NCSX

Twisted Racetrack Coil

Final Design Review

P. Fogarty, K. Freudenberg, T. Hargrove,

G. Lovett, B. Nelson, P. Goranson, D. Williamson

October 15, 2004

ornl

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Charge to Reviewers

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- Have the TRC requirements been appropriately defined? Have the means to verify that the requirements have been met been identified?
- Has the design been adequately defined for component fabrication and coil assembly?
- Is the assembly procedure been adequately defined in the MIT/QA plan and supporting procedures? Does the assembly procedure appear reasonable and consistent with the coil design?
- Does the assembly procedure and metrology plan (including measurement and compensation) appear suitable to achieve the tight tolerance requirement for control of the current center?
- Do the planned safety controls appear adequate?
- Is the test plan adequately defined? Have instrumentation requirements for the TRC been defined consistent with the test plan?

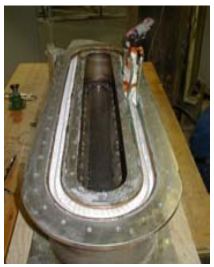
Presentation Outline

- Introduction
- Requirements
- Design Description
- Performance
- Fabrication (J. Chrzanowski)
- Test Plan (B. Nelson)
- Schedule (J. Chrzanowski)

Purpose of TRC is to verify MC components

- The twisted racetrack coil is the 3rd demo coil, first to demonstrate a prototypical winding assembly

Univ. of Tenn. Coil

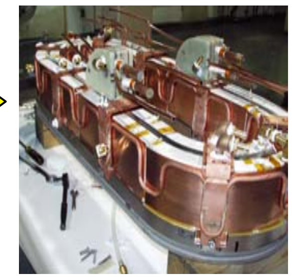


First use of selected epoxy system for VPI
Complete

Straight Tee Section

First use of “Bag Mold” for VPI
Complete

Racetrack Coil

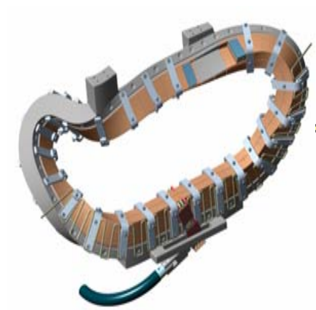


- Develop winding & metrology techniques & tooling
- Train crews
- **Complete**

Inch-Worm Winding

- Final coil lead config
- First use of autoclave for VPI
- **October 04**

Twisted Racetrack Coil



First use of manufacturing processes
-**May 05**

Production Coils

TRC coil shape is derived from modular coils

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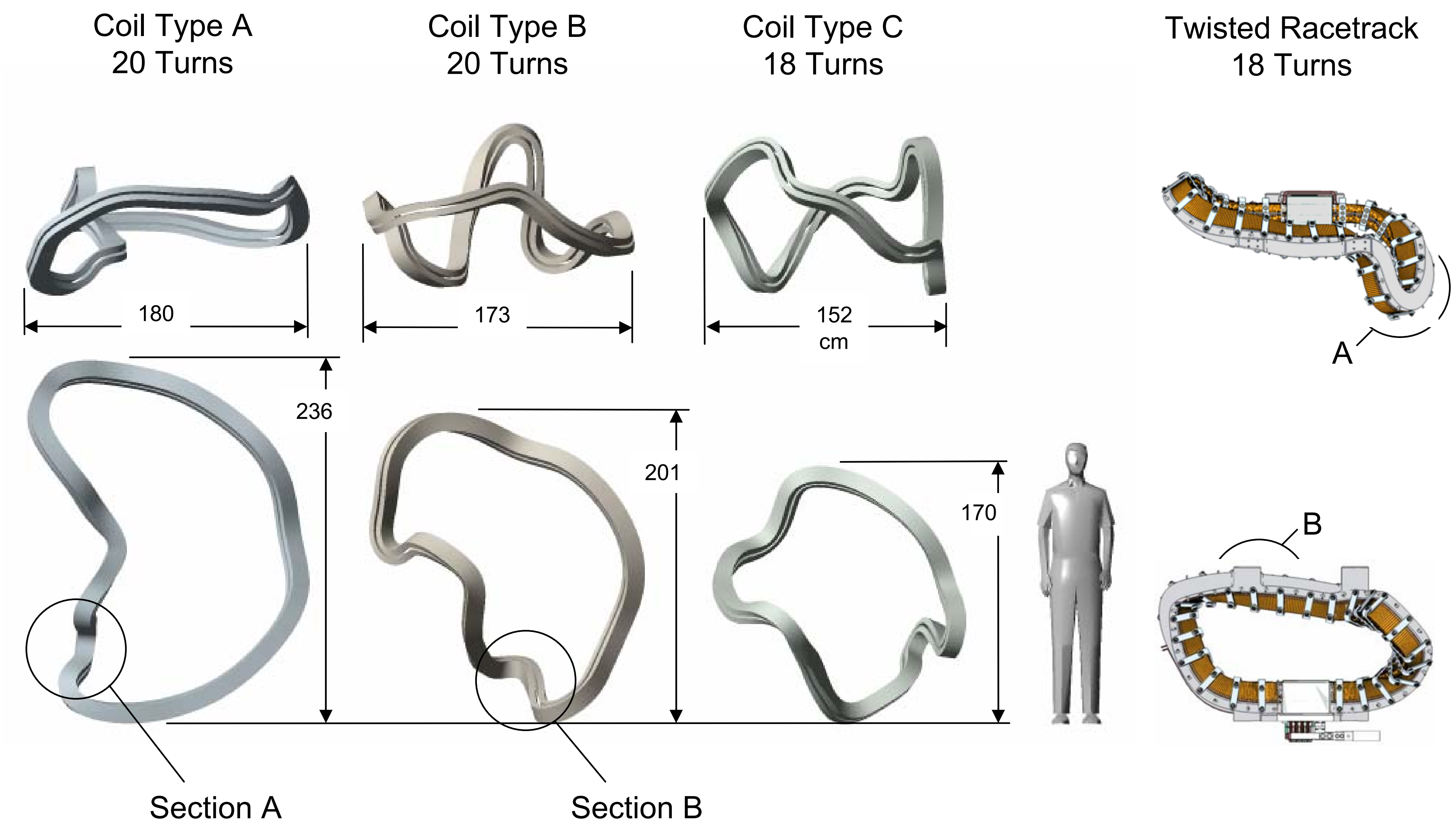

TRC addresses MC functional requirements

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Twisted Racetrack Coil

Modular Coil Requirements:

The winding forms provide an accurate means of positioning the conductor during the winding and vacuum-pressure impregnation (VPI) process

Machined surfaces within 0.020-in of CAD profile

- Toroidal, poloidal electrical segmentation
- Access for NBI, ICRH, diagnostics, personnel
- Support vessel, interface with PF/TF coil structure

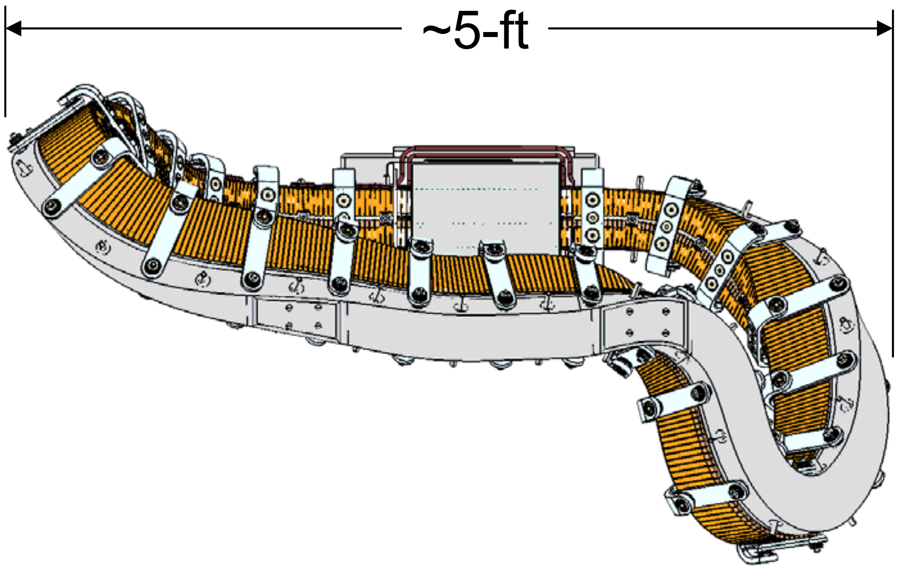
→ Winding form was fabricated to same specification as MCWF

Windings provide the basic QA field configuration

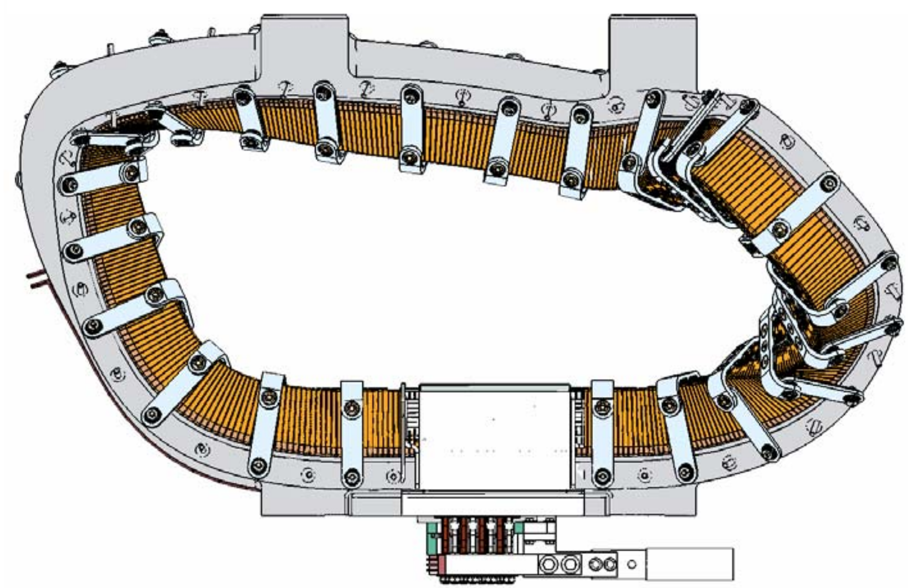
- Field up to 2-T for 1-s with 15-min rep rate
  → TRC can operate at ¾ full current, same temperature and rep rate
- Winding center accurate to +/- 0.060-in (1.5-mm)
  → Winding, measurement techniques identical to modular coil plan
- Independent control of each coil type for flexibility
- Feedback for coil protection system
  → Voltage taps and flux loops can be used to demonstrate a system

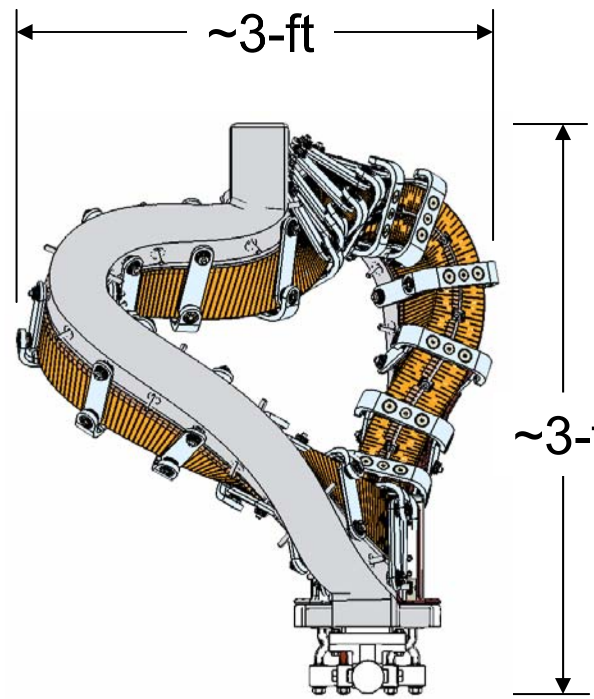
Design for 150 cool-down cycles, 130,000 pulses over >10 years of operation

