PPPL Calculation Form

Calculation # NCSX-CALC-132-02 Revision # 0 WP #, if any (ENG-032) 132

Purpose of Calculation: (Define why the calculation is being performed.)

Check of Myatt Consulting,Inc stress analysis of the NCSX PF4,5,&6 Coils.

References (List any source of design information including computer program titles and revision levels.)

1.Myatt Consulting,Inc. memo Dated: 18 Feb.2004 (attached)
2. F.Dahlgren PF4 Analysis check memo Dated: 21 Feb. 2008 (attached)

Assumptions (Identify all assumptions made as part of this calculation.)

See Refs. 1 & 2

Calculation (Calculation is either documented here or attached)

See Refs. 1 & 2

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

The Myatt consulting analysis was checked and results were in resonable agreement with the current PF4 analysis. Basic assumptions of clamped boundary conditions and material properties in the analysis agree with the coil support design and published property data.

Cognizant Engineer's printed name, signature, and date

Jim Chrzanowski, 22 Feb. 2008 Jim Chrzanowski

Digitally signed by Jim Chrzanowski
DN: cn=Jim Chrzanowski, o=PPPL, ou=Enginering, email=jchrzano@pppl.gov, c=US
Date: 2008.02.25 14:35:17 -05'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Fred Dahlgren, 22 Feb. 2008

Checker's printed name, signature, and date

? Signature Not Verified fdahlgre

Digitally signed by fdahlgre
DN: cn=fdahlgre, o=PPPL, c=US
Date: 2008.02.25 09:55:44 -05'00'

Jim,

I have run various PF-coil scenarios with the mod coil fields included using the DFORCE7 code which models coaxial field coils and conductor filaments representing the modular coils. These results were conveyed to Mike Kalish in Dec.'07 and are attached below.

I have also made runs that upped the current in PF1a to 46.7kA per Mike Z.s' request.
He is hoping to run these at 64kA which may not be possible due to stress & thermal limitations.

The worst case average hoop stress (other than PF1a) is 2.38 ksi in PF4 for the 320kA ohmic scenario @t=2.06 sec. (Note there may not be sufficient volt-secs. in the PF1a swing to get the full 320kA plasma current). A comparison of earlier FEA runs with DFORCE7 results for PF1a indicate that the average hoop stress calculated by DFORCE7 is generally 60-70% of the peak stress calculated by the FEA analysis of PF1a. I would expect similar peaking factors for the other PF coils.

To varify this and as a check on Len Myatts' analysis results I have built an FEA ANSYS model of PF4 which contains all the discrete turns and turn-to-turn insulation (see attachment A below for a brief description of this PF4 analysis).

Summarizing these results:

Myatts' PF4 EM load only peak stress: 2,784 psi (19.2 MPa)
DFORCE7 PF4-EM load only (PF1a @ 46.7kA): 2,385 psi (16.5 MPa)
My recent PF4 FEA model results: 3,368 psi (23.2 MPa)
Myatts' PF4 EM + thermal peak stress: 7 ksi (48 MPa)

For the other run scenarios the EM load hoop & combined stresses are less than 2ksi. When thermal cool-down radial constraints are added, 9.5ksi (65 MPa) for PF5 &6 are estimated based on max. single pulse temp.rise from 77 K (note, this needs to be varified by analysis).The exception is PF1a which is up to ~11 ksi peak & ~7ksi for the average hoop stress in most scenarios.This is predominantly due to the self fields generated at 46.7kA.

Conclusion:

None of these results appear to challenge the project conductor allowable of 16,000 psi (110 MPa), although it should be emphasized that large thermal differences between the coils and supporting structure must be avoided during cool-down and during operations. Large temperature differences will exceed allowables in the coil and possibly the support structure and further analysis should be done to quantify the maximum permissible temperature difference (post FDR).

Myatts' analysis also points out that the epoxy-glass insulation does not meet the projects' shear-compression & normal tensile allowables in many areas of the coils if a fully bonded design is assumed. If de-lamination is assumed only the in-plane tension/compression and flatwise compression need to be considered and these meet the project criteria. This would probably indicate a primary electrical insulating layer (Mylar or Kapton?) under the epoxy-glass turn-to turn wrap.

The DFORCE7 run summaries are attached below (dfout7d-xxx.txt).

ATTACHMENT A: A Preliminary analysis check for NCSX PF-4 coil

An FEA model for PF4 was created to check the results of Len Myatts' original PF coil analysis for the NCSX poloidal field coil design. The model was built for the ANSYS FEA program using 20-node brick elements for the individual coil turns and turn-to-turn insulation. Equivalent isotropic material properties were used to properly represent the copper conductor with a reduced Youngs' modulus to simulate an internal cooling hole, and orthotropic properties for the conductor insulation. Layer-to layer and turn-to-turn transitions were also included, with the turn transitions represented by a full 360 degree spiral per turn and the layer transition as joggles spanning about 10 degrees at the lead stem area of the coil. Figure 1 below shows the full 360 model which includes shortened lead stems.

