MEMORANDUM

Date: April 7, 2009
To: Charles Neumeyer, Phil Heitzenroeder, NSTX Distribution
From: Peter Titus
Subject: Coupled Electromagnic-Thermal Analysis

My ANSYS simulation was run using the waveforms provided by Charlie Neumeyer, and Phil's extended hub joint model. The nominal TF current profile, with the forced ramp-down and the faulted L/R decay TF current profiles were run. There are no feasibility issues with the extended hub concept that result from this analysis. Local currents, and temperatures are acceptable, and stresses are low. Details of the flex joint and its connection to the hub have not been considered however.

Results from the February 26 presentation needed a number of corrections/updates

- Correct Turn Multiplier
- Correct Thermal Conduction of Air
- Correct Inner Leg Conduction Cross Section by use of a Fictitious Packing Fraction
- 6.5 Seconds Flattop
- Start temperature should be 12C.

As a sanity check, a BASIC program with copper property subroutines were used that have been run for a benchmarked simulation of the MERIT pulsed magnet. The results of theses analyses are shown in Figures 29-33 at the end of this memo. The difference between the nominal and the fault L/R scenario was only three degrees in the ANSYS simulations and BASIC Simulations. The nominal scenario yielded an average end temperature of 364.2K and the faulted L/R simulation ended at 367.15K. The variation in current density across the TF inner leg at the upper inner corner is only 20% -See figures 16 and 17 There are local peaks in current density where the flex connects to the extension. These will need to be addressed with Joint local models.

The analysis is up-down symmetric. The shorter extension at the lower end of the TF is not modeled differently from the top. It has the same 2.5 inch corner radius. The model has evolved since October 2008 and had different inner leg dimensions than the latest project data, so an adjustment was made with a packing fraction input. This is shown in Figure 1 The cross sectional area that C. Neumeyer uses is 4.4522 sq in.

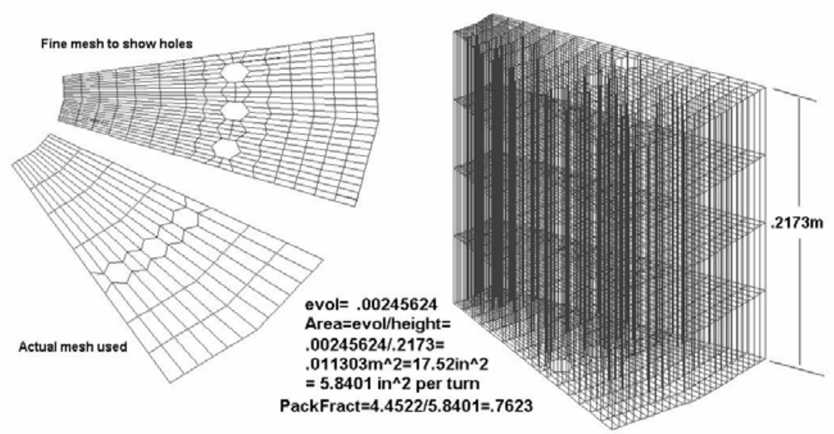

Figure 1 Inner Leg Cross Section Adjustments

Coupled Electromagnic-Thermal Analysis Model

Two parallel analyses are used to evaluate the loosely coupled problem of current distribution in a TF conductor "blade"

The heat generation rates from the current distribution in the electromagnetic solution are passed to a thermal analysis of the same time point in which the transient heat conduction solution is obtained. The temperatures are then passed to an electromagnetic solution of the next time point, which in turn passes the next set of heat generation rates. This is continued through the pulse time history. The accuracy of the solution depends upon the number of time steps dividing the pulse. The electromagnetic analysis uses SOLID97 ANSYS elements. Air must be modeled around the coil.

Because of the minimal stray fields from a tokamak, no boundary elements are used.

Air elements have three vector potential degrees of freedom. The coil elements have the volt degree of freedom added. The flux normal condition is used at the cyclic symmetry boundaries. The thermal analysis uses SOLID70 elements.

The analysis is completed with a structural pass in which the temperatures and Lorentz forces are read with an LDREAD command from the electromagnetic and thermal post process files.

ANSYS Input listinga are included near the end of this memo.

