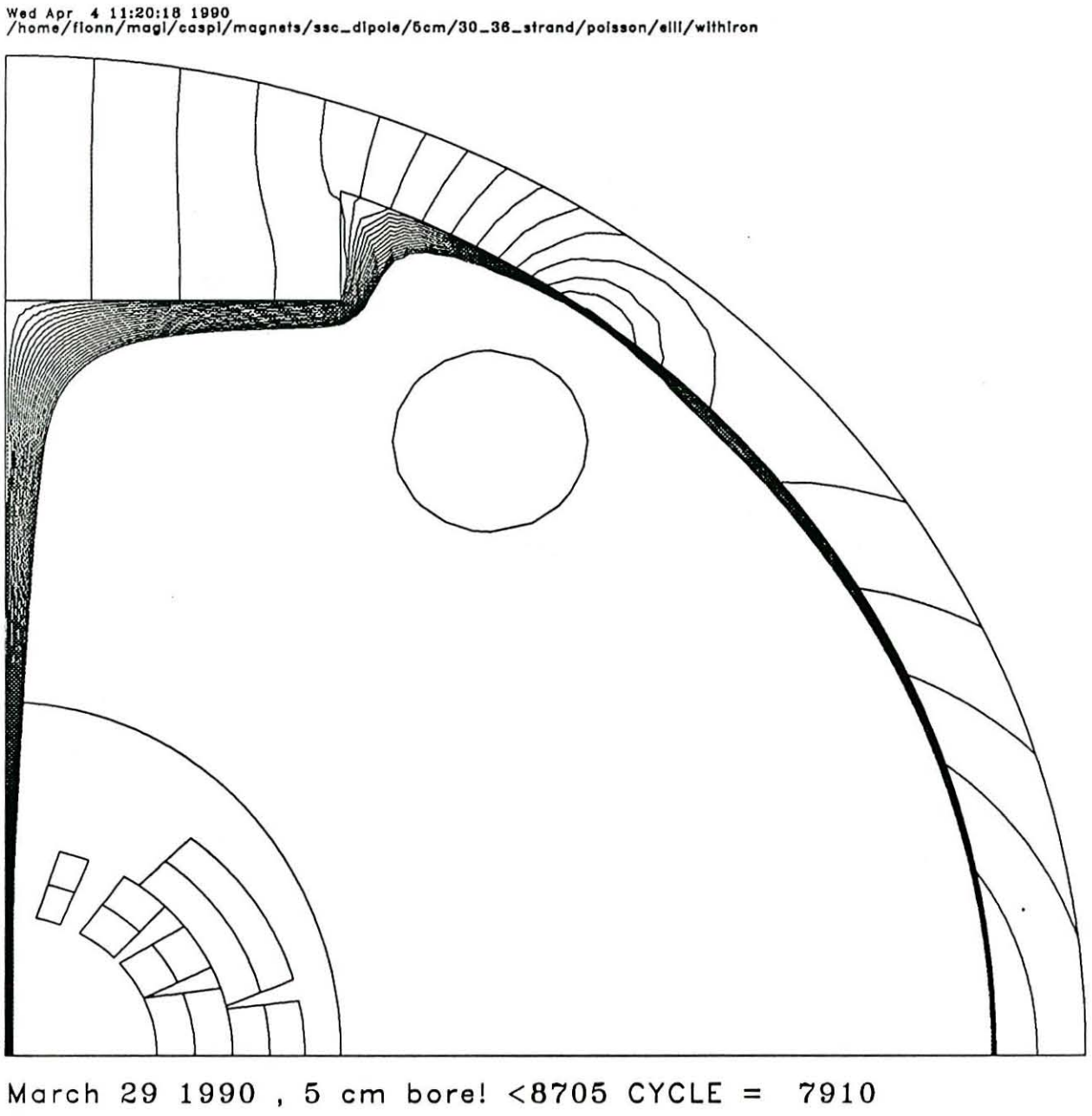


Figure 9 Fringe field.

