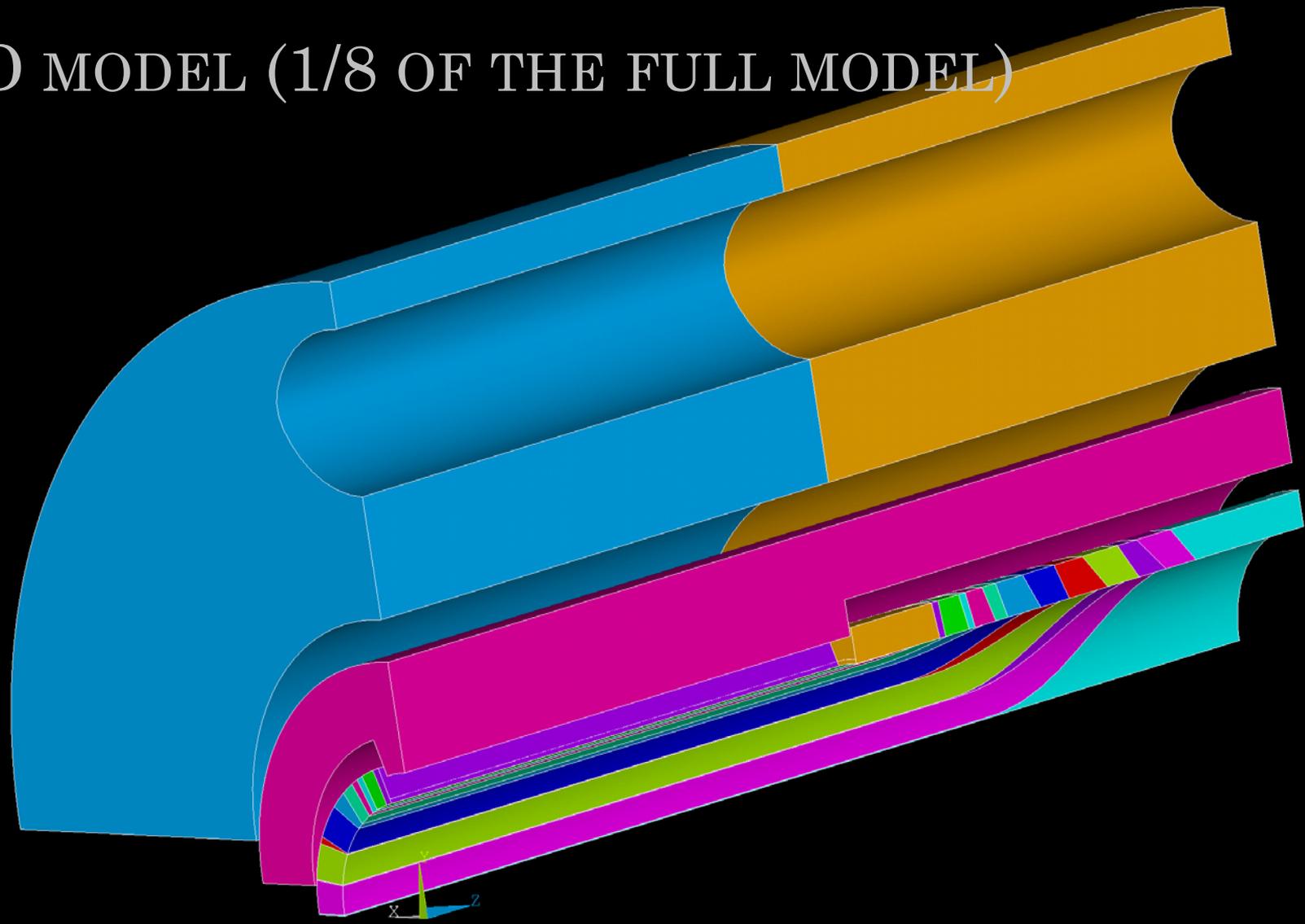


MEETING GSI/INFN

3D Mechanics

Stefania Farinon, November 4th 2009

3D MODEL (1/8 OF THE FULL MODEL)



LOADSTEPS

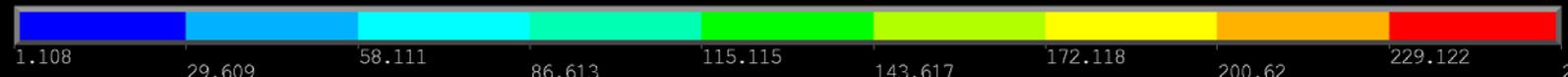
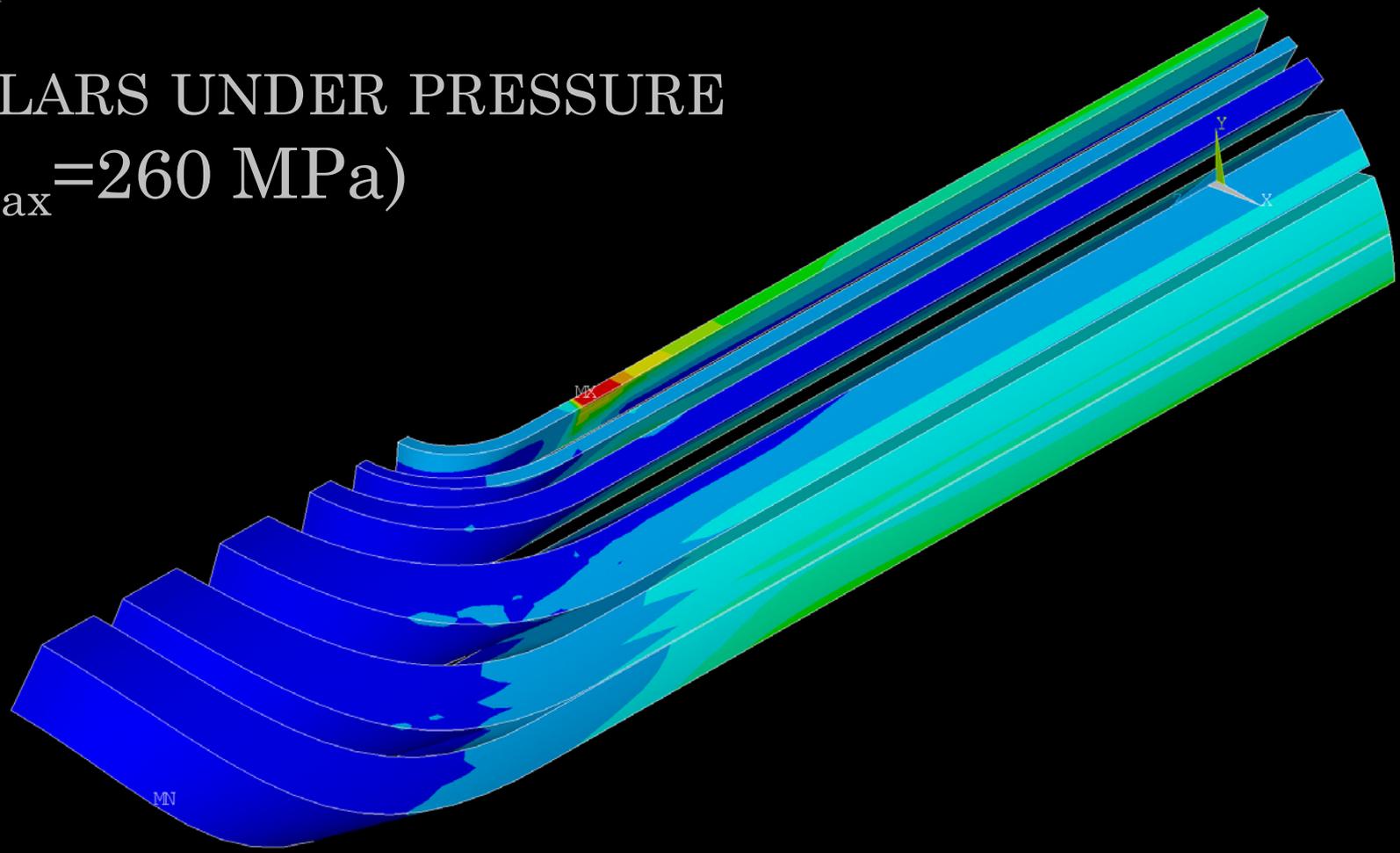
		half Δy between collars (μm)	half Δy between yokes (μm)
1	collars under pressure	0	—
2	collar pressure release	40	—
3	iron yoke under pressure	20	0
4	yoke pressure release	35	200/2
5	cool-down	35	55/2
6	energization	35	40/2

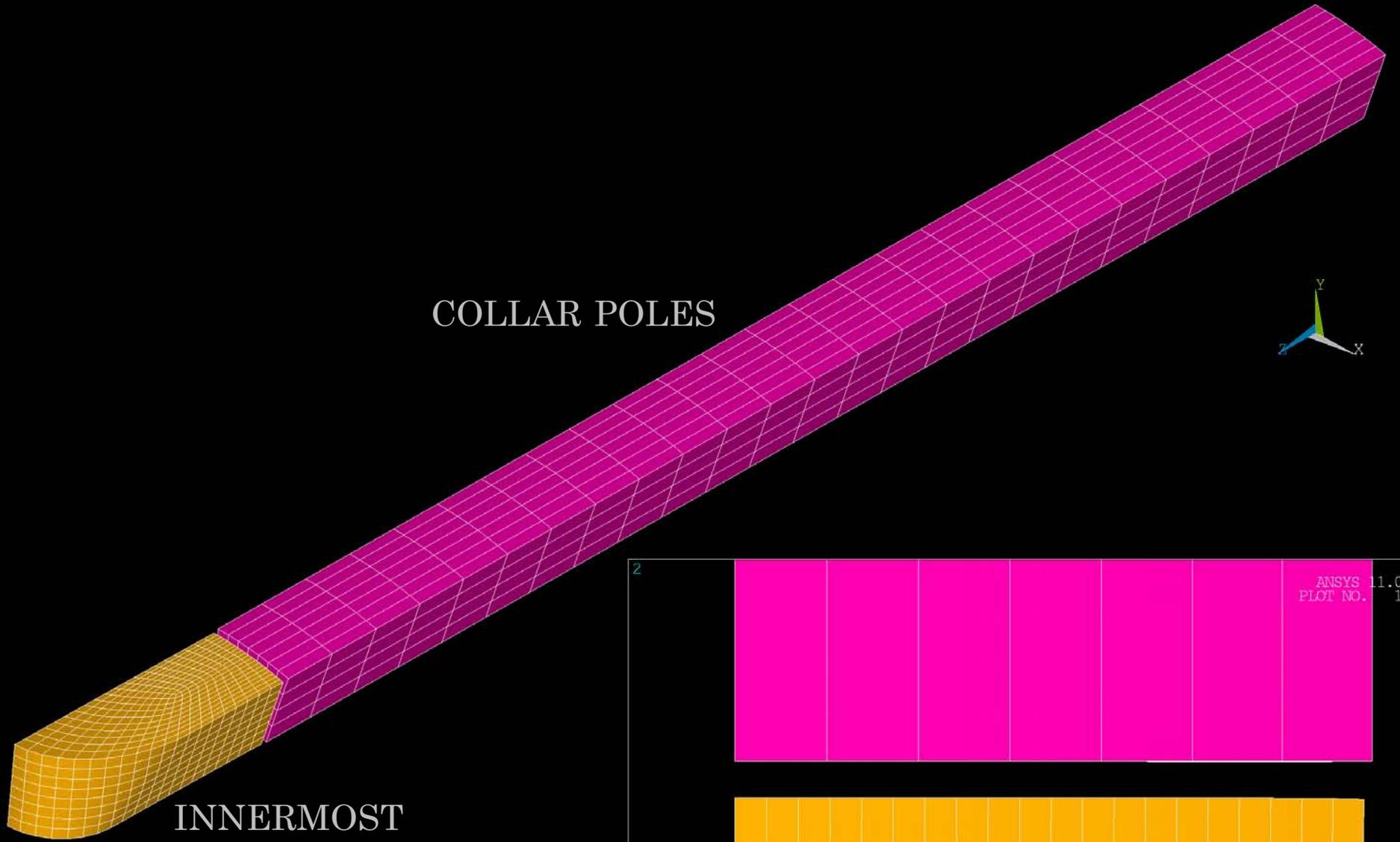
1
NODAL SOLUTION
STEP=4
SUB =6
TIME=4
SEQV (AVG)
DMX =.803948
SMN =1.108
SMX =257.624

