

2-D Thermal Analyses for Alternative Cooling Designs

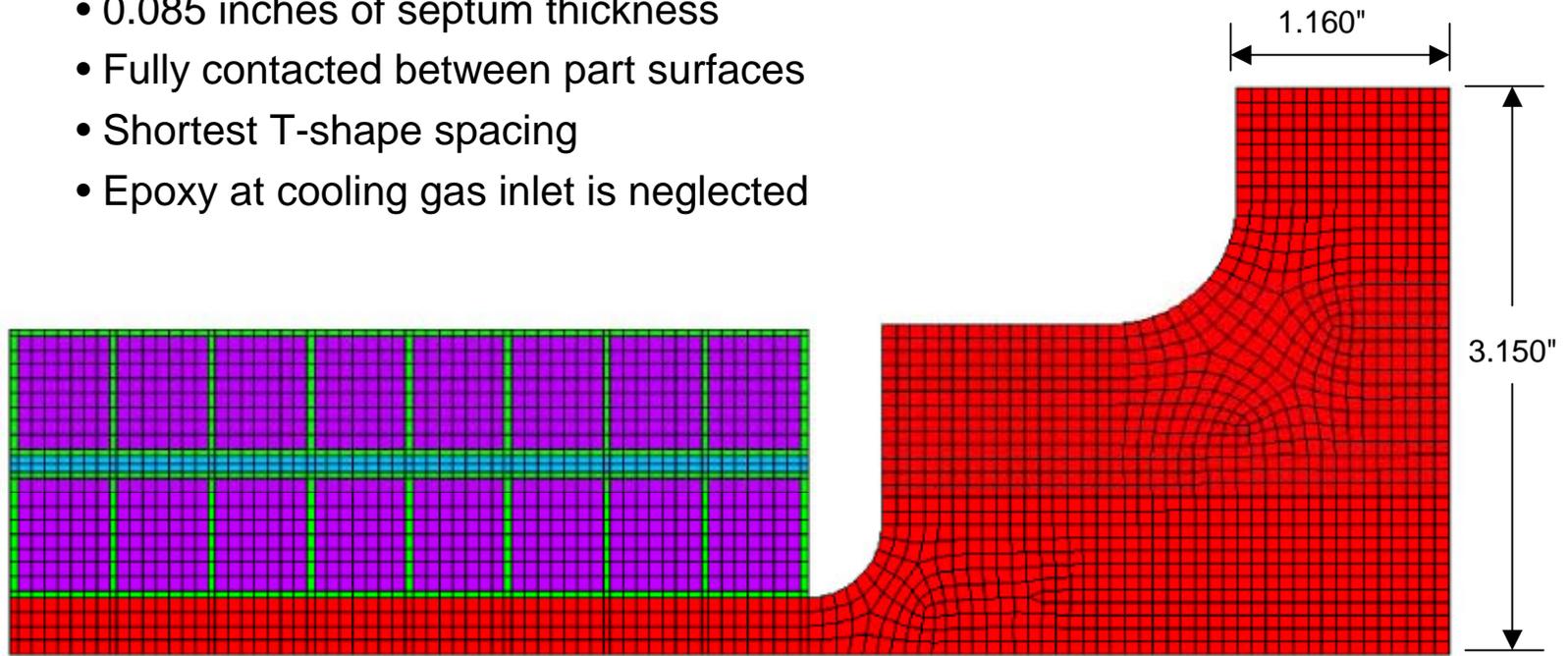
H. M. Fan

PPPL

November 30, 2001

Finite Element Model

- 2-D model
- Half symmetric model is used
- T-shape is cast into the shell
- Cable contains 75% of copper and 25% of epoxy
- 0.040 inches of insulation thickness
- 0.085 inches of septum thickness
- Fully contacted between part surfaces
- Shortest T-shape spacing
- Epoxy at cooling gas inlet is neglected



Basic Model - Model A

Cryogenics Material Properties

- **Specific Heat (J/kg-K)**

	80K	100K	150K	200K
Cable	171.4	212.3	270.1	300.7
Septum	205.1	255.3	324.1	359.0
Insulation 348.9	413.7	537.0	626.8	
Shell & T-beam	215.3	275.5	362.1	416.4

- **Thermal Conductivity (W/m-K)**

	80K	100K	150K	200K
Cable	397.0	346.2	313.7	305.2
Septum	529.3	461.5	418.1	407.0
Insulation 0.128	0.142	0.163	0.175	
Shell & T-beam	8.114	9.224	11.17	12.63

Note: Cable contains 75% of copper and 25% of epoxy

Coil Currents and Ohmic Heating

- Current profile from web address:
http://www.pppl.gov/me/NCSX_Engineering/Technical_Data/MOD00/Inputs_1.7T.htm

Turn Current Profile of Modular Coil (A)

Coil	Time (s)								
	-1.8	-1.5	0	0.1	0.158083	0.258083	0.458083	1.658083	1.958083
M1	0	0	19832	19832	16897	17907	17907	0	0
M2	0	0	18553	18553	16574	17649	17649	0	0
M3	0	0	19189	19189	17158	18352	18352	0	0
M4	0	0	20287	20287	16626	17755	17755	0	0

Power of ohmic Heating (W/m³)

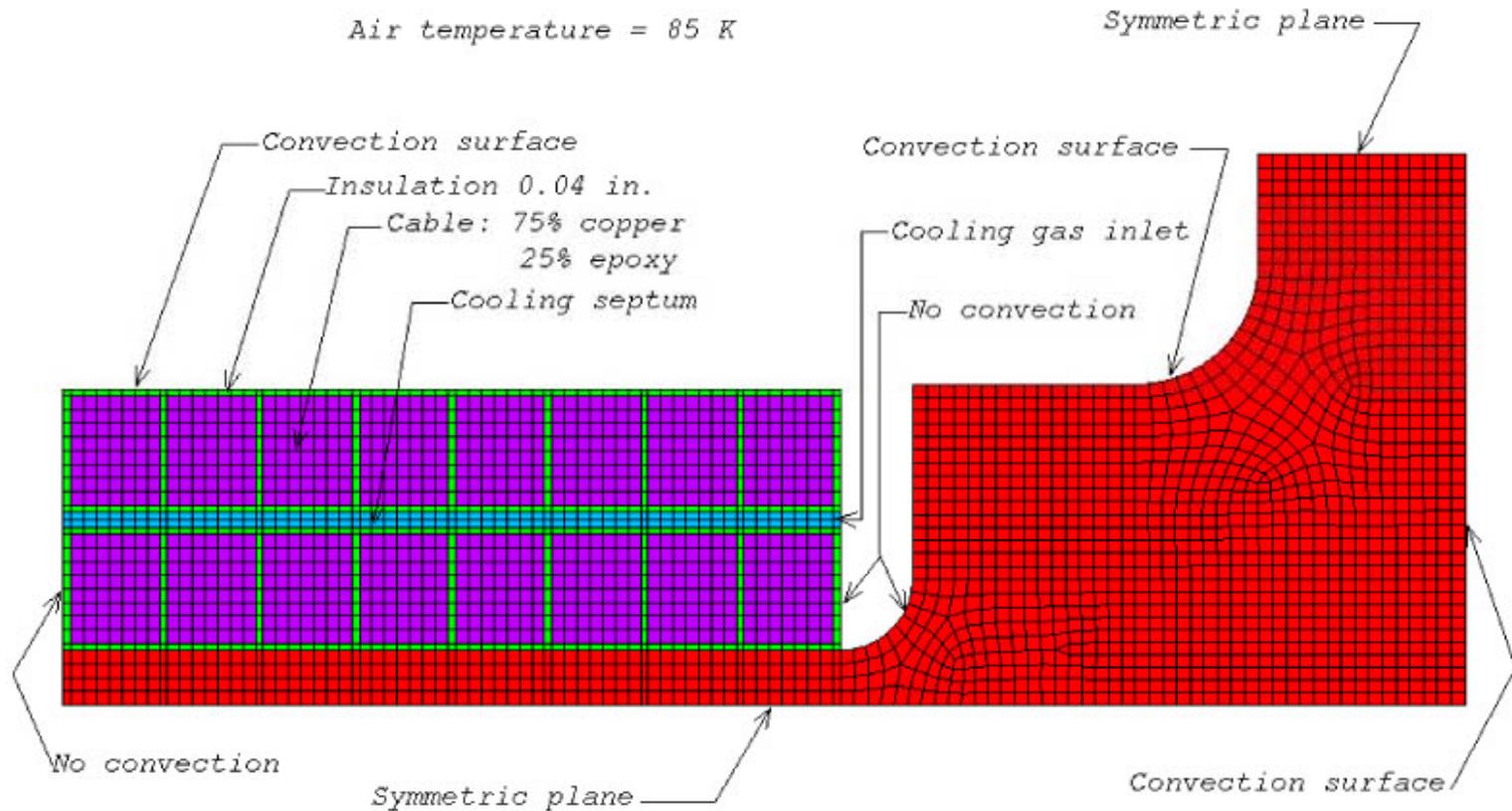
Time (s)	-1.8	-1.5	0	0.1	0.158083	0.258083	0.458083	1.658083	1.958083
μ (ohm-m)	2.36E-09	2.36E-09	3.52E-09	3.78E-09	3.91E-09	4.11E-09	4.55E-09	5.52E-09	5.52E-09
M1	0.00E+00	0.00E+00	3.41E+07	3.66E+07	2.75E+07	3.24E+07	3.59E+07	0.00E+00	0.00E+00
M2	0.00E+00	0.00E+00	2.98E+07	3.20E+07	2.64E+07	3.15E+07	3.49E+07	0.00E+00	0.00E+00
M3	0.00E+00	0.00E+00	3.19E+07	3.42E+07	2.83E+07	3.41E+07	3.77E+07	0.00E+00	0.00E+00
M4	0.00E+00	0.00E+00	3.56E+07	3.83E+07	2.66E+07	3.19E+07	3.53E+07	0.00E+00	0.00E+00

