SC-MAG-651

A 12 Tesla Dipole For the VLHC*

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During the summer of 1998 I spent four months in KEK Japan working on a 12 T dipole for the Very Large Hadron Collider (VLHC). This work was in part a collaboration between KEK, FermiLab with LBNL support on a conceptual 2 layer design using Nb_3Sn conductor. The high field option focused on a "cosine-θ" design according to what previously has been learned during the 13.5 T LBNL D20 program. We assumed a bore size of 50 mm and the strand diameter of 1.0 mm. Several different design iterations were made but we report here on the final design only.

Assuming a current density of 1525 A/mm^2 at 12 T with realistic iron, the short sample central field will reach 11.6 T at a maximum current of 16950 A. An improved conductor with a current density of 2000 A/mm^2 in the none copper will generate 12.4 T at 18410 A.

We report here on the magnet and coil cross section, load line, field quality and maximum field, return and lead "end" geometry, forces and stress analysis.

Cross Section

The 2 layer magnet is made of a single 28 strand cable that is 14.24 mm wide, surrounded by a collar (spacer) that is 8 mm wide and an iron yoke 166.0 mm thick for a total outer radius of 250 mm (including outer shell). Details are included in Table I below. The cross section was made with 4 wedges and with a pole gap that is as wide as possible. The field was optimized with infinite permeability iron and analyzed for the real iron case using the program POISSON (Fig. 1,2 and 3). The POISSON output is summarized in Table II with the load line, short sample curve and harmonics plotted in Fig. 4. Figures 5 and 6 are the Lorentz forces on each turn computed analytically while Fig. 2 sums up the forces on each conductor block (program FORCE).

End Region

The coil geometry in the end regions was generated using the programs BEND, tkBend and Magprep. The 3D field harmonics were computed using the program FIGEND. Figures 7 and 8 show the return end geometry and Figures 9,11 and 12 plot the associated field harmonics. Figure 10 is a plot of the integrated harmonics along the return end. Figures 13 and 14 show the maximum field along the pole turn of layers 1 and 2. As shown, there is no rise in the field in the end region and we expect the maximum field to remain in the straight section. Figures 15,16 and 17 show both layers including return and lead ends as well as the layer to layer transition. Figures 18 and 19 contain the end spacers rulings for the return end.

Stress

A 2D stress analysis was made using an axis-symmetric model with anisotropic properties[b] subjected to mechanical and thermal constrains. The analysis assumes average properties in each shell and for the iron the Young's Modulus in the azimuthal direction was used as a parameter. We assume a stainless steel collar, an iron yoke and an iron yoke with properties that are averaged with the size and location of the aluminum bar. Figure 20 is the azimuthal stress for three different averages, Fig. 21 and 22 shows the cooldown effect. Similar plots are shown for the radial stress (Fig. 23–25) and the radial displacement (Fig. 26–28).

[b] "Stress-Strain in Shells Under Mechanical, Thermal and Magnetic Loads" S. Caspi, K.Chow, G. Millos and C. Taylor, SC-MAG-616, March 1998.

	LAYER 1	LAYER 2
CONDUCTOR	Nb_3Sn	Nb_3Sn
strand diameter (mm)	1.0	1.0
Cu/Non Cu Ratio	0.85	0.85
number of strand	2x14	2x14
insulation thickness at 70 MPa (mm)	0.12	0.12
BARE CABLE		
cable width at 35 MPa (mm)	14.2378	14.2378
mid-thickness at 35 MPa (mm)	1.7850	1.7850
minor edge (mm)	1.6607	1.6607
major edge (mm)	1.9092	1.9092
keystone angle (deg)	1.00	1.00
inner edge packing factor	0.9458	0.9458
outer edge packing factor	0.823	0.823
width packing factor	0.98	0.98
INSULATED CABLE		
cable width at 35 MPa (mm)	14.5378	14.5378
mid-thickness at 35 MPa (mm)	2.0250	2.0250
minor edge (mm)	1.9007	1.9007
major edge (mm)	2.1492	2.1492
radial insulation (mm)	0.15	0.15
RADIAL BUILDUP		RADIUS
mandrel radius (mm)	24.5936	24.5936
stainless steel shim (mm)	0.1270	24.7206
glass wrap	0.2794	25.0
layer 1 inner radius (insul.) mm	25.0	25.0
layer 1 inner radius (bare) mm	0.150	25.150
layer 1 outer radius (bare) mm	14.2378	39.3878
layer 1 outer radius (insul.) mm	0.150	39.5378
glass wrap	0.2794	39.8172
layer 2 inner radius (bare) mm	0.150	39.9672
layer 2 outer radius (bare) mm	14.2378	54.2050

Table 1 Radial build-up (Continued) . . .

layer 2 outer radius (insul.) mm	0.150	54.3550
glass wrap	0.2794	54.6344
stainless steel shim	0.508	55.1424
Kapton	0.127	55.2694
spacer inner radius (mm)		55.2694
spacer outer radius (mm)	8.0	63.2694
iron inner radius (mm)		63.2694
iron outer radius (mm)	166.0	229.2694
shell outer radius (mm)	20.0	249.2694

Table 1 Radial build-up

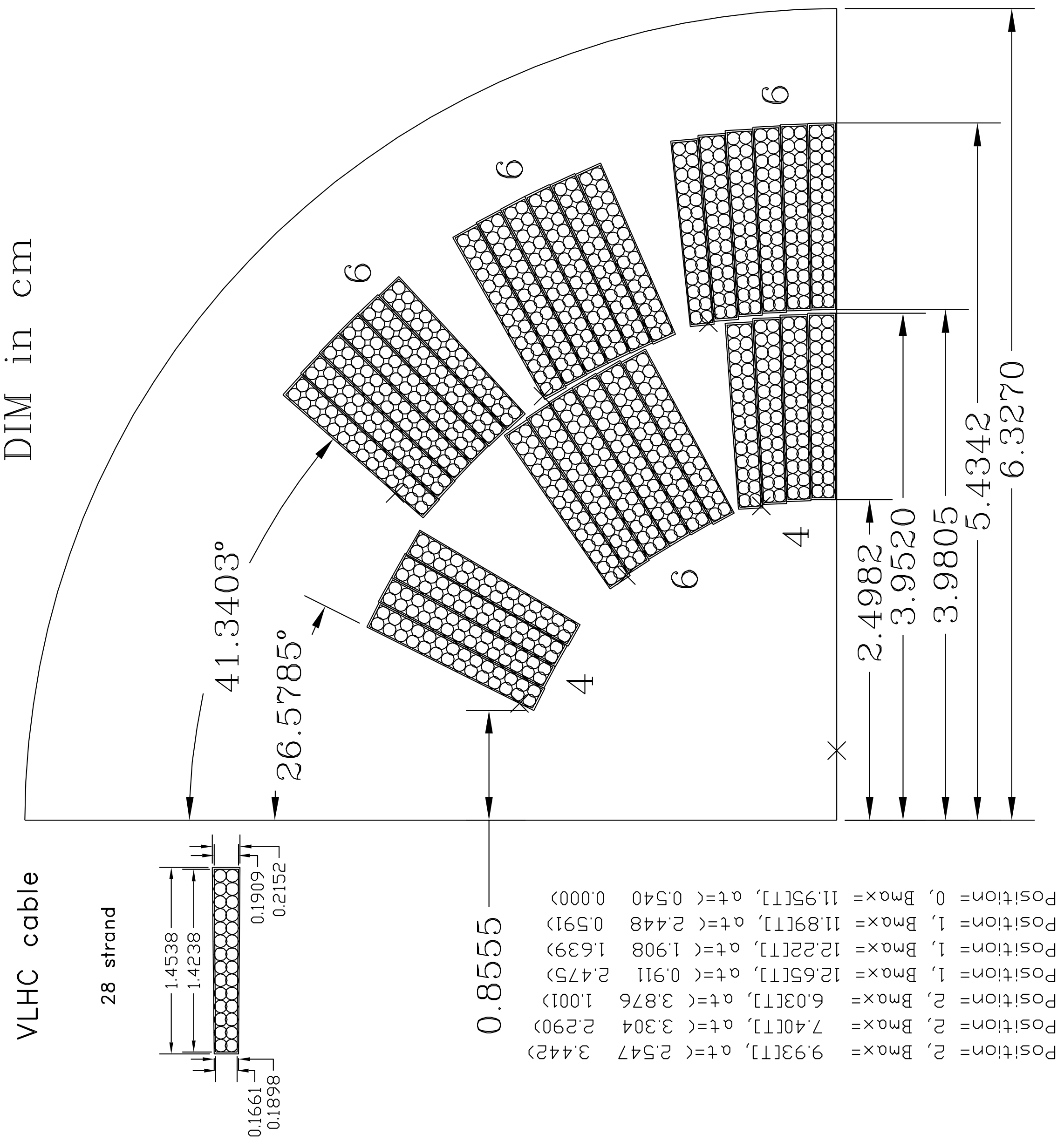

Figure 1 A 4 wedge design. Field values are for infinite permeability iron and I=15817 A.

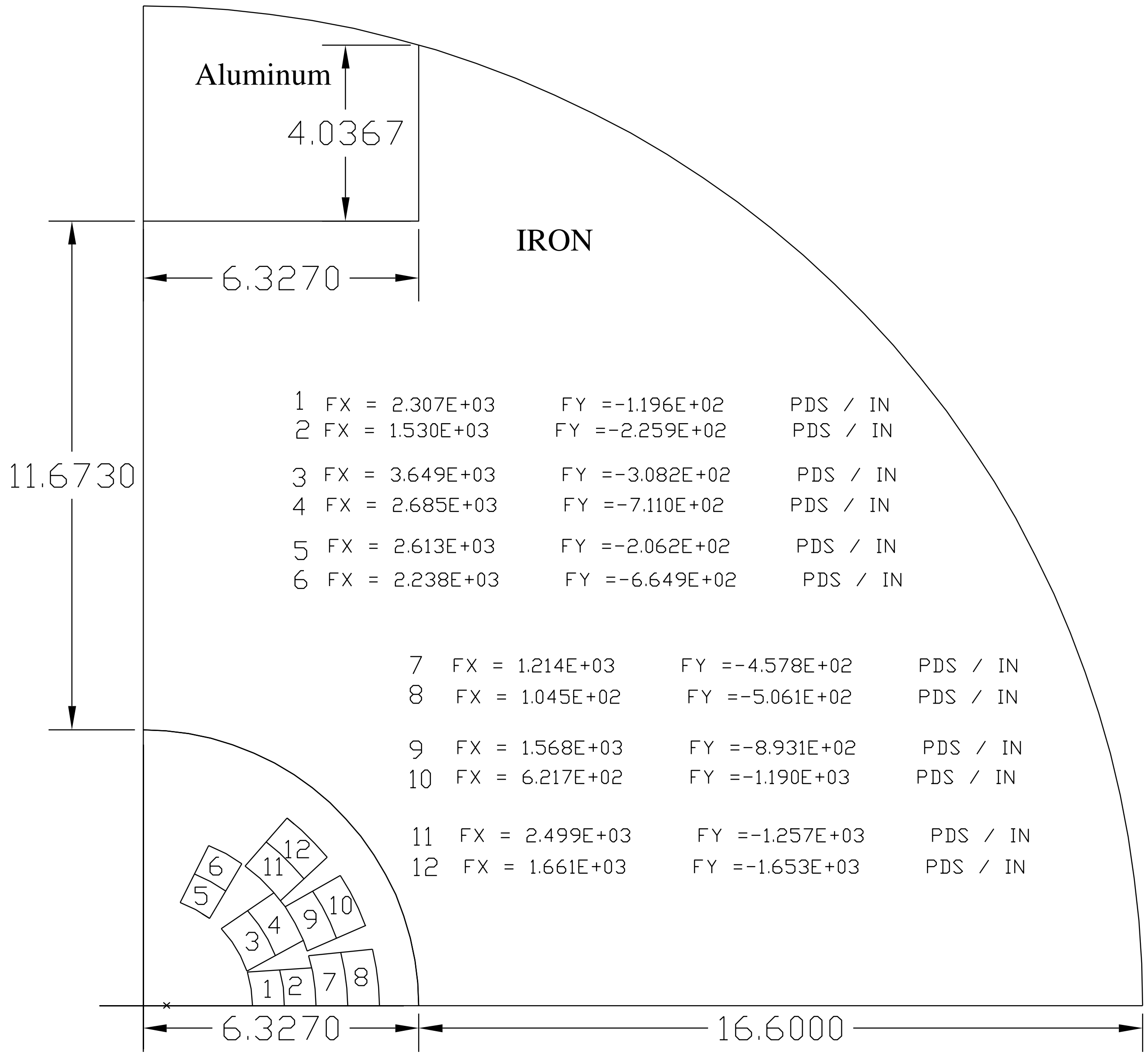

Figure 2 Poisson model (forces at I=18 kA)

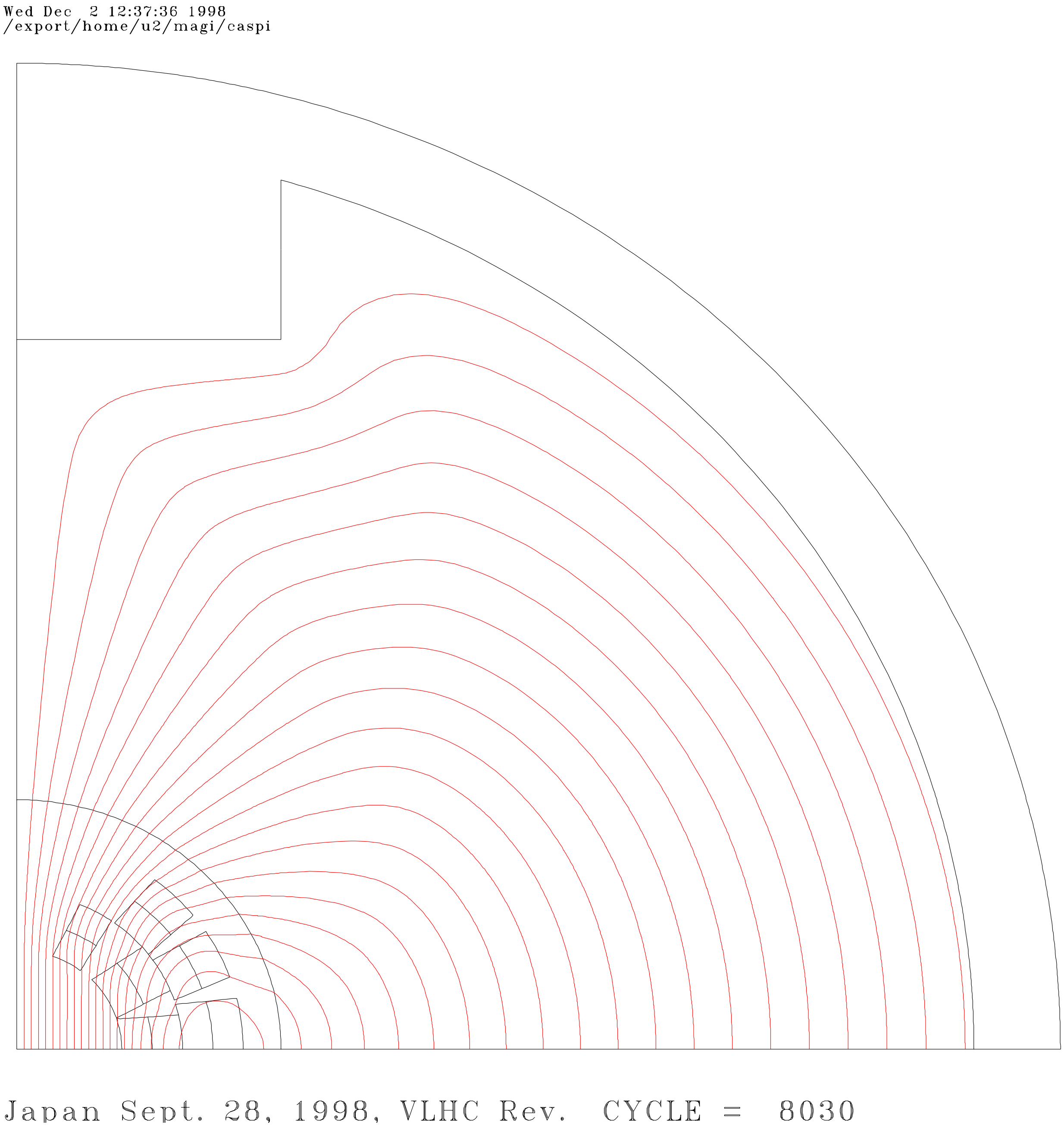

Figure 3 High field flux plot.