Coil Assembly

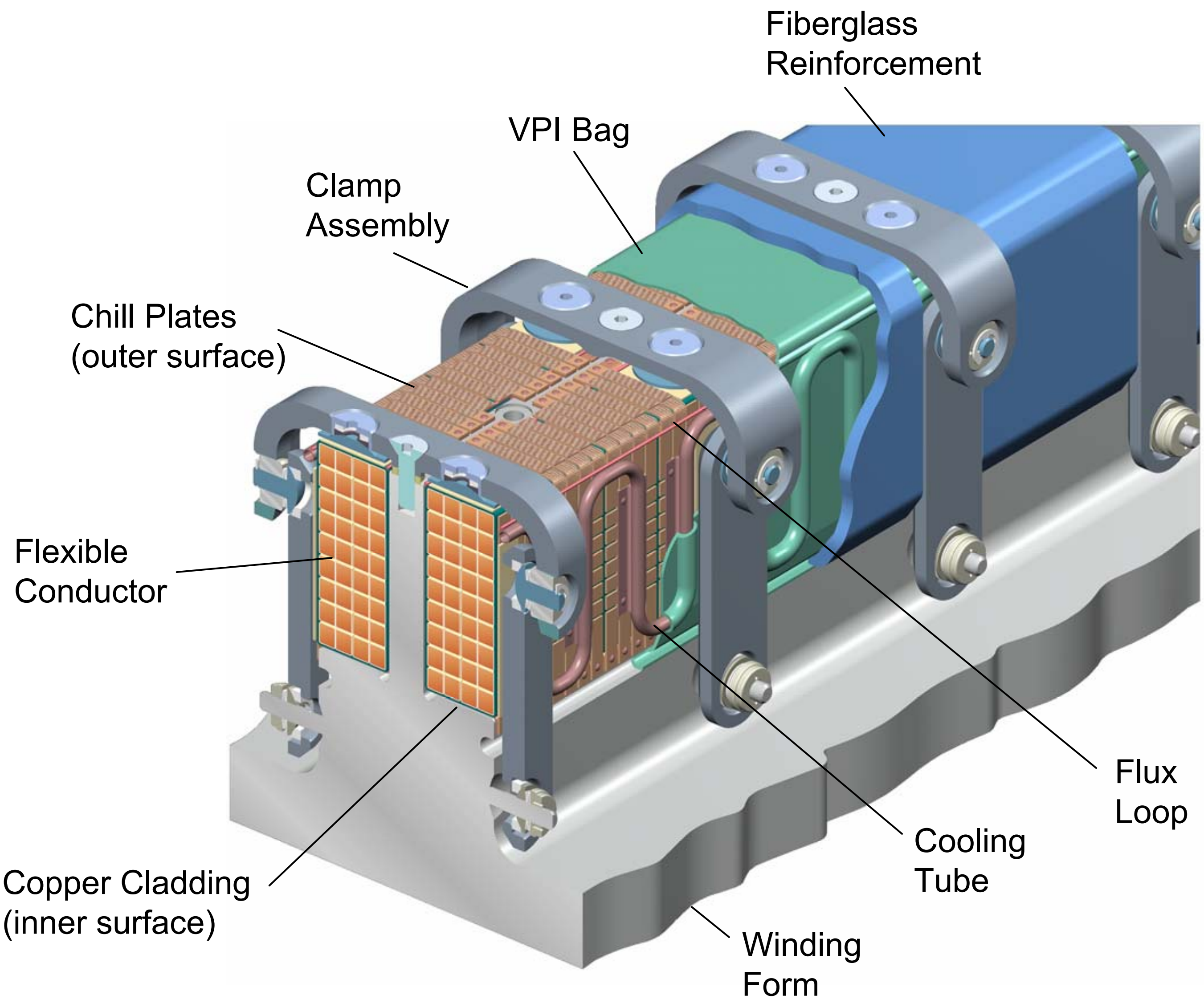


Weight = 1,250-lbs





Winding Pack



Pro/E Assembly Model Tree

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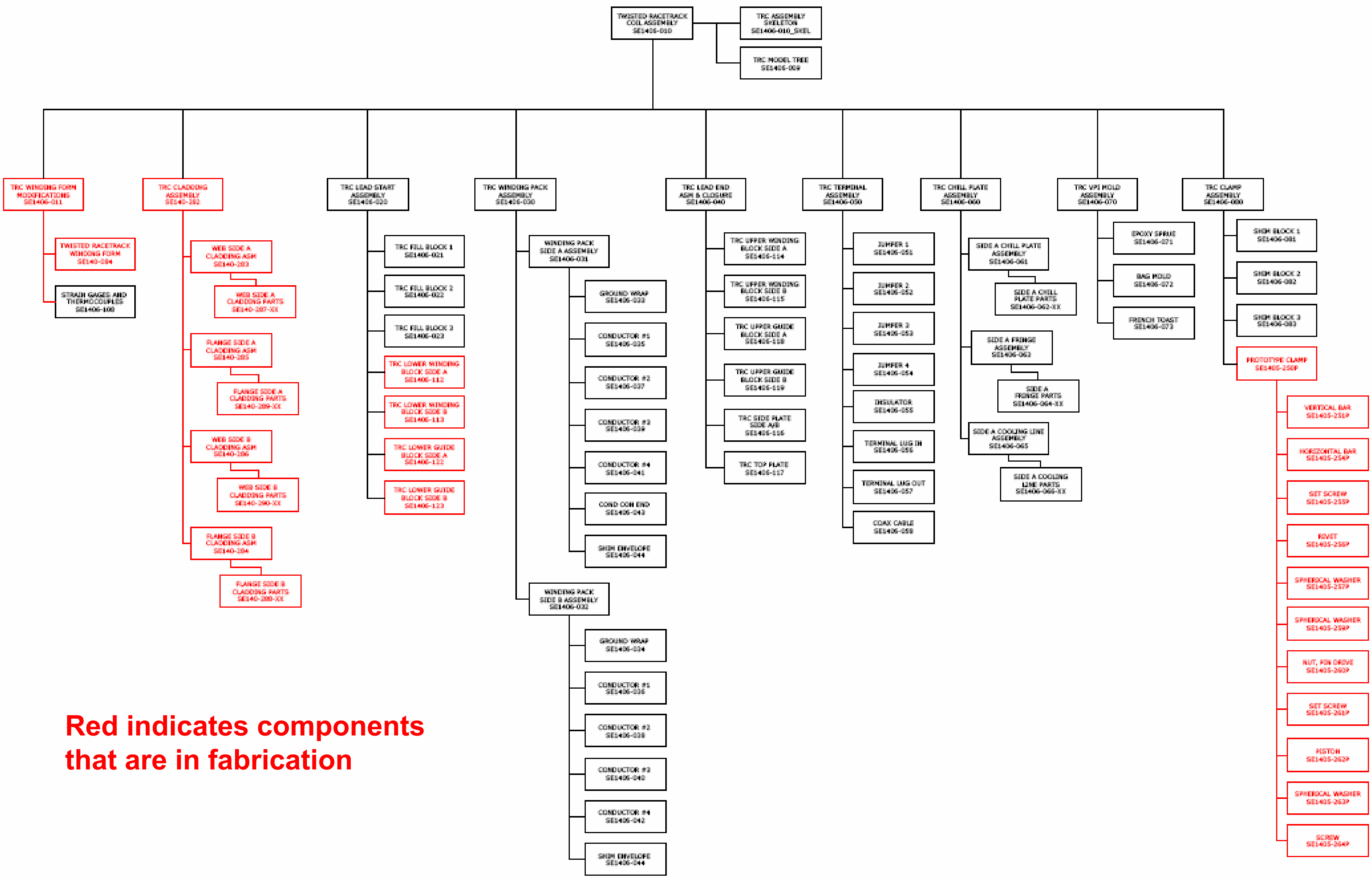
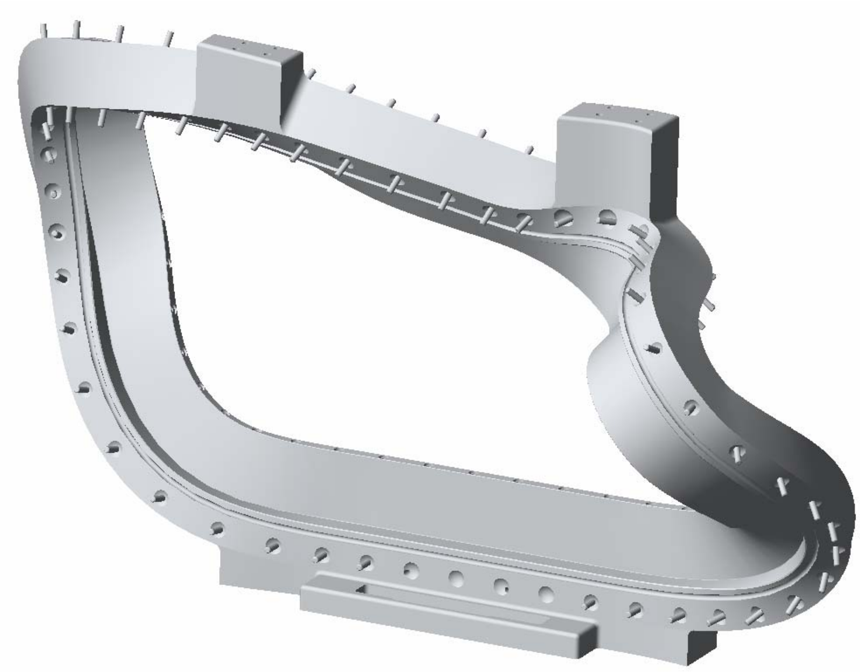
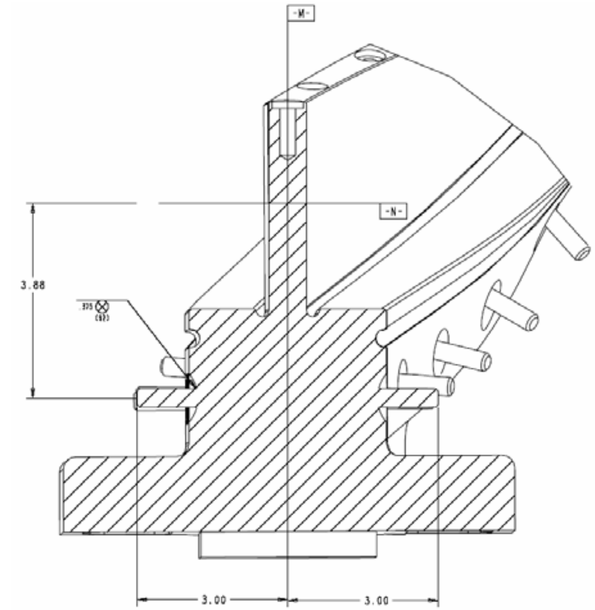


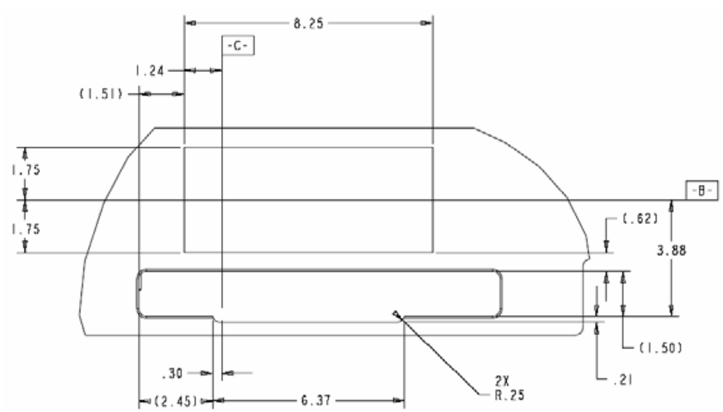
Red indicates components that are in fabrication

Winding Form Modifications

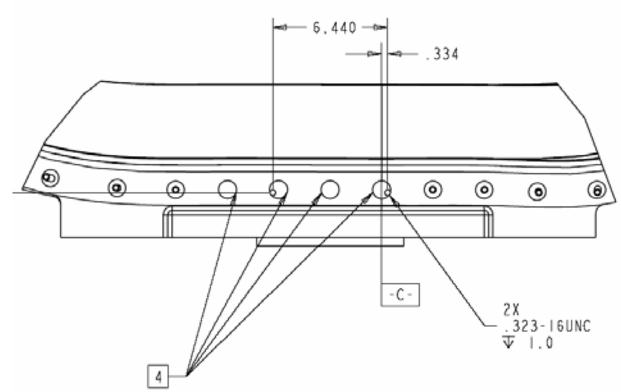




Welded studs and plate



Leads slot widened



Tapped holes for lead blocks

Terminal Block Start

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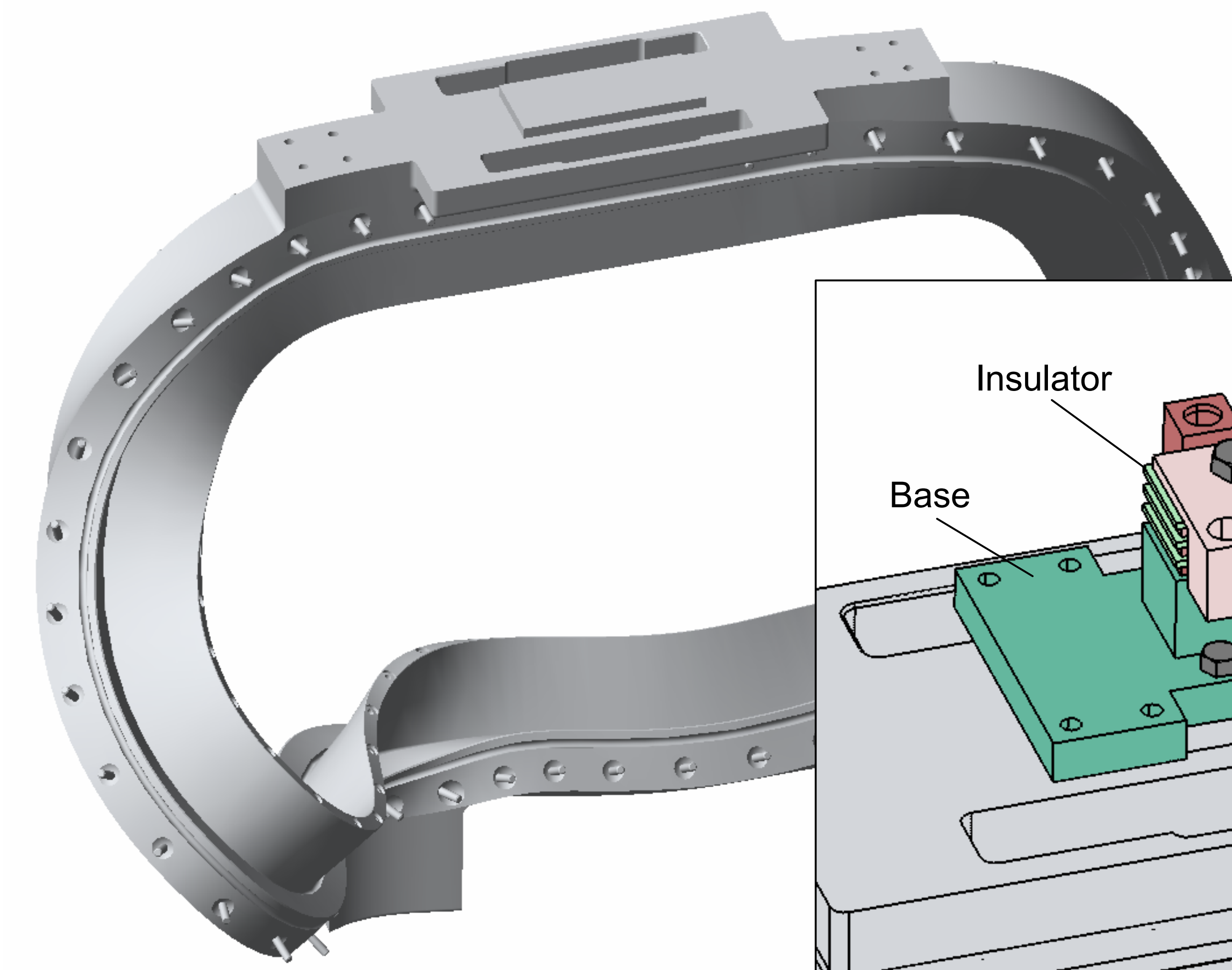