ANSYS 11.0
JUL 2 2009
16:45:13
PLOT NO. 1

COLLARS UNDER PRESSURE

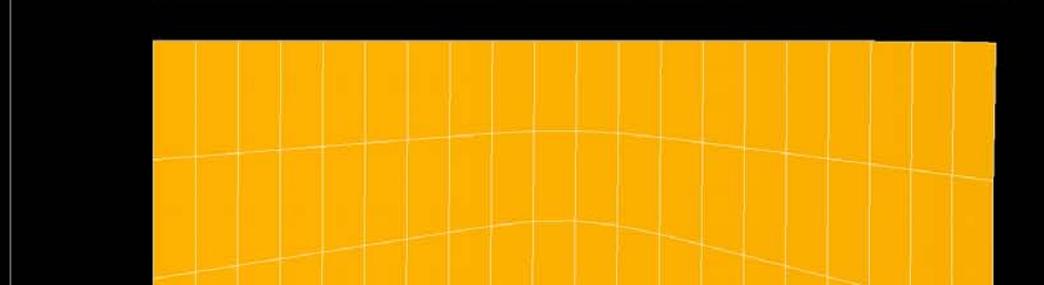
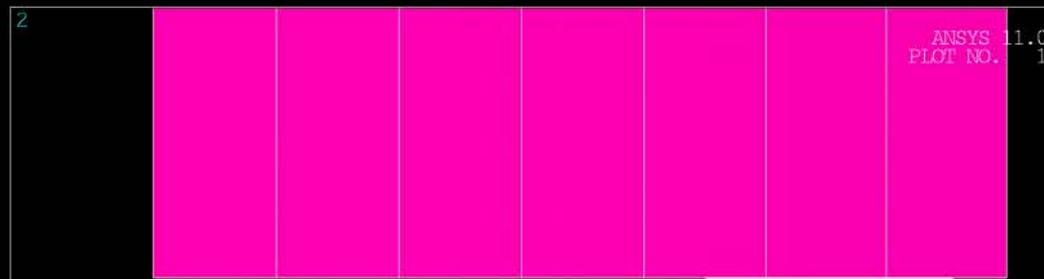
($\sigma_{\max} = 260 \text{ MPa}$)





COLLAR POLES

INNERMOST
END FILLER



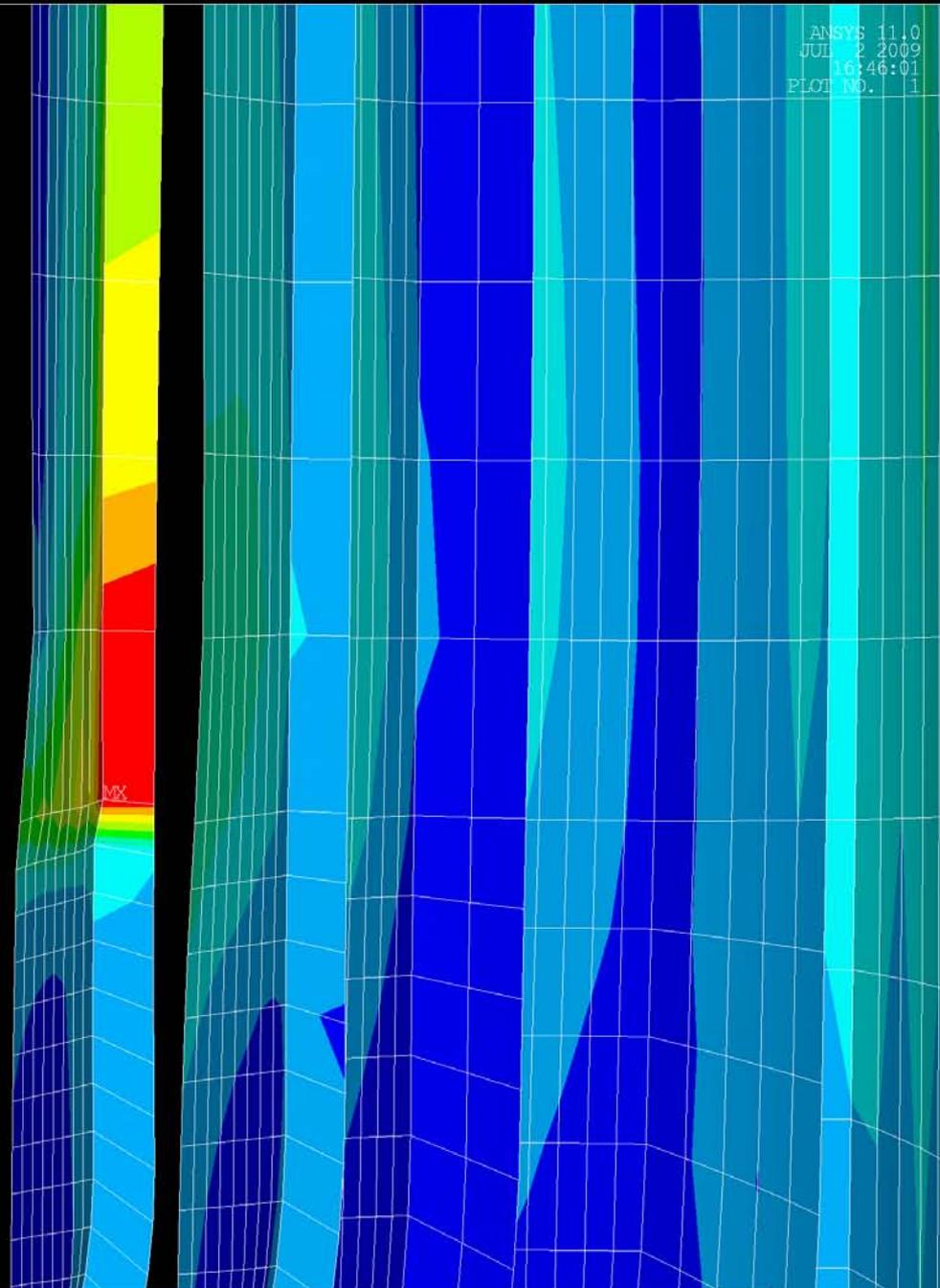
NODAL SOLUTION

STEP=4
SUB =6
TIME=4
SEQV (AVG)
DMX =.803948
SMN =1.108
SMX =257.624

ANSYS 11.0
JUL 2 2009
16:46:01
PLOT NO. 1

COLLARS UNDER PRESSURE

($\sigma_{\max} = 260 \text{ MPa}$,
displacements are 10
times amplified)

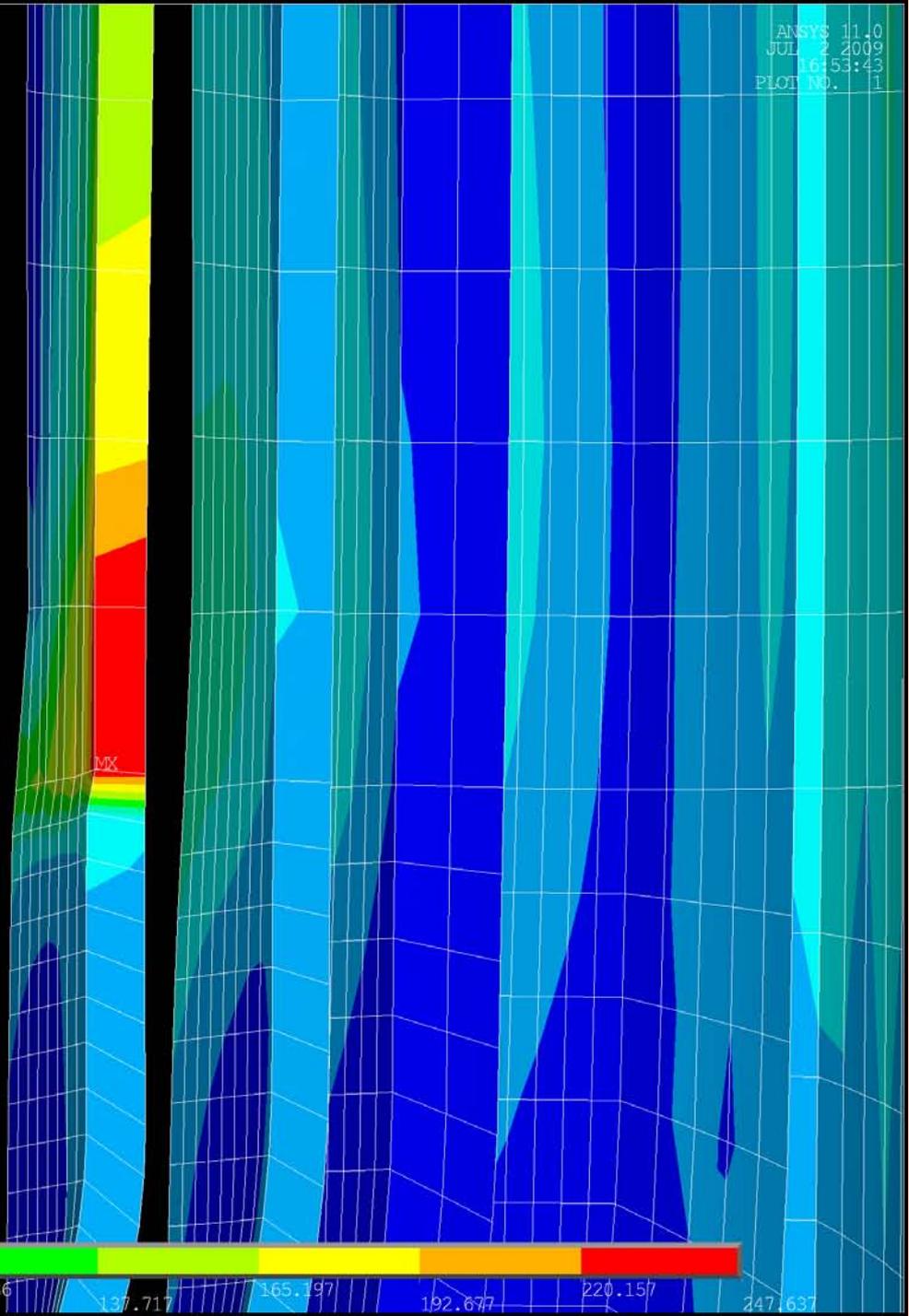


NODAL SOLUTION
STEP=3
SUB =12
TIME=3
SEQV (AVG)
DMX =.80389
SMN =.315434
SMX =247.637

ANSYS 11.0
JUL 2 2009
16:53:43
PLOT NO. 1

COLLAR PRESSURE RELEASE

(σ_{max} = 250 MPa,
displacements are 10
times amplified)