- Heat of ohmic heating in one pulse is 6.31 J/m³ for M4 coil

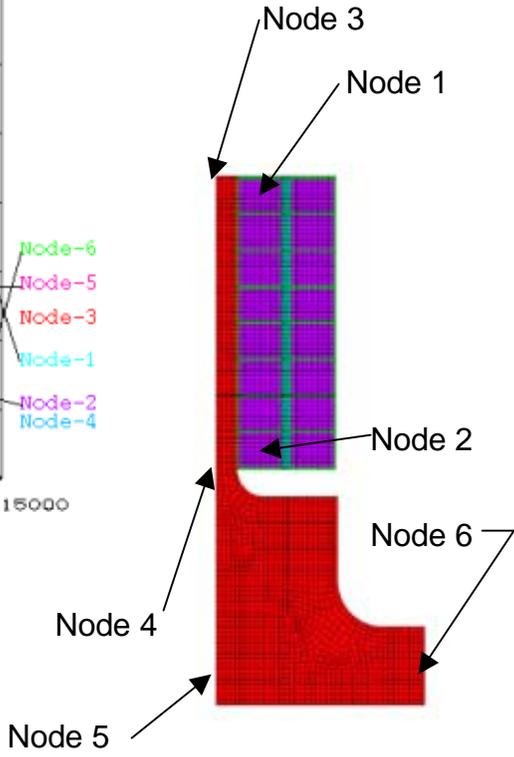
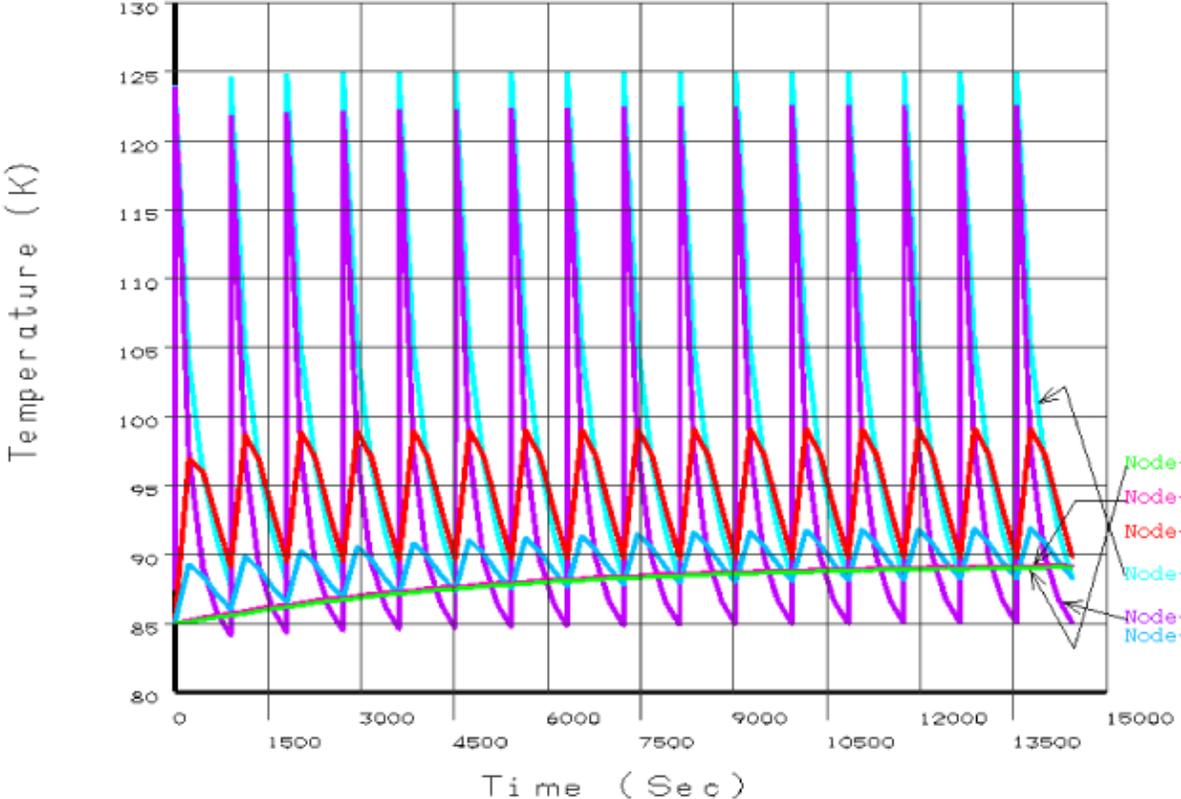
Transient Thermal Analysis

- Temperature constraint at cooling gas inlet is 80 K.
- The starting temperatures for both the coil and coil structure are 85 K.
- Ambient air temperature is fixed at 85 K.
- The film coefficient is assumed to be $4.0 \text{ W/m}^2\text{-K}$.
- The thermal properties for specific heat and thermal conductivity are temperature-dependent.
- Values of cable resistivity depend on the M4 coil temperatures which are calculated from adiabatic condition as shown in web address:
http://www.pppl.gov/me/NCSX_Engineering/Technical_Data/MOD00/Calculations_1.7T.htm
- Power of ohmic heating calculated for the M4 coil from -1.5 seconds to 1.658083 seconds is used for thermal load input.
- Thermal load varies linearly between two time steps.
- Cooling period between pulses is 15 minutes.

