MERIT Collaboration Meeting

October 17,18,19 2005

15T Pulsed Magnet for Mercury Target Development

Neutrino Factory and Muon Collider Collaboration

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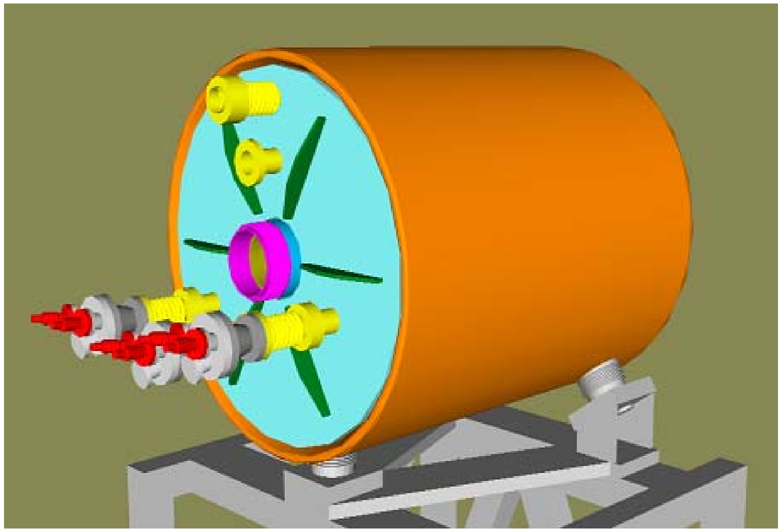
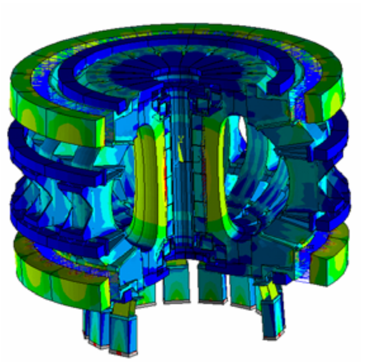
With Contributions from David Nguyen of CVIP, Dave Rakos of Everson, and Bob Weggel

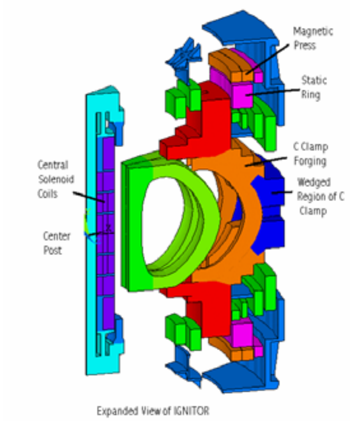


MERIT Pulsed Magnet –Inertially Cooled , 80K LN2 Cooled Between Shots

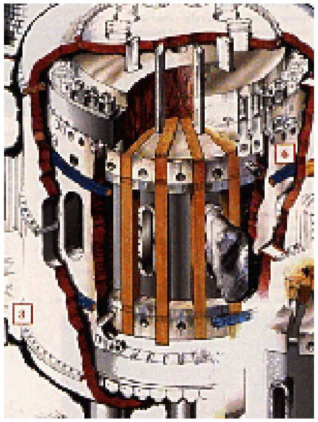
BNL pulsed magnet design builds off of copper magnet experience in fusion research:



FIRE – Preconceptual Design and Snowmass Review. Inertially Cooled Beryllium Copper , LN2 Cooling Between Shots, with a Helium Purge to Limit Activation.



IGNITOR – Snowmass Review. - Inertially Cooled Copper , 30K He Gas Cooled Between Shots.



Alcator C-Mod. MIT-PSFC operating Tokamak –Inertially Cooled, LN2 cooled between shots.

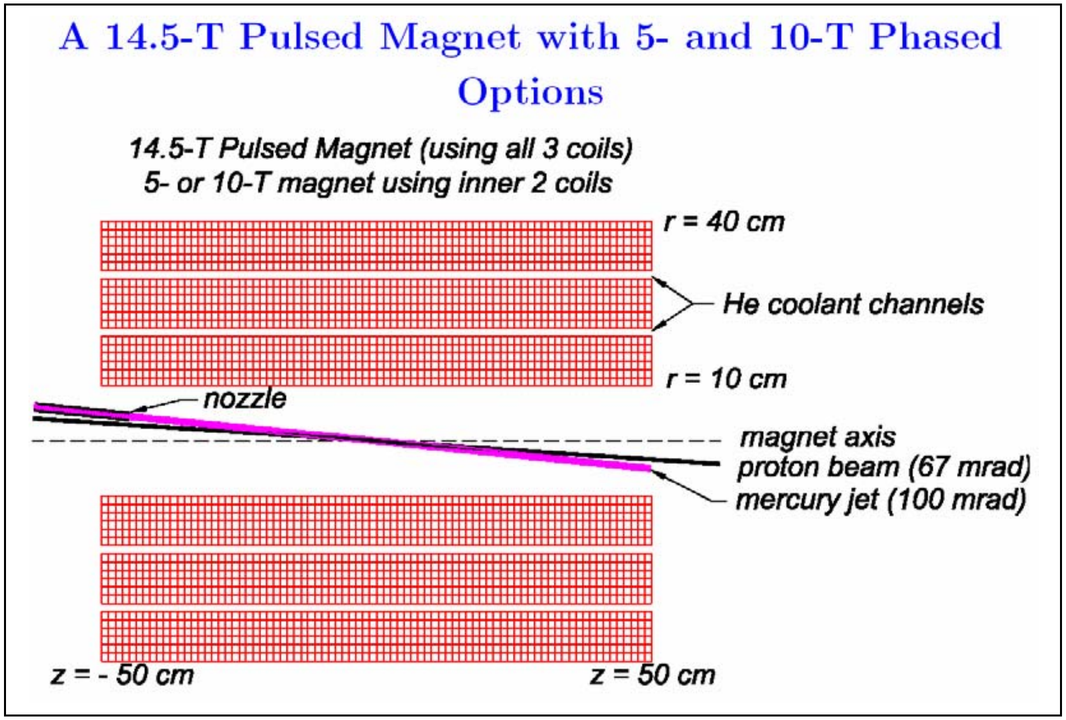
Cost issues dictated a modest coil design.

Power supply limitations dictate a compact, low inductance, high packing fraction design.

A three segment, layer wound solenoid is used for the pulsed magnet. External segment leads allow series and parallel connections.

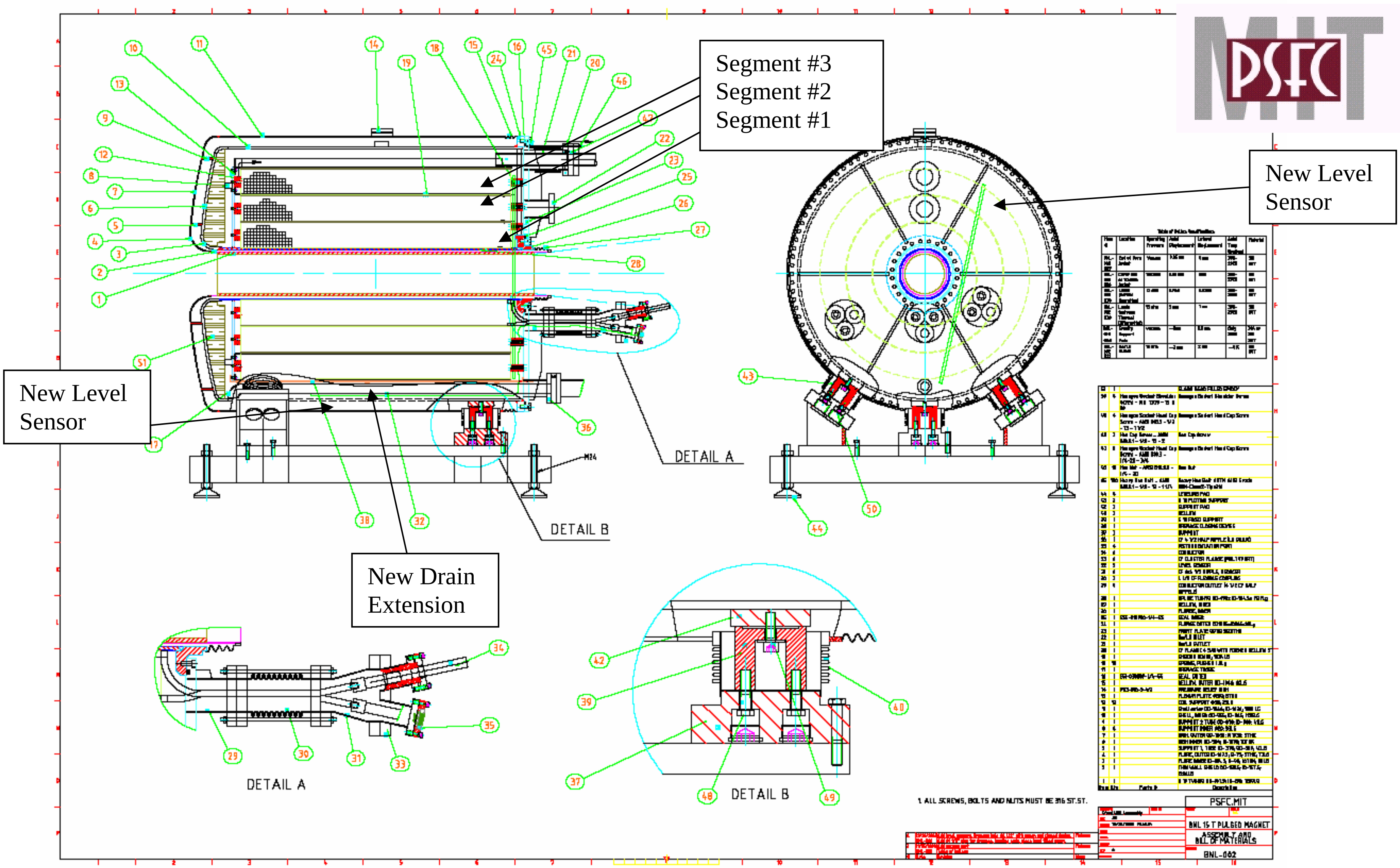
The conductor is half inch square, cold worked OFHC copper.

The coil is inertially cooled with options for liquid nitrogen or gaseous Helium cooling between shots. Coolant flows through axial channels in the coil.



Draft Test plan, Pictures, Drawings and Calculations at: http://www.psfc.mit.edu/people/titus/#BNL%20Memos

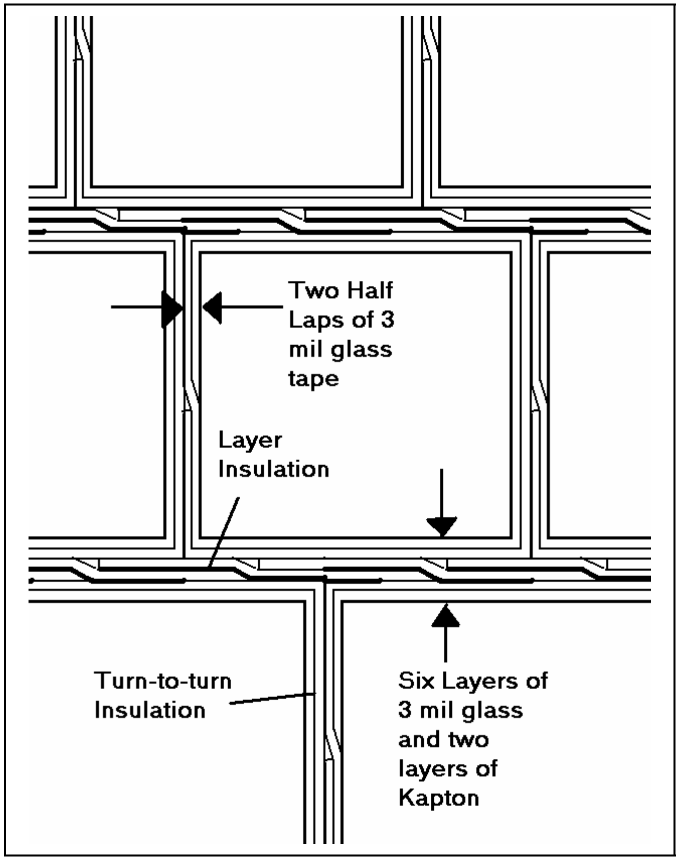
Bob Weggel performed the coil/power supply simulations. He has picked operating temperatures, and basic coil build.



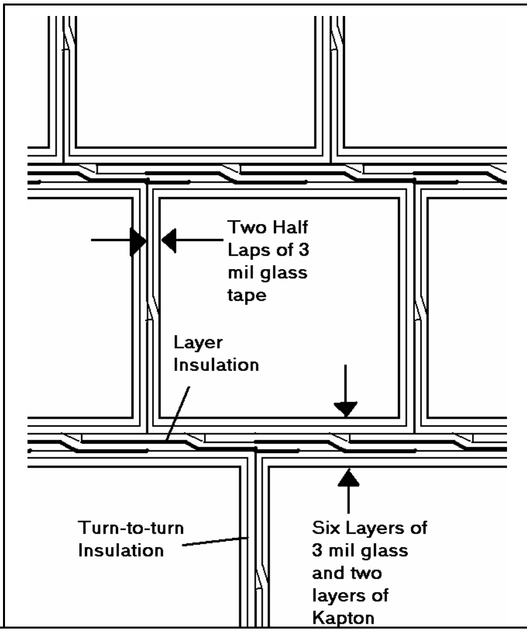
Segment #3
Segment #2
Segment #1
New Level Sensor
New Level Sensor
New Drain Extension
DETAIL A
DETAIL B
DETAIL A
DETAIL B
1. ALL SCREWS, BOLTS AND NUTS MUST BE 316 ST.ST.
PSFC.MIT
BNL 15 T PULSED MAGNET
ASSEMBLY AND BILL OF MATERIALS
BNL-002

Coil Description:

	Mode 1	Mode 2	Mode3
Number of Segments operating:	2	2	3
Number of turns per segment	624	624	624
Total number of turns active	1248	1248	1872
Layers in each coil segment	8	8	8
Turns per layer	78	78	78
Conductor radial thickness	.0116698 m .45944 in	.0116698 m .45944 in	.0116698 m .45944 in
Conductor Axial thickness	.012516m .49274359 in	.012516m .49274359 in	.012516m .49274359 in
Max Operating Field Bore CL	5T	10T	15.0T
Max Field at Magnet			
Max Terminal Current	3600A	7200A	7200A
Coolant Working Fluid	77K LN2	65K LN2	30 K Helium Gas
Terminal Voltage	150V	300V	300V
Layer to Layer Volts	18	36	24
Turn-to-Turn Volts	0.12	0.24	.16
Design Life			1000 full power pulses
Cryostat Pressure -Initial Operating			12 atm
Cryostat Pressure – During Cooldown			15atm max
Initial Temperature	84K	74K	80K
Temp Rise	5.8K	21.7K	48.3K
Final temperature			78.3

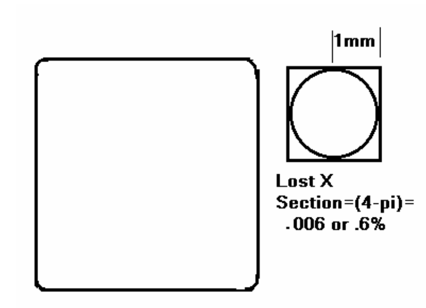


Conductor Dimensions



conductor dimensions with 2 millimeter channel tolerance
radial dim 1.1669799e-2 m .45944 in
Axial dim 1.2515712e-2 m .49274359 in
packing fraction= .92998827

These packing fractions are based on the coil winding pack and exclude the channel. If the 2 mm channel is included, the packing fraction drops to .911.



Corner Radius

- Kapton is the limiting element in the thermal conduction through the coil.
- Kapton was expected to be wound around the conductor. This produced the equivalent of 5 mils of Kapton between layers.
- To improve conduction, Kapton is used only between the layers. Turn to turn voltage is lower than layer to layer. The turn to turn voltage is less than the rule of thumb for He breakdown voltage (1 volt/mil at 1 atmosphere) for the insulation thickness proposed.
- The layer to layer voltage exceeds this however, and would need the Kapton if there was an imperfection in the epoxy/glass insulation. Half laps of kapton and fiberglass, similar to the CS model coil will retain some structural integrity.
- Once a layer of conductor is wound, a layer of Kapton/glass would be wound on the completed layer of conductor. This produces the thermal conduction equivalent of 3 mils of Kapton rather than 5 if the conductor is wrapped individually. Every 8th layer channel strips are layed on.

Keystoning:

H/(2*r)= .012/.1/2=6% (elastic strain) For Plastic bending, (poisson=.5) the Keystoning contraction is 3% at the smallest radius (Same as Everson test bend).

Three Keystone specs are suggested. The keystone geometry for the first segment should be .012/.15/2*.5=2%

The worst case loss in packing fraction is 1%, Average loss is .5%

Keystone allowances in outer two segments are 1.2%, and .86%. Packing fraction losses in outer two segments are .15%, and .007%

Whole Magnet loss of .2%+Corner Loss of .6%=.8%

Voltage Capability

Number of Segments operating:	3
Number of turns per segment	624
Total Magnet Terminal Voltage Spec	700V
Segment Terminal Voltage	233V
Layer to Layer Volts	30
Turn-to-Turn Volts	0.37

The turn to turn insulation has 4 layers of 3 mil fiberglass tape, for a total of 12 mils of insulation thickness. This is postulated to crack, and He gas to have penetrated. The standoff possible with such a crack is 1 volt per mil, based on the rule of thumb for He breakdown voltage at 1 atm. - or 12 volts.

The layer to layer insulation is 6 layers of 3 mil fiberglass and 2 layers of 1 mil Kapton. This is ~20 mil or .508 mm thick insulation. The ITER design limit for an insulation system which includes both barrier(Kapton film) and fiberglass-epoxy is 3kV/mm (with a safety factor of 10). Based on this, the layer to layer voltage that our system could withstand is 3000*.508 or 1524 volts. This same insulation is used for voltage to ground, so this sets the voltage limit for the magnet.

Most of the insulation that has been specified for the BNL magnet is either a practical minimum - the half lap of fiberglass on the conductor, or to cover "manhandling" of the winding process. The layer to layer insulation system with 20 mils total thickness could only handle 20V if it cracked and filled with He.

The Kapton, which is quite ductile at room temp is supposed to maintain a film barrier after being crushed during winding. – It survived well in Everson test bend.

✓ Engineering Calculations are "Complete" –Reviews and small refinements continue

- An example, from a BNL review: - Cryostat bolting thread shear.