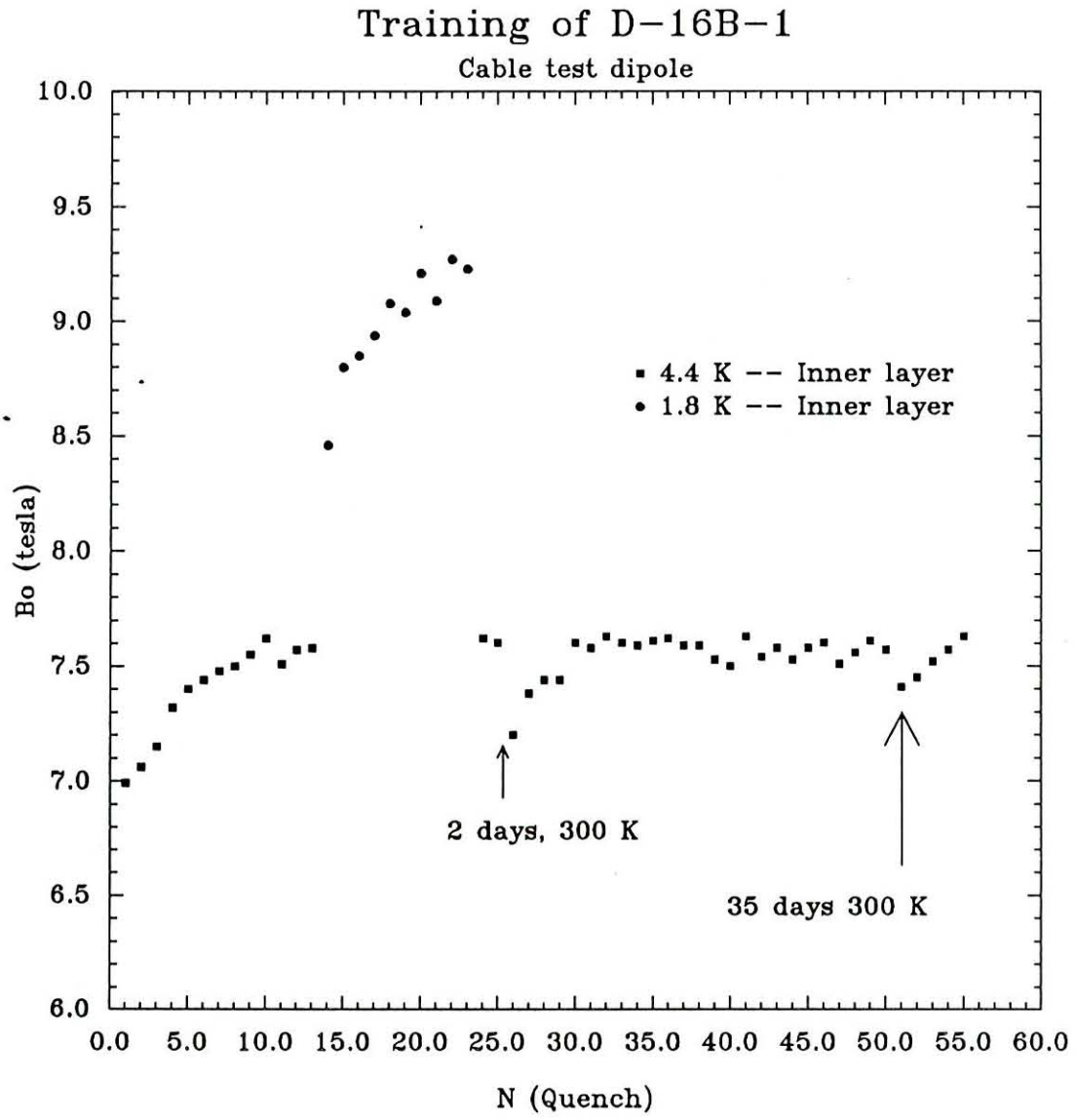


Figure 10 Performance of a 5cm bore dipole with, two layers of 28 and 36 strands , 4 wedges and close in iron.

Appendix A PK input and output.

INPUT

```
 NEW SSC DIPOLE 30 strands inner 36 outer march 29 1990
        1 N1         .7000E+01 .2000E+01 .4000E+01 .1000E+02
        2 W2         .7200E+00 .1000E-06 .7200E+00 .3000E+01
        3 N3         .5000E+01 .2000E+01 .5000E+01 .1000E+02
        4 W4         .2706E+01 .2360E-06 .3500E+00 .9000E+01
        5 N5         .5000E+01 .2000E+01 .4000E+01 .9000E+01
        6 W6         .7614E+01 .1000E-06 .7500E+00 .9000E+01
        7 N7         .3000E+01 .2000E+01 .2000E+01 .5000E+01
       11 N11        .7000E+01 .3000E+01 .3000E+01 .1300E+02
       12 W12        .7975E+00 .4984E-06 .7200E+00 .4000E+01
       13 N13        .2200E+02 .3000E+01 .1300E+02 .2500E+02

$FCNIN RFE=5.575  ,ROPT=1.0,QUAD=.false.,DIPOLE=.true.,LSYM=4
 align=.false. AMP=6000.0 $
$crit t0 = 4.35  nstrands(1) = 30 nstrands(2)= 36
     ds(1) = 0.0318  ds(2) = 0.0255
     rcusc(1) = 1.3 rcusc(2) = 1.8 f(1) = 1.0 f(2) = 1.0
     jm(1) = 2750.0 jm(2) = 2750.
     tbm(1) = 4.2 tbm(2) = 4.2
     bm(1) = 5.0 bm(2) = 5.0 $
   1    4
2        -21.64     1.  <---------- required at ROPT=1.25 cm
4        -0.4985    1.  <---------- required at ROPT=1.25 cm
6        0.0        1.
8        0.0        1.
   2
1  4.0   7.         2.5247       3.7439    1.        63.40      10.3
2  4.0   3.         3.8049       4.9733    1.        51.77      7.95
$TWIST pb(5) = 16.0     pb(3) = 17.0 pb(7)=13.8672 $
$KEY $
$WIDTH $
FIX                1
FIX                3
FIX                5
FIX                7
FIX               11
FIX               13
CALL FCN           3
CALL FCN           6
PUNCH
EXIT
END
```

OUTPUT

Transfer function = 12.463572

0 N	BN/B0	BPR	BEFF	AN/B0	APR	AEFF
0	0.1000E+01	10000.00	18.13	0.0000E+00	0.00	0.00
2	-0.1385E-02	-13.85	-0.03	0.0000E+00	0.00	0.00
4	-0.1991E-04	-0.20	0.00	0.0000E+00	0.00	0.00
6	0.2155E-05	0.02	0.00	0.0000E+00	0.00	0.00
8	0.3247E-05	0.03	0.00	0.0000E+00	0.00	0.00
10	-0.2881E-06	0.00	0.00	0.0000E+00	0.00	0.00
12	0.3178E-07	0.00	0.00	0.0000E+00	0.00	0.00
14	0.1265E-07	0.00	0.00	0.0000E+00	0.00	0.00
16	-0.5316E-08	0.00	0.00	0.0000E+00	0.00	0.00
18	0.2715E-09	0.00	0.00	0.0000E+00	0.00	0.00

0B EVALUATED AT R = 1.00000

0NEXT COMMAND...
****
*** 8****CALL FCN 6.00000
****
Peak fields and critical currents

Layer 1: Bpeak = 7.7743 T at (0.5423, 2.5806) on the Top
Superconducting cable geometry:
Operating temperature is 4.35 K
# strands = 30 strand dia = 0.031800 in , Cu:SC = 1.30 degradation factor = 1.00
Jc = 2750.0 A/mm^2, Bm = 5.00 T @ 4.20 K
Area-SC = .6684E-01 cm^2/turn; Area-Cu = .8689E-01cm^2/turn;
Jcu = 690.5624 A/mm^2/turn

