MC Collaboration Meeting

February 14 - 17, 2005

LBNL Berkeley, California

nTOF11 15-T Pulsed Magnet for Mercury Target Development

Neutrino Factory and Muon Collider Collaboration

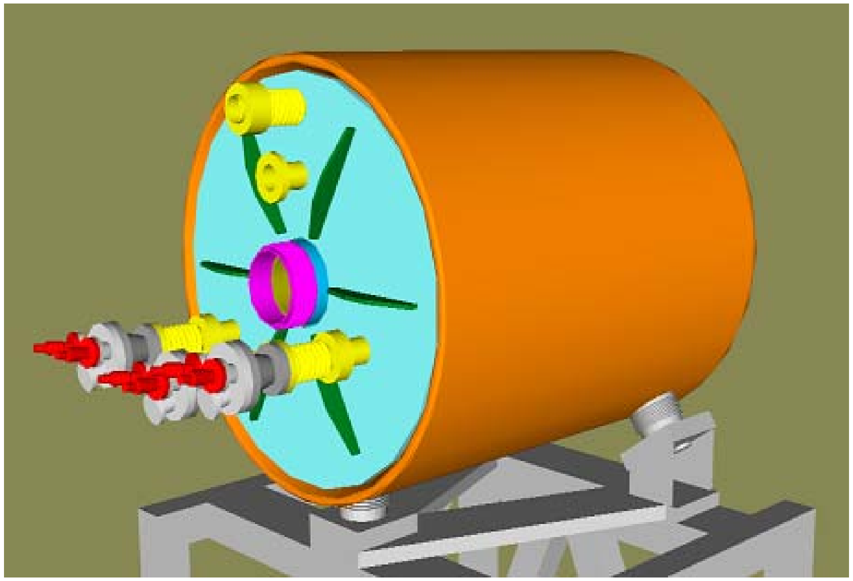
Peter H. Titus

MIT Plasma Science and Fusion Center

(617) 253 1344, titus@psfc.mit.edu,

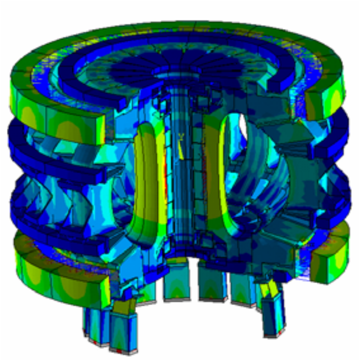
http://www.psfc.mit.edu/people/titus

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

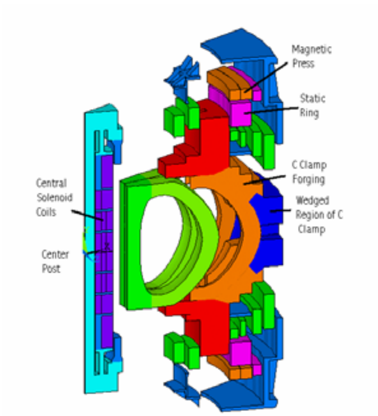


BNL Pulsed Magnet –Inertially Cooled , 80K LN2 Cooled Between Shots

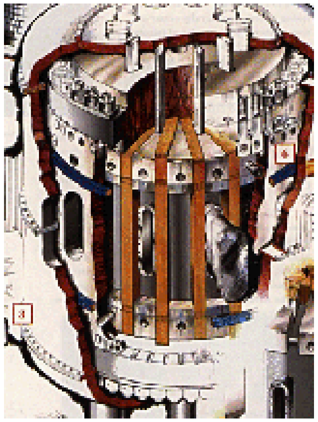
BNL pulsed magnet design builds off of copper magnet experience in fusion research:



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.

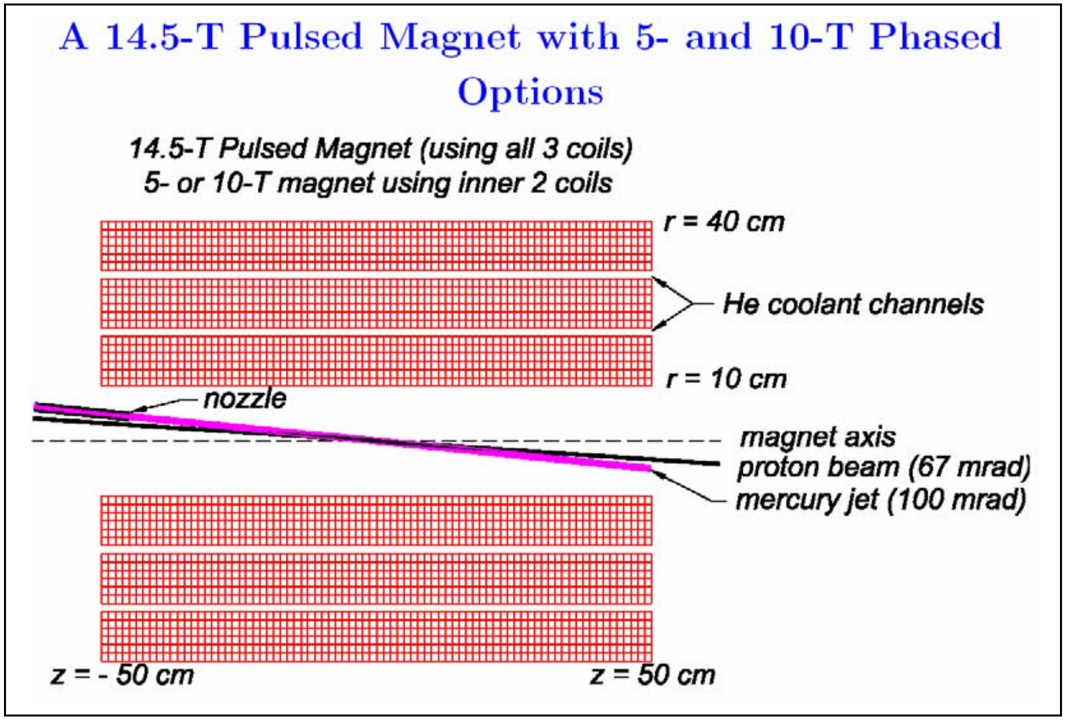
Cost issues dictated a modest coil design.

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.

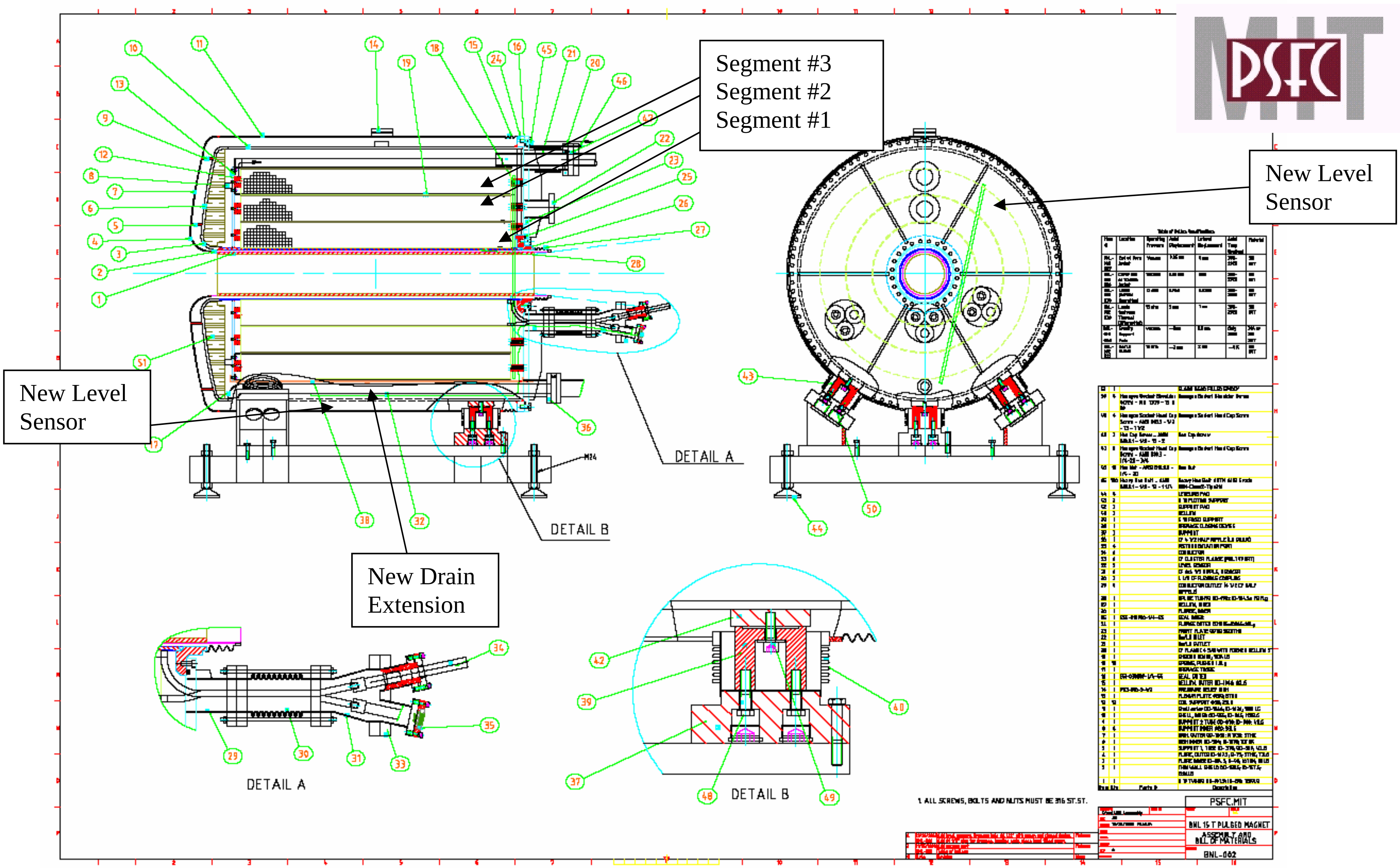
The conductor is half inch square, cold worked OFHC copper.