I (A)	Xcm	Ycm	Bmax(T)	Bo(T)	Tf (T/A)	b2(unit)	b4(unit)	b6(unit)	b8(unit)
3600	0.96	2.51	2.9	-2.72	-7.56278	0.0098	0.00936	0.004181	0.003934
5400	0.96	2.51	4.34	-4.08	-7.55648	0.2632	0.01078	0.004085	0.003868
7200	0.96	2.51	5.72	-5.38	-7.48069	3.141	0.03519	0.003293	0.003056
9000	0.96	2.51	7.034	-6.618	-7.35367	5.861	0.100	0.00359	0.001617
10800	0.96	2.51	8.294	-7.80	-7.220	7.042	0.148	0.003874	-0.00041
12600	0.96	2.51	9.515	-8.935	-7.09103	7.051	0.1679	0.004221	-0.001972
14400	0.96	2.51	10.701	-10.033	-6.96736	6.413	0.1677	0.004213	-0.003404
16200	0.96	2.51	11.8525	-11.095	-6.84877	5.32	0.1554	0.003989	-0.00477
18000	0.96	2.51	12.9741	-12.123	-6.735	4.058	0.1391	0.003716	-0.006095
18000 inf. mu	0.96	2.51	14.4863	-13.6150	-7.5639	0	0	0	0

Table 2 Various field values as a function of current (data from POISSON)

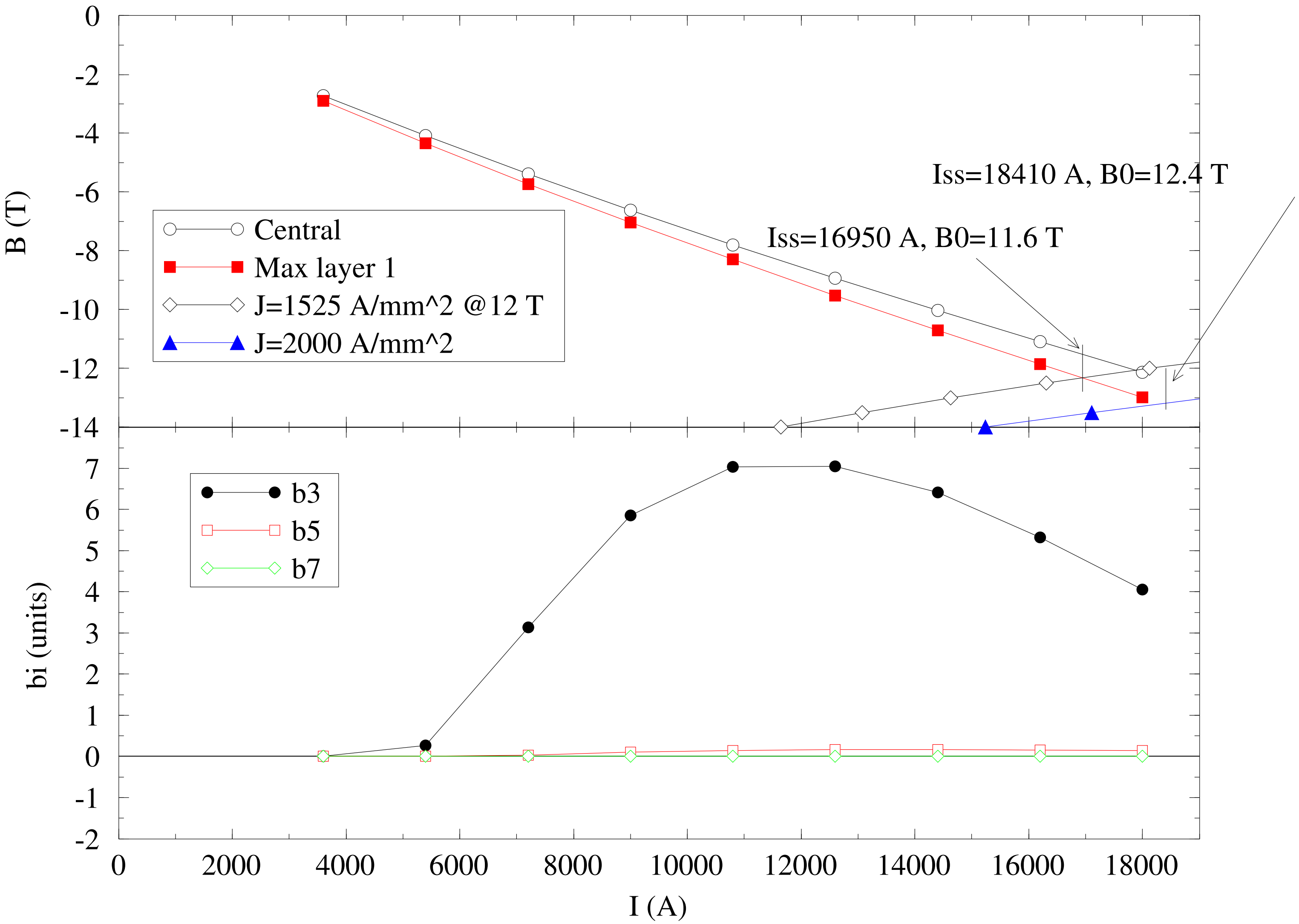

Figure 4 Load lines and multipoles.

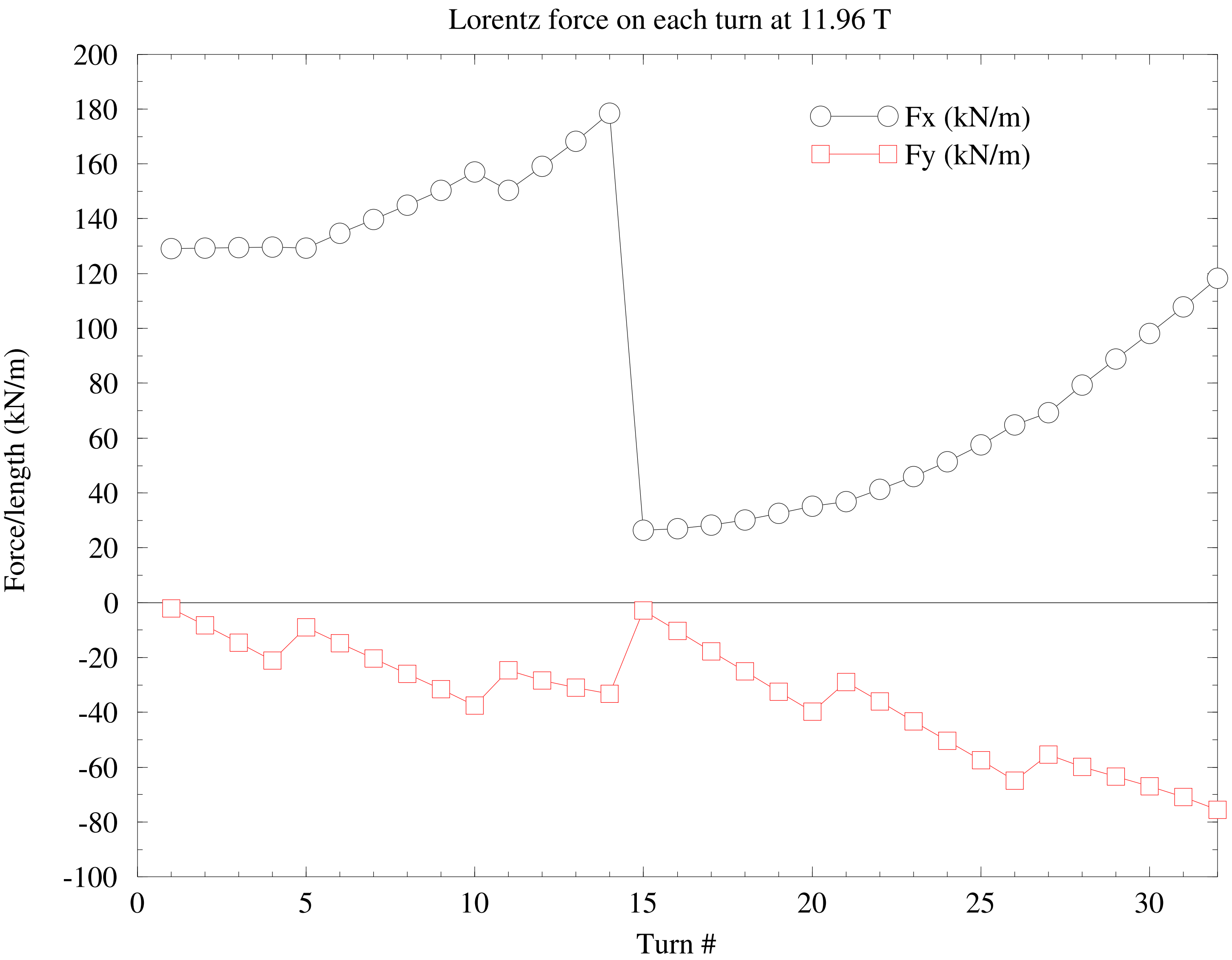

Figure 5 The Lorentz force on each turn (Cartesian). Data generated with infinite iron at I=15817 A

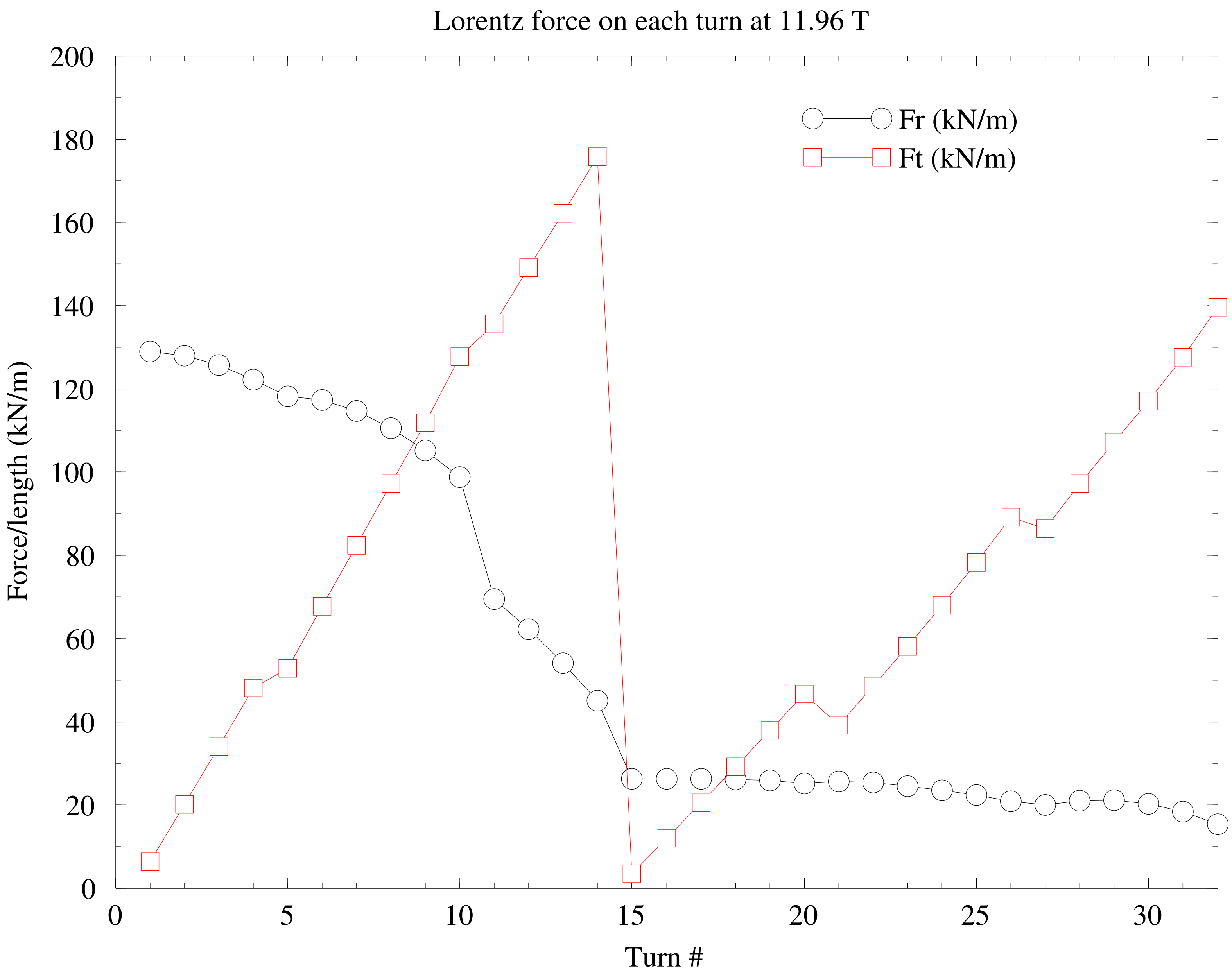

Figure 6 The Lorentz force on each turn (radial). Data generated with infinite iron at I=15817 A