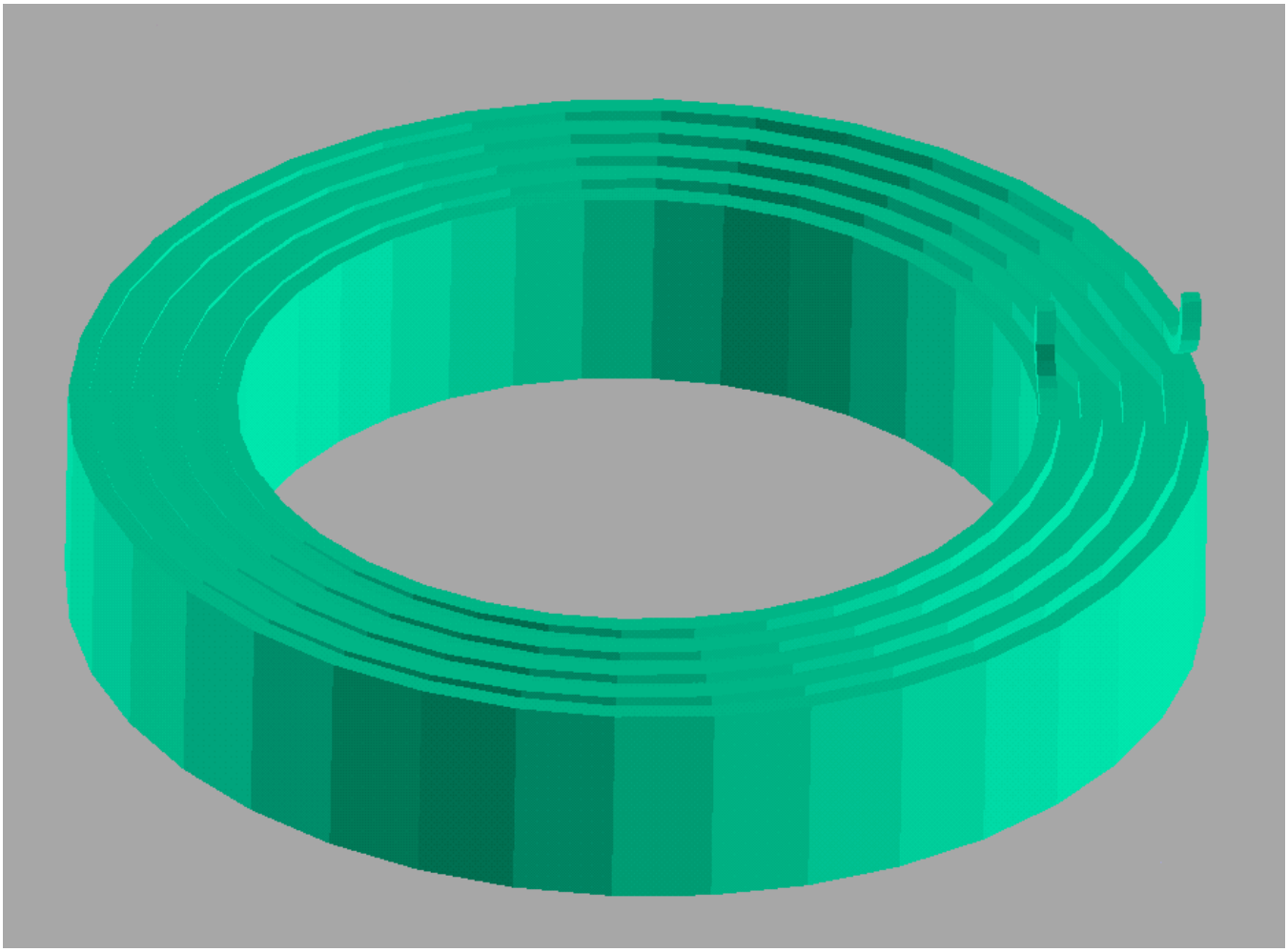

Figure 1. ANSYS FEA model of PF-4 coil for NCSX

The results of the analysis are summarized in figures 2 thru 5. Figure 2 is a contour plot of the SRSS displacements of the coil indicating a maximum deflection at the outer lead stem of about 0.0045". Since the lead clamp design was not yet available for this analysis, no constraints were put on the radial deflection of the leads and only two discrete points were coupled in the circumferential direction. The reaction force from the circumferential constraints at the leads was about 15 lbs. Due to the lack of radial constraints (other than an assumed shear bond to adjacent turn insulation), this should represent a worst case upper bound on displacements at the lead stems.

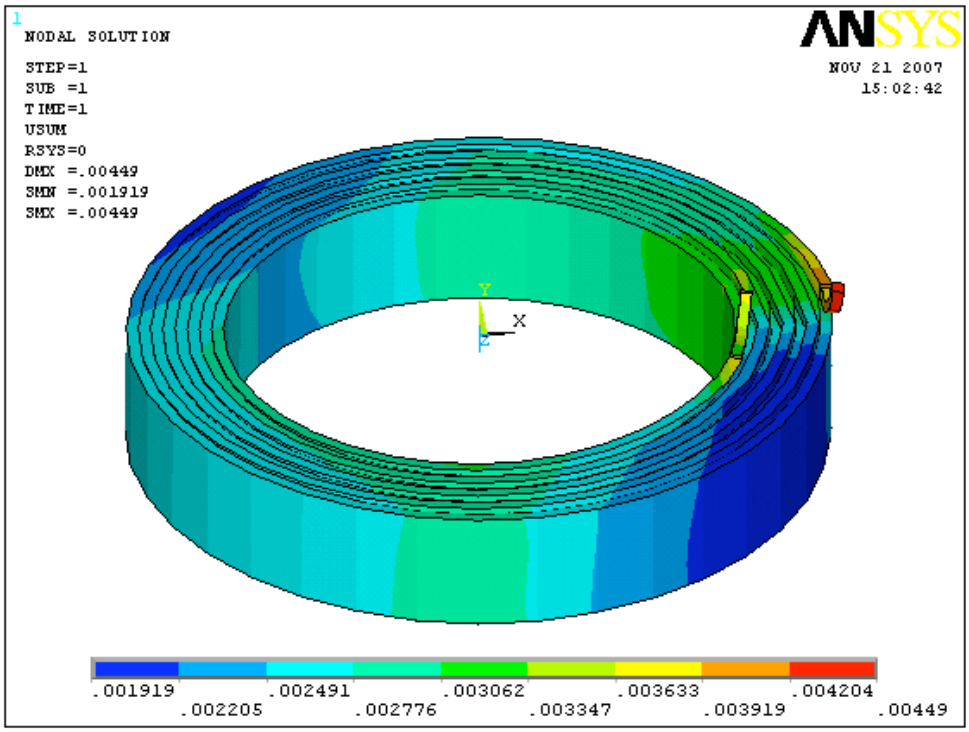

Figure 2. SRSS displacement contours of PF4 for NCSX

Figure 3 is a contour plot of the Tresca stress intensity in PF4. The peak Tresca stress is seen to be ~3.4 ksi occurring at the inner radius near the lead stem.

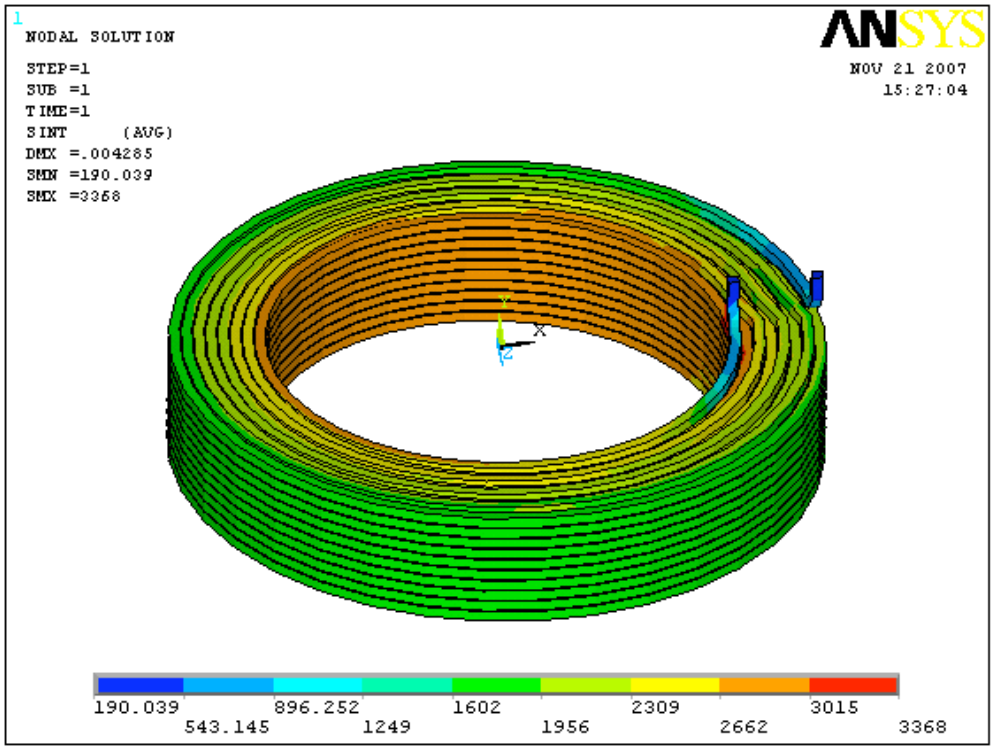

Figure 3. Tresca stress contours of PF4 for NCSX

Figure 4 are the Tresca stress intensity contours at the inner lead stem curved transition indicating the peak is ~1.3 ksi on the upper-outer corner of the turn.