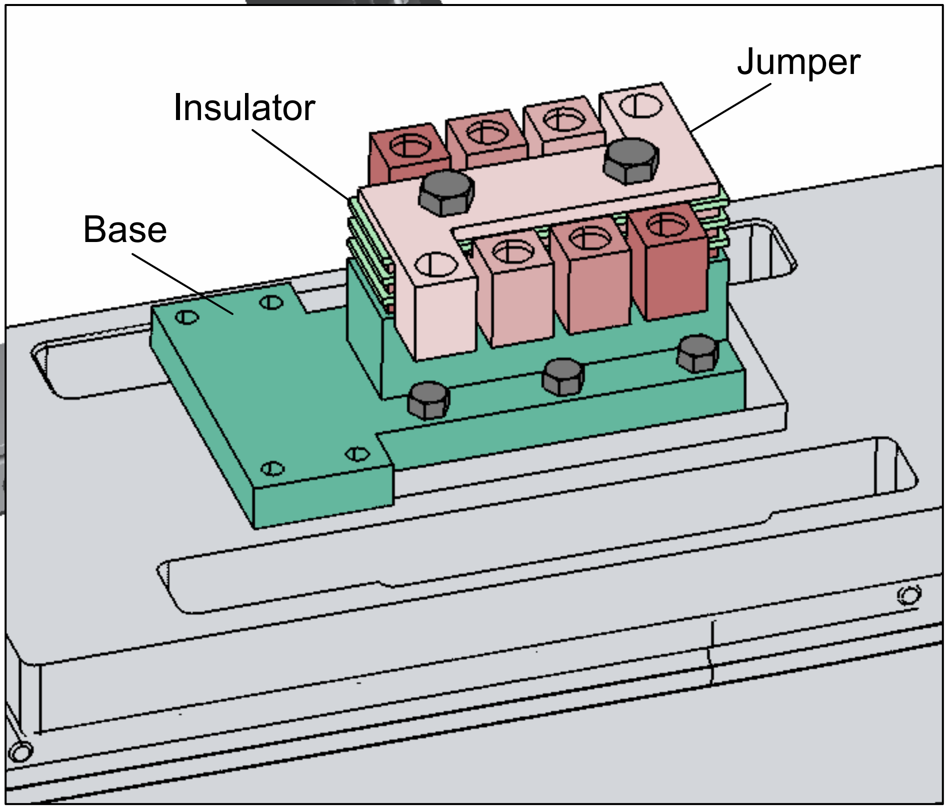

Copper Cladding

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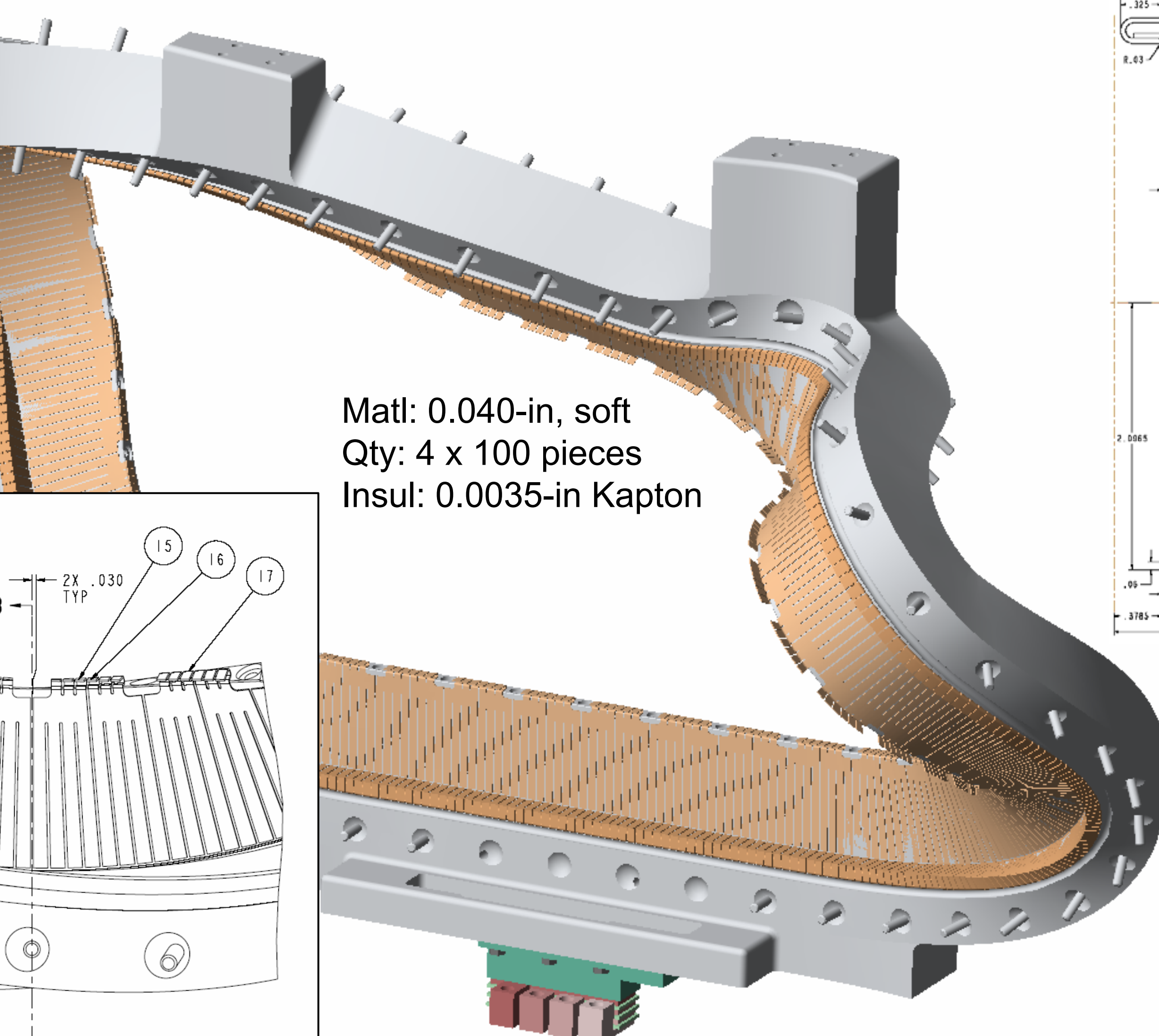
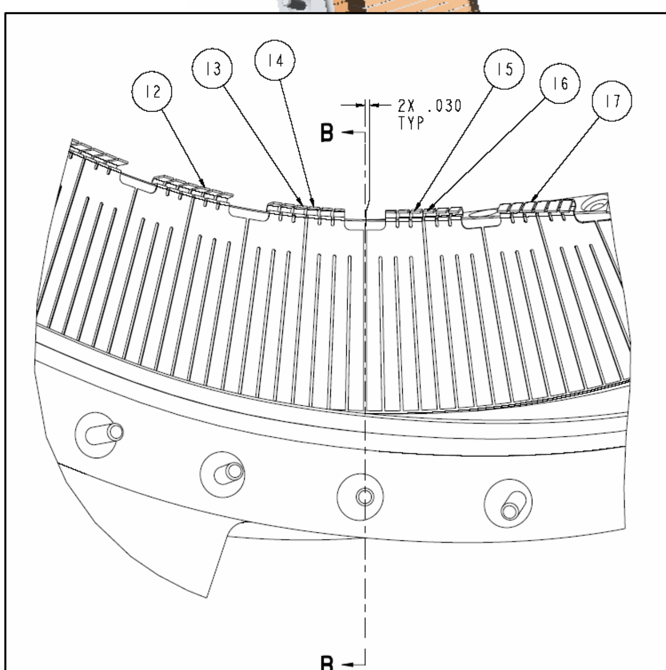
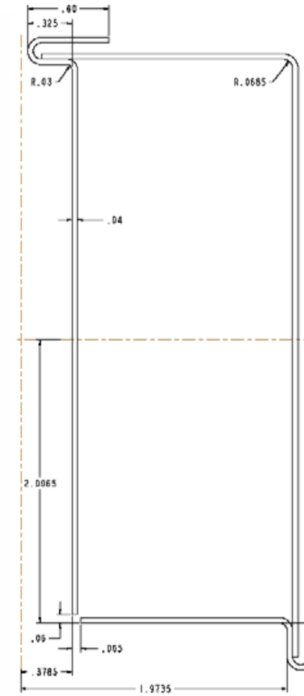


Matl: 0.040-in, soft
Qty: 4 x 100 pieces
Insul: 0.0035-in Kapton





Section View

Lead Block Start

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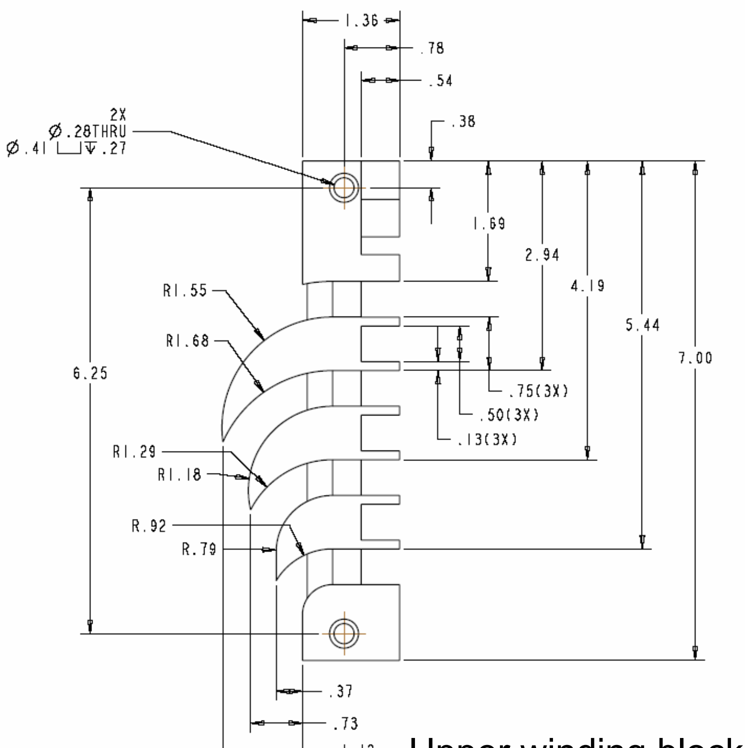
Matl: G11-CR laminate

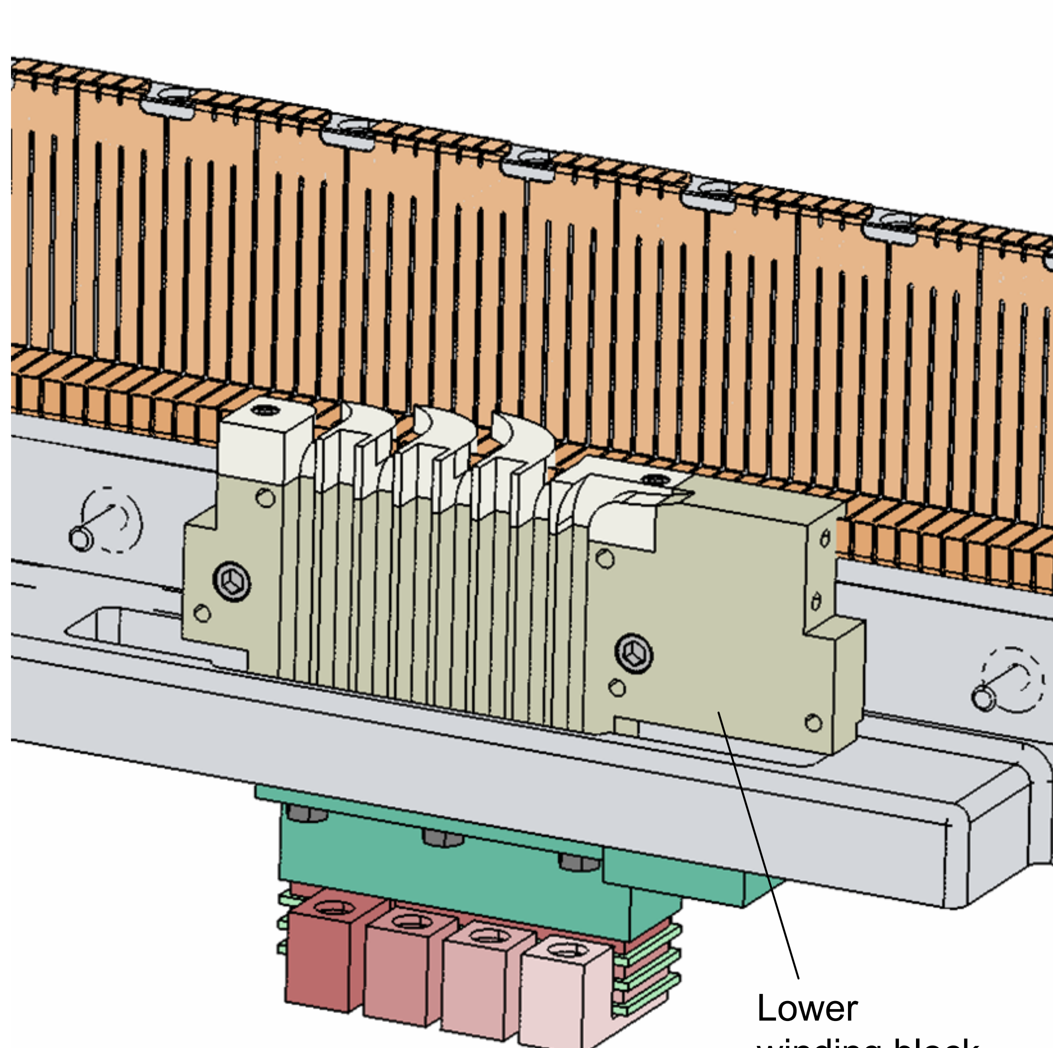
Qty: 2 per side + additional
fill blocks for TRC slot
(SE1406-022 thru -024)