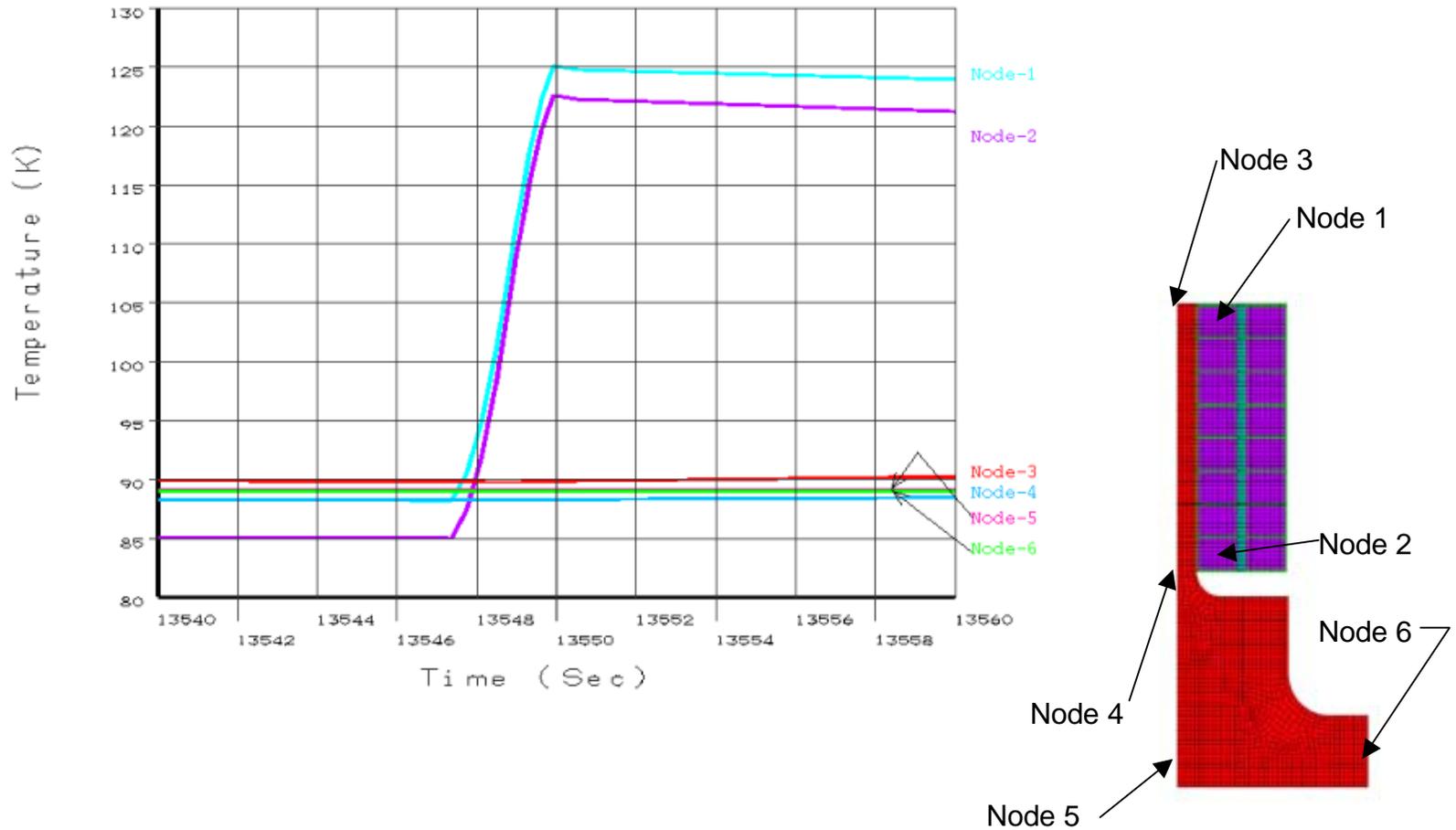
Boundary Conditions for Model A



Temperature vs. Time on selected nodes of Model A



Temperature vs. Time at the 16th Heating Cycle



Temperature Distribution at The First Heating and Cooling Cycles – Model A

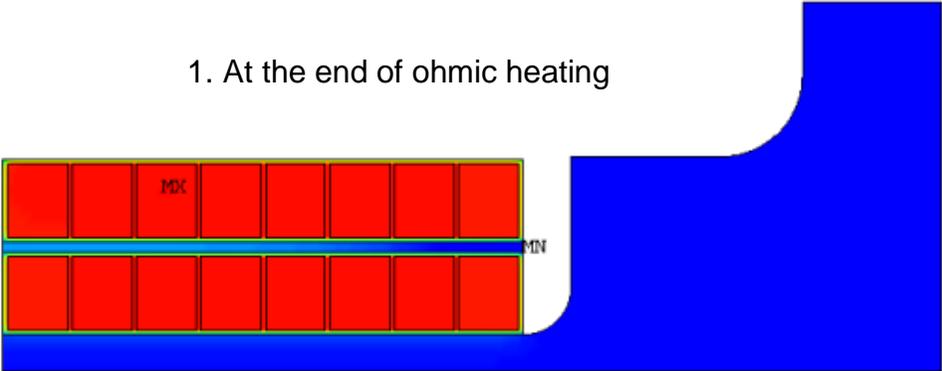
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ANSYS 5.6.2
JUL 24 2001
10:15:35
NODAL SOLUTION
STEP=6
SUB =3
TIME=3.158
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =80
SMX =124.113

```

80
84.901
89.803
94.704
99.606
104.507
109.409
114.31
119.212
124.113

1. At the end of ohmic heating



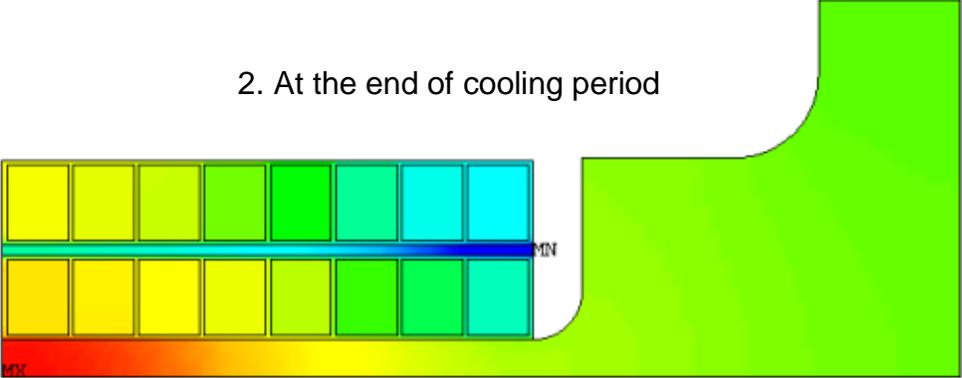
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ANSYS 5.6.2
JUL 24 2001
10:17:28
NODAL SOLUTION
STEP=7
SUB =4
TIME=903.158
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =80
SMX =89.118

```

80
81.013
82.026
83.039
84.053
85.066
86.079
87.092
88.105
89.118

2. At the end of cooling period

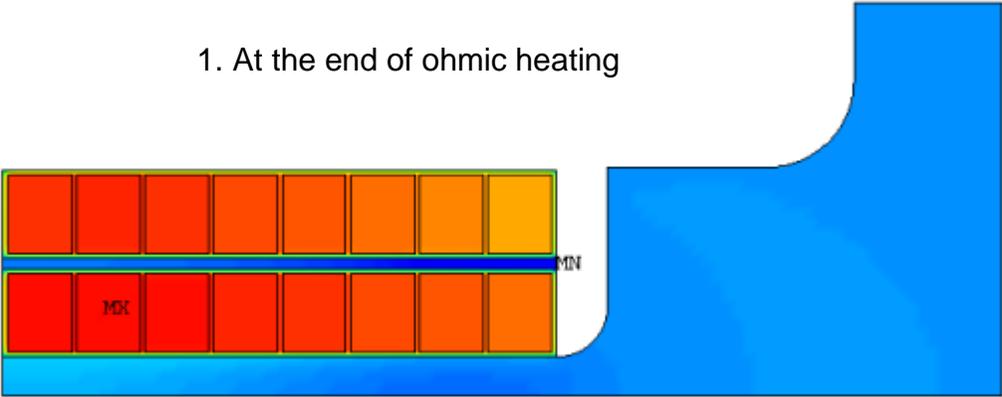


Temperature Distribution at The 16th Heating and Cooling Cycles – Model A

ANSYS 5.6.2
 JUL 24 2001
 09:47:09
 NODAL SOLUTION
 STEP=111
 SUB =3
 TIME=13551
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =124.91

80
84.99
89.98
94.97
99.96
104.95
109.94
114.93
119.92
124.91

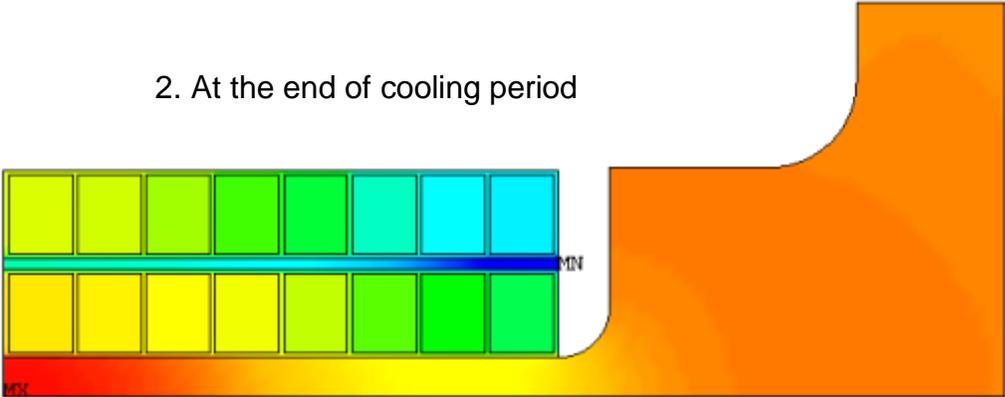
1. At the end of ohmic heating



ANSYS 5.6.2
 JUL 24 2001
 09:45:06
 NODAL SOLUTION
 STEP=112
 SUB =4
 TIME=14451
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =89.793

80
81.088
82.176
83.264
84.352
85.44
86.528
87.616
88.705
89.793

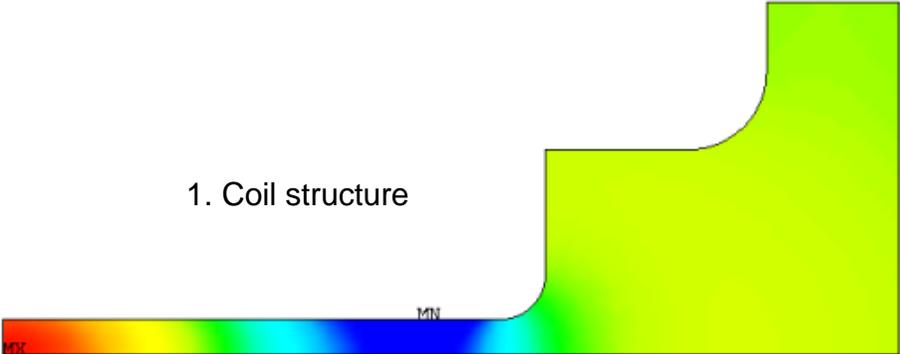
2. At the end of cooling period



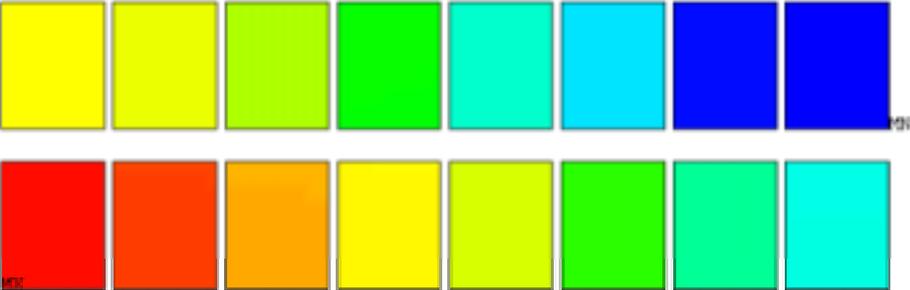
Temperature Distribution in Coil Structure and Coil at The End of 16th Cooling Cycles