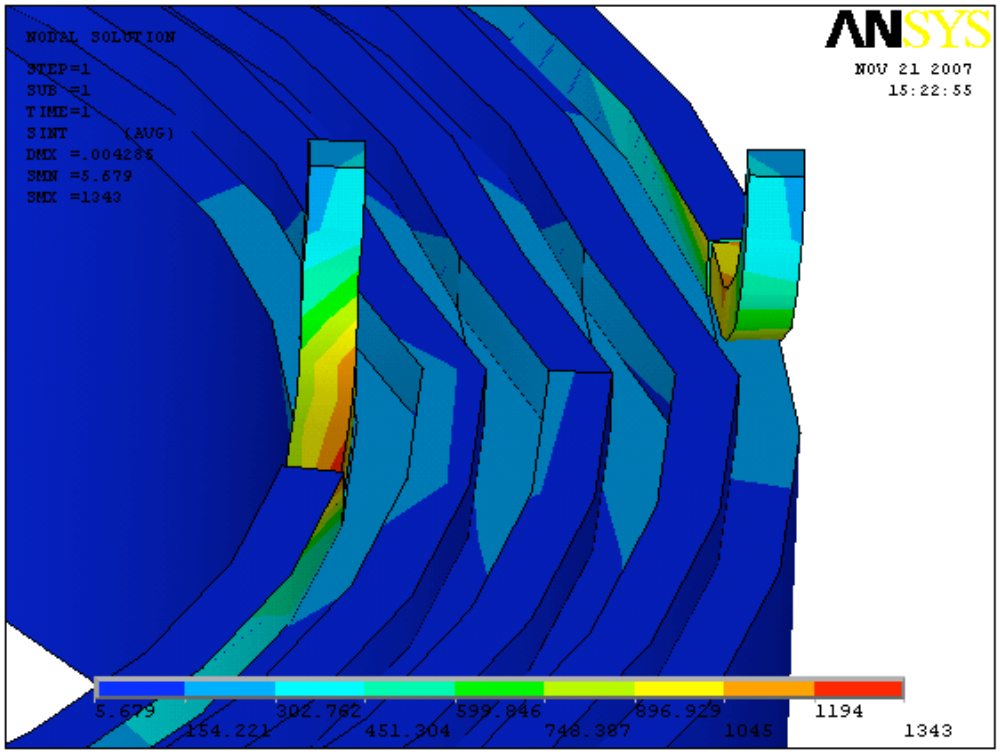

Figure 4. Tresca Stress contours at the lead stems of PF4 for NCSX

Figure 5 is a plot of the Tresca stress contours in the epoxy glass turn-to-turn insulation at the inner lead stem indicating a peak stress of about 900 psi.

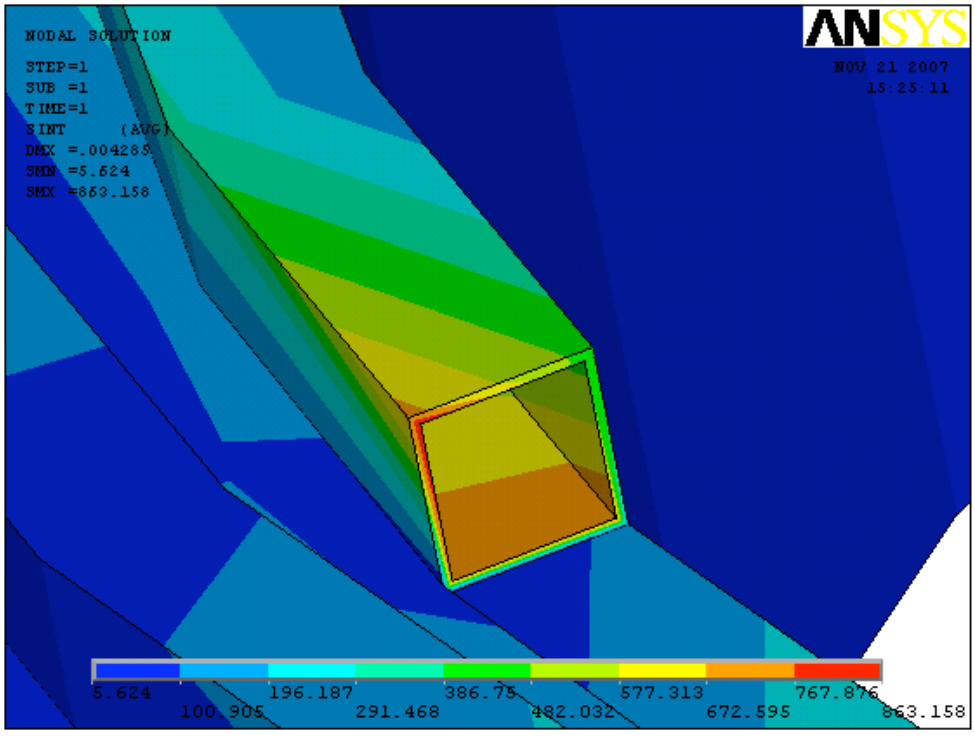

Figure 5. Tresca stress contours in the insulation of PF4 for NCSX

Conclusions:

In general the results of this analysis confirm the results of earlier DFORCE7 calculations and the FEA results obtained by Len Myatts analysis with the project allowable in the conductor of 110 MPa (16 ksi) not being seriously challenged. Since the DFORCE7 code results do not model coil details and lead stem areas, they tended to under estimate the peak stresses in the coils compared to the PF4 FEA results, but yield reasonably accurate values for the average membrane stress in the conductors. Myatts' analysis was done with the assumption of the old SS casting support scheme which assumed a vertical support (and radial support if clamped) at every TF coil. Another difference to note is Myatts' analysis used scenarios which included PF1a, PF1b, and PF1c which are no longer being considered for the MIE design. The DFORCE and current PF4 FEA loads use loading with the reclaimed PF1 coils from NSTX and various coil currents to maximize volt-seconds. Also, the present support configuration has only six supports for PF4 and 15-cantilevered brackets supporting the two outer PF5 & PF6 coils creating a somewhat wider gap between support points at the A-A joint locations. Since all the EM loading conditions typically produce small coil stresses these differences in the supporting structure should not significantly affect these results. A comparison of Myatts' EM only stress in PF4 of 19.2 MPa (2784 psi) to the current PF4 analysis which yields a peak stress of 3368 psi tends to confirm this. Myatts caveat concerning the avoidance of temperature differentials between coils and supporting structure during cool down is still applicable with the most recent support scheme which fixes the pf coils by clamping to a relatively rigid stainless steel structure.

References:

1. dfout7d-ohmic-1.7T@t=.140-peal-PF4.txt
2. dfout7d-2.0T@t=0.192-peak-pf456-209kA-Plasma.txt
3. dfout7d-320kA-ohmic:@t=0.206sec.-46.7kA-PF1a.txt
4. dfout7d-HiBeta-1.7T@t=.240-peak-pf4.txt
5. dfout7d-ohmic:1.7T@t=.0-peak-pf5&pf6.txt
6. dfout7d-HiBeta:1.7T@t=0-peak-pf5&6.txt
7. dfout7d-2.0T@t=.192-peak-pf4.txt
8. PF4-5-6 Coil Analysis SA R01.doc (Myatt Consulting, Inc.)