PEAK STRESS IN THE LAST TURN

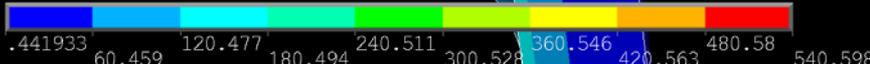
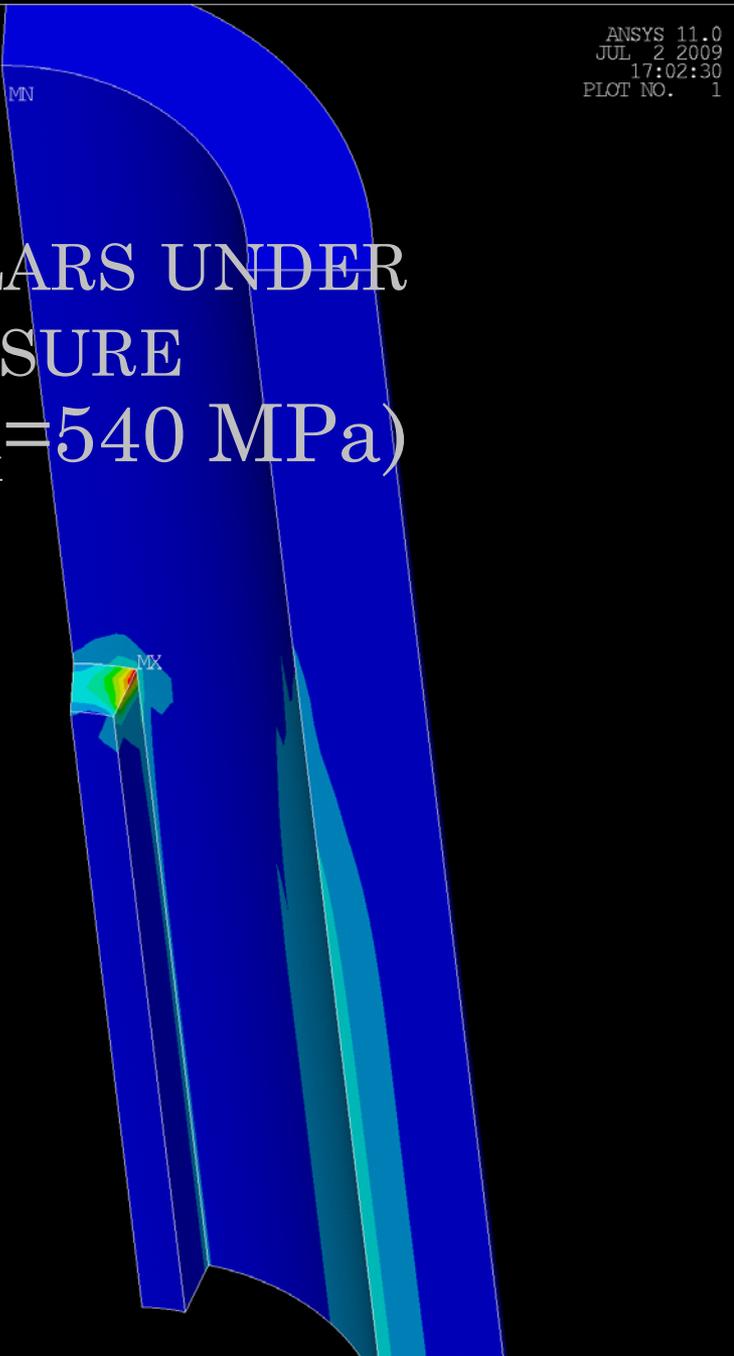
	σ_{\max} (MPa)
collars under pressure	257.6
collar pressure release	247.6
iron yoke under pressure	274.1
yoke pressure release	261.3
cool-down	227.6
energization	168.5

1
NODAL SOLUTION
STEP=4
SUB =6
TIME=4
SEQV (AVG)
DMX =12.001
SMN =.441933
SMX =540.598

ANSYS 11.0
JUL 2 2009
17:02:30
PLOT NO. 1

COLLARS UNDER PRESSURE

($\sigma_{\max} = 540 \text{ MPa}$)

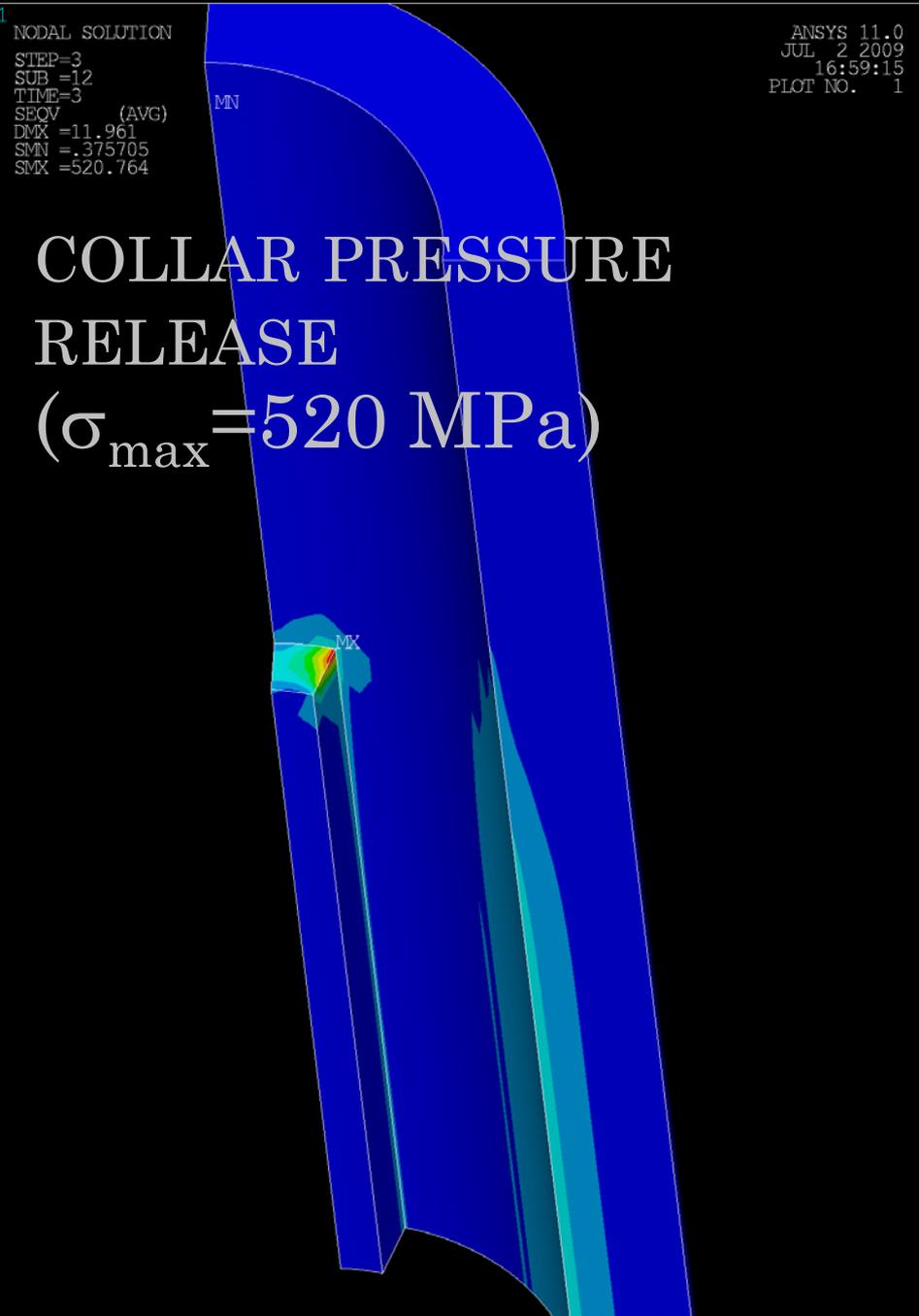


1
NODAL SOLUTION
STEP=3
SUB =12
TIME=3
SEQV (AVG)
DMX =11.961
SMN =.375705
SMX =520.764

ANSYS 11.0
JUL 2 2009
16:59:15
PLOT NO. 1

COLLAR PRESSURE RELEASE

($\sigma_{\max} = 520 \text{ MPa}$)



MIDPLANE AVERAGE STRESSES 3D (2D)

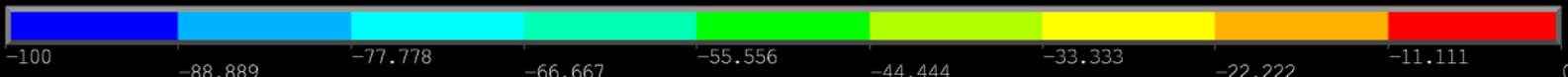
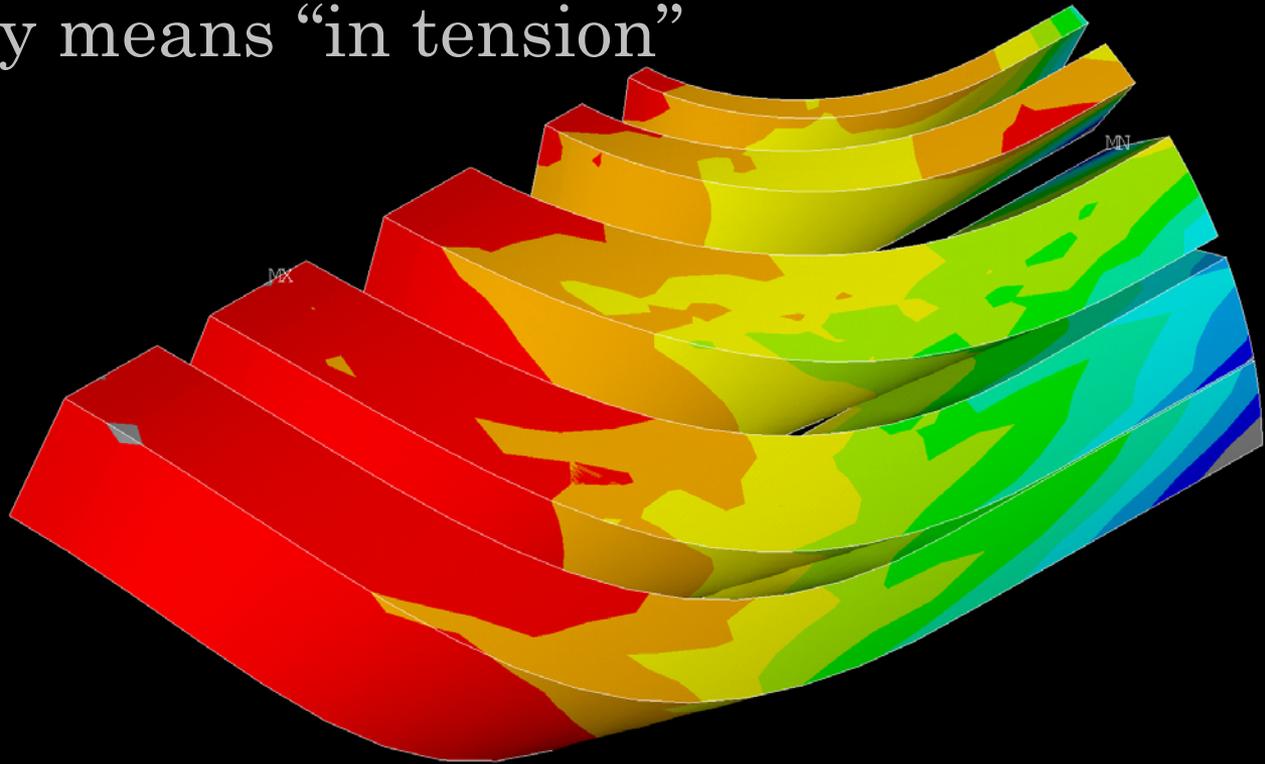
	$\langle \sigma_y \rangle$ (MPa)	$\langle \sigma_{eqv} \rangle$ (MPa)
collars under pressure	-92 (-78)	72 (73)
collar pressure release	-86 (-64)	67 (61)
iron yoke under pressure	-101 (-78)	80 (73)
yoke pressure release	-91 (-68)	72 (64)
cool-down	-53 (-38)	49 (39)
energization	-53 (-43)	47 (42)