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



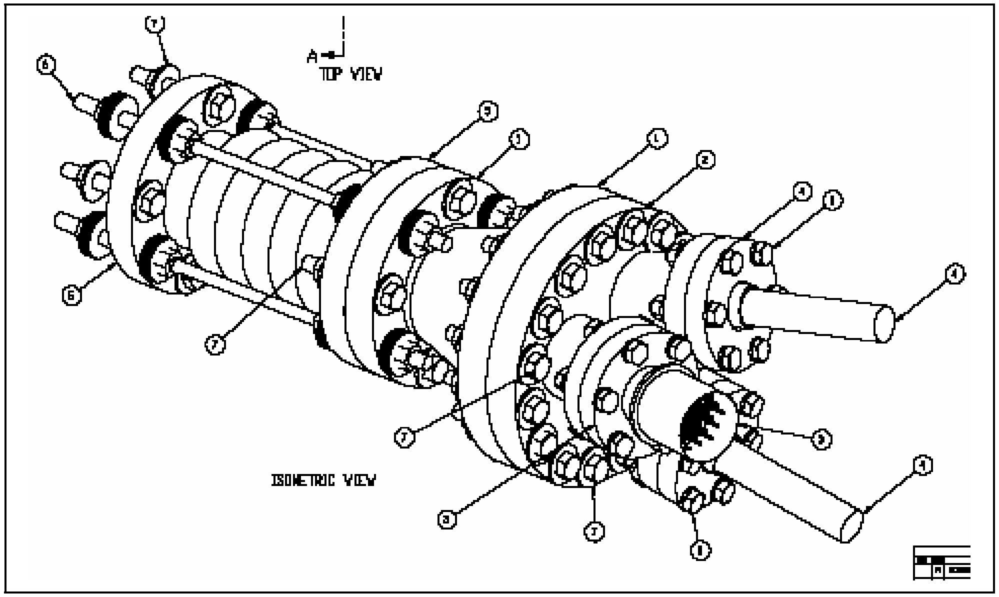
Draft Test plan, Pictures, Drawings and Calculations at: http://www.psfc.mit.edu/people/titus/#BNL%20Memos

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

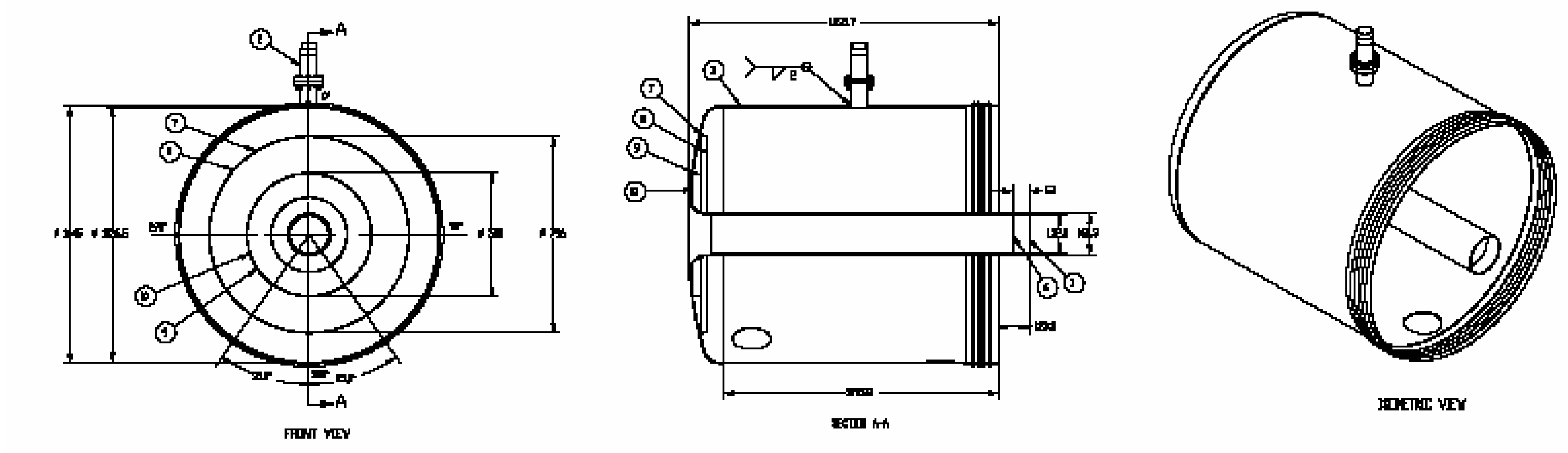
Status of Vessel Drawing Submittal by CVIP

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



Major dished heads have been manufactured and delivered to CVIP. Large cover has been partially machined.

Change Order Items Not yet Submitted to CVIP

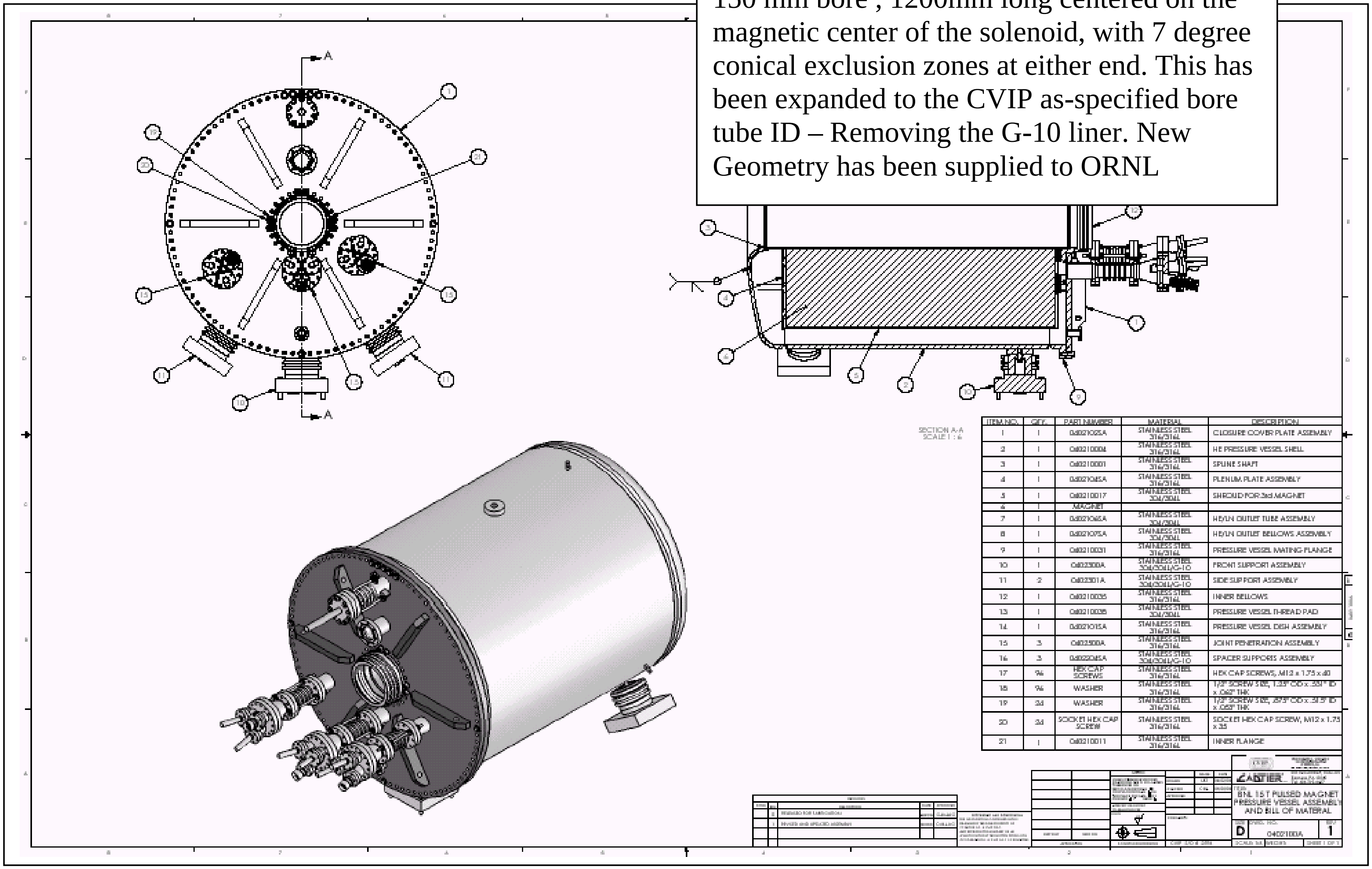


Segment of Vacuum Jacket Drawing under Review

CVIP Drawings - Continued

Experimental Volume Spec:

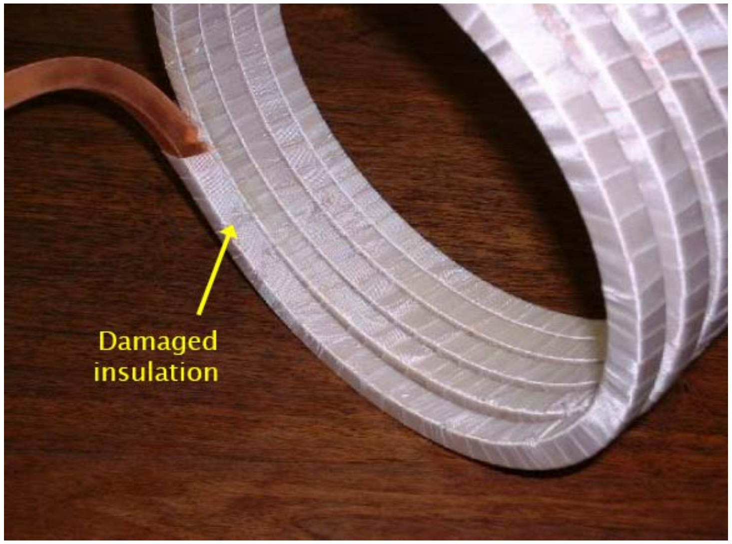
150 mm bore , 1200mm long centered on the magnetic center of the solenoid, with 7 degree conical exclusion zones at either end. This has been expanded to the CVIP as-specified bore tube ID – Removing the G-10 liner. New Geometry has been supplied to ORNL



Fabrication Status

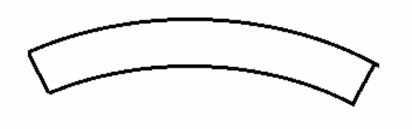
Everson autoclave (Box with Doors) Epoxy pumping equipment, and vacuum pumps) – Used for all three coil segments

Winding Machine with the beginnings of segment #1



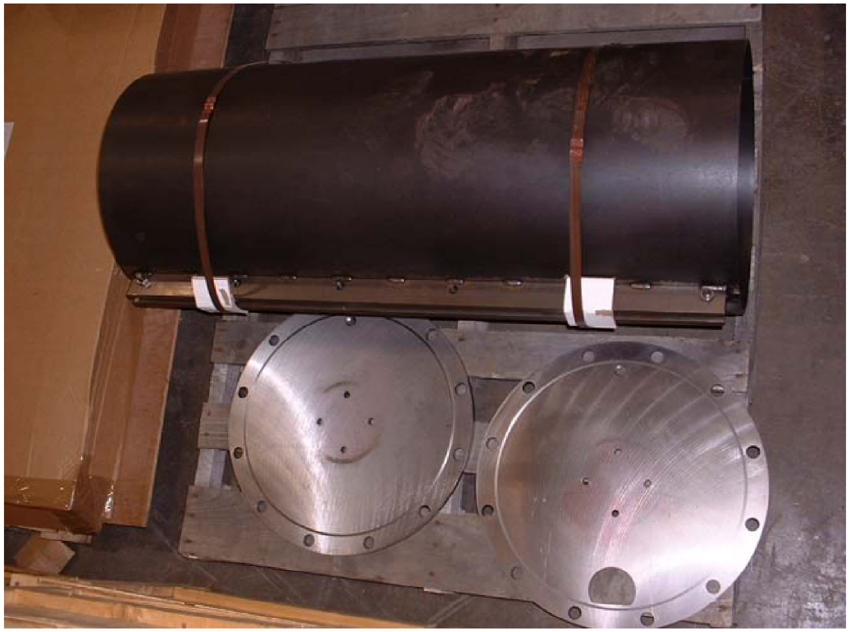
Results of the test bend. Roller geometry was improved to avoid fiberglass tape cuts.

Segment #1
As of Thursday January 27th :

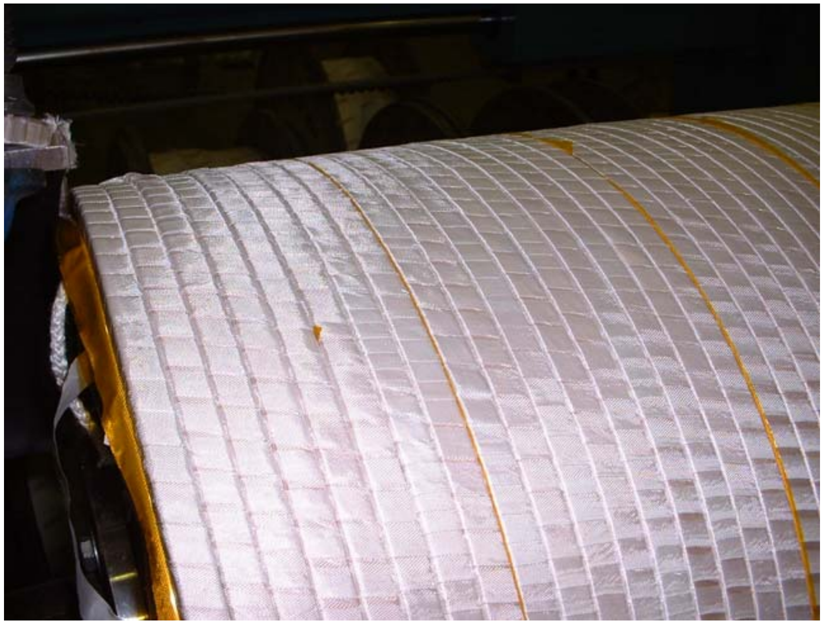


Kapton arc sections inserted between every eighth turn on those layers that face the cooling channels

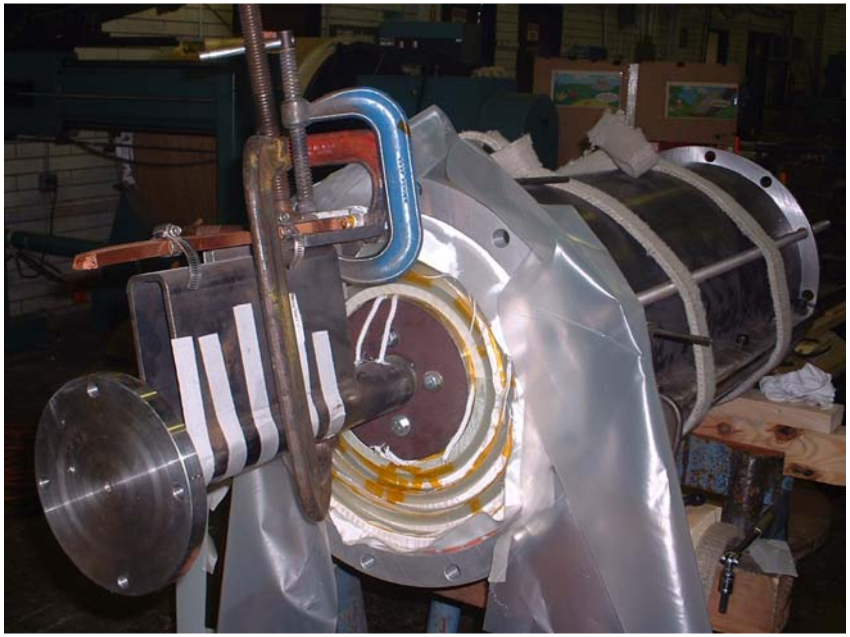
The inner segment (Segment #1) has been impregnated at Everson and has been sent out for final machining of the OD. – This will be the first test on machinability of the outer rib geometry



Coil Mold for Segment #1. Succesfully 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

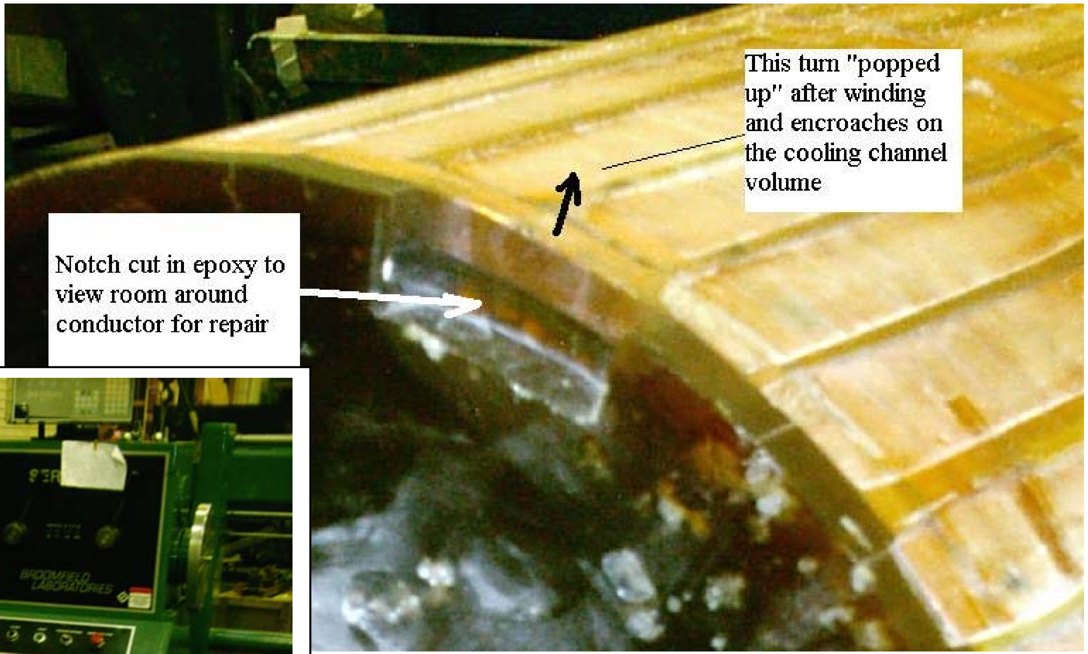
Segment #1 – Continued

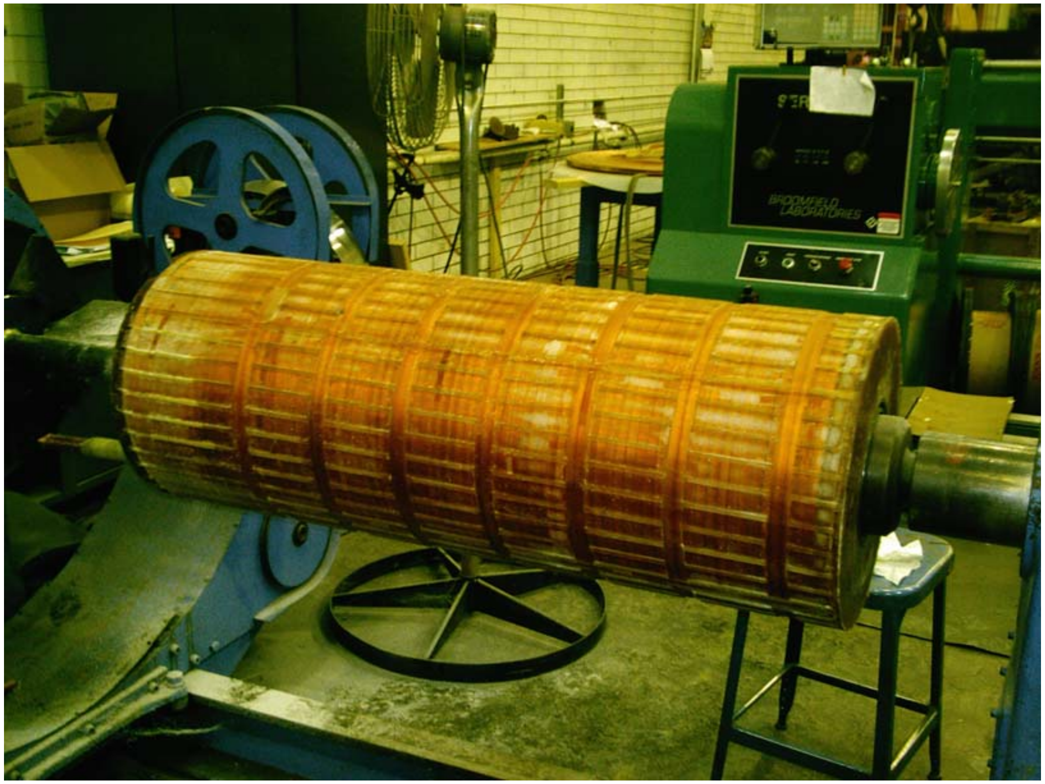
Segment #1 out of the mold. External Silicon fillers that form the “waffle” pattern have not yet been removed

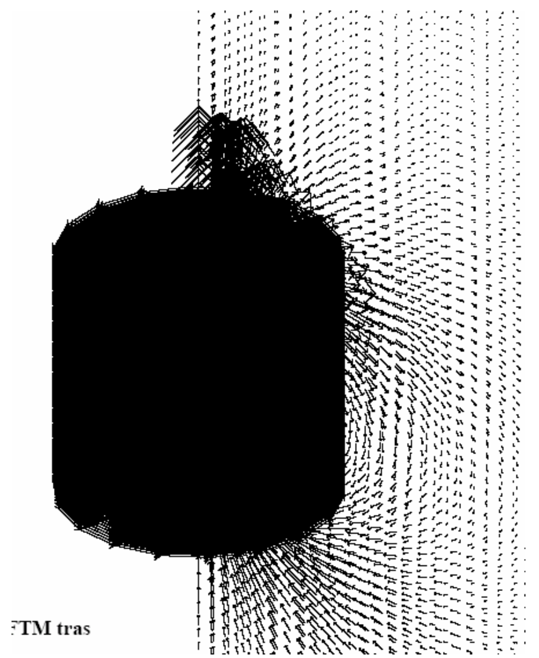
Conductor Non-Conformance Simulation
Circuit Simulation for the Displaced Segment #1 Conductor

A conductor in segment 1 shifted radially outward and encroached on the channel spaces. It was damaged during the machining operation.

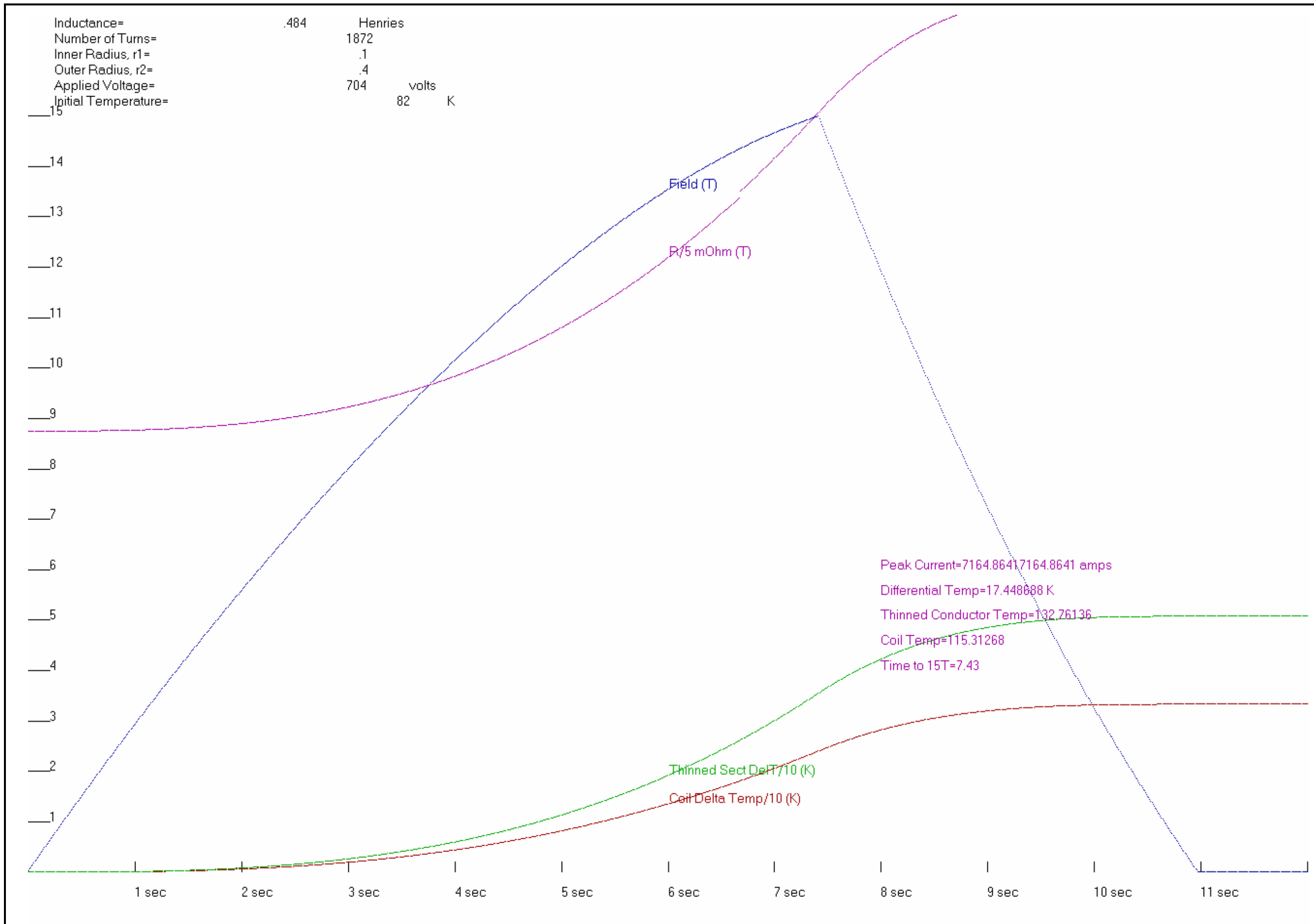
Ribs were knocked off during an initial attempt to machine the coil on a lathe. They switched to a vertical mill




Segment #1 with it's OD machined.



Inductance Calculation from Field-Volume Integral



Bob Weggels electrical simulations are the simulations of record. However a coil simulation was run with a local conductor cross section reduced by 25%.

The local temperature went 17.4K higher than the rest of the coil.

The hoop compressive stress is E*alpha*delta T or 100GPa*10e-6* 17.4 or 17.4 MPa. This is compression and offsets the Lorentz force hoop tensile stress.

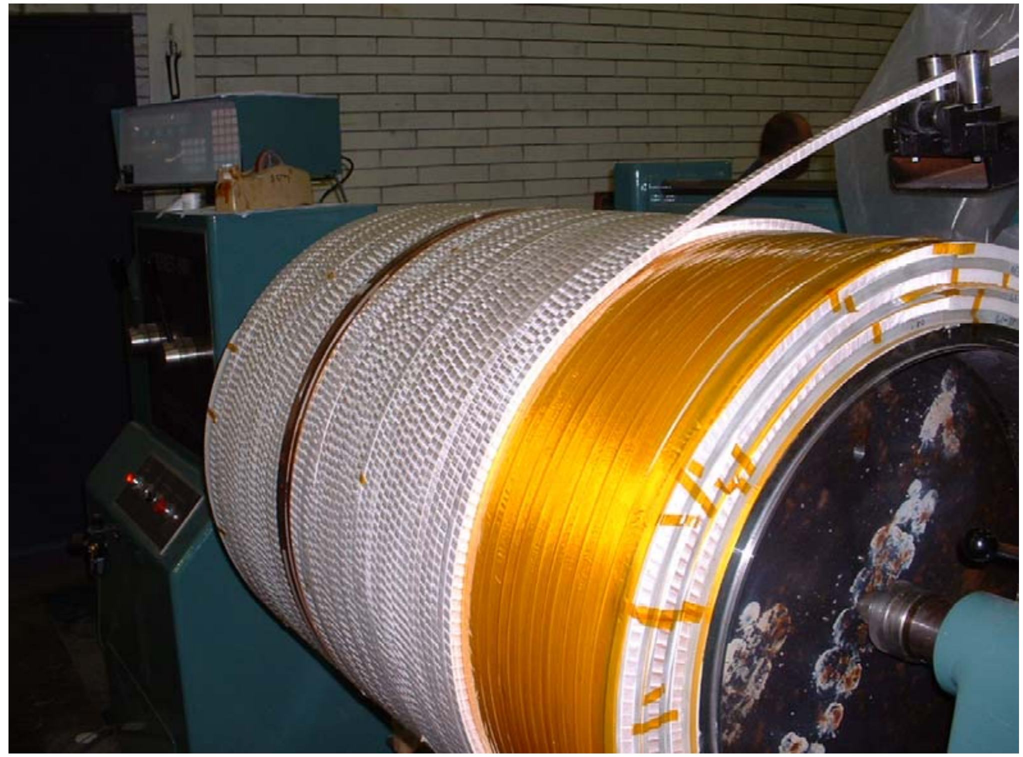
The outer turn R/t ratio is 20 so the radial tensile stress is 17.4/20 or less than 1.0 MPa. Remove the copper in the way of the cooling channels

Segment #2

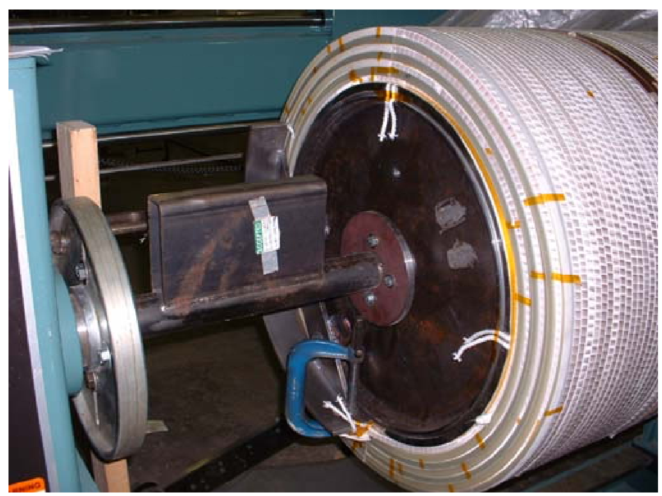
As of Thursday January 27th :

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

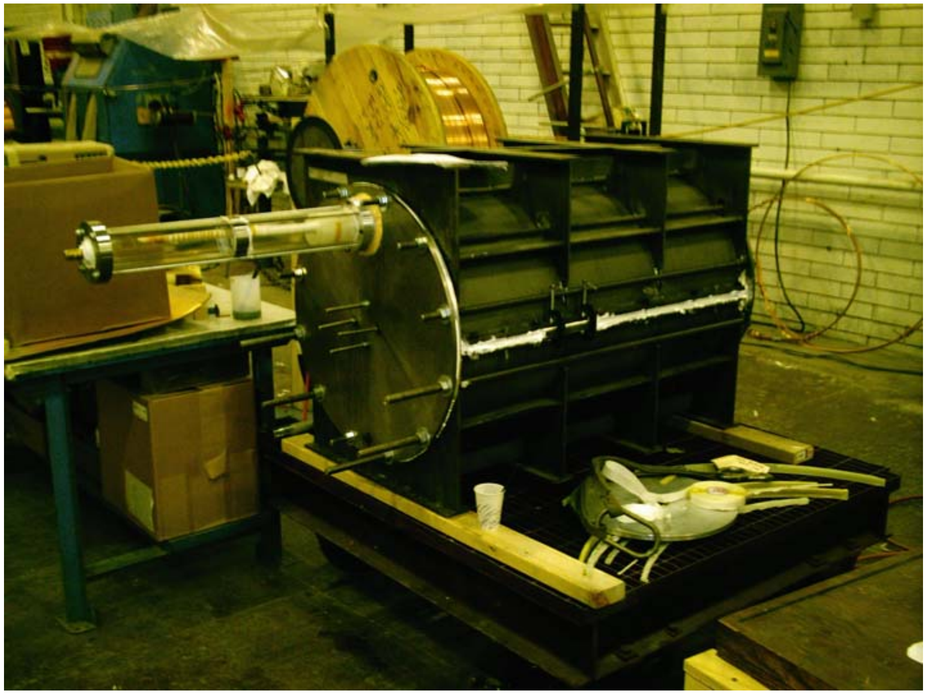
Segment #2 being assembpled in the mold.



Winding Segment #2

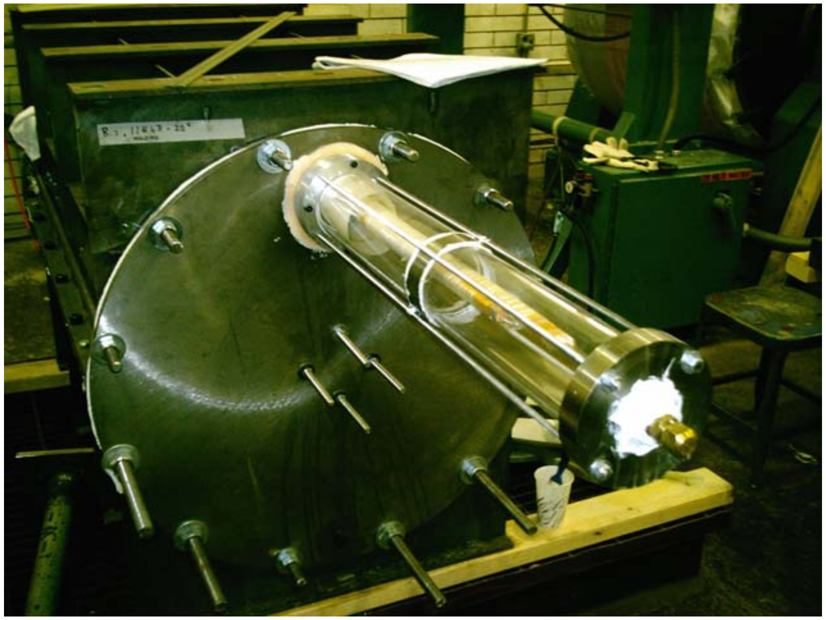


There was a leak in the longitudinal seam weld. This required application of RTV caulk and additional time to wait for the cure. This was to be held at 2 atm for 12 hrs prior to impregnation

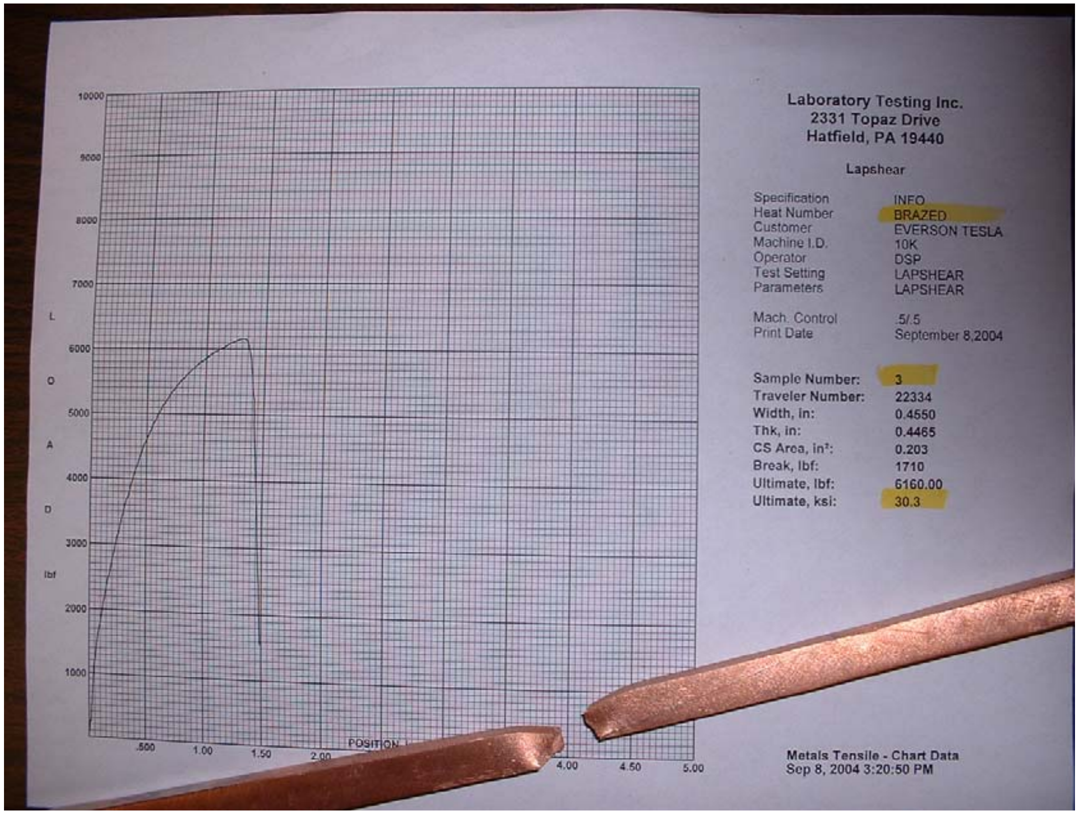


Segment #2 Mold (with Coil enclosed)

Segment #2 Lower Half of Mold

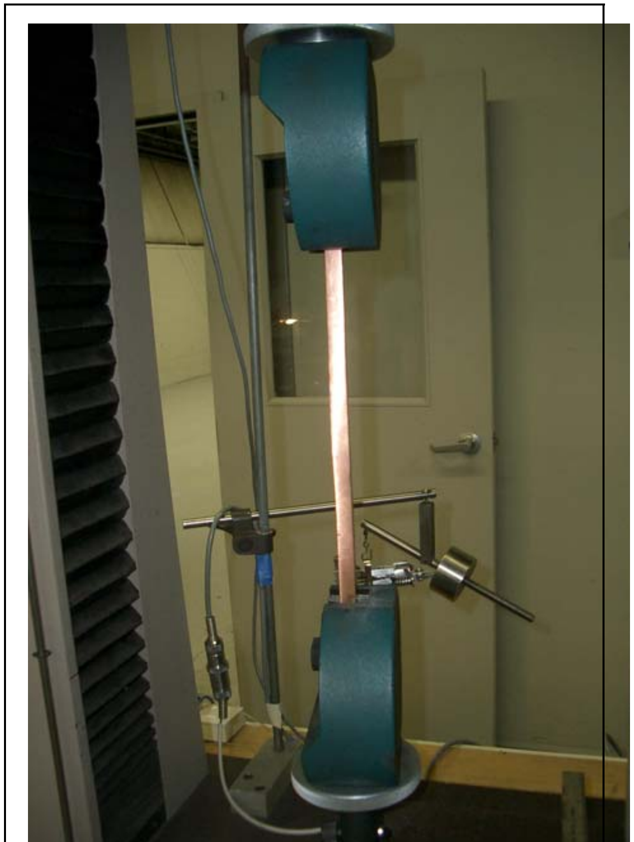


Segment #3 has Silver Solder Joints and these needed to be qualified prior to winding.



Load Displacement plot of Silver Solder Joint.

Faint indication of silver soldered scarf joint



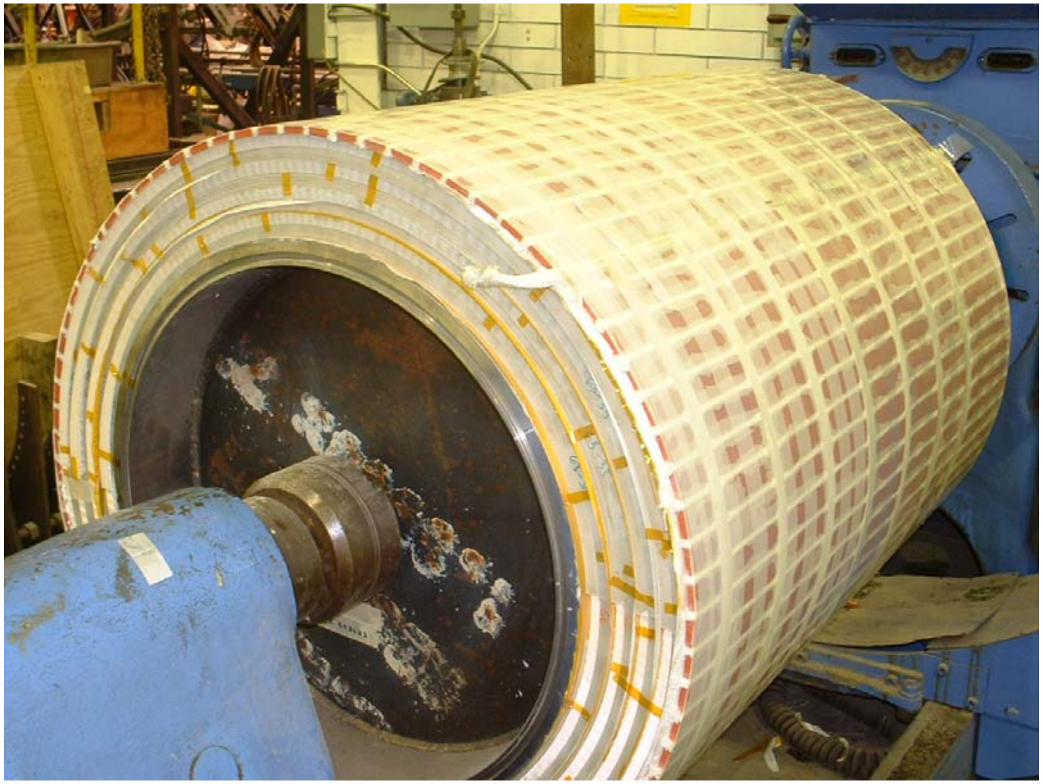
Silver Solder Joint Tensile Test

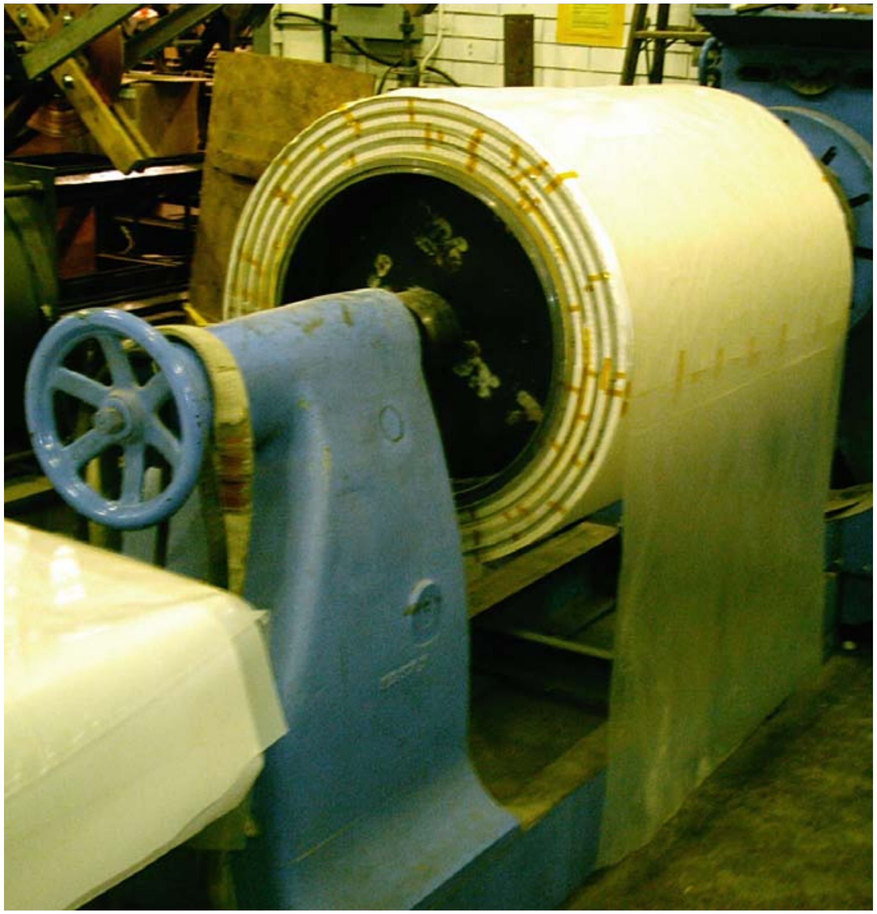
Segment #3

As of Thursday January 27th :

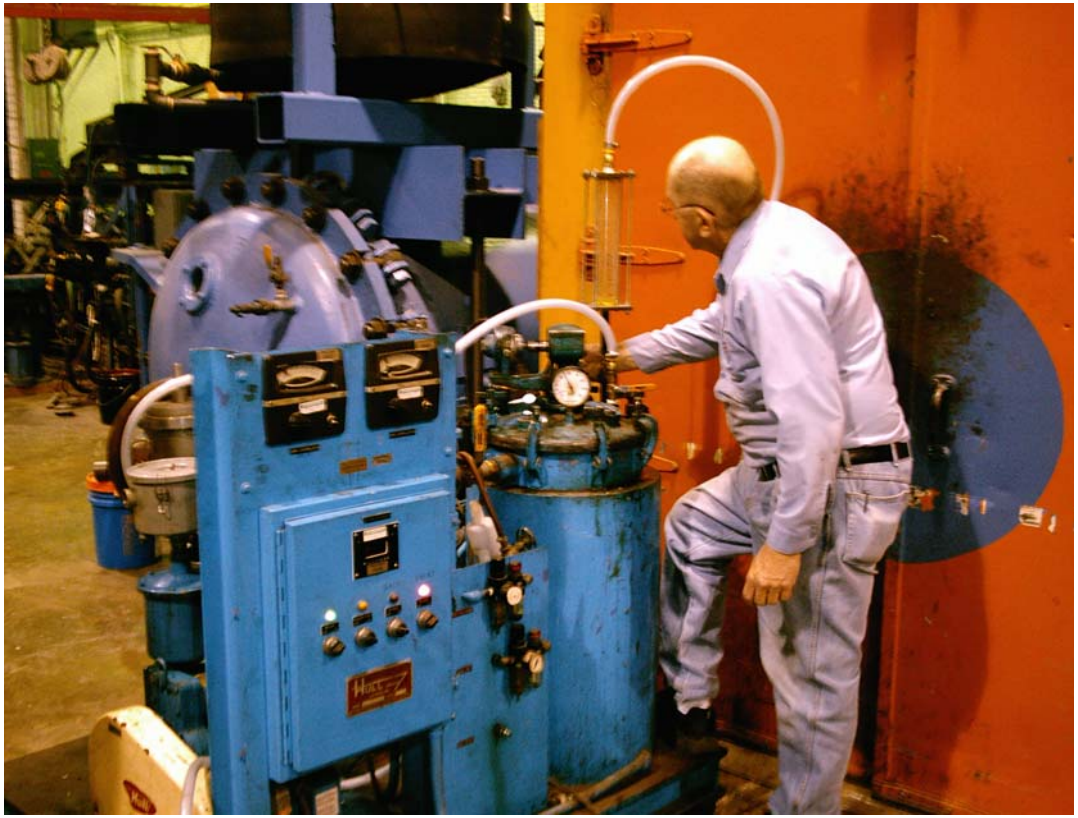
Segment #3 has been wound and the outer "waffle" pattern has been applied. This is scheduled for impregnation Feb 2 to 4

Segment #3 with Dave Rakos standing next to the coil for scale





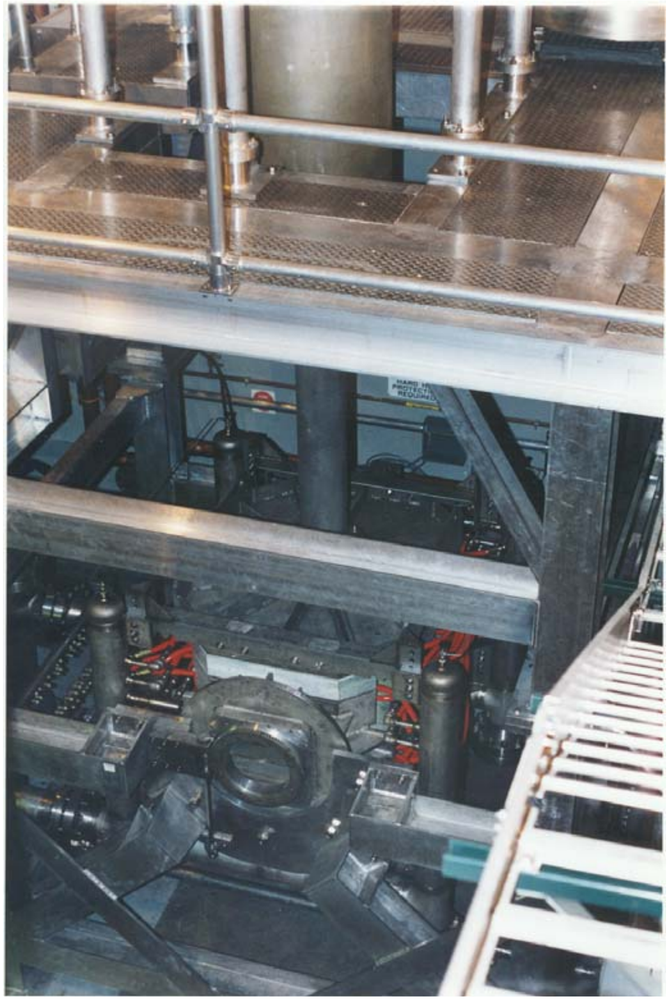
Segment #3 - As of Feb 7 2005 it was epoxy filled and the cure process was begun



A vacuum is maintained on the mold (inside the autoclave box) with a vacuum pump (not shown) to the right of the autoclave). The epoxy tank is at an atmosphere gage. Ron adjusts epoxy flow manually. After the mold is filled, pressure is cycled to drive off bubbles. The mold is under pressure during the cure cycle to minimize the remaining bubbles.

Epoxy fill site glass. Everson doesn't have a good method to measure the flow going into the coil

Plans for Testing at MIT:

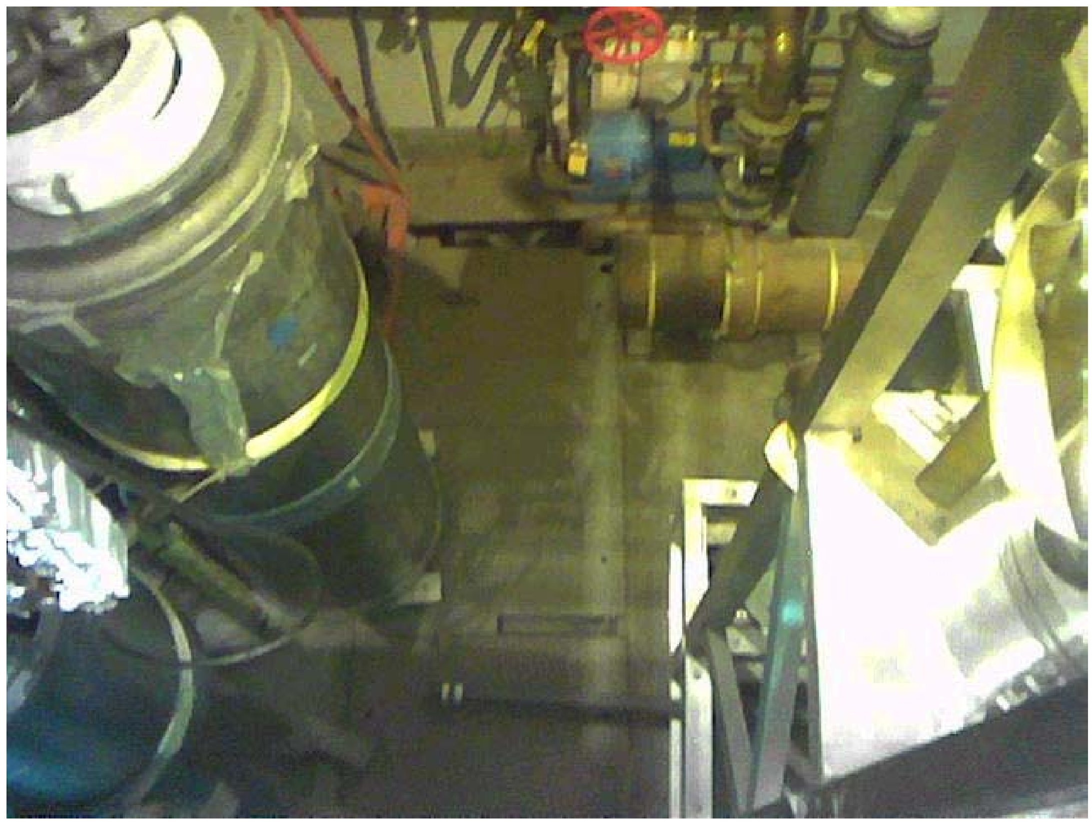


Lower Water Cooled Split Pair Copper Magnet - The BNL Pulsed Magnet will be in front of this, where the HXC Prototype cryostat is now positioned.

A formal proposal for testing has been submitted to BNL, and approval is imminent. 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.

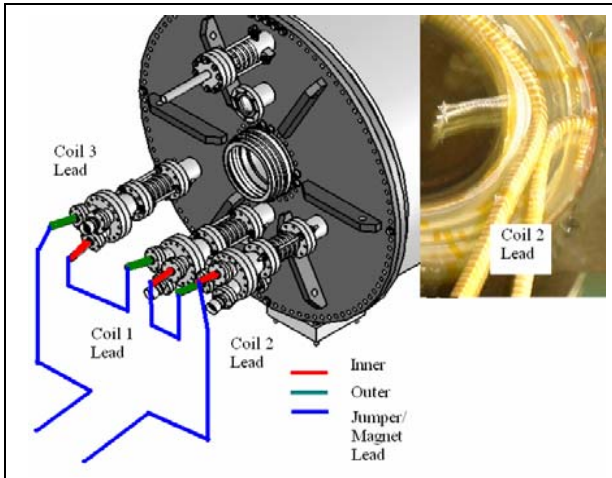
PTF Upper Cryostat

View of test area at floor level



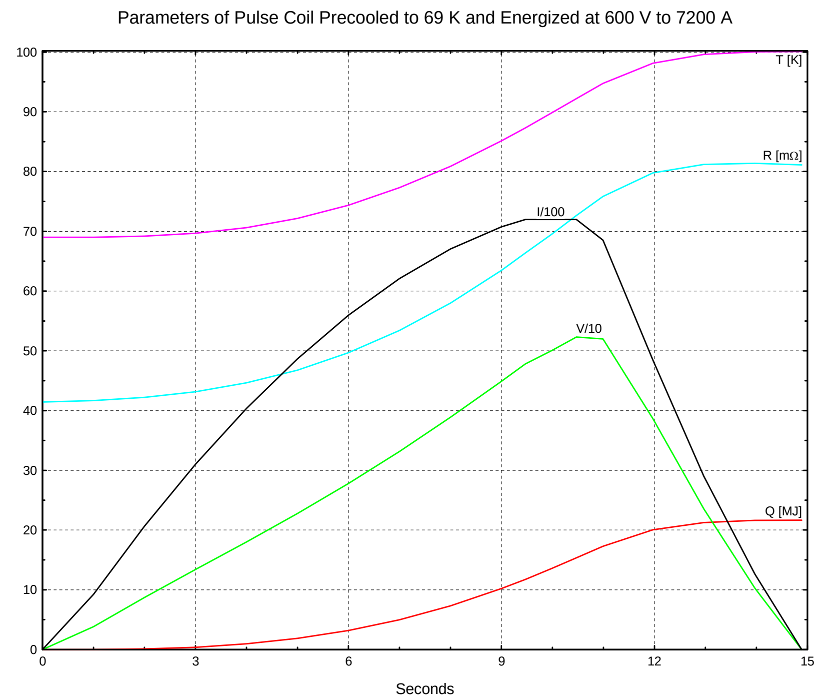
View of the test area floor. The dewars at left and HCX components at right need to be removed

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

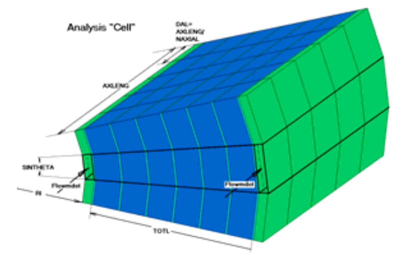


Bob Weggel's 10-14 analysis of the LN2 magnet operation

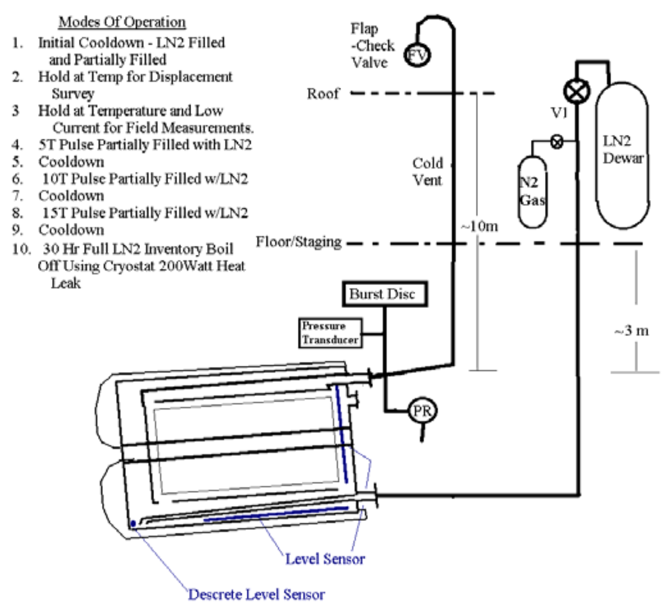
Cryogenic System for the Test

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.

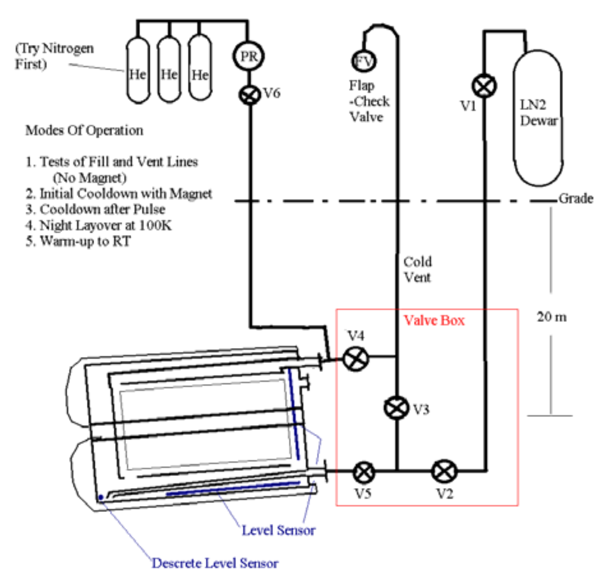
The requirement to remove the LN2 during the experiments in CERN stems from the radiation environment causing activation of Nitrogen, and the creation of Ozone. Neither of these problems exists during preoperational testing. This allows a further simplification of the system planned for CERN. The system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



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



Cryogenic System Planned for use at MIT



Cryogenic System Planned for use at CERN – As of November 23, 2004

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.

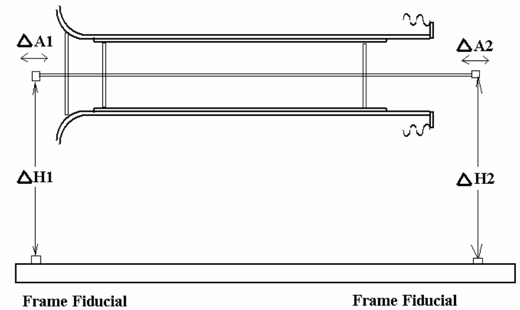
Inductance Measurement

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

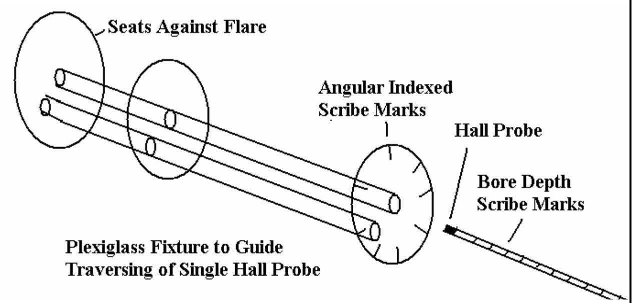
5T Test

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)



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 cassette



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

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