2.0T@t=0.192-peak-pf456-209kA-Plasma

NUMBER OF NON-CIRCULAR COILS: 12

MOD COIL #	NO. OF SEGMENTS	CURRENT (A-T)	#SEG/GRP
1	400	200530.0	400
2	801	200530.0	400
3	1202	182300.0	400
4	1603	182300.0	400
5	2004	200530.0	400
6	2405	200530.0	400
7	2806	200530.0	400
8	3207	200530.0	400
9	3608	182300.0	400
10	4009	182300.0	400
11	4410	200530.0	400
12	4811	200530.0	400

CURRENTS IN COIL GROUPS

1 1 46696.0 2 2 -7795.0 3 3 2349.0 4 4 7300.0 5 5 -209700.0 BZE = 0.0000

COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400

0

COIL NUMBER	NUMBER OF TURNS	SUPPORT WIDTH	SPAN LENGTH	CU WIDTH	CU HEIGHT	# OF SUPPORTS	INDUCTANCE	STORED ENERGY
1	48.00000	0.04000	0.01781	0.04000	0.50800	20.0	0.0032034	0.349E+07
2	80.00000	0.05000	0.13221	0.19100	0.25300	18.0	0.0202973	0.617E+06
3	24.00000	0.06000	0.71597	0.09800	0.16300	18.0	0.0155657	0.429E+05
4	14.00000	0.06000	0.88981	0.05200	0.18600	18.0	0.0077726	0.207E+06
5	1.00000	0.05000	0.19435	0.30000	0.30000	36.0	0.0000106	0.234E+06

Coil	R1	R2	Z1	Z2	Amp-Turns	Units	Z-center
1	0.164	0.204	0.146	0.654	2241408.000	3	0.400
2	0.427	0.618	1.456	1.709	-623600.000	3	1.583
3	2.174	2.272	1.448	1.612	56376.000	3	1.530
4	2.695	2.747	0.861	1.047	102200.000	3	0.954
5	1.250	1.550	-0.150	0.150	-209700.000	3	0.000
6	0.164	0.204	-0.654	-0.146	2241408.000	3	-0.400
7	0.427	0.618	-1.709	-1.456	-623600.000	3	-1.583
8	2.174	2.272	-1.612	-1.448	56376.000	3	-1.530
9	2.695	2.747	-1.047	-0.861	102200.000	3	-0.954

Note: un = 1 units are: inch-tesla-weber
un = 2 units are: inch-gauss-maxwell
un = 3 units are: meter-tesla-weber

0

COIL	A M IN	Z M IN	NI A A	FZ N LB	FR/L N/M LB/IN	FZ/L N/M LB/IN	S-HOOP N/M SQ PSI	COMBINED STRESS PSI	DFL-R	DFL-Z	HOOP STRAIN
1	0.184	0.400	2.241E+06	-1.016E+05	4.126E+06	-8.790E+04	4.706E+07				
	7.244	15.748	2.241E+06	-2.286E+04	2.357E+04	-5.022E+02	6.828E+03	6.829E+03	3.092E-03	-4.688E-11	4.268E-04
2	0.522	1.583	-6.236E+05	4.834E+04	2.097E+05	1.474E+04	4.071E+06				
	20.551	62.323	-6.236E+05	1.087E+04	1.198E+03	8.420E+01	5.907E+02	5.940E+02	7.587E-04	4.001E-08	3.692E-05
3	2.223	1.530	5.638E+04	-7.619E+03	2.029E+03	-5.455E+02	5.593E+05				
	87.520	60.236	5.638E+04	-1.714E+03	1.159E+01	-3.116E+00	8.115E+01	9.676E+01	4.439E-04	-9.045E-06	5.072E-06
4	2.721	0.954	1.022E+05	3.827E+04	1.446E+03	2.239E+03	8.358E+05				
	107.126	37.559	1.022E+05	8.608E+03	8.258E+00	1.279E+01	1.213E+02	2.687E+02	8.121E-04	1.135E-04	7.581E-06
5	1.400	0.000	-2.097E+05	1.603E+05	-4.826E+03	1.822E+04	-7.481E+04				
	55.118	0.000	-2.097E+05	3.605E+04	-2.757E+01	1.041E+02	-1.086E+01	1.271E+01	-3.740E-05	3.581E-08	-6.785E-07
6	0.184	-0.400	2.241E+06	1.169E+05	4.117E+06	1.011E+05	4.695E+07				
	7.244	-15.748	2.241E+06	2.630E+04	2.352E+04	5.778E+02	6.813E+03	6.813E+03	3.085E-03	5.394E-11	4.258E-04
7	0.522	-1.583	-6.236E+05	-1.344E+04	2.050E+05	-4.097E+03	3.980E+06				
	20.551	-62.323	-6.236E+05	-3.022E+03	1.171E+03	-2.341E+01	5.775E+02	5.784E+02	7.418E-04	-1.112E-08	3.609E-05
8	2.223	-1.530	5.638E+04	1.889E+04	3.307E+03	1.353E+03	9.112E+05				
	87.520	-60.236	5.638E+04	4.249E+03	1.889E+01	7.728E+00	1.322E+02	1.709E+02	7.233E-04	2.243E-05	8.264E-06
9	2.721	-0.954	1.022E+05	4.854E+03	3.745E+03	2.839E+02	2.165E+06				
	107.126	-37.559	1.022E+05	1.092E+03	2.139E+01	1.622E+00	3.142E+02	3.329E+02	2.104E-03	1.440E-05	1.964E-05

1

HiBeta:1.7T@t=0-peak-pf5&6:

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 NUMBER OF NON-CIRCULAR COILS:   12
 MOD COIL #   NO. OF SEGMENTS   CURRENT (A-T)  #SEG/GRP
    1            400                200530.0      400
    2            801                200530.0      400
    3           1202                182300.0      400
    4           1603                182300.0      400
    5           2004                200530.0      400
    6           2405                200530.0      400
    7           2806                200530.0      400
    8           3207                200530.0      400
    9           3608                182300.0      400
   10           4009                182300.0      400
   11           4410                200530.0      400
   12           4811                200530.0      400
 CURRENTS IN COIL GROUPS

     1  1   46696.0     2  2   -1688.0     3  3    7728.0     4  4   -7924.0     5  5       0.0 BZE =     0.0000
  COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400
    0
  COIL NUMBER      NUMBER OF TURNS  SUPPORT WIDTH    SPAN  LENGTH      CU WIDTH   CU HEIGHT   # OF SUPPORTS   INDUCTANCE        STORED ENERGY
   1                     48.00000        0.04000        0.01781        0.04000        0.50800     20.0         0.0032034       0.349E+07
   2                     80.00000        0.05000        0.13221        0.19100        0.25300     18.0         0.0202973       0.289E+05
   3                     24.00000        0.06000        0.71597        0.09800        0.16300     18.0         0.0155657       0.465E+06
   4                     14.00000        0.06000        0.88981        0.05200        0.18600     18.0         0.0077726       0.244E+06