b[t]	ic@p1[a]	-or+100a/mm2	
4.00000000	20987.2431	-763.172477	763.172477
4.20000000	20267.7228	-737.008100	737.008100
4.40000000	19548.5807	-710.857478	710.857478
4.60000000	18829.8496	-684.721804	684.721804
4.80000000	18111.5663	-658.602410	658.602410
5.00000000	17393.7719	-632.500796	632.500796
5.20000000	16676.5128	-606.418649	606.418649
5.40000000	15959.8416	-580.357877	580.357877
5.60000000	15243.8178	-554.320647	554.320647
5.80000000	14528.5092	-528.309426	528.309426
6.00000000	13813.9937	-502.327043	502.327043
6.20000000	13100.3606	-476.376748	476.376748
6.40000000	12387.7133	-450.462301	450.462301
6.60000000	11676.1720	-424.588073	424.588073
6.80000000	10965.8773	-398.759175	398.759175
7.00000000	10256.9946	-372.981624	372.981624
7.20000000	9549.72008	-347.262548	347.262548
7.40000000	8844.28773	-321.610463	321.610463
7.60000000	8140.97950	-296.035618	296.035618
7.80000000	7440.13789	-270.550469	270.550469
8.00000000	6742.18323	-245.170299	245.170299
8.20000000	6047.63710	-219.914076	219.914076

```
 8.40000000          5357.15475          -194.805627          194.805627
 8.60000000          4671.57093          -169.875307          169.875307
 8.80000000          3991.96579          -145.162392          145.162392
 9.00000000          3319.76223          -120.718626          120.718626
 Icp/Io = 1.2550 Bco/Bp = 1.0565, Bss = 8.1337 T @ 6277.3671 A
 Layer  2: Bpeak =     6.7297 T at (    2.3372,   3.1847  )  on the Top
 Superconducting cable geometry:
 Operating temperature is   4.35 K
 # strands =  36 strand dia = 0.025500 in , Cu:SC = 1.80 degradation factor = 1.00
 Jc =   2750.0 A/mm^2, Bm = 5.00 T @ 4.20 K
 Area-SC = .4236E-01 cm^2/turn; Area-Cu = .7625E-01cm^2/turn;
 Jcu =  786.8585 A/mm^2/turn
b[t]                 ic@pl[a]          -or+100a/mm2
 4.00000000          13302.4785          -483.726490          483.726490
 4.20000000          12846.4203          -467.142556          467.142556
 4.40000000          12390.6019          -450.567340          450.567340
 4.60000000          11935.0440          -434.001598          434.001598
 4.80000000          11479.7698          -417.446176          417.446176
 5.00000000          11024.8056          -400.902023          400.902023
 5.20000000          10570.1808          -384.370209          384.370209
 5.40000000          10115.9284          -367.851944          367.851944
 5.60000000          9662.08648          -351.348599          351.348599
 5.80000000          9208.69788          -334.861741          334.861741
 6.00000000          8755.81193          -318.393161          318.393161
 6.20000000          8303.48529          -301.944920          301.944920
 6.40000000          7851.78350          -285.519400          285.519400
 6.60000000          7400.78275          -269.119373          269.119373
 6.80000000          6950.57212          -252.748077          252.748077
 7.00000000          6501.25649          -236.409327          236.409327
 7.20000000          6052.96013          -220.107641          220.107641
 7.40000000          5605.83143          -203.848416          203.848416
 7.60000000          5160.04908          -187.638148          187.638148
 7.80000000          4715.83017          -171.484733          171.484733
 8.00000000          4273.44110          -155.397858          155.397858
 8.20000000          3833.21248          -139.389545          139.389545
 8.40000000          3395.55965          -123.474896          123.474896
 8.60000000          2961.01167          -107.673152          107.673152
 8.80000000          2530.25320          -92.0092072          92.0092072
 9.00000000          2104.18612          -76.5158588          76.5158588
 Icp/Io = 1.1848 Bco/Bp = 1.0734, Bss = 7.0830 T @ 6315.0385 A
```

poisson stuff for CIRCULAR high density high μ iron

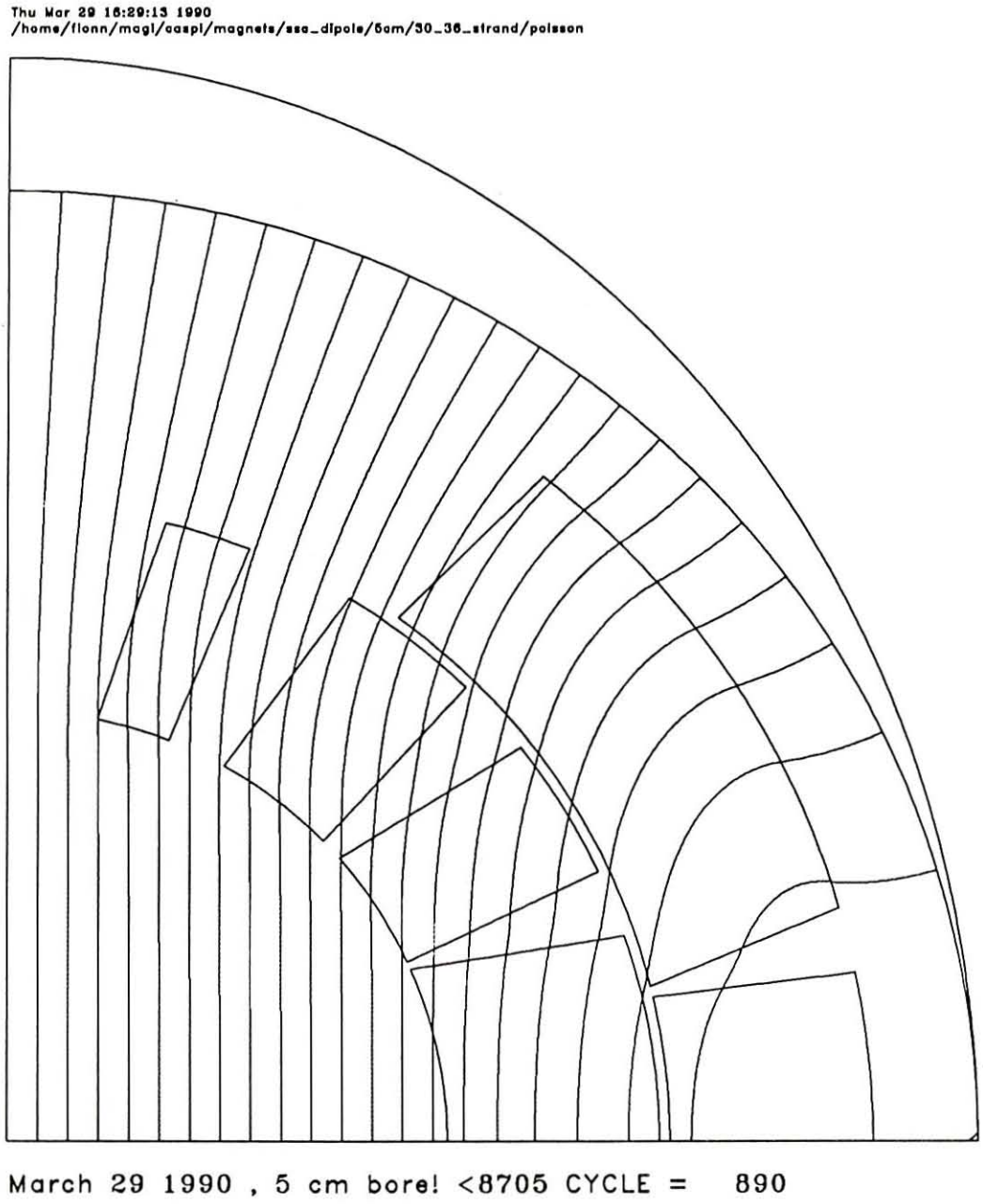


Figure 11 High density POISSON output for circular iron at r=5.575 cm.