Free of burrs, sharp edges

Slot widens for extra turn insulation



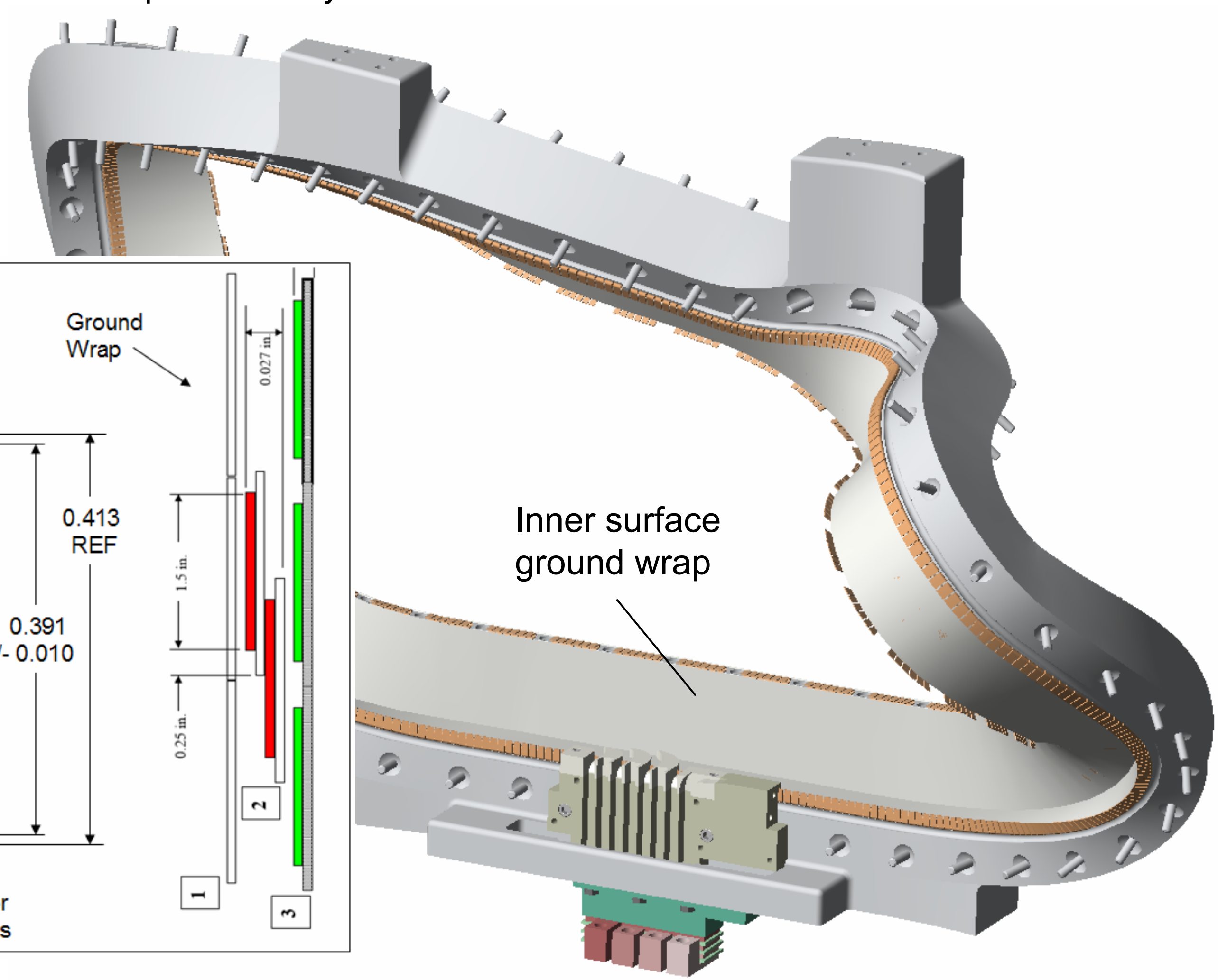
Upper winding block

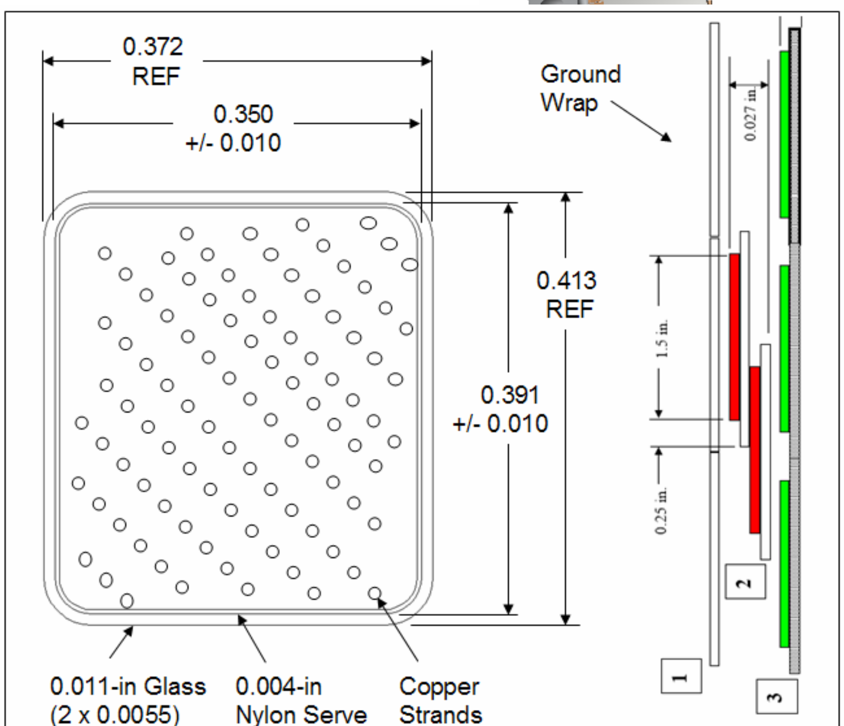


Lower winding block

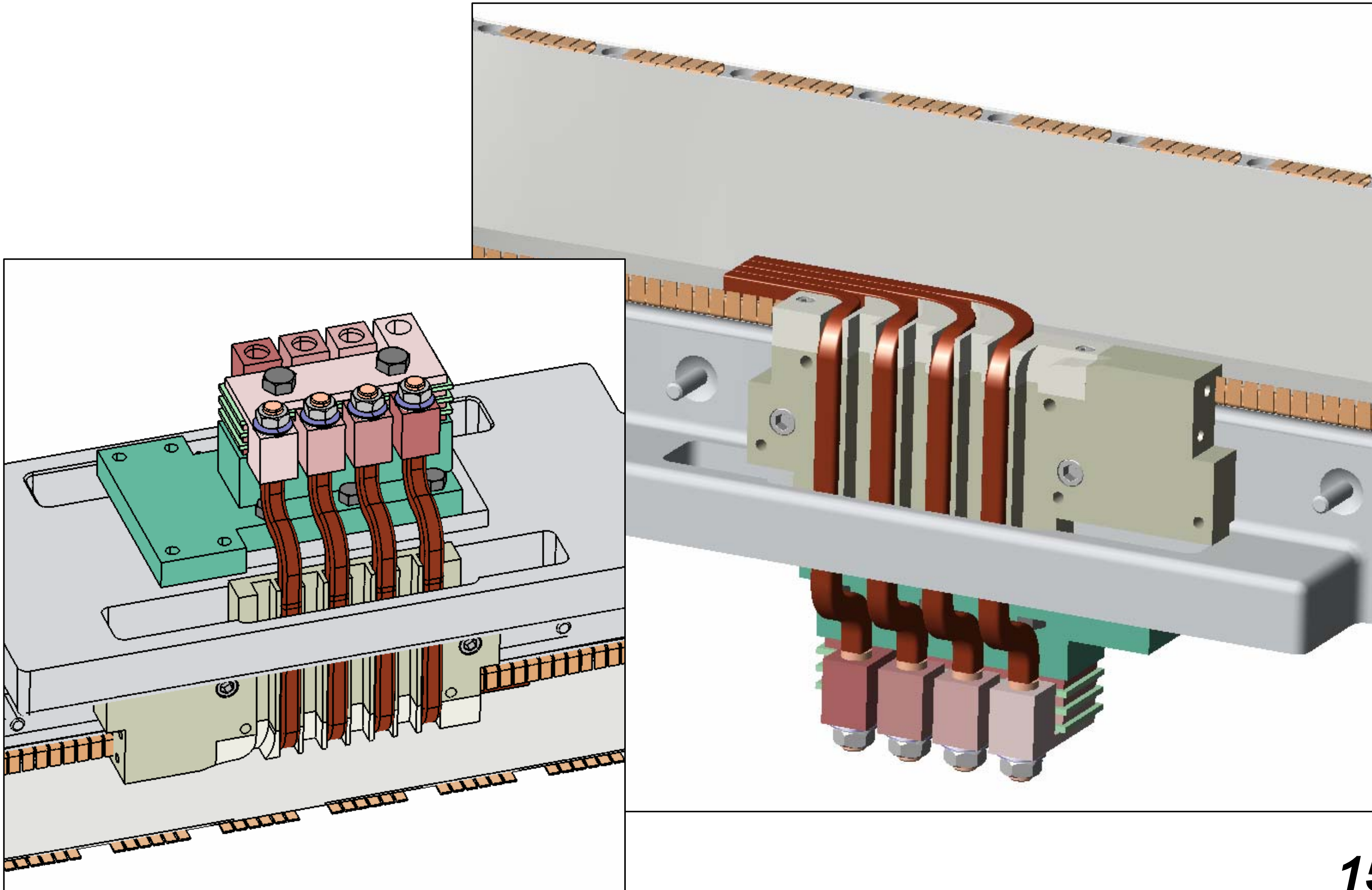
Ground Insulation

The total thickness of 0.0445-in is composed of three layers:
1) butt-lapped layer of 0.007-in S2 glass,
2) half-lapped layer of 2-in wide x 0.007-in S2 glass and 1.5-in wide x 0.0065-in adhesive Kapton tape
3) butt-lapped layer of the same composite as layer #2





Winding Start



Winding Pack Shims

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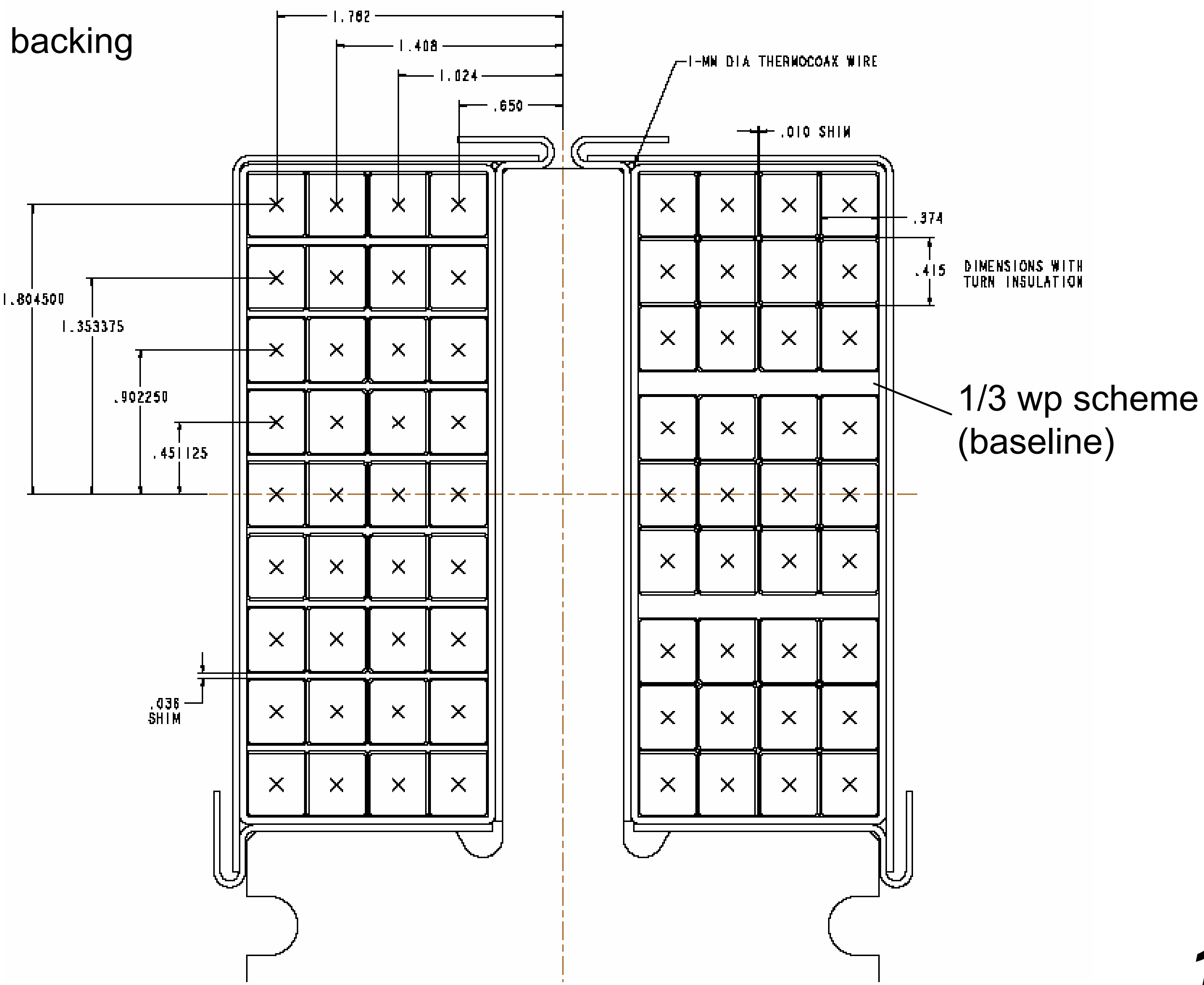
Material – The shim material is S2 glass cloth with adhesive backing

Size and Weight – shims are cut from xx-in wide x yy-in thick glass tape

Temporarily attached by adhesive backing



Winding Finish

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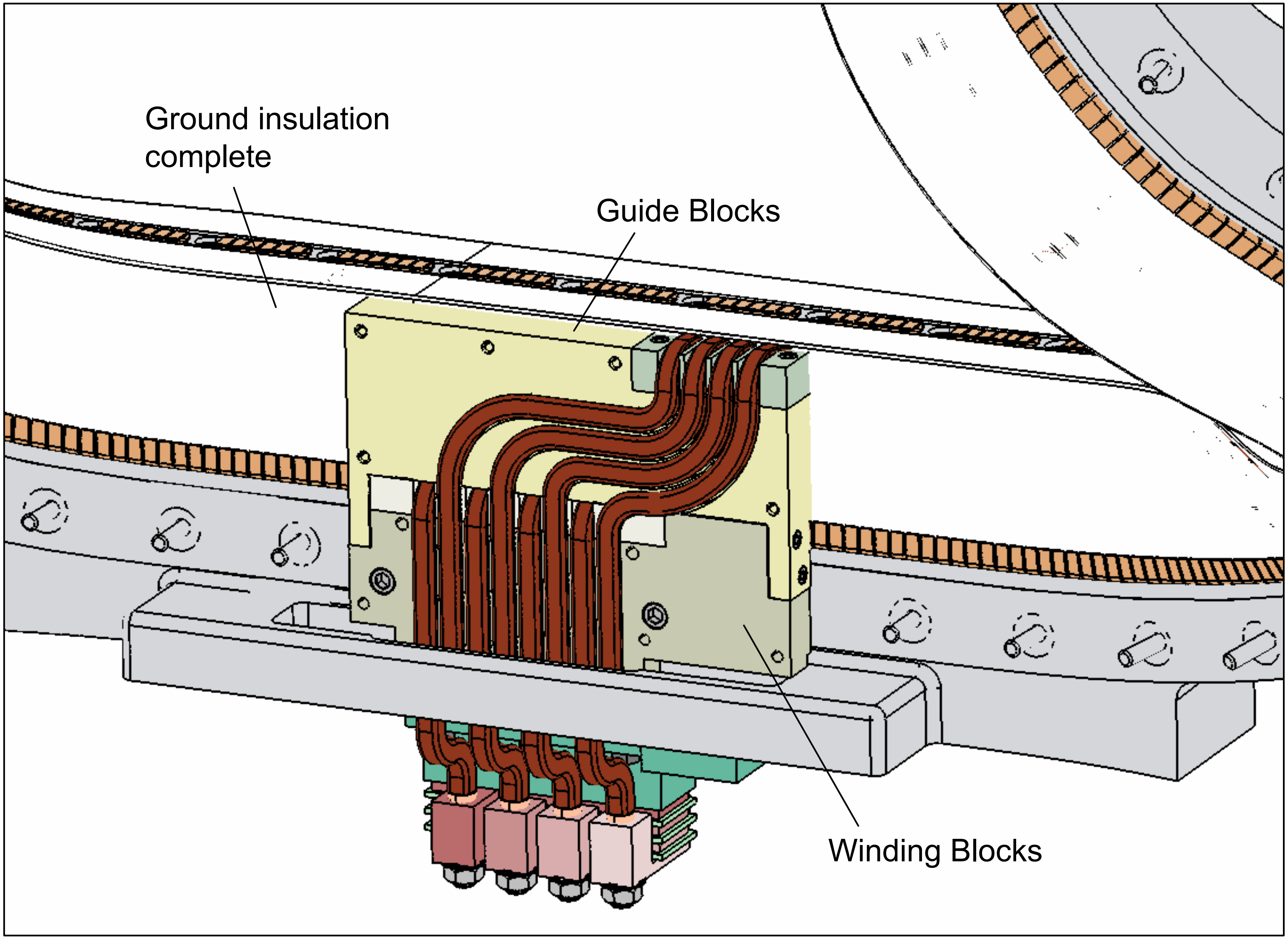