 Coil        R1             R2             Z1             Z2      Amp-Turns    Units       Z-center
  1          0.164          0.204          0.146          0.654    2241408.000    3          0.400
  2          0.427          0.618          1.456          1.709    -135040.000    3          1.583
  3          2.174          2.272          1.448          1.612     185472.000    3          1.530
  4          2.695          2.747          0.861          1.047    -110936.000    3          0.954
  5          0.164          0.204         -0.654         -0.146    2241408.000    3         -0.400
  6          0.427          0.618         -1.709         -1.456    -135040.000    3         -1.583
  7          2.174          2.272         -1.612         -1.448     185472.000    3         -1.530
  8          2.695          2.747         -1.047         -0.861    -110936.000    3         -0.954
 Note: un = 1 units are:  inch-tesla-weber
       un = 2 units are:  inch-gauss-maxwell
       un = 3 units are: meter-tesla-weber
0
  COIL     A       Z       NI           FZ           FR/L         FZ/L         S-HOOP       COMBINED
           M       M       A            N             N/M          N/M         N/M SQ       STRESS
          IN      IN       A            LB           LB/IN        LB/IN        PSI          PSI          DFL-R          DFL-Z     HOOP STRAIN


    1   0.184   0.400    2.241E+06   -9.272E+04    4.335E+06   -8.020E+04    4.943E+07
        7.244  15.748    2.241E+06   -2.085E+04    2.476E+04   -4.582E+02    7.173E+03    7.174E+03    3.248E-03   -4.277E-11    4.483E-04

    2   0.522   1.583   -1.350E+05    1.207E+04    4.373E+03    3.681E+03    8.488E+04
       20.551  62.323   -1.350E+05    2.715E+03    2.498E+01    2.103E+01    1.232E+01    1.315E+01    1.582E-05    9.993E-09    7.698E-07

    3   2.223   1.530    1.855E+05    7.522E+04   -8.828E+02    5.386E+03   -2.433E+05
       87.520  60.236    1.855E+05    1.692E+04   -5.043E+00    3.077E+01   -3.530E+01    1.894E+02   -1.931E-04    8.930E-05   -2.206E-06

    4   2.721   0.954   -1.109E+05   -8.938E+04    5.335E+03   -5.228E+03    3.085E+06
      107.126  37.559   -1.109E+05   -2.010E+04    3.048E+01   -2.987E+01    4.476E+02    7.919E+02    2.997E-03   -2.651E-04    2.798E-05

    5   0.184  -0.400    2.241E+06    1.080E+05    4.325E+06    9.344E+04    4.932E+07
        7.244 -15.748    2.241E+06    2.430E+04    2.471E+04    5.338E+02    7.157E+03    7.158E+03    3.241E-03    4.983E-11    4.473E-04

    6   0.522  -1.583   -1.350E+05   -4.514E+03    3.358E+03   -1.376E+03    6.519E+04
       20.551 -62.323   -1.350E+05   -1.015E+03    1.919E+01   -7.863E+00    9.460E+00    9.771E+00    1.215E-05   -3.737E-09    5.913E-07

    7   2.223  -1.530    1.855E+05   -3.813E+04    3.320E+03   -2.730E+03    9.148E+05
       87.520 -60.236    1.855E+05   -8.576E+03    1.896E+01   -1.560E+01    1.327E+02    2.109E+02    7.261E-04   -4.526E-05    8.296E-06

    8   2.721  -0.954   -1.109E+05    4.257E+04    2.839E+03    2.490E+03    1.642E+06
      107.126 -37.559   -1.109E+05    9.574E+03    1.622E+01    1.422E+01    2.382E+02    4.022E+02    1.595E-03    1.263E-04    1.489E-05