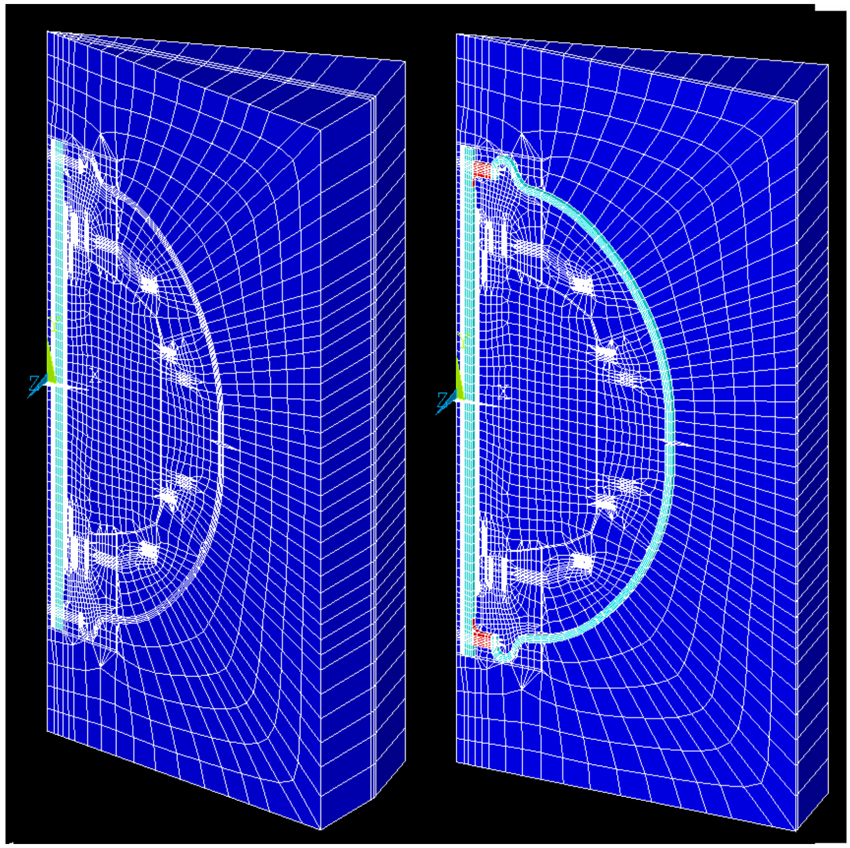

Figure 2 NSTX Electromagnetic Model , Including Air

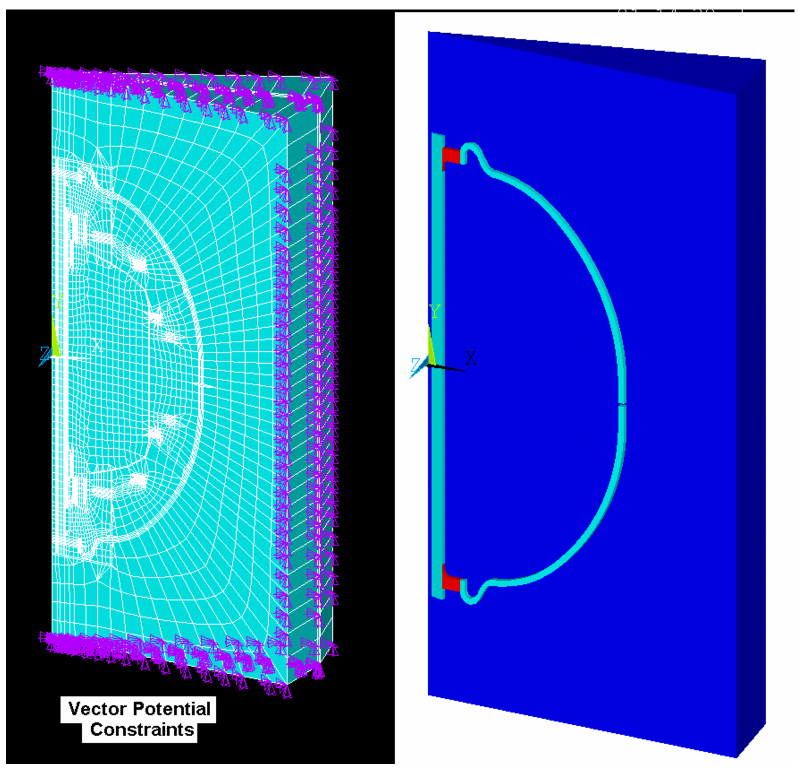

Figure 3 More Model Plots

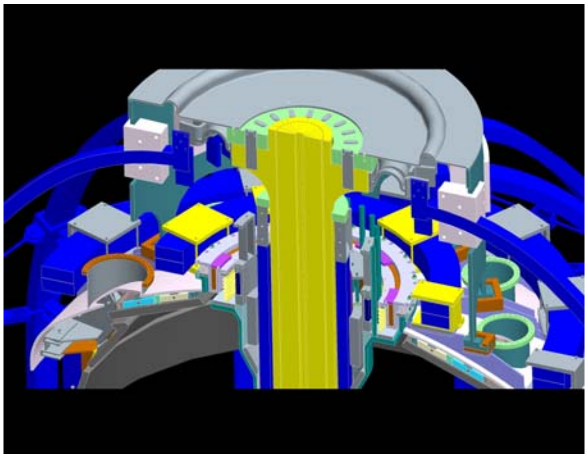

Figure 4 Phil's Extended Hub Concept

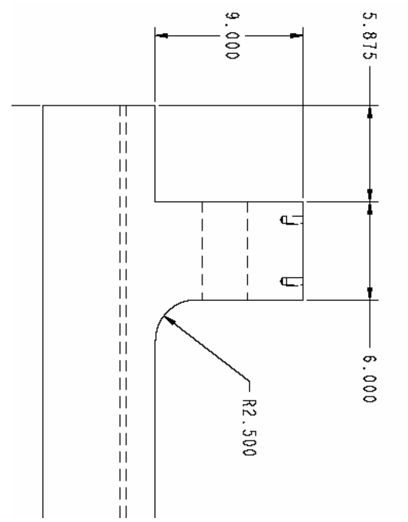

Figure 5

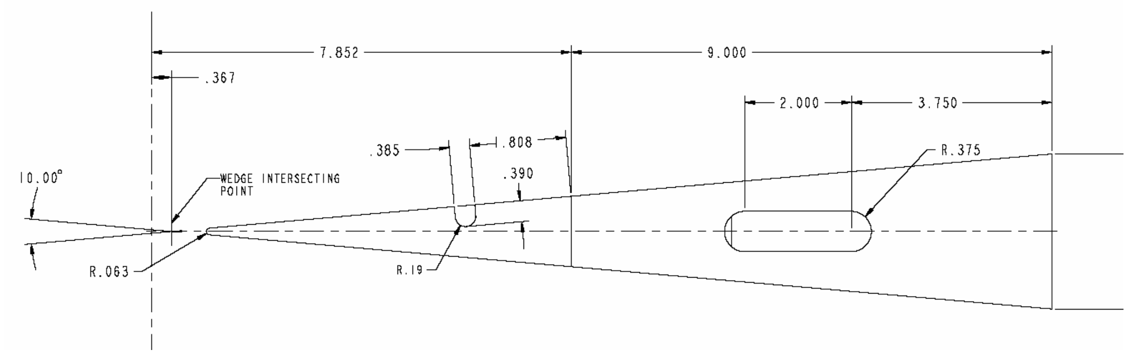

Figure 6

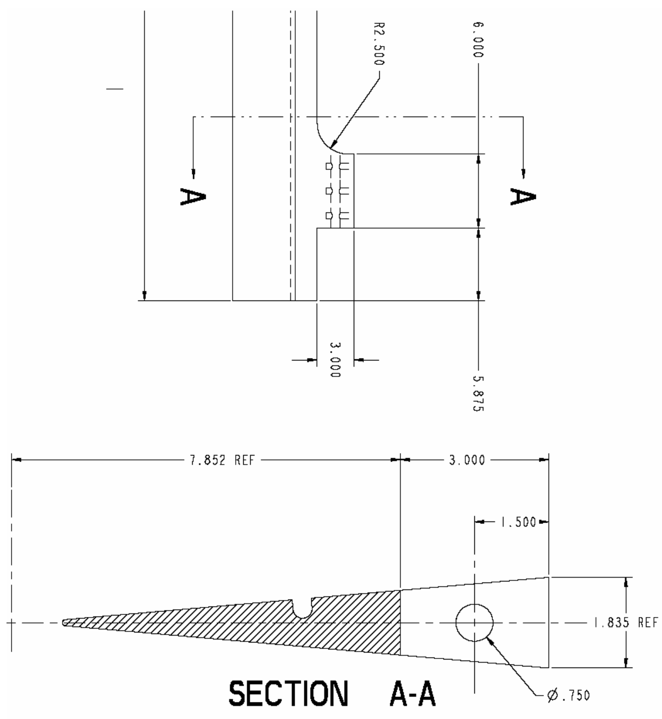

Figure 7

ANSYS NSTX TF Profile Input

```
*if,b_0,eq,2,then
!     NSTX Normal Pulse
NumSteps=29
tfbscale=1.0
t1= .1   $ i1= 0
t2= .2  $ i2= 0
t3= 1.952   $ i3= 15690.906*tfbscale
t4= 2.072   $ i4= 38658.746*tfbscale
t5= 2.192   $ i5= 58169.054*tfbscale
t6= 2.312   $ i6= 74742.32*tfbscale
t7= 2.432   $ i7= 88820.681*tfbscale
t8= 2.552   $ i8= 100779.71*tfbscale
t9= 2.672   $ i9= 110938.46*tfbscale
t10= 2.792   $ i10= 119567.93*tfbscale
t11= 2.912   $ i11= 126898.33*tfbscale
t12= 3.032   $ i12= 129777.84*tfbscale
t13= 4.0   $ i13= 129777.84*tfbscale
t14= 5.0     $ i14= 129777.84*tfbscale
t15= 6.0   $ i15= 129777.84*tfbscale
t16= 7.0   $ i16= 129777.84*tfbscale
t17= 8.0   $ i17= 129777.84*tfbscale
t18= 9.0   $ i18= 129777.84*tfbscale
t19= 9.512   $ i19= 129777.84*tfbscale
t20= 9.632   $ i20= 91022.609*tfbscale
t21= 9.752   $ i21= 58895.183*tfbscale
t22= 9.872   $ i22= 32262.092*tfbscale
t23= 9.992   $ i23= 10183.711*tfbscale
t24= 10.136   $ i24= 0
t25= 15.0   $ i25= 0
t26= 20.0   $ i26= 0
t27= 30.0   $ i27= 0
t28= 40.0   $ i28= 0
t29= 1000.0   $ i29= 0
*endif
```

```
*if,b_0,eq,3,then
!     NSTX Faulted Pulse
NumSteps=51
t1= .1   $ i1= 0
t2= .2   $ i2= 0
t3= 1.952   $ i3= 15690.906
t4= 2.072   $ i4= 38658.746
t5= 2.192   $ i5= 58169.054
t6= 2.312   $ i6= 74742.32
t7= 2.432   $ i7= 88820.681
t8= 2.552   $ i8= 100779.71
t9= 2.672   $ i9= 110938.46
t10= 2.792   $ i10= 119567.93
t11= 2.912   $ i11= 126898.33
t12= 3.032   $ i12= 129777.84
t13= 4.00   $ i13= 129777.84
t14= 5.00   $ i14= 129777.84
t15= 6.00   $ i15= 129777.84
t16= 7.00   $ i16= 129777.84
t17= 8.00   $ i17= 129777.84
t18= 9.512   $ i18= 129777.84
t19= 9.632   $ i19= 113132.22
t20= 9.752   $ i20= 98621.613
t21= 9.872   $ i21= 85972.17
t22= 9.992   $ i22= 74945.174
t23= 10.136   $ i23= 63563.326
t24= 10.256   $ i24= 55410.543
t25= 10.376   $ i25= 48303.454
t26= 10.496   $ i26= 42107.938
t27= 10.616   $ i27= 36707.073
t28= 10.736   $ i28= 31998.937
t29= 10.856   $ i29= 27894.677
t30= 10.976   $ i30= 24316.839
t31= 11.096   $ i31= 21197.903
t32= 11.216   $ i32= 18479.01
t33= 11.336   $ i33= 16108.848
t34= 11.456   $ i34= 14042.689
t35= 11.576   $ i35= 12241.54
t36= 11.696   $ i36= 10671.411
t37= 11.816   $ i37= 9302.6701
t38= 11.936   $ i38= 8109.4875
t39= 12.056   $ i39= 7069.3453
t40= 12.176   $ i40= 6162.6142
t41= 12.296   $ i41= 5372.1826
t42= 12.416   $ i42= 4683.1337
t43= 12.536   $ i43= 4082.4638
t44= 12.656   $ i44= 3558.8372
t45= 12.776   $ i45= 3102.3723
t46= 12.896   $ i46= 2704.4546
t47= 13.016   $ i47= 2357.5748
t48= 15.0   $ i48= 1000
t49= 20.0   $ i49= 100
t50= 40.0   $ i50= 0.0
t51= 1000.0   $ i51= 0.0
*endif
```

Copper Specific Heat

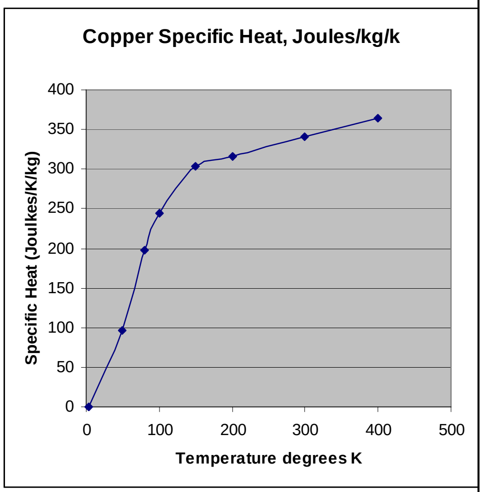

Figure 9 Specific Heat as implemented in NTFTM2

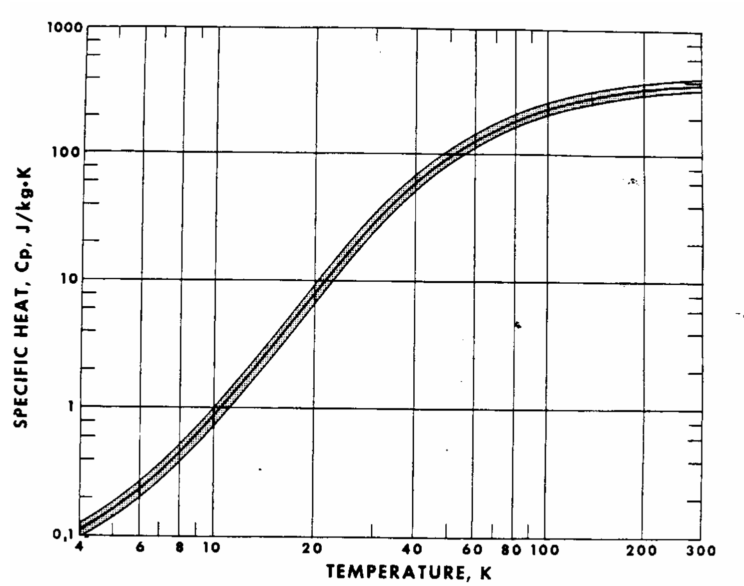

Figure 10 Specific Heat of Copper

Figure 2. Dependence of specific heat, C_p, upon temperature; 4 – 300 K. The scatter band represents two S.D.'s about a fourth order logarithmic regression equation based upon 456 measurements on annealed and cold-worked copper. The equation is

$$\log C_p = 1.131 - 9.454 (\log T) + 12.99 (\log T)^2 - 5.501 (\log T)^3 + 0.7637 (\log T)^4,$$

where C_p has units of J kg^{-1} K^{-1} and 4 K ≤ T ≤ 300 K.