End Regions

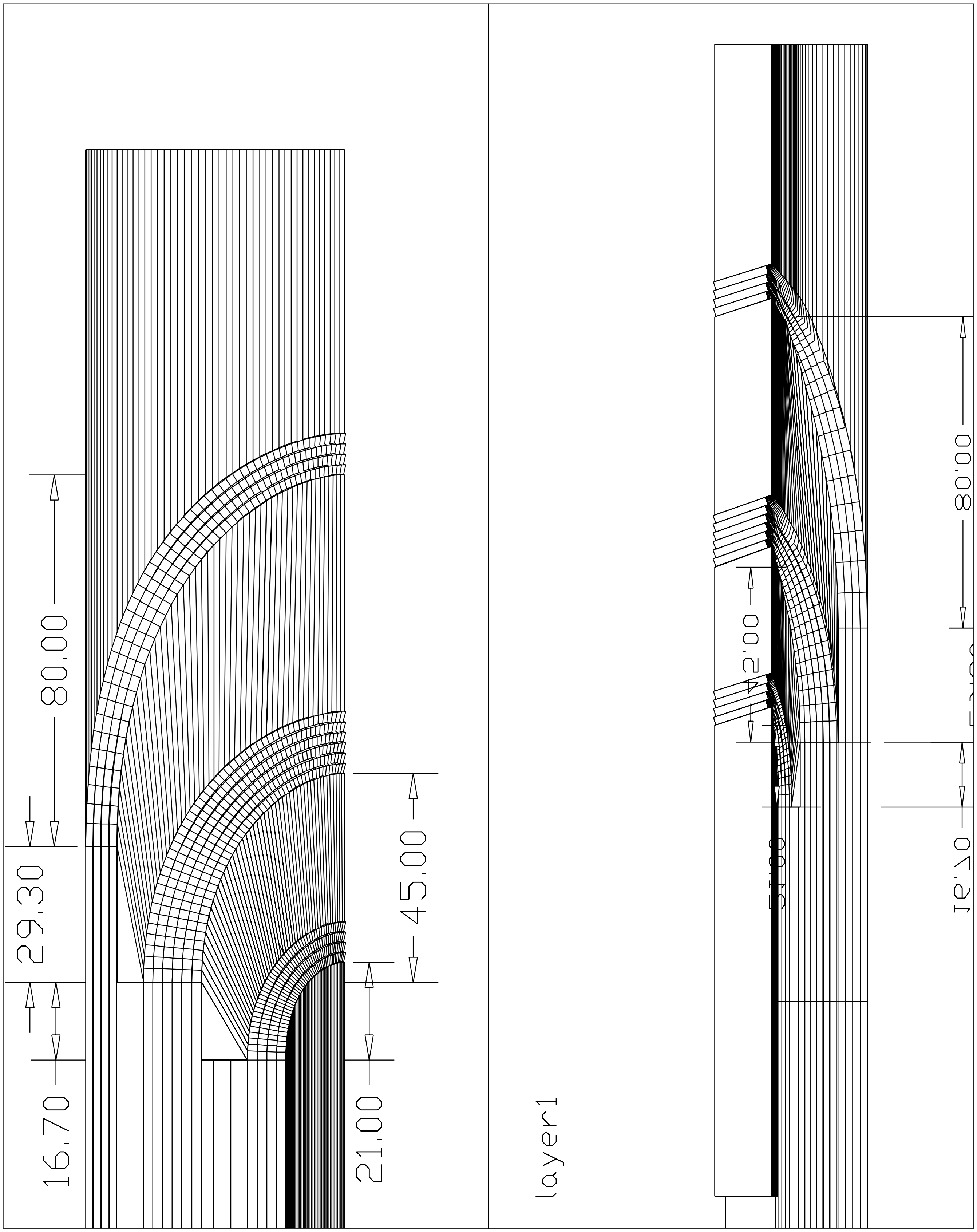

Figure 7 Return end — layer 1

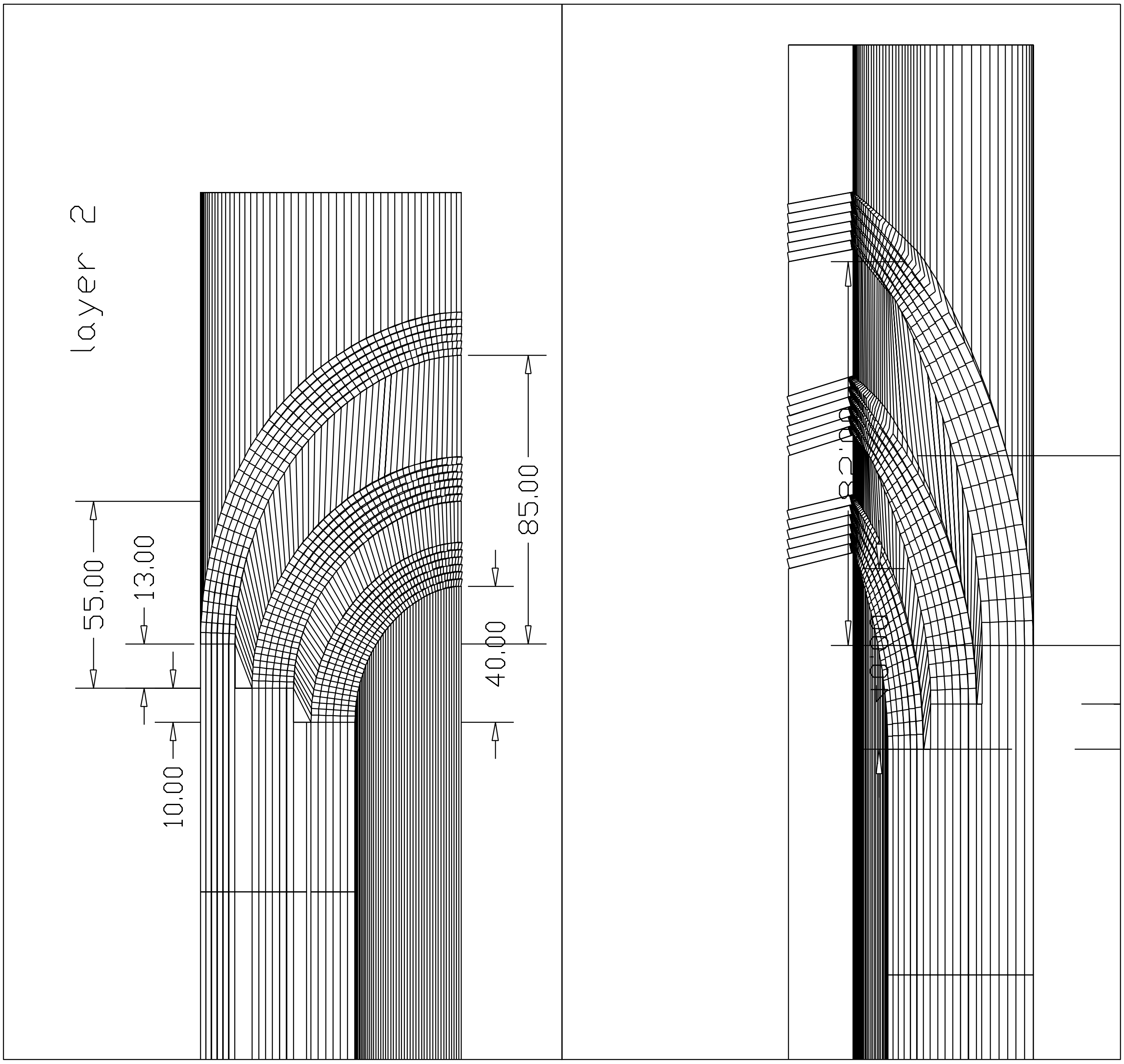

Figure 8 Return end — layer 2

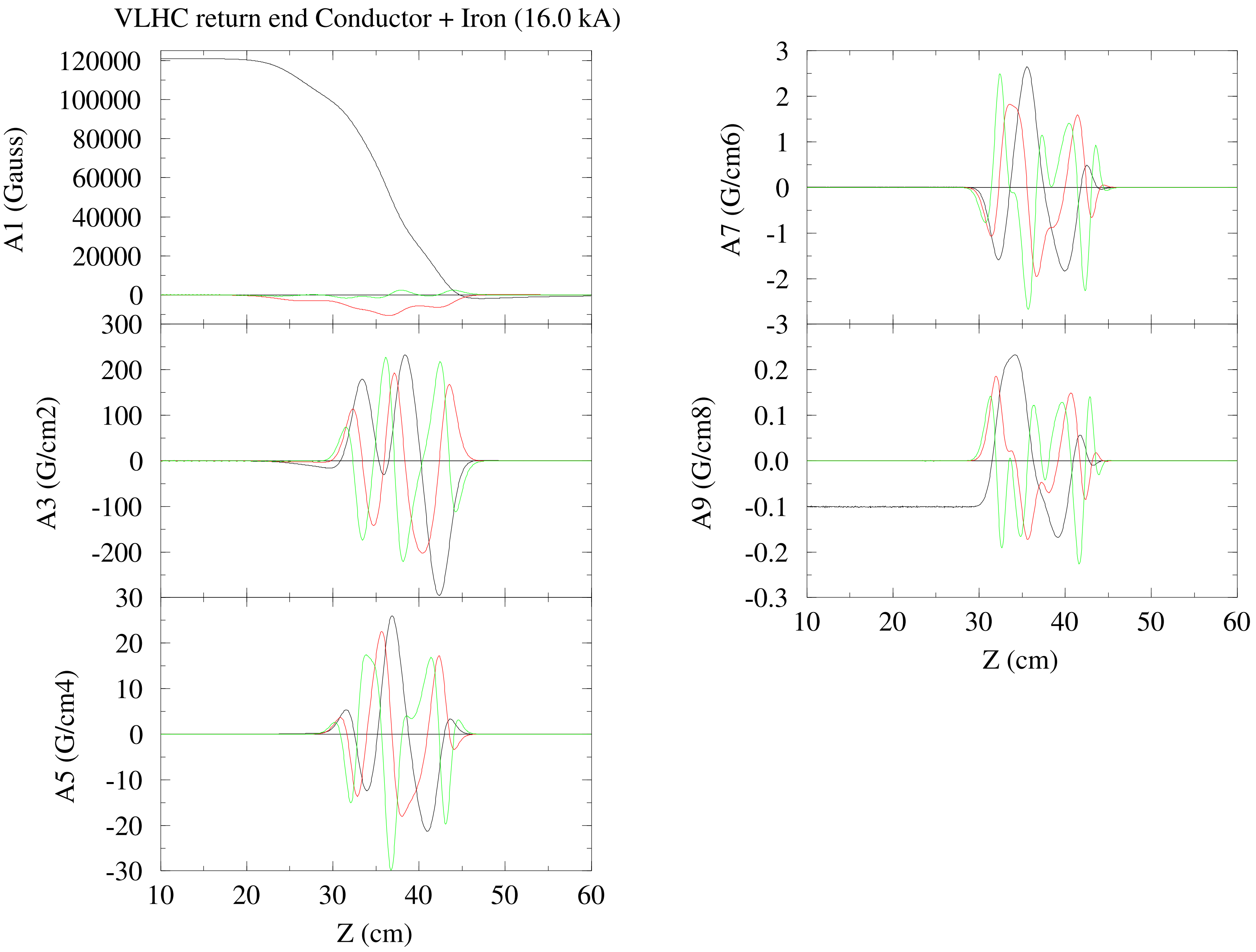

Figure 9 Return end harmonics — including conductor and iron (I=16 kA)

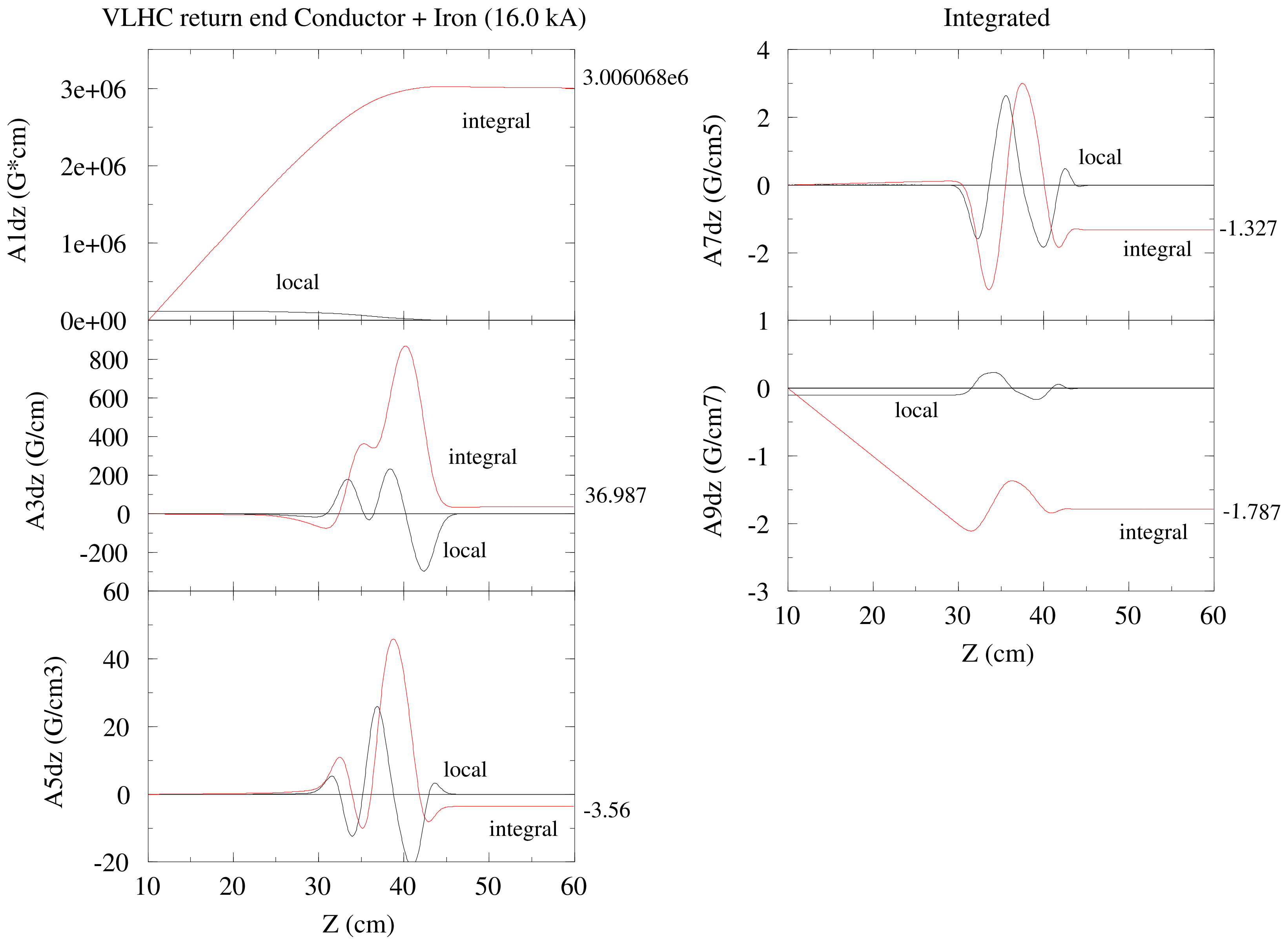

Figure 10 Integrated harmonics

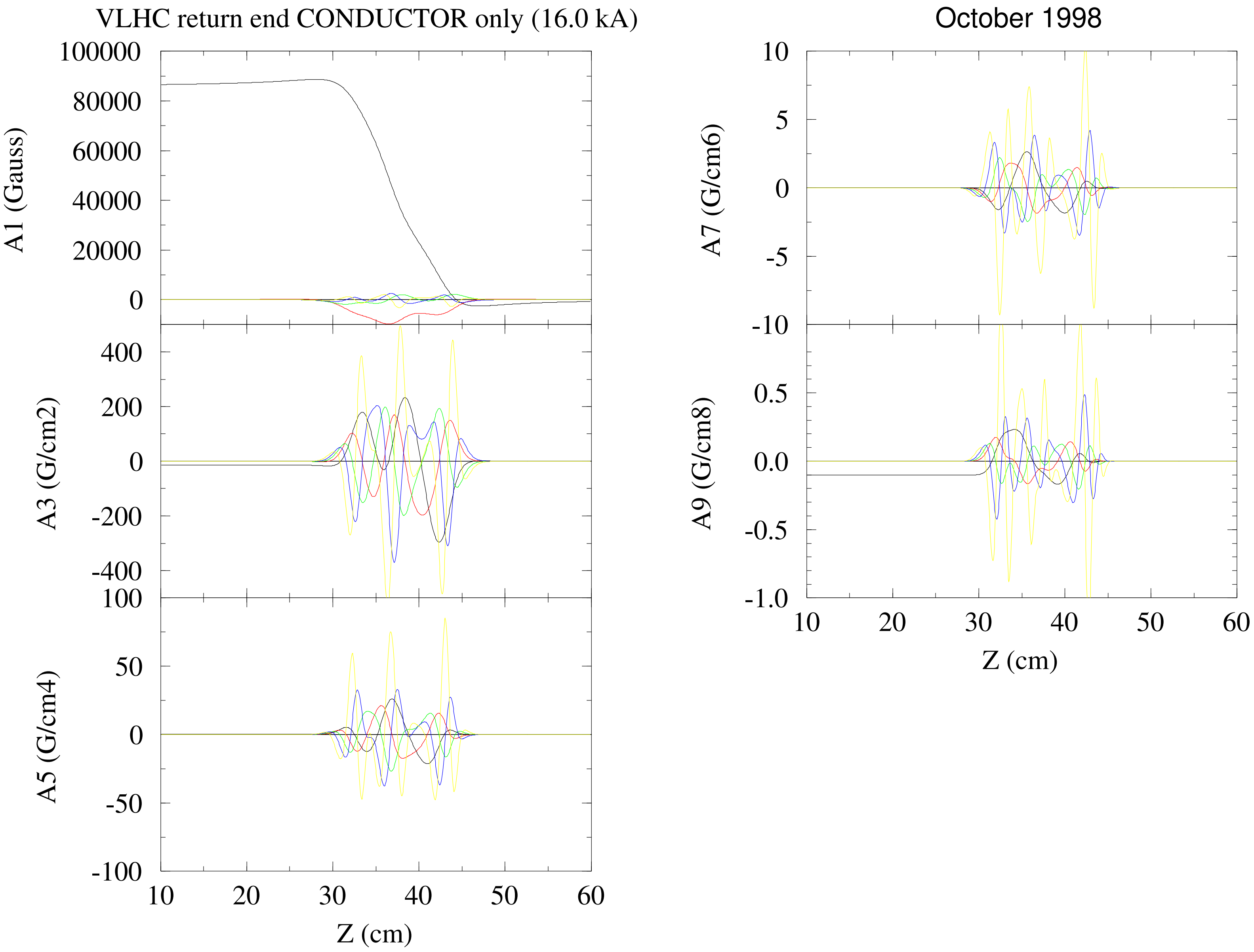

Figure 11 Return end harmonics — Conductor only (I=16 kA)