Design Pressure= 15 atm

```
Allowable Bolt Stress= 57000
Bolt Ultimate Strength= 110000
Bolt Yield Strength= 95000
Number of Inner Bolts: 24
Number of Outer Bolts: 96
Bolt Tensile Area= .1416   Bolt Thread
Shear Area= .53014376
Tensile Load on inner Cyl: 110378.99
lbs
Tensile Load on inner Cyl: 491009.75 N
Inner Bolt Tensile Stress 32479.694
Inner Bolt Pull Out Shear Stress
8675.2406
Inner Bolt Tensile Factor Of Safety
1.1289105
Inner Bolt Shear Factor Of Safety
1.8443293
Inner Cylinder Stress Based on Bolt
Loading 178.33716 MPa
Tensile Load on outer Cyl: 138553.87
lbs
Tensile Load on outer Cyl: 616342.83 N
Outer Bolt Tensile Stress 10192.581
Outer Bolt Pull Out Stress 1837.6278
Outer Bolt Factor Of Safety 3.5973878
Outer Bolt Shear Factor of Safety=
8.7068776
Outer Cylinder Stress Based on Bolt
Loading 20.309319 MPa
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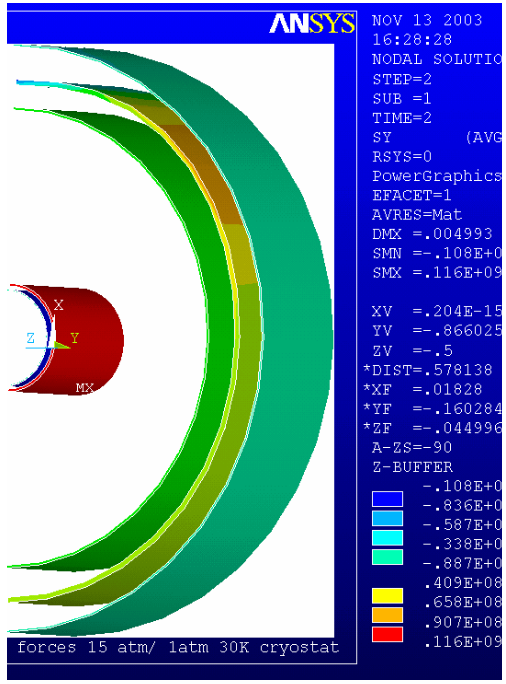


The axial tension in the bore tube is 116 MPa, which is lower than the bolt Basic program calculations predict (178 MPa). The reported inner bolt tension

FED-STD-H28
31 March 1978

coefficient of friction, other combined stresses will be directly proportional to the wrench torque.

Thread Shear Area.—The diameter corresponding to the effective thread shear area will vary with the relative unit tensile strengths of the materials of the internal and external threads. When the external and internal threads are manufactured from materials of equal unit tensile strength, failure will usually take place simultaneously in both threads at or near a diameter equal to the basic pitch diameter. The shear area (AS) for external and internal threads made of such materials can be computed from the following formula:

$$AS = 3.1416E\frac{L_e}{2}$$

where

E = basic pitch diameter
L_e = length of engagement at basic pitch diameter.

When the unit tensile strength of the external thread material greatly exceeds that of the internal thread material, as in the case of a threaded hole in a cast aluminum block mated with a 100,000 psi ultimate strength material bolt, the shear area of the internal thread (AS_n) can be computed from the following formulas:

(1) For simplified calculations that will provide shear areas within about 5 percent of those given by the precise formula shown below, the shear area of the internal thread may be computed as follows:

$$AS_n = 3.1416E\frac{3L_e}{4}$$

Excerpt from ref 15, the Federal Standards for Screw Threads, showing the recommended thread shear area for strong bolts in a weak threaded hole.

Conductor Allowable and Cold Work Spec

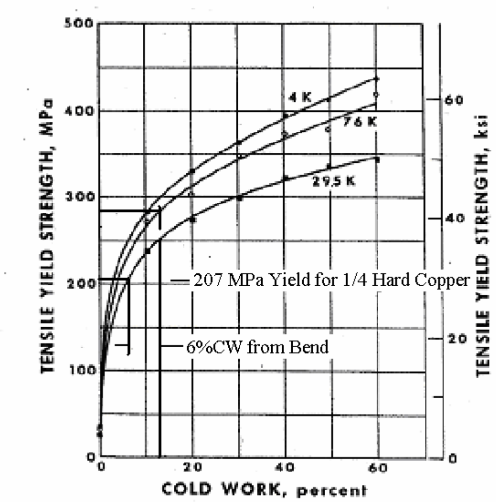
For Fusion magnets the inner skin of the solenoid is allowed to reach the yield - Treating this stress as a bending stress with a 1.5*Sm allowable with Sm based on 2/3 Yield.

Interpolated values:, Work hardened copper-, OFHC c10100 60% red

temp deg k	77	90	100	125	150	200	250	275	292
yield	374	369.	365.	356.	347.	328.	317.	312.	308.
ultimate	476.	466.	458.	439.	420.	383.	365.	356.	350.

The conductor is specified as half hard in the spec. Everson has purchased ¼ hard conductor to ease the bending operation, with the expectation that the cold work associated with the forming process will produce an adequate yield. ¼ hard copper would have a yield of 30 ksi or 207 MPa. 160MPa is needed.

From the Figure this would correspond to cold work of about 15%. The bending operation would introduce an additional 6% (see section 4.4) Hardness is assumed to correlate with %cold work.

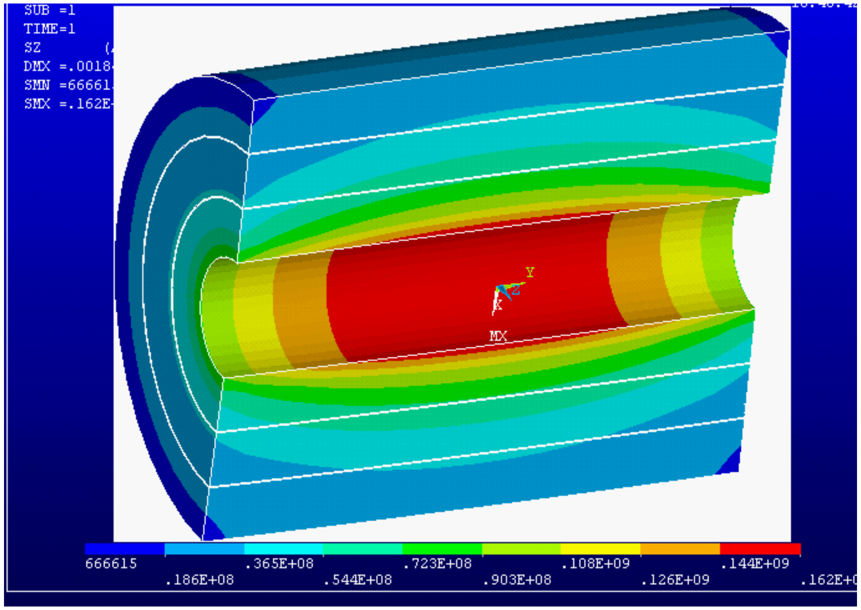


Copper Properties Marked-up with Expected Yields. For Segment 1 ID with CW at 100 K, about 270 MPa would be expected