1 NODAL SOLUTION
STEP=6
SUB =6
TIME=6
SY (AVG)
RSYS=1
DMX =.455657
SMN =-118.532
SMX =1.447

AZIMUTHAL STRESS ON COIL END BEFORE COOL

ANSYS 11.0
JUL 3 2009
14:10:06
PLOT NO. 1

DOWN
0 (red) → -100 MPa (blue)
grey means "in tension"

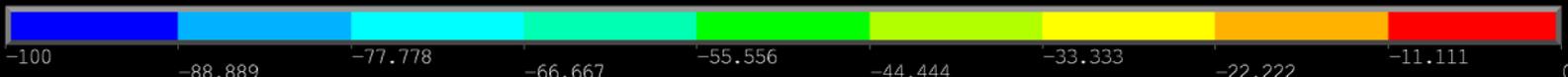
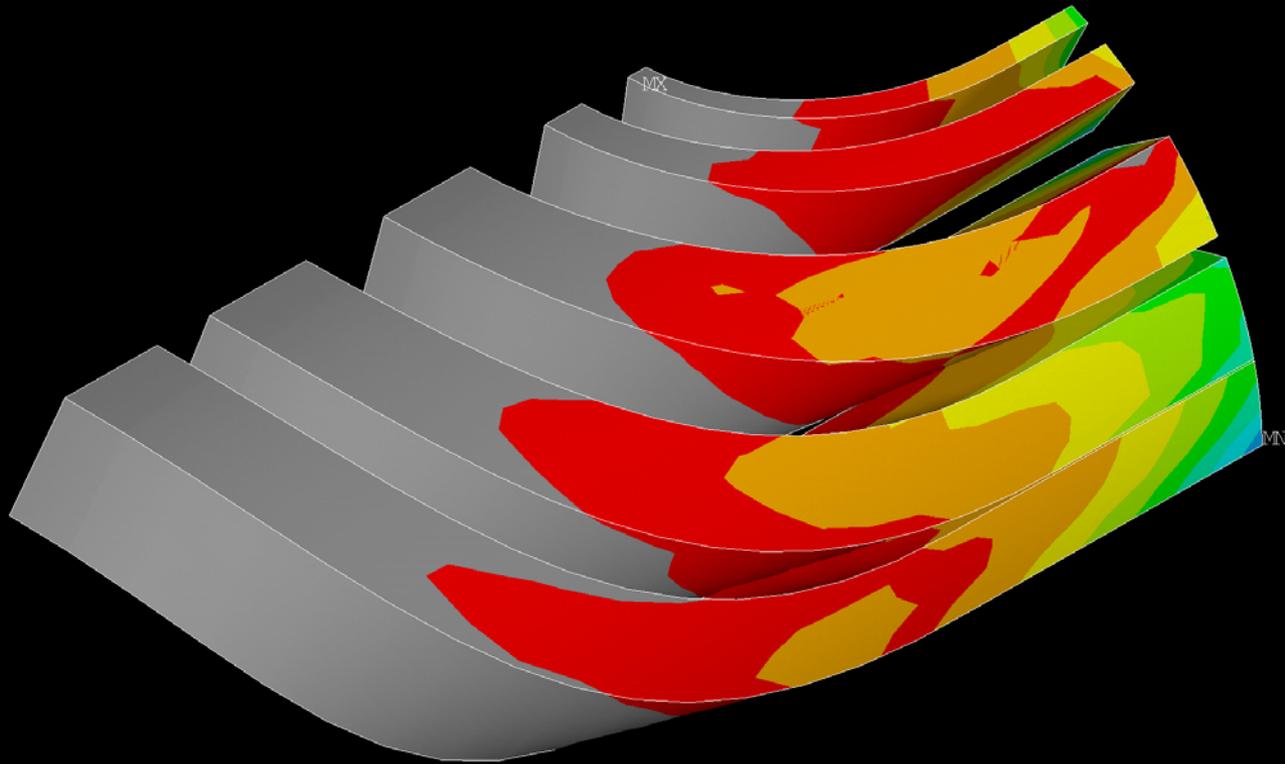


1 NODAL SOLUTION

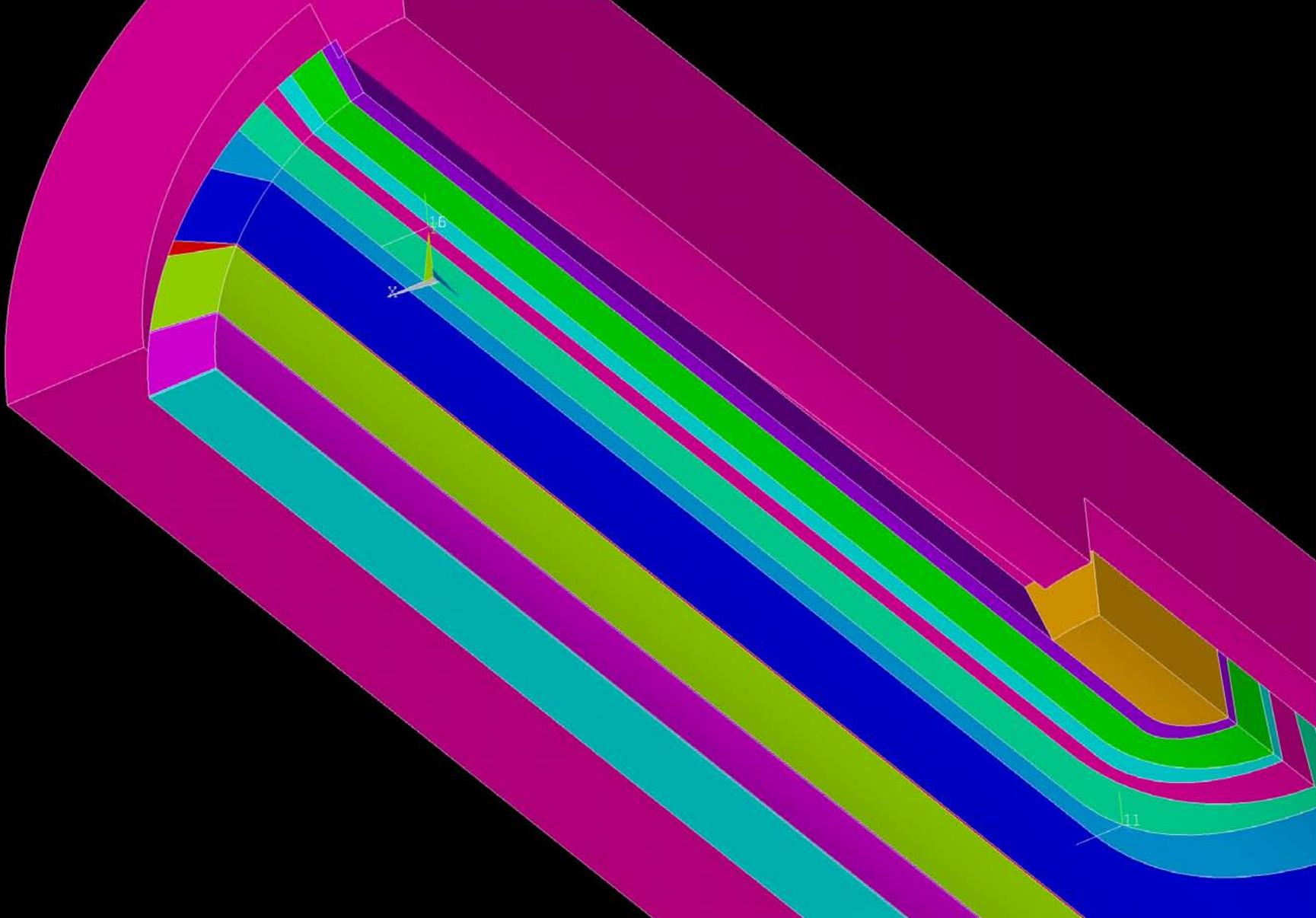
STEP=7
SUB =6
TIME=7
SY (AVG)
RSYS=1
DMX =.986806
SMN =-84.815
SMX =33.571

ANSYS 11.0
JUL 3 2009
14:16:29
PLOT NO. 1

AZIMUTHAL STRESS ON COIL END AFTER COOL DOWN (0→-100 MPa)



SOLUTION 1: TAPERING OF THE COLLAR POLE

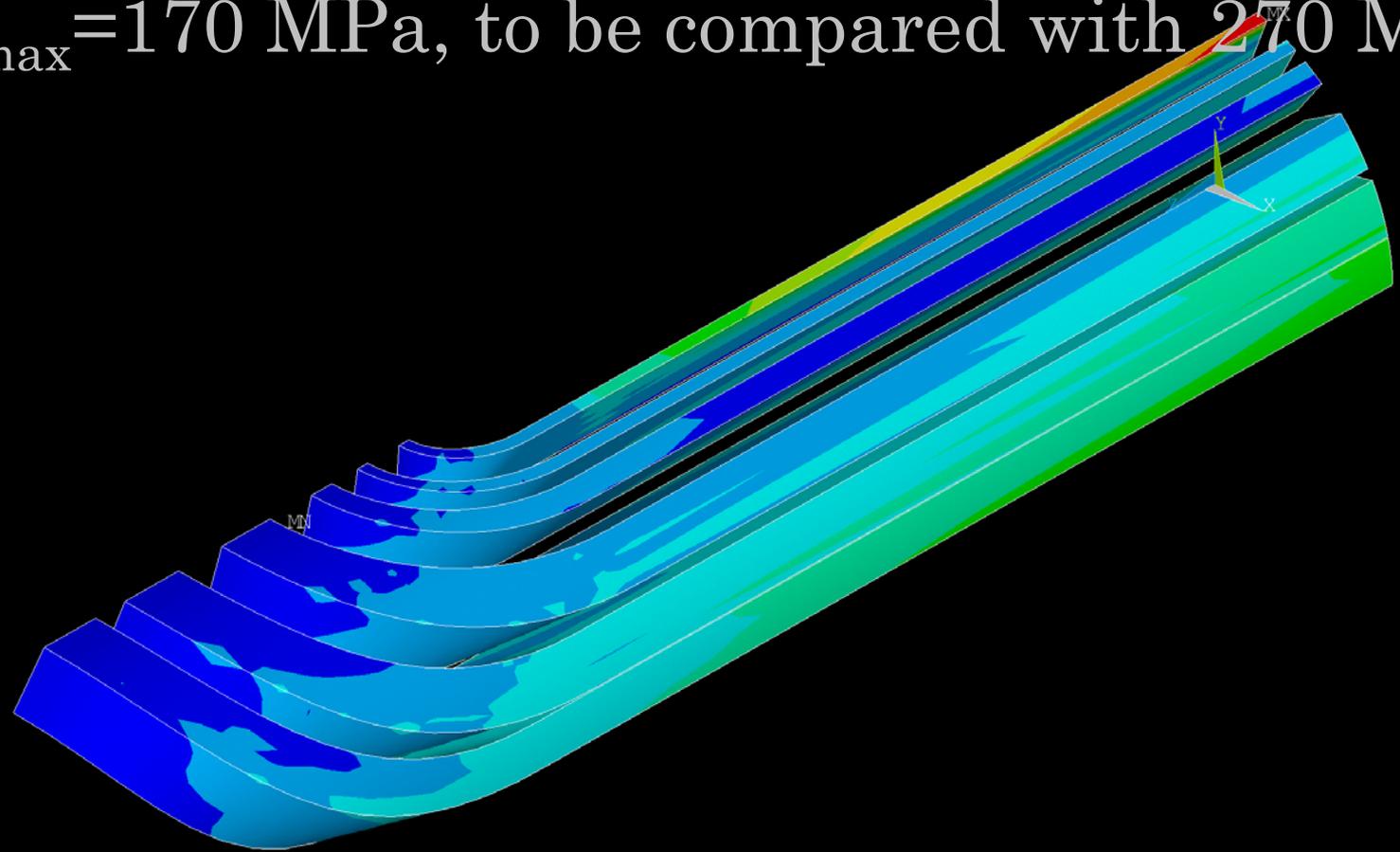


NODAL SOLUTION
STEP=5
SUB =6
TIME=5
SEQV (AVG)
DMX =16.210
SMN =5.174
SMX =172.662

ANSYS 11.0
JUL 3 2009
14:32:17
PLOT NO. 1

AZIMUTHAL STRESS BEFORE COOL DOWN WITH TAPERED COLLAR POLE

(σ_{\max} = 170 MPa, to be compared with 270 MPa)