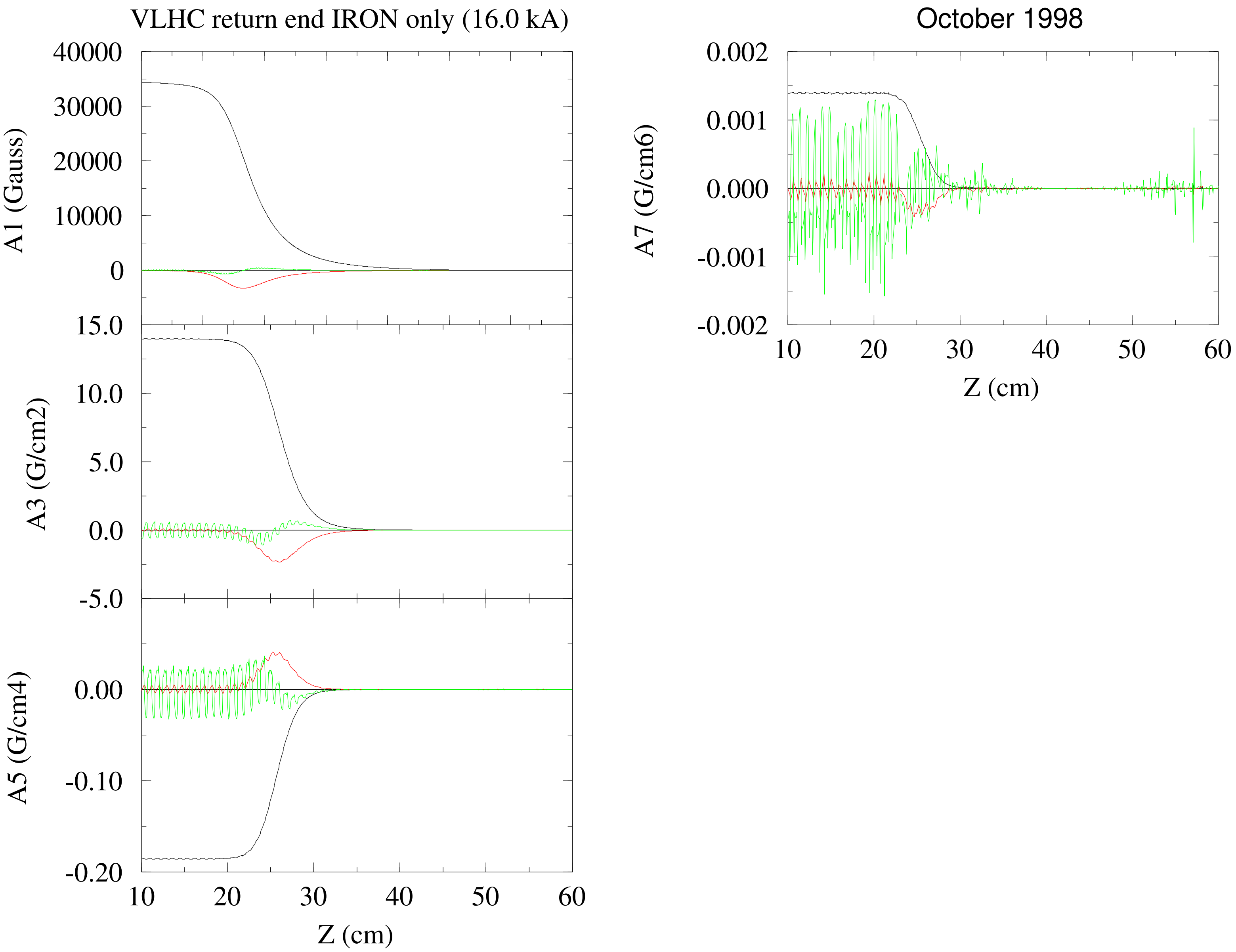

Figure 12 Return end harmonics — Iron contribution

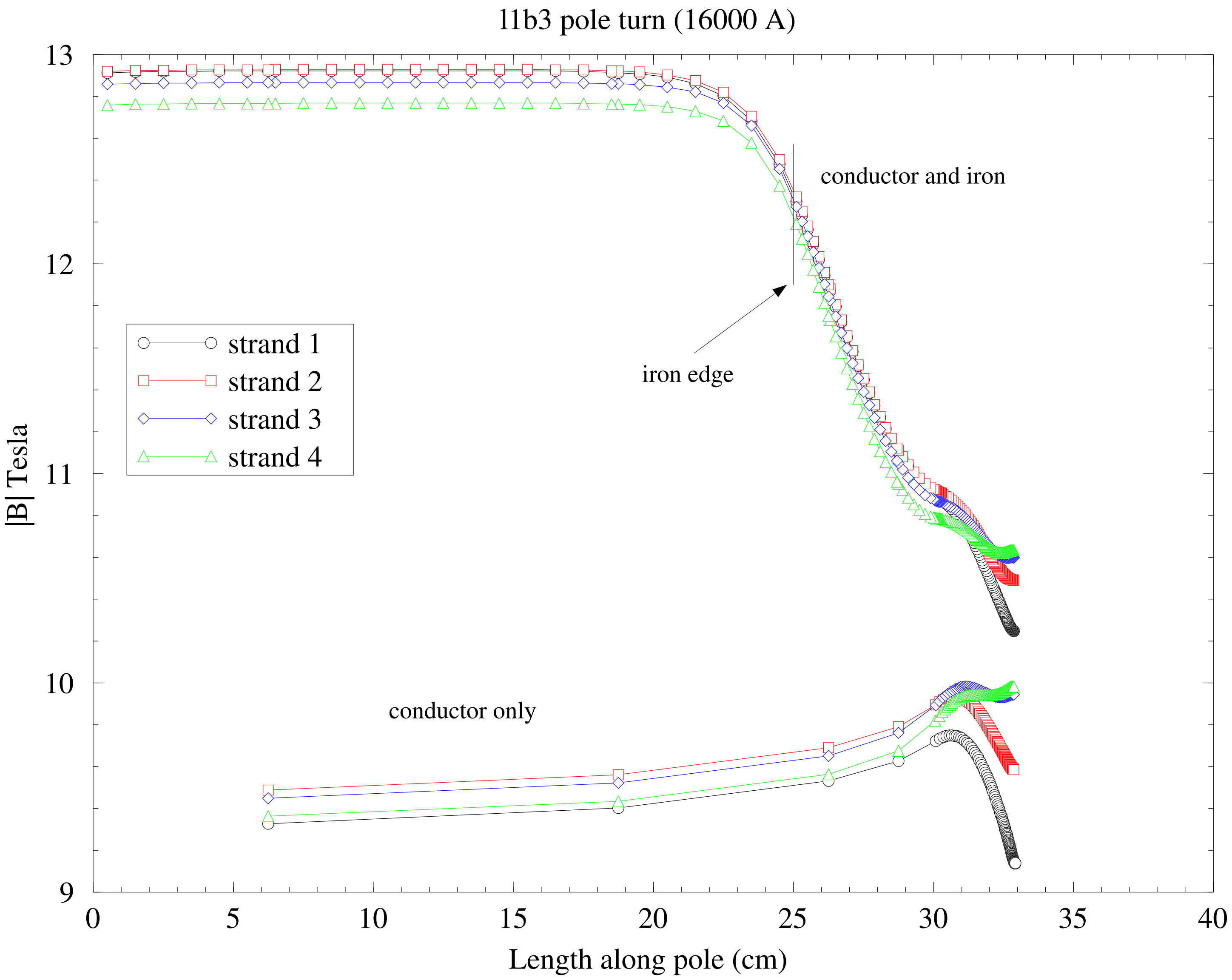

Figure 13 Maximum Field along pole of layer 1 (I=16 kA)

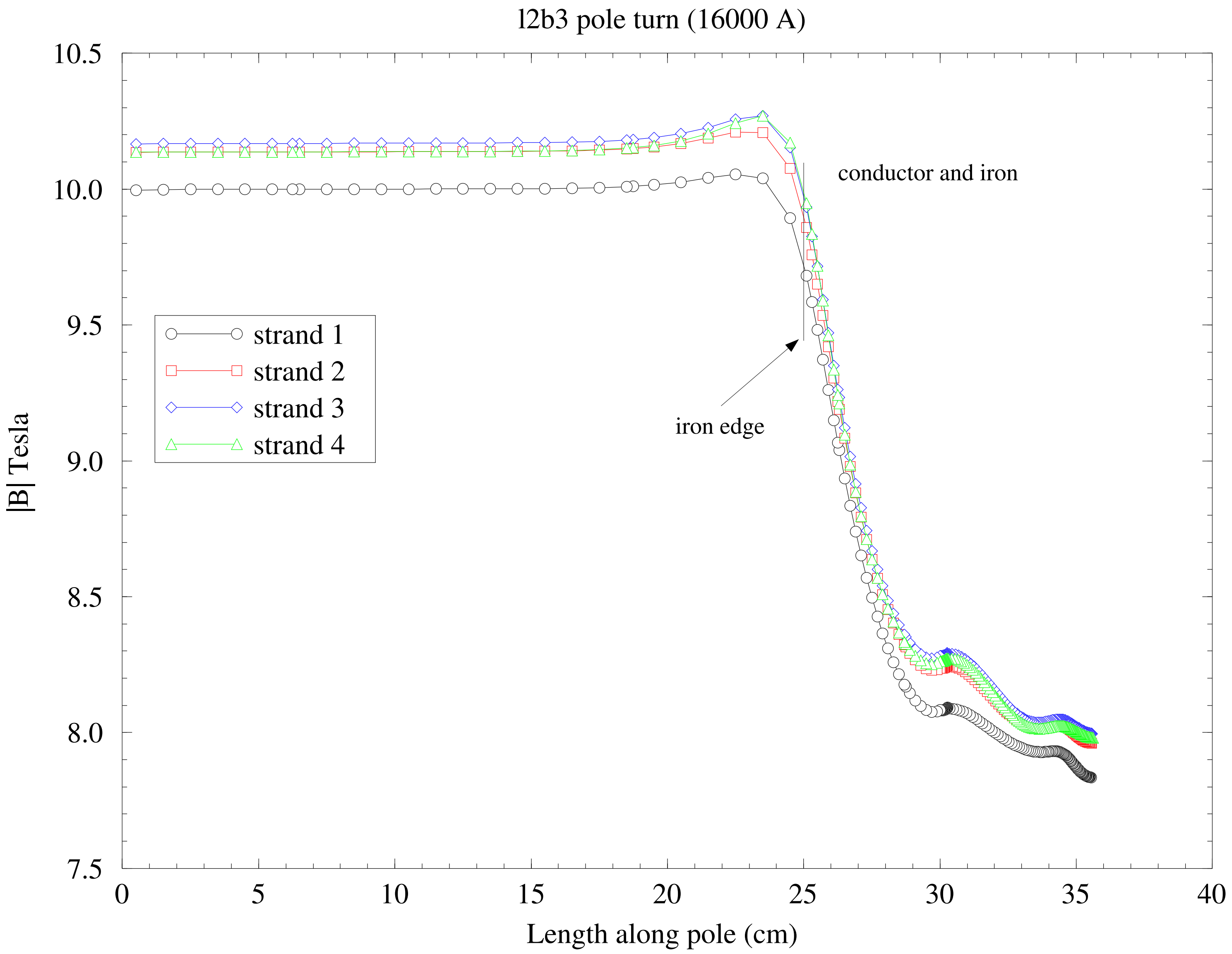

Figure 14 Maximum Field along pole of layer 2 (I=16 kA)