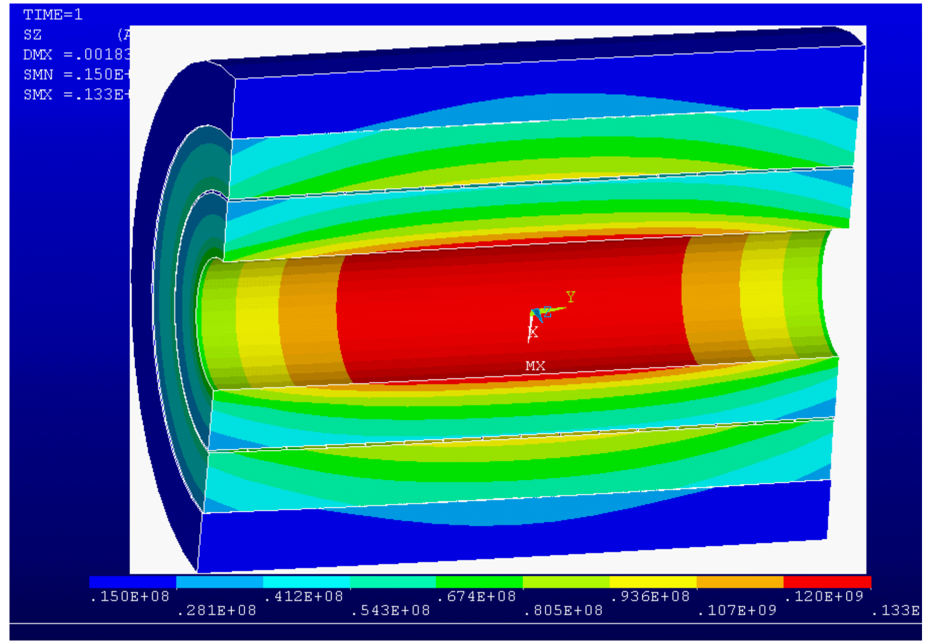
High Strength Bolts Specs (Needed Especially for Inner Closure Head Bolt Circle):

ASTM A193 Grade B8M - Class 2 - Type 316
for 3/4" diameter and under: Su = 110,000 psi , Sy = 95,000 psi

Coil Stress Analysis



Hoop Stress, all coil segments fully energized. The Von Mises stress plot is similar with a peak of 165 MPa, Tresca is 166 MPa.



Re-run with gap elements the hoop stress went down to 133 MPa

The full performance configuration is limiting in terms of hoop stress and equivalent stress. It also has some radial stresses that will have to be mitigated with parting planes at the segment boundaries, or within the winding.

Operational Thermal Stresses.

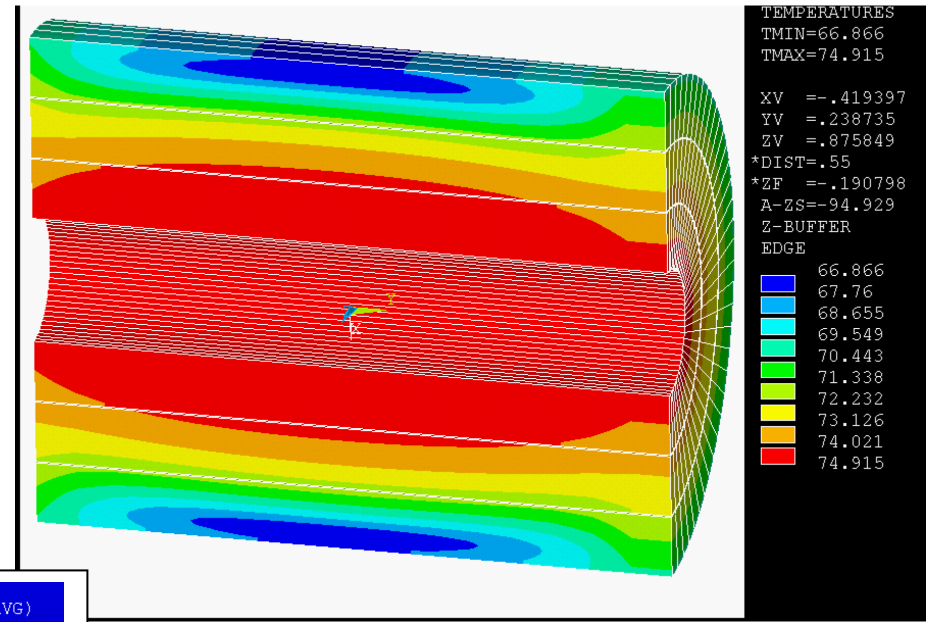
Although a constant current density coil, heat-up during a pulse is not uniform due to the magneto-resistive effects.

Temperatures were calculated for the 15 sec ramp-up, and 2 sec flat top and a 7 sec ramp down. The NIST Kohler plot and fitted equation was used for the magneto-resistance.

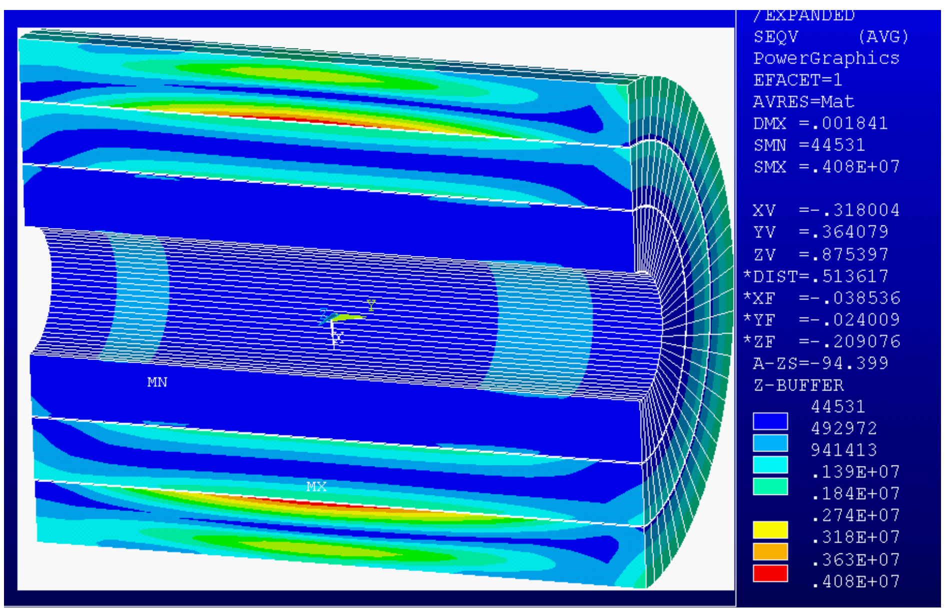
In my calculations, the temperatures were low compared with Bob Weggel's. The difference was the conservatism the Bob applied to his analysis from the scatter of the Kohler plot.

To make some progress on the stress calculations I stretched the time scale to come closer to Bob's temperature distribution.

The stresses from this analysis are small, less than 5 MPa.



Temperatures with magneto-resistive effects, 15.0T

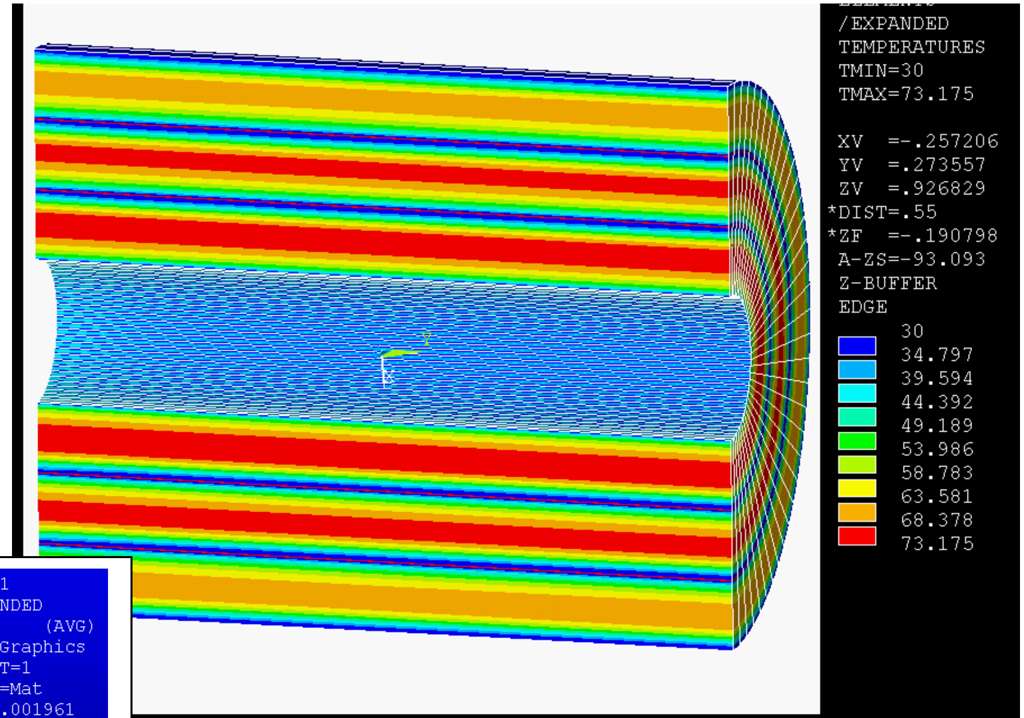


Resulting VonMises Stresses due to Temperature including the magneto-resistive effects, 15.0T.

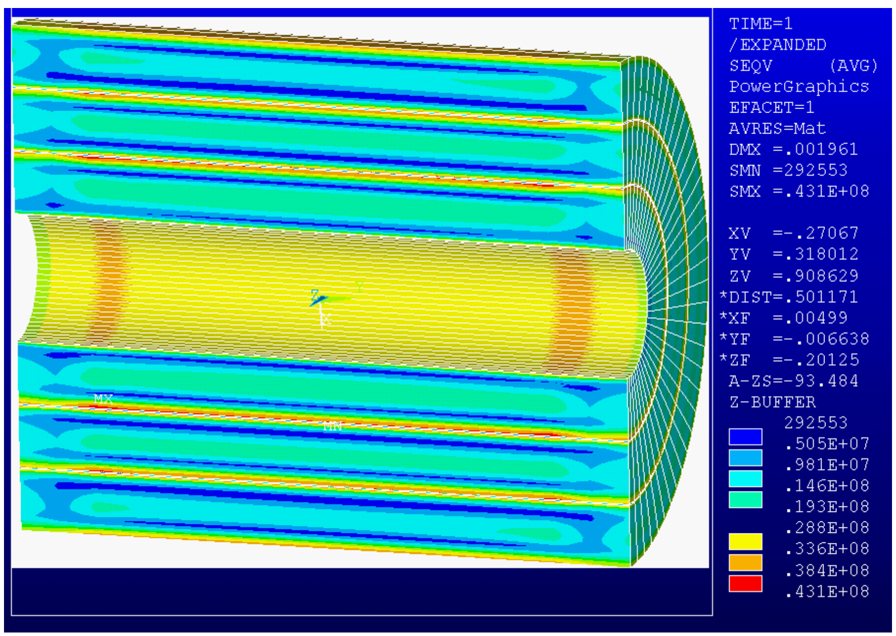
Cooldown Stresses –Von Mises

The channels were held at 30K and the temperature distribution was obtained by averaging nodal temperatures with the final temp distribution from the heat-up calculations. This is not rigorous, and is essentially assumed, but it is representative of temperature distribution, and will serve to provide guidance for further analysis and design.

The VonMises stress is relatively modest, at 43MPa



Cooldown Temperature distribution

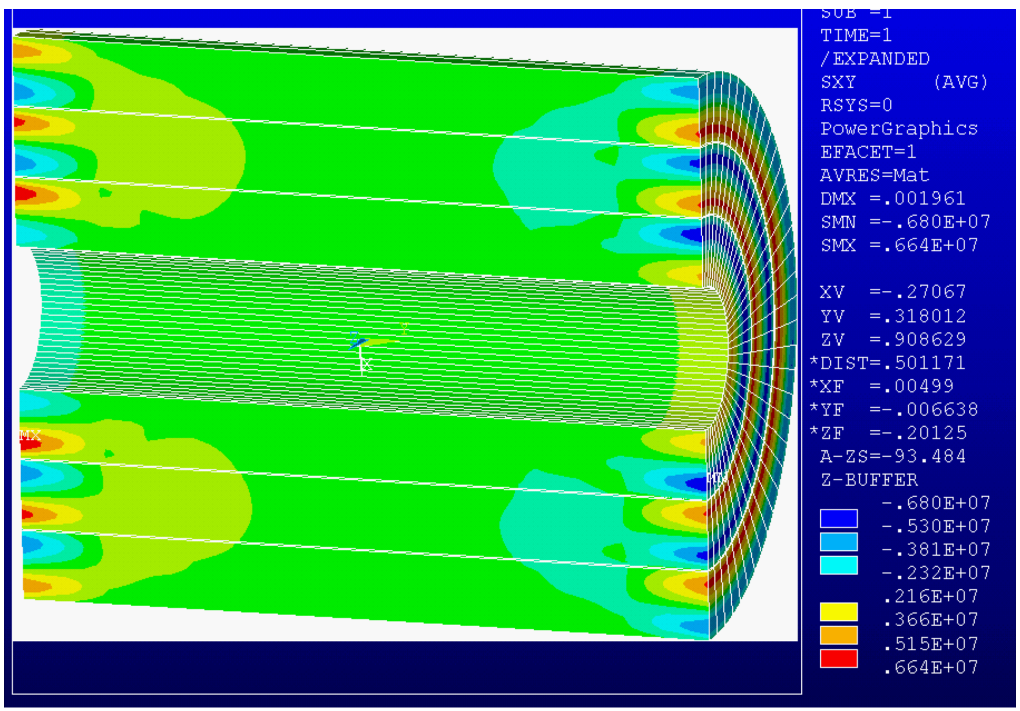


“Smeared” VonMises stress

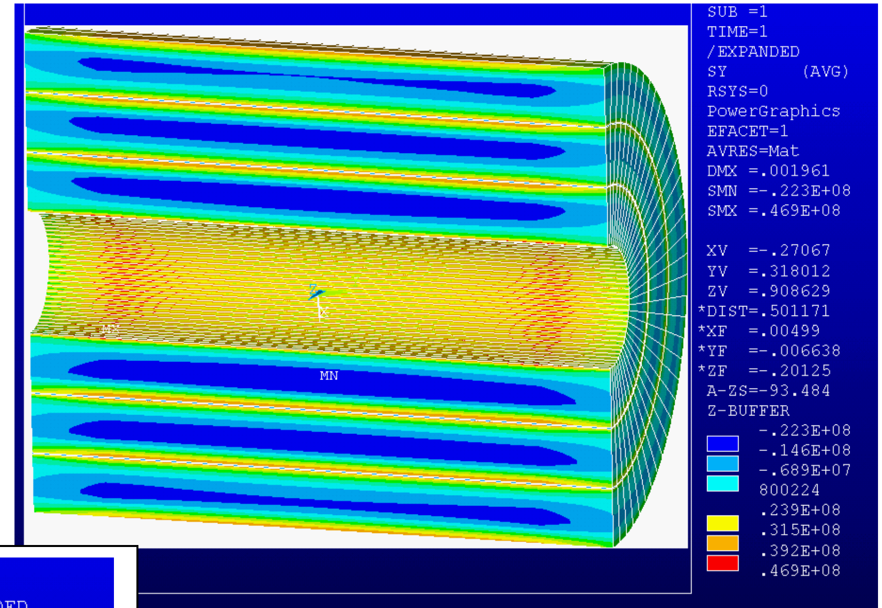
Cooldown Stresses –Shear and Axial Tension

The axial tension near the channels is approaching 50 MPa, beyond the design capacity of epoxy bonded systems. Some provision will have to be made to either throttle the cooling gas to limit the channel temperature or design to allow the bond failure.

The shear stresses that peak at 7MPa are within the usual allowables for insulation systems, for which design allowables are in the range of 15 to 30 MPa (with no aid from compression)

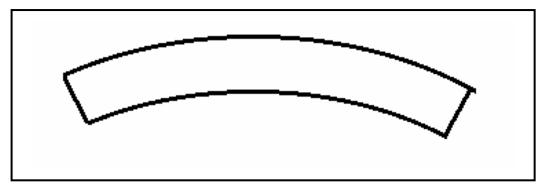


Shear stresses due to the cool down temperature distribution



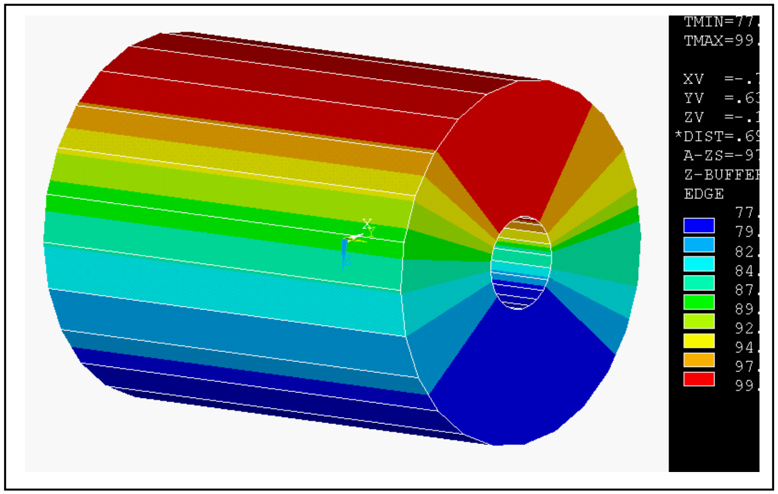
Axial tension

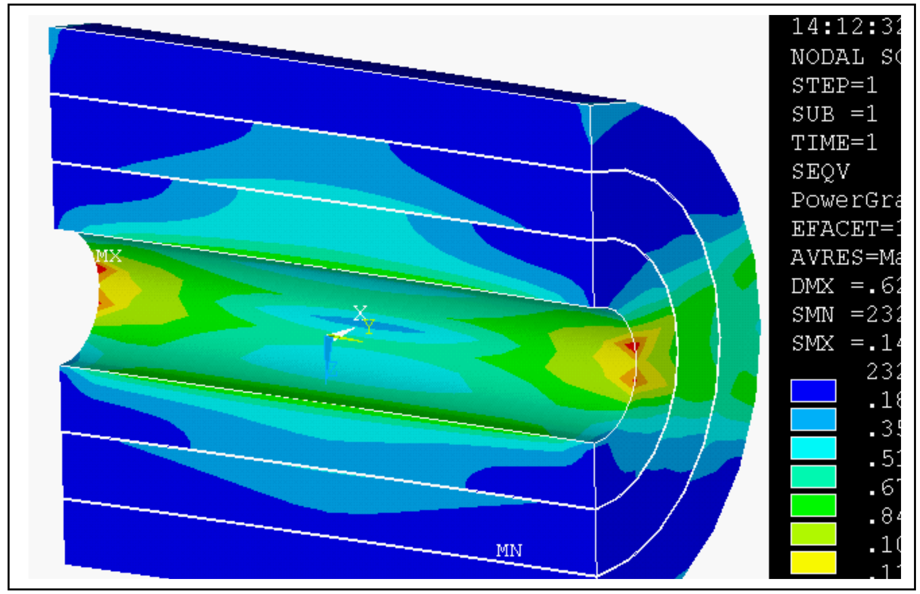
The Axial Tension will be relieved with Kapton "Arcs" every eighth turn.

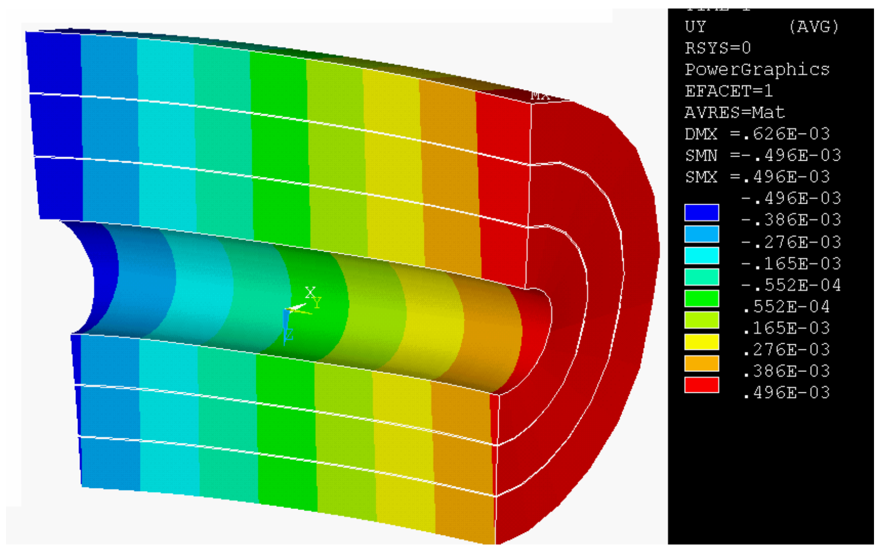


Cooldown Stress, Global Thermal Differential.

If there is stratification of He gas or if LN2 floods the bottom of the cryostat there could be a significant thermal differential between top and bottom of the coil. A 77 to 100 K variation is assumed. The resulting 15 MPa stress is Acceptable

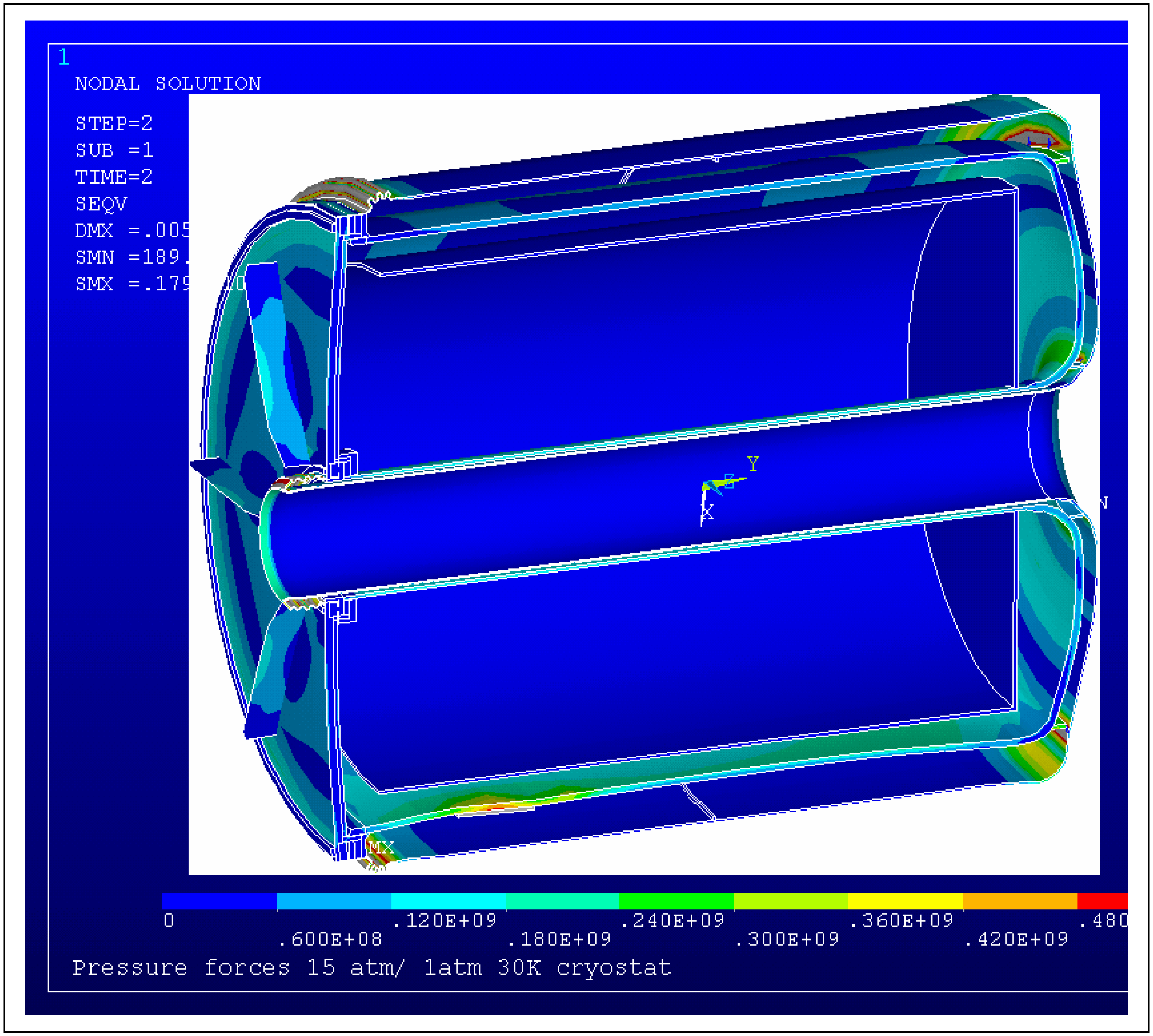






Resulting Displacements

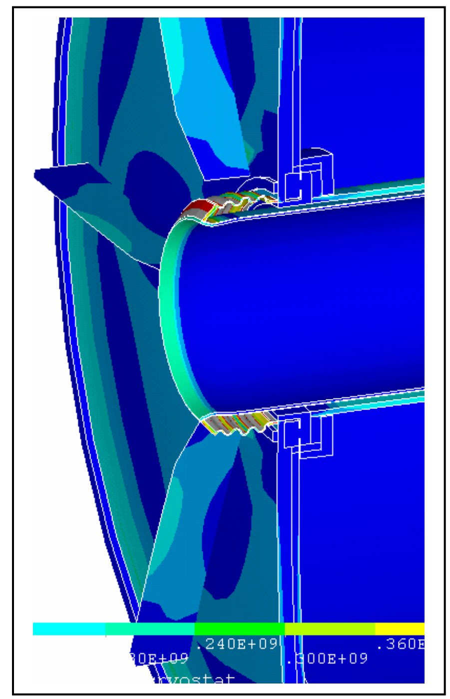
Latest Cryostat Model



Cover Stiffeners are 1cm thick.

Updated bellows models are "representative" They are purchased based on a performance spec.