Figure 11 More on theSpecific Heat

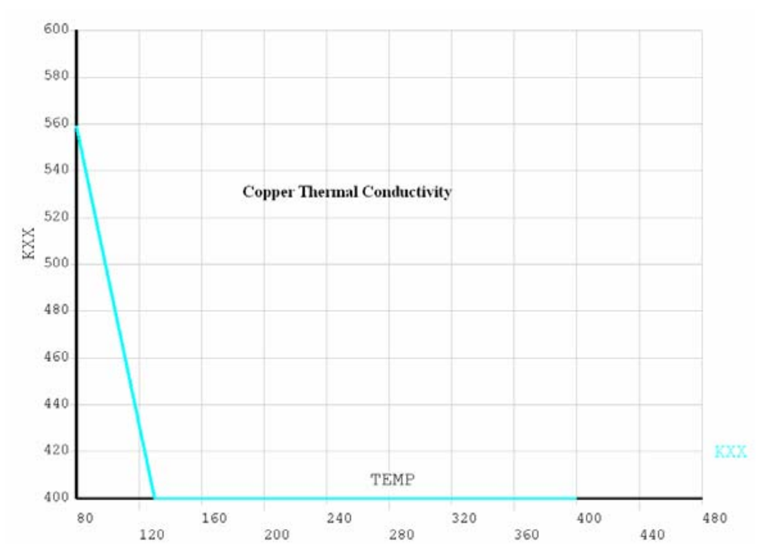

Figure 12 KXX Material Plot from the NSTX Electromagnetic-Thermal run

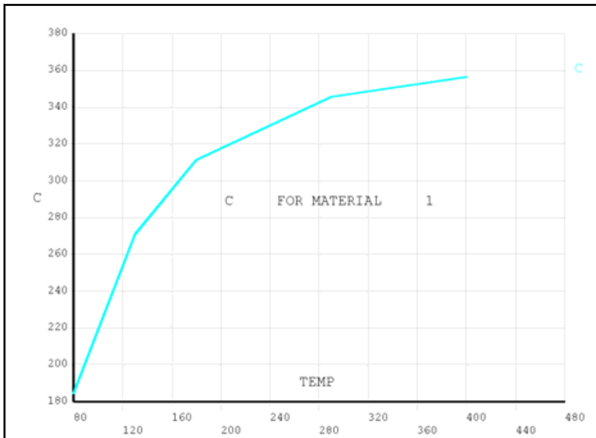

Figure 13 Copper Specific Heat from the NSTX Electromagnetic-thermal run

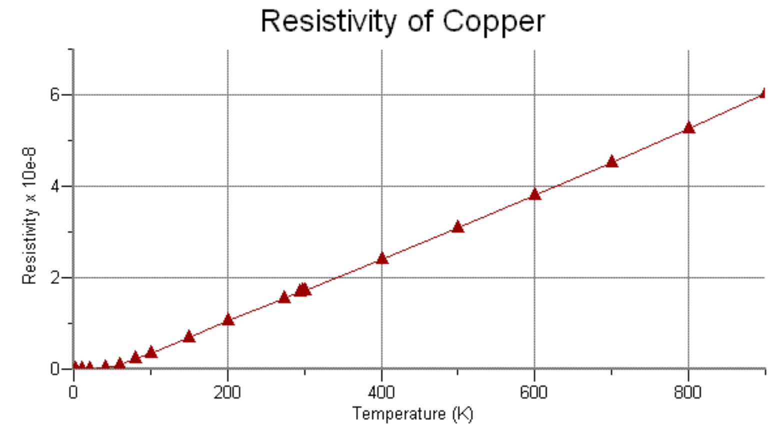

Figure 14 Copper Resistivity

```
mpdata,kxx,1,,559,400,400,400,210     !TF Conductor Inboard Leg
mpdata,kxx,2,,559,400,400,400,210     !TF Conductor Outboard Leg
mpdata,kxx,14,,559,400,400,400,210     !TF Conductor
mpdata,kxx,10,,.001,.001,.001,.001,.001     !Air

mpdata,rsvx,1,,.218e-8/packf,.572e-8/packf,.925e-8/packf,1.703e-8/packf,5.1460e-8/packf  !TF Conductor
mpdata,rsvx,2,,.218e-8/packfo,.572e-8/packfo,.925e-8/packfo,1.703e-8/packfo,5.1460e-8/packfo  !TF Conductor Outboard Leg
mpdata,rsvx,14,,.218e-8/packf,.572e-8/packf,.925e-8/packf,1.703e-8/packf,5.1460e-8/packf  !TF Conductor
```

```
sub copprop(temp,rho,cp)
if temp<80 then let rho=.218e-8
if temp>=80 then let rho=.218e-8+(.572e-8-.218e-8)/50*(temp-80)
if temp>=130 then let rho=.572e-8+(.925e-8-.572e-8)/50*(temp-130)
if temp>=180 then let rho=.925e-8+(1.703e-8-.925e-8)/110*(temp-180)
if temp>=290 then let rho=1.703e-8+(2.480e-8-1.703e-8)/110*(temp-290)
if temp<=80 then let cp=205
if temp>=80 then let cp=205+(301-205)/50*(temp-80)
if temp>=130 then let cp=301+(346-301)/50*(temp-130)
if temp>=180 then let cp=346+(384-346)/110*(temp-180)
if temp>=290 then let cp=384+(396-384)/110*(temp-290)
let cp=cp*8950   !  Conversion from cm to m
!!   ANSYS uses a specific heat based on mass at 130 deg K and based on
!!   meters c is input as 310. Multiply this by a mass density of
!!   8950 and divide by 1e9 = 2.77e-3. The above relation yields 2.677e-3
!     UNITS of CP ARE JOULE/(CM^3-DEG K) , ONE JOULE = ONE WATT-SEC
!
let tc=temp
!From Bob Weggel for Tc=20 to 100 K:  The electrical
!resistivity (for copper with a residual resistivity of 0.05
!microhm-centimeters, a residual resistivity ratio of only about 34), the fit
!is (0.0498 - 0.1075 T^2 - 0.5670 T^3 + 2.5157 T^4) / (1 + 0.5706 T^2 +
!3.7308 T^3).
If tc<100 then
let rho= (0.0498-0.1075*(Tc/100)^2-
0.5670*(tc/100)^3+2.5157*(tc/100)^4)/(1+0.5706*(tc/100)^2+3.7308*(tc/100)^3)
let rho=rho/1e8  !convert from microhm-cm to ohm-m
let cp=(0.4353-0.2763*(tc/100)+21.0459*(tc/100)^2)*(tc/100)^2/(1-2.6997*(tc/100)+7.4479*(tc/100)^2-
2.5654*(tc/100)^3+6.5265*(tc/100)^4)
let cp=cp*1e6   ! convert from J/cm^3K to J/m^3K
end if
end sub
```