Chill Plates and Tubing/Fringe

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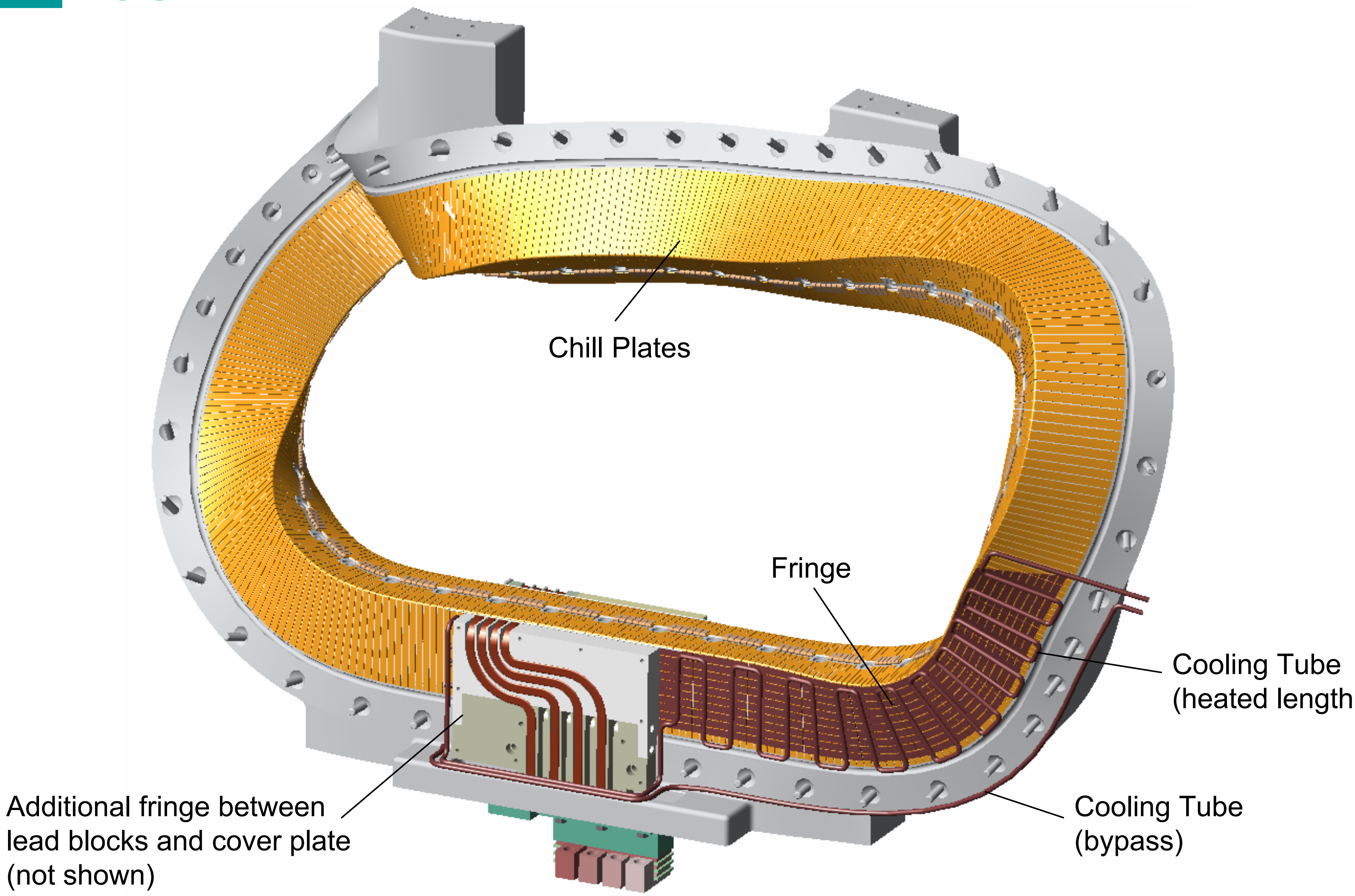
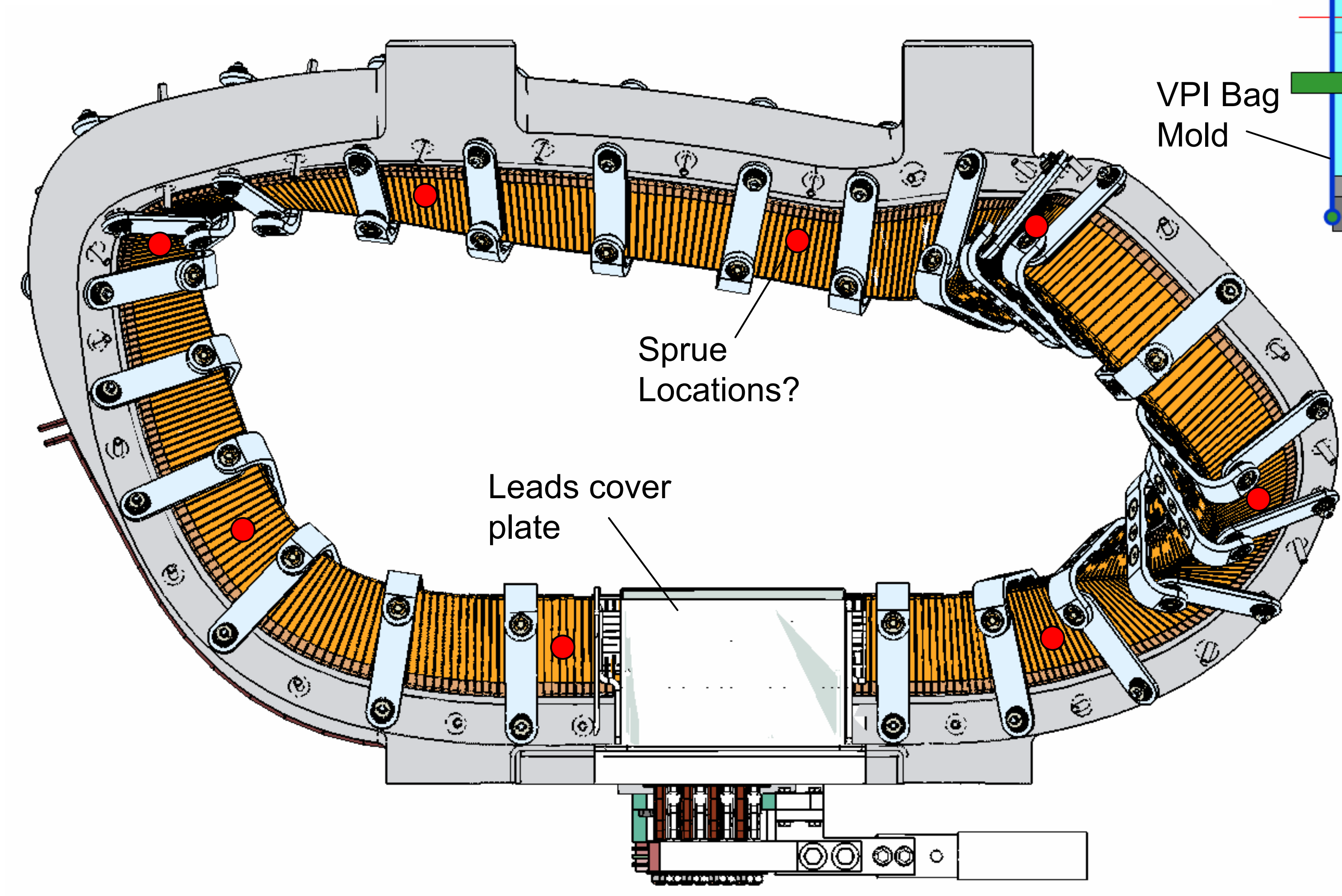
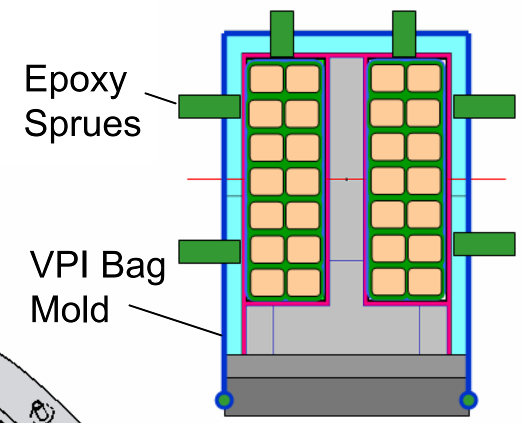
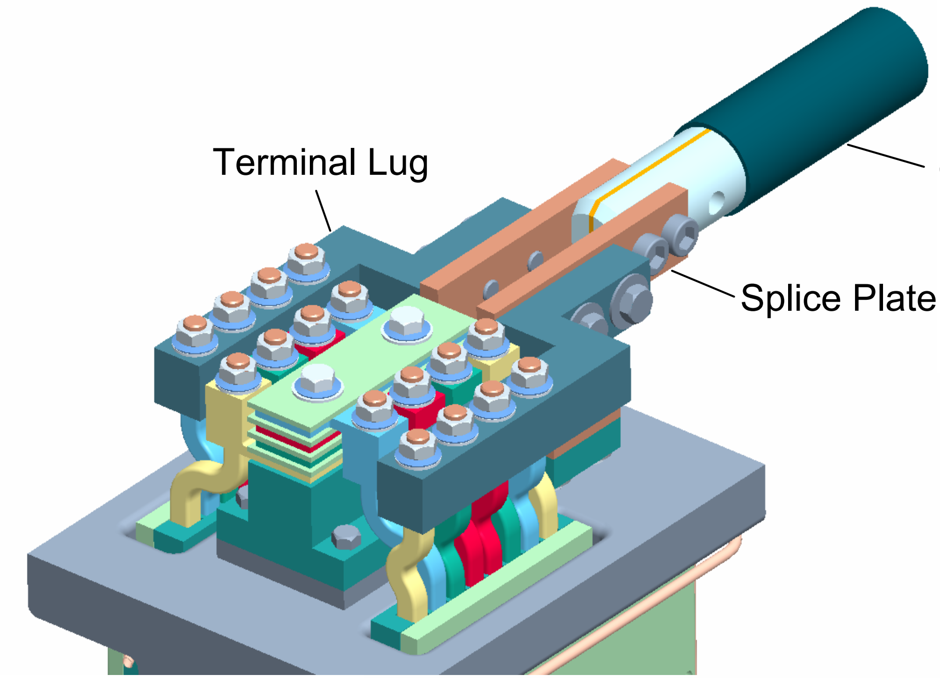