NODAL SOLUTION
 STEP=112
 SUB =4
 TIME=14451
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =87.631
 SMX =89.793

■	87.631
■	87.871
■	88.111
■	88.352
■	88.592
■	88.832
■	89.072
■	89.312
■	89.552
■	89.793



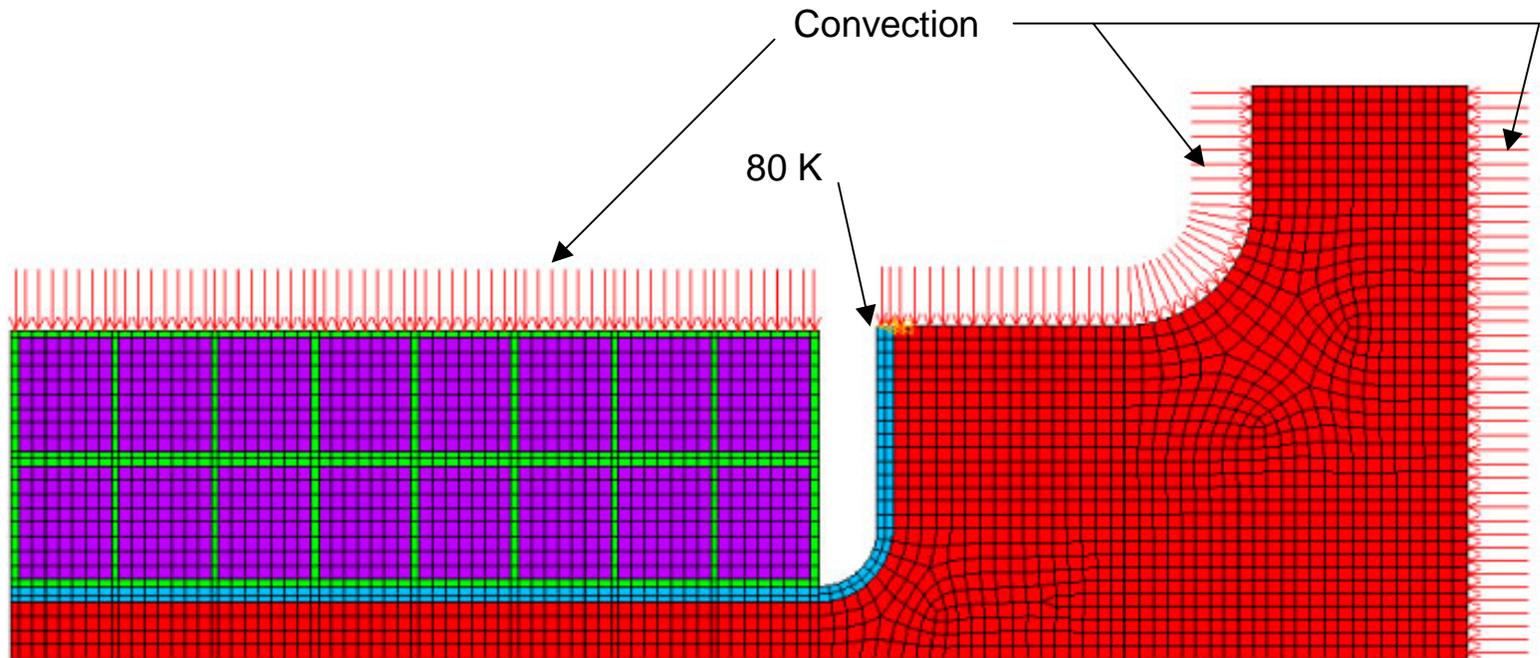
2. Coil turns



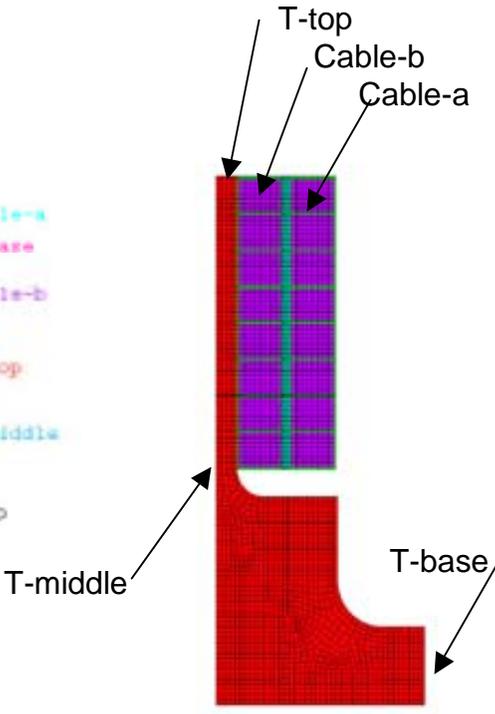
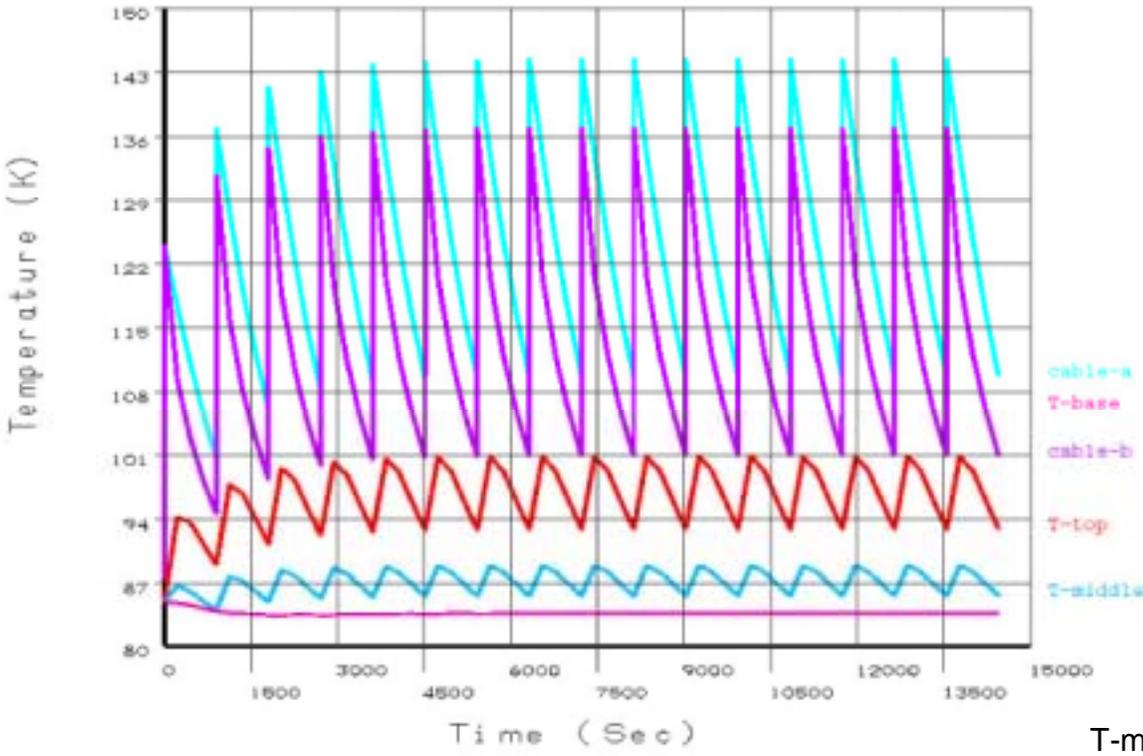
NODAL SOLUTION
 STEP=112
 SUB =4
 TIME=14451
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =82.913
 SMX =88.206

■	82.913
■	83.501
■	84.089
■	84.677
■	85.266
■	85.854
■	86.442
■	87.03
■	87.618
■	88.206

Septum Placed Between Coil and Coil Structure – Model B

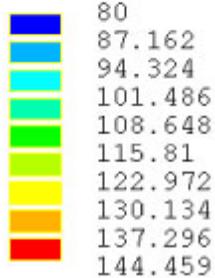


Temperature vs. Time on Selected Nodes of Model B

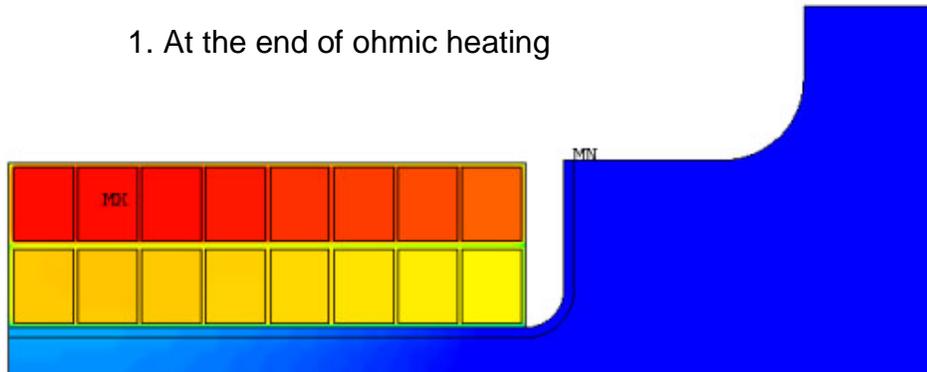


Temperature Distribution at The 16th Heating and Cooling Cycles – Model B

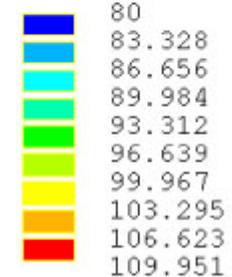
ANSYS 5.6.2
 AUG 10 2001
 09:32:32
 NODAL SOLUTION
 STEP=111
 SUB =3
 TIME=13551
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =144.459