B Field Results

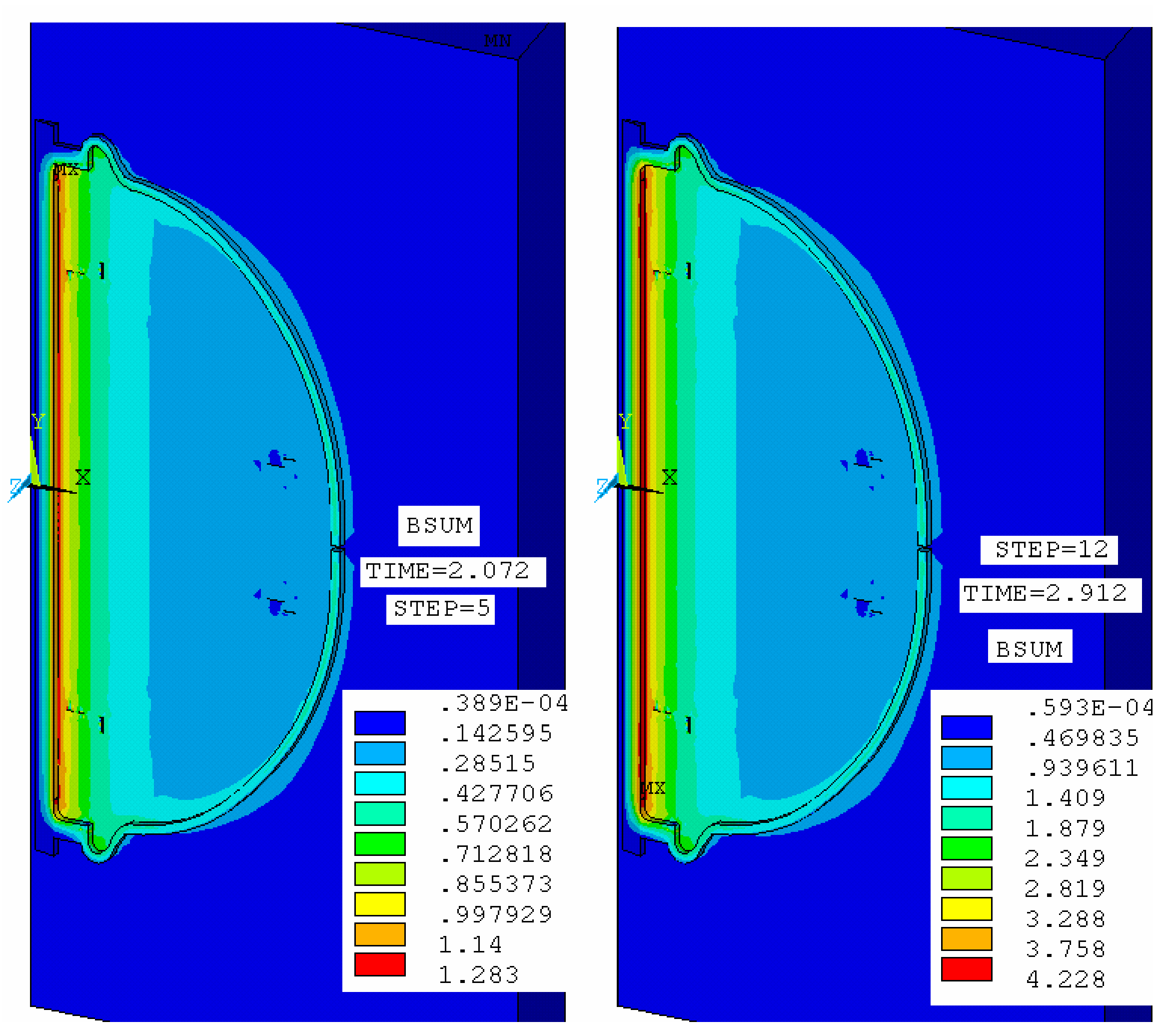

Figure 15 Field Plots

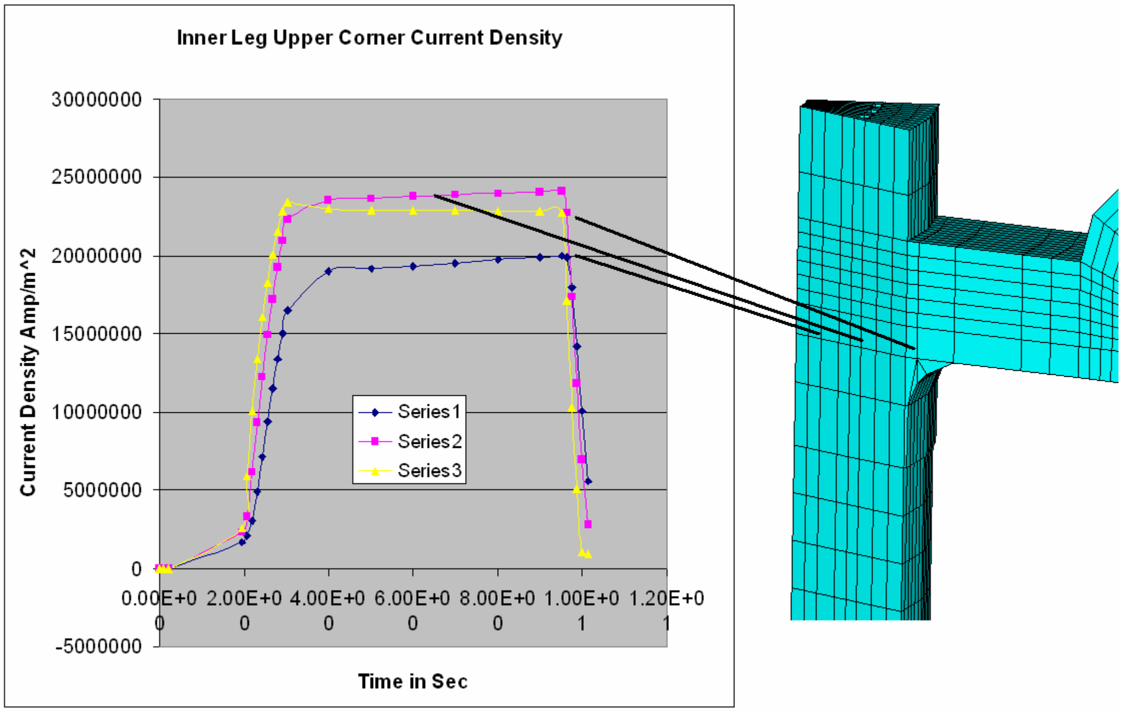

Figure 16 Current Density Throughout the Nominal Pulse Across the TF

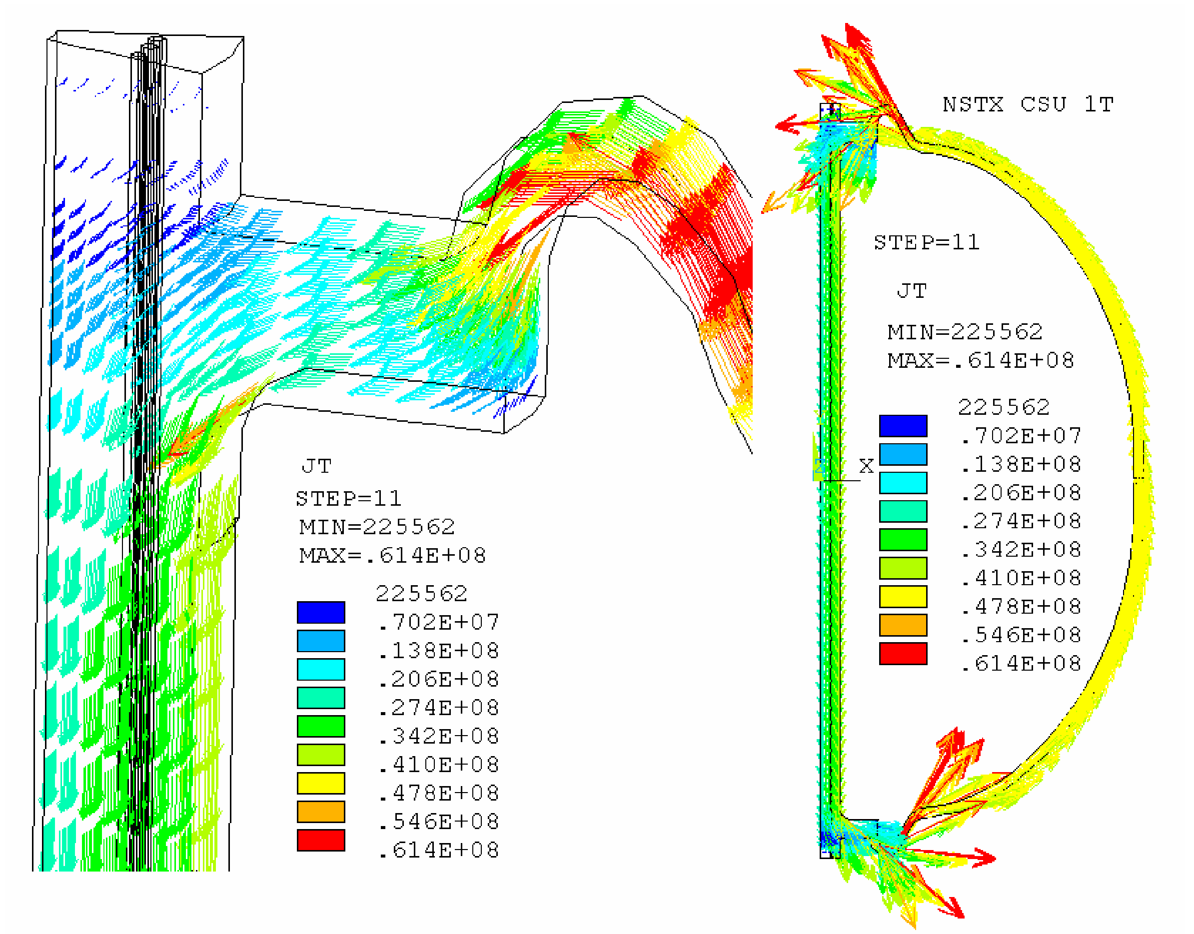

Figure 17 Current Density at the End of the Ramp-Up

In Coupled Electromagnic-Thermal Thermal Results

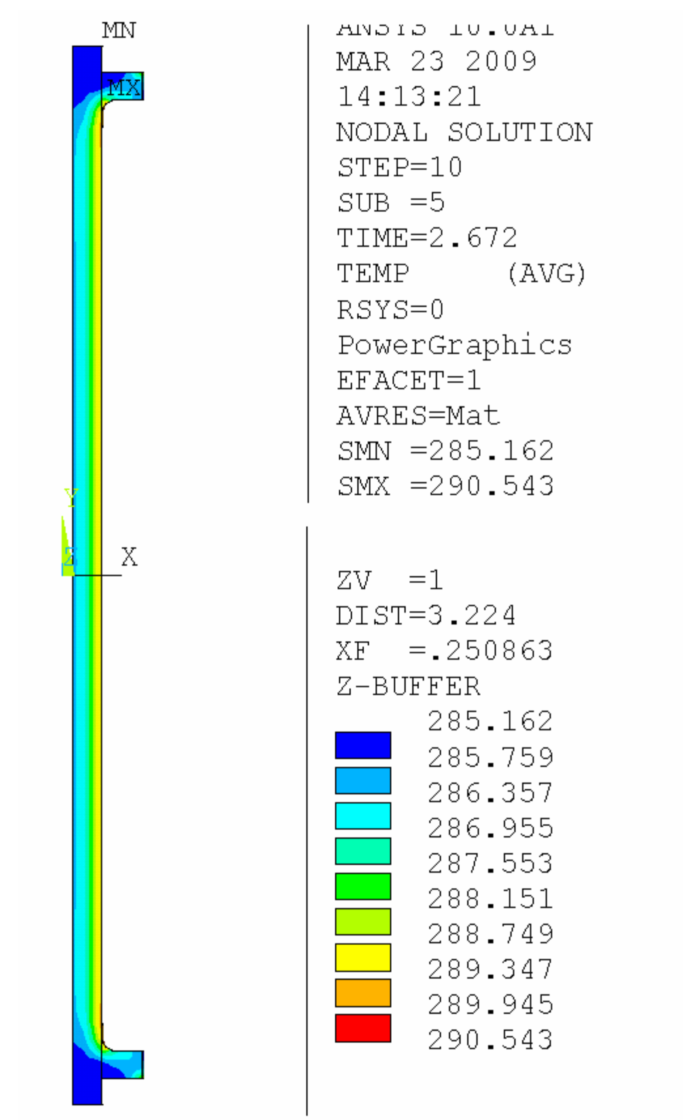

Figure 18 Temperature Results End of Ramp-Up

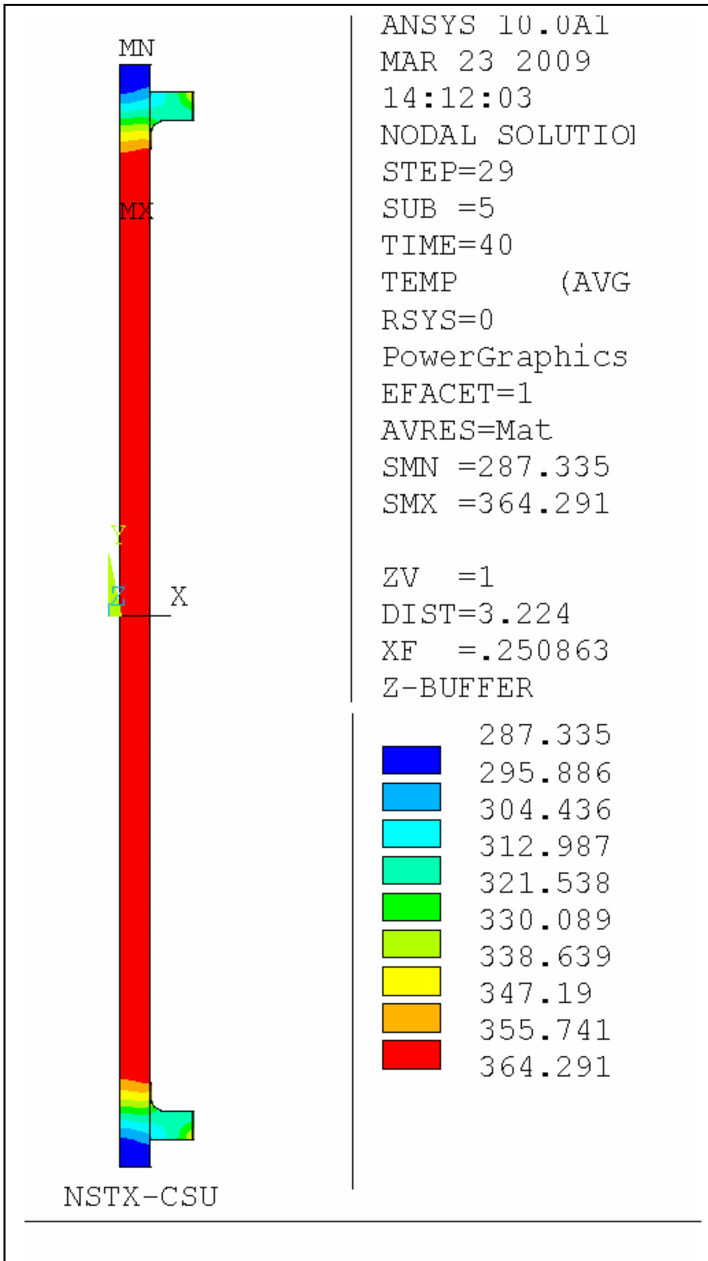

Figure 19 Tenmperature Results End of Pulse

ner Leg Temp, Nominal Scenario

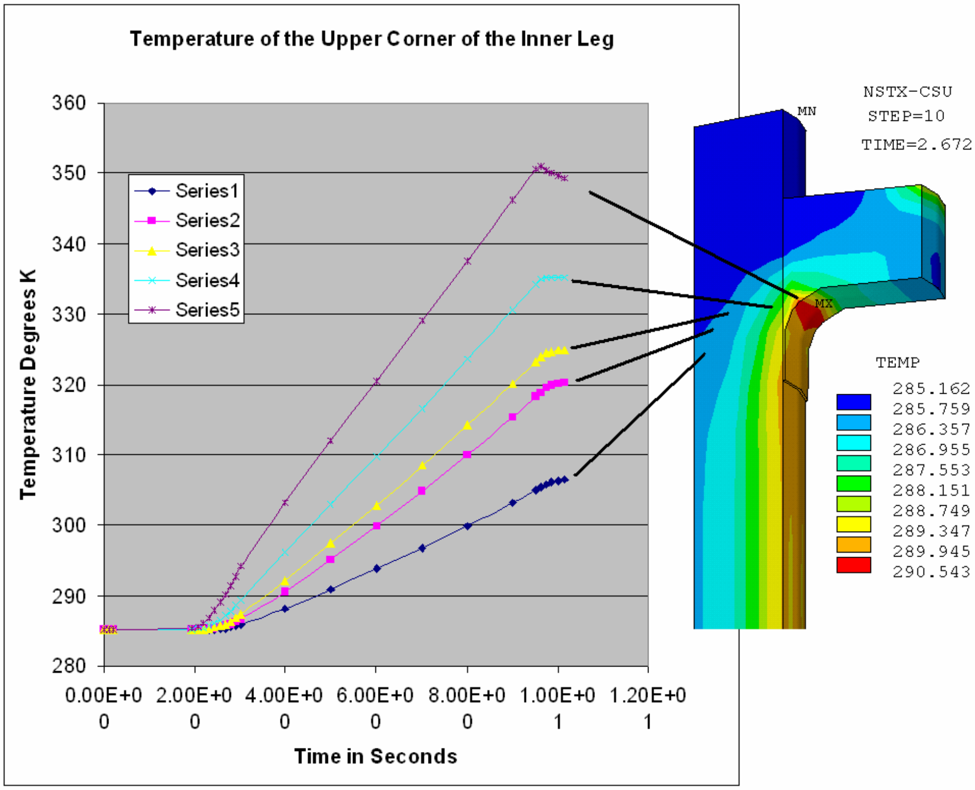

Figure 20 Upper Inner Corner Temperature Time History