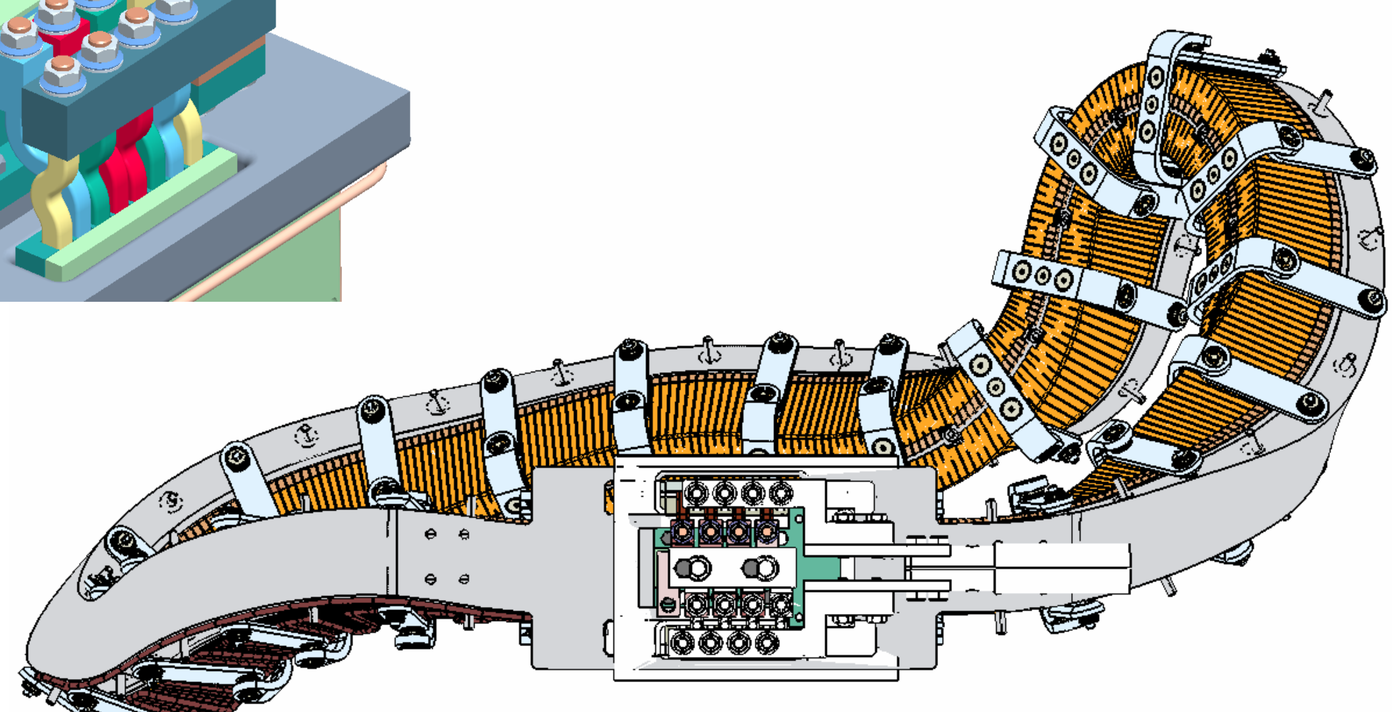
Leads Closure, VPI, and Clamps





Electrical Power Connection





Bottom View

Instrumentation

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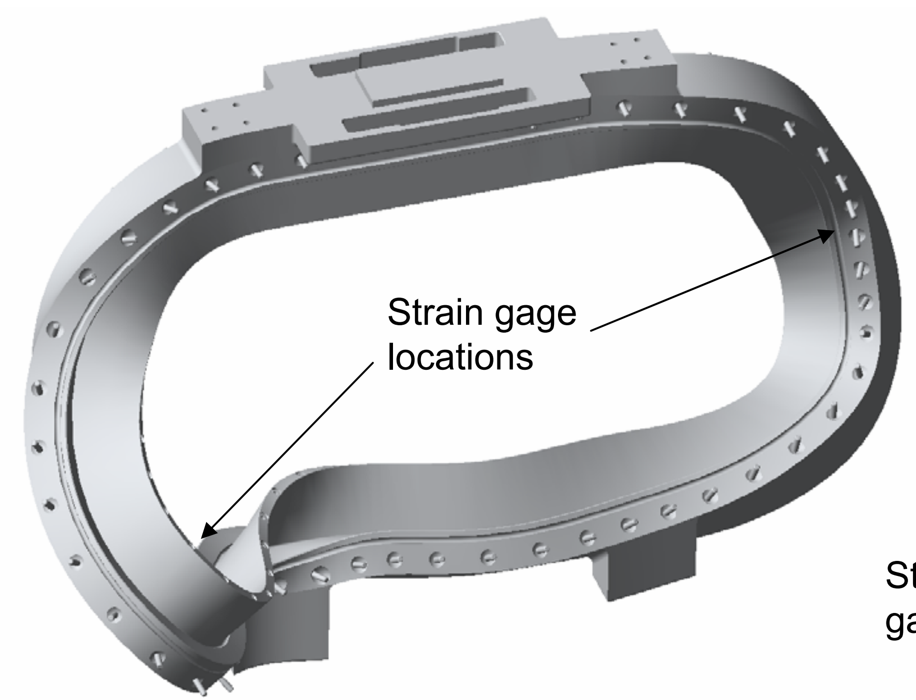
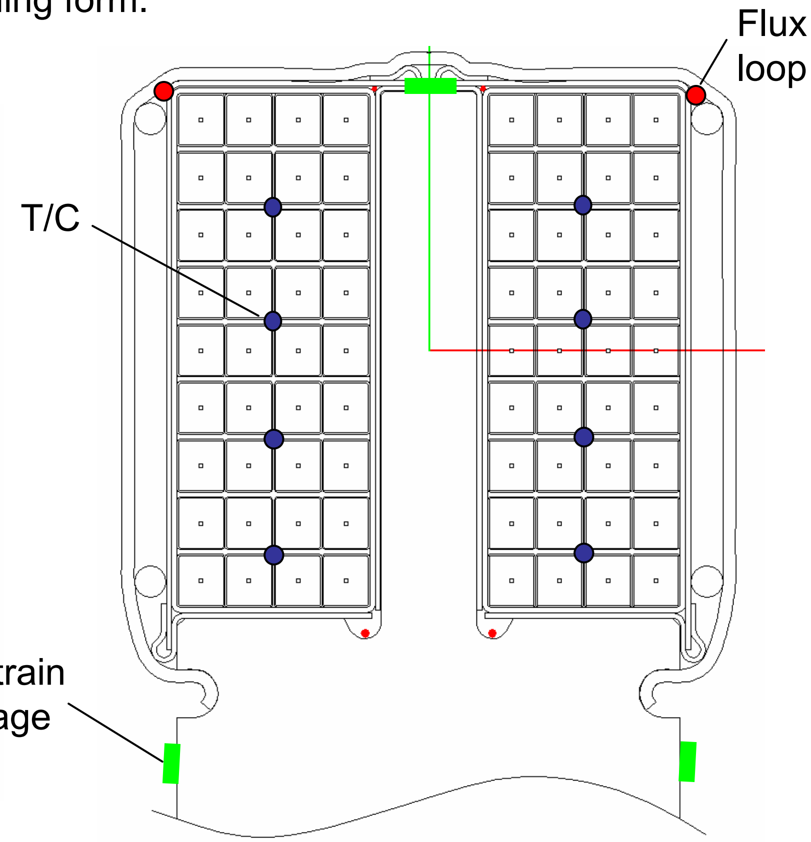
Fiber optic strain gage -Three each at each end of the coil, located at the tip of the tee web and the inside/outside surface of the tee base. Two additional strain gages to be located near and opposite the coil leads.

Type-E thermocouple - Within a coil plane, opposite the leads region, thermocouples shall be located in the middle of each winding pack and spaced vertically between the layers.

Flux loop - Wires shall be located at the outer corner, plasma side of each winding pack. Terminations routed along the lead block to the base of the winding form.

Voltage tap -





Electrical Parameters

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Calculated quantity		Flat Racetrack	Twisted Racetrack	Prototype (Coil type C)	Production Coil type A	Production Coil type B	Production Coil type C
Number of elec turns per winding pack		14	9	9	10	10	9
Number of electrical turns per coil		28	18	18	20	20	18
Number of physical turns per electrical turn		1	4	4	4	4	4
Conductor width, with serve	in	0.625	0.350	0.350	0.350	0.350	0.350
Conductor height, with serve	in	0.500	0.391	0.391	0.391	0.391	0.391
packing fraction		0.78	0.78	0.78	0.78	0.78	0.78
Winding resistance at RT	ohms	1.366E-02	7.201E-02	1.506E-02	1.848E-02	1.802E-02	1.506E-02
Winding resistance at 120K	ohms	1.772E-03	2.111E-02	5.136E-02	6.304E-02	6.146E-02	5.136E-02
Winding resistance at 80K	ohms	7.835E-04	1.081E-02	6.662E-03	8.177E-03	7.972E-03	6.662E-03
Inductance - windings only	Henries	6.63E-04	7.91E-03	7.90E-03	1.240E-02	9.230E-03	7.900E-03
Time constant - windings only, RT	seconds	4.85E-02	1.10E-01	5.25E-01	6.71E-01	5.12E-01	5.25E-01
Time constant - windings only, 120K	seconds	3.74E-01	3.75E-01	1.54E-01	1.97E-01	1.50E-01	1.54E-01
Time constant - windings only, 80K	seconds	8.46E-01	7.32E-01	1.19E+00	1.52E+00	1.16E+00	1.19E+00
Max operating current per elec turn	Amps	N/A	N/A	N/A	40908	41561	40598
Maximum test current	Amps						

Electromagnetic Analysis

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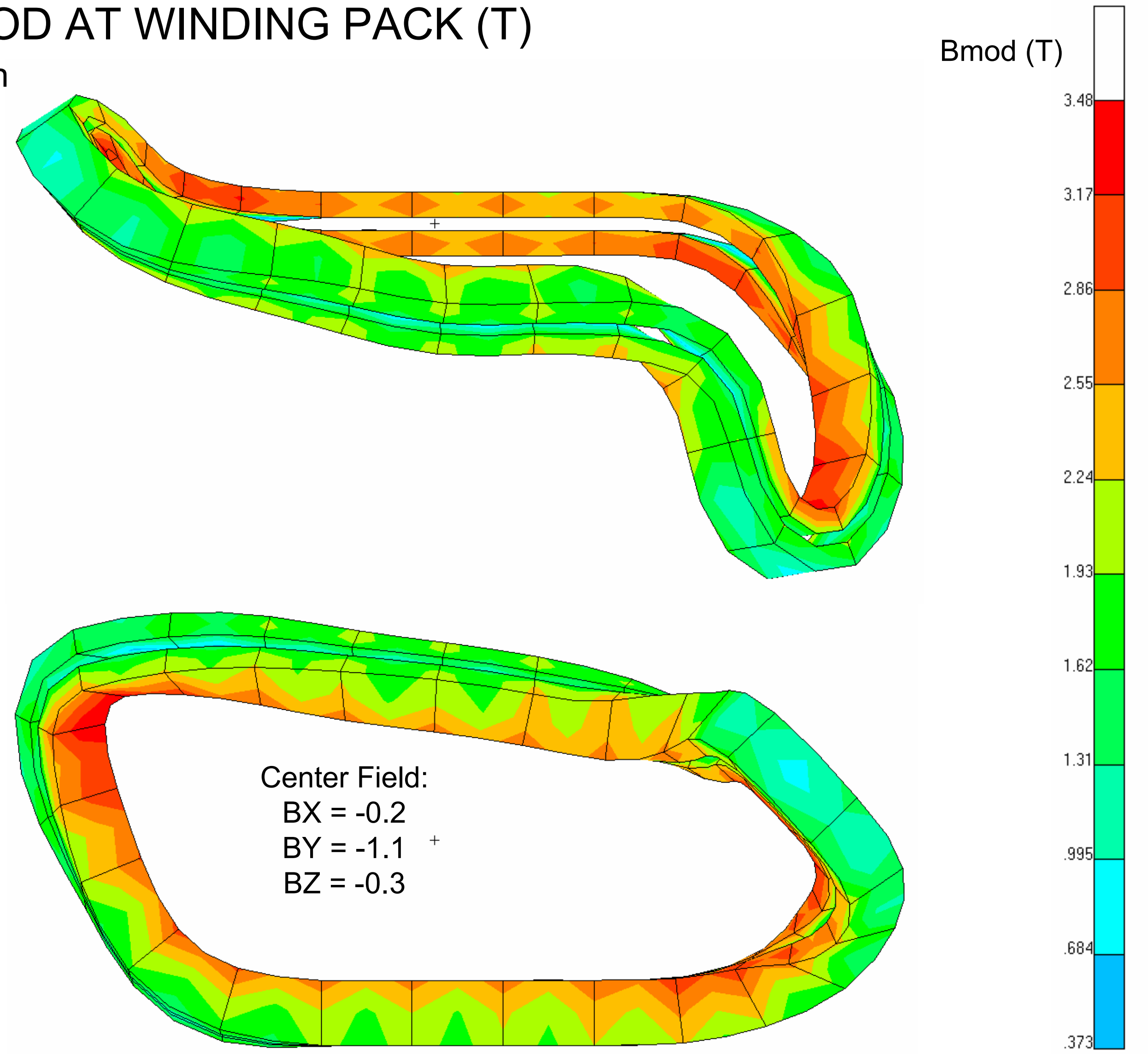
TRC B-MOD AT WINDING PACK (T)

- 42 kA/turn



EM Force Comparison

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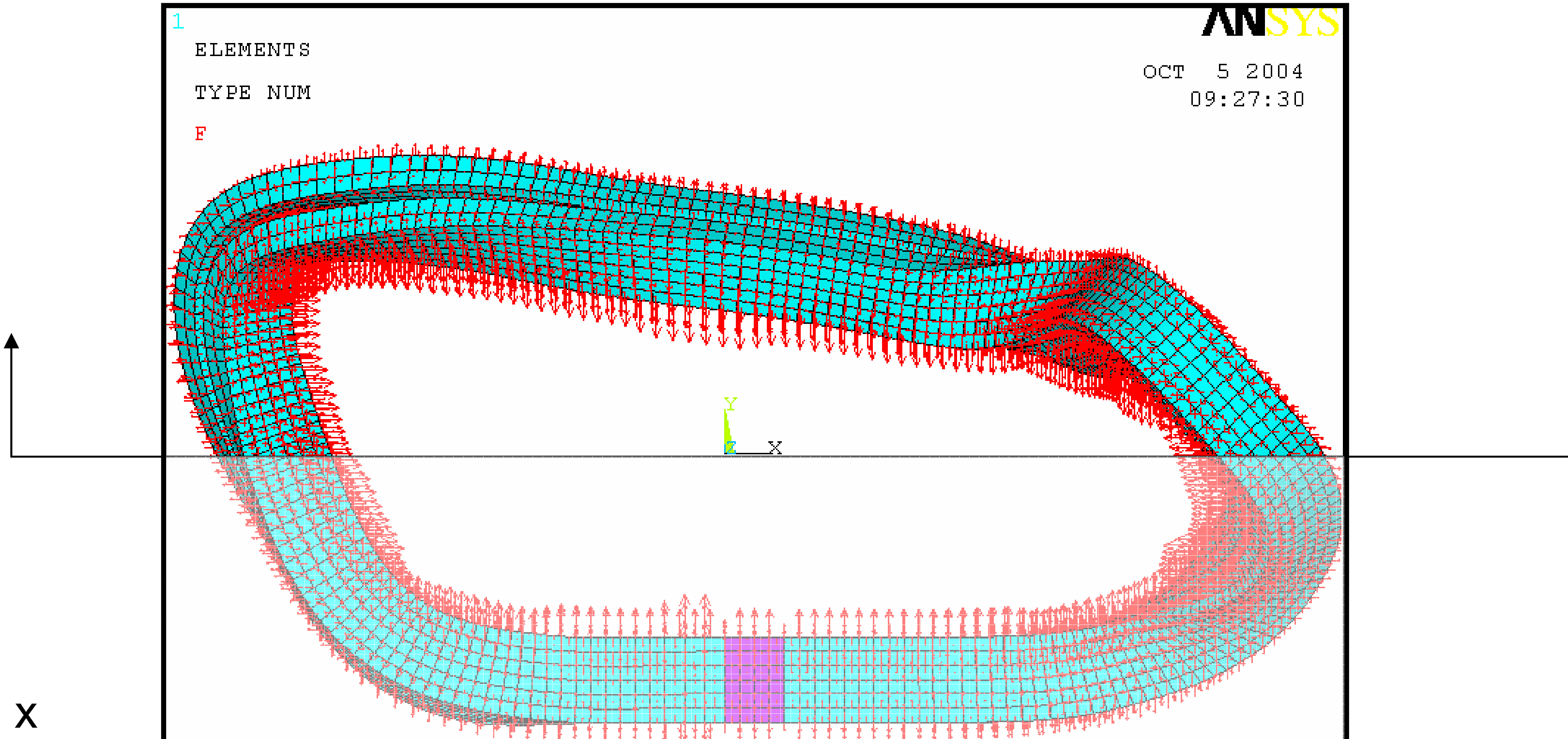
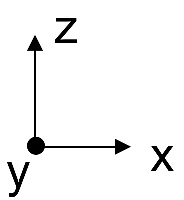


Summation only includes nodes on upper half of model



Comparison Coordinate system

	Units	Sum Fx	Sum Fy	Sum Fz
ANSYS	N	-144,576	-124,400	453,894
MAGFOR	N	-109,806	-112,042	435,450

Twisted Racetrack: Linear Results for 31.5 kamps/turn

Model includes:

- Clamp Preload = 125 lbs.
- Thermal shrinkage of 0.04% (400$\mu\varepsilon$) to account only for the cool-down to cryogenic.
- Magnetic nodal force loading for ¾ of the max current (42 kAmps) used for the real coils.