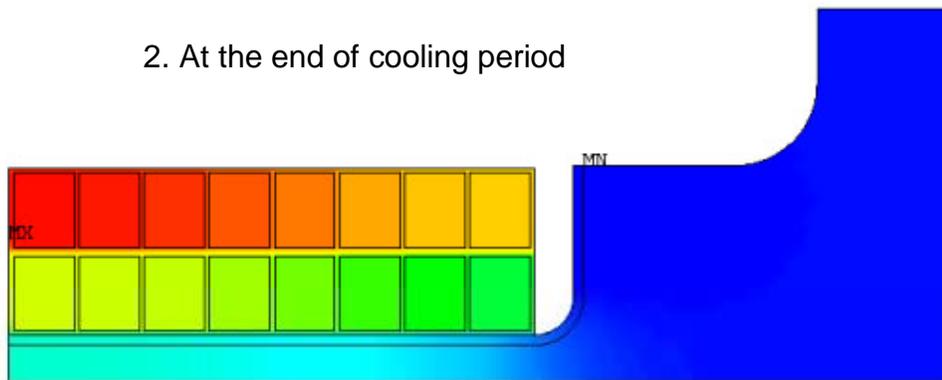
1. At the end of ohmic heating



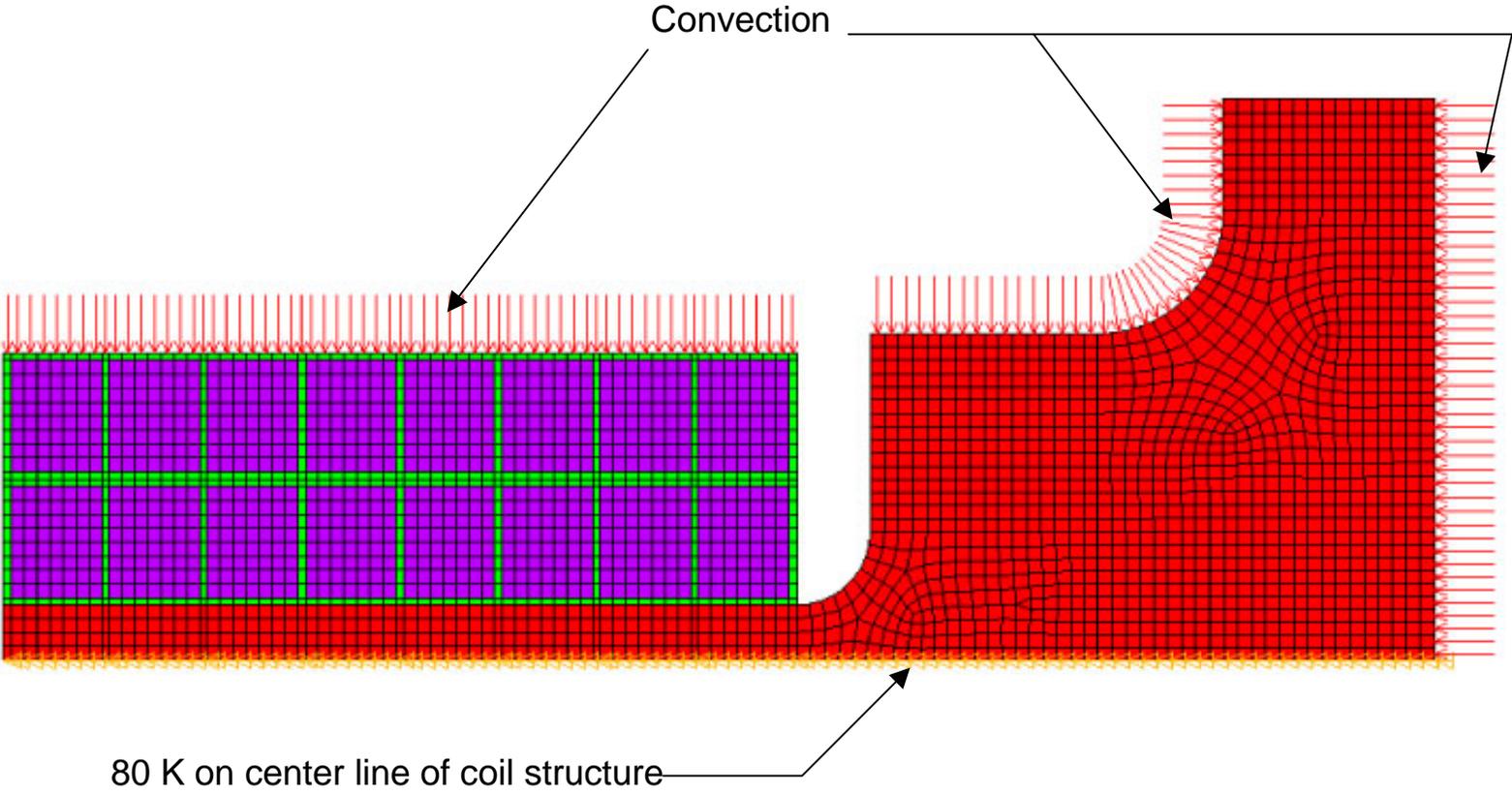
ANSYS 5.6.2
 AUG 10 2001
 09:31:05
 NODAL SOLUTION
 STEP=112
 SUB =4
 TIME=14451
 TEMP (AVG)
 RSYS=0
 PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =109.951



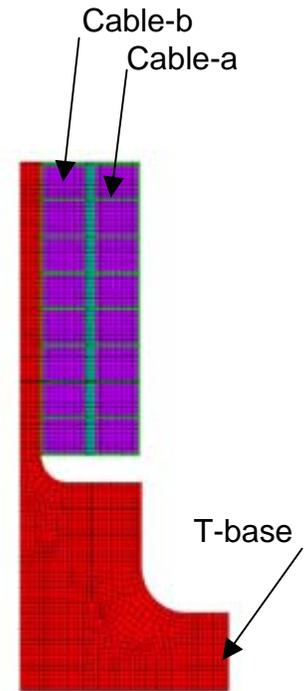
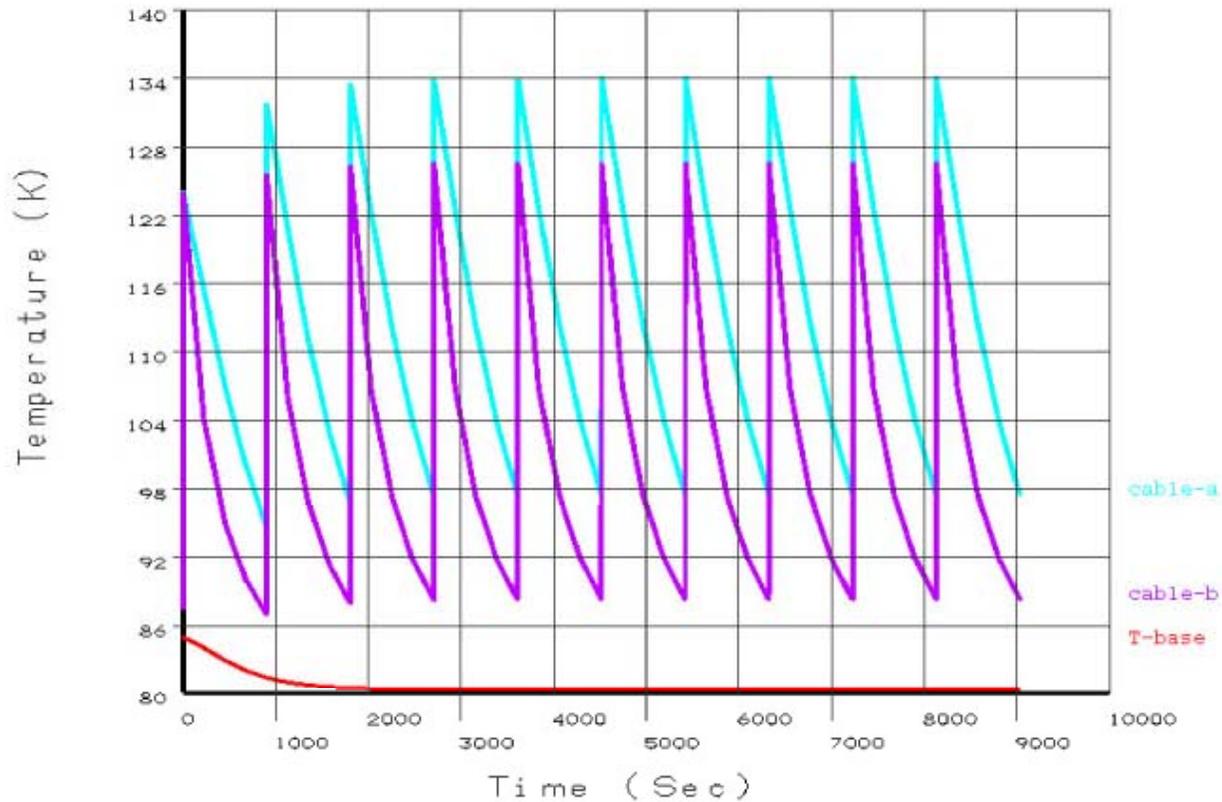
2. At the end of cooling period