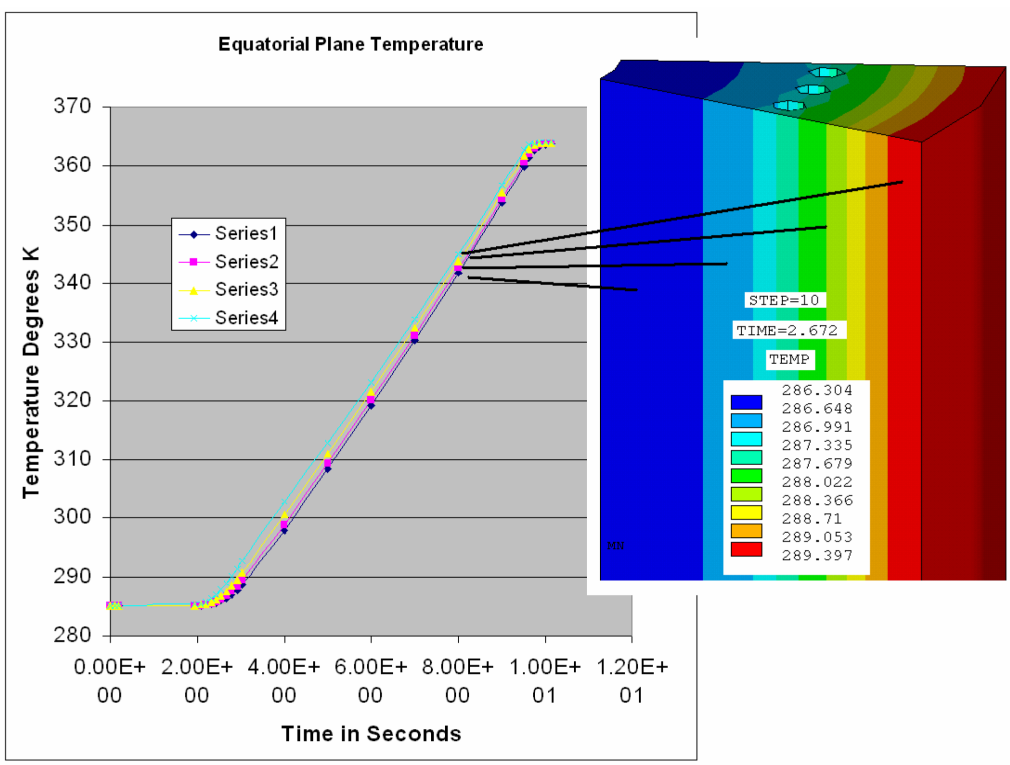

Figure 21 Equatorial Plane Time History. End average temperature is 364.197

Inner Leg Temperature, L/R Fault

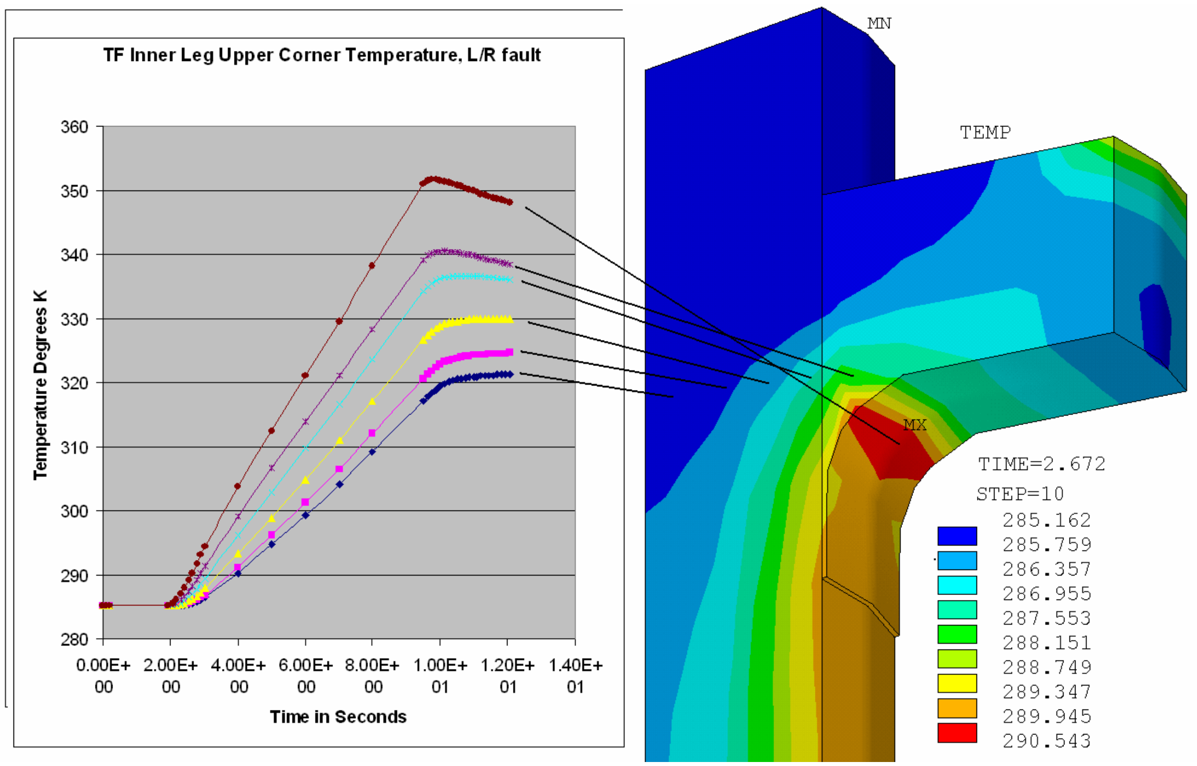

Figure 22 Upper Inner Corner Temperature Time History

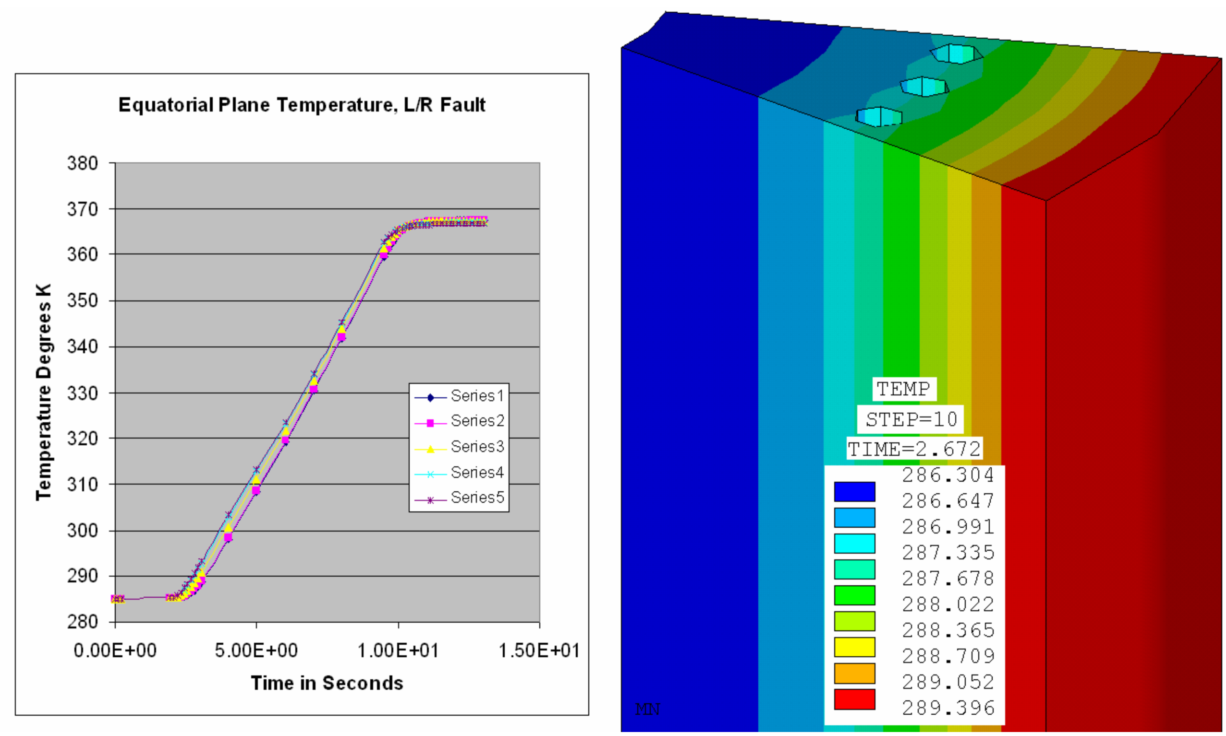

Figure 23 Equatorial Plane Time History. End average temperature is 367.15

Structural Pass

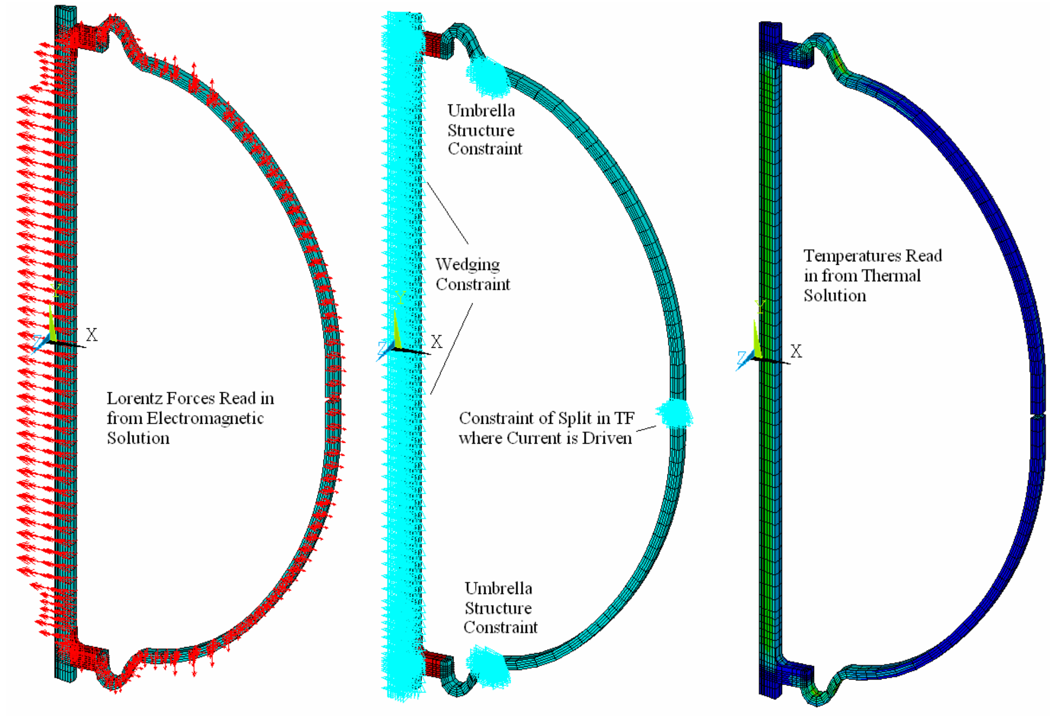

Figure 24 Structural Pass Forces, Constraints, and Temperatures

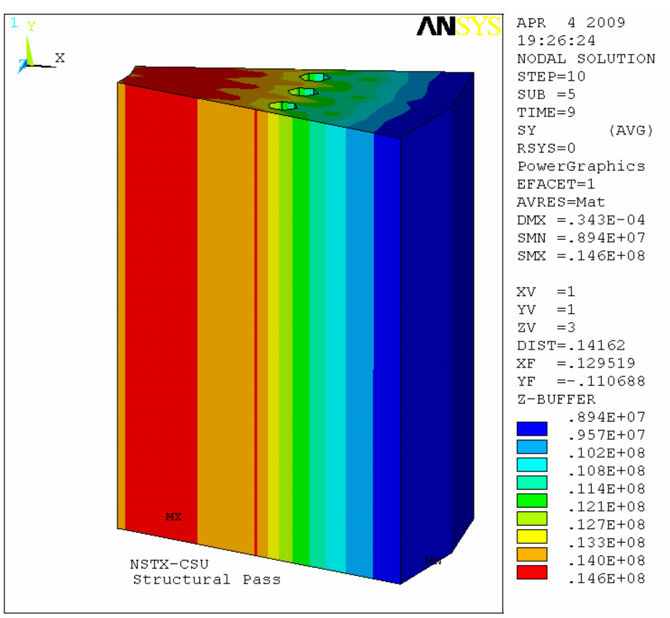

Figure 25 Results from the Electromagnetic-Thermal Model

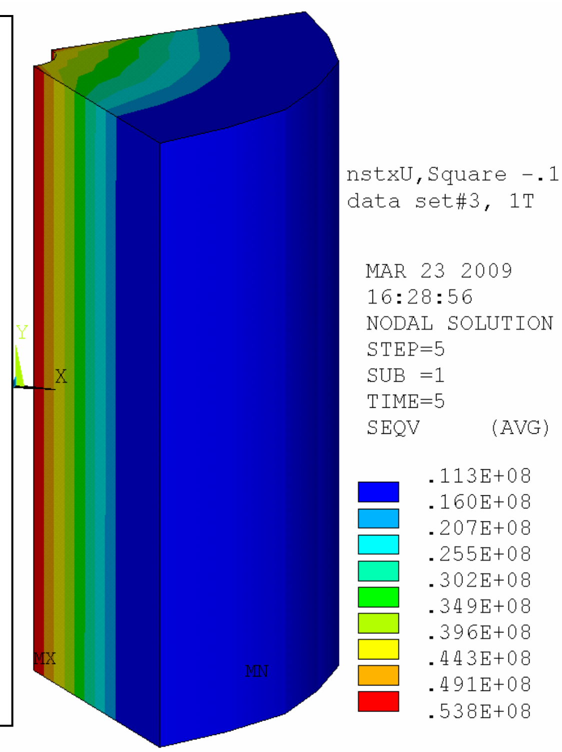