Model and mesh with new clamp that attaches to the base of the tee.

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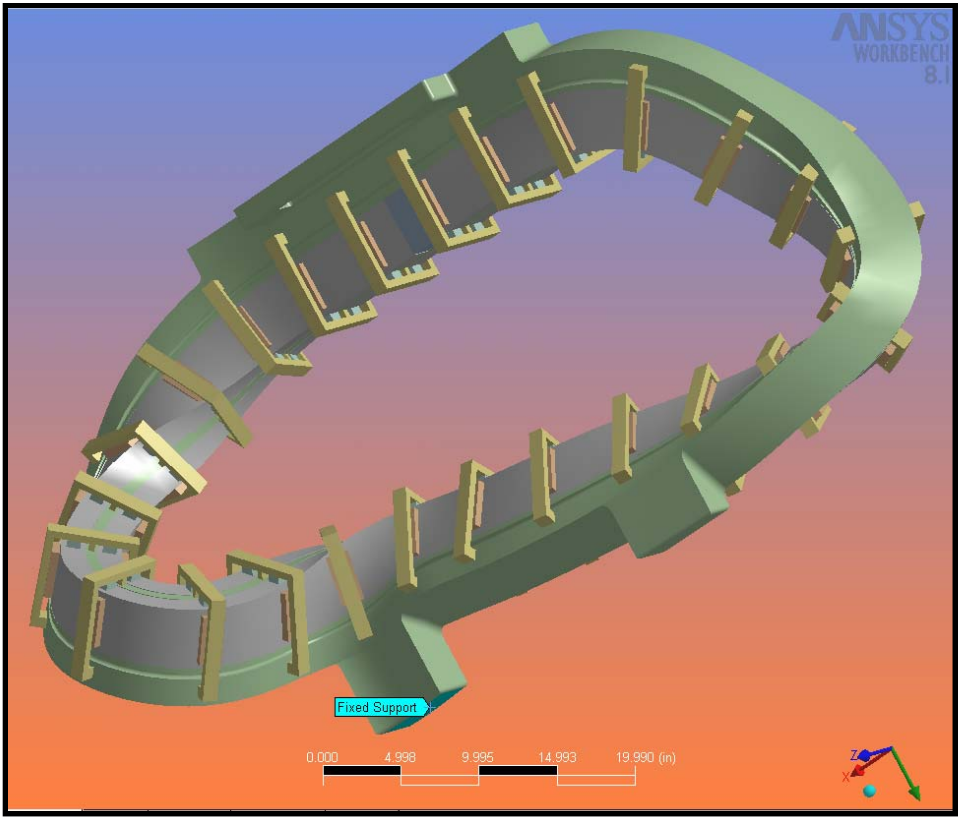
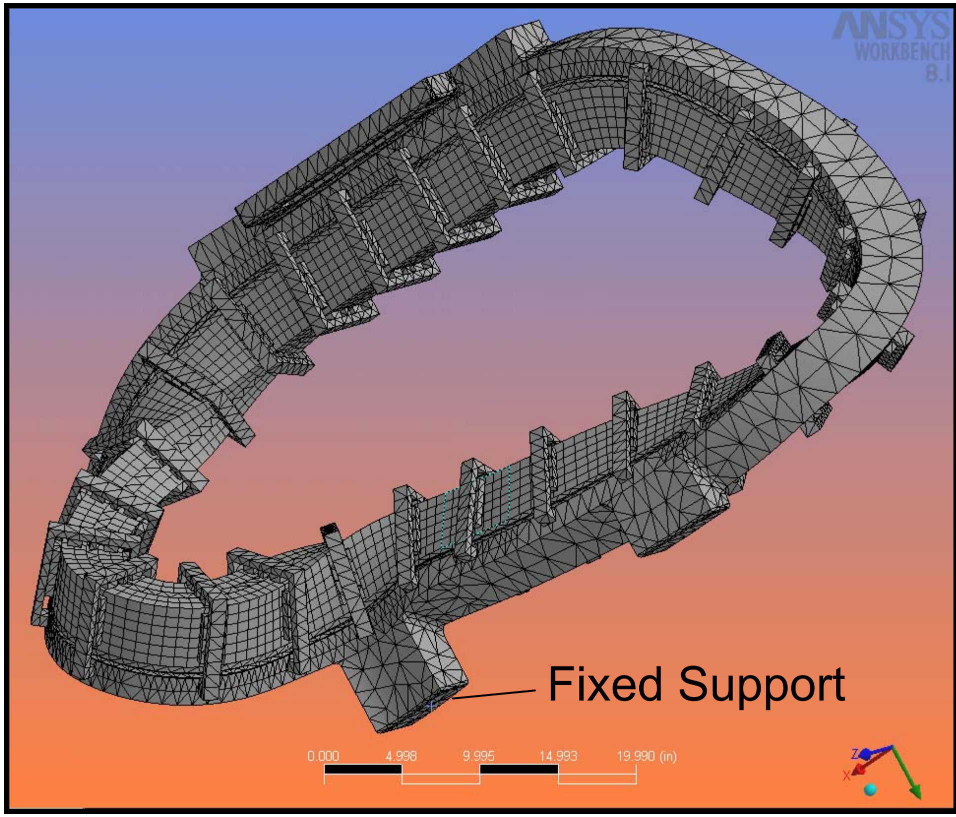
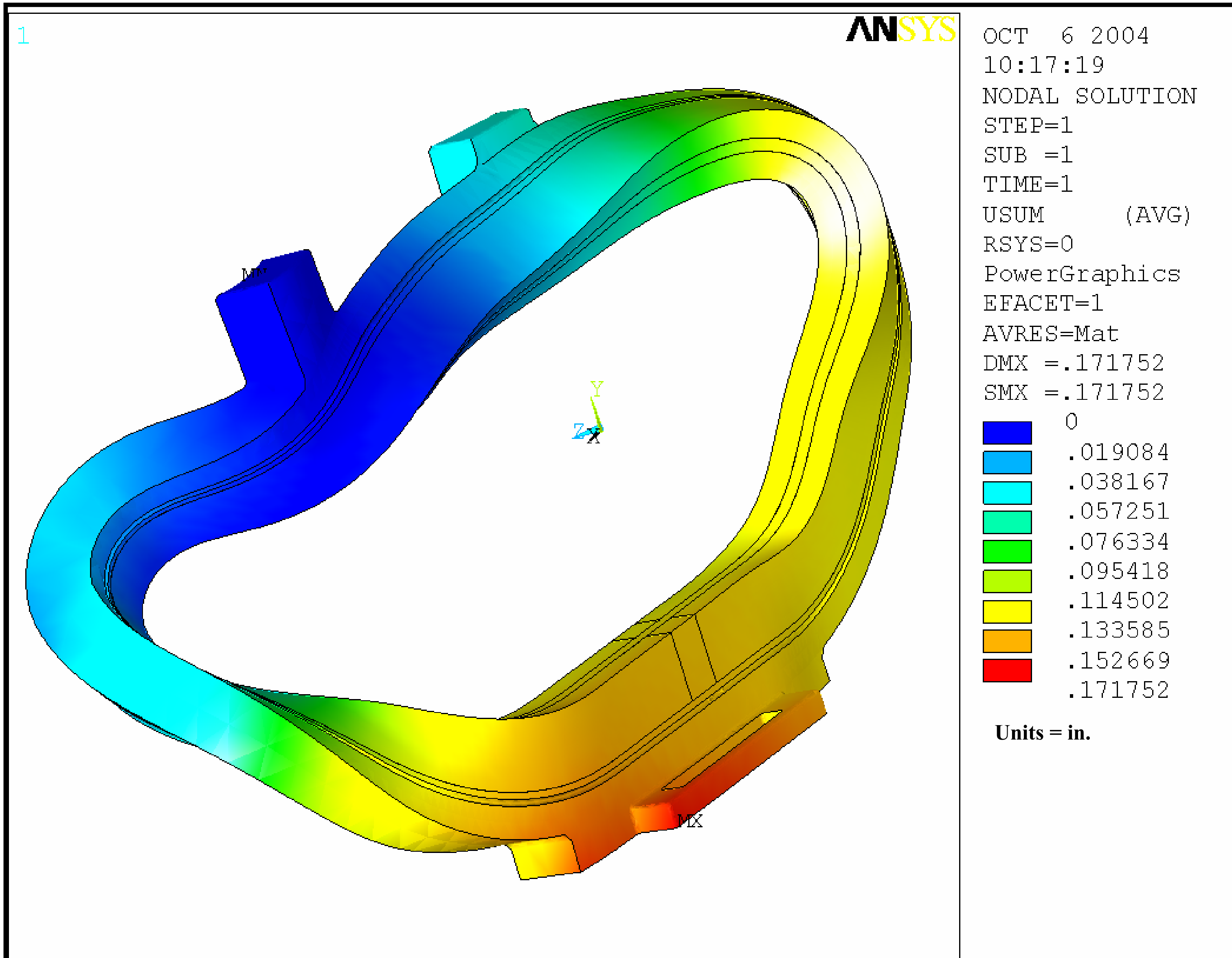


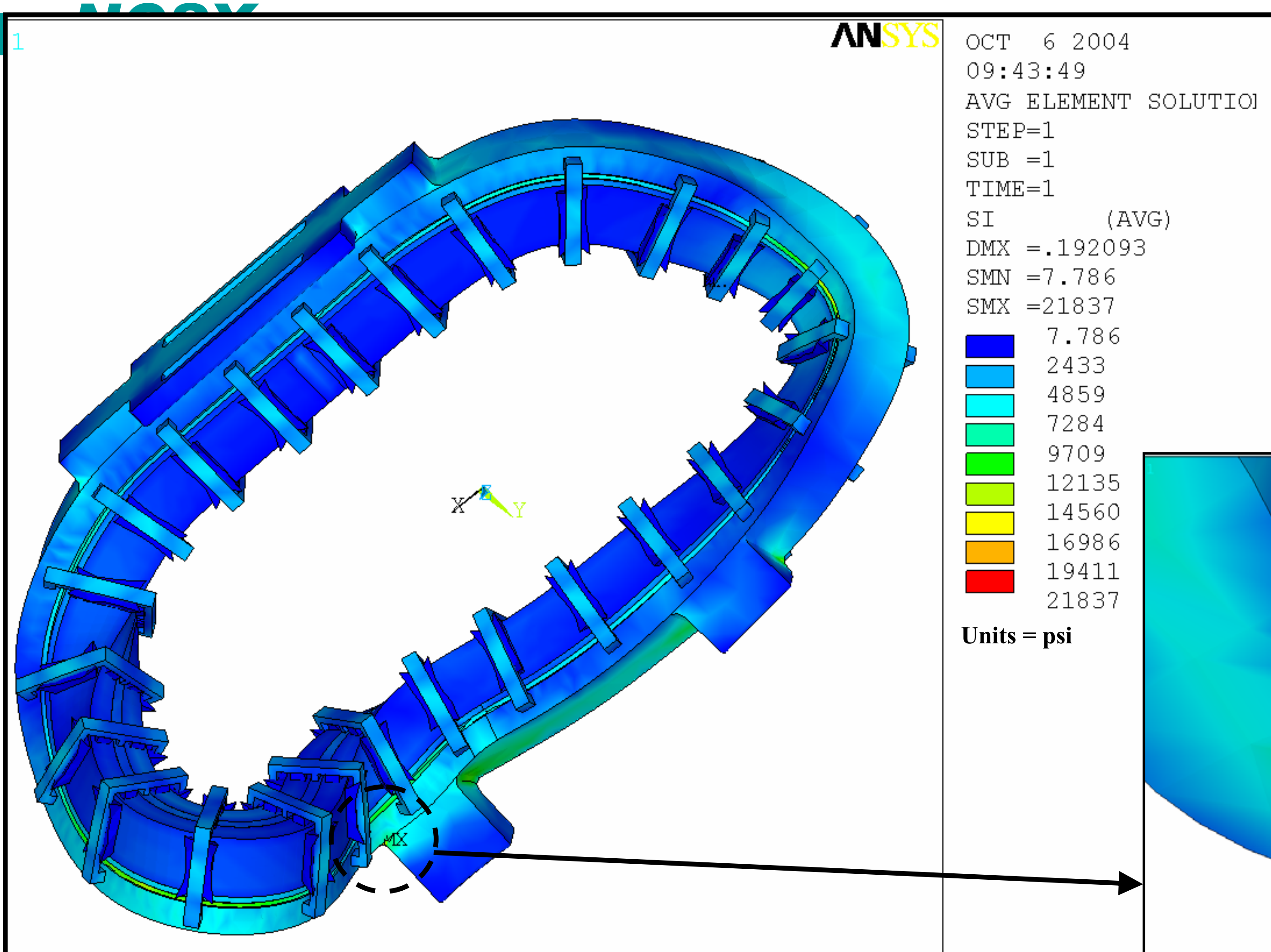


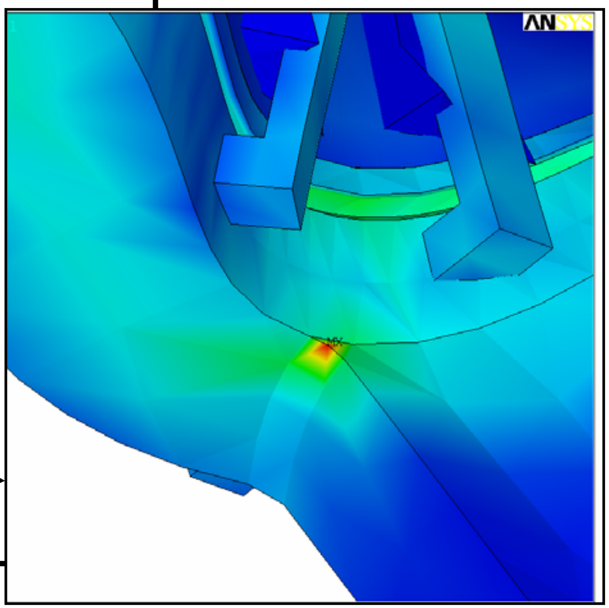
Deflection



1
ANSYS
OCT 6 2004
10:17:19
NODAL SOLUTION
STEP=1
SUB =1
TIME=1
USUM (AVG)
RSYS=0
PowerGraphics
EFACET=1
AVRES=Mat
DMX =.171752
SMX =.171752
0
.019084
.038167
.057251
.076334
.095418
.114502
.133585
.152669
.171752
Units = in.
MN
MX
Y
Z
X