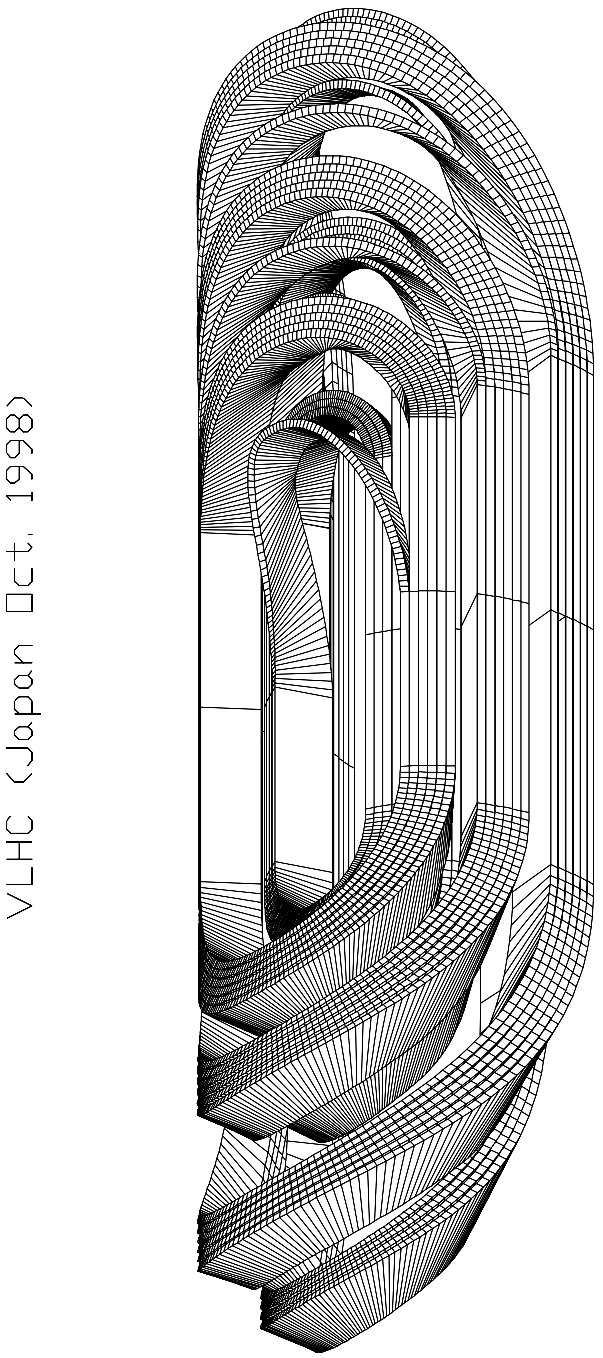

Figure 15 Layer 1 and 2 coils

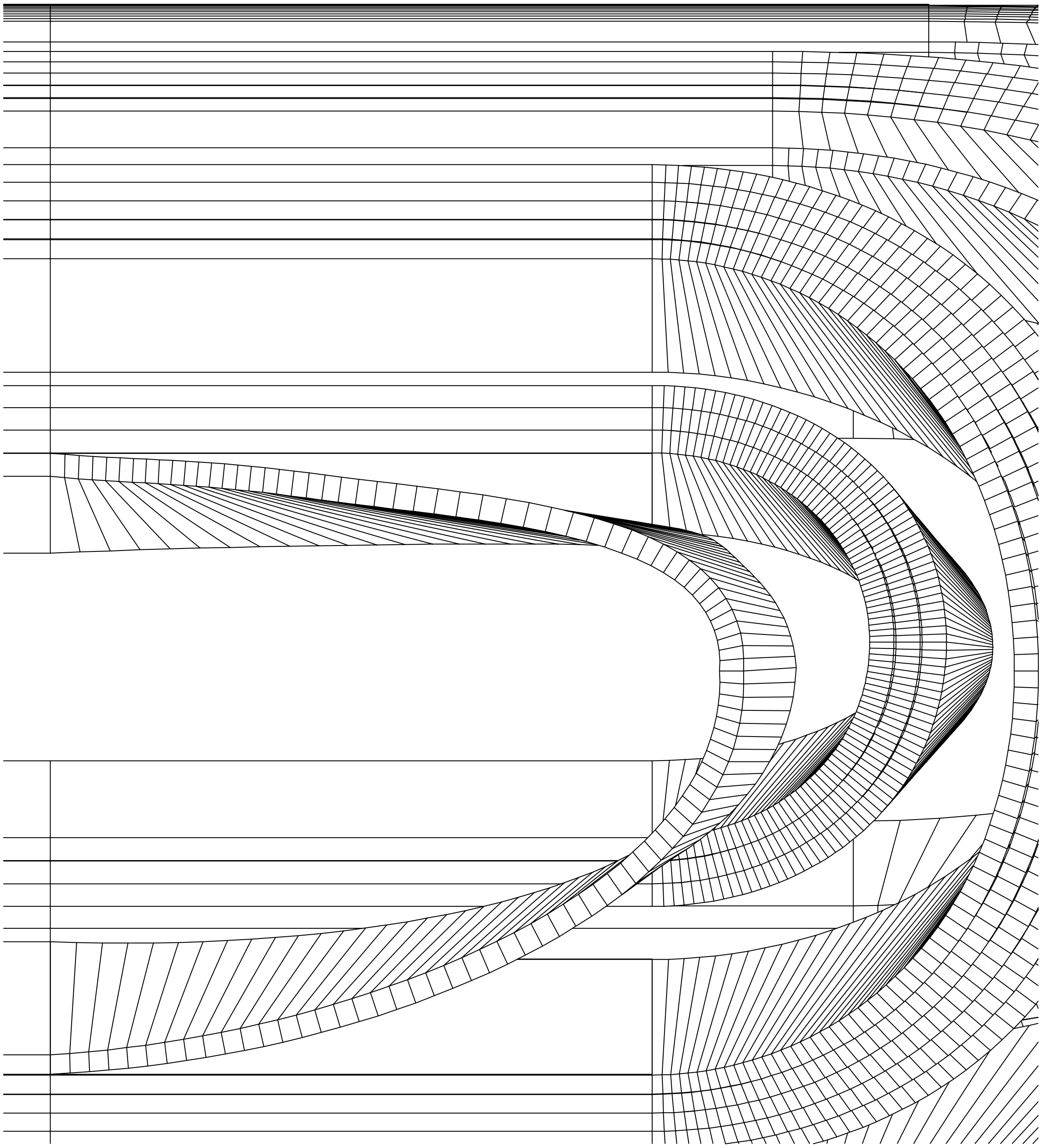

Figure 16 Layer to layer transition

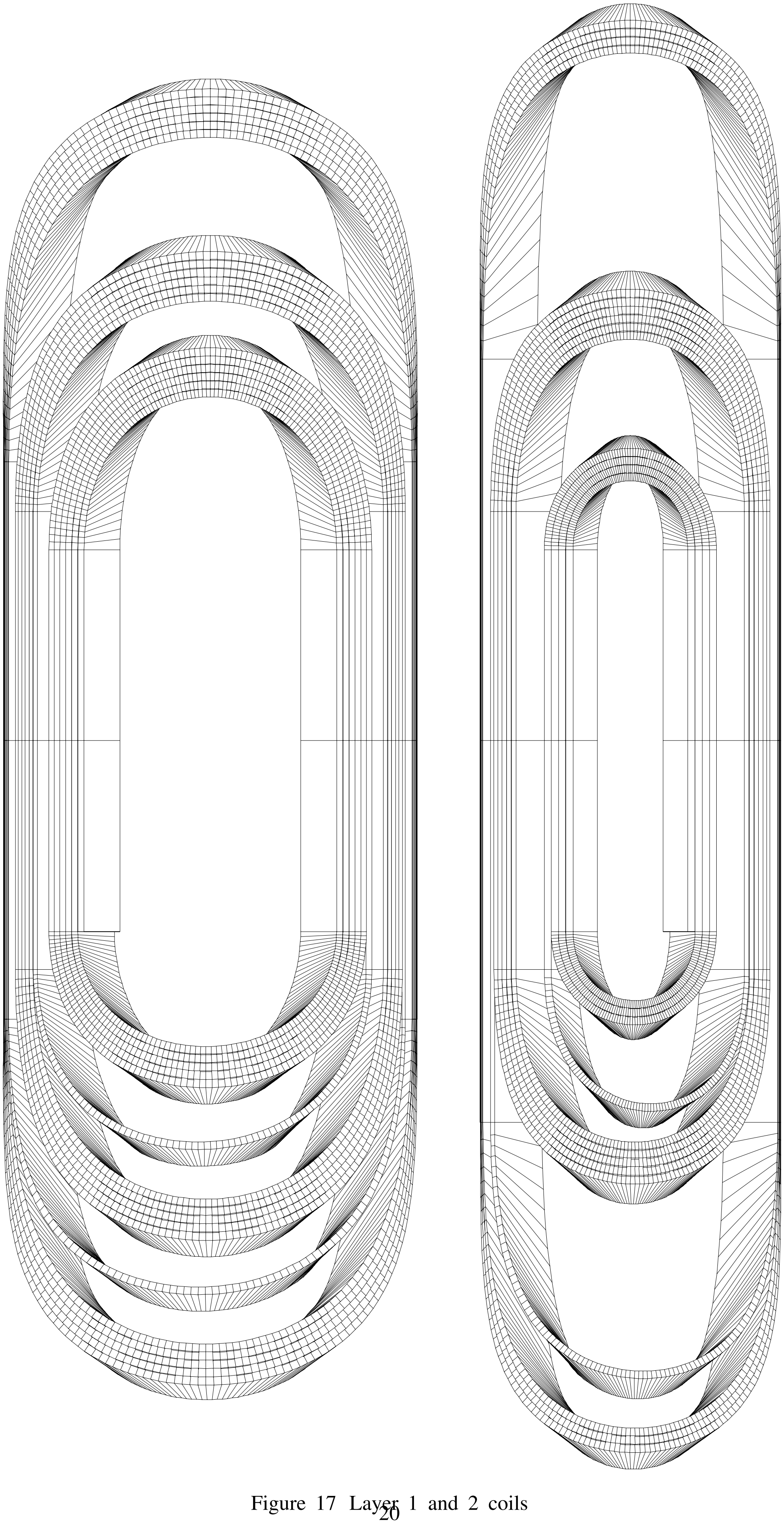

Figure 17 Layer 1 and 2 coils

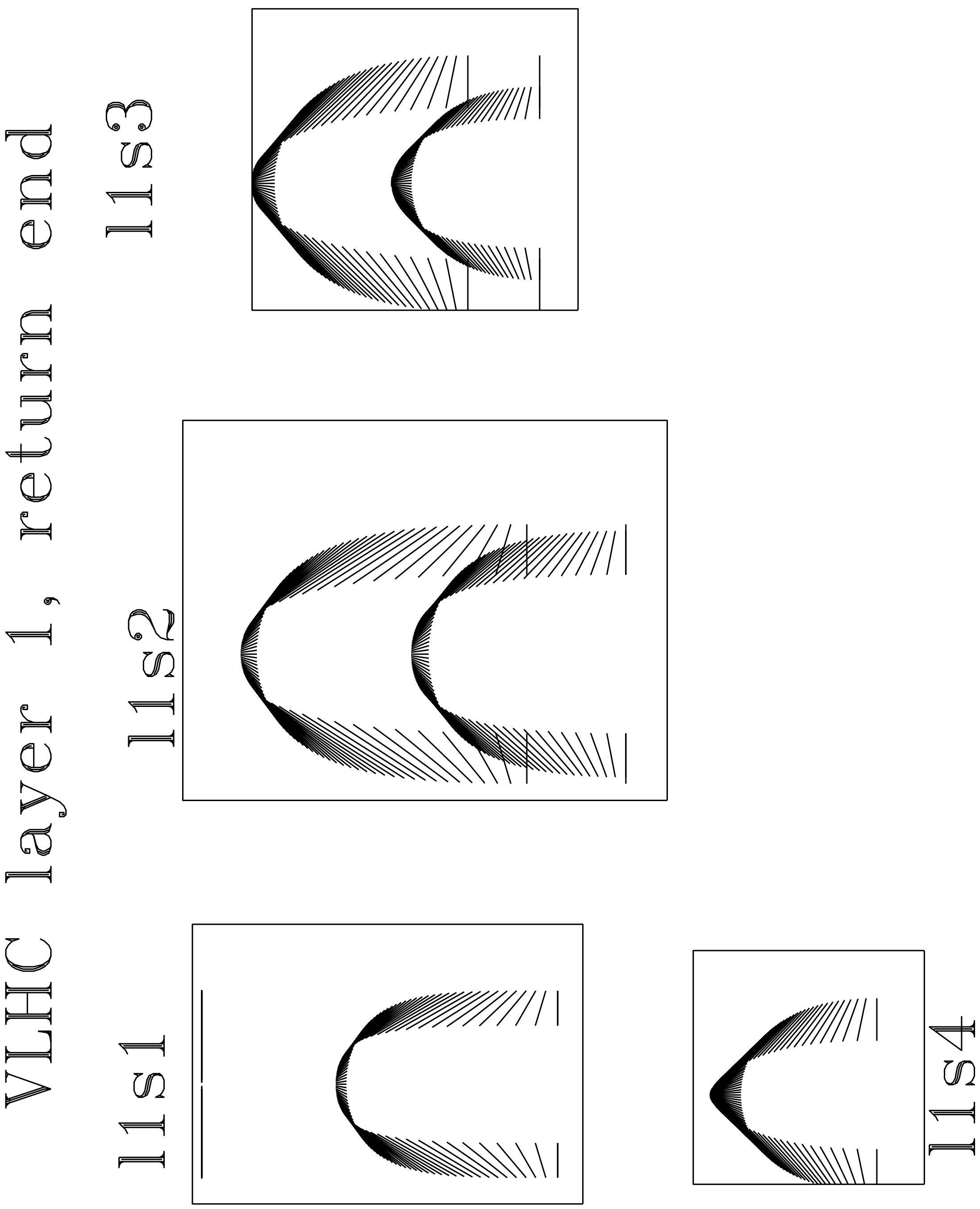

Figure 18 Layer 1 end spacers rulings

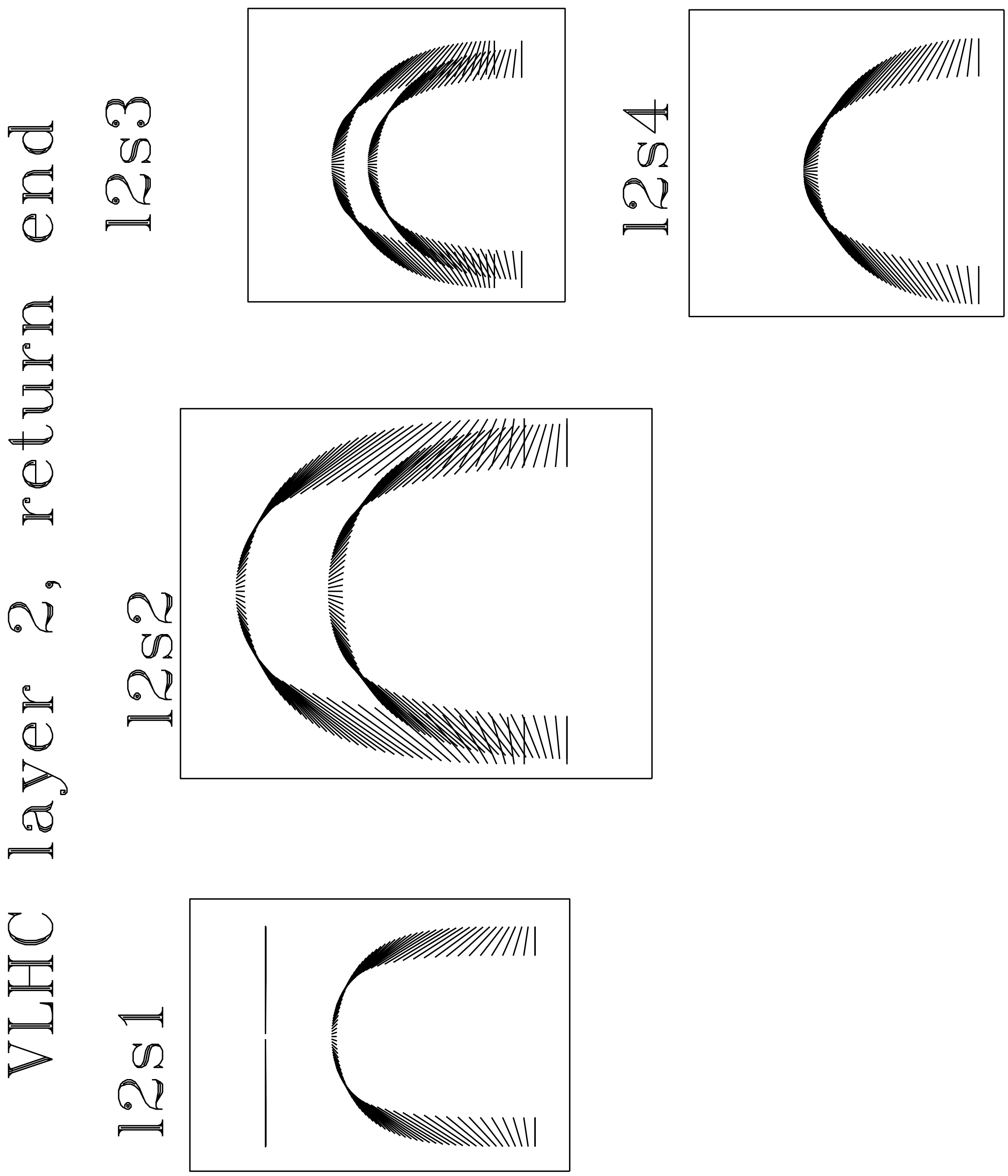

Figure 19 Layer 2 end spacers rulings

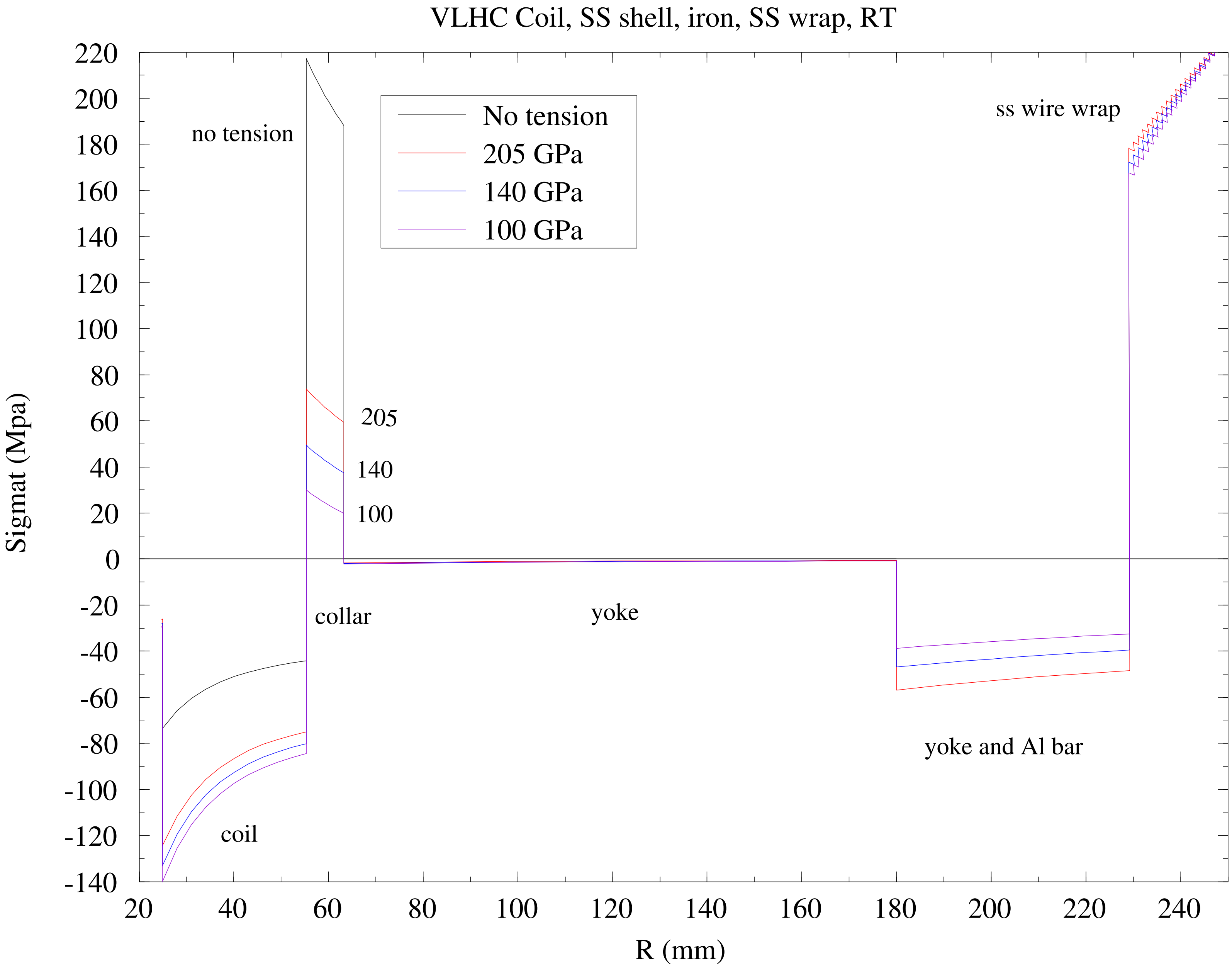

Figure 20 Azimuthal Stress using a SS wire wrap — room temperature

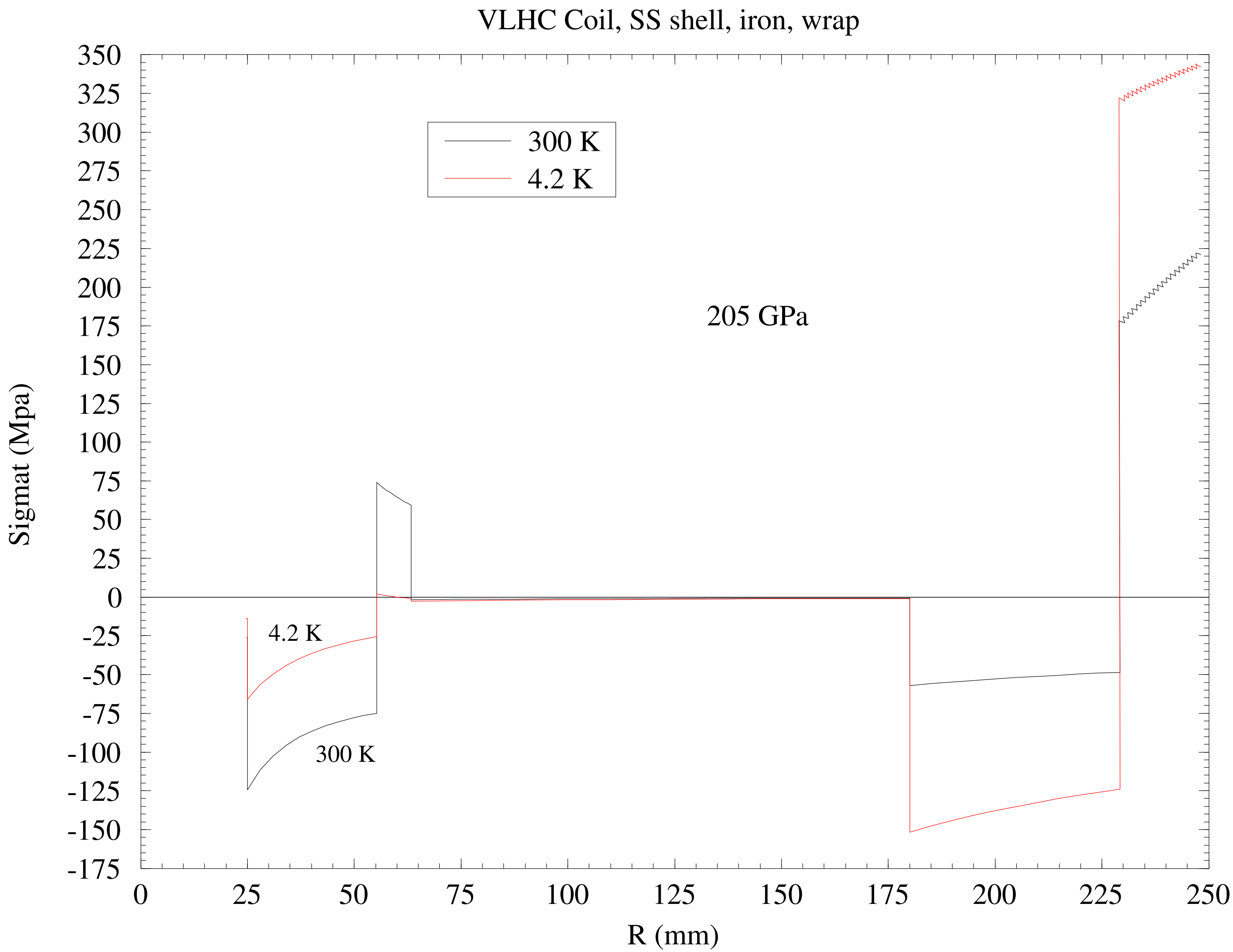

Figure 21 Azimuthal Stress using a SS wire wrap — warm vs. cold

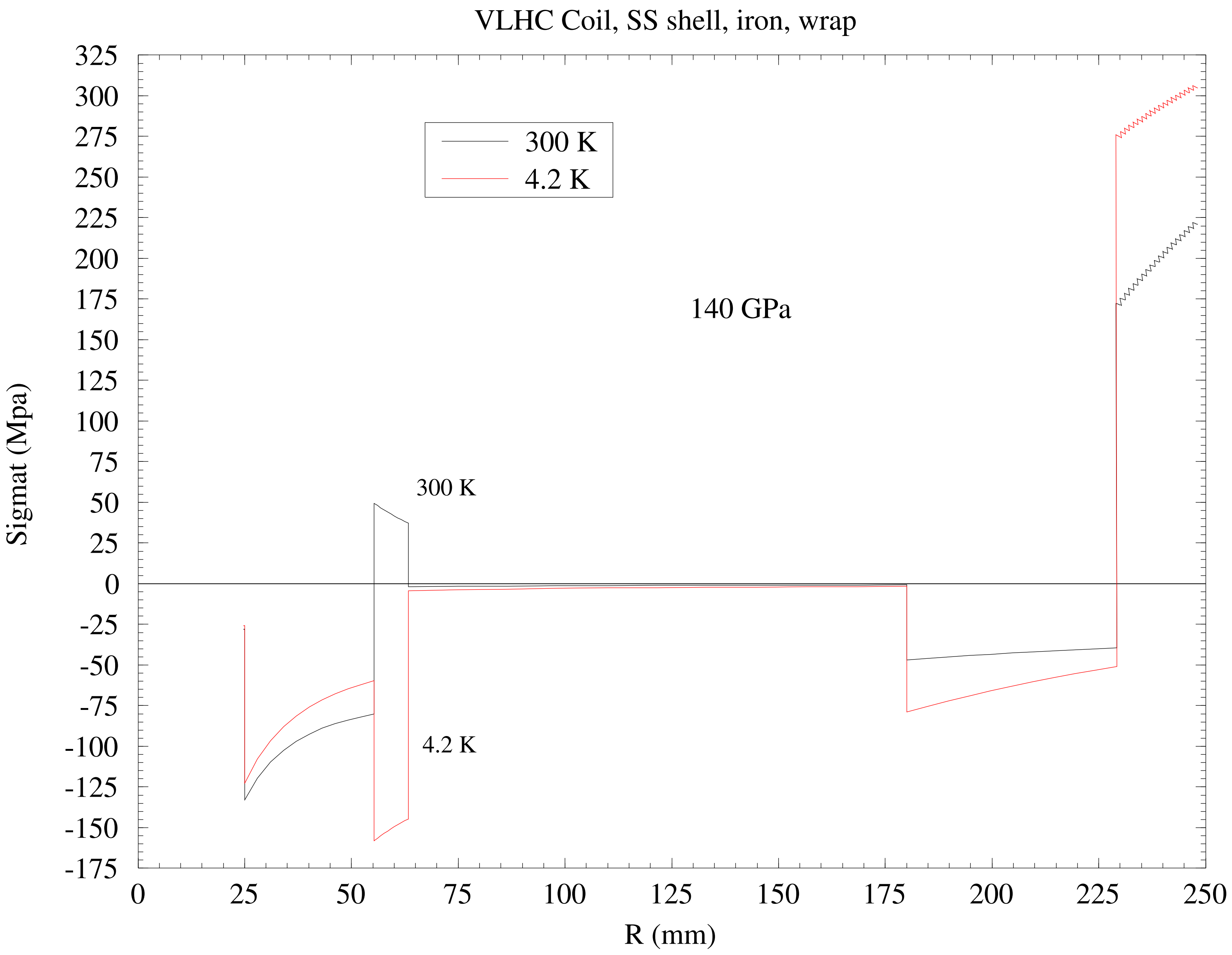

Figure 22 Azimuthal Stress using a SS wire wrap — cold vs. warm

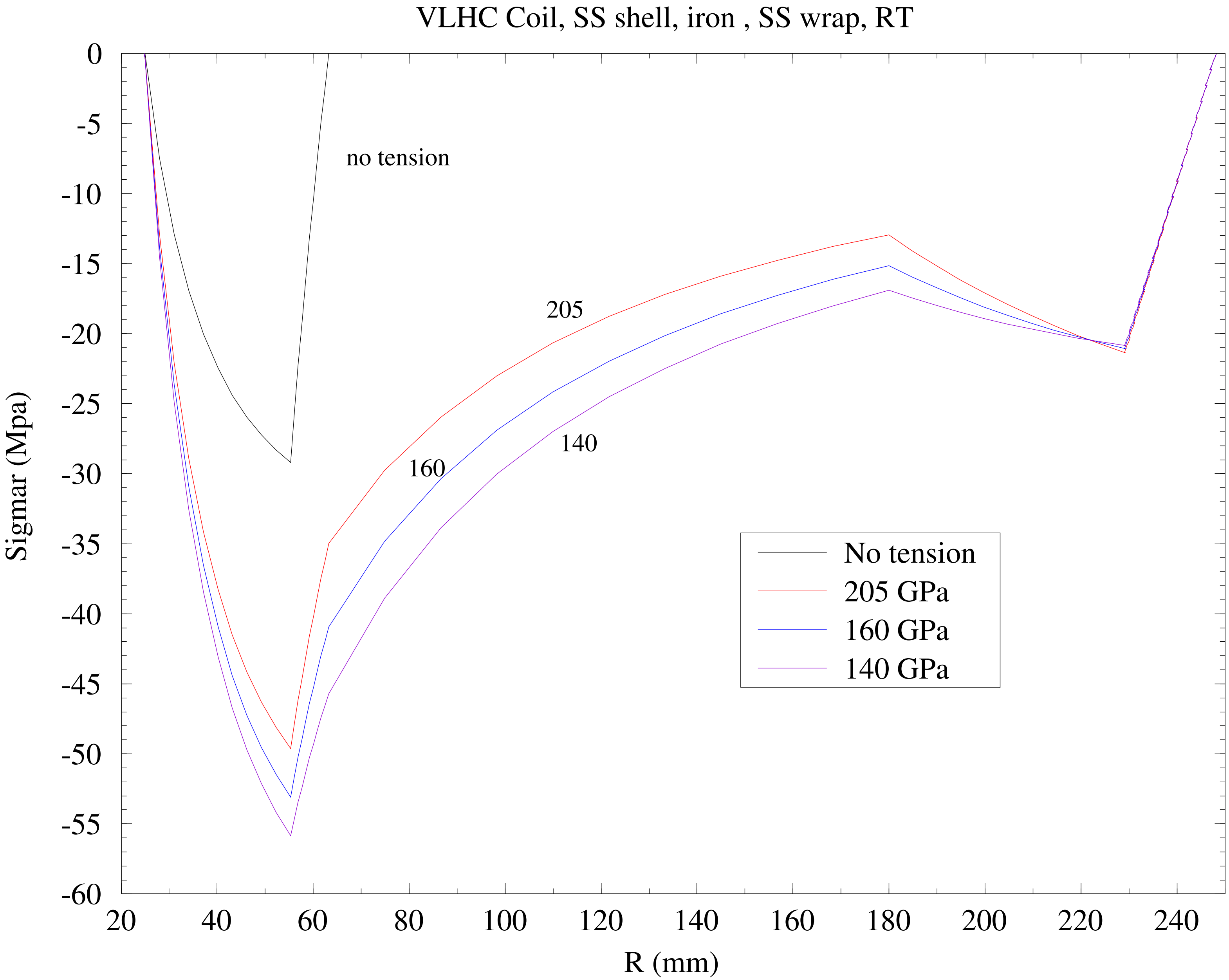

Figure 23 Radial Stress using a SS wire wrap — room temperature

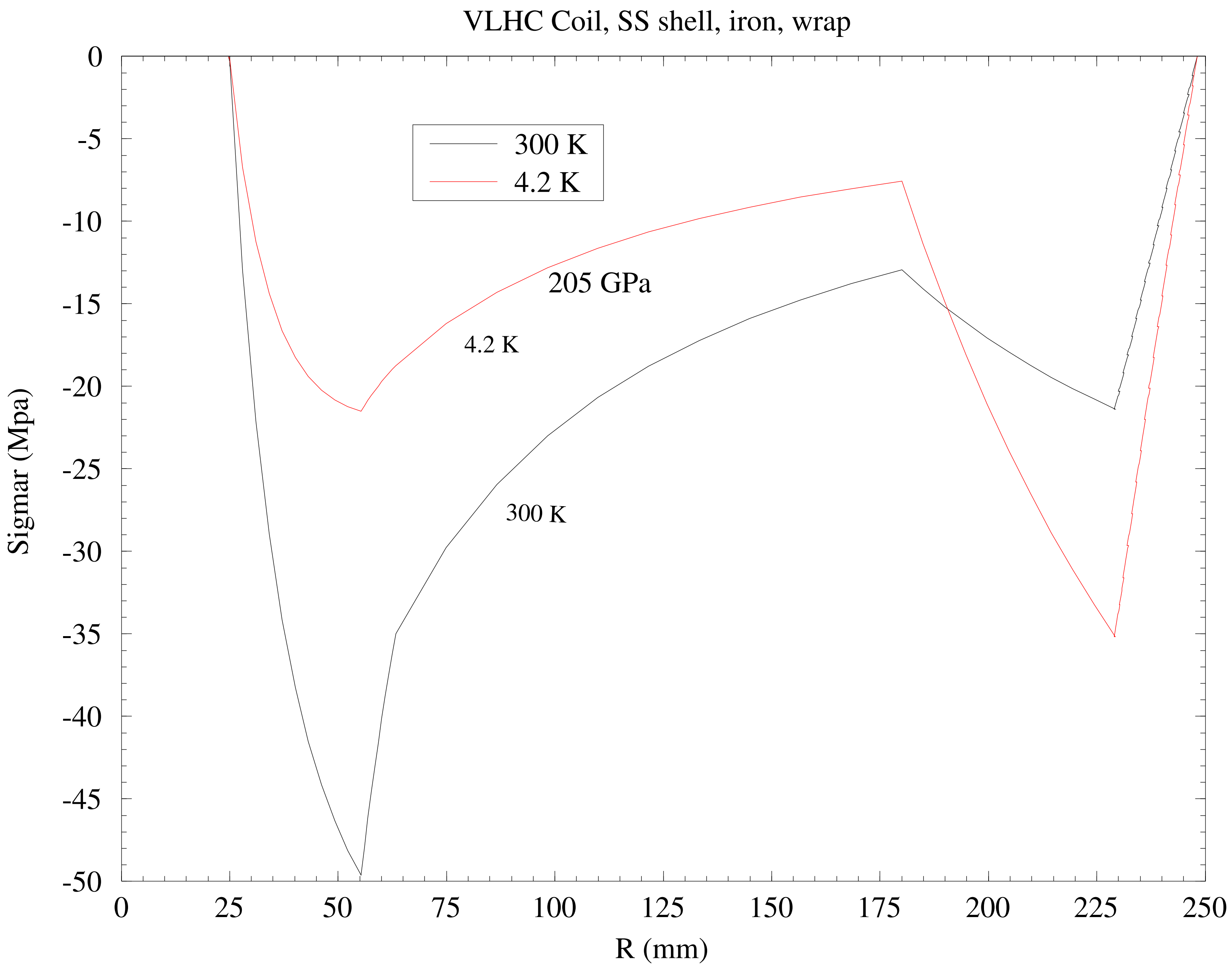

Figure 24 Radial Stress using a SS wire wrap — warm vs. cold

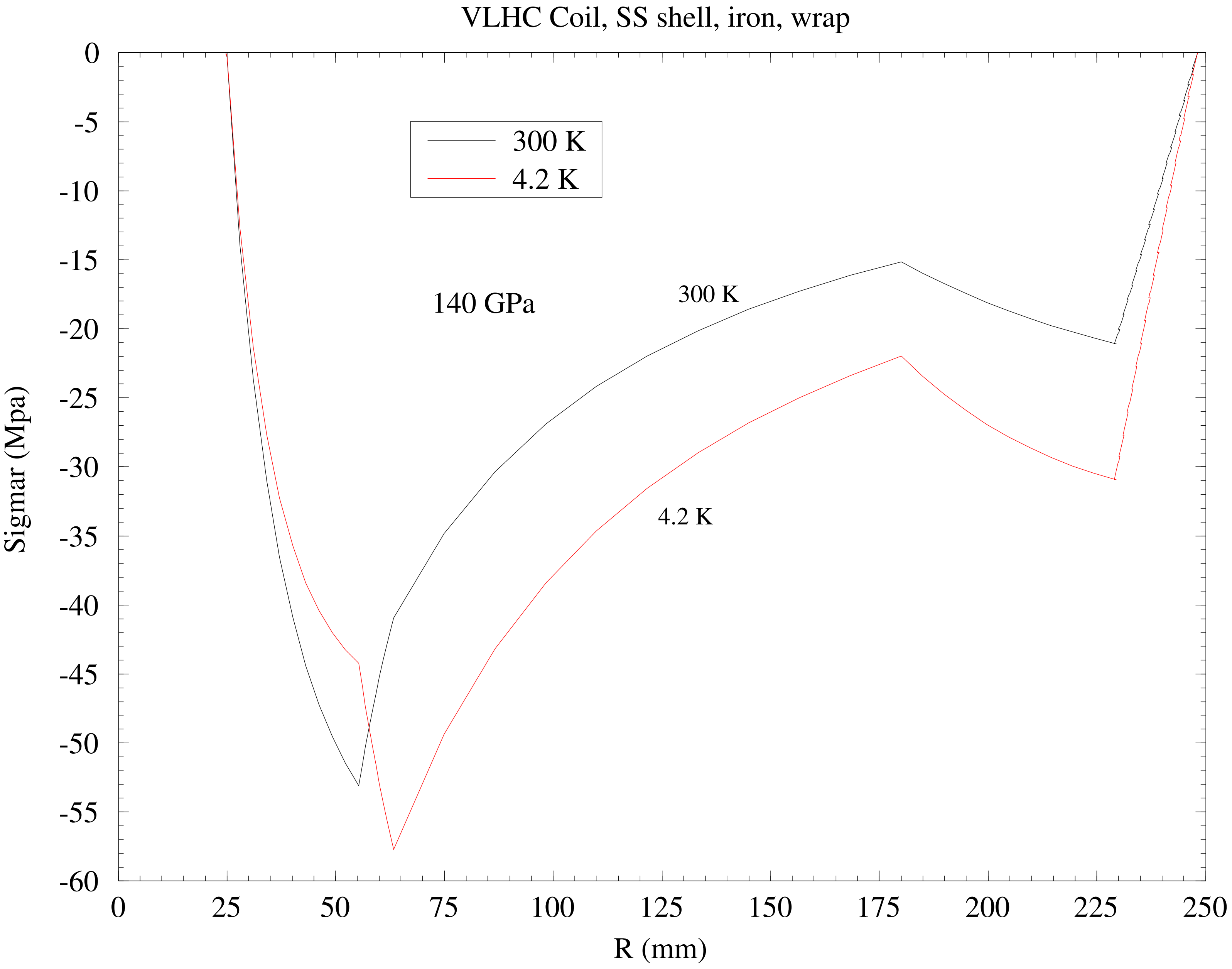

Figure 25 Radial Stress using a SS wire wrap — warm vs. cold

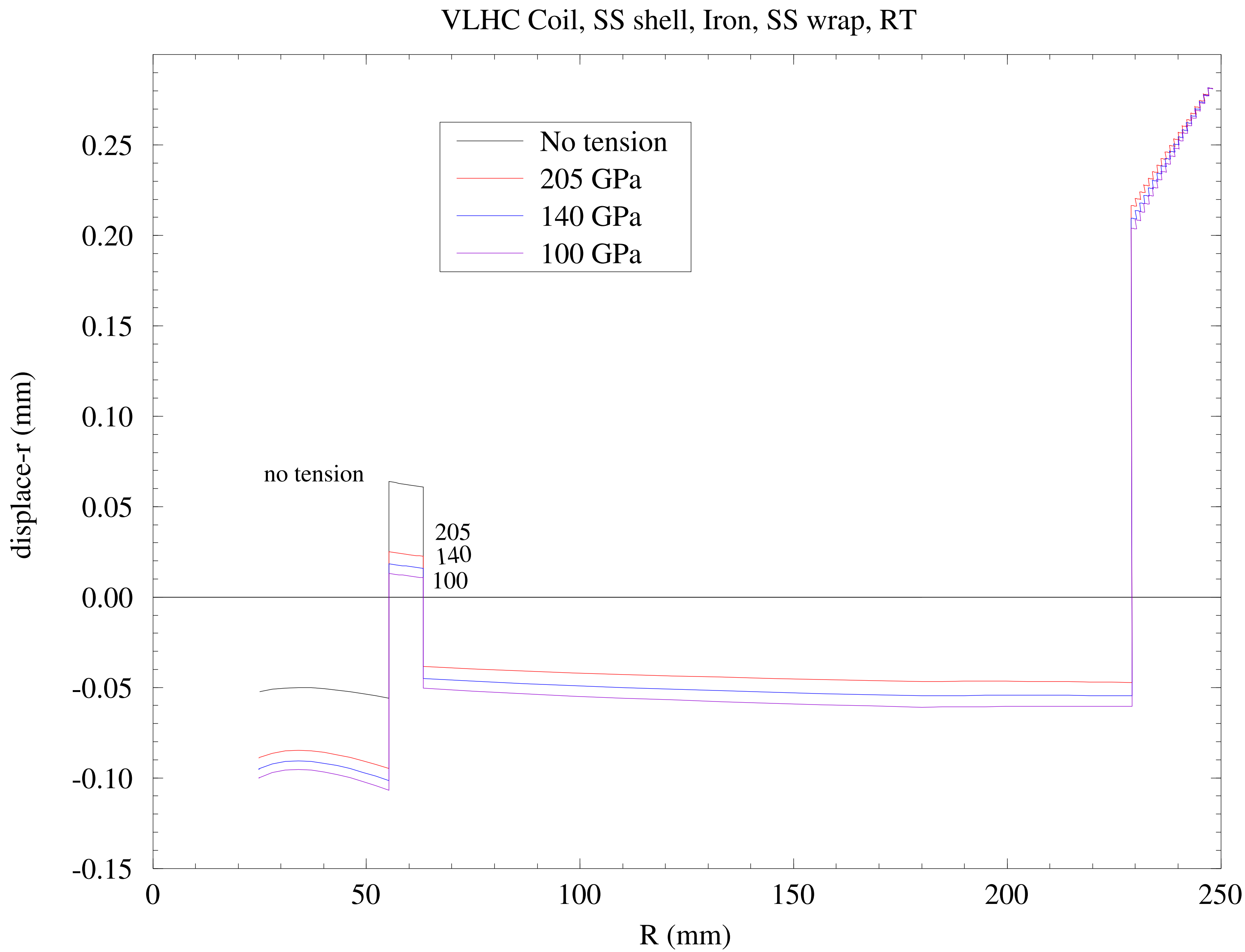

Figure 26 Radial displacement using a SS wire wrap

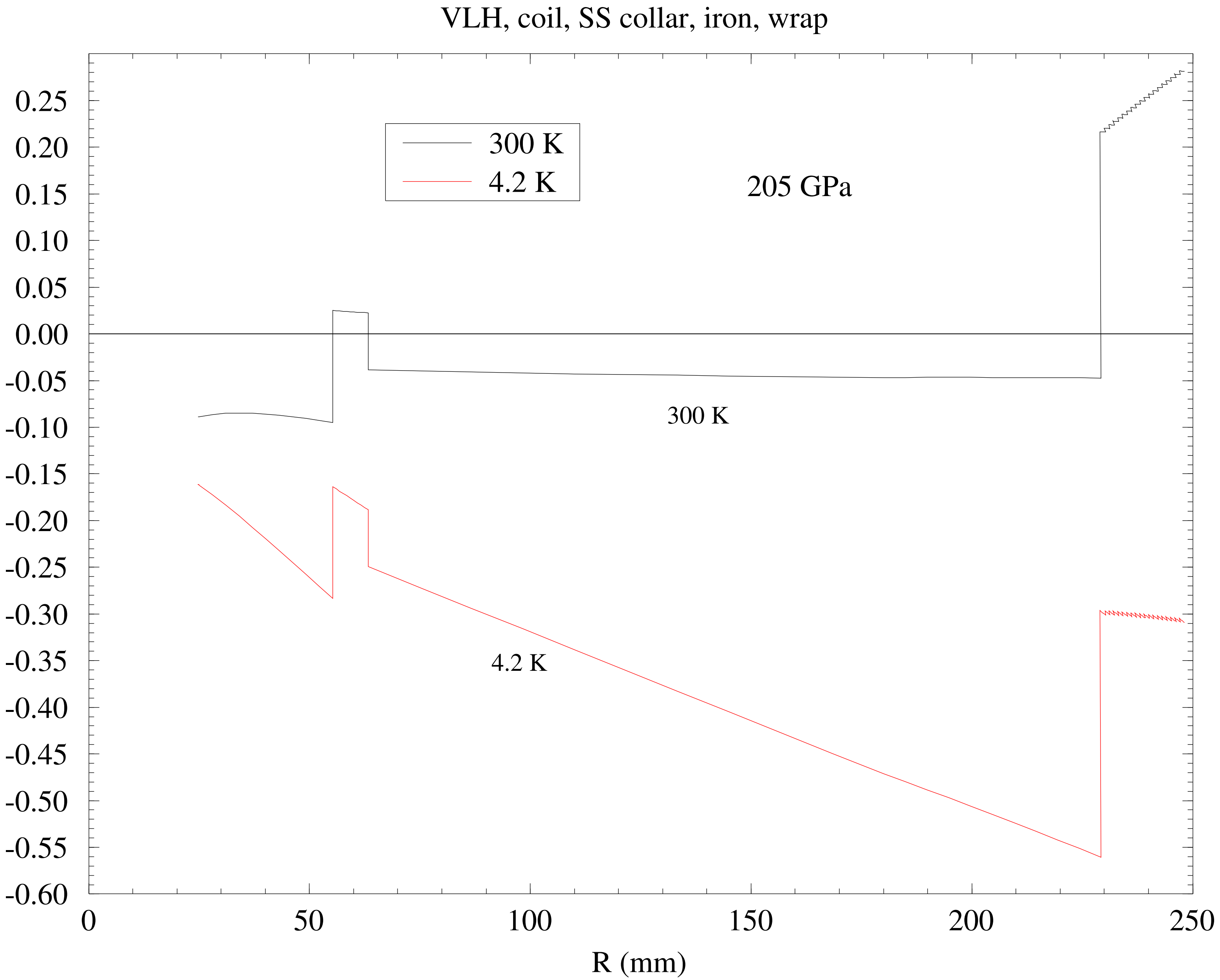

Figure 27 Radial displacement using a SS wire wrap — cold vs. warm

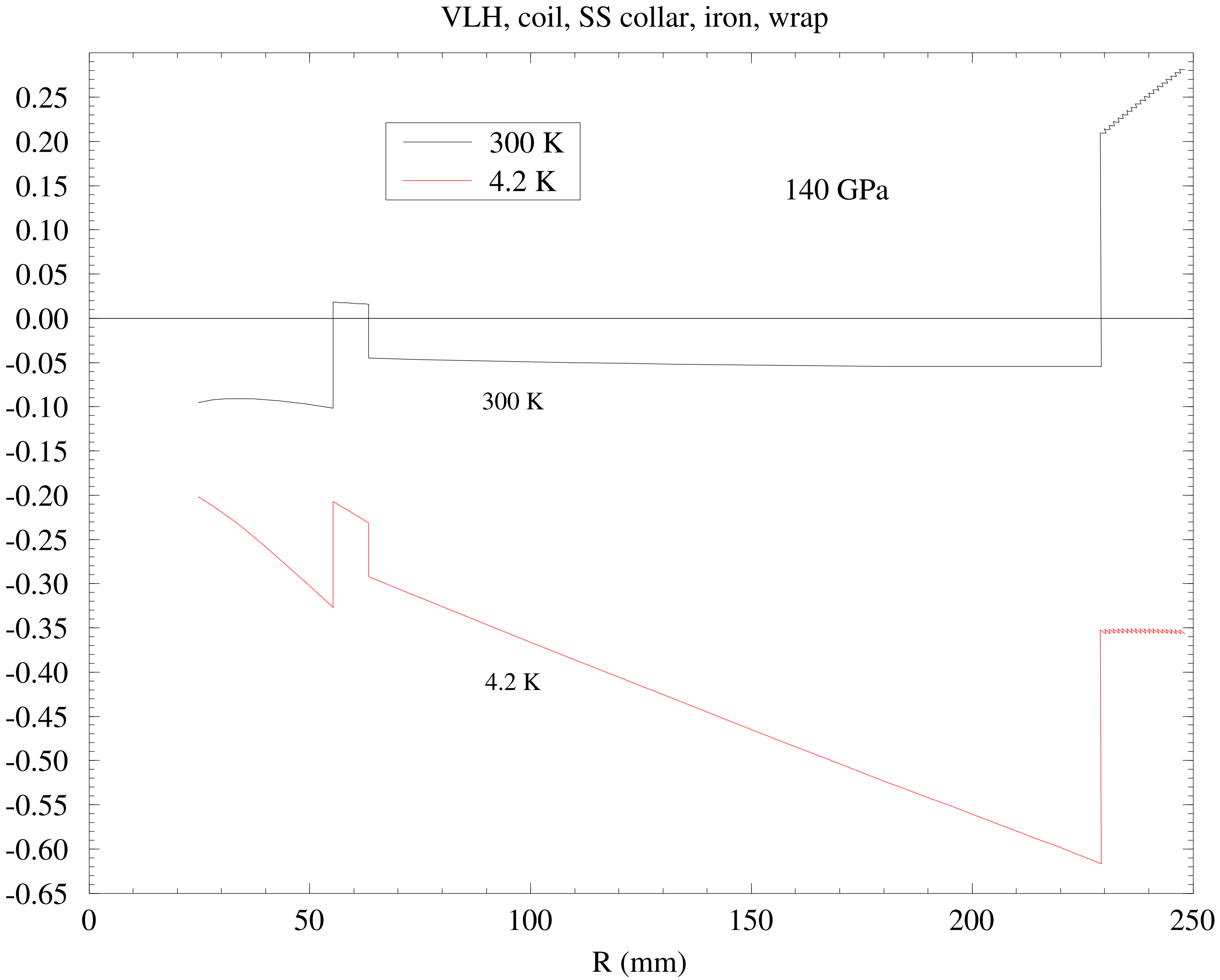

Figure 28 Radial displacement using a SS wire wrap — cold vs. warm

Appendix A PKlbl — input, output

input

```
set title
Nb3Sn dipole for VLHC, Japan October  1998
parameters
  1 'block 1 L1'  0.40000D+01   0.20000D+01   0.40000D+01   0.60000D+01    1
  2 'wedge 1   '  0.98271D+00   0.10000D+00   0.50000D+00   0.20000D+01    0
  3 'block 2   '  0.60000D+01   0.20000D+01   0.50000D+01   0.70000D+01    1
  4 'wedge 2   '  0.83713D+01   0.10000D+00   0.35000D+00   0.95000D+01    0
  5 'block 3   '  0.40000D+01   0.20000D+01   0.20000D+01   0.50000D+01    1
  6 'block 1 L2'  0.60000D+01   0.20000D+01   0.40000D+01   0.80000D+01    1
  7 'wedge 1   '  0.18796D+01   0.10000D+00   0.20000D+00   0.70000D+01    0
  8 'block 2   '  0.60000D+01   0.20000D+01   0.40000D+01   0.80000D+01    1
  9 'wedge 2   '  0.27504D+01   0.10000D+00   0.20000D+00   0.70000D+01    0
 10 'block 3   '  0.60000D+01   0.10000D+01   0.40000D+01   0.80000D+01    1

 $FCNIN RFE=6.3270 ,ROPT=1.25 ,QUAD=.false.,DIPOLE=.true.,LSYM=4
   AMP=15817.0 debug=1 t0=4.35 $
!
!  input for cable
!
!
cable=1,radial_width=1.4238,thickness=0.2025,keystone=0.02485,
     strands=28,strand_diameter=0.10,degradation_factor=1.0,
     cu_sc_ratio=0.85,
     material=2,jm=2750.0,bm=5.00,tbm=4.20
harmonics
 2        0.0       1.
 4        0.0       1.
 6        0.0       1.
end
geometry
costheta=.true.,rblock_0=.false.,rblock_45=.false.
bore_radius=2.45936
layer,start_layer=0.012,parameters=1-5,insulation=0.05564
layer,start_layer=0.012,parameters=6-10,insulation=0.05794
end
fix 1
fix 3
fix 5
fix 6
fix 8
fix 10
minimize
CALL FCN           6
EXIT
END
```

output

```
          **** PARAMETER ****
dipole                     : T
quadrupole                 : F
costheta geometry          : T
block 0 degree geometry    : F
block 45 degree geometry   : F
enddesign                  : F
symmetry                   : 4
units                      : 3
fscale                     : 0.10E+04
bore radius                :     2.459 [cm]
iron inner radius          :     6.327 [cm]
radius for optimization    :     1.250 [cm]
Draw trapez (1=yes, 0=no)  :         1
Current/turn               :  15817.00 [A]
Operating temperature      :      4.35 [K]
```

```
          **** LAYER Characteristics ****

 Layer nr Start pos.[cm] Nr sectors 1st param  Insulation[cm] Current-factor Align
    1             0.012          5         1        0.056        1.000         0
    2             0.012          5         6        0.058        1.000         0

          **** CABLE Characteristics ****

Cable.nr width[cm] thickness [cm] keystone [cm] strandnr pack.factor J [A/mm**2]
     1     1.4238         0.2025        0.0249       28      0.0000      0.0000



   **** Peak fields and critical currents ****
--------------------------------------------------------------------------

Peak field inside aperture on : 0.00  0.00  0.00  0.71  0.71  0.71  0.71  0.00

Bpeak =    11.946229 at (    0.000000,    0.166931 )
Bpeak =    11.946163 at (    0.540175,    0.707106 )
Bpeak =    11.946270 at (    0.707106,    0.540175 )
Bpeak =    11.946314 at (    0.540175,    0.000000 )
Max. Field on square close to bore center (0,0 1,0 1,1 1,0) :  11.9463 [T]
-----------------------------------------------------------------------------
layer 1 blk 1
--------------

Bpeak =    11.888946 at (    2.448455,    0.590513 )
Bpeak =    11.542435 at (    2.437649,    0.769673 )
Bpeak =     5.871434 at (    3.857890,    0.868886 )
Bpeak =    11.877348 at (    2.449499,    0.579963 )
Layer/Block  1: Bpeak =    11.8889 T at (    2.4485,  0.5905  )  on the Toe

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]

Short sample field limit, calculated according to M.I.Greens..........
Bss =      8.26 [T] @   924.933 [A/mm*2], I =  10994.78 [A], Gain =  0.695
Short sample field limit, calculated according to Morgans method......
Bss =      8.18 [T] @   915.451 [A/mm*2], I =  10882.06 [A], Gain =  0.688
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     12.43 [T] @  1391.488 [A/mm*2], I =  16540.76 [A], Gain =  1.046

-----------------------------------------------------------------------------
layer 1 blk 2
--------------



Bpeak =    12.224257 at (    1.907540,    1.639472 )
Bpeak =    12.017290 at (    1.818240,    1.779988 )
Bpeak =     8.516412 at (    2.988686,    2.583013 )
Bpeak =    12.201137 at (    1.921100,    1.620049 )
Layer/Block  1: Bpeak =    12.2243 T at (    1.9075,  1.6395  )  on the Toe

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]

Short sample field limit, calculated according to M.I.Greens..........
Bss =      8.31 [T] @   904.030 [A/mm*2], I =  10746.30 [A], Gain =  0.679
Short sample field limit, calculated according to Morgans method......
```

```
Bss =      8.22 [T] @   894.729 [A/mm*2], I =  10635.74 [A], Gain =  0.672
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     12.53 [T] @  1363.601 [A/mm*2], I =  16209.27 [A], Gain =  1.025
-----------------------------------------------------------------------------
layer 1 blk 3
--------------

Bpeak =    12.539169 at (    0.871589,    2.372159 )
Bpeak =    12.645303 at (    0.911214,    2.475027 )
Bpeak =    10.275475 at (    1.499454,    3.650247 )
Bpeak =    12.333926 at (    1.035976,    2.299215 )
Layer/Block  1: Bpeak =    12.6453 T at (    0.9112,  2.4750  )  on the Top

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]

Short sample field limit, calculated according to M.I.Greens..........
Bss =      8.35 [T] @   879.085 [A/mm*2], I =  10449.77 [A], Gain =  0.661
Short sample field limit, calculated according to Morgans method......
Bss =      8.27 [T] @   869.951 [A/mm*2], I =  10341.20 [A], Gain =  0.654
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     12.64 [T] @  1330.280 [A/mm*2], I =  15813.18 [A], Gain =  1.000
-----------------------------------------------------------------------------
layer 2 blk 1
--------------

Bpeak =     6.030925 at (    3.876425,    1.001116 )
Bpeak =     5.810080 at (    3.862753,    1.145679 )
Bpeak =     2.769158 at (    5.278626,    1.293819 )
Bpeak =     5.976925 at (    3.880971,    0.956475 )
Layer/Block  2: Bpeak =     6.0309 T at (    3.8764,  1.0011  )  on the Toe

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]

Short sample field limit, calculated according to M.I.Greens..........
Bss =      7.04 [T] @  1552.388 [A/mm*2], I =  18453.40 [A], Gain =  1.167
Short sample field limit, calculated according to Morgans method......
Bss =      6.99 [T] @  1541.545 [A/mm*2], I =  18324.51 [A], Gain =  1.159
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     10.10 [T] @  2229.371 [A/mm*2], I =  26500.77 [A], Gain =  1.675
-----------------------------------------------------------------------------
layer 2 blk 2
--------------

Bpeak =     7.387517 at (    3.295525,    2.280415 )
Bpeak =     7.396653 at (    3.303624,    2.289661 )
Bpeak =     5.156511 at (    4.532162,    2.986243 )
Bpeak =     7.000548 at (    3.394593,    2.122547 )
Layer/Block  2: Bpeak =     7.3967 T at (    3.3036,  2.2897  )  on the Top

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]
```

```
Short sample field limit, calculated according to M.I.Greens..........
Bss =      7.45 [T] @  1340.260 [A/mm*2], I =  15931.81 [A], Gain =  1.007
Short sample field limit, calculated according to Morgans method......
Bss =      7.39 [T] @  1329.192 [A/mm*2], I =  15800.24 [A], Gain =  0.999
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     10.80 [T] @  1943.709 [A/mm*2], I =  23105.08 [A], Gain =  1.461
-----------------------------------------------------------------------------
layer 2 blk 3
--------------

Bpeak =     9.554088 at (    2.373367,    3.228439 )
Bpeak =     9.926177 at (    2.547444,    3.442339 )
Bpeak =     7.865560 at (    3.306282,    4.304259 )
Bpeak =     9.448399 at (    2.519694,    3.122552 )
Layer/Block  2: Bpeak =     9.9262 T at (    2.5474,   3.4423  )  on the Top

Superconducting cable : Operating temperature :  4.35 [K], Cable type :  1
Number strands =   28, strand diameter    = 0.100000 [cm]
Cu:SC ratio    = 0.85, degradation factor =     1.00
Critical current density =   2750.0, [A/mm^2] for Bm = 5.00 [T] @ 4.20 [K]
Area-SC                  =     0.1189 [cm^2/turn]
Area-Cu                  =     0.1010 [cm^2/turn]
Current density in Cu    =  1565.4132 [A/mm^2/turn]
Current density in SC    =  1330.6013 [A/mm^2/turn]
Current density in cable =   719.2439 [A/mm^2/turn]

Short sample field limit, calculated according to M.I.Greens..........
Bss =      7.98 [T] @  1069.742 [A/mm*2], I =  12716.14 [A], Gain =  0.804
Short sample field limit, calculated according to Morgans method......
Bss =      7.90 [T] @  1059.389 [A/mm*2], I =  12593.08 [A], Gain =  0.796
Short sample field limit, calculated according to NbSn D20 cable......
Bss =     11.82 [T] @  1583.972 [A/mm*2], I =  18828.85 [A], Gain =  1.190


Multipole transfer functions

  n        bn

  0 dipole         0.1197E+06
  2 sextupole     -0.5834E-05
  4 decapole       0.8260E-05
  6 14-pole       -0.7088E-04
  8 18-pole       -0.9022E+00
 10 22-pole        0.3201E+00
 12 26-pole        0.4661E-02
 14 30-pole       -0.3520E-02
 16 34-pole        0.1736E-03
 18 38-pole        0.3346E-05

Transfer function       :       7.5657 [G/A]  at 15817.00 A
Total area of conducter :       9.2262 [cm**2]
Total number of turns   :           32
Inner radius of coil    :       2.5119 [cm]
Outer radius of coil    :       5.9785 [cm]
Short sample limit calculated with M.I.Greens.......... is   0.661 lower
Short sample limit calculated with Morgans method...... is   0.654 lower
Short sample limit calculated with NbSn D20 cable...... is   1.000 lower

*** HARMONICS ***    evaluated at a radius of    1.25000 [cm]
  n              bn/b0        bpr      Beff        an/b0        apr      Aeff

  0 dipole      0.1000E+01  10000.00 174043.96    0.0000E+00      0.00      0.00
  2 sextupole  -0.4875E-10      0.00      0.00    0.0000E+00      0.00      0.00
  4 decapole    0.6903E-10      0.00      0.00    0.0000E+00      0.00      0.00
  6 14-pole    -0.5923E-09      0.00      0.00    0.0000E+00      0.00      0.00
  8 18-pole    -0.7539E-05     -0.45     -7.82    0.0000E+00      0.00      0.00
 10 22-pole     0.2675E-05      0.25      4.34    0.0000E+00      0.00      0.00
 12 26-pole     0.3895E-07      0.01      0.10    0.0000E+00      0.00      0.00
 14 30-pole    -0.2942E-07     -0.01     -0.12    0.0000E+00      0.00      0.00
 16 34-pole     0.1451E-08      0.00      0.01    0.0000E+00      0.00      0.00
 18 38-pole     0.2796E-10      0.00      0.00    0.0000E+00      0.00      0.00

                    *** CONTRIBUTION FROM PARTS ***

index  part number variable name contribution
```

```
  1       1         block 1 L1           0.1653
  2       2         wedge 1              0.0000
  3       3         block 2              0.2127
  4       4         wedge 2              0.0000
  5       5         block 3              0.0798
  6       6         block 1 L2           0.2079
  7       7         wedge 1              0.0000
  8       8         block 2              0.1876
  9       9         wedge 2              0.0000
 10      10         block 3              0.1466

Program run finished at Fri Sep 25 01:12:30 1998


ROOM TEMPERATURE PROPERTIES FOR STRESS ANALYSIS
layer  ,Ri ,Ro ,Er ,Et ,Pt alfar,alfat ,Ba       ,Bb  ,current-density, tension (lb/inch)
Interferance
line 3
line 4
0.000000D+00  0.000000D+00
1   24.72D+00 25.0D+00   3.50000D+10  7.3000D+09  3.00D-01  0.00D+00  0.0D+00  0.00D+00  0.00D+00  0.0D+00  0.00D+00
0.0d0
1   25.0D+00  55.26940D+00  3.50000D+10  3.5000D+10  3.00D-01  0.00D+00  0.0D+00  0.00D+00  0.00D+00  0.0D+00  0.00D+
00
0.12d0
1  55.26940D+00  63.2694D+00  1.9500D+11   1.9500D+11  2.94D-01  0.0D+00  0.0D+00 0.0D+00  0.0D+00 0.0D+00  0.0D+00
-6.1022435397800D-02
1  63.2694D+00  180.0D+00 2.0500D+11 1.0D+09  2.94D-02  0.0D+00  0.0D+00  0.0D+00 0.00D+00  0.0D+00  0.0D+00
0.0d0
1  180.0D+00  229.2694D+00 2.0500D+11 1.0D+11  2.94D-01  0.0D+00  0.0D+00  0.0D+00 0.00D+00  0.0D+00  0.0D+00
0.0d0
19 229.2694D+00 248.2694D+00 1.9500D+11  1.9500D+11 2.94D-01  0.00D+00  0.0D+00  0.0D+00 0.0D+00  0.0D+00  1.27D+03

COLD
layer  ,Ri ,Ro ,Er ,Et ,Pt alfar,alfat ,Ba       ,Bb  ,current-density, tension (lb/inch)
Interferance
line 3
line 4
0.000000D+00  0.000000D+00
1   24.72D+00 25.0D+00   3.50000D+10  7.3000D+09  3.0D-01 -0.0039d0  -0.00459d0  0.00D+00  0.00D+00  0.0D+00  0.00D+0
0
0.0d0
1   25.0D+00  55.26940D+00  3.50000D+10  3.5000D+10  3.0D-01 -0.0039d0  -0.00459d0  0.00D+00  0.00D+00  0.0D+00  0.00
D+00
0.12d0
1  55.26940D+00  63.2694D+00  1.9500D+11   1.9500D+11  2.94D-01 -0.003d0 -0.003d0 0.0D+00  0.0D+00 0.0D+00  0.0D+00
-6.1022435397800D-02
1  63.2694D+00  180.0D+00 2.0500D+11 1.0D+09  2.94D-02 -0.00189d0 -0.00189d0  0.0D+00 0.00D+00  0.0D+00  0.0D+00
0.0d0
1  180.0D+00  229.2694D+00 2.0500D+11 1.0D+11  2.94D-01 -0.00189d0 -0.00259d0  0.0D+00 0.00D+00  0.0D+00  0.0D+00
0.0d0
19 229.2694D+00 248.2694D+00 1.9500D+11  1.9500D+11 2.94D-01 -0.003d0 -0.003d0  0.0D+00 0.0D+00  0.0D+00  1.27D+03
(sol) cold %
```