Figure 26 Results from the Global Analysis of the "Titus Joint"

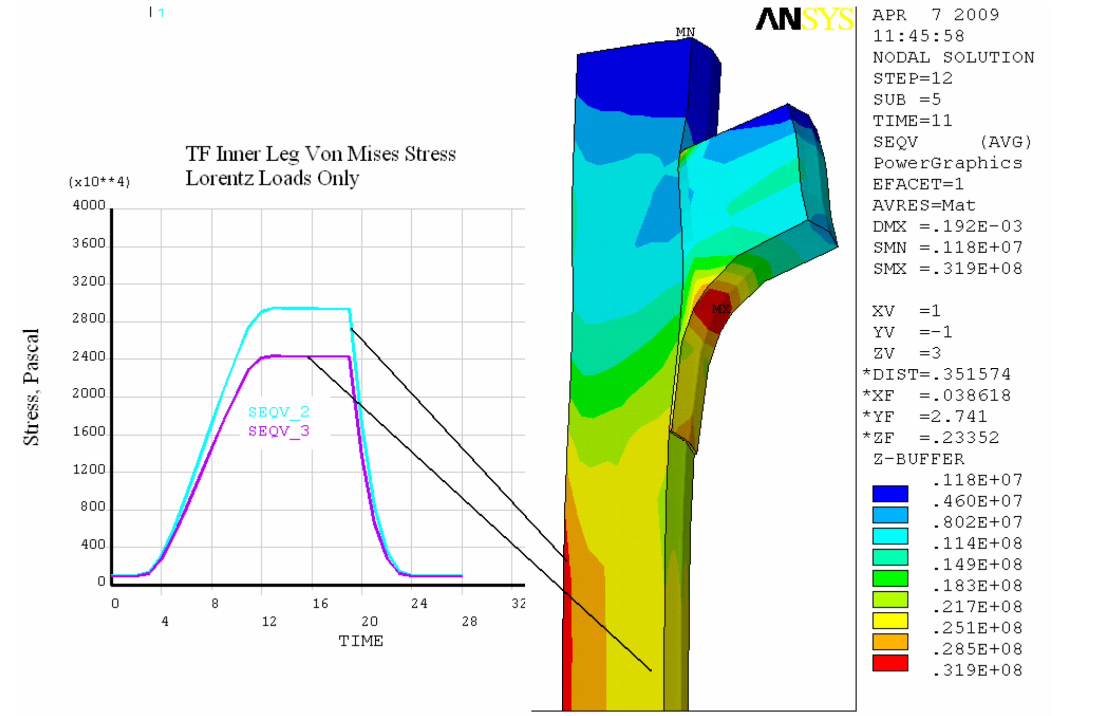

Figure 27 Inner Leg Stress Time History – No Thermal Stresses

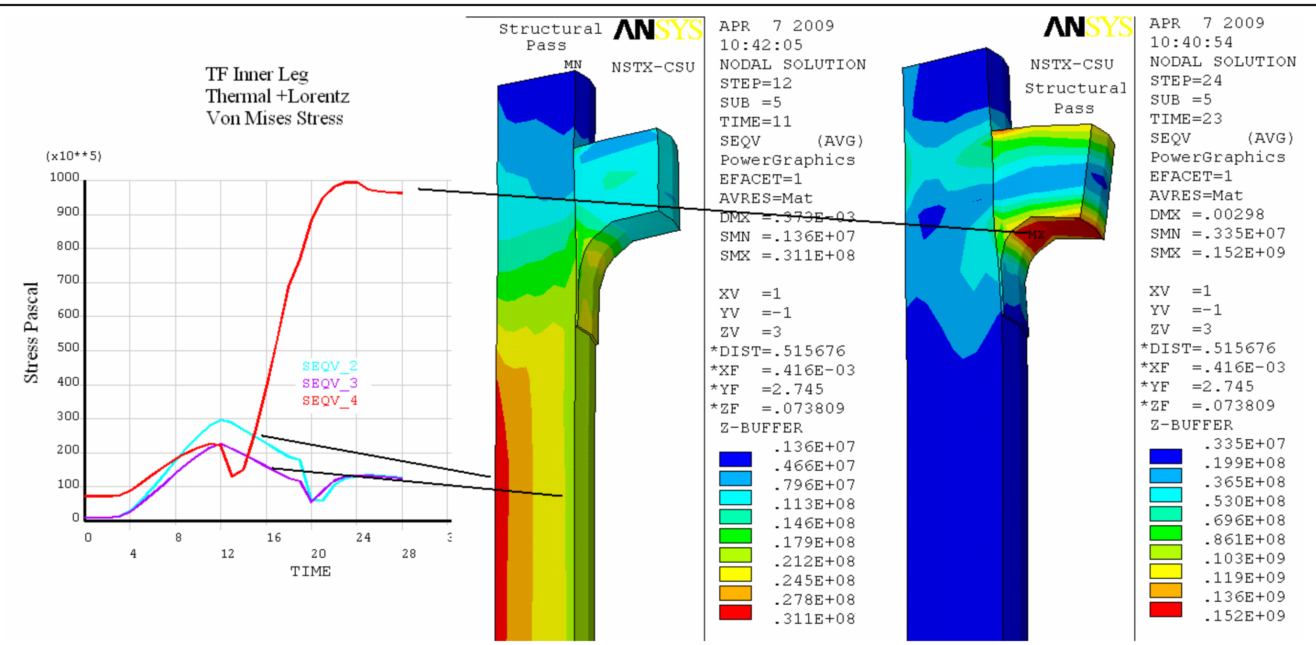

Figure 28 Inner Leg Von Mises Stress Time History – With Thermal Stress. The higher stress at the end of the pulse results from the restraint of center stack thermal expansion by a stiff modeling of the joint loop. This for the Nominal TF Currernt Profile.

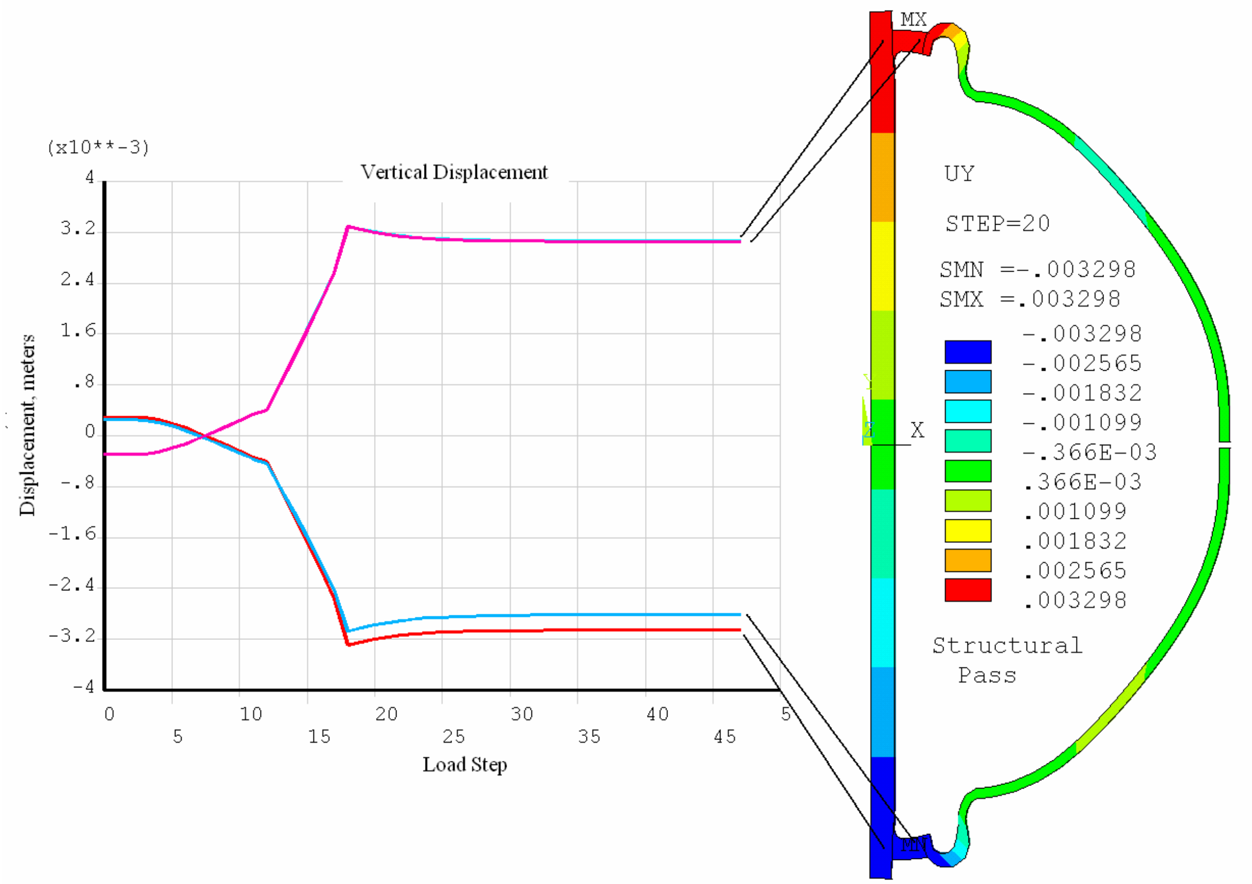

Figure 29 Vertical Motion of the TF Inner Leg. This includes both Thermal motion and TF Lorentz Force motions, but not the effects of the CS.