AUTOMESH

```
March 29 1990 , 5 cm bore! <870527.0922>
$geo NREG=8   XMAX=5.5750  YMAX=6.3565
      dx=0.05 $
$reg npoint=9 mat=1 $
$PO  X=0.0 Y=0.0$
$PO  nt=1 x0=0.0 y0=0.0 r=2.5247 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.7439 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.8049 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=4.9733 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=5.5750 theta=0.0 $
$PO  nt=4 x0=0.0 y0=0.0 r=6.3565 theta=90.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=5.575  theta=90.0 $
$PO  x=0.0 y=0.0 $
$REG mat=1 NPOINT=4 $
$PO nt = 1 x0=0.0 y0=0.0 r= 5.5750 theta=0.0 $
$PO NT=4 X0=0.0 Y0=0.0 R=6.3565 THETA=90.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=5.5750 THETA=90.0 $
$PO NT=2 X0=0.0 Y0=0.0 R=5.5750 THETA=0.0 $
$REG mat=1 cur=-42000.0 NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=0.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.7439 THETA=0.0 $
$PO NT=2 X0=0.0 Y0=0.0 R=3.7439 THETA=18.7505 $
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=23.5518   $
$PO NT=2 X0=0.0 Y0=0.0 R=2.5247 THETA=0.0 $
$REG mat=1 cur=-30000.0 NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r= 2.5247 THETA= 24.62795  $
$PO NT=1 x0=0.0 y0=0.0 r= 3.7439    THETA=24.9473    $
$PO NT=2 x0=0.0 y0=0.0 r= 3.7439   theta=38.0432  $
$PO NT=1 x0=0.0 y0=0.0 R= 2.5247 THETA=41.05246 $
$PO NT=2 x0=0.0 y0=0.0 R=2.5247 THETA=24.62795   $
$REG mat=1 cur=-30000.0 NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r= 2.5247 THETA=44.12712 $
$PO NT=1 x0=0.0 y0=0.0 r= 3.7439 theta=45.3070 $
$PO NT=2 x0=0.0 y0=0.0 r= 3.7439 theta=58.3948 $
$PO NT=1 x0=0.0 y0=0.0 R=2.5247 THETA=60.55156 $
$PO NT=2 x0=0.0 y0=0.0 R=2.5247 THETA= 44.12712 $
$REG mat=1 cur=-18000. NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=68.50 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.7439  THETA=68.2611 $
$PO NT=2 X0=0.0 Y0=0.0 R=3.7439  THETA=76.02156 $
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=78.2147 $
$PO NT=2 X0=0.0 Y0=0.0 R=2.5247 THETA=68.50 $
$REG mat=1 cur=-42000. NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r=3.8049  THETA=0.0 $
$PO NT=1 x0=0.0 y0=0.0 r=4.9733 theta=0.0 $
$PO NT=2 x0=0.0 y0=0.0 r=4.9733 theta=11.4562 $
$PO NT=1 x0=0.0 y0=0.0 R= 3.8049 THETA=12.8409 $
$PO NT=2 x0=0.0 y0=0.0 R= 3.8049 THETA=0.0 $
$REG mat=1 cur=-132000.0 NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R= 3.8049 THETA=13.81276 $
$PO NT=1 X0=0.0 Y0=0.0 R= 4.9733 THETA=15.9473 $
$PO NT=2 X0=0.0 Y0=0.0 R= 4.9733 THETA=51.7280 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.8049  THETA= 53.861588 $
$PO NT=2 X0=0.0 Y0=0.0 R= 3.8049 THETA= 13.81276 $
```

POISSON INPUT

```
0  dump
*6 -2
```

```
*66 1.0
*46 6
*43 21
*45 21
*54 0.5 0.6 2.55 2.65
*110 10 19 1.0 90. 1.0 0.0 S COUNT
-1 dump
```

POISSON OUTPUT

```
-
 April 17 1990 , 5 cm bore! <8705

 XJFACT = 1 , Mu infinite

0 13  62  -4.385105E+04    0.58000    2.63000    2805.587   78119.888   78170.252   -8.4374E+03    1.4692E+04

0Pole Pairs      N(AN)/R        N(An)/R/A1     N(BN)/R        N(Bn)/R/B1     ABS(N(CN)/R)      Units
 Dipole       -7.4794E+04     1.0000E+04    0.0000E+00     0.0000E+00     7.4794E+04     10000.0000
 Sextupole     9.8284E+01    -1.3141E+01    0.0000E+00     0.0000E+00     9.8284E+01       -13.1406
 Decapole      1.2792E+00    -1.7104E-01    0.0000E+00     0.0000E+00     1.2792E+00        -0.1710
 14-pole      -1.2291E-01     1.6433E-02    0.0000E+00     0.0000E+00     1.2291E-01         0.0164
 18-pole      -1.6972E-01     2.2691E-02    0.0000E+00     0.0000E+00     1.6972E-01         0.0227
 22-pole       6.0490E-02    -8.0876E-03    0.0000E+00     0.0000E+00     6.0490E-02        -0.0081
 26-pole      -7.0624E-03     9.4425E-04    0.0000E+00     0.0000E+00     7.0624E-03         0.0009
 30-pole      -7.0823E-03     9.4691E-04    0.0000E+00     0.0000E+00     7.0823E-03         0.0009
 34-pole       4.2967E-02    -5.7447E-03    0.0000E+00     0.0000E+00     4.2967E-02        -0.0057
 38-pole       5.4120E-02    -7.2359E-03    0.0000E+00     0.0000E+00     5.4120E-02        -0.0072
```