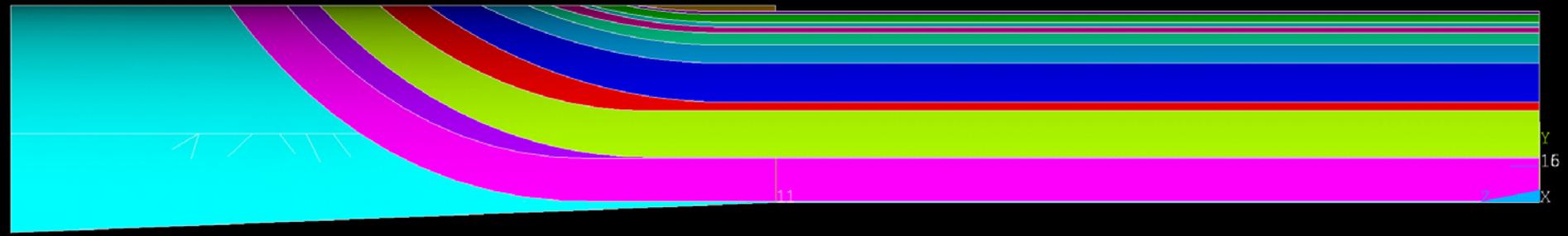
PEAK STRESS IN THE LAST TURN

	σ_{\max} (MPa) normal collar pole	σ_{\max} (MPa) tapered collar pole
collars under pressure	257.6	166.8
collar pressure release	247.6	162.4
iron yoke under pressure	274.1	172.6
yoke pressure release	261.3	169.0
cool-down	227.6	160.6
energization	168.5	83.8

MIDPLANE AVERAGE STRESSES 3D (2D) WITH TAPERED COLLAR POLE

	$\langle \sigma_y \rangle$ (MPa)	$\langle \sigma_{eqv} \rangle$ (MPa)
collars under pressure	-78 (-78)	62 (73)
collar pressure release	-72 (-64)	58 (61)
iron yoke under pressure	-86 (-78)	69 (73)
yoke pressure release	-77 (-68)	62 (64)
cool-down	-41 (-38)	41 (39)
energization	-41 (-43)	39 (42)

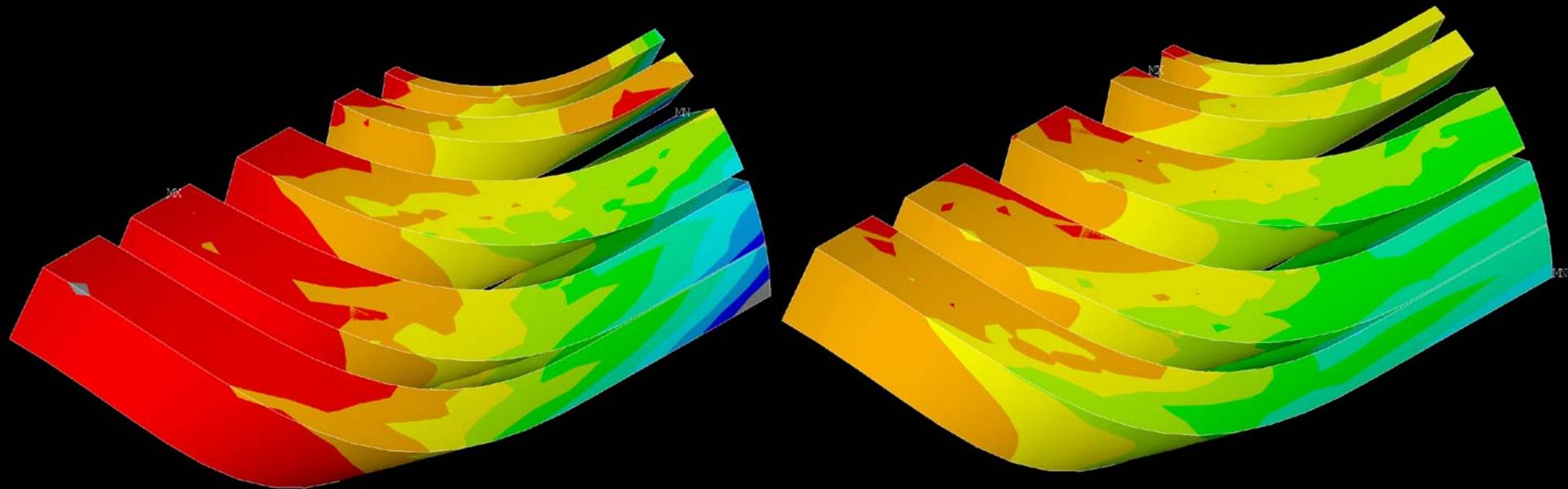
SOLUTION 2: MIDPLANE TAPERED SHIM



AZIMUTHAL STRESS BEFORE COOL DOWN (0 → -100 MPa)

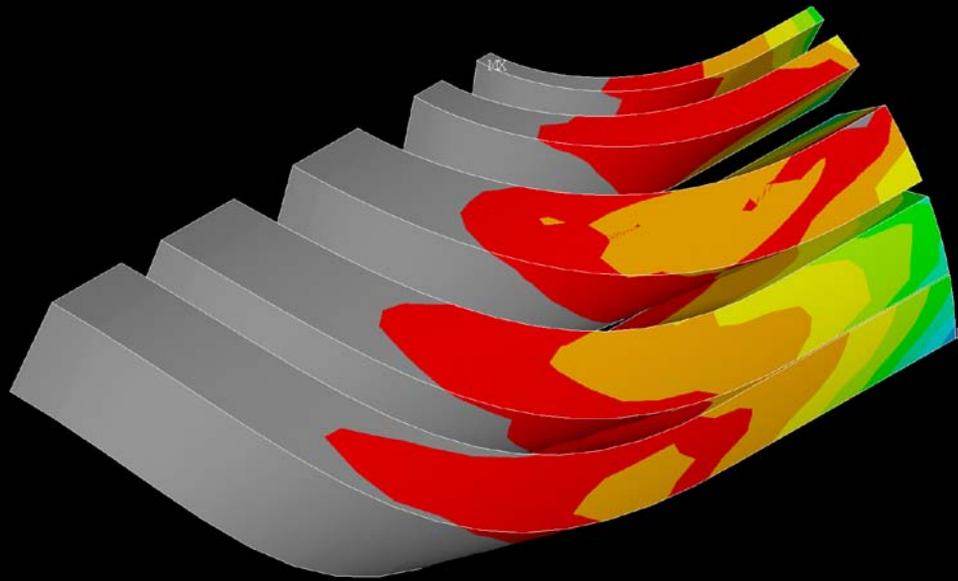
NO MIDPLANE TAPERED SHIM

WITH MIDPLANE TAPERED SHIM

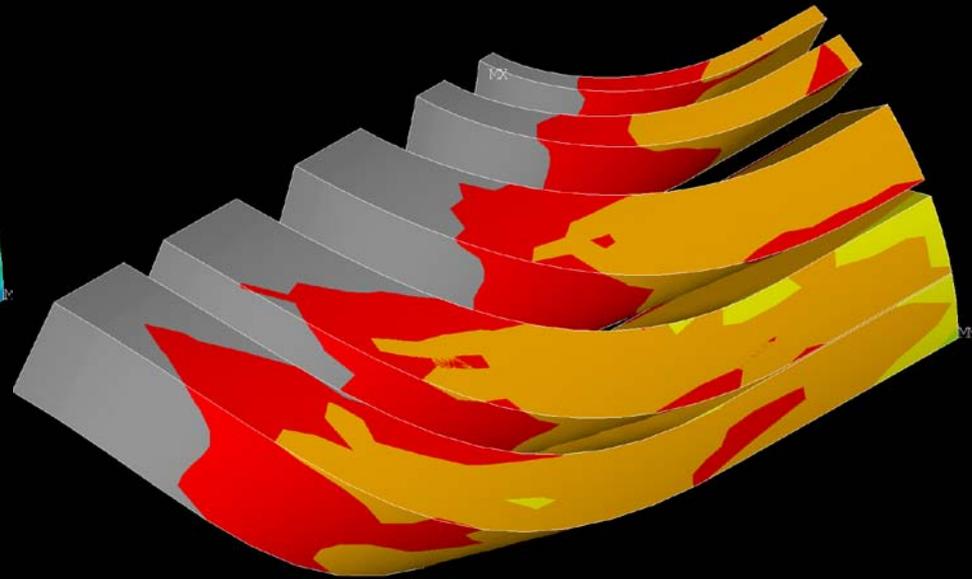


AZIMUTHAL STRESS AFTER COOL DOWN (0 → -100 MPa)