**Discontinuity stress(<400 MPa) at Cryostat flare to dished head meets 3Sm
allowable at the weld of 480, Membrane stress meets 160 MPa allowable**



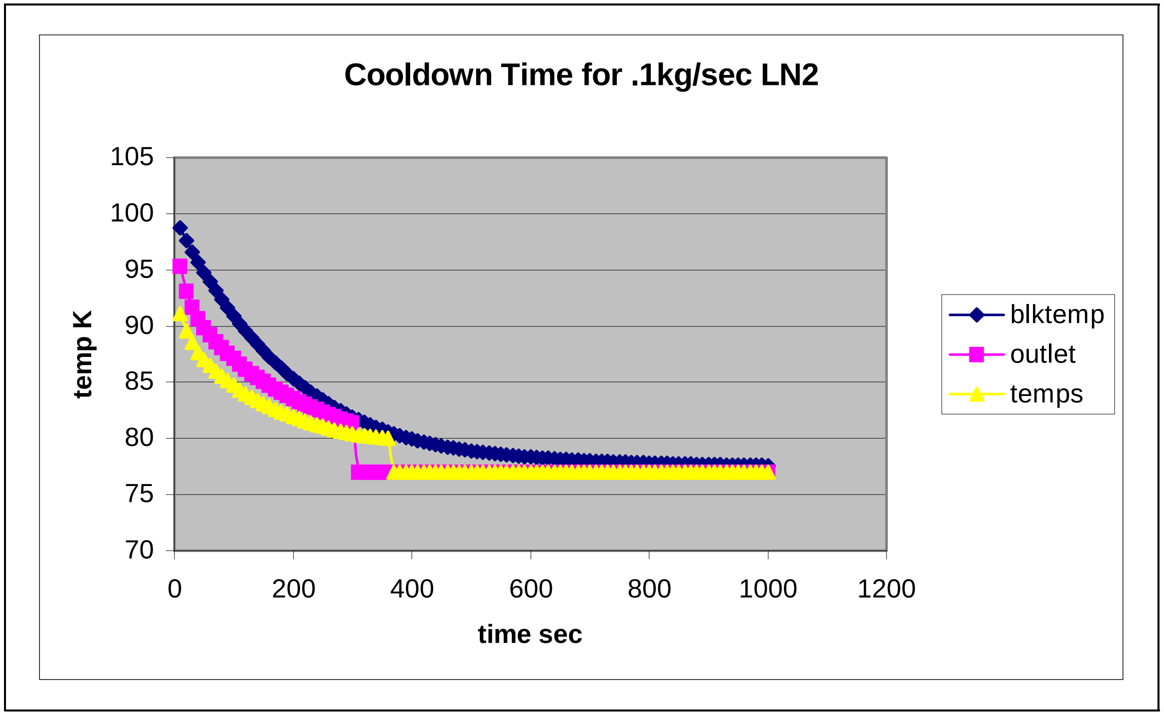
Two Phase N2 Cooling

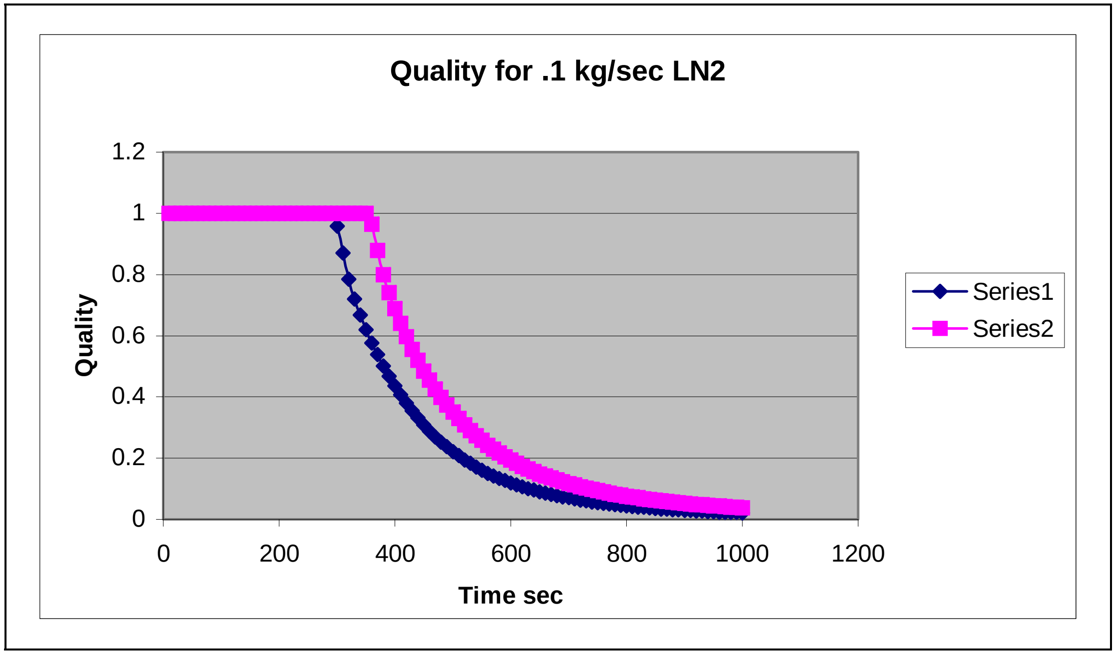
Axial Flow Is Still Assumed in the Analysis.

Design Features are Being Added to Encourage Vertical Natural Convection.

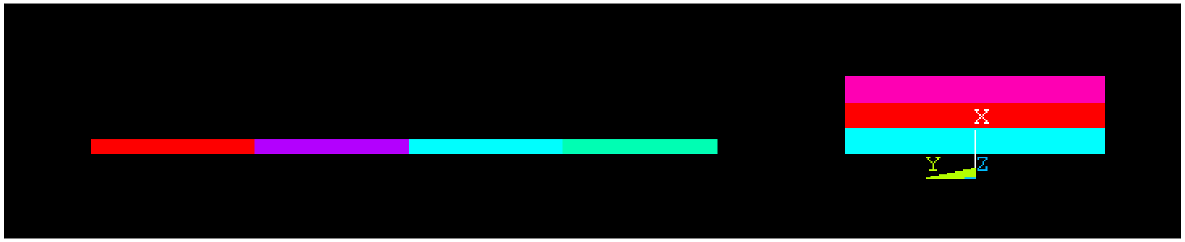
The intention is to control the LN2 flow with a proportional valve to provide only as much LN2 as is fully vaporized by the surface heat flux. After 700 sec, this would be only .1 * .1 = .01 kg/s

For the sub-cooled option requiring the use of a vacuum pump. Directly vent the cold gas until .05kg/sec LN2 is reached.

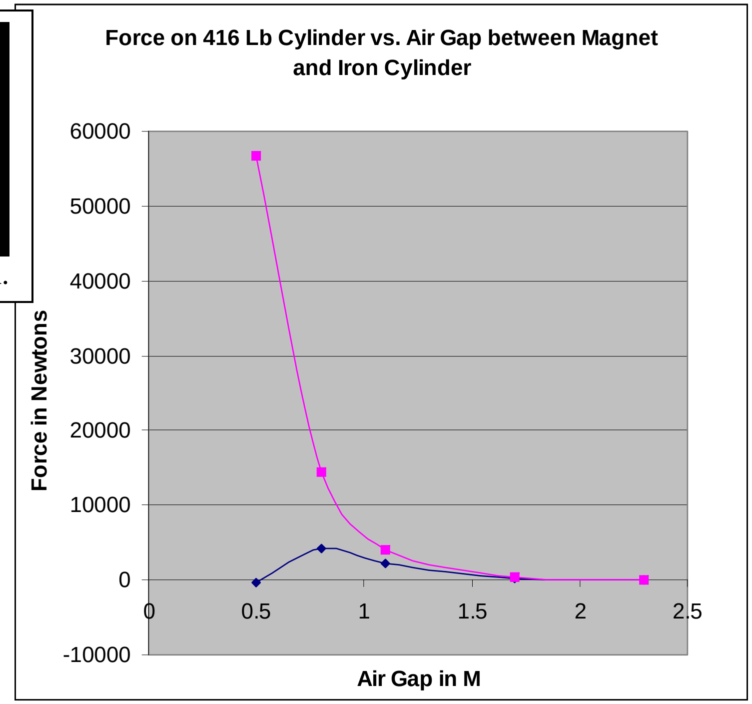


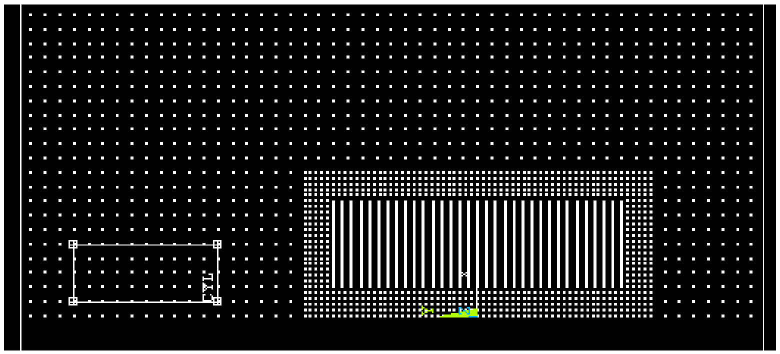


Loads on Iron Cylinders

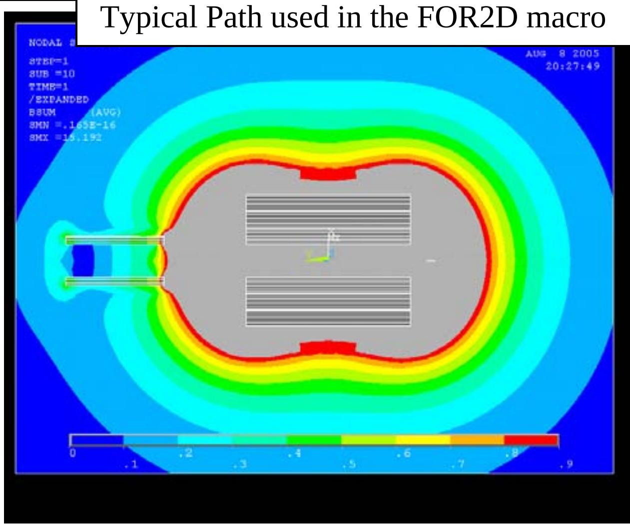


Model (shown without air) with 4 material regions used in the parametric study of cylinder position.

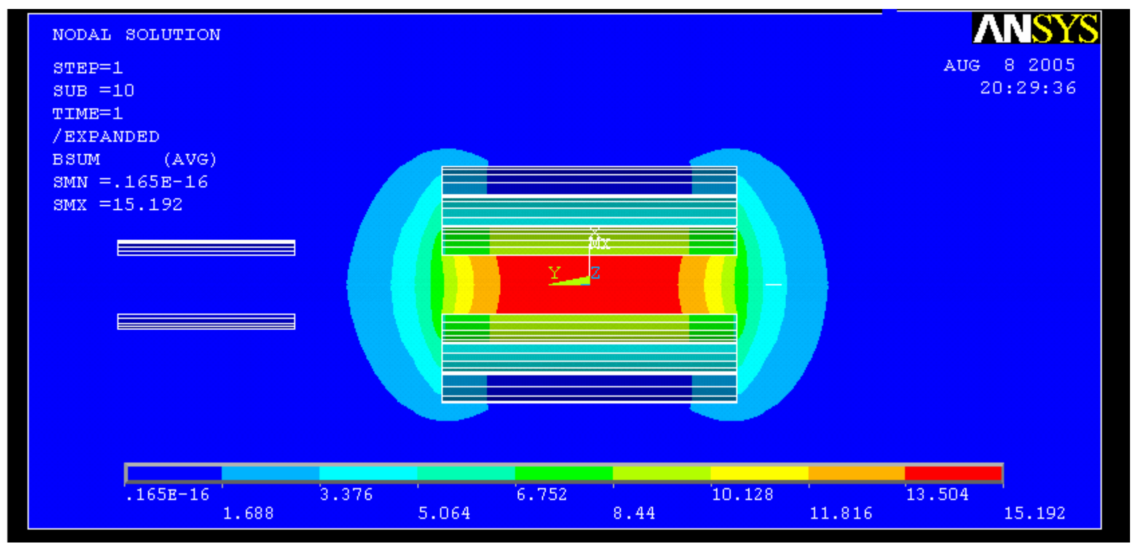




Typical Path used in the FOR2D macro



Field distribution for a .5m air gap between magnet and iron cylinder. The red contour is .9T

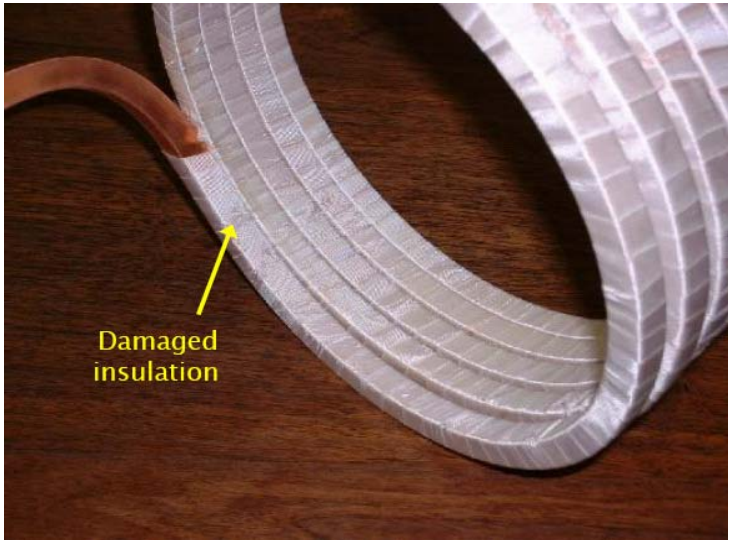


Field Distribution Near the Magnet with a .5 m air gap between magnet and cylinder.

Fabrication Status

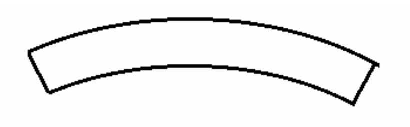
Winding Machine with the beginnings of segment #1

Everson autoclave (Box with Doors) Epoxy pumping equipment, and vacuum pumps) – Used for all three coil segments



Results of the test bend. Roller geometry was improved to avoid fiberglass tape cuts.

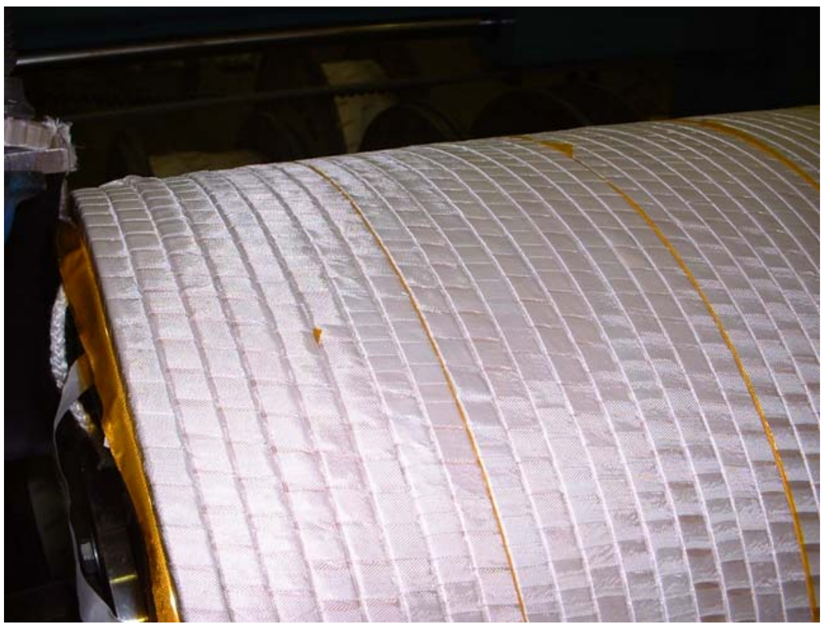
Segment #1
As of Thursday January 27th 2005:



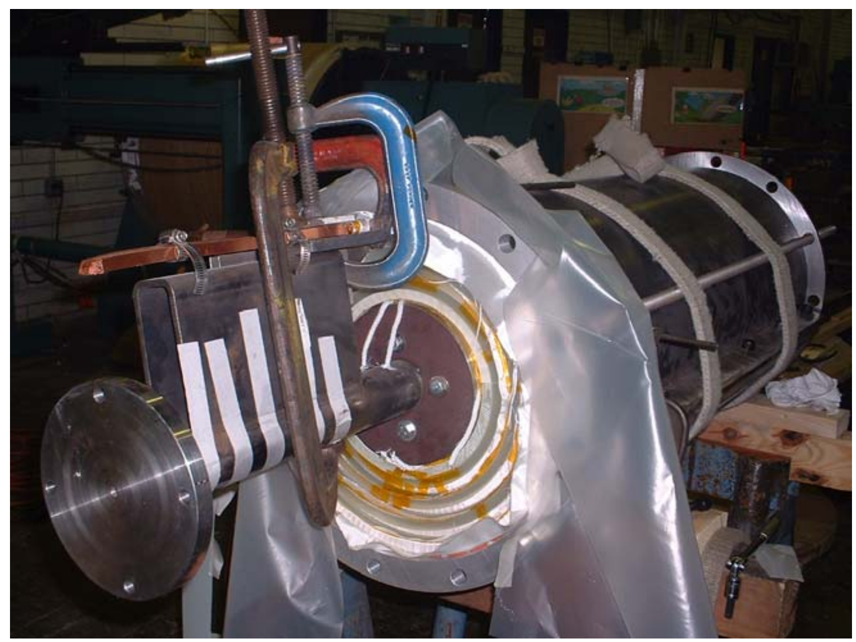
Kapton arc sections inserted between every eighth turn on those layers that face the cooling channels

The inner segment (Segment #1) has been impregnated at Everson and has been sent out for final machining of the OD. – This will be the first test on machinability of the outer rib geometry

Coil Mold for Segment #1. Successfully used for its impregnation



Segment #1 being wound. Photo taken by Dave Rakos at Everson 09-08-04. Kapton layer spaced at every eighth turn relieves axial tension in the layers near the cooling channels. First Layer, Coil Segment#2



Segment 1 showing formed leads and portions of the mold

Segment #1 – Continued

Manufacturing Challenges

Winding ½ hard 12mm square copper on a .1m radius without crushing or cutting the Kapton and/or glass tape.

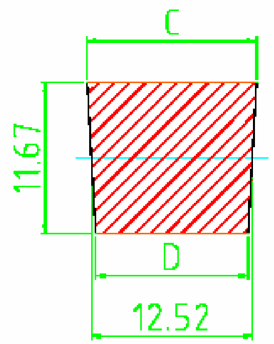
Qualify Annealed Copper Yielding, and "leaning" on next coil
(Insulation strains are a problem)

Accept lesser degree of cold work, and qualify by bending strains and hardness measurements

Pre-roll to an intermediate radius with a roll set then apply Insulation, then wind down

Keystoning

The magnet is constructed of three segments. Different anti- keystoning was specified for each of the three segments based on the mid build radius of curvature. Test winding confirmed the spec, but the actual winding produced a larger effect at the ID than was anticipated.



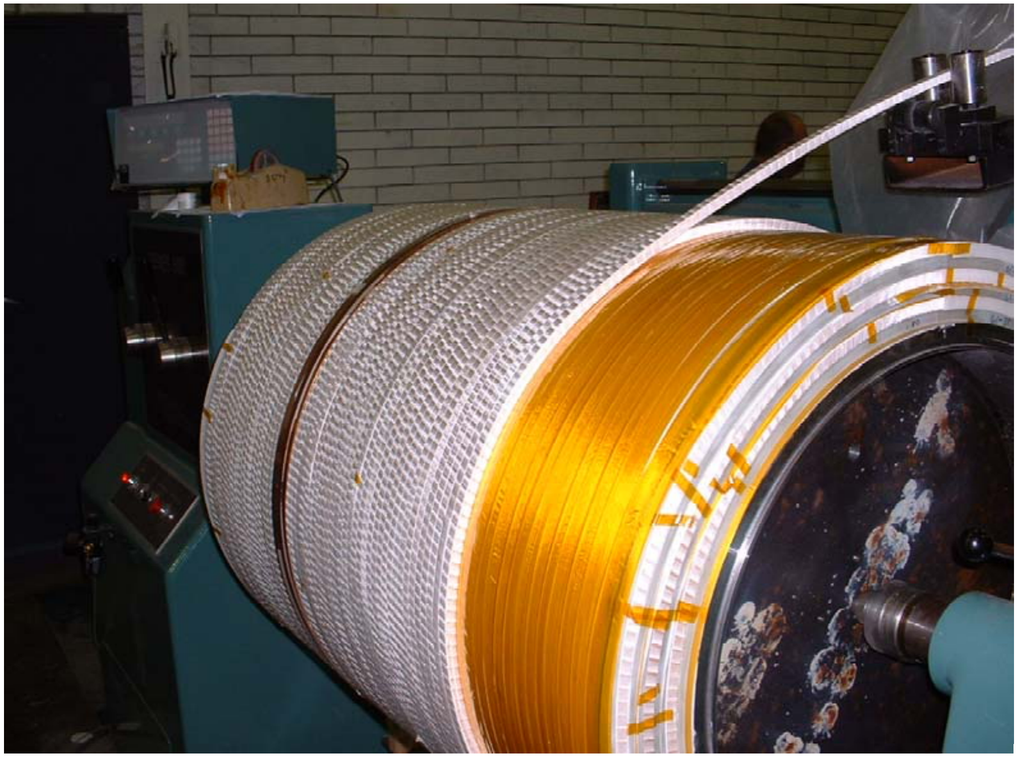
A	C	D
1-st Magnet	12.65	12.39
2-nd Magnet	12.62	12.42
3-rd Magnet	12.57	12.47

Segment #2

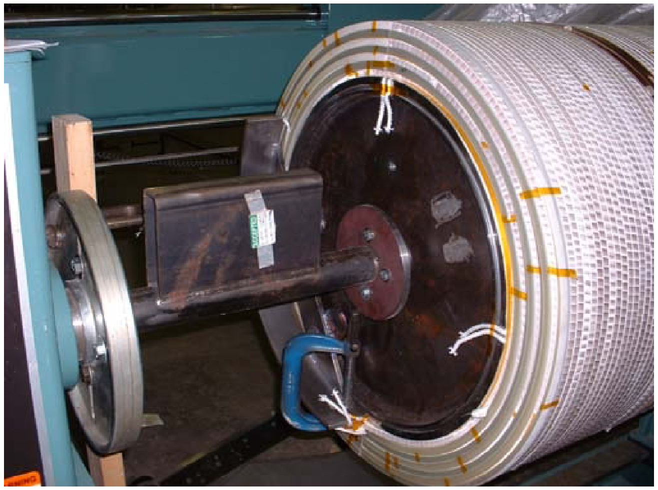
As of Thursday January 27th 2005:

Segment #2 has been impregnated and is cooling. It has not yet been removed from the mold.

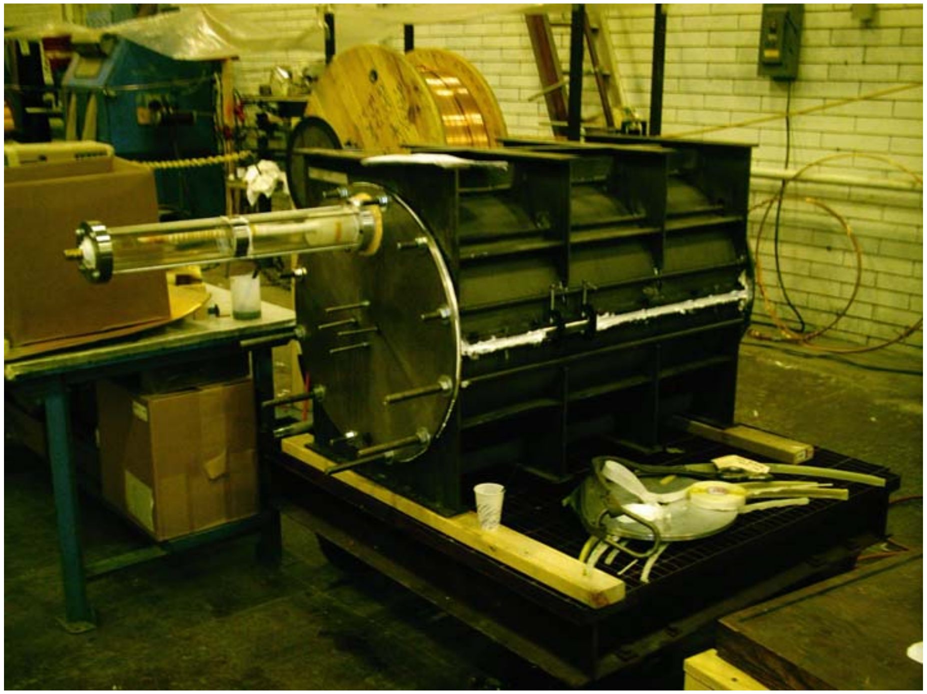
Segment #2 being assembpled in the mold.



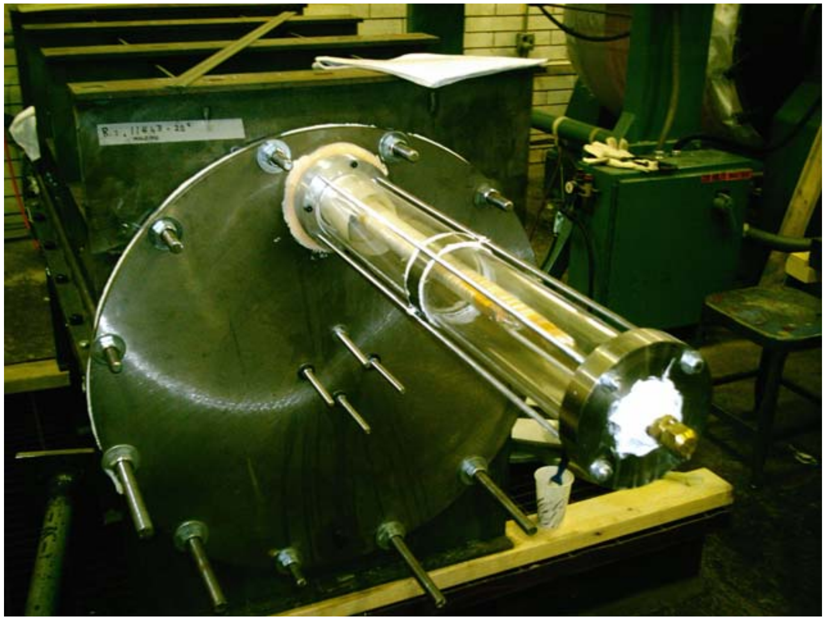
Winding Segment #2