poisson stuff for ELLIPTICAL high density high μ iron

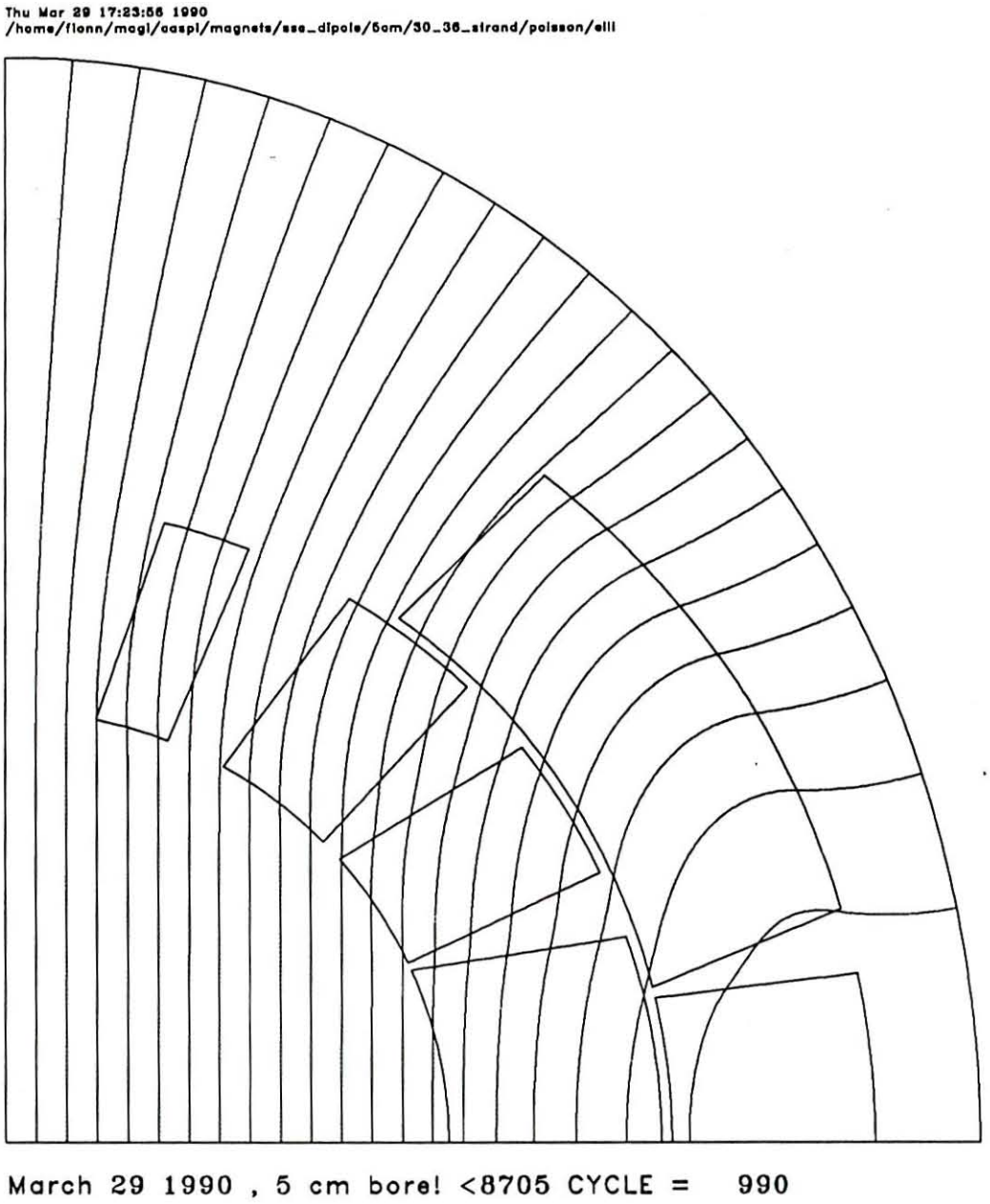


Figure 12 High density POISSON output for elliptical iron at x=5.575 cm. y=6.3565 cm

AUTOMESH

```
March 29 1990 , 5 cm bore! <870527.0922>
$geo NREG=8   XMAX=5.5750  YMAX=6.3565
      dx=0.05 $
$reg npoint=9 mat=1 $
$PO  X=0.0 Y=0.0$
$PO  nt=1 x0=0.0 y0=0.0 r=2.5247 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.7439 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.8049 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=4.9733 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=5.5750 theta=0.0 $
$PO  nt=4 x0=0.0 y0=0.0 r=6.3565 theta=90.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=5.575  theta=90.0 $
$PO  x=0.0 y=0.0 $
$REG mat=1 NPOINT=4 $
$PO nt = 1 x0=0.0 y0=0.0 r= 5.5750 theta=0.0 $
$PO NT=4 X0=0.0 Y0=0.0 R=6.3565 THETA=90.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=5.5750 THETA=90.0 $
$PO NT=2 X0=0.0 Y0=0.0 R=5.5750 THETA=0.0 $
$REG mat=1 cur=-42000.0 NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=0.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.7439 THETA=0.0 $
$PO NT=2 X0=0.0 Y0=0.0 R=3.7439 THETA=18.7505 $
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=23.5518   $
$PO NT=2 X0=0.0 Y0=0.0 R=2.5247 THETA=0.0 $
$REG mat=1 cur=-30000.0 NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r= 2.5247 THETA= 24.62795  $
$PO NT=1 x0=0.0 y0=0.0 r= 3.7439    THETA=24.9473    $
$PO NT=2 x0=0.0 y0=0.0 r= 3.7439   theta=38.0432  $
$PO NT=1 x0=0.0 y0=0.0 R= 2.5247 THETA=41.05246 $
$PO NT=2 x0=0.0 y0=0.0 R=2.5247 THETA=24.62795   $
$REG mat=1 cur=-30000.0 NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r= 2.5247 THETA=44.12712 $
$PO NT=1 x0=0.0 y0=0.0 r= 3.7439 theta=45.3070 $
$PO NT=2 x0=0.0 y0=0.0 r= 3.7439 theta=58.3948 $
$PO NT=1 x0=0.0 y0=0.0 R=2.5247 THETA=60.55156 $
$PO NT=2 x0=0.0 y0=0.0 R=2.5247 THETA= 44.12712 $
$REG mat=1 cur=-18000. NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=68.50 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.7439  THETA=68.2611 $
$PO NT=2 X0=0.0 Y0=0.0 R=3.7439  THETA=76.02156 $
$PO NT=1 X0=0.0 Y0=0.0 R=2.5247 THETA=78.2147 $
$PO NT=2 X0=0.0 Y0=0.0 R=2.5247 THETA=68.50 $
$REG mat=1 cur=-42000. NPOINT=5$
$PO NT=1 x0=0.0 y0=0.0 r=3.8049  THETA=0.0 $
$PO NT=1 x0=0.0 y0=0.0 r=4.9733 theta=0.0 $
$PO NT=2 x0=0.0 y0=0.0 r=4.9733 theta=11.4562 $
$PO NT=1 x0=0.0 y0=0.0 R= 3.8049 THETA=12.8409 $
$PO NT=2 x0=0.0 y0=0.0 R= 3.8049 THETA=0.0 $
$REG mat=1 cur=-132000.0 NPOINT=5$
$PO NT=1 X0=0.0 Y0=0.0 R= 3.8049 THETA=13.81276 $
$PO NT=1 X0=0.0 Y0=0.0 R= 4.9733 THETA=15.9473 $
$PO NT=2 X0=0.0 Y0=0.0 R= 4.9733 THETA=51.7280 $
$PO NT=1 X0=0.0 Y0=0.0 R=3.8049  THETA= 53.861588 $
$PO NT=2 X0=0.0 Y0=0.0 R= 3.8049 THETA= 13.81276 $
```

POISSON INPUT

```
0  dump
*6 -2
```

```
*66 1.0
*46 6
*43 21
*45 21
*54 0.5 0.6 2.55 2.65
*110 10 19 1.0 90. 1.0 0.0 S COUNT
-1 dump
```