ANSYS Input Listing
Coupled Electromagnetic-Thermal Analysis

```
/batch
/config,nproc,7
runn=21
estep=0
tstep=0
/title, NSTX CSU 1T  run#%runn%
tfact=1.0    !Time Scaling Factor
curfact=1.0         !
numturns=3   !Number of turns in the TF coil being modeled

b_0=1.0    !NSTX My Linear 5 sec flattop Pulse
b_0=3.0    !NSTX Faulted Pulse
b_0=2.0    !NSTX Charlie's Normal Pulse

StartTemp = 273.15+12
NumSteps=49
packf=.754
packf=.7623
packfo=.9

*if,b_0,eq,1.0,then
/com
/com Reference 1 T wave form
/com
NumSteps=21
tfbscale=1.0
rampup=1
flattop=5
rampdown=3
TFI=129778
t1= 0.1*rampup   $i1= .1*tfi*tfbscale
t2= 0.2*rampup   $i2= .2*tfi*tfbscale
t3= 0.3*rampup   $i3= .3*tfi*tfbscale
t4= 0.4*rampup   $i4= .4*tfi*tfbscale
t5= 0.5*rampup   $i5= .5*tfi*tfbscale
t6= 0.6*rampup   $i6=.6*tfi*tfbscale
t7= 0.7*rampup   $i7=.7*tfi*tfbscale
t8= 0.8*rampup   $i8=.8*tfi*tfbscale
t9= 0.9*rampup   $i9=.9*tfi*tfbscale
t10=rampup+.2*flattop  $i10=tfi*tfbscale
t11=rampup+.4*flattop   $i11=tfi*tfbscale
t12=rampup+.6*flattop  $i12=tfi*tfbscale
t13=rampup+.8*flattop   $i13=tfi*tfbscale
t14=rampup+1.0*flattop  $i14=tfi*tfbscale
t15=rampup+flattop+.1*rampdown   $i15= .9*tfi*tfbscale
t16=rampup+flattop+.5*rampdown   $i16= .5*tfi*tfbscale
t17=rampup+flattop+.7*rampdown   $i17= .3*tfi*tfbscale
t18=rampup+flattop+1.1*rampdown   $i18=.1*tfi*tfbscale
t19=rampup+flattop+1.3*rampdown  $i19=  .05*tfi*tfbscale
t20=rampup+flattop+1.5*rampdown   $i20= .01*tfi*tfbscale
t21=rampup+flattop+10.0*rampdown   $i21= .001*tfi*tfbscale
```

```
*endif


/com

*if,b_0,eq,2,then
!     NSTX Normal Pulse
NumSteps=29
tfbscale=1.0
t1= .1   $ i1= 0
t2= .2  $ i2= 0
t3= 1.952   $ i3= 15690.906*tfbscale
t4= 2.072   $ i4= 38658.746*tfbscale
t5= 2.192   $ i5= 58169.054*tfbscale
t6= 2.312   $ i6= 74742.32*tfbscale
t7= 2.432   $ i7= 88820.681*tfbscale
t8= 2.552   $ i8= 100779.71*tfbscale
t9= 2.672   $ i9= 110938.46*tfbscale
t10= 2.792   $ i10= 119567.93*tfbscale
t11= 2.912   $ i11= 126898.33*tfbscale
t12= 3.032   $ i12= 129777.84*tfbscale
t13= 4.0   $ i13= 129777.84*tfbscale
t14= 5.0     $ i14= 129777.84*tfbscale
t15= 6.0   $ i15= 129777.84*tfbscale
t16= 7.0   $ i16= 129777.84*tfbscale
t17= 8.0   $ i17= 129777.84*tfbscale
t18= 9.0   $ i18= 129777.84*tfbscale
t19= 9.512   $ i19= 129777.84*tfbscale
t20= 9.632   $ i20= 91022.609*tfbscale
t21= 9.752   $ i21= 58895.183*tfbscale
t22= 9.872   $ i22= 32262.092*tfbscale
t23= 9.992   $ i23= 10183.711*tfbscale
t24= 10.136   $ i24= 0
t25= 15.0   $ i25= 0
t26= 20.0   $ i26= 0
t27= 30.0   $ i27= 0
t28= 40.0   $ i28= 0
t29= 1000.0   $ i29= 0
*endif

*if,b_0,eq,3,then
!     NSTX Faulted Pulse
NumSteps=51
t1= .1   $ i1= 0
t2= .2   $ i2= 0
t3= 1.952   $ i3= 15690.906
t4= 2.072   $ i4= 38658.746
t5= 2.192   $ i5= 58169.054
t6= 2.312   $ i6= 74742.32
t7= 2.432   $ i7= 88820.681
t8= 2.552   $ i8= 100779.71
t9= 2.672   $ i9= 110938.46
t10= 2.792   $ i10= 119567.93
```

```
t11= 2.912   $ i11= 126898.33
t12= 3.032   $ i12= 129777.84
t13= 4.00   $ i13= 129777.84
t14= 5.00   $ i14= 129777.84
t15= 6.00   $ i15= 129777.84
t16= 7.00   $ i16= 129777.84
t17= 8.00   $ i17= 129777.84
t18= 9.512   $ i18= 129777.84
t19= 9.632   $ i19= 113132.22
t20= 9.752   $ i20= 98621.613
t21= 9.872   $ i21= 85972.17
t22= 9.992   $ i22= 74945.174
t23= 10.136   $ i23= 63563.326
t24= 10.256   $ i24= 55410.543
t25= 10.376   $ i25= 48303.454
t26= 10.496   $ i26= 42107.938
t27= 10.616   $ i27= 36707.073
t28= 10.736   $ i28= 31998.937
t29= 10.856   $ i29= 27894.677
t30= 10.976   $ i30= 24316.839
t31= 11.096   $ i31= 21197.903
t32= 11.216   $ i32= 18479.01
t33= 11.336   $ i33= 16108.848
t34= 11.456   $ i34= 14042.689
t35= 11.576   $ i35= 12241.54
t36= 11.696   $ i36= 10671.411
t37= 11.816   $ i37= 9302.6701
t38= 11.936   $ i38= 8109.4875
t39= 12.056   $ i39= 7069.3453
t40= 12.176   $ i40= 6162.6142
t41= 12.296   $ i41= 5372.1826
t42= 12.416   $ i42= 4683.1337
t43= 12.536   $ i43= 4082.4638
t44= 12.656   $ i44= 3558.8372
t45= 12.776   $ i45= 3102.3723
t46= 12.896   $ i46= 2704.4546
t47= 13.016   $ i47= 2357.5748
t48= 15.0   $ i48= 1000
t49= 20.0   $ i49= 100
t50= 40.0   $ i50= 0.0
t51= 1000.0   $ i51= 0.0
*endif


/com


! CREATE BASE ELECTROMAGNETIC SOLUTION
/filnam,elect
/PREP7
antype,trans
/COM   11-25-98   Electrical/Thermal analysis
ET,1,97,1    ! (Ax, Ay, Az, VOLT) EM for current regions
```

```
et,2,97,0    ! (Ax, Ay, Az) EM for air
et,3,124     !resistor element
TREF,292.0
*create,matt
/COM   MAT,6  TF COIL COPPER, Inner Leg
/COM   MAT,9  TF COIL COPPER, Outer Leg
/COM   MAT,8  Air

mp,dens,1,8950
mp,dens,2,8950
mp,dens,3,8950
mp,dens,14,8950
mp,murx,1,1.0
mp,murx,2,1.0
mp,murx,3,1.0
mp,murx,14,1.0
mptemp,,80,130,180,290,800
mpdata,kxx,1,,559,400,400,400,210     !TF Conductor Inboard Leg
mpdata,kxx,2,,559,400,400,400,210     !TF Conductor Outboard Leg
mpdata,kxx,14,,559,400,400,400,210     !TF Conductor
mpdata,kxx,10,,.001,.001,.001,.001,.001     !Air



mpdata,rsvx,1,,.218e-8/packf,.572e-8/packf,.925e-8/packf,1.703e-8/packf,5.1460e-8/packf  !TF Conductor
mpdata,rsvx,2,,.218e-8/packfo,.572e-8/packfo,.925e-8/packfo,1.703e-8/packfo,5.1460e-8/packfo           !TF Conductor Outboard Leg
mpdata,rsvx,14,,.218e-8/packf,.572e-8/packf,.925e-8/packf,1.703e-8/packf,5.1460e-8/packf                  !TF Conductor

mpdata,c,1,,205*packf,301*packf,346*packf,384*packf,462*packf   !TF Conductor
mpdata,c,2,,205*packfo,301*packfo,346*packfo,384*packfo,462*packfo   !TF Conductor
mpdata,c,14,,205*packfo,301*packfo,346*packfo,384*packfo,462*packfo   !TF Conductor
*end
*use,matt
/com
/input,nba4,mod     ! Input of Model Geometry

dof,emf,curr
LOCAL,12,1,0,0,0,0,-90.0,0.0
CSYS,12  $NROTAT,all

nsel,x,3.999,4.01
d,all,ax,0.0    ! Added 2-2-98
d,all,ay,0.0
d,all,az,0.0
nsel,z,4.19,4.21
nasel,z,-4.21,-4.19
d,all,ax,0.0
d,all,ay,0.0
d,all,az,0.0    !added 2-2-98
nall
eall
```

```
esel,type,1
nelem
ninv
d,all,volt,0.0
nall
eall
csys,0
esel,mat,2
nelem
nrsel,x,2.49,2.58
nrsel,y,-.0201,-.0199
d,all,volt,0.0
nall
eall
tunif,StartTemp
esel,mat,2
nelem
nrsel,x,2.49,2.58
nrsel,y,.0199,.0201,
cp,1,volt,all
nall
eall
*get,currentnode,cp,1,term,1,node
f,CurrentNode,amps,10.0
save
fini

/solu
nsubst,5,10,3
time,.01
f,CurrentNode,amps,10.0
/com Elecromagnetic Solution
estep=estep+1
solve
save
fini

! CREATE BASE THERMAL SOLUTION
/filnam,therm
/PREP7
antype,trans
/title, NSTX-CSU run#%runn%
et,1,70      ! (TEMP) Thermal
et,2,70
TREF,292.0
tunif,StartTemp
csys,0
esel,type,1
nelem
ninv
d,all,temp,StartTemp
nall
```

```
eall
save
fini

/solu
solcon,on
nsubst,5,10,3
time,.01
/com Thermal Solution
tstep=tstep+1
solve
save
fini


!    SETUP TRANSIENT MACRO
*create,load
parsav,,file,parm
/filnam,elect
resume
parres,change,file,parm
/solu
antype,trans,rest
/com solve electromagnetic problem
time,timpt
ldread,temp,last,,,,therm,rst
f,CurrentNode,amps,curamp
!estep=estep+1
solve
save
parsav,,file,parm
fini

/com set up current/thermal solution
/filnam,therm
resume
parres,change,file,parm
/solu
antype,trans,rest
/com Thermal Solution
time,timpt
ldread,hgen,last,,,,elect,rst
tstep=tstep+1
solve
save
parsav,,file,parm
fini

*end

!   START TRANSIENT

*do,ls,1,NumSteps,1
```

```
timpt=t%ls%*tfact
curamp=i%ls%*numturns*curfact
/TITLE, NSTX-CSU %timpt% sec RUN#%runn%
*use,load
*enddo


save
fini
/exit
```

Structual Pass ANSYS Input Listing

```
/batch
/filnam,file
/prep7
resu,elect,db
antype,static
ET,1,45,,,,
ex,1,117e9
ex,2,117e9
ex,14,117e9
alpx,1,17e-6
alpx,14,17e-6
/title, NSTX-CSU run#%runn% Structural Pass

LOCAL,12,1,0,0,0,0,-90.0,0.0
CSYS,12  $NROTAT,all
/com Displacement Constraints
nsel,y,-15.1,-14.9
d,all,uy,0.0
nsel,y,14.9,15.1
d,all,uy,0.0


esel,type,1
nelem
nrsel,x,.82,1.0
d,all,all,0.0
esel,type,1
nelem
nrsel,z,-.03,.03
nrsel,x,2,10
d,all,uz,0.0
d,all,uy,0.0

esel,type,1
nelem
save
fini

/solu

*do,ti,1,29,1
ldread,temp,ti,0,tim,,therm,rst     ! Comment this out for a Lorentz Only Solution
```

```
ldread,force,ti,0,tim,,elect,rst
time,tim
solve
save
*enddo

fini
/exit
```

Results of a True Basic Thermal Simulation

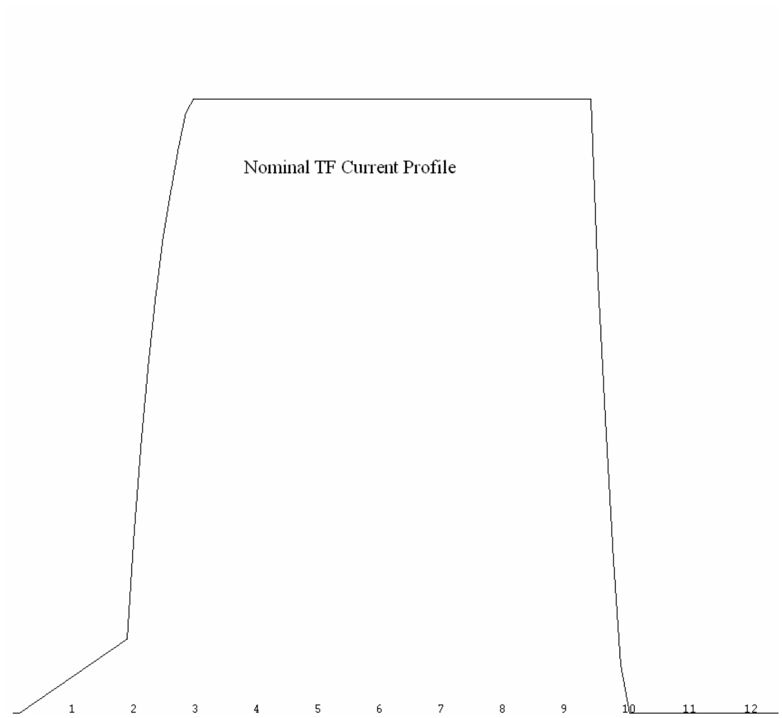

Figure 30 TF Current Profile

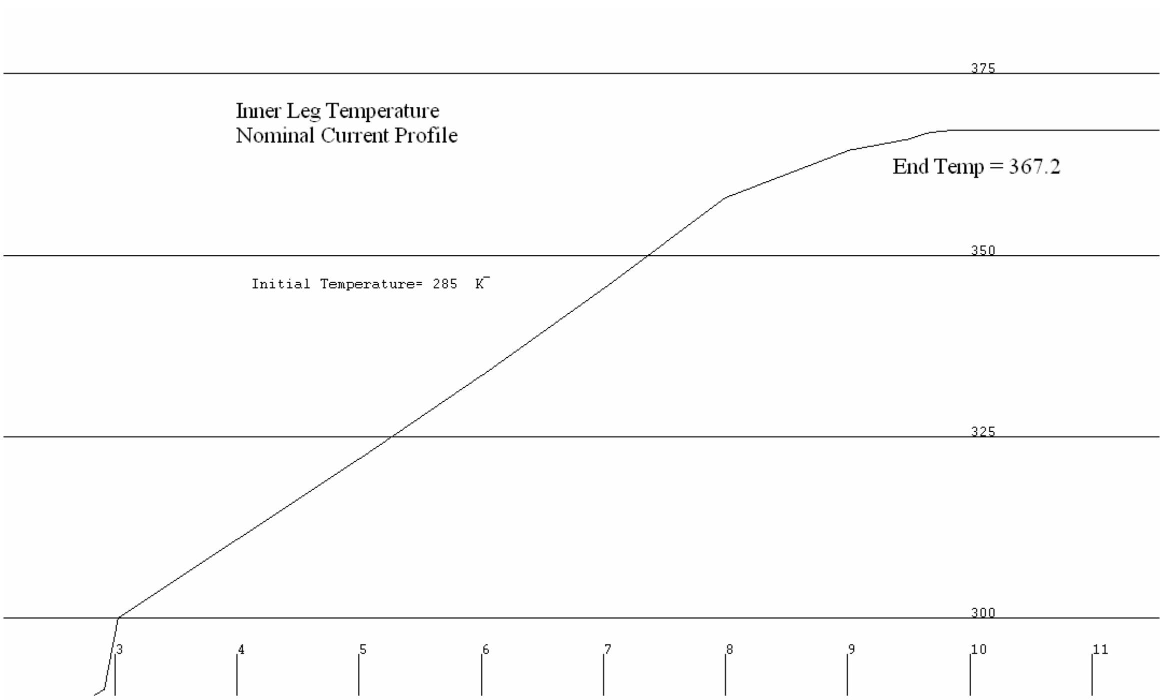

Figure 31 Temperature Time History

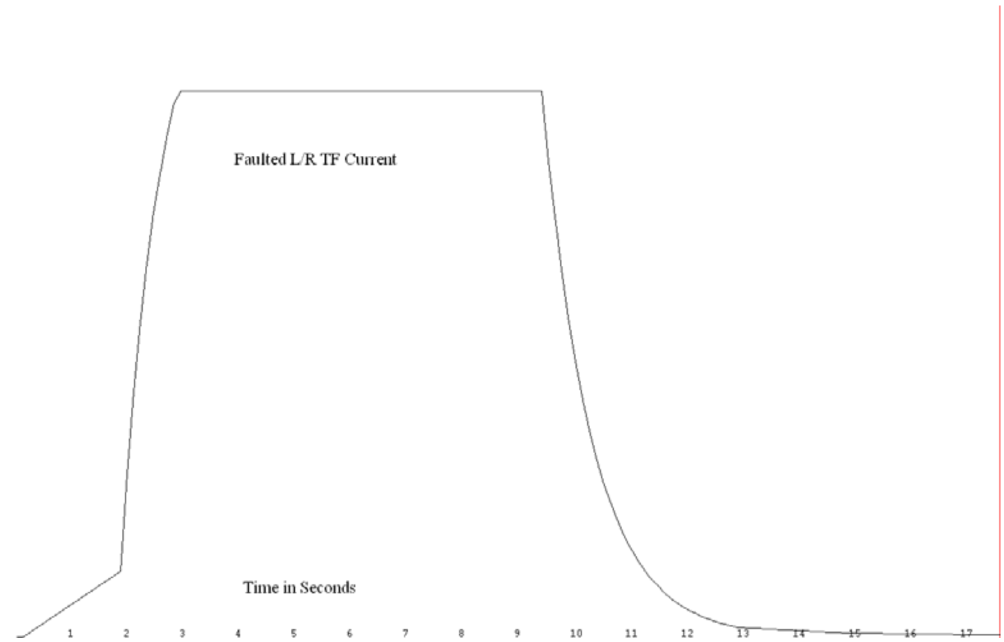

Figure 32 L/R Current Profile

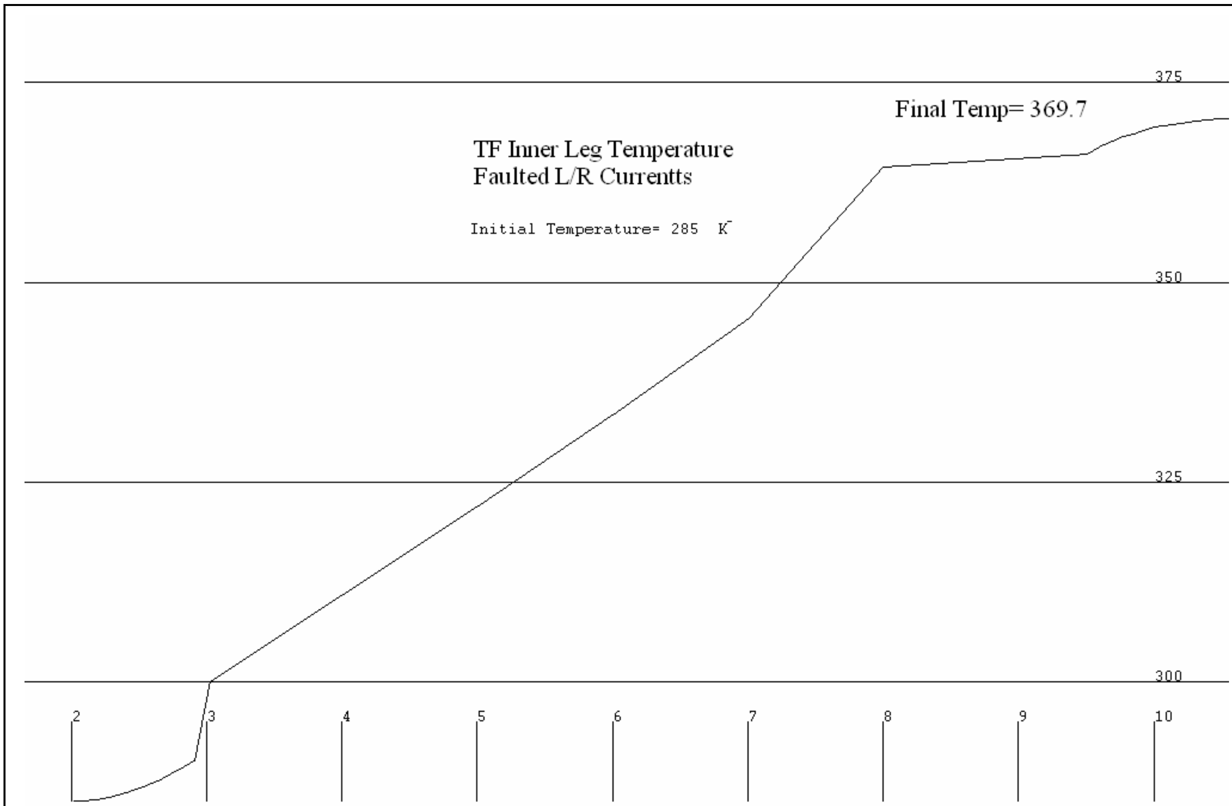

Figure 33 Temperature Time History