Temperature Constraint on Center Line of T-Shape Coil Structure – Model C



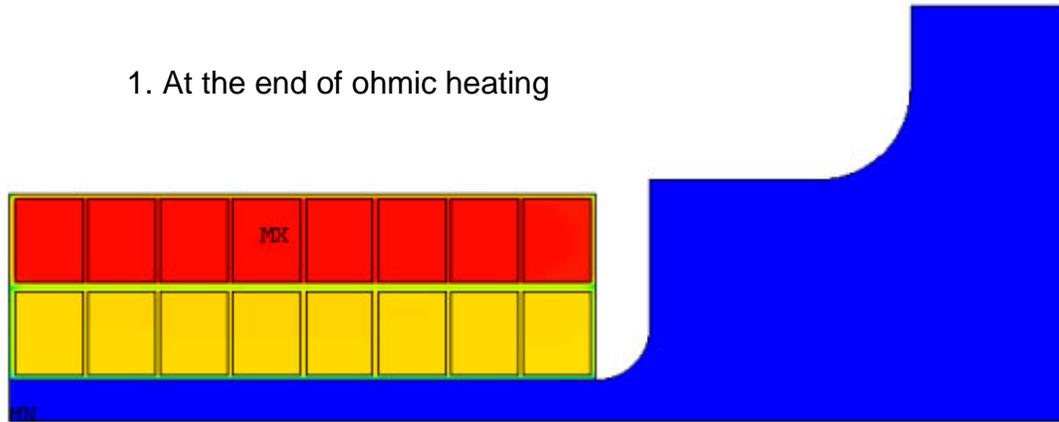
Temperature vs. Time on Selected Nodes of Model C