Stress Intensity for twisted racetrack coil assembly

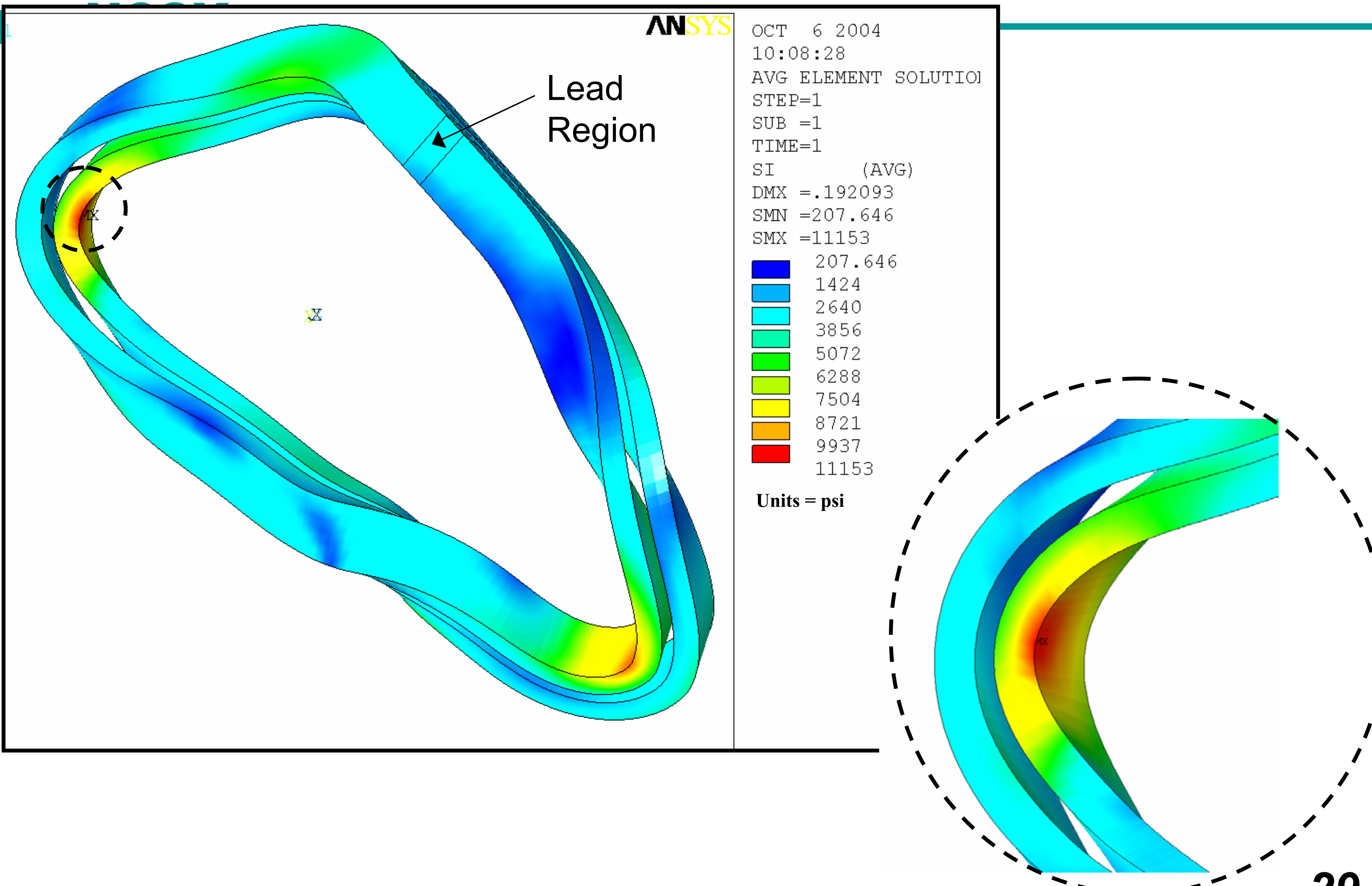




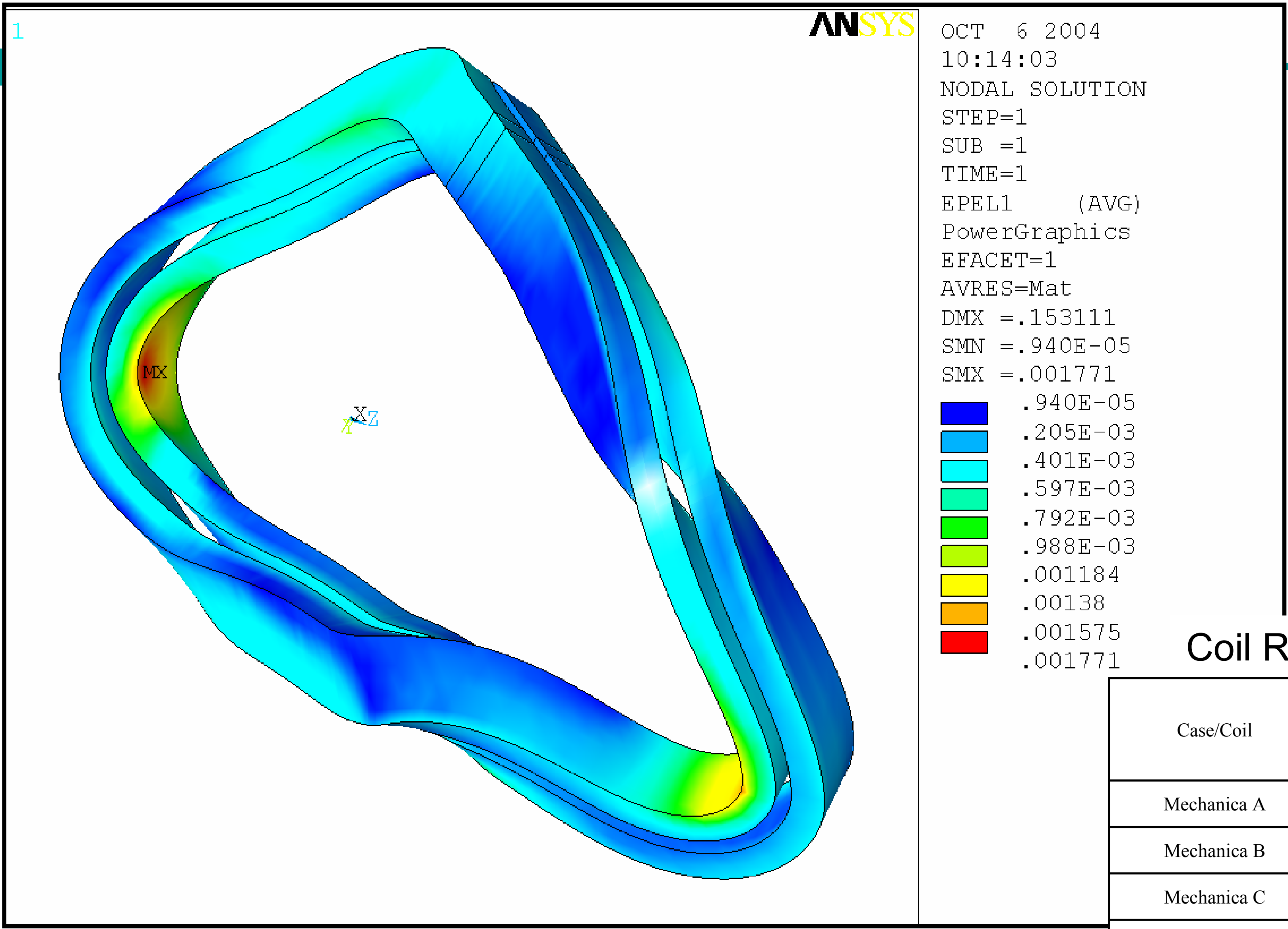
Linear Results for 31.5 kamps/turn

Very local Max Stress occurs at joint of restrained leg.

Stress Intensity of Winding Pack



Max Principle Strain



Coil Results

Case/Coil	Max Principal Strain (mm/mm)
Mechanica A	0.0011
Mechanica B	0.0012
Mechanica C	0.0015
Ansys A	0.0013
Ansys B	0.0010
Ansys C	0.0012

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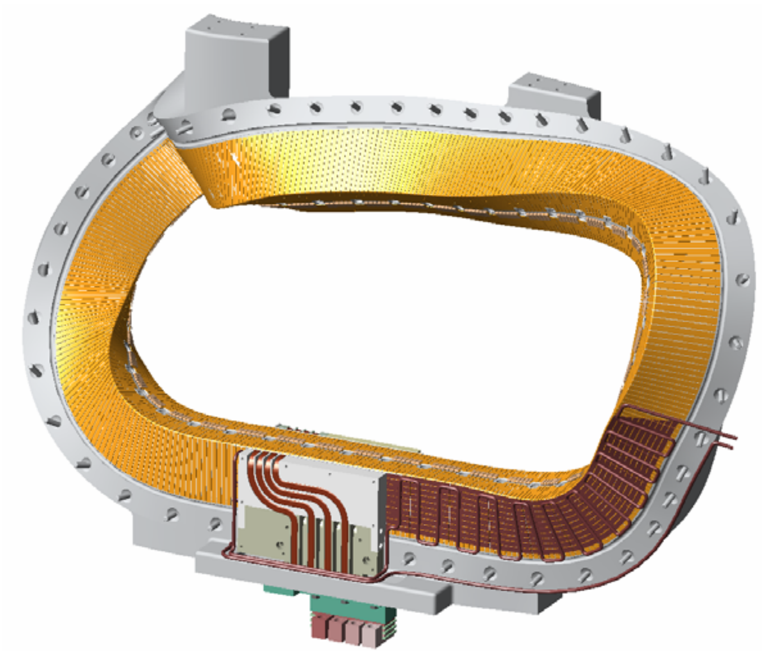
Twisted Racetrack Summary				
	Current (kAmps)	Max Stress Tee (ksi)	Max Stress winding (ksi)	Max principle strain (in/in)
Linear	42	44.7	18.9	0.002996
Linear	33	21.8	11.1	0.001771
non-linear	42	73.8	13.3	0.002987
non-linear	33	41.5	7.7	0.001656

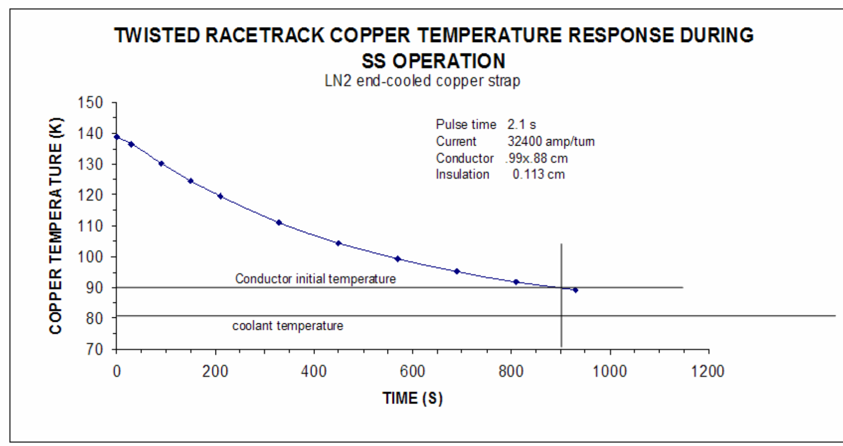
Real Coils [2T high Beta loading applied.]				
Coil	Winding Stress (ksi)	Shell/Tee Stress (ksii)	Max Principal Strain (in/in)	Gap [Laterial] (mm)
Mechanica A	10.5	24.7	0.0011	0.0889
Mechanica B	11.5	39.0	0.00012	0.5842
Mechanica C	12.9	32.0	0.0015	0.8128
Ansys A	11.5	33.5	0.0013	0.2
Ansys B	9.6	36.1	0.001	0.5
Ansys C	11.0	32.9	0.0012	0.6

Coil Cooling

- Lumped capacitance calc indicates 2-sec pulse at 32-kA/turn will heat WP to 125-K
- Cool-down time slightly longer than 15-min, ratchets to 90-137K SS
- Minimal rise in LN2 temp (6.7-C)

	Modular Coil Type			
	A	B	C	TRC
No. cooling circuits / coil	8	8	8	8
Coil one-turn length (in)	291	283	263	144
Circuit length w/o bends (in)	146	142	132	72
Depth of winding pack (in)	4.5	4.5	4.0	4.0
No. switchbacks / circuit	49	47	44	24
Total circuit length (in)	364	354	307	168
Total circuit length (ft)	30	29	26	14
No. 90-deg bends	97	94	88	48
Line diameter (in)	0.25	0.25	0.25	0.25





P. Goranson

Conclusion

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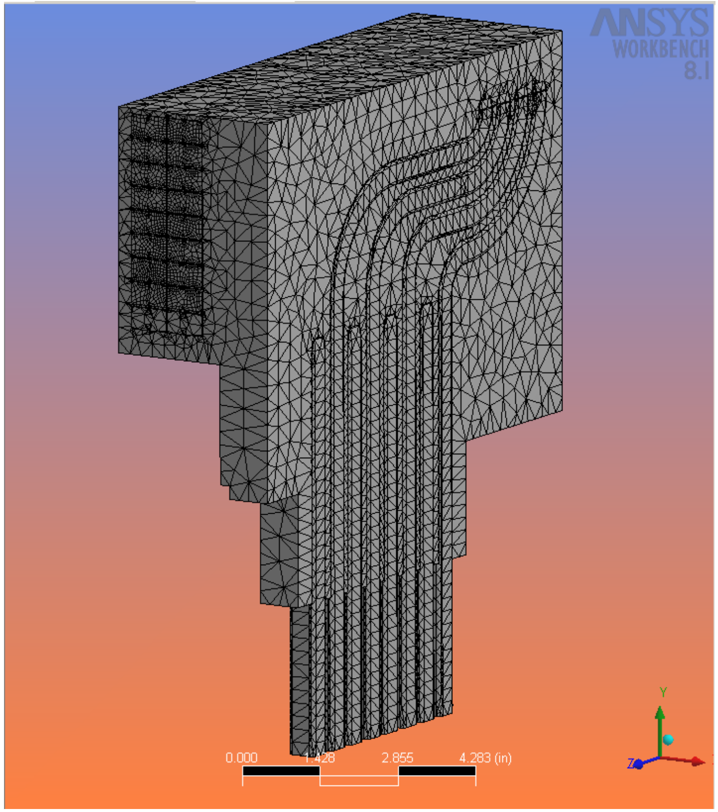
- TRC design complete except for chill plate developed shapes, tube and fringe revised layout
- EM and structural analysis of leads needs to be completed

Next topics –

- Fabrication (J. Chrzanowski)
- Testing (B. Nelson)
- Schedule



ANSYS mesh of winding block assembly