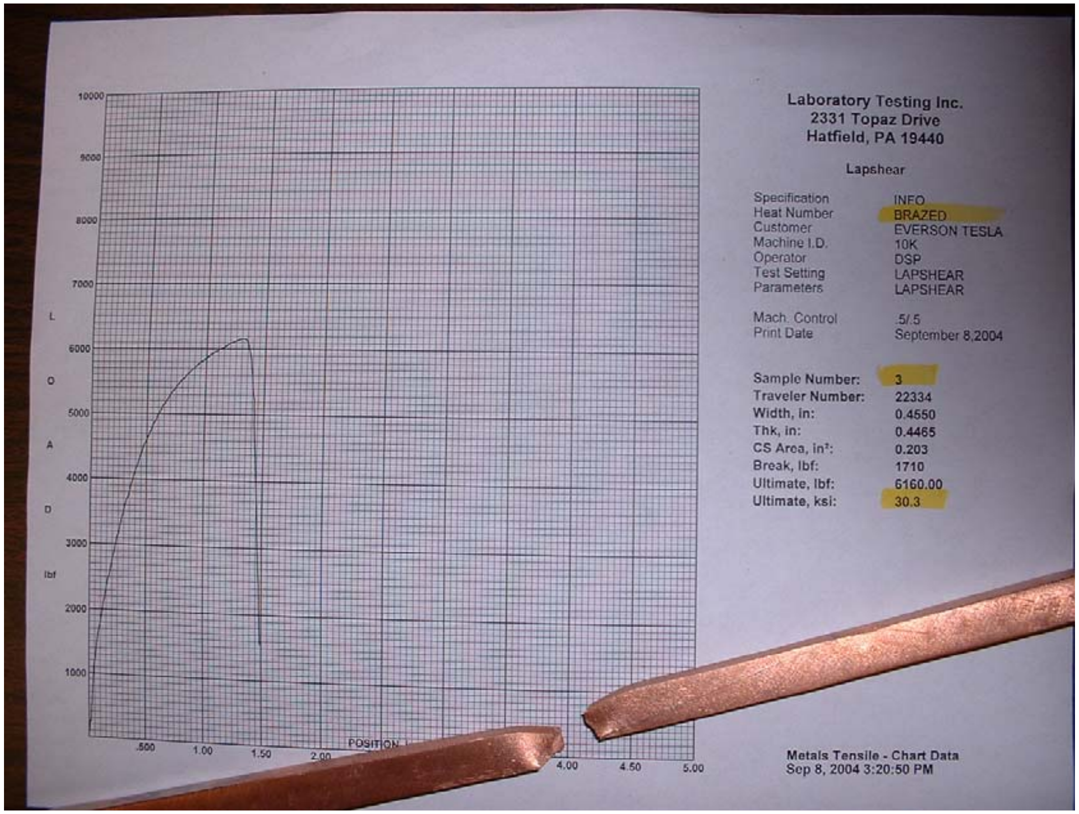
There was a leak in the longitudinal seam weld. This required application of RTV caulk and additional time to wait for the cure. This was to be held at 2 atm fopr 12 hrs prior to impregnation



Segment #2 Mold (with Coil enclosed)

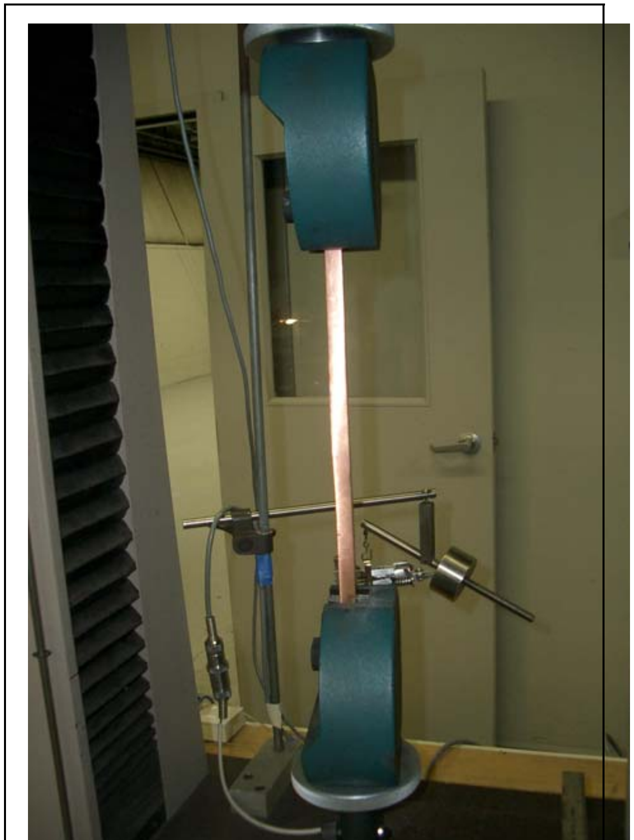


Segment #3 has Silver Solder Joints and these needed to be qualified prior to winding.



Load Displacement plot of Silver Solder Joint.


Faint indication of silver soldered scarf joint

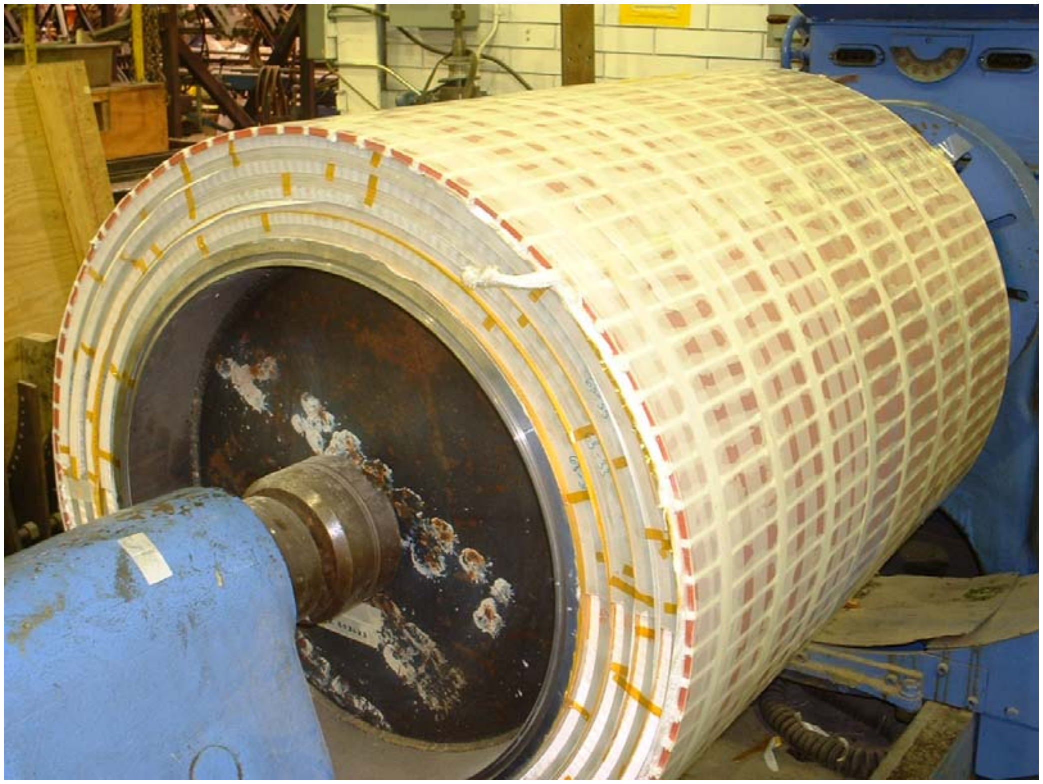

Silver Solder Joint Tensile Test

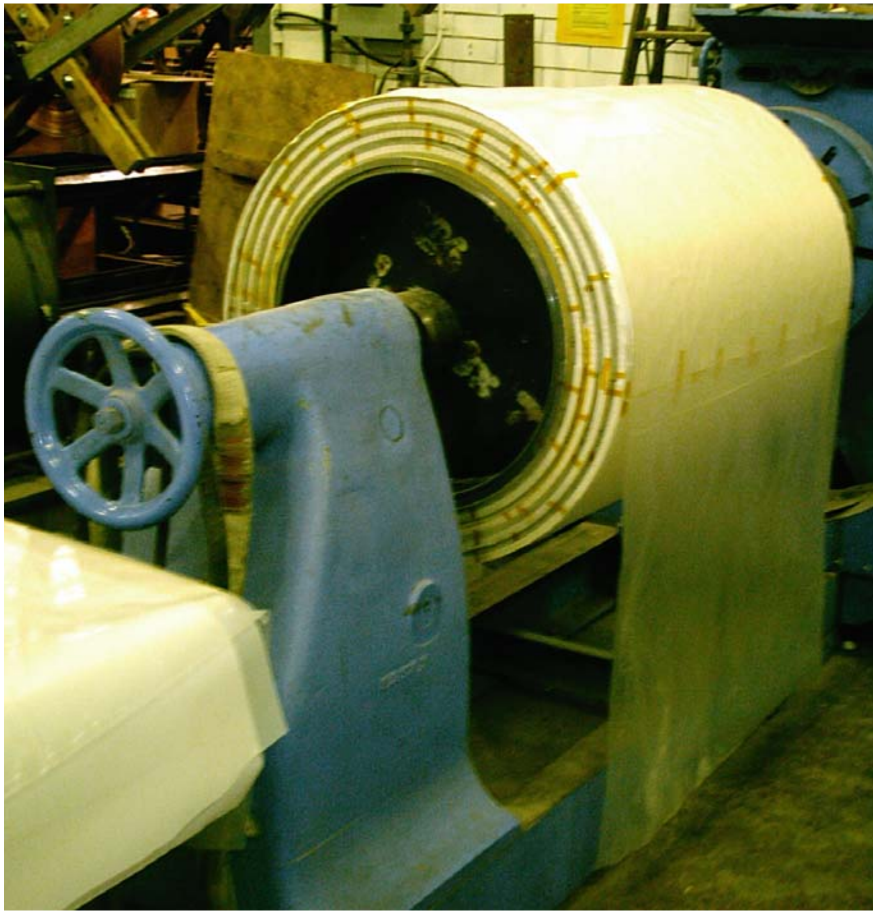
Segment #3

As of Thursday January 27th :

Segment #3 has been wound and the outer “waffle” pattern has been applied. This is scheduled for impregnation Feb 2 to 4

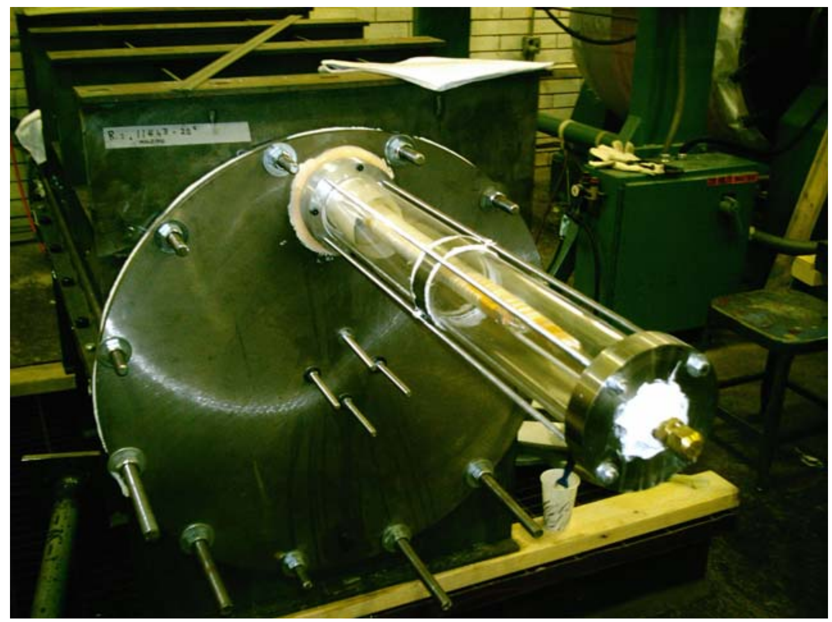
Segment #3 wit Dave Rakos standing next to the coil for





Impregnation molds

Segment #2 Lower Half of Mold



Segment 1 Mold showing sight glass

There was a leak in the longitudinal seam weld. This required application of RTV caulk and additional time to wait for the cure. This was to be held at 2 atm for 12 hrs prior to impregnation

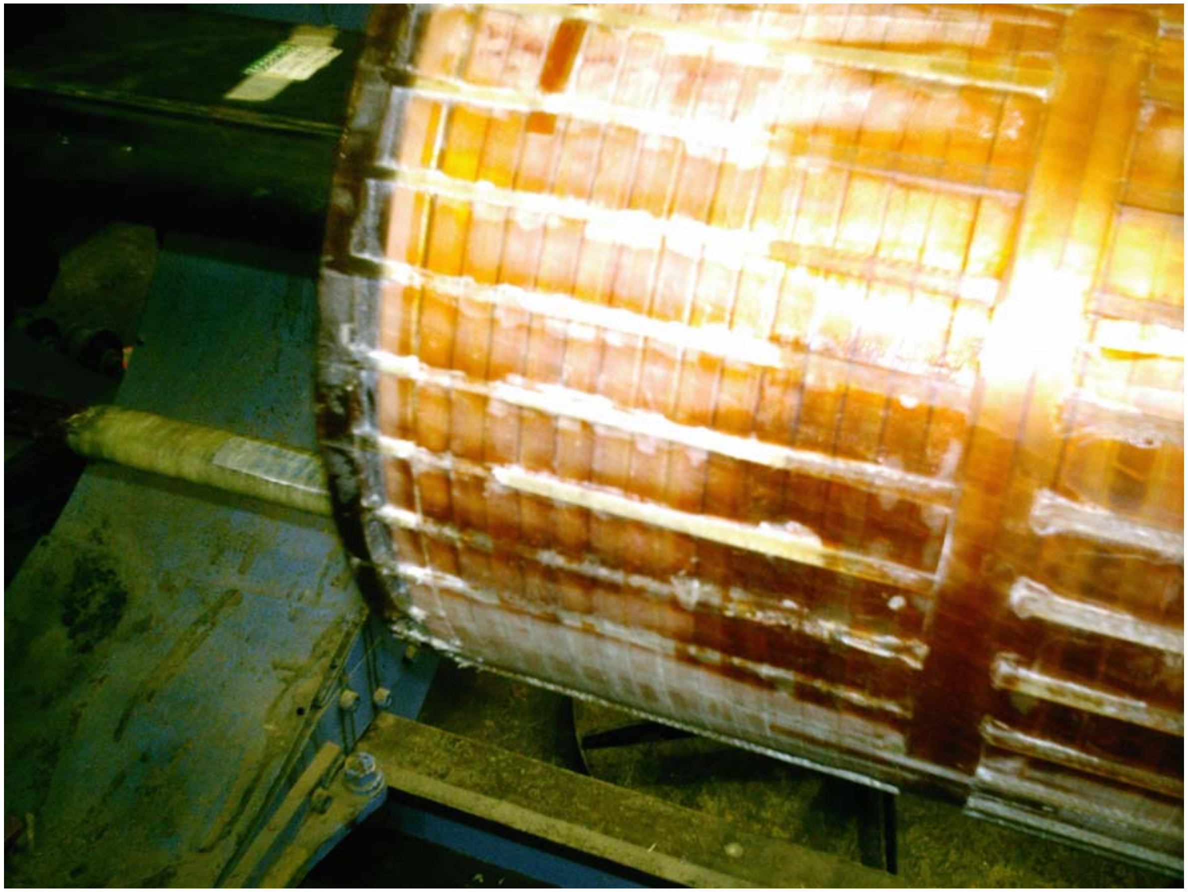
Segment 2 Mold

Impregnated Coils

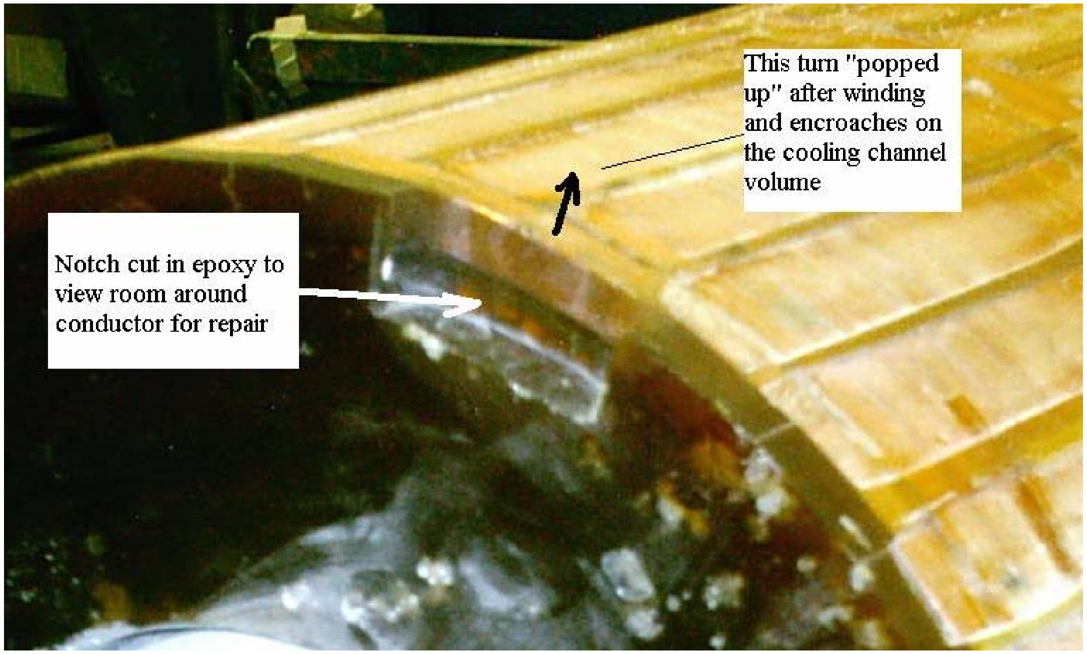
Segment #1 out of the mold. External Silicon fillers that form the “waffle
have not yet been removed

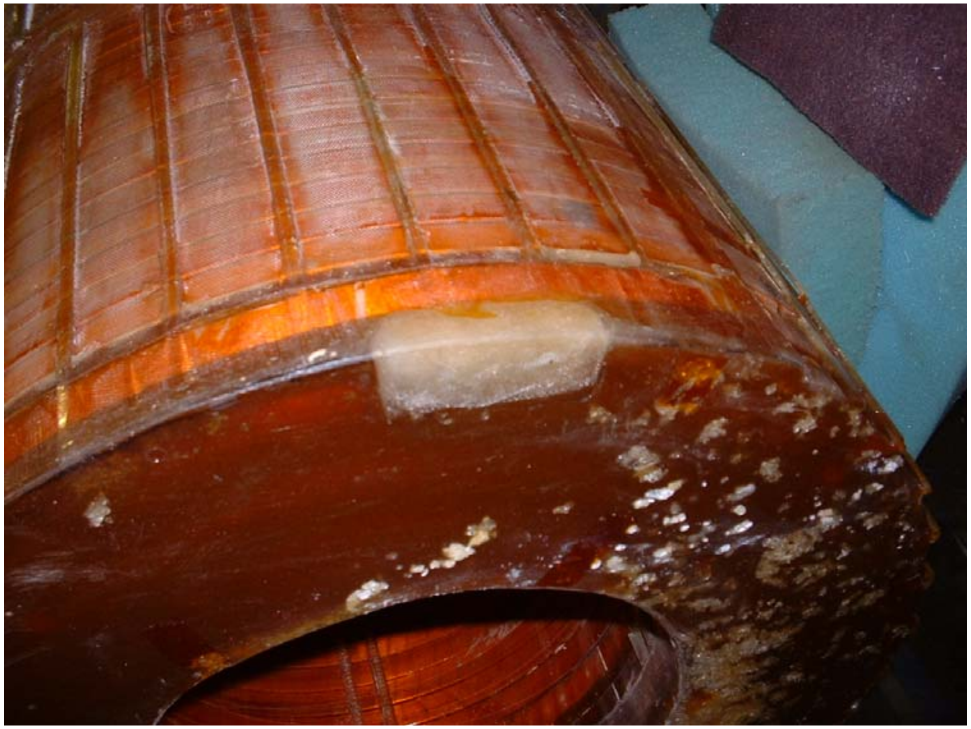
Segment #1 Bore – Will be fitted to CVIP’s Bore tube

OD Machining Operations

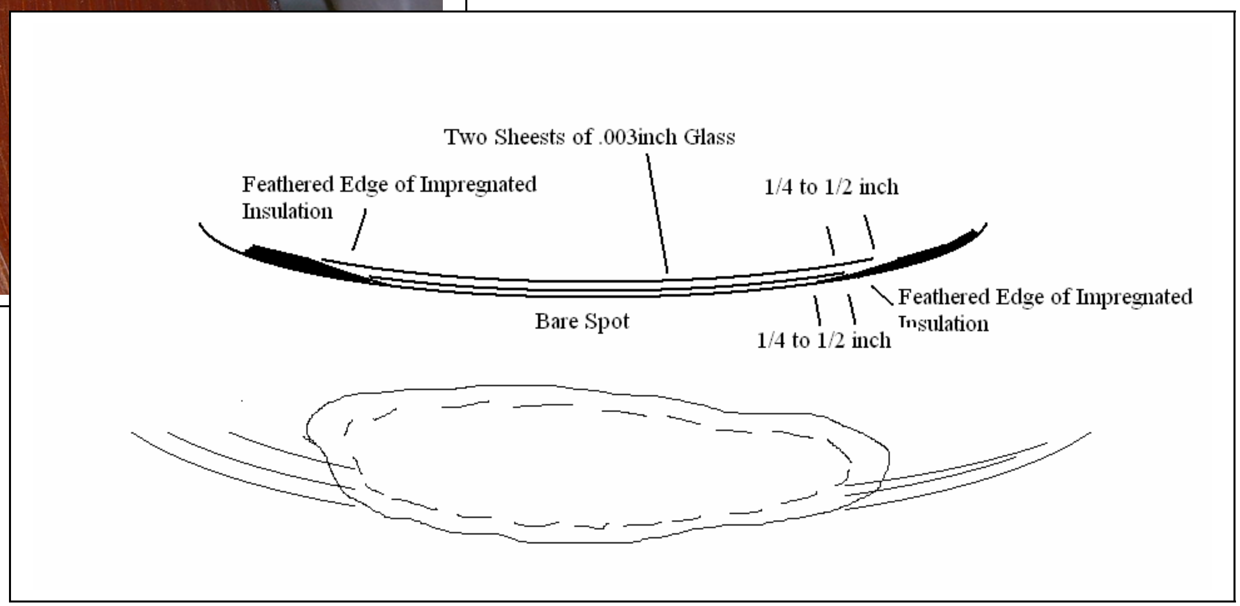


Damaged Turn




Segment 1 repair of notch

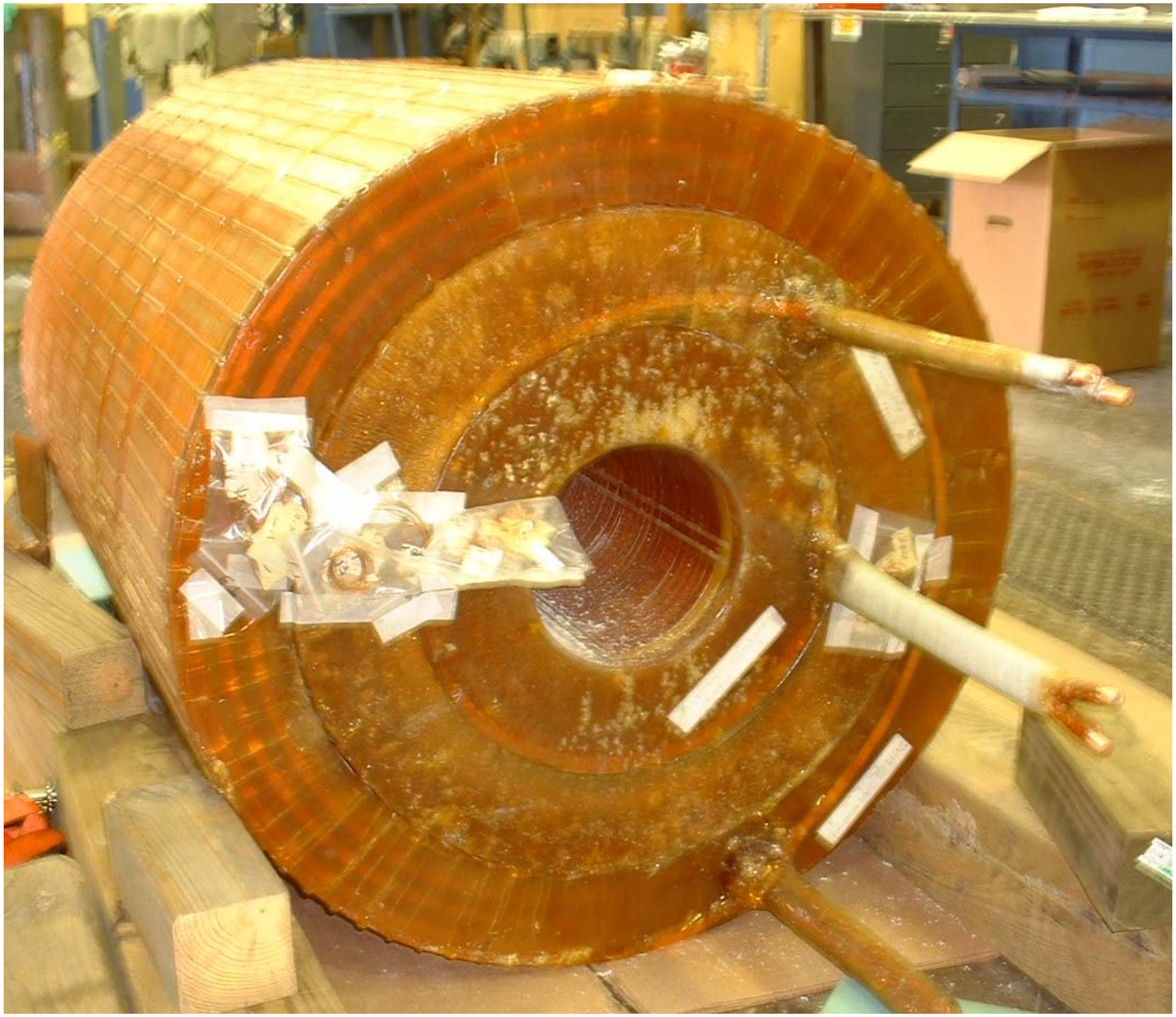
Failed Impregnation and Repair

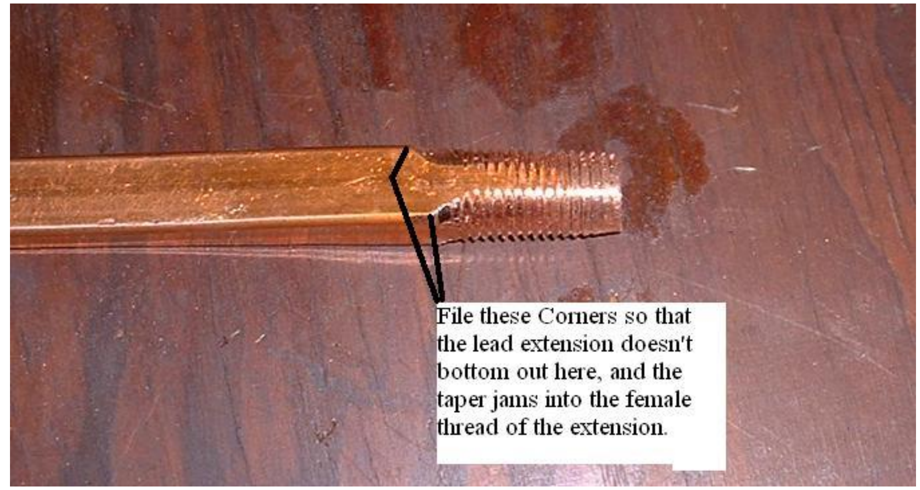


Nesting

Successfully nested coils – Segment 1 in Segment 2

Three Nested Coils with Instrumentation





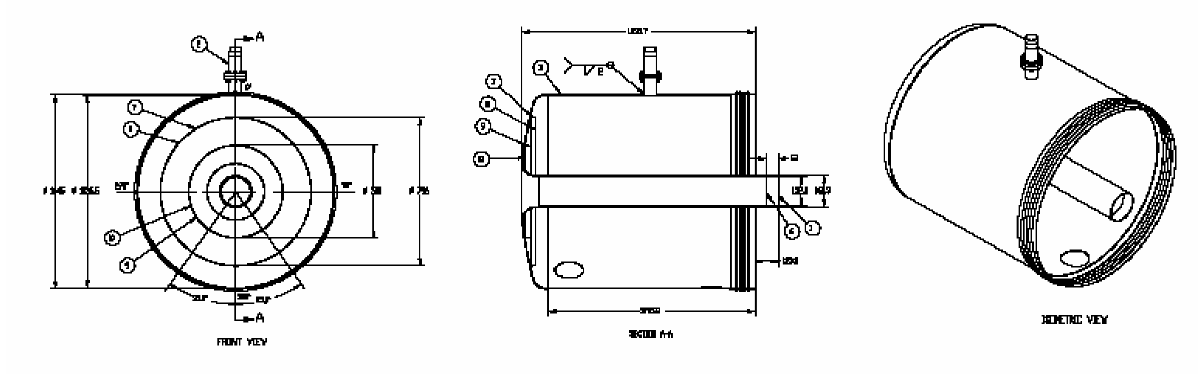
Lead Pipe Thread


Leads threaded with the coils being prepared for shipping

Vessel Manufacturing Experience

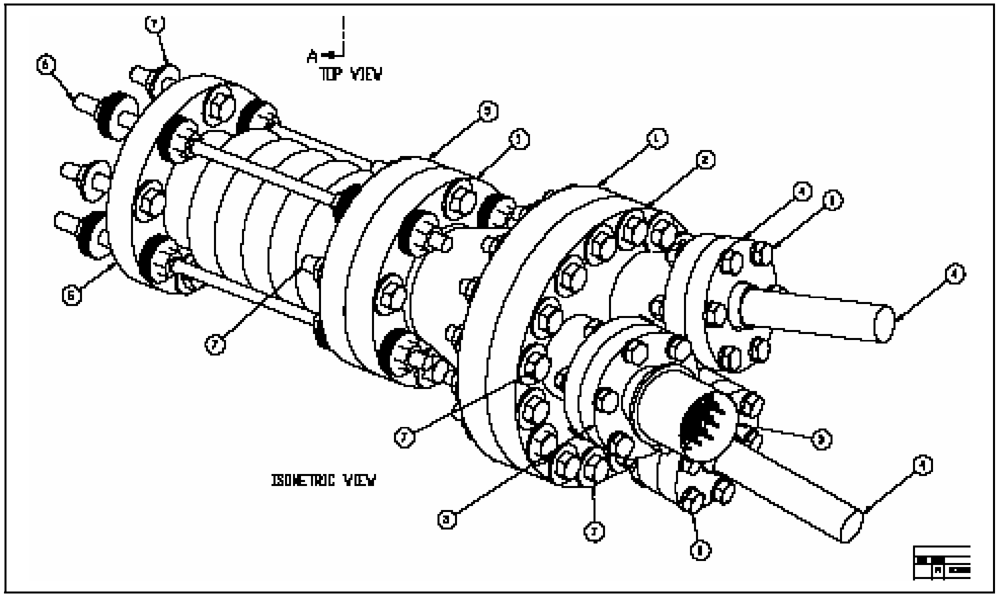
Status of Vessel Drawing Submittal by CVIP

Inner Vessel drawings complete and all approved.
Outer vessel drawings Complete and approved
Final manufacturing procedure is approved, but there are some additions.



Segment of Vacuum Jacket Drawing under Review

Change Order Items Have been Submitted to CVI, and prices negotiated and accepted



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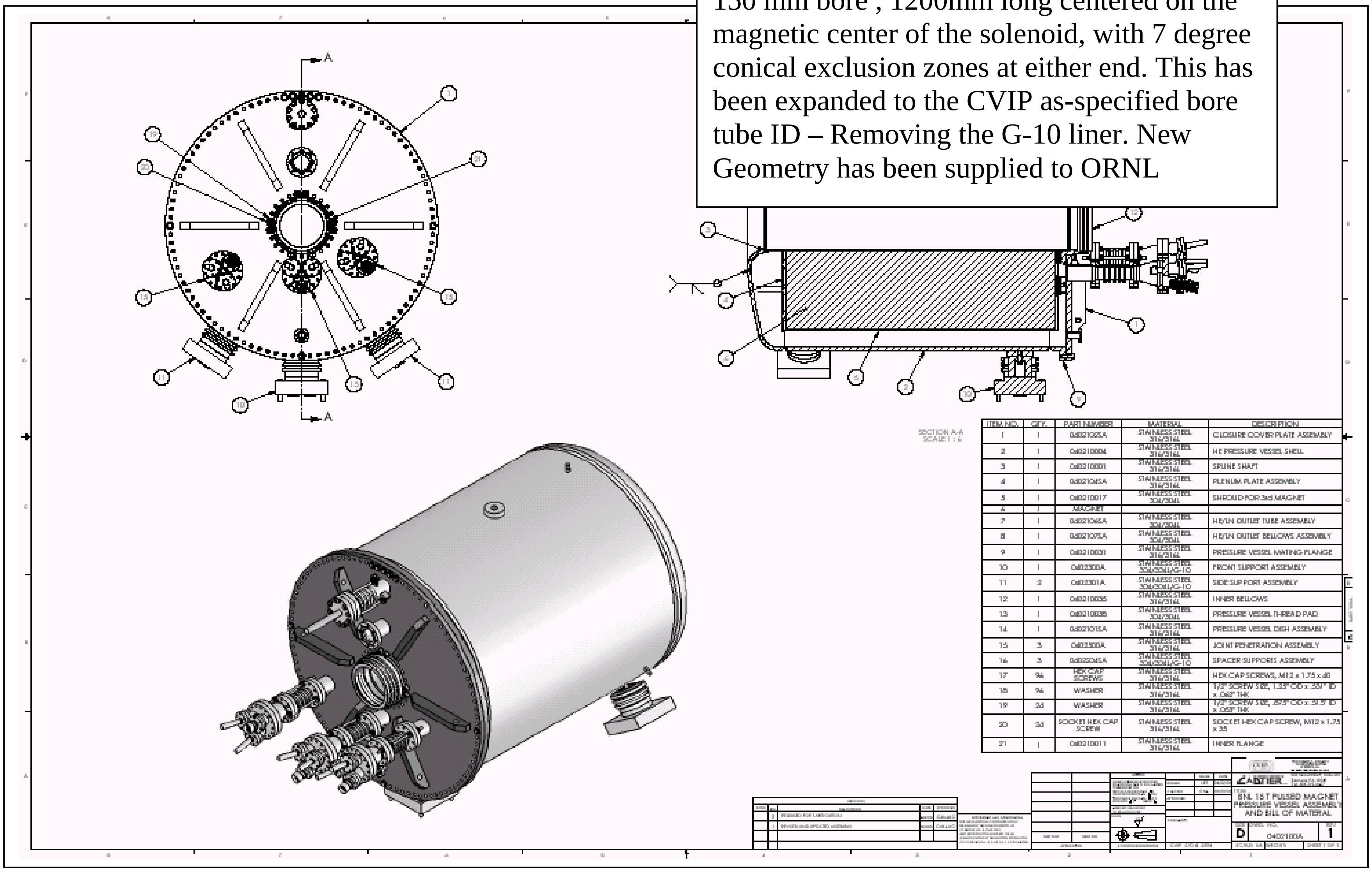
CVIP Drawings - Continued

Experimental Volume Spec:

150 mm bore , 1200mm long centered on the magnetic center of the solenoid, with 7 degree conical exclusion zones at either end. This has been expanded to the CVIP as-specified bore tube ID – Removing the G-10 liner. New Geometry has been supplied to ORNL



ITEM NO.	QTY.	PART NUMBER	MATERIAL	DESCRIPTION
1	1	04021025A	STAINLESS STEEL 316/316L	CLOSURE COVER PLATE ASSEMBLY
2	1	04021000 4	STAINLESS STEEL 316/316L	HE PRESSURE VESSEL SHELL
3	1	0402100001	STAINLESS STEEL 316/316L	SPLINE SHAFT
4	1	04021045A	STAINLESS STEEL 316/316L	PLENUM PLATE ASSEMBLY
5	1	0402100017	STAINLESS STEEL 304/304L	SHROUD FOR 3rd MAGNET
6	1	MAGNET		
7	1	04021065A	STAINLESS STEEL 304/304L	HE/LN OUTLET TUBE ASSEMBLY
8	1	04021075A	STAINLESS STEEL 304/304L	HE/LN OUTLET BELLOWS ASSEMBLY
9	1	0402100031	STAINLESS STEEL 316/316L	PRESSURE VESSEL MATING FLANGE
10	1	0402300A	STAINLESS STEEL 304/304L/G-10	FRONT SUPPORT ASSEMBLY
11	2	0402301A	STAINLESS STEEL 304/304L/G-10	SIDE SUPPORT ASSEMBLY
12	1	0402100035	STAINLESS STEEL 316/316L	INNER BELLOWS
13	1	0402100038	STAINLESS STEEL 304/304L	PRESSURE VESSEL THREAD PAD
14	1	04021015A	STAINLESS STEEL 316/316L	PRESSURE VESSEL DISH ASSEMBLY