Temperature Distribution at The 10th Heating and Cooling Cycles – Model C

ANSYS 5.6.2
 AUG 14 2001
 11:27:46
 NODAL SOLUTION
 STEP=69
 SUB =3
 TIME=8132
 TEMP (AVG)
 RSYS=0

1. At the end of ohmic heating

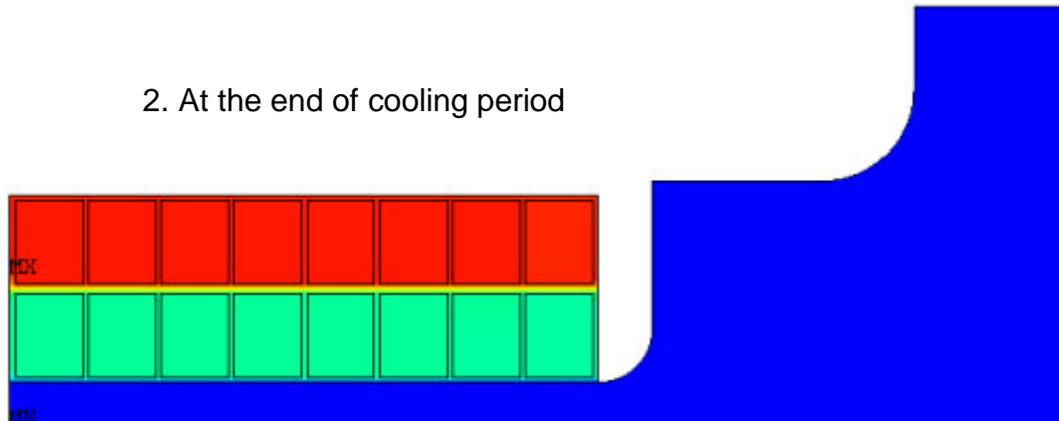


PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =134.293

80
86.033
92.065
98.098
104.13
110.163
116.196
122.228
128.261
134.293

ANSYS 5.6.2
 AUG 14 2001
 11:24:02
 NODAL SOLUTION
 STEP=70
 SUB =4
 TIME=9032
 TEMP (AVG)
 RSYS=0

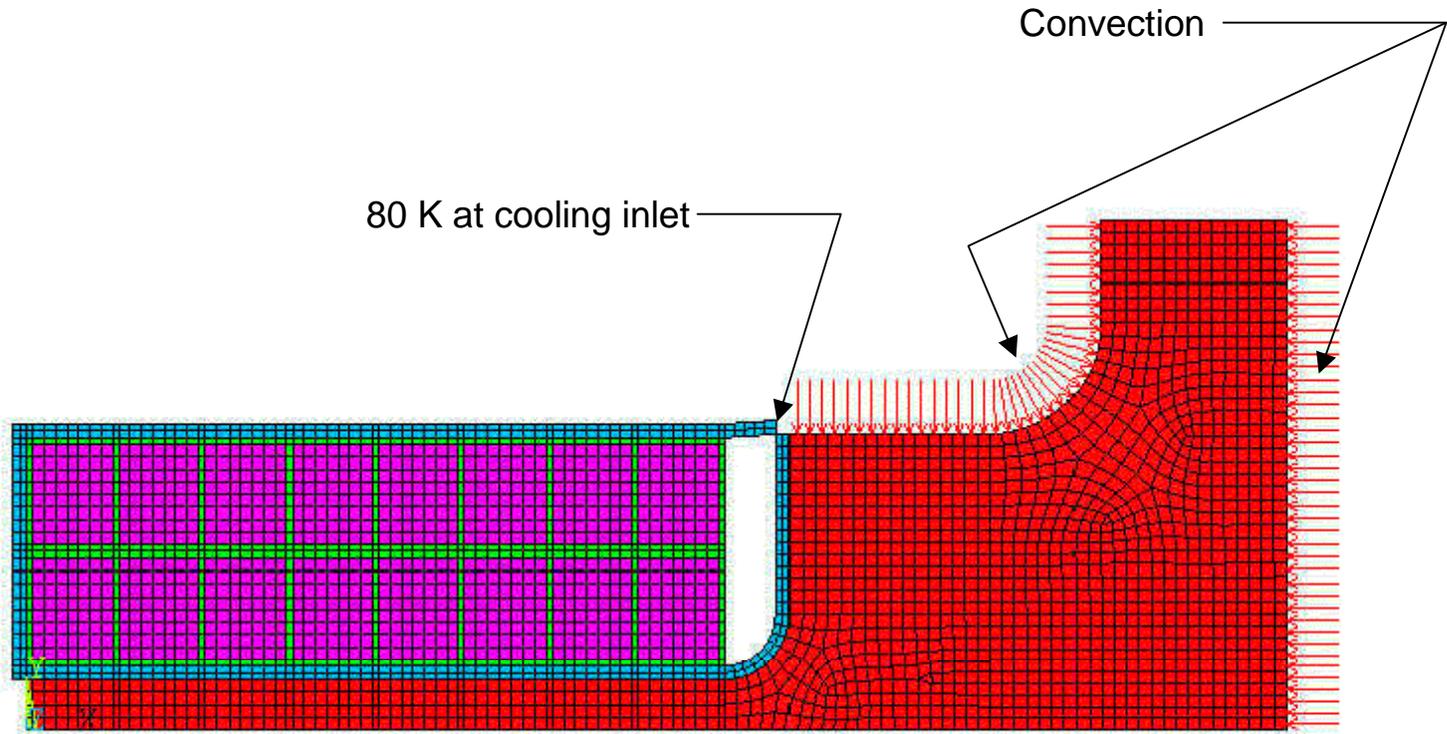
2. At the end of cooling period



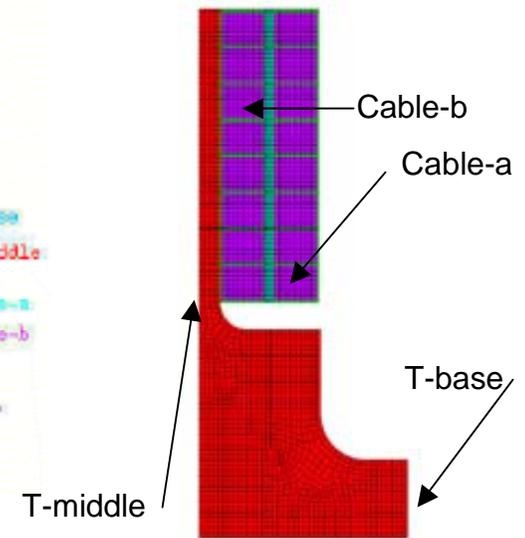
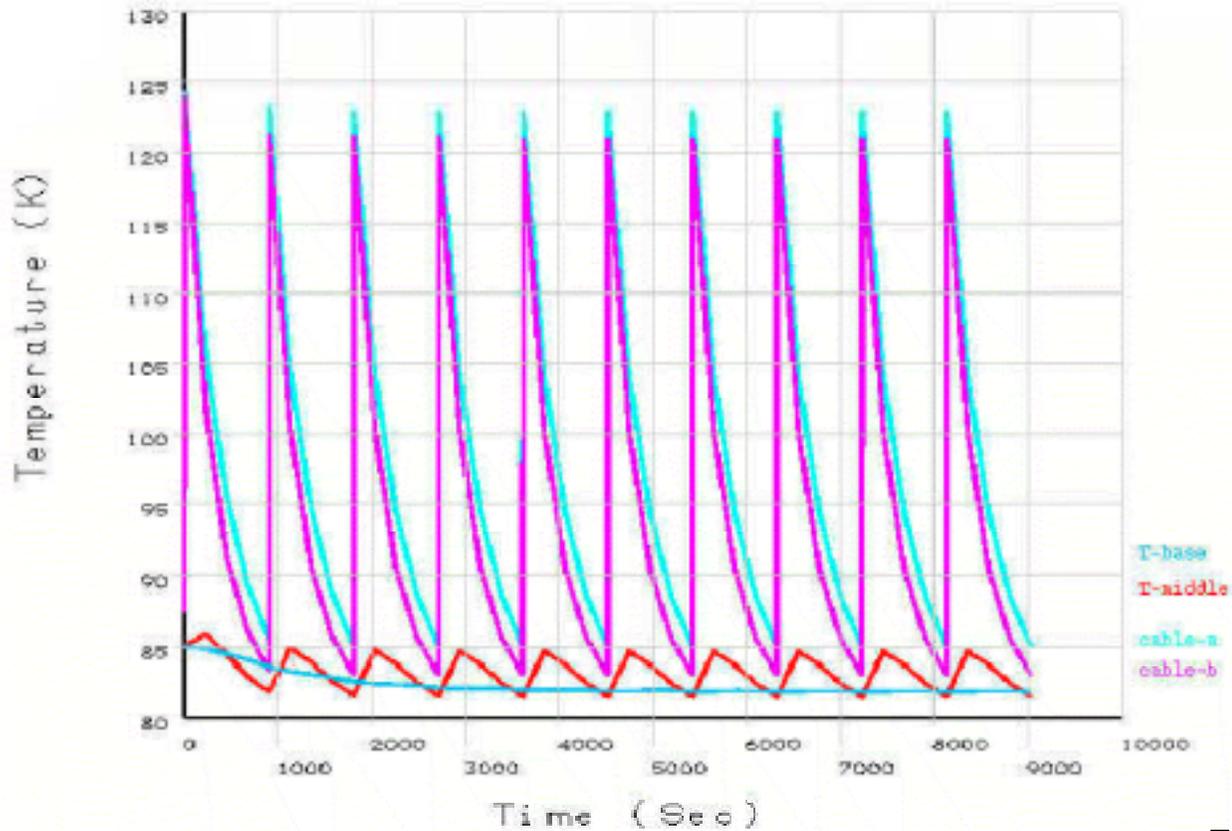
PowerGraphics
 EFACET=1
 AVRES=Mat
 SMN =80
 SMX =97.646

80
81.961
83.921
85.882
87.843
89.804
91.764
93.725
95.686
97.646

Cooling Septum Wrapping Around Coils – Model D



Temperature vs. Time on Selected Nodes of Model D



Temperature Distribution at The 10th Heating and Cooling Cycles – Model D

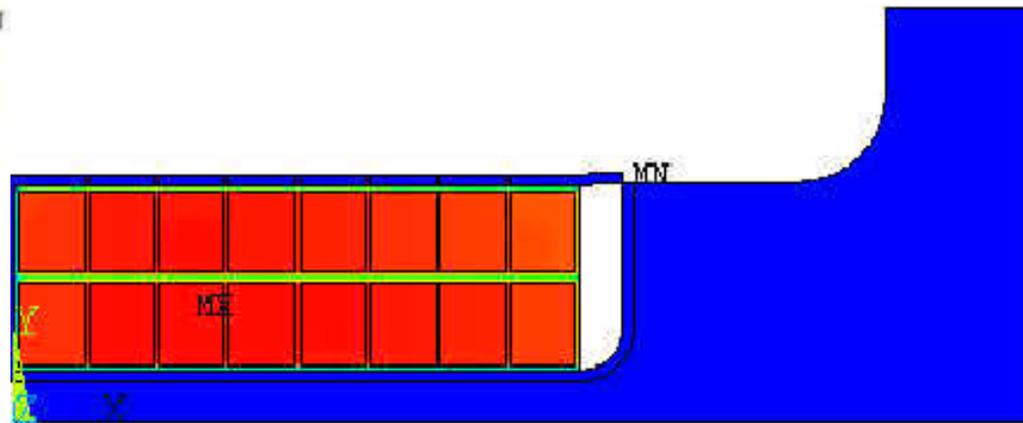
```

ANSYS 5.6.2
NOV 29 2001
14:29:58
NODAL SOLUTION
STEP=69
SUB =3
TIME=8132
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =80
SMX =122.659

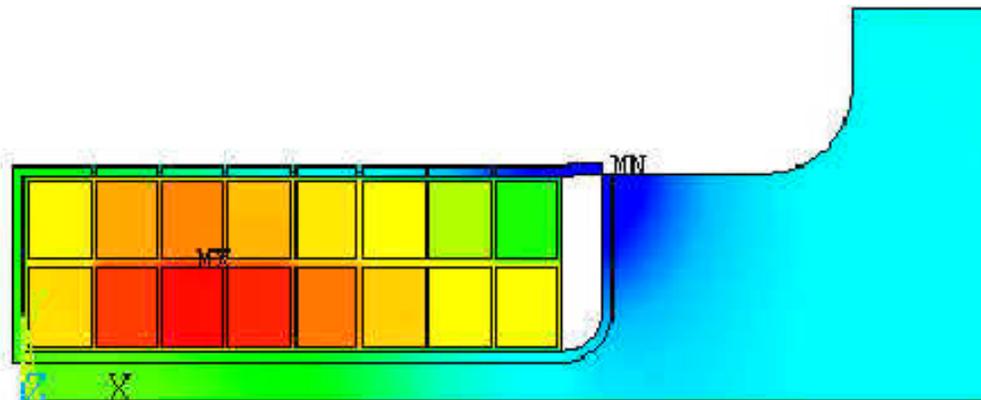
```

80
84.74
89.48
94.22
98.96
103.7
108.44
113.18
117.92
122.659

1. At the end of ohmic heating



2. At the end of cooling period



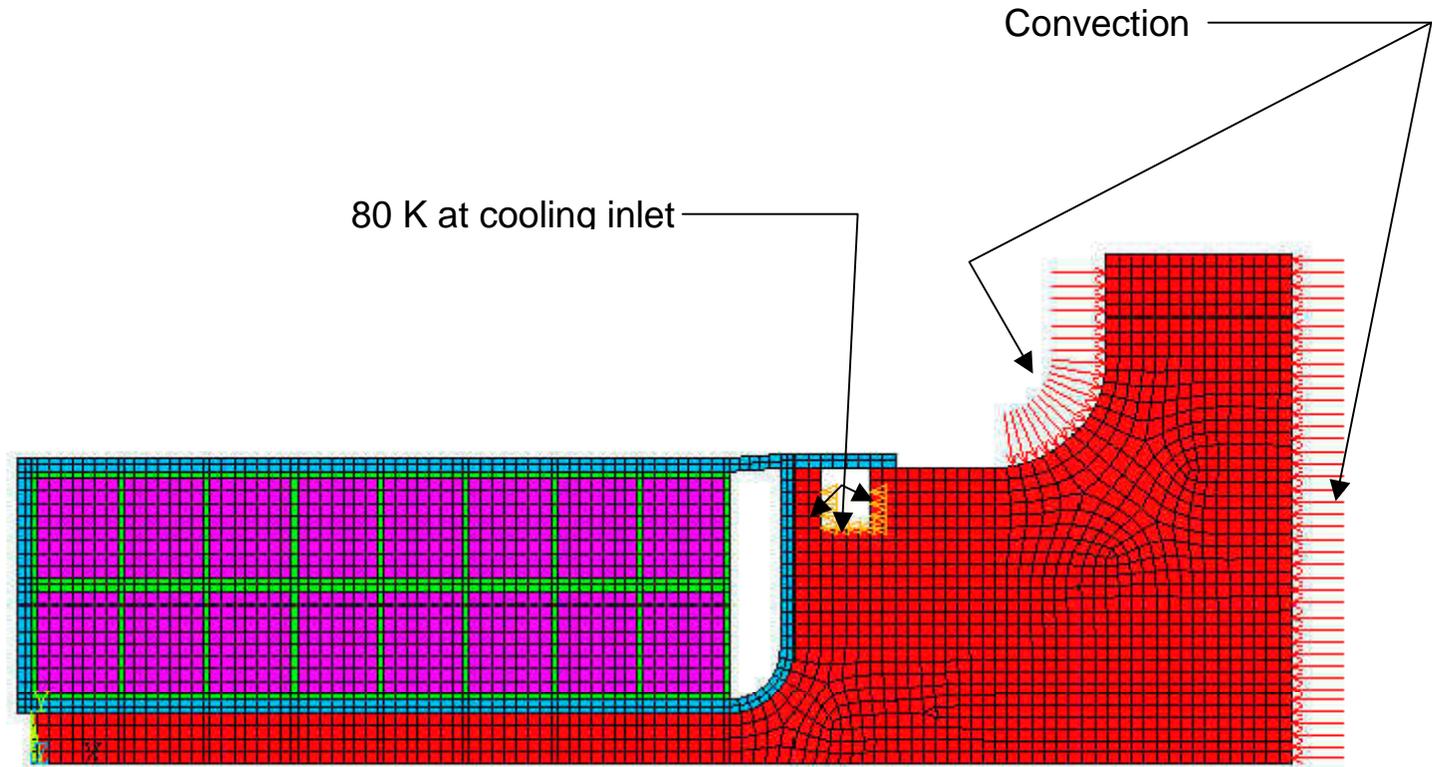
```

ANSYS 5.6.2
NOV 29 2001
14:27:24
NODAL SOLUTION
STEP=70
SUB =4
TIME=9032
TEMP (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
SMN =80
SMX =85.024

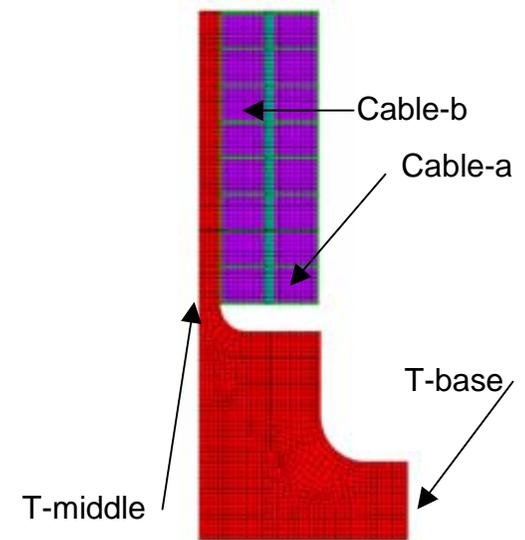
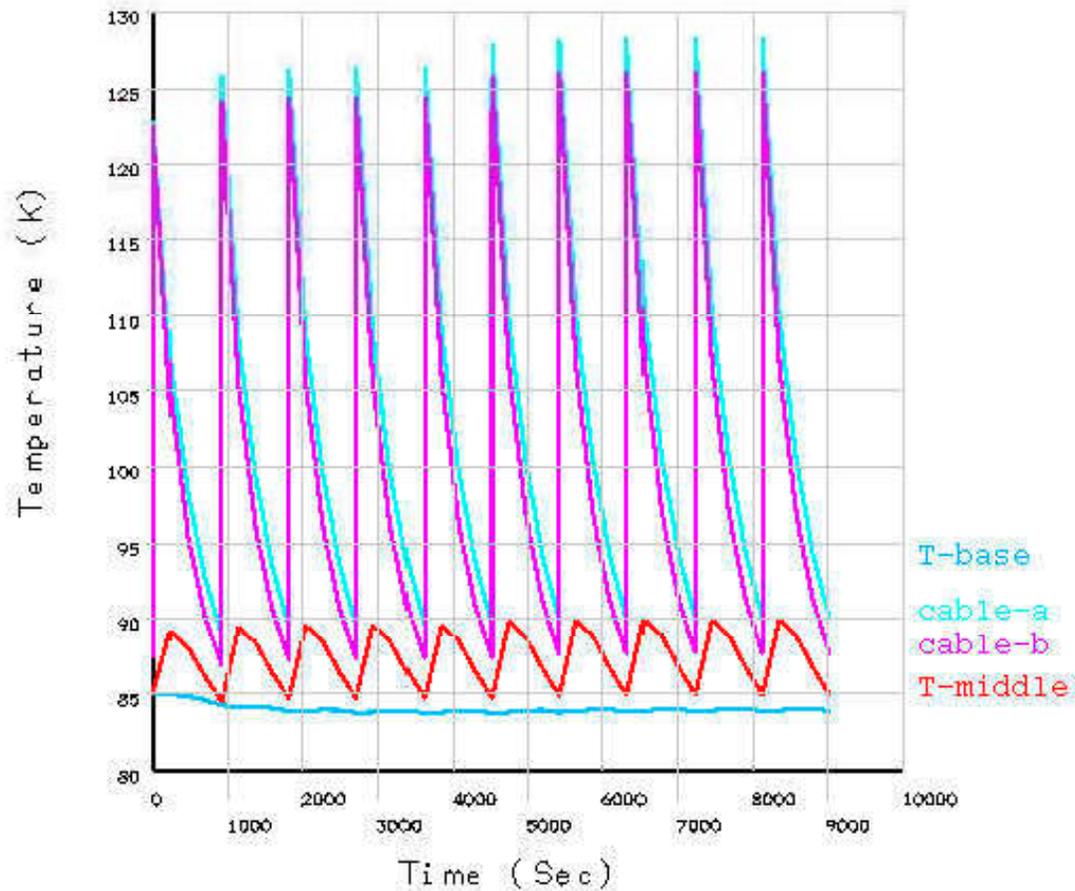
```

80
80.558
81.116
81.675
82.233
82.791
83.349
83.907
84.465
85.024

Cooling Septum Wrapping Around Coils – Model E



Temperature vs. Time on Selected Nodes of Model E



Temperature Distribution at The 10th Heating and Cooling Cycles – Model E

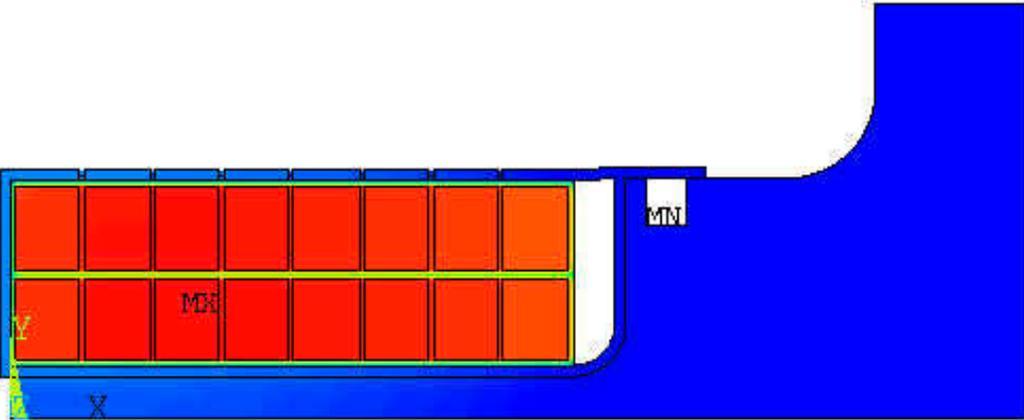
```

ANSYS 5.6.2
NOV 29 2001
18:26:11
NODAL SOLUTION
STEP=69
SUB =3
TIME=8132
TEMP (AVG)
RSYS=0
PowerGraphics
EPACET=1
AVRES=Mat
SMN =80
SMX =128.085

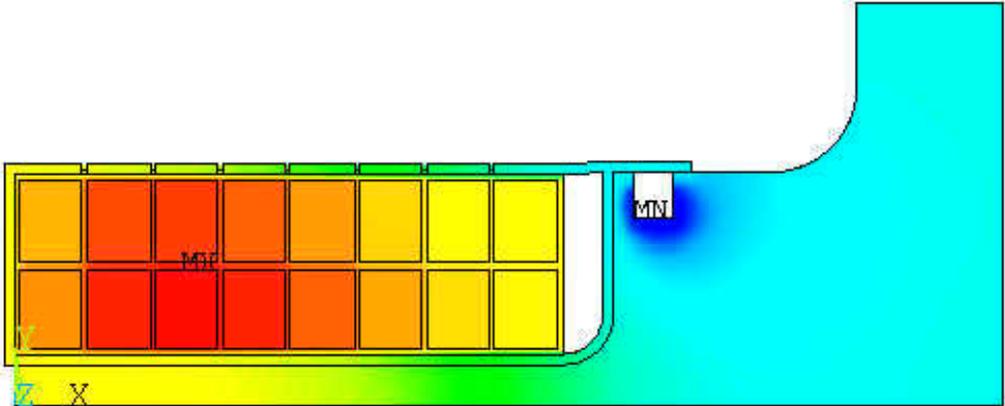
```

80
85.343
90.685
96.028
101.371
106.714
112.056
117.399
122.742
128.085

1. At the end of ohmic heating



2. At the end of cooling period



```

ANSYS 5.6.2
NOV 29 2001
18:24:49
NODAL SOLUTION
STEP=70
SUB =4
TIME=9032
TEMP (AVG)
RSYS=0
PowerGraphics
EPACET=1
AVRES=Mat
SMN =80
SMX =90.048

```

80
81.116
82.233
83.349
84.466
85.582
86.699
87.815
88.931
90.048