NO MIDPLANE TAPERED SHIM

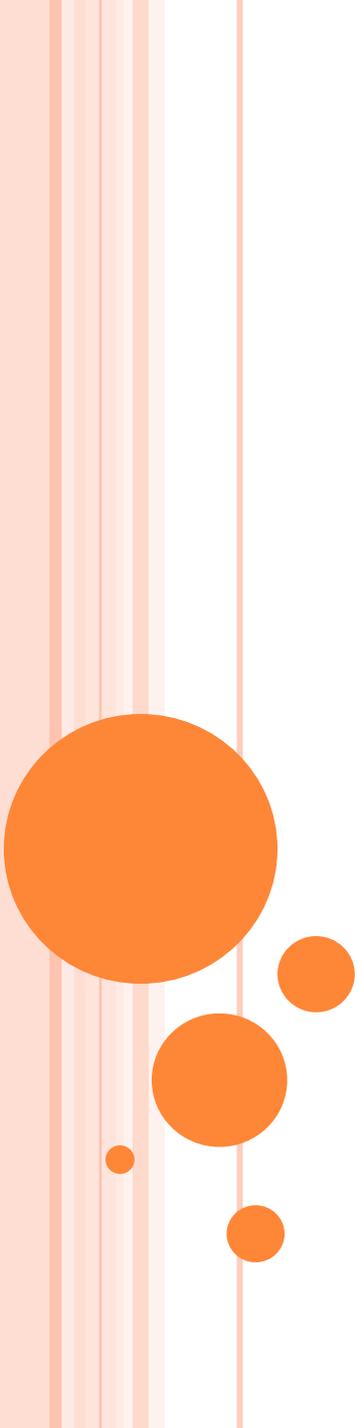


NO MIDPLANE TAPERED SHIM



LONGITUDINAL LENGTHENING OF WINDING

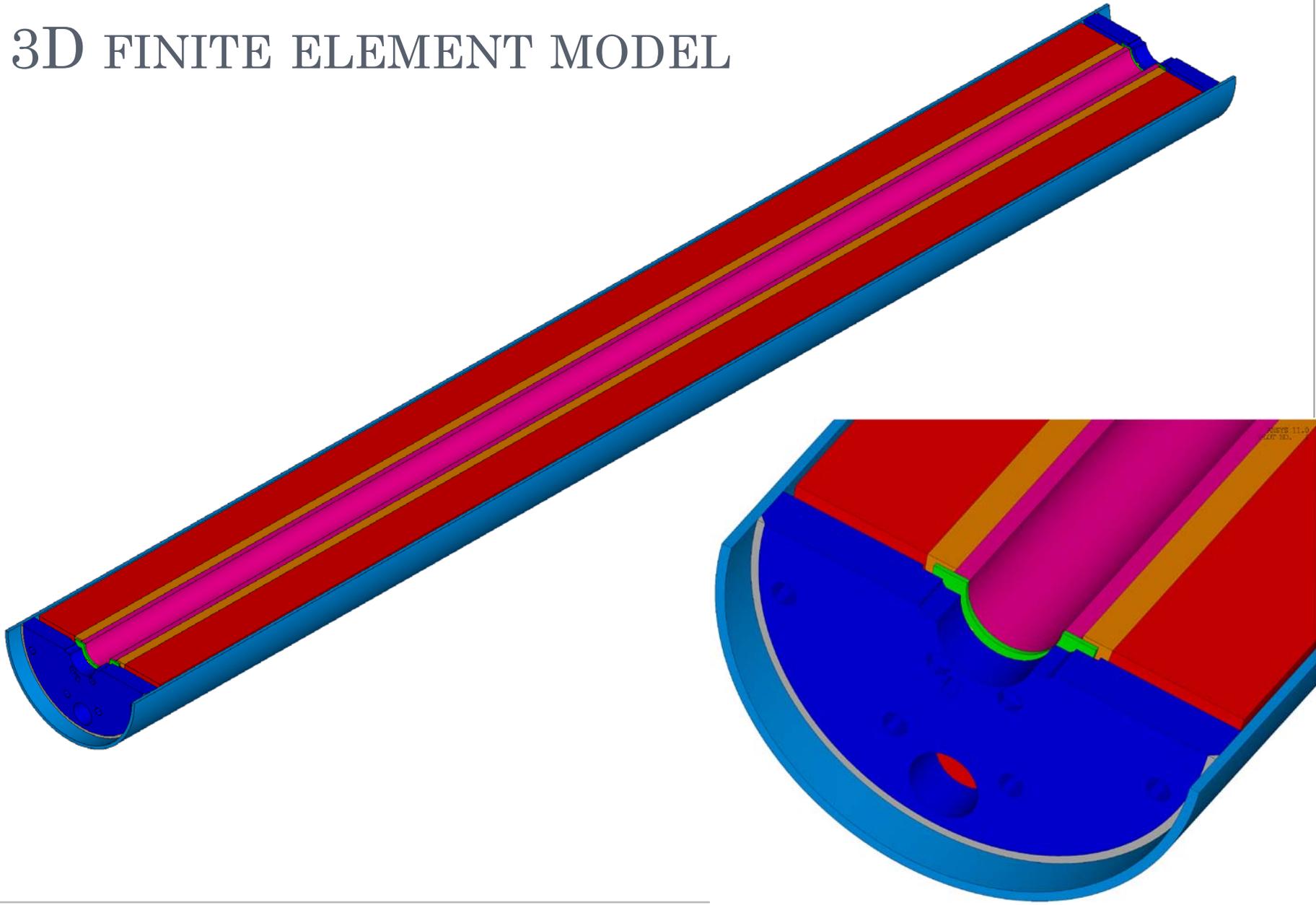
	$\mu_r = 0.5$ (mm)	$\mu_r = 0.1$ (mm)
collars under pressure	+0.19	+0.28
collar pressure release	+0.18	+0.26
iron yoke under pressure	+0.27	+0.38
yoke pressure release	+0.24	+0.32
cool-down	-1.13	-1.21
energization	-1.07	-1.02
	} $\Delta L=0.06$	} $\Delta L=0.19$



EFFECT OF LONGITUDINAL PRE- STRESS ON FLANGE AND OUTER SHELL

Stefania Farinon, November 4th 2009

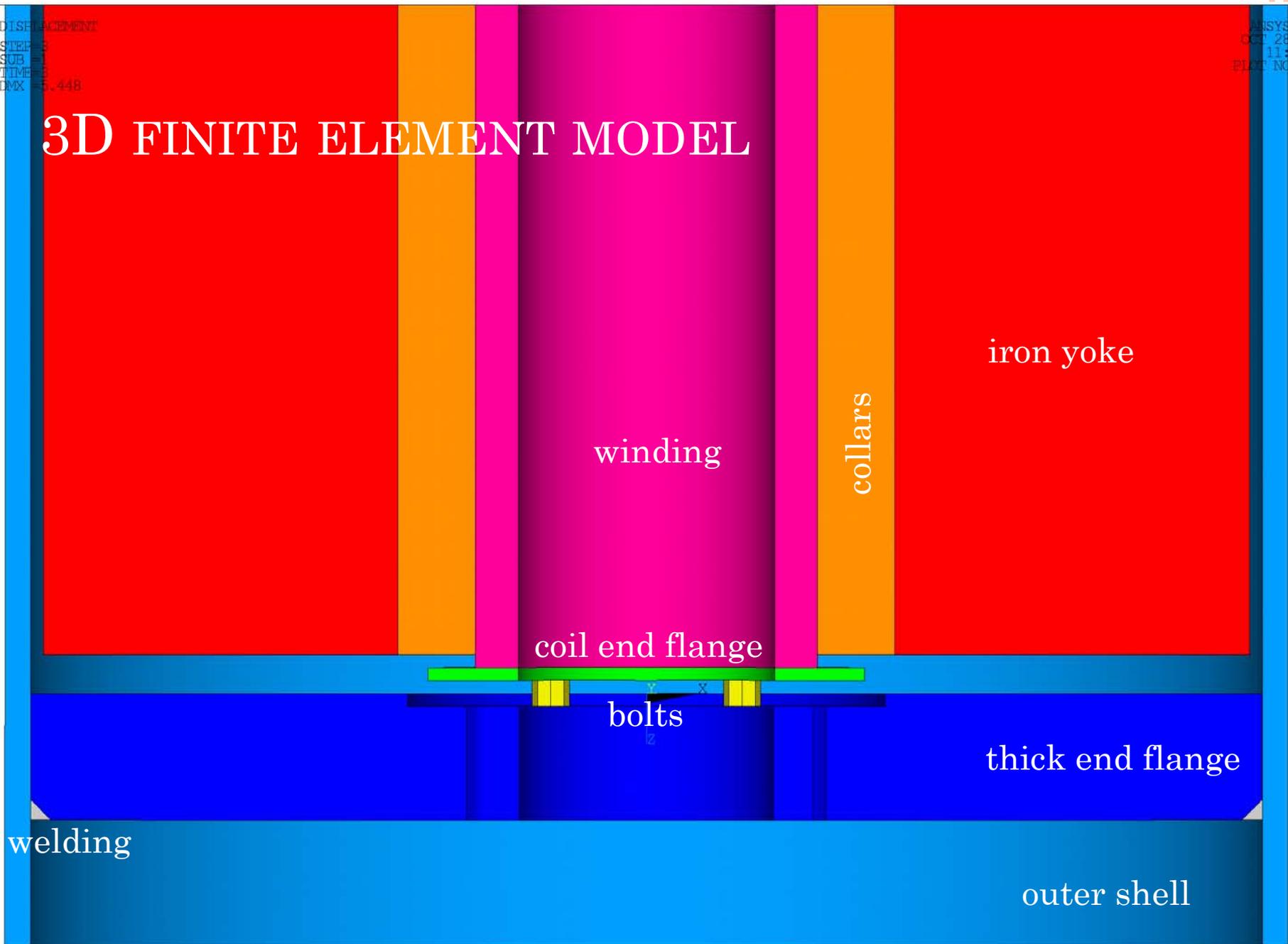
3D FINITE ELEMENT MODEL



DISPLACEMENT
STEP = 3
SUB = 1
TIME = 0
DMX = 5.448

ANSYS 11.0
OCT 28 2009
11:36:20
PLIST NO. 1

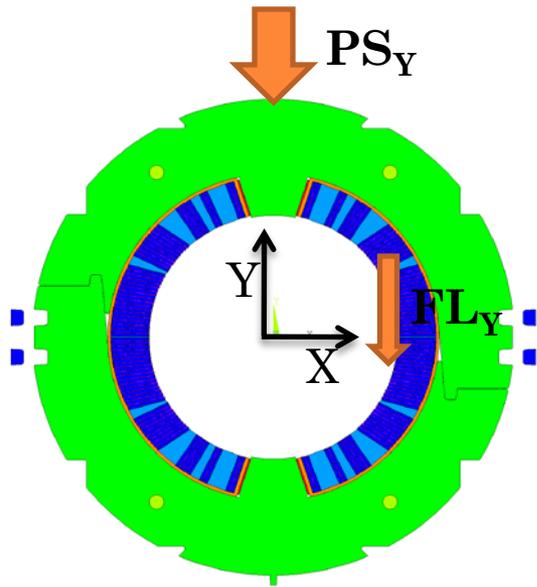
3D FINITE ELEMENT MODEL



WHAT'S THE USE OF PRE-STRESS?

- Pre-stress loads in compression the coil ends, to avoid that they could be loaded in traction once the magnet has been energized
- It is crucial to understand which fraction of the Lorentz forces we have to face