15	3	0402500A	STAINLESS STEEL 316/316L	JOINT PENETRATION ASSEMBLY
16	3	04022045A	STAINLESS STEEL 304/304L/G-10	SPACER SUPPORTS ASSEMBLY
17	96	HEX CAP SCREWS	STAINLESS STEEL 316/316L	HEX CAP SCREWS, M12 x 1.75 x 40
18	96	WASHER	STAINLESS STEEL 316/316L	1/2" SCREW SIZE, 1.25" OD x .531" ID x .062" THK
19	24	WASHER	STAINLESS STEEL 316/316L	1/2" SCREW SIZE, .875" OD x .515" ID x .062" THK
20	24	SOCKET HEX CAP SCREW	STAINLESS STEEL 316/316L	SOCKET HEX CAP SCREW, M12 x 1.75 x 35
21	1	0402100011	STAINLESS STEEL 316/316L	INNER FLANGE

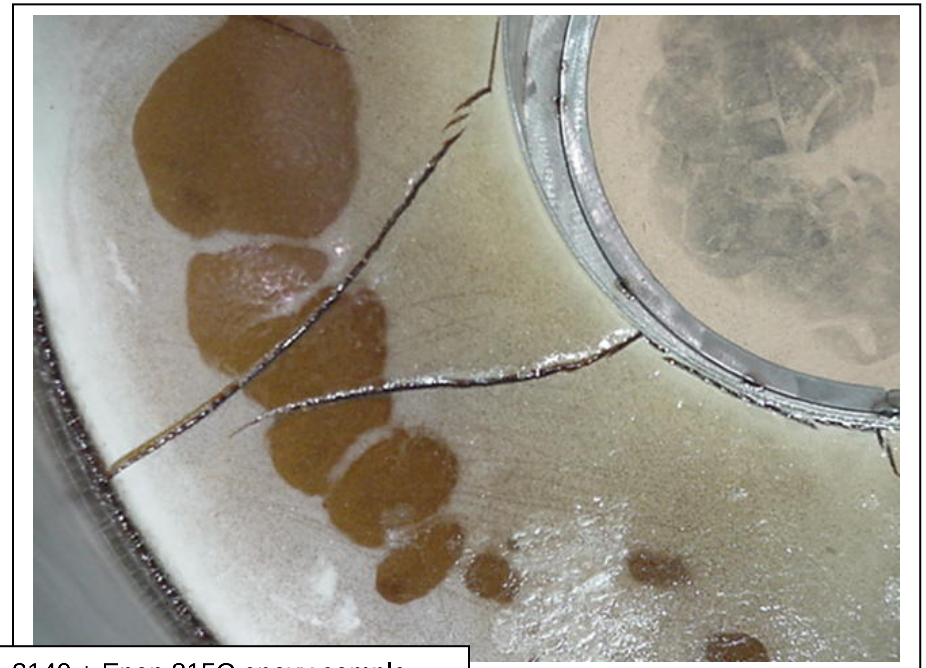
Metallic seals for the cover flange

Outer Vacuum Shell at CVIP

P

The Inner Cold Vessel at CVIP

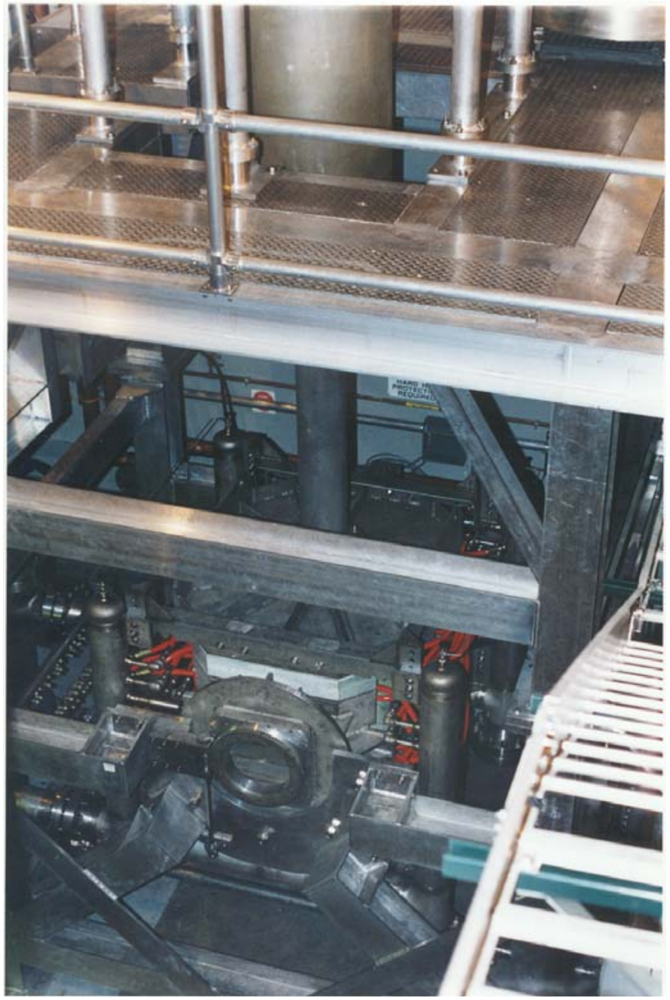
LN2 Volume Reduction Fillers



Attached are pictures of Epikure 3140 + Epon 815C epoxy sample. We did not use glass bead as filler because we think it may come loose and damage the valve sit of N2 flow control. It's also not recommend by the manufacture.

OK- The only problem with deleting the glass bead is that the contraction of the epoxy is about twice that of steel. With the glass bead, the contraction is close to steel. As long as the fillers are not bonded to the steel it will be OK, otherwise we will have some scary noises when we cool down for the first time. In our larger experiment across the street they use quartz sand for filler, and haven't had problems with fouling valves, but they do have screens in the sump. Even pure epoxy has flakes and chips that can clog valves – especially when it cracks on cooldown. I think these should be flushed out during the tests at MIT. Eliminating the glass filler eliminates a concern that I didn't talk to you about: activation of any boron containing glass. So leaving out the filler eliminates one more type of material that might activate. "Epoxy only" filler in the dished head will shrink about 3 mm on the diameter with respect to the steel. You had talked about welding some studs or tabs to the head to hold the epoxy block to the head. The contraction could shear off studs. If they are closer to the ID they would probably just bend.

Plans for Testing at MIT:

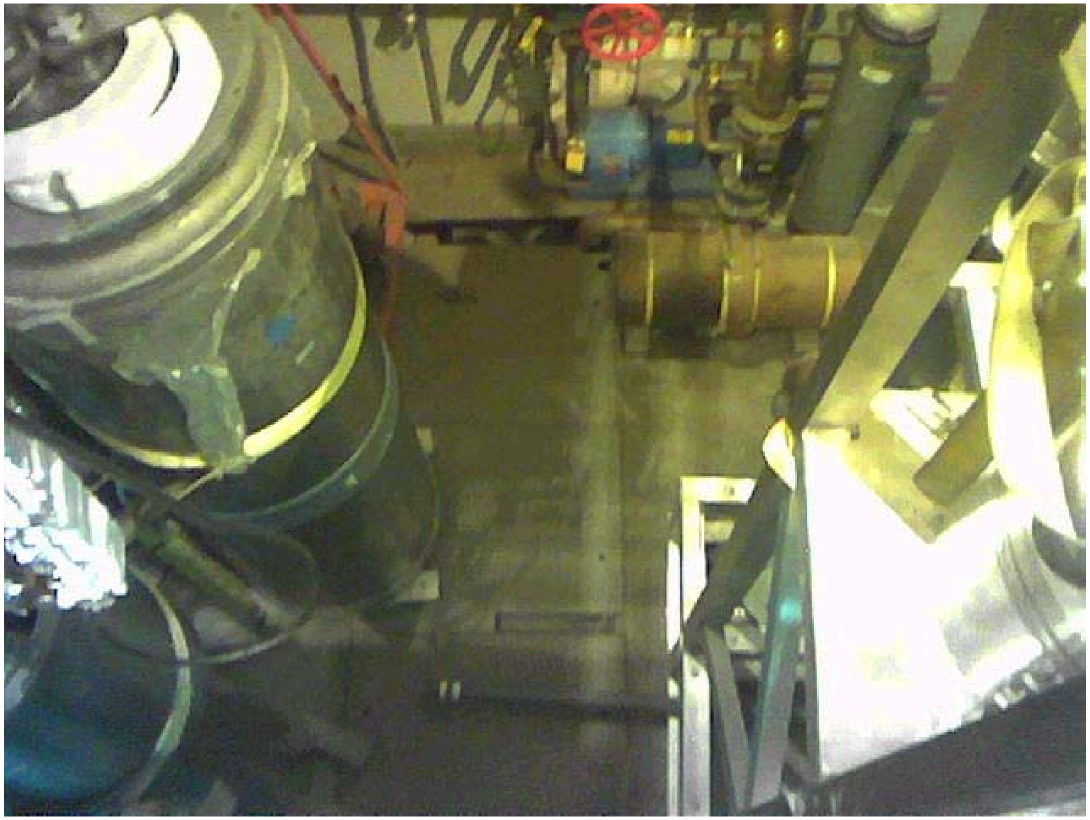


Lower Water Cooled Split Pair Copper Magnet - The BNL Pulsed Magnet will be in front of this, where the HXC Prototype cryostat is now positioned.

The test location is the Pulsed Test Facility (PTF) at MIT-PSFC primarily used for testing of superconducting joints in a transient high field background. The test area will need to be cleared of extraneous equipment. Magnetic materials and tools will be removed.

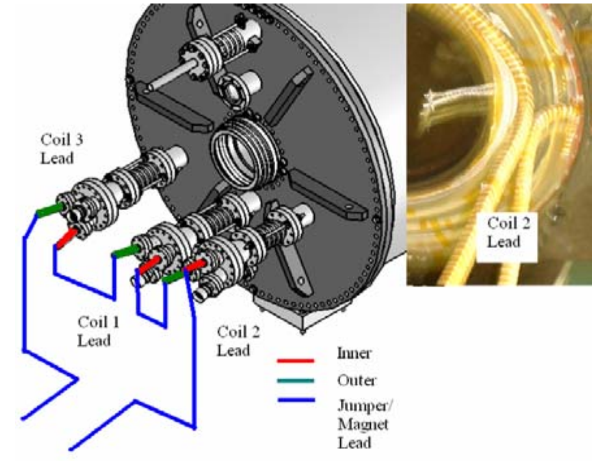
PTF Upper Cryostat

View of test area at floor level



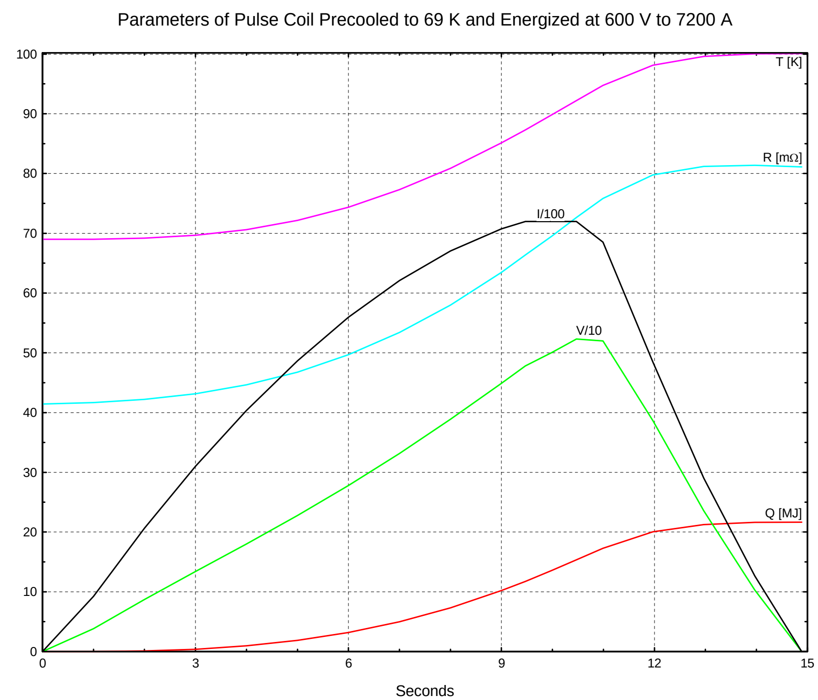
View of the test area floor. The dewars at left and HCX components at right need to be removed

Review of the current /voltage profiles indicates that the PTF power supplies will meet the test requirements. Modifications/Repairs are needed and will progress with approval of the Test plan proposal.



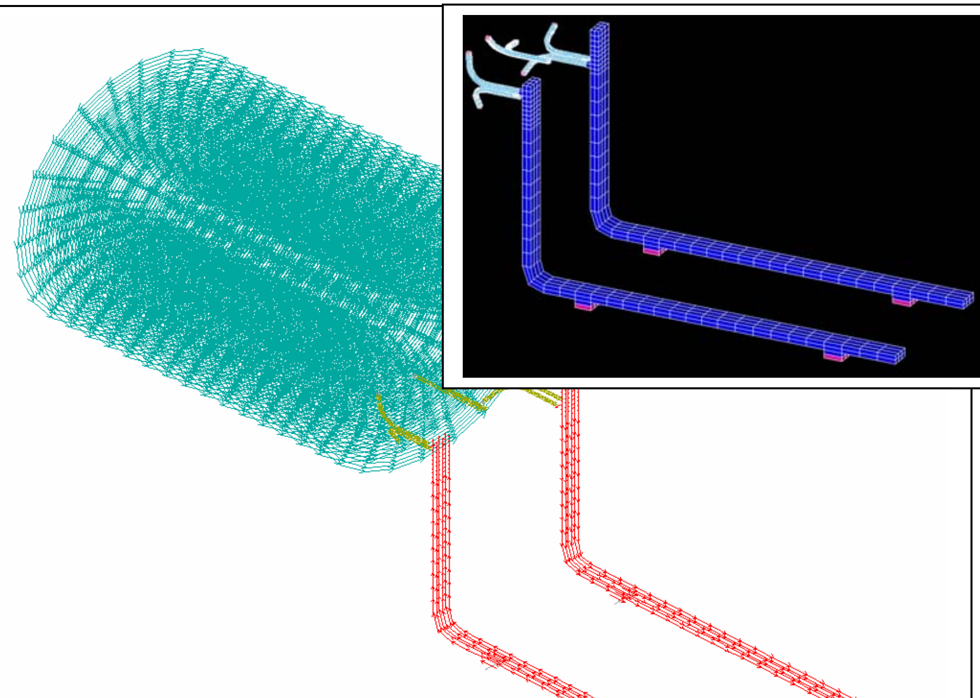
MIT-PSFC will Fabricate Jumpers ,Leads and supports.


PTF Power Supplies



Bob Weggel's 10-14 analysis of the LN2 magnet operation

The leads are modeled as 1 X 3 inch bar/strap.



Biot Savart M

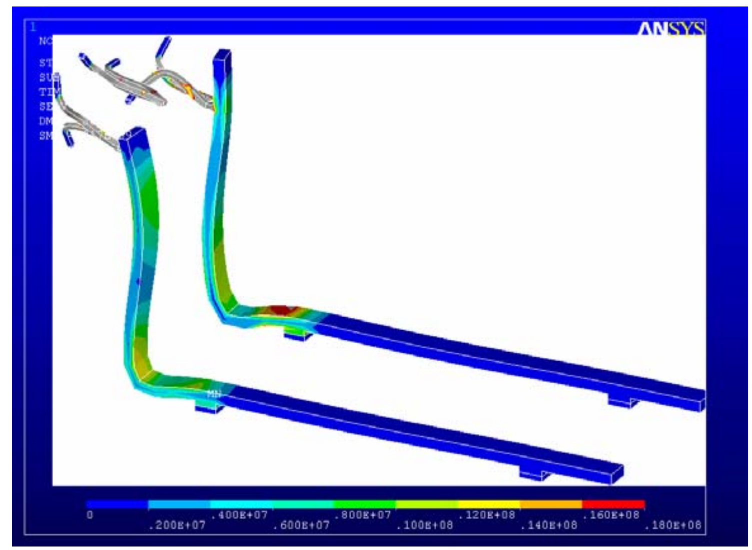
Loads on the Bus Bar Extensions

The total reaction for the 2 pads on the rear lead are:

FX 113.73N
FY 1982N
FZ –24.5N

The total reaction for the 2 pads on the front lead are:

FX 627N
FY 1714N
FZ –17.25N



Strap Stress is only 18 MPa.

Cryogenic System for the Test