POISSON OUTPUT

```
-
 April 17 1990 , 5 cm bore! <8705

 XJFACT = 1 , Mu infinite

0 13  62  -4.113954E+04    0.58000    2.63000    3057.824   73451.639   73515.261   -8.8891E+03    1.4697E+04

0Pole Pairs      N(AN)/R        N(An)/R/A1      N(BN)/R        N(Bn)/R/B1      ABS(N(CN)/R)      Units
 Dipole       -7.0752E+04     1.0000E+04     0.0000E+00     0.0000E+00     7.0752E+04     10000.0000
 Sextupole    -4.3237E+00     6.1111E-01     0.0000E+00     0.0000E+00     4.3237E+00         0.6111
 Decapole     -1.7004E-01     2.4034E-02     0.0000E+00     0.0000E+00     1.7004E-01         0.0240
 14-pole      -1.2690E-01     1.7936E-02     0.0000E+00     0.0000E+00     1.2690E-01         0.0179
 18-pole      -1.8256E-01     2.5803E-02     0.0000E+00     0.0000E+00     1.8256E-01         0.0258
 22-pole       6.8101E-02    -9.6253E-03     0.0000E+00     0.0000E+00     6.8101E-02        -0.0096
 26-pole       3.0965E-02    -4.3766E-03     0.0000E+00     0.0000E+00     3.0965E-02        -0.0044
 30-pole       9.6226E-03    -1.3600E-03     0.0000E+00     0.0000E+00     9.6226E-03        -0.0014
 34-pole       2.9262E-02    -4.1358E-03     0.0000E+00     0.0000E+00     2.9262E-02        -0.0041
 38-pole       3.9711E-02    -5.6127E-03     0.0000E+00     0.0000E+00     3.9711E-02        -0.0056
```

poisson stuff for ELLIPTICAL low density real μ iron

AUTOMESH

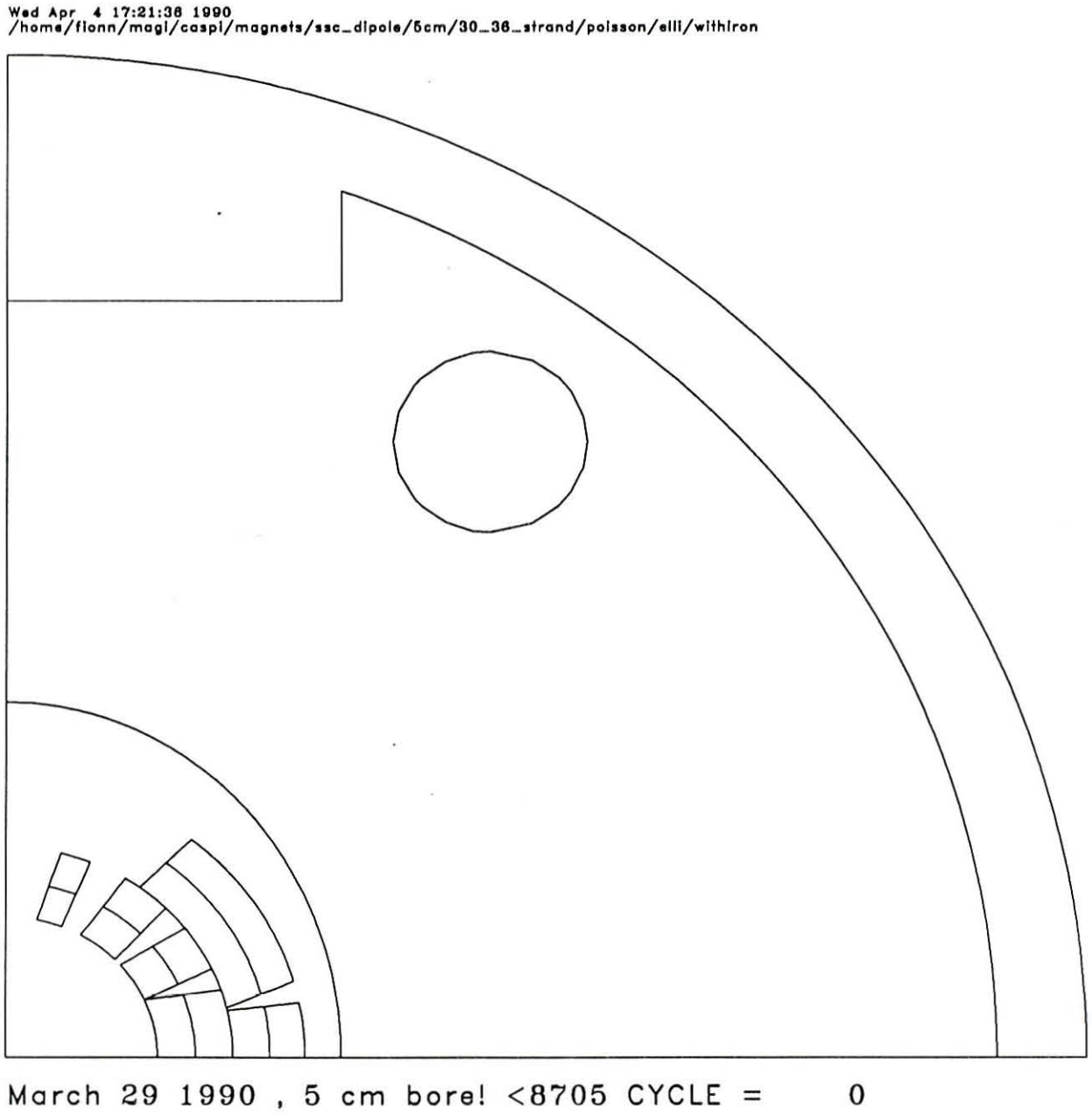


Figure 13 Low density DUMP 0

```
March 29 1990 , 5 cm bore! <870527.0922>
$geo NREG=17   XMAX=18.1  YMAX=18.1
    xreg1=6.0 xreg2=7.0
    yreg1=7.0  yreg2=7.5
      dx=0.12 $
$reg npoint=12 mat=1 $
$PO  X=0.0 Y=0.0$
$PO  nt=1 x0=0.0 y0=0.0 r=2.52491 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.7439 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=3.8049 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=4.9733 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=5.5750 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=17.30 theta=0.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=18.0 theta=0.0 $
$PO  nt=2 x0=0.0 y0=0.0 r=18.0 theta=90.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=17.3 theta=90.0 $
$PO  nt=1 x0=0.0 y0=0.0 r=6.3565  theta=90.0 $
$PO  x=0.0 y=0.0 $
$REG MAT=2 NPOINT=7 $
$PO  NT=1 X0=0.0 Y0=0.0 R=5.575 THETA=0.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=16.51 THETA=0.0 $
$PO  NT=2 X0=0.0 Y0=0.0 R=16.51 THETA=70.2648 $
$PO  NT=1 X0=0.0 Y0=0.0 R=14.6752 THETA=67.673 $
$PO  NT=1 X0=0.0 Y0=0.0 R=13.575 THETA=90.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=6.3565 THETA=90.0 $
$PO  NT=4 X0=0.0 Y0=0.0 R=5.575 THETA=0.0$
$REG MAT=1 NPOINT=5 $
$PO  NT=1 X0=8.0514 Y0=11.0410 R=1.6256 THETA=0.0 $
$PO  NT=2 X0=8.0514 Y0=11.0410 R=1.6256 THETA=90.0 $
$PO  NT=2 X0=8.0514 Y0=11.0410 R=1.6256 THETA=180.0 $
$PO  NT=2 X0=8.0514 Y0=11.0410 R=1.6256 THETA=270.0 $
$PO  NT=2 X0=8.0514 Y0=11.0410 R=1.6256 THETA=360.0 $
$REG MAT=1 NPOINT=4 $
$PO  NT=1 X0=0.0  Y0=0.0 R=5.575 THETA=0.0 $
$PO  NT=4 X0=0.0  Y0=0.0 R=6.3565 THETA=90.0 $
$PO  NT=1 X0=0.0  Y0=0.0 R=5.575 THETA=90.0 $
$PO  NT=2 X0=0.0  Y0=0.0 R=5.575 THETA=0.0 $
$REG mat=513 NPOINT=5 $
$PO nt=1 x0=0.0 y0=0.0 r= 17.3 theta=0.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=18.0 THETA=0.0 $
$PO NT=2 X0=0.0 Y0=0.0 R=18.0 THETA=90.0 $
$PO NT=1 X0=0.0 Y0=0.0 R=17.3 THETA=90.0 $
$PO nt = 2 x0=0.0 y0=0.0 r= 17.3 theta=0.0 $
$REG MAT=1 CUR=21000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=0.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=0.0 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=20.8868 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52485 THETA=24.2159 $
$PO  NT=2 X0=0.0 Y0=0.0 R=2.52491 THETA=0.0 $
$REG MAT=1 CUR=21000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=0.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=0.0 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=18.7062 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=20.8868 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=0.0 $
$REG MAT=1 CUR=15000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52485 THETA=24.2159 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=24.6585 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=39.2464 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=41.1243 $
$PO  NT=2 X0=0.0 Y0=0.0 R=2.52485 THETA=24.2159 $
$REG MAT=1 CUR=15000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=24.6585 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=24.9517 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=38.0065 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=39.2464 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=24.6585 $
```

```
$REG MAT=1 CUR=15000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=44.1083 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=44.8347 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=59.2386 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=60.5712 $
$PO  NT=2 X0=0.0 Y0=0.0 R=2.52491 THETA=44.1083 $
$REG MAT=1 CUR=15000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=44.8347 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=45.3158 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=58.3572 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=59.2386 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=44.8347 $
$REG MAT=1 CUR=9000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=68.5087 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=68.3611 $
 $PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=76.8962 $
$PO  NT=1 X0=0.0 Y0=0.0 R=2.52491 THETA=78.2545 $
$PO  NT=2 X0=0.0 Y0=0.0 R=2.52491 THETA=68.5087 $
$REG MAT=1 CUR=9000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=68.3611 $
 $PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=68.2633 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=75.9978 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.15263 THETA=76.8962 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.15263 THETA=68.3611 $
$REG MAT=1 CUR=21000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=0.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=0.0 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.38818 THETA=12.0664 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=12.9042 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=0.0 $
$REG MAT=1 CUR=21000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=0.0 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.9733 THETA=0.0 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.9733 THETA=11.4609 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=12.0664 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.38818 THETA=0.0 $
$REG MAT=1 CUR=66000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=13.741 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=15.0442 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.38818 THETA=52.7275 $
$PO  NT=1 X0=0.0 Y0=0.0 R=3.77442 THETA=54.0307 $
$PO  NT=2 X0=0.0 Y0=0.0 R=3.77442 THETA=13.741 $
$REG MAT=1 CUR=66000.0 NPOINT=5 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=15.0442 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.9733 THETA=15.9845 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.9733 THETA=51.7872 $
$PO  NT=1 X0=0.0 Y0=0.0 R=4.38818 THETA=52.7275 $
$PO  NT=2 X0=0.0 Y0=0.0 R=4.38818 THETA=15.0442 $
```

POISSON INPUT

```
0  dump
*6 -2
*66 1.23
*46 6
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*110 8 10 1.0 90. 1.0 0.0 S COUNT
1  dump
*6 0
*126 21
*129 1
*66 1.23
```

```
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
2 dump
*6 0
*126 21
*129 1
*66 1.15
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
3 dump
*6 0
*126 21
*129 1
*66 1.077
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
4 dump
*6 0
*126 21
*129 1
*66 1.0
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
5 dump
*6 0
*126 21
*129 1
*66 0.923076923
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
6 dump
*6 0
*126 21
*129 1
*66 0.769230769
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10  1.0 90. 1.0 0.0 S COUNT
7 dump
*6 0
*126 21
*129 1
*66 0.6153846
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110  8 10 1.0 90. 1.0 0.0 S COUNT
8 dump
*6 0
```

```
*126 21
*129 1
*66 0.4615384
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110  8 10 1.0 90. 1.0 0.0 S COUNT
9 dump
*6 0
*126 21
*129 1
*66 0.307692
*43 21
*45 21
*54 0.4 0.8 2.4 2.8
*46 6
*110 8 10 1.0 90. 1.0 0.0 S COUNT
-1 dump
```

Editted POISSON output

1.3:1 cu/sc

```
../out_edit.pois
baseline
9 dumps
72 separate harmonics

     I[A]     x[cm]      y[cm]     Bmax [T]
    2769.2   0.56000    2.52000    3.38577
    3692.3   0.56000    2.52000    4.51012
    4615.4   0.56000    2.52000    5.59327
    5538.5   0.56000    2.52000    6.59992
    6000.0   0.56000    2.52000    7.07462
    6462.0   0.56000    2.52000    7.53449
    6900.0   0.56000    2.52000    7.95931
    7380.0   0.56000    2.52000    8.41798
    7380.0   0.56000    2.52000    9.02532

     I[A]       Bo[T]      Tf [T/A]       b2         b4          b6          b8
    2769.2      -3.2650     -11.7903   -0.00986    0.01217    0.005274    0.004749    0.002971    0.002756     0.00
    3692.3      -4.3489     -11.7783   -0.01583    0.02599    0.005193     0.00475    0.002945    0.002741    0.002
    4615.4      -5.3910     -11.6805      .1016       .1024    0.005181    0.004987    0.002881    0.002733    0.002
    5538.5      -6.3544     -11.4732      -.2877      .1672    0.006191    0.005186    0.002508    0.002498    0.001
    6000.0      -6.8046      -11.341      -1.197      .1807    0.006674    0.005532    0.002352    0.002473    0.001
    6462.0      -7.2380     -11.2009      -2.529      .1766    0.006801    0.006025    0.002245    0.002516    0.001
    6900.0      -7.6362      -11.067      -3.998      .1638    0.006714     0.00654    0.002156    0.002581    0.001
    7380.0      -8.0654     -10.9287      -5.527      .1503    0.006978    0.007383    0.002246    0.002822    0.001
    7380.0      -8.7037     -11.7936           0          0           0           0           0           0
Mu infinite iron point
Deleted B =         9.0253200
 Operating temperature is    4.35 K
 # strands =  30 strand dia = 0.031800 in , Cu:SC = 1.30 degradation factor = 1.00
 Jc =    2750.0 A/mm^2, Bm = 5.00 T @ 4.20 K
 Area-SC = .6684E-01 cm^2/turn; Area-Cu = .8689E-01cm^2/turn;
 Jcu =  666.4232 A/mm^2/turn
 True Jc =         866.35016
Bore =          6.600000 [T]    5790.264549 [A]       5.292875 [K]
Conductor =     6.858886 [T]    5790.264549 [A]       5.167384 [K]
Short sample    7.955758 [T]    6896.337524 [A]       4.349992 [K]
Bore maximum    7.632870 [T]    6896.337524 [A]       4.559254 [K]
```

1.5:1 cu/sc

```
../out_edit.pois
baseline
9 dumps
72 separate harmonics

     I[A]     x[cm]      y[cm]      Bmax [T]
    2769.2   0.56000    2.52000    3.38577
    3692.3   0.56000    2.52000    4.51012
    4615.4   0.56000    2.52000    5.59327
    5538.5   0.56000    2.52000    6.59992
    6000.0   0.56000    2.52000    7.07462
    6462.0   0.56000    2.52000    7.53449
    6900.0   0.56000    2.52000    7.95931
    7380.0   0.56000    2.52000    8.41798
    7380.0   0.56000    2.52000    9.02532

     I[A]       Bo[T]       Tf [T/A]       b2          b4          b6          b8
    2769.2     -3.2650      -11.7903    -0.00986    0.01217    0.005274    0.004749    0.002971    0.002756     0.00
    3692.3     -4.3489      -11.7783    -0.01583    0.02599    0.005193     0.00475    0.002945    0.002741    0.002
    4615.4     -5.3910      -11.6805       .1016       .1024    0.005181    0.004987    0.002881    0.002733    0.002
    5538.5     -6.3544      -11.4732      -.2877       .1672    0.006191    0.005186    0.002508    0.002498    0.001
    6000.0     -6.8046       -11.341      -1.197       .1807    0.006674    0.005532    0.002352    0.002473    0.001
    6462.0     -7.2380      -11.2009      -2.529       .1766    0.006801    0.006025    0.002245    0.002516    0.001
    6900.0     -7.6362       -11.067      -3.998       .1638    0.006714     0.00654    0.002156    0.002581    0.001
    7380.0     -8.0654      -10.9287      -5.527       .1503    0.006978    0.007383    0.002246    0.002822    0.001
    7380.0     -8.7037      -11.7936           0           0           0           0           0           0
Mu infinite iron point
Deleted B =         9.0253200
 Operating temperature is   4.35 K
 # strands =  30 strand dia = 0.031800 in , Cu:SC = 1.50 degradation factor = 1.00
 Jc =   2750.0 A/mm^2, Bm = 5.00 T @ 4.20 K
 Area-SC = .6149E-01 cm^2/turn; Area-Cu = .9223E-01cm^2/turn;
 Jcu =  627.7900 A/mm^2/turn
 True Jc =         941.68496
Bore =          6.600000 [T]   5790.264549 [A]      5.213945 [K]
Conductor =     6.858886 [T]   5790.264549 [A]      5.086287 [K]
Short sample    7.825698 [T]   6762.242798 [A]      4.350007 [K]
Bore maximum    7.510960 [T]   6762.242798 [A]      4.550897 [K]
```

1.0:1 cu/sc

```
../out_edit.pois
baseline
9 dumps
72 separate harmonics

     I[A]     x[cm]      y[cm]      Bmax [T]
    2769.2   0.56000    2.52000    3.38577
    3692.3   0.56000    2.52000    4.51012
    4615.4   0.56000    2.52000    5.59327
    5538.5   0.56000    2.52000    6.59992
    6000.0   0.56000    2.52000    7.07462
    6462.0   0.56000    2.52000    7.53449
    6900.0   0.56000    2.52000    7.95931
    7380.0   0.56000    2.52000    8.41798
    7380.0   0.56000    2.52000    9.02532

     I[A]       Bo[T]       Tf [T/A]       b2          b4          b6          b8
    2769.2     -3.2650      -11.7903    -0.00986    0.01217    0.005274    0.004749    0.002971    0.002756     0.00
```

```
    3692.3      -4.3489      -11.7783    -0.01583     0.02599    0.005193     0.00475    0.002945    0.002741    0.002
    4615.4      -5.3910      -11.6805       .1016       .1024    0.005181    0.004987    0.002881    0.002733    0.002
    5538.5      -6.3544      -11.4732      -.2877       .1672    0.006191    0.005186    0.002508    0.002498    0.001
    6000.0      -6.8046       -11.341      -1.197       .1807    0.006674    0.005532    0.002352    0.002473    0.001
    6462.0      -7.2380      -11.2009      -2.529       .1766    0.006801    0.006025    0.002245    0.002516    0.001
    6900.0      -7.6362       -11.067      -3.998       .1638    0.006714     0.00654    0.002156    0.002581    0.001
    7380.0      -8.0654      -10.9287      -5.527       .1503    0.006978    0.007383    0.002246    0.002822    0.001
    7380.0      -8.7037      -11.7936           0           0           0           0           0           0
Mu infinite iron point
Deleted B =         9.0253200
 Operating temperature is    4.35 K
 # strands =  30 strand dia = 0.031800 in , Cu:SC = 1.00 degradation factor = 1.00
 Jc =    2750.0 A/mm^2, Bm = 5.00 T @ 4.20 K
 Area-SC = .7686E-01 cm^2/turn; Area-Cu = .7686E-01cm^2/turn;
 Jcu =  753.3480 A/mm^2/turn
 True Jc =         753.34797
Bore =           6.600000 [T]    5790.264549 [A]       5.411088 [K]
Conductor =      6.858886 [T]    5790.264549 [A]       5.288693 [K]
Short sample     8.160818 [T]    7110.878906 [A]       4.350007 [K]
Bore maximum     7.824761 [T]    7110.878906 [A]       4.573660 [K]
```