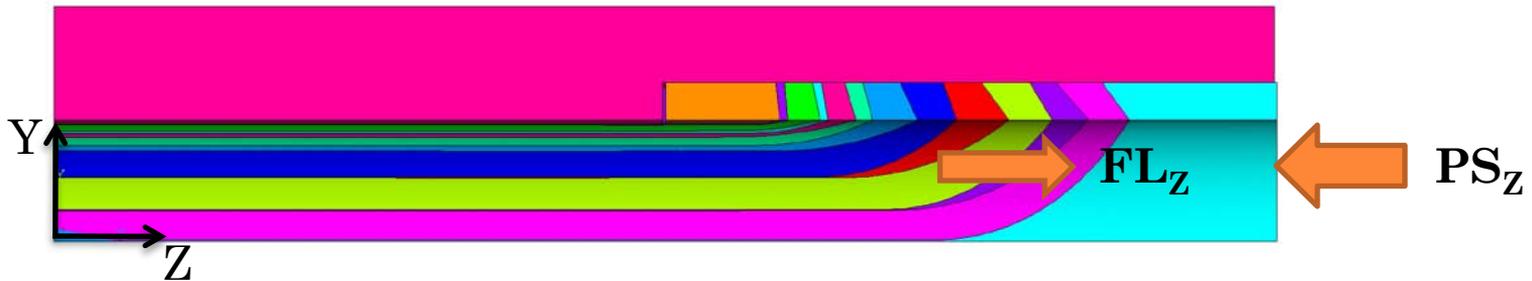
AXIAL AND LONGITUDINAL PRE-STRESS



$$PS_Y > FL_Y$$

no Y displacement of winding

FL_Y partially replaces PS_Y

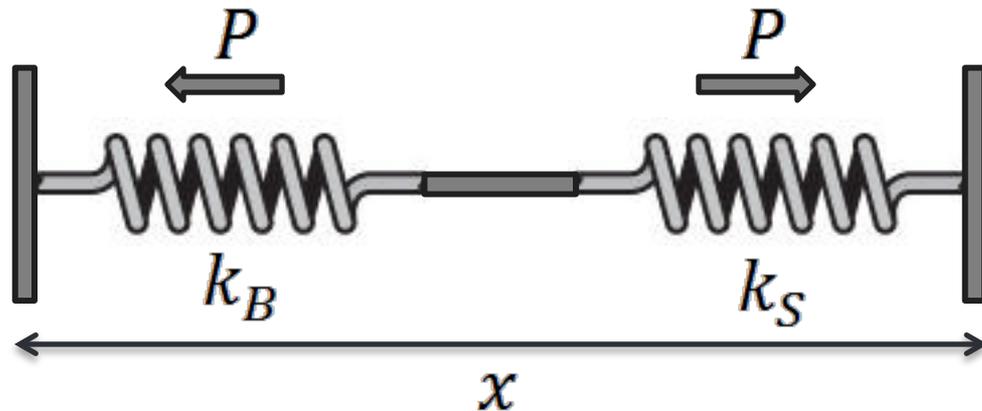


$$PS_Z > \text{effective } FL_Z$$

PS_Z impose Z displacement to winding

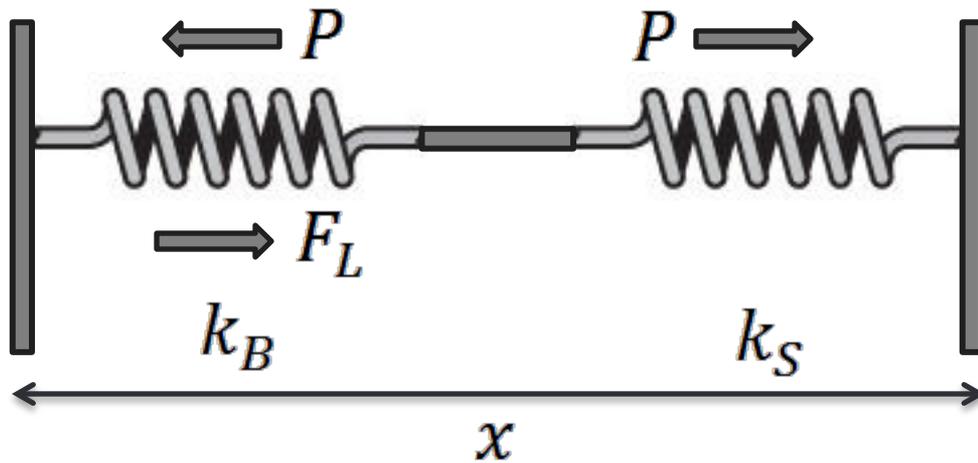
Applied UZ partially recovered by active FL_Z

LOADING OF PRE-STRESS



$$\begin{cases} P = k_B x_B = k_S x_S \\ x = x_B + x_S \end{cases} \quad \Rightarrow \quad P = \frac{k_B k_S}{k_B + k_S} x$$

MAGNET ENERGIZATION



- only a fraction of the Lorentz forces contributes to the stress on the outer shell and flange
- this expression is valid for a concentrated force

$$\begin{cases} T - F_L = k_B x_B \\ T = k_S x_S \\ x = x_B + x_S \end{cases}$$

$$x = x_B + x_S = \frac{T - F_L}{k_B} + \frac{T}{k_S} = \frac{k_B + k_S}{k_B k_S} P$$

$$\Rightarrow T = \frac{k_S}{k_B + k_S} F_L + P$$

DISTRIBUTED FORCE

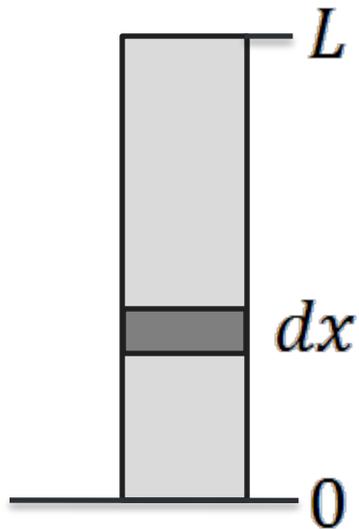
elongation of infinitesimal dx is:

$$d(\Delta x) = \frac{F_{dx}}{K_{dx}} = \frac{\int_x^L \frac{F}{L} dx}{\frac{L}{dx} K}$$

$$\Delta x = \int_0^L \left(\frac{1}{LK} \int_x^L \frac{F}{L} dx \right) dx$$

$$= \int_0^L \frac{F}{KL^2} (L - x) dx$$

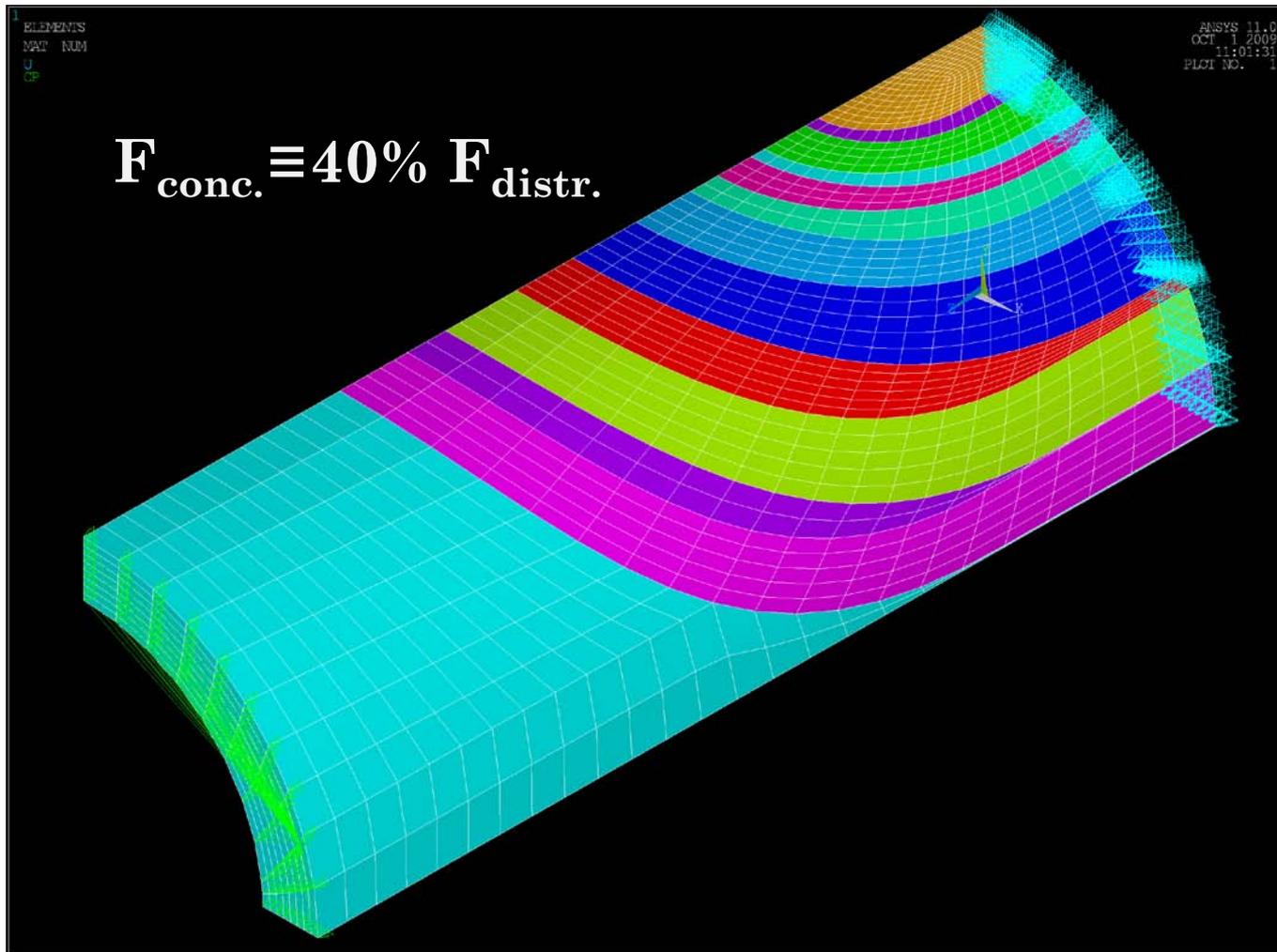

$$\Delta x = \frac{F}{2K}$$



total distributed force: F

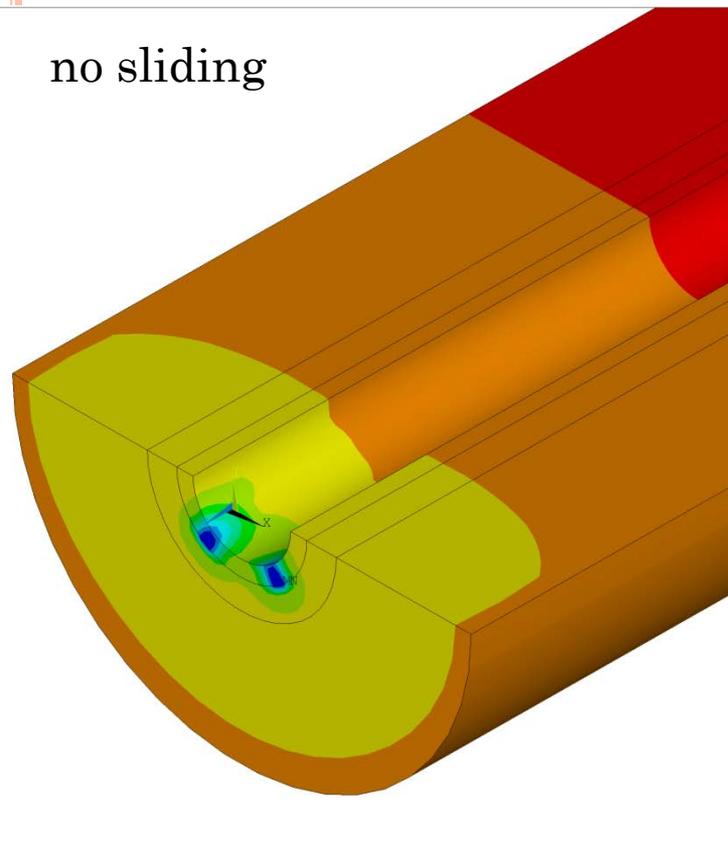
total elastic constant: K

REAL DISTRIBUTION



LONGITUDINAL DISPLACEMENTS

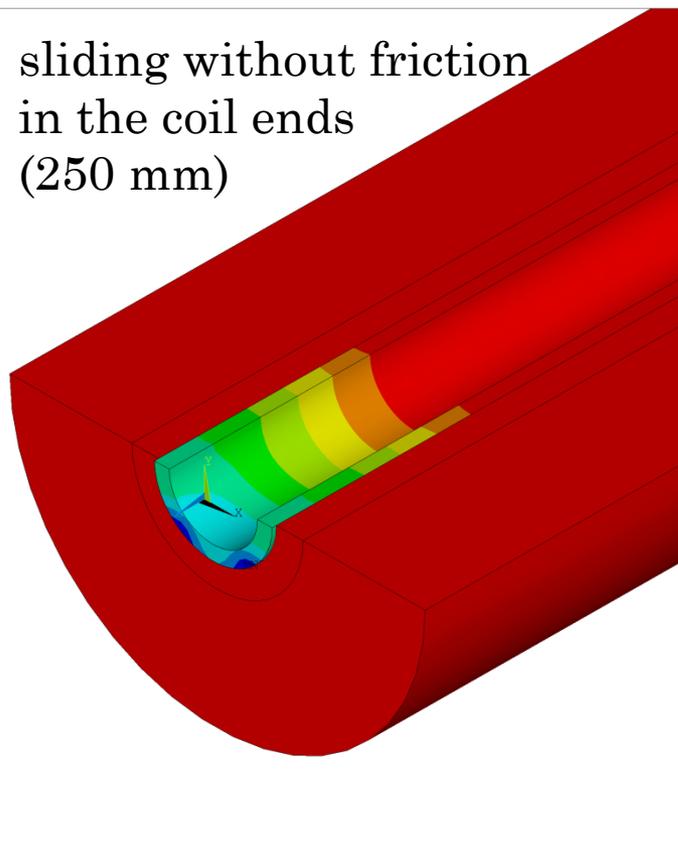
no sliding



```
ANSYS 11.0
OCT 28 2009
14:47:00
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.102347
SMN =-.102021
SMX =-.071415
-.102021
-.09862
-.09522
-.091819
-.088418
-.085018
-.081617
-.078216
-.074816
-.071415
```

effective $FL_z=7.3$ kN

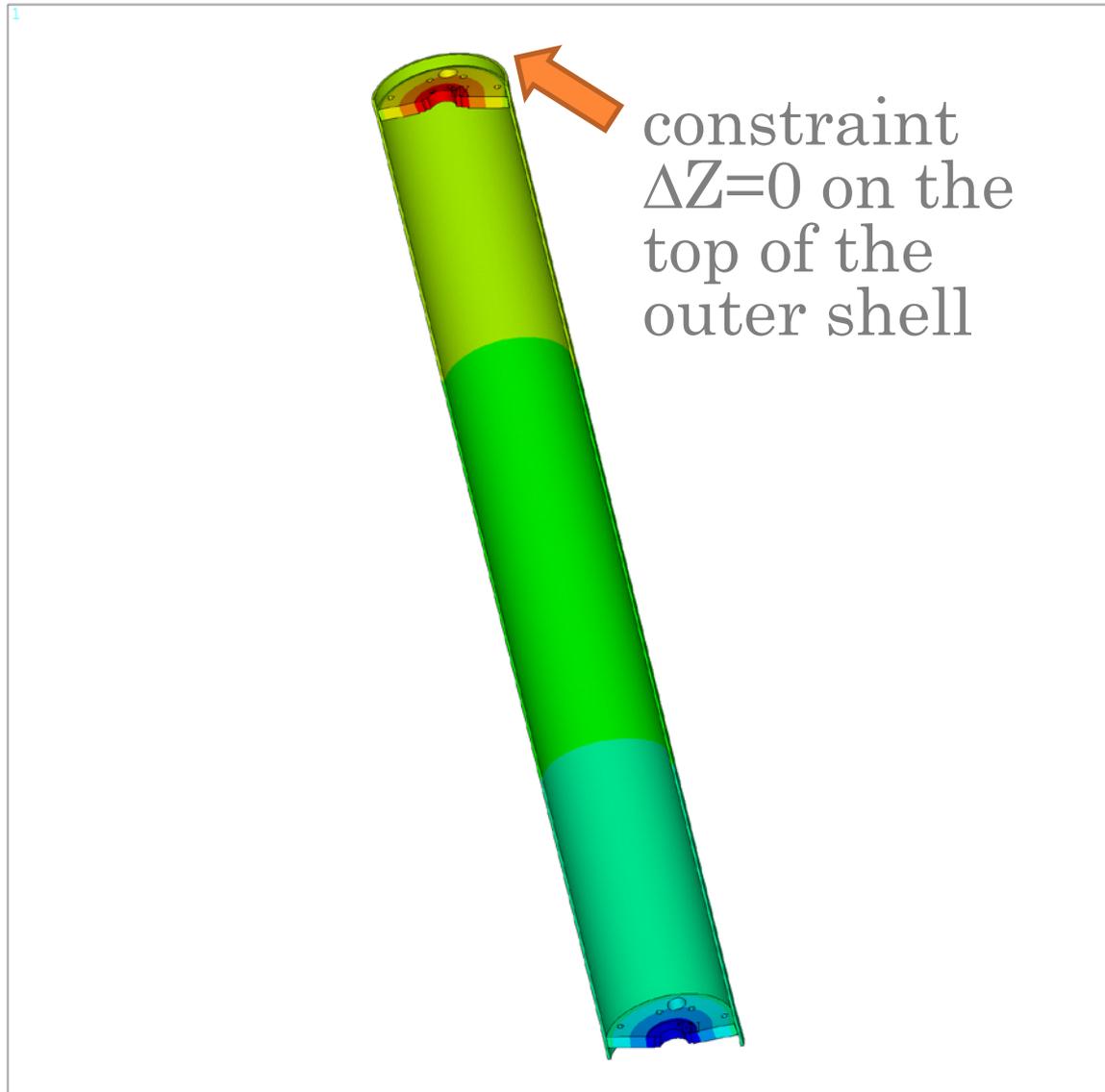
sliding without friction
in the coil ends
(250 mm)



```
ANSYS 11.0
OCT 28 2009
14:50:34
PLOT NO. 1
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
UZ (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.657372
SMN =-.657074
SMX =-.080749
-.657074
-.593038
-.529002
-.464966
-.40093
-.336894
-.272857
-.208821
-.144785
-.080749
```

effective $FL_z=28.9$ kN

EFFECT OF GRAVITY DURING TEST AT LASA



```
ANSYS 11.0  
OCT 29 2009  
16:03:28  
PLOT NO. 1  
NODAL SOLUTION  
STEP=1  
SUB =1  
TIME=1  
UZ (AVG)  
RSYS=0  
PowerGraphics  
EFACET=1  
AVRES=Mat  
DMX =.189839  
SMN =-.189792  
SMX =.112033  
-.189792  
-.156256  
-.12272  
-.089184  
-.055647  
-.022111  
.011425  
.044961  
.078497  
.112033
```

REACTION ON END FLANGES

PESI SIS_300

Descrizione Oggetto	Peso Totale [Kg]
Beam tube	21.2
Avvolgimento superiore	65.0
Avvolgimento inferiore	65.0
Contromassa	7.0
Collar	511.5
Chiavette Collar	4.0
Spine Collar	3.5
Flange di testa collar	5.0
Semigiogo	4280.0
Tubi Gioghi	20.2
Tiranti	29.8
C-clamp Giogo	48.7
Barra d'irrigidimento	26.0
Recooling pipe	14.3
Flangia di testa L.C.	44.7
Flangia di testa L.O.C.	43.9
Guscio Esterno	527.2
Totale	5717

- total weight: 5668 kg
- winding weight: 5050.7 kg

- initial pre-stress:
 - $P_i = 56.2$ kN
- gravity:
 - $P_{up} = 29.4$ kN = $P_i - 54.3\%$ of coil weight
 - $P_{down} = 78.8$ kN = $P_i + 45.7\%$ of coil weight
- Lorentz forces:
 - $T_{up} = 58.3$ kN = $P_{up} + 28.9$ kN
 - $T_{down} = 107.6$ kN = $P_{down} + 28.9$ kN

VON MISES STRESS PRE-STRESS OF 5.6 kN

$\langle \sigma_{\text{eqv}} \rangle = 9 \text{ MPa}$

ANSYS 11.0
OCT 29 2009
16:30:15
PLOT NO. 1

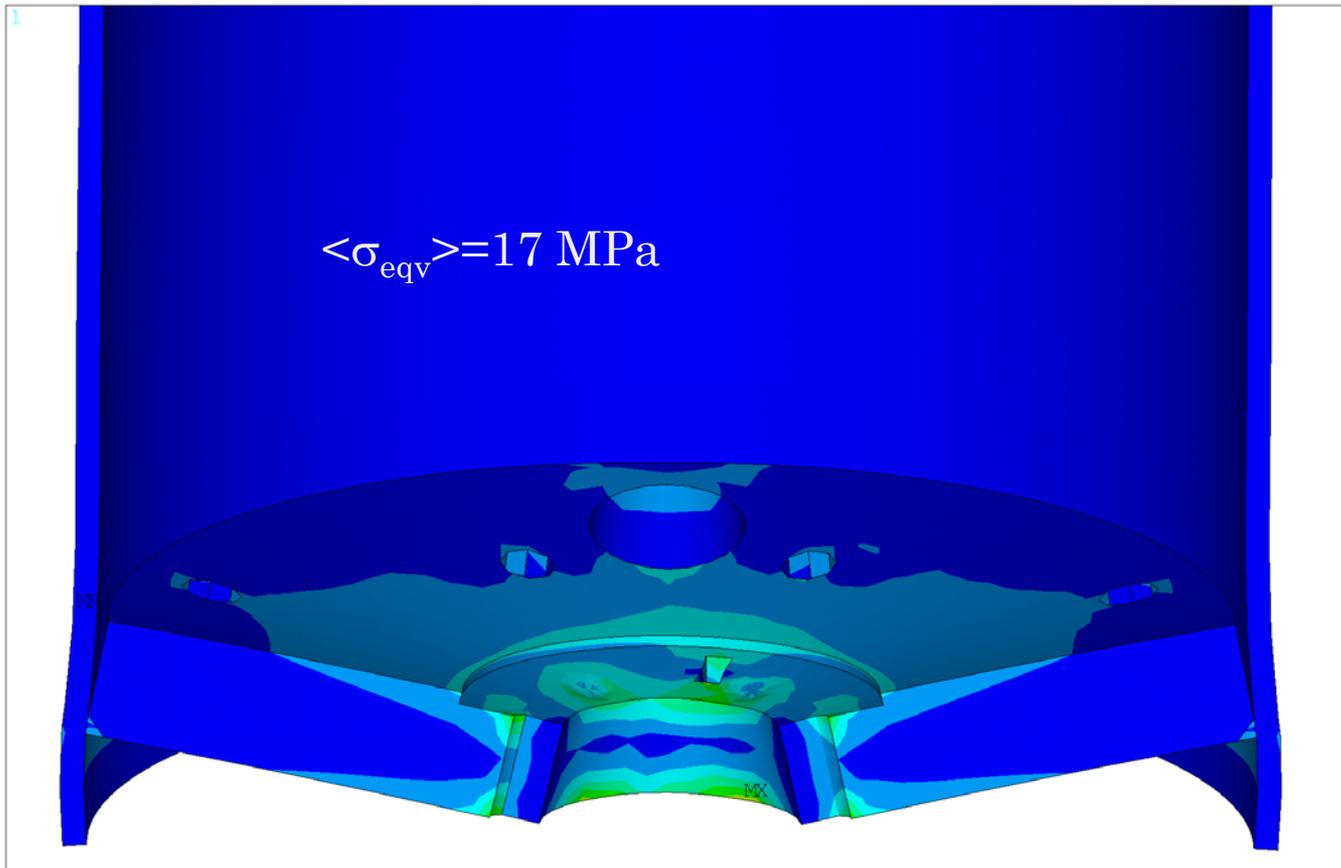
	.583366
	14.026
	27.468
	40.91
	54.353
	67.795
	81.238
	94.68
	108.122
	121.565

VON MISES STRESS PRE-STRESS OF 5.6 kN + GRAVITY

$\langle \sigma_{\text{eqv}} \rangle = 13 \text{ MPa}$

ANSYS 11.0
OCT 29 2009
16:31:01
PLOT NO. 1
0.802242
19.72
38.637
57.555
76.473
95.39
114.308
133.226
152.143
171.061

VON MISES STRESS - PRE-STRESS OF 5.6 kN + GRAVITY + LORENTZ FORCES



ANSYS 11.0
OCT 29 2009
16:32:52
PLOT NO. 1

1.108
27.027
52.946
78.865
104.784
130.703
156.622
182.54
208.459
234.378