Only atmospheric liquid nitrogen cooling will be employed during pre-operational testing at MIT, although the system is intended to retain the capability to be cooled using gaseous Helium, or sub-cooled LN2.

The requirement to remove the LN2 during the experiments in CERN stems from the radiation environment causing activation of Nitrogen, and the creation of Ozone. Neither of these problems exists during preoperational testing. This allows a further simplification of the system planned for CERN. The system at MIT will simply be a feed and exhaust, and will pulse with remnants of LN2 in the magnet.

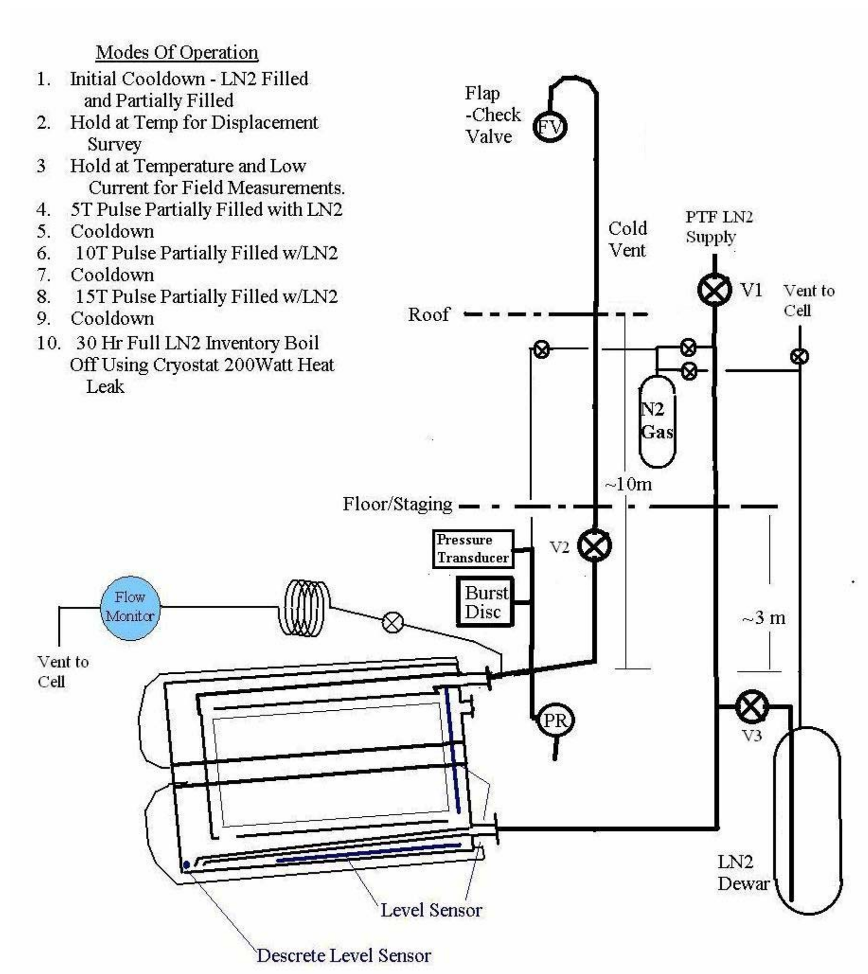
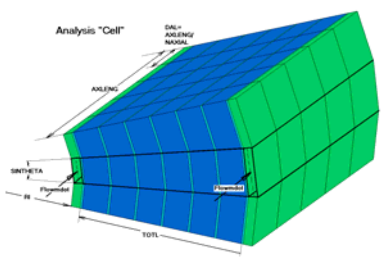
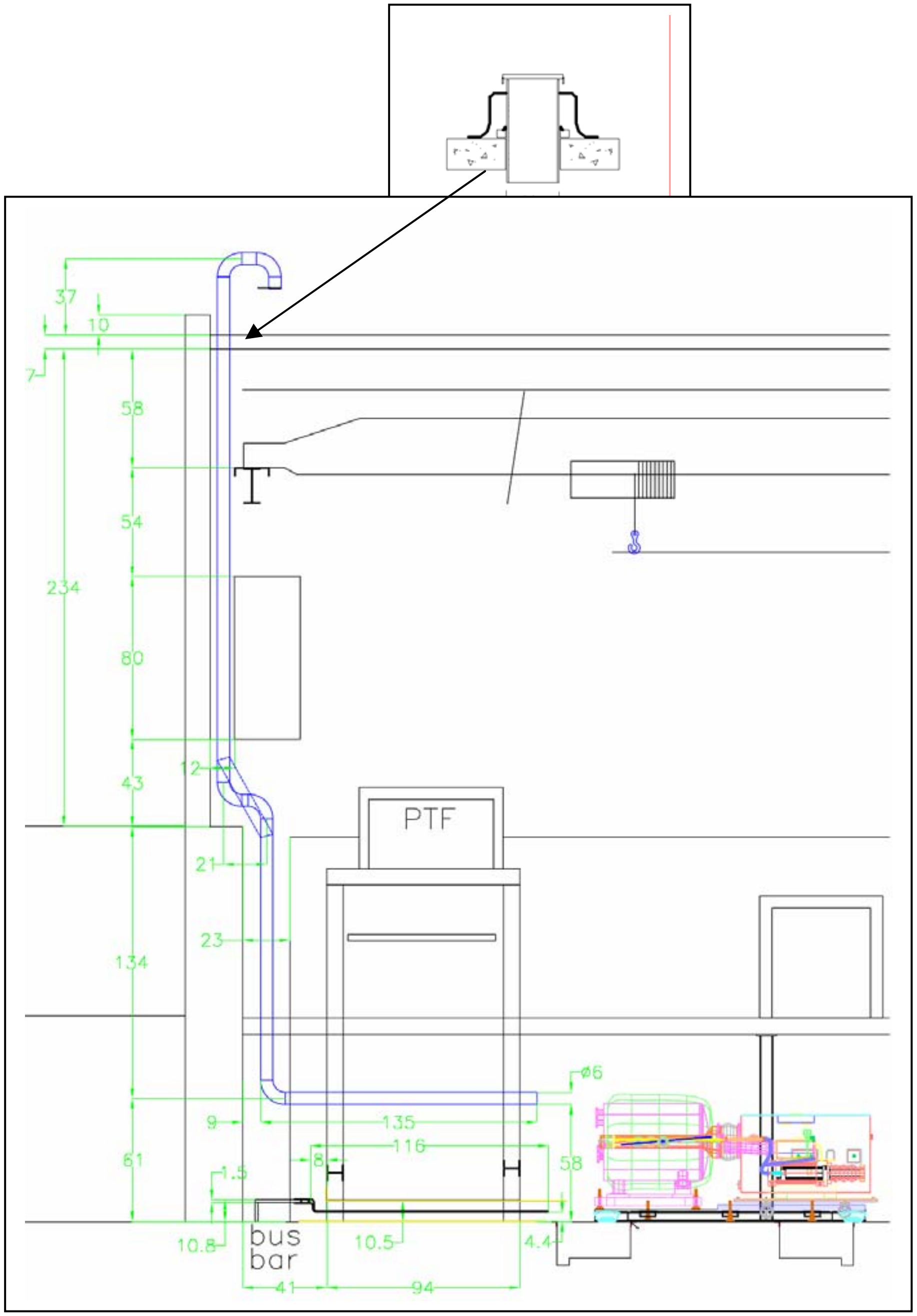


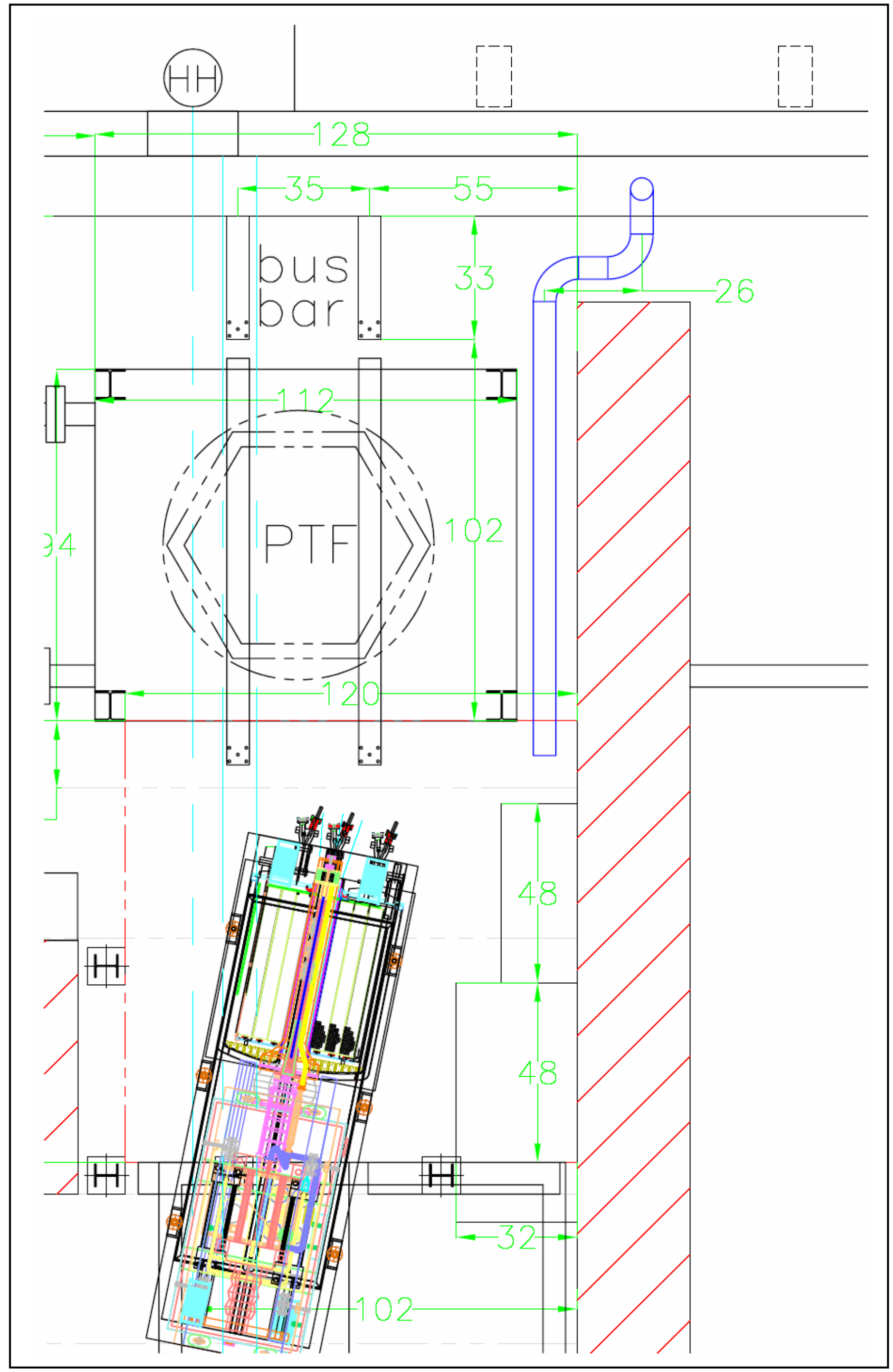
Figure 6.0-3 Cryogenic System Planned for Use at MIT



The Simulation originally assumed axial gas flow. Circumferential grooves have been added to allow pool boiling cooling.



37
10
7
58
54
234
80
43
12
21
23
134
9
61
1.5
10.8
bus bar
41
94
10.5
116
135
8
58
4.4
ø6
PTF



HH
128
35
55
bus bar
33
26
112
PTF
102
120
48
48
32
102

Main Elements of the Planned Test Procedure

Initial Set-Up

Baseline data for CERNOX sensors at RT

First Room Temperature Electrical Tests

Hipot the coils.

Initial Cooldown, Dimensional Characterization

Stabilize at 80 to 77K. Check instrumentation, Baseline data for CERNOX sensors at LN2 temperature. Check Level sensors. Compare Capacative and discrete sensors.

Boil-Off – Heat Leak Test

At ½ fill height, measure level change with respect to time, Calculate heat leak

Record Cold Dimensional Changes

Map bore dimensional changes due to cooldown.

Inductance Measurement

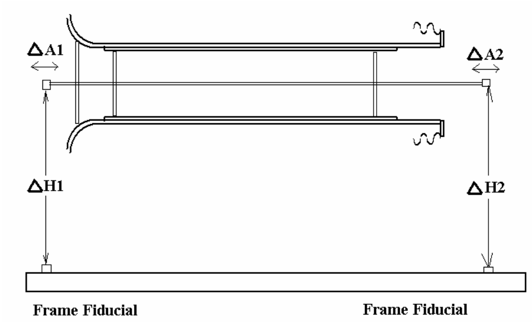
Measure 3 coil low current static resistance. Measure constant-Low Voltage current ramp

5T Test

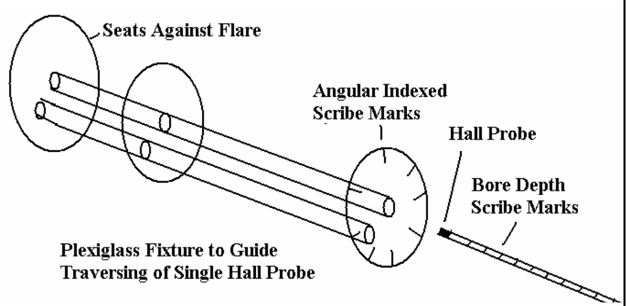
Demonstrate temperature uniformity in the three coil segments. Check target current time traces. Obtain final temperatures for the three coil segments. Check against predictions.

10T Test (First)

Demonstrate temperature uniformity in the three coil segments. Check target current time traces. Obtain final temperatures for the three coil segments. Check against predictions.



Cooldown Displacement Measurements
The fixture is a rod or tube with circular disks that fit against the bore and one disk at the end that rests against the flare in the vacuum jacket. The flare is the entry point for the mercury jet



Field Mapping is planned with one Hall Probe at Low Current. Field will scale with current. There are no non-linearities. A Shunt resistor will be used to calibrate CERN power supplies to MIT's

Time to cool with primarily gaseous cooling (1/3 fill height of LN2)

10T Test (Second)

Demonstrate temperature uniformity in the three coil segments
Time to cool with primarily pool boiling cooling (2/3 fill height of LN2)

Second Room Temperature Electrical Tests

Warm to RT. Conduct Electrical tests

10T Test (Third)

Slow cool to 80K, Run 10T test. Check target current time traces. Obtain final temperatures for the three coil segments. Check against predictions.
Cool with LN2 1/3 fill height to 80 K. Stabilize temperatures in 3 coils.

15T Test (First)

Demonstrate 15T operational capability. Check target current time traces. Obtain final temperatures for the three coil segments. Check against predictions.

15T Test (Second)

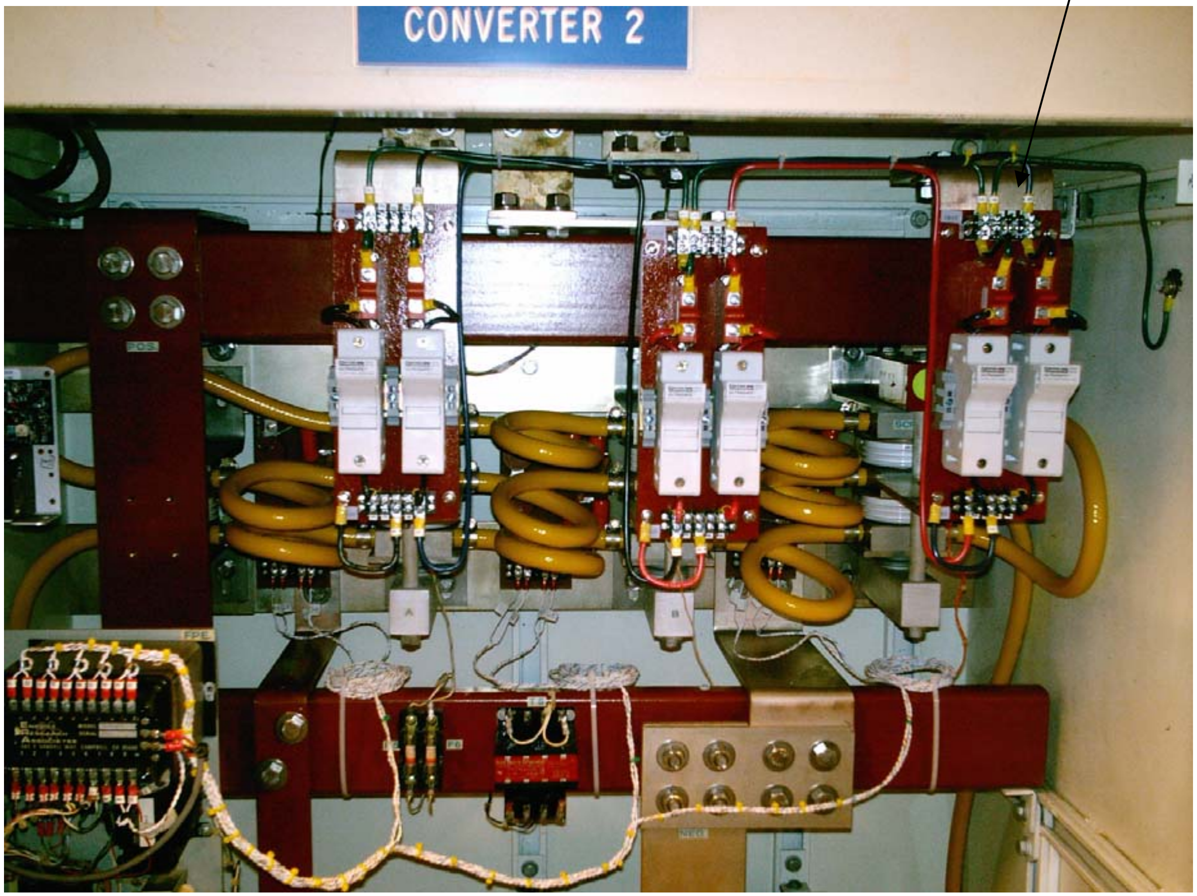
Demonstrate 15T operational capability. Check target current time traces. Obtain final temperatures for the three coil segments. Check against predictions.
Cooling Behavior 2/3 immersed, Obtain Time temperature plot for cooldown