1
```

320kA-ohmic:@t=0.206sec.-46.7kA-PF1a

NUMBER OF NON-CIRCULAR COILS: 12

MOD COIL #	NO. OF SEGMENTS	CURRENT (A-T)	#SEG/GRP
1	400	200530.0	400
2	801	200530.0	400
3	1202	182300.0	400
4	1603	182300.0	400
5	2004	200530.0	400
6	2405	200530.0	400
7	2806	200530.0	400
8	3207	200530.0	400
9	3608	182300.0	400
10	4009	182300.0	400
11	4410	200530.0	400
12	4811	200530.0	400

CURRENTS IN COIL GROUPS

1 1 46696.0 2 2 -15155.0 3 3 5050.0 4 4 4730.0 5 5 -320000.0 BZE = 0.0000

COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400

0

COIL NUMBER	NUMBER OF TURNS	SUPPORT WIDTH	SPAN LENGTH	CU WIDTH	CU HEIGHT	# OF SUPPORTS	INDUCTANCE	STORED ENERGY
1	48.00000	0.04000	0.01781	0.04000	0.50800	20.0	0.0032034	0.349E+07
2	80.00000	0.05000	0.13221	0.19100	0.25300	18.0	0.0202973	0.233E+07
3	24.00000	0.06000	0.71597	0.09800	0.16300	18.0	0.0155657	0.198E+06
4	14.00000	0.06000	0.88981	0.05200	0.18600	18.0	0.0077726	0.869E+05
5	1.00000	0.05000	0.19435	0.30000	0.30000	36.0	0.0000106	0.545E+06

Coil	R1	R2	Z1	Z2	Amp-Turns	Units	Z-center
1	0.164	0.204	0.146	0.654	2241408.000	3	0.400
2	0.427	0.618	1.456	1.709	-1212400.000	3	1.583
3	2.174	2.272	1.448	1.612	121200.000	3	1.530
4	2.695	2.747	0.861	1.047	66220.000	3	0.954
5	1.250	1.550	-0.150	0.150	-320000.000	3	0.000
6	0.164	0.204	-0.654	-0.146	2241408.000	3	-0.400
7	0.427	0.618	-1.709	-1.456	-1212400.000	3	-1.583
8	2.174	2.272	-1.612	-1.448	121200.000	3	-1.530
9	2.695	2.747	-1.047	-0.861	66220.000	3	-0.954

Note: un = 1 units are: inch-tesla-weber
un = 2 units are: inch-gauss-maxwell
un = 3 units are: meter-tesla-weber

0

COIL	A M IN	Z M IN	NI A A	FZ N LB	FR/L N/M LB/IN	FZ/L N/M LB/IN	S-HOOP N/M SQ PSI	COMBINED STRESS PSI	DFL-R	DFL-Z	HOOP STRAIN
1	0.184	0.400	2.241E+06	-1.165E+05	3.910E+06	-1.007E+05	4.459E+07				
	7.244	15.748	2.241E+06	-2.619E+04	2.234E+04	-5.755E+02	6.471E+03	6.471E+03	2.930E-03	-5.372E-11	4.044E-04
2	0.522	1.583	-1.212E+06	7.501E+04	8.468E+05	2.287E+04	1.644E+07				
	20.551	62.323	-1.212E+06	1.687E+04	4.838E+03	1.307E+02	2.385E+03	2.390E+03	3.064E-03	6.209E-08	1.491E-04
3	2.223	1.530	1.212E+05	5.975E+03	5.254E+03	4.278E+02	1.448E+06				
	87.520	60.236	1.212E+05	1.344E+03	3.001E+01	2.444E+00	2.101E+02	2.223E+02	1.149E-03	7.093E-06	1.313E-05
4	2.721	0.954	6.622E+04	4.104E+04	3.862E+02	2.400E+03	2.233E+05				
	107.126	37.559	6.622E+04	9.230E+03	2.207E+00	1.371E+01	3.241E+01	1.905E+02	2.170E-04	1.217E-04	2.026E-06
5	1.400	0.000	-3.200E+05	2.446E+05	4.534E+03	2.781E+04	7.027E+04				
	55.118	0.000	-3.200E+05	5.501E+04	2.590E+01	1.589E+02	1.020E+01	1.302E+01	3.513E-05	5.464E-08	6.373E-07
6	0.184	-0.400	2.241E+06	1.318E+05	3.901E+06	1.140E+05	4.448E+07				
	7.244	-15.748	2.241E+06	2.964E+04	2.228E+04	6.512E+02	6.455E+03	6.456E+03	2.923E-03	6.078E-11	4.034E-04
7	0.522	-1.583	-1.212E+06	-7.163E+03	8.377E+05	-2.184E+03	1.626E+07				
	20.551	-62.323	-1.212E+06	-1.611E+03	4.786E+03	-1.248E+01	2.360E+03	2.360E+03	3.031E-03	-5.929E-09	1.475E-04
8	2.223	-1.530	1.212E+05	1.826E+04	8.000E+03	1.308E+03	2.204E+06				
	87.520	-60.236	1.212E+05	4.108E+03	4.570E+01	7.470E+00	3.199E+02	3.573E+02	1.750E-03	2.168E-05	1.999E-05
9	2.721	-0.954	6.622E+04	-1.309E+04	1.876E+03	-7.659E+02	1.085E+06				
	107.126	-37.559	6.622E+04	-2.945E+03	1.072E+01	-4.375E+00	1.574E+02	2.079E+02	1.054E-03	-3.884E-05	9.838E-06

1

ohmic:1.7T@t=.0-peak-pf5&pf6:

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 NUMBER OF NON-CIRCULAR COILS:   12
 MOD COIL #   NO. OF SEGMENTS   CURRENT (A-T)  #SEG/GRP
    1            400                200530.0      400
    2            801                200530.0      400
    3           1202                182300.0      400
    4           1603                182300.0      400
    5           2004                200530.0      400
    6           2405                200530.0      400
    7           2806                200530.0      400
    8           3207                200530.0      400
    9           3608                182300.0      400
   10           4009                182300.0      400
   11           4410                200530.0      400
   12           4811                200530.0      400
 CURRENTS IN COIL GROUPS

     1  1   46696.0     2  2   -4495.0     3  3    7293.0     4  4    8195.0     5  5       0.0 BZE =     0.0000
  COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400
    0
  COIL NUMBER      NUMBER OF TURNS  SUPPORT WIDTH    SPAN  LENGTH      CU WIDTH   CU HEIGHT   # OF SUPPORTS   INDUCTANCE        STORED ENERGY
   1                     48.00000        0.04000        0.01781        0.04000        0.50800     20.0         0.0032034       0.349E+07
   2                     80.00000        0.05000        0.13221        0.19100        0.25300     18.0         0.0202973       0.205E+06
   3                     24.00000        0.06000        0.71597        0.09800        0.16300     18.0         0.0155657       0.414E+06
   4                     14.00000        0.06000        0.88981        0.05200        0.18600     18.0         0.0077726       0.261E+06

 Coil        R1             R2             Z1             Z2      Amp-Turns    Units       Z-center
  1         0.164          0.204          0.146          0.654    2241408.000    3          0.400
  2         0.427          0.618          1.456          1.709    -359600.000    3          1.583
  3         2.174          2.272          1.448          1.612     175032.000    3          1.530
  4         2.695          2.747          0.861          1.047     114730.000    3          0.954
  5         0.164          0.204         -0.654         -0.146    2241408.000    3         -0.400
  6         0.427          0.618         -1.709         -1.456    -359600.000    3         -1.583
  7         2.174          2.272         -1.612         -1.448     175032.000    3         -1.530
  8         2.695          2.747         -1.047         -0.861     114730.000    3         -0.954
 Note: un = 1 units are:  inch-tesla-weber
       un = 2 units are:  inch-gauss-maxwell
       un = 3 units are: meter-tesla-weber
0
  COIL     A       Z       NI           FZ           FR/L         FZ/L         S-HOOP       COMBINED
           M       M       A            N             N/M          N/M         N/M SQ       STRESS
          IN      IN       A            LB           LB/IN        LB/IN        PSI          PSI          DFL-R          DFL-Z     HOOP STRAIN


    1   0.184   0.400    2.241E+06   -1.023E+05    4.470E+06   -8.846E+04    5.097E+07
        7.244  15.748    2.241E+06   -2.300E+04    2.553E+04   -5.053E+02    7.397E+03    7.397E+03    3.349E-03   -4.717E-11    4.623E-04

    2   0.522   1.583   -3.596E+05    3.891E+04    3.753E+04    1.186E+04    7.285E+05
       20.551  62.323   -3.596E+05    8.753E+03    2.144E+02    6.778E+01    1.057E+02    1.084E+02    1.358E-04    3.221E-08    6.607E-06

    3   2.223   1.530    1.750E+05   -6.410E+04    1.247E+04   -4.589E+03    3.436E+06
       87.520  60.236    1.750E+05   -1.442E+04    7.124E+01   -2.622E+01    4.987E+02    6.300E+02    2.728E-03   -7.610E-05    3.117E-05

    4   2.721   0.954    1.147E+05    5.631E+04    8.673E+02    3.294E+03    5.015E+05
      107.126  37.559    1.147E+05    1.267E+04    4.955E+00    1.882E+01    7.277E+01    2.897E+02    4.872E-04    1.670E-04    4.548E-06

    5   0.184  -0.400    2.241E+06    1.176E+05    4.460E+06    1.017E+05    5.086E+07
        7.244 -15.748    2.241E+06    2.645E+04    2.548E+04    5.810E+02    7.381E+03    7.381E+03    3.342E-03    5.423E-11    4.613E-04

    6   0.522  -1.583   -3.596E+05   -1.879E+04    3.483E+04   -5.729E+03    6.761E+05
       20.551 -62.323   -3.596E+05   -4.226E+03    1.990E+02   -3.273E+01    9.811E+01    9.940E+01    1.260E-04   -1.555E-08    6.132E-06

    7   2.223  -1.530    1.750E+05    9.911E+04    1.644E+04    7.096E+03    4.529E+06
       87.520 -60.236    1.750E+05    2.229E+04    9.390E+01    4.054E+01    6.572E+02    8.603E+02    3.595E-03    1.177E-04    4.108E-05

    8   2.721  -0.954    1.147E+05   -7.900E+03    3.449E+03   -4.621E+02    1.994E+06
      107.126 -37.559    1.147E+05   -1.777E+03    1.970E+01   -2.640E+00    2.894E+02    3.198E+02    1.937E-03   -2.343E-05    1.808E-05

1
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2.0T@t=.192-peak-pf4

NUMBER OF NON-CIRCULAR COILS: 12

MOD COIL #	NO. OF SEGMENTS	CURRENT (A-T)	#SEG/GRP
1	400	200530.0	400
2	801	200530.0	400
3	1202	182300.0	400
4	1603	182300.0	400
5	2004	200530.0	400
6	2405	200530.0	400
7	2806	200530.0	400
8	3207	200530.0	400
9	3608	182300.0	400
10	4009	182300.0	400
11	4410	200530.0	400
12	4811	200530.0	400

CURRENTS IN COIL GROUPS

1 1 46696.0 2 2 -7795.0 3 3 2349.0 4 4 7300.0 5 5 0.0 BZE = 0.0000

COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400

0

COIL NUMBER	NUMBER OF TURNS	SUPPORT WIDTH	SPAN LENGTH	CU WIDTH	CU HEIGHT	# OF SUPPORTS	INDUCTANCE	STORED ENERGY
1	48.00000	0.04000	0.01781	0.04000	0.50800	20.0	0.0032034	0.349E+07
2	80.00000	0.05000	0.13221	0.19100	0.25300	18.0	0.0202973	0.617E+06
3	24.00000	0.06000	0.71597	0.09800	0.16300	18.0	0.0155657	0.429E+05
4	14.00000	0.06000	0.88981	0.05200	0.18600	18.0	0.0077726	0.207E+06

Coil	R1	R2	Z1	Z2	Amp-Turns	Units	Z-center
1	0.164	0.204	0.146	0.654	2241408.000	3	0.400
2	0.427	0.618	1.456	1.709	-623600.000	3	1.583
3	2.174	2.272	1.448	1.612	56376.000	3	1.530
4	2.695	2.747	0.861	1.047	102200.000	3	0.954
5	0.164	0.204	-0.654	-0.146	2241408.000	3	-0.400
6	0.427	0.618	-1.709	-1.456	-623600.000	3	-1.583
7	2.174	2.272	-1.612	-1.448	56376.000	3	-1.530
8	2.695	2.747	-1.047	-0.861	102200.000	3	-0.954

Note: un = 1 units are: inch-tesla-weber
un = 2 units are: inch-gauss-maxwell
un = 3 units are: meter-tesla-weber

0

COIL	A M IN	Z M IN	NI A	FZ N LB	FR/L N/M LB/IN	FZ/L N/M LB/IN	S-HOOP N/M SQ PSI	COMBINED STRESS PSI	DFL-R	DFL-Z	HOOP STRAIN
1	0.184	0.400	2.241E+06	-1.124E+05	4.313E+06	-9.725E+04	4.919E+07				
	7.244	15.748	2.241E+06	-2.529E+04	2.464E+04	-5.556E+02	7.138E+03	7.138E+03	3.232E-03	-5.186E-11	4.461E-04
2	0.522	1.583	-6.236E+05	6.331E+04	1.940E+05	1.930E+04	3.766E+06				
	20.551	62.323	-6.236E+05	1.424E+04	1.108E+03	1.103E+02	5.464E+02	5.508E+02	7.019E-04	5.240E-08	3.415E-05
3	2.223	1.530	5.638E+04	-1.534E+04	2.148E+03	-1.098E+03	5.919E+05				
	87.520	60.236	5.638E+04	-3.451E+03	1.227E+01	-6.275E+00	8.589E+01	1.173E+02	4.698E-04	-1.821E-05	5.368E-06
4	2.721	0.954	1.022E+05	2.593E+04	1.100E+03	1.517E+03	6.359E+05				
	107.126	37.559	1.022E+05	5.832E+03	6.283E+00	8.664E+00	9.228E+01	1.922E+02	6.179E-04	7.690E-05	5.768E-06
5	0.184	-0.400	2.241E+06	1.277E+05	4.304E+06	1.105E+05	4.908E+07				
	7.244	-15.748	2.241E+06	2.873E+04	2.459E+04	6.313E+02	7.122E+03	7.123E+03	3.225E-03	5.893E-11	4.451E-04
6	0.522	-1.583	-6.236E+05	-2.841E+04	1.893E+05	-8.661E+03	3.675E+06				
	20.551	-62.323	-6.236E+05	-6.389E+03	1.081E+03	-4.948E+01	5.333E+02	5.352E+02	6.849E-04	-2.351E-08	3.333E-05
7	2.223	-1.530	5.638E+04	2.662E+04	3.425E+03	1.905E+03	9.439E+05				
	87.520	-60.236	5.638E+04	5.986E+03	1.957E+01	1.089E+01	1.370E+02	1.915E+02	7.492E-04	3.159E-05	8.560E-06
8	2.721	-0.954	1.022E+05	1.720E+04	3.399E+03	1.006E+03	1.965E+06				
	107.126	-37.559	1.022E+05	3.868E+03	1.942E+01	5.746E+00	2.852E+02	3.515E+02	1.910E-03	5.100E-05	1.783E-05

1

ohmic:1.7T@t=.140-peak-pf4:

NUMBER OF NON-CIRCULAR COILS: 12

MOD COIL #	NO. OF SEGMENTS	CURRENT (A-T)	#SEG/GRP
1	400	200530.0	400
2	801	200530.0	400
3	1202	182300.0	400
4	1603	182300.0	400
5	2004	200530.0	400
6	2405	200530.0	400
7	2806	200530.0	400
8	3207	200530.0	400
9	3608	182300.0	400
10	4009	182300.0	400
11	4410	200530.0	400
12	4811	200530.0	400

CURRENTS IN COIL GROUPS

1 1 46696.0 2 2 -7030.0 3 3 135.0 4 4 4932.0 5 5 0.0 BZE = 0.0000

COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400

0

COIL NUMBER	NUMBER OF TURNS	SUPPORT WIDTH	SPAN LENGTH	CU WIDTH	CU HEIGHT	# OF SUPPORTS	INDUCTANCE	STORED ENERGY
1	48.00000	0.04000	0.01781	0.04000	0.50800	20.0	0.0032034	0.349E+07
2	80.00000	0.05000	0.13221	0.19100	0.25300	18.0	0.0202973	0.502E+06
3	24.00000	0.06000	0.71597	0.09800	0.16300	18.0	0.0155657	0.142E+03
4	14.00000	0.06000	0.88981	0.05200	0.18600	18.0	0.0077726	0.945E+05

Coil	R1	R2	Z1	Z2	Amp-Turns	Units	Z-center
1	0.164	0.204	0.146	0.654	2241408.000	3	0.400
2	0.427	0.618	1.456	1.709	-562400.000	3	1.583
3	2.174	2.272	1.448	1.612	3240.000	3	1.530
4	2.695	2.747	0.861	1.047	69048.000	3	0.954
5	0.164	0.204	-0.654	-0.146	2241408.000	3	-0.400
6	0.427	0.618	-1.709	-1.456	-562400.000	3	-1.583
7	2.174	2.272	-1.612	-1.448	3240.000	3	-1.530
8	2.695	2.747	-1.047	-0.861	69048.000	3	-0.954

Note: un = 1 units are: inch-tesla-weber
un = 2 units are: inch-gauss-maxwell
un = 3 units are: meter-tesla-weber

0

COIL	A M IN	Z M IN	NI A A	FZ N LB	FR/L N/M LB/IN	FZ/L N/M LB/IN	S-HOOP N/M SQ PSI	COMBINED STRESS PSI	DFL-R	DFL-Z	HOOP STRAIN
1	0.184	0.400	2.241E+06	-1.104E+05	4.260E+06	-9.547E+04	4.859E+07				
	7.244	15.748	2.241E+06	-2.482E+04	2.434E+04	-5.454E+02	7.050E+03	7.051E+03	3.192E-03	-5.091E-11	4.406E-04
2	0.522	1.583	-5.624E+05	5.442E+04	1.700E+05	1.659E+04	3.300E+06				
	20.551	62.323	-5.624E+05	1.224E+04	9.711E+02	9.480E+01	4.788E+02	4.826E+02	6.150E-04	4.505E-08	2.993E-05
3	2.223	1.530	3.240E+03	-4.489E+02	4.088E+01	-3.214E+01	1.126E+04				
	87.520	60.236	3.240E+03	-1.010E+02	2.335E-01	-1.836E-01	1.635E+00	2.554E+00	8.941E-06	-5.329E-07	1.022E-07
4	2.721	0.954	6.905E+04	1.270E+04	3.484E+02	7.427E+02	2.015E+05				
	107.126	37.559	6.905E+04	2.856E+03	1.991E+00	4.243E+00	2.924E+01	7.815E+01	1.957E-04	3.766E-05	1.827E-06
5	0.184	-0.400	2.241E+06	1.257E+05	4.251E+06	1.087E+05	4.848E+07				
	7.244	-15.748	2.241E+06	2.827E+04	2.428E+04	6.211E+02	7.035E+03	7.035E+03	3.185E-03	5.797E-11	4.397E-04
6	0.522	-1.583	-5.624E+05	-2.295E+04	1.658E+05	-6.997E+03	3.218E+06				
	20.551	-62.323	-5.624E+05	-5.161E+03	9.470E+02	-3.997E+01	4.669E+02	4.685E+02	5.998E-04	-1.900E-08	2.918E-05
7	2.223	-1.530	3.240E+03	1.097E+03	1.143E+02	7.853E+01	3.149E+04				
	87.520	-60.236	3.240E+03	2.467E+02	6.529E-01	4.486E-01	4.570E+00	6.817E+00	2.500E-05	1.302E-06	2.856E-07
8	2.721	-0.954	6.905E+04	1.644E+04	1.902E+03	9.615E+02	1.100E+06				
	107.126	-37.559	6.905E+04	3.697E+03	1.087E+01	5.493E+00	1.596E+02	2.229E+02	1.068E-03	4.876E-05	9.974E-06

1

HiBeta-1.7T@t=.240-peak-pf4:

NUMBER OF NON-CIRCULAR COILS: 12

MOD COIL #	NO. OF SEGMENTS	CURRENT (A-T)	#SEG/GRP
1	400	200530.0	400
2	801	200530.0	400
3	1202	182300.0	400
4	1603	182300.0	400
5	2004	200530.0	400
6	2405	200530.0	400
7	2806	200530.0	400
8	3207	200530.0	400
9	3608	182300.0	400
10	4009	182300.0	400
11	4410	200530.0	400
12	4811	200530.0	400

CURRENTS IN COIL GROUPS

1 1 46696.0 2 2 -6371.0 3 3 2044.0 4 4 6235.0 5 5 0.0 BZE = 0.0000

COAXIAL COIL FORCES AND STRESSES - LAMINATED BEAM APPROXIMATION - SHEAR FACTOR = .400

0

COIL NUMBER	NUMBER OF TURNS	SUPPORT WIDTH	SPAN LENGTH	CU WIDTH	CU HEIGHT	# OF SUPPORTS	INDUCTANCE	STORED ENERGY
1	48.00000	0.04000	0.01781	0.04000	0.50800	20.0	0.0032034	0.349E+07
2	80.00000	0.05000	0.13221	0.19100	0.25300	18.0	0.0202973	0.412E+06
3	24.00000	0.06000	0.71597	0.09800	0.16300	18.0	0.0155657	0.325E+05
4	14.00000	0.06000	0.88981	0.05200	0.18600	18.0	0.0077726	0.151E+06

Coil	R1	R2	Z1	Z2	Amp-Turns	Units	Z-center
1	0.164	0.204	0.146	0.654	2241408.000	3	0.400
2	0.427	0.618	1.456	1.709	-509680.000	3	1.583
3	2.174	2.272	1.448	1.612	49056.000	3	1.530
4	2.695	2.747	0.861	1.047	87290.000	3	0.954
5	0.164	0.204	-0.654	-0.146	2241408.000	3	-0.400
6	0.427	0.618	-1.709	-1.456	-509680.000	3	-1.583
7	2.174	2.272	-1.612	-1.448	49056.000	3	-1.530
8	2.695	2.747	-1.047	-0.861	87290.000	3	-0.954

Note: un = 1 units are: inch-tesla-weber
un = 2 units are: inch-gauss-maxwell
un = 3 units are: meter-tesla-weber

0

COIL	A M IN	Z M IN	NI A A	FZ N LB	FR/L N/M LB/IN	FZ/L N/M LB/IN	S-HOOP N/M SQ PSI	COMBINED STRESS PSI	DFL-R	DFL-Z	HOOP STRAIN
1	0.184	0.400	2.241E+06	-1.083E+05	4.321E+06	-9.367E+04	4.928E+07				
	7.244	15.748	2.241E+06	-2.436E+04	2.469E+04	-5.351E+02	7.151E+03	7.151E+03	3.238E-03	-4.995E-11	4.469E-04
2	0.522	1.583	-5.097E+05	5.115E+04	1.266E+05	1.560E+04	2.458E+06				
	20.551	62.323	-5.097E+05	1.150E+04	7.235E+02	8.909E+01	3.567E+02	3.602E+02	4.582E-04	4.234E-08	2.229E-05
3	2.223	1.530	4.906E+04	-1.080E+04	1.488E+03	-7.734E+02	4.101E+05				
	87.520	60.236	4.906E+04	-2.430E+03	8.501E+00	-4.418E+00	5.950E+01	8.164E+01	3.255E-04	-1.282E-05	3.719E-06
4	2.721	0.954	8.729E+04	2.251E+04	6.272E+02	1.317E+03	3.626E+05				
	107.126	37.559	8.729E+04	5.064E+03	3.583E+00	7.523E+00	5.262E+01	1.393E+02	3.523E-04	6.677E-05	3.289E-06
5	0.184	-0.400	2.241E+06	1.236E+05	4.311E+06	1.069E+05	4.917E+07				
	7.244	-15.748	2.241E+06	2.780E+04	2.463E+04	6.108E+02	7.135E+03	7.136E+03	3.230E-03	5.702E-11	4.459E-04
6	0.522	-1.583	-5.097E+05	-2.262E+04	1.228E+05	-6.898E+03	2.384E+06				
	20.551	-62.323	-5.097E+05	-5.089E+03	7.016E+02	-3.941E+01	3.459E+02	3.475E+02	4.443E-04	-1.873E-08	2.162E-05
7	2.223	-1.530	4.906E+04	2.061E+04	2.600E+03	1.476E+03	7.163E+05				
	87.520	-60.236	4.906E+04	4.636E+03	1.485E+01	8.431E+00	1.039E+02	1.462E+02	5.686E-04	2.447E-05	6.497E-06
8	2.721	-0.954	8.729E+04	1.432E+04	2.591E+03	8.376E+02	1.498E+06				
	107.126	-37.559	8.729E+04	3.221E+03	1.480E+01	4.785E+00	2.174E+02	2.726E+02	1.456E-03	4.247E-05	1.359E-05

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