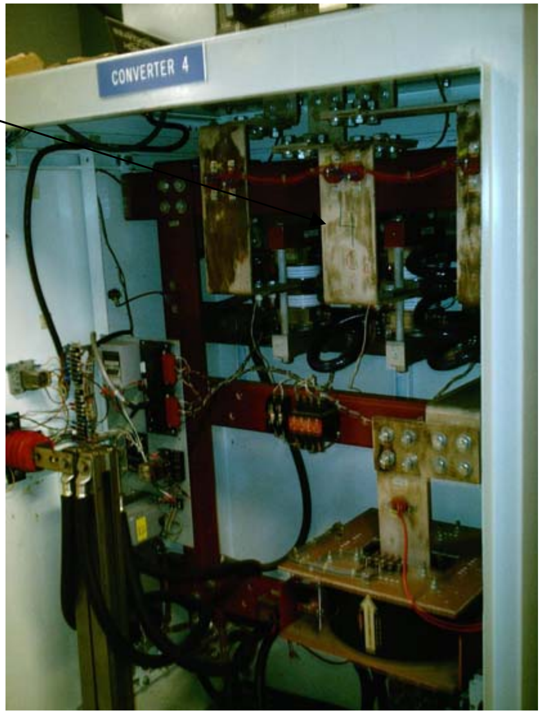
Third Room Temperature Electrical Tests

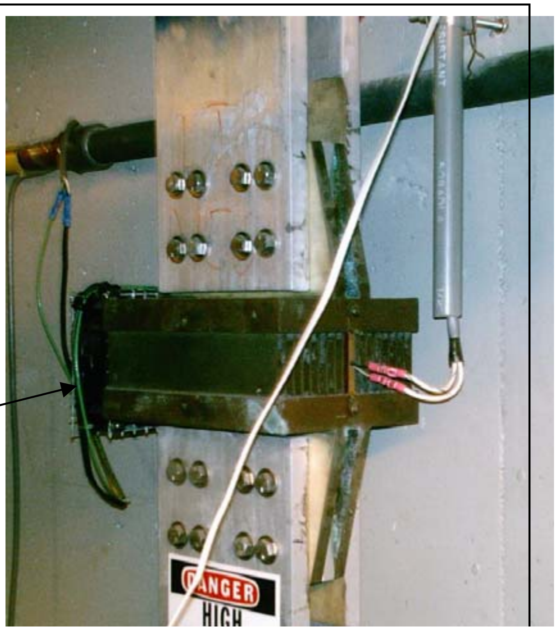
Report Test Results

Power Supply Upgrades and Modifications

Over Voltage Protection



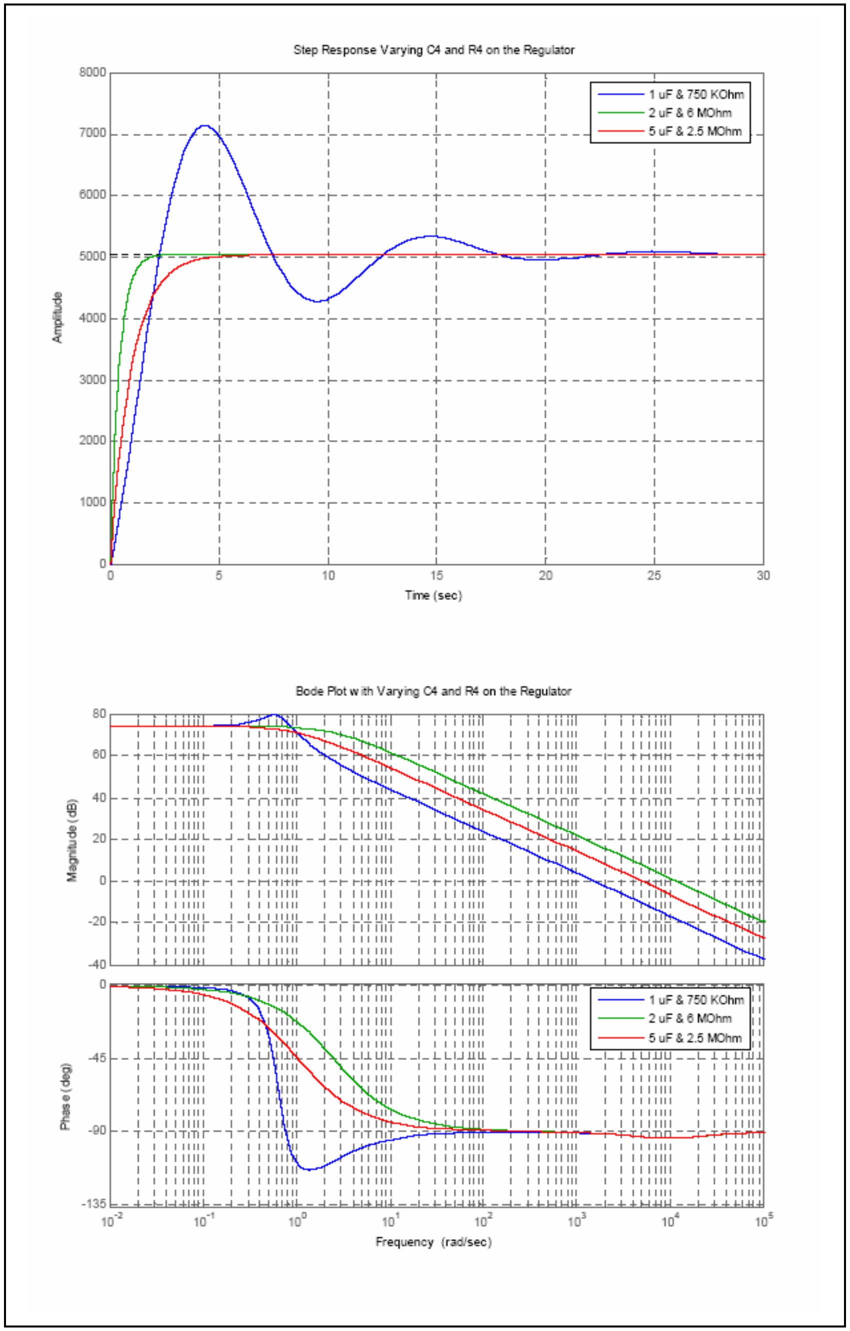


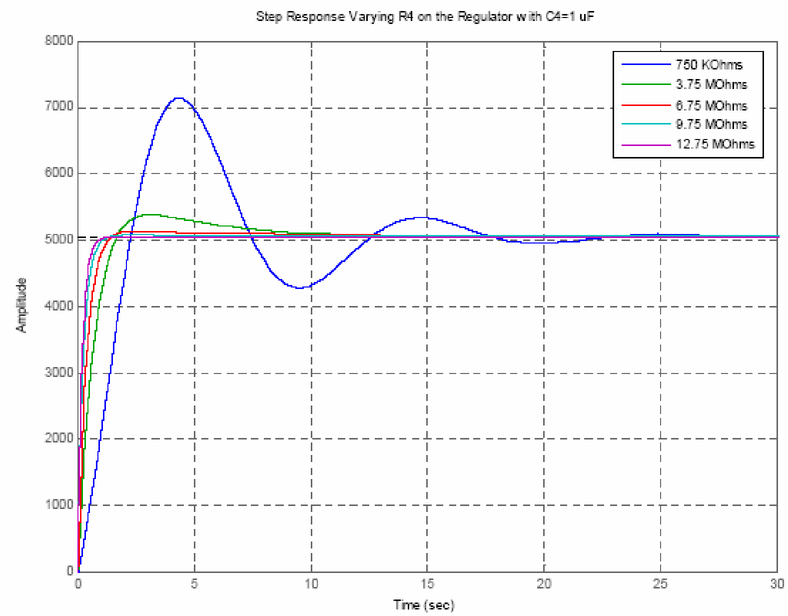


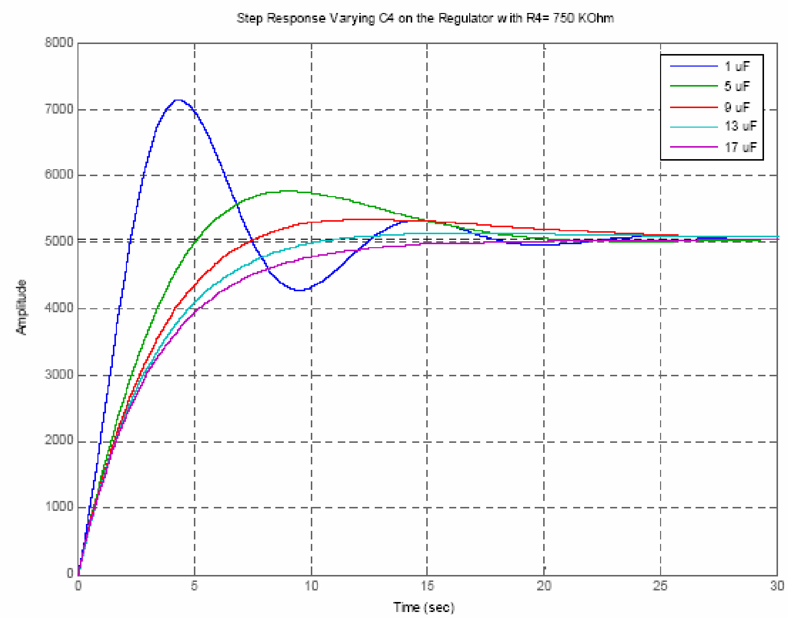
Current Shunt

West End Converters Feedback

I ran my West End Converter Feedback Model with the BNL magnet impedance of 0.484 H and 0.040 Ohm. The results indicate that the regulator will need to be tuned to this load. The current resistance and capacitance on the integrator of the regulator have been set for the 1J load of 0.0106 H and 0.0116 Ohms and their respective values are 750 KOhm and 1 uF. The simulations indicate that these values should be increased and the model suggests values of around 6 MegOhm and 2 uF greatly improve the performance of the system for the BNL magnet. Variable resistor and capacitance devices could be used to tune in the feedback circuit. Attached are figures generated from the simulation results.




Step Response Varying R4 on the Regulator with C4=1 uF
750 KOhms
3.75 MOhms
6.75 MOhms
9.75 MOhms
12.75 MOhms
Amplitude
Time (sec)


Step Response Varying C4 on the Regulator with R4= 750 KOhm
1 uF
5 uF
9 uF
13 uF
17 uF
Amplitude
Time (sec)

Safety, Operational Controls

There are other experiments in the vicinity of the PTF area that may be affected by stray fields. LDX, VTF, particularly its control equipment, and Rick Tempkin's accelerator will either need to be shown insensitive to the field produced by the magnet, or there will be operational controls on the BNL tests to preclude concurrent operation of the BNL magnet and the other experiments.

Magnetic materials will have to be kept clear of the magnet. We should probably consider limited access to the ground floor are near the magnet because of the electrical, cryogenic and magnetic hazards.

Oxygen Depletion Sensors

A vent line exhausting to the roof is being built. This should eliminate normal venting og N2 gas. Catherine Fiore indicated that C-Mod has a number of portable sensors that are used during C-Mod operation. The will be beginning operation in Feb 2005 and these will not be available to us. I need to check with LDX to see if they have fixed monitors in the cell, but Two portables in the PTF "pit" are needed. These cost around $600 apiece. Maybe we can borrow them from Brookhaven, Rutherford or CERN. Catherine will accept this kind of equipment from a collaborating lab.

Magnetic Field Hazard

The 15 Tesla Pulsed magnet will have a significant stray field. Field maps of the cell will be generated and notices will be posted in accordance with MIT standards.

Magnetic fields have set off fire alarms. When the magnet is first energized, the fire marshal will be in attendance to shut off fire alarms as needed.

Over-Pressure Protection

The Gaseous N2 vent line will be provided with a pressure relief valve, and a burst disk. These will vent into the cell.

Cryogenic Hazards

The lead end especially will be subject to cryogenic temperatures. with attendant frostbite/ burn hazards.

Electrical Hazards:

MIT-PSFC Lock-out procedures will be followed: http://psfcwww2.psfc.mit.edu/esh/locktag.html

Plasma Science and Fusion Center

Office of Environment, Safety, and Health 190 Albany Street, NW21 2nd floor

617-253-8440 (Catherine Fiore, head) 617-253-8917 (Matt Fulton, Facilities Manager)
617-258-5473 (Nancy Masley, administrator) 617-253-5982 (Bill Byford, assistant safety officer)
Fax 617-252-1808

Data Acquisition: