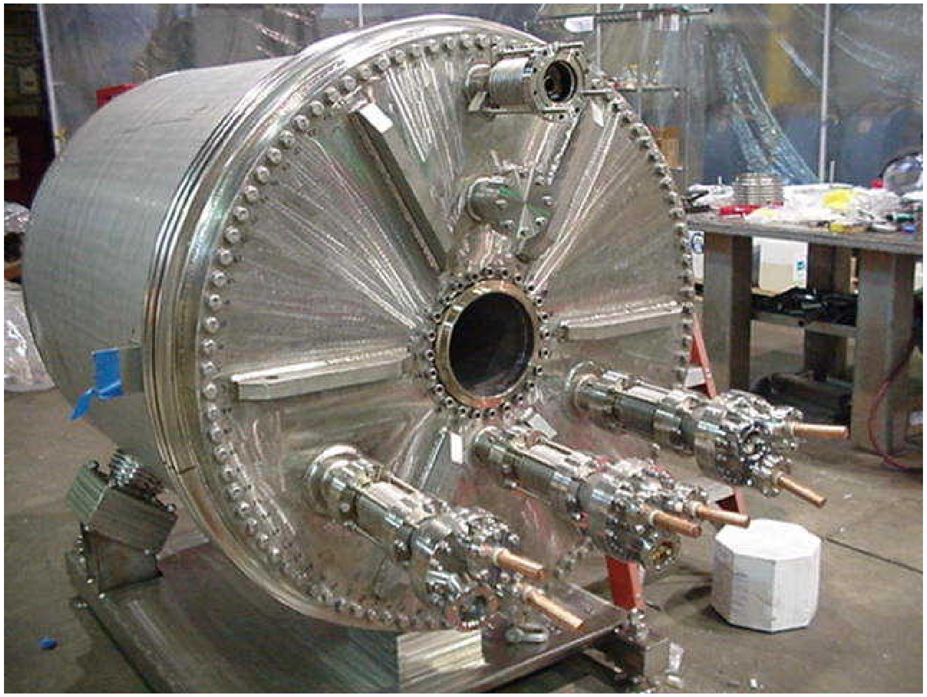
# Review of the MERIT Experiment

## Magnet Status and Testing Plans

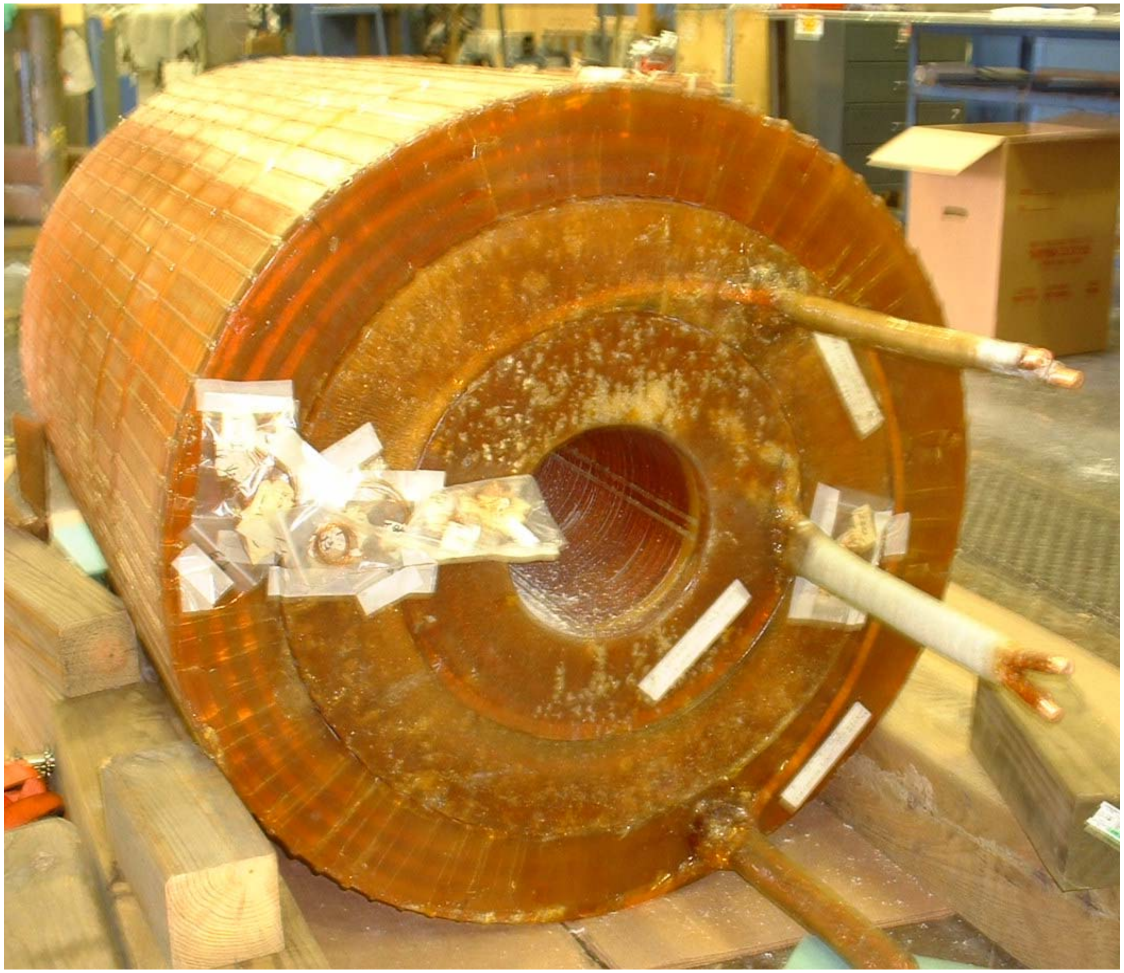
## Monday December 10, 2005



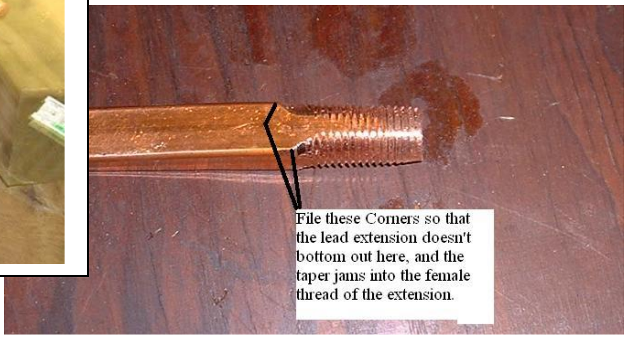
**MERIT Pulsed Magnet –Inertially Cooled , 80K LN2 Cooled Between Shots**

**Peter H. Titus**
**MIT Plasma Science and Fusion Center**
***(617) 253 1344, titus@psfc.mit.edu, http://www.psfc.mit.edu/people/titus***

## Nested Coils as They Appeared at Everson Prior to Shipping to CVIP.



Leads threaded, Coils being prepared for shipping




Lead Pipe Thread

# CVIP Vessel Manufacturing Status

**Final alignment of terminations was made. Gland nut components assembled well ad will be readily changed-out if needed.**

**Instrumentation was assembled, -Not soldered to Instrumentation pins – This will be done at MIT because of needed rewiring. (Each Cernox temperature sensor has 4 wires. Some current sources need to be connected in series, while maintaining separate voltage tap leads. The Discrete level sensor had all diode common ground connections wired to pin terminations – not enough pins)**
**]**
**Assembly has been completed after slight fit-up problem with outer bolt circle.**

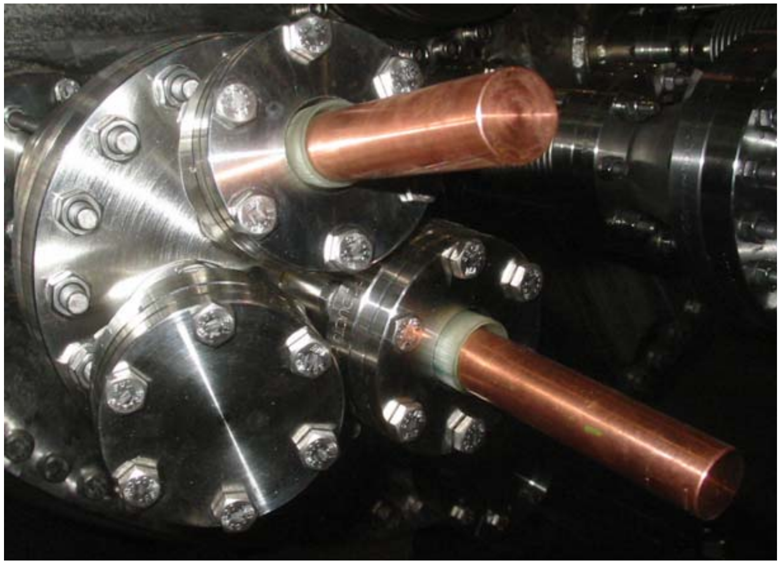
**The cold vessel was pneumatically tested to 245 psi or 16.66 atm. This was in accordance with ASME div I Pneumatic test requirements for 1.10 times the design pressure- no attempt was made to take credit for the lower temperature allowables.**

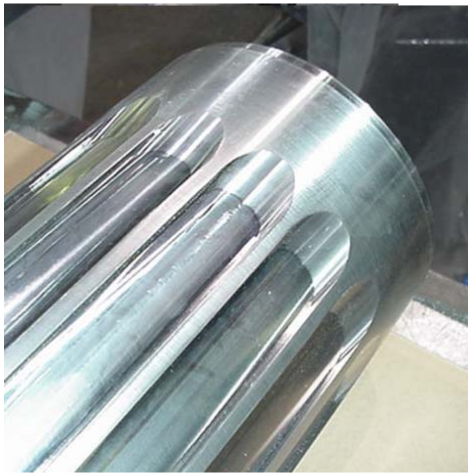
**Metal Seals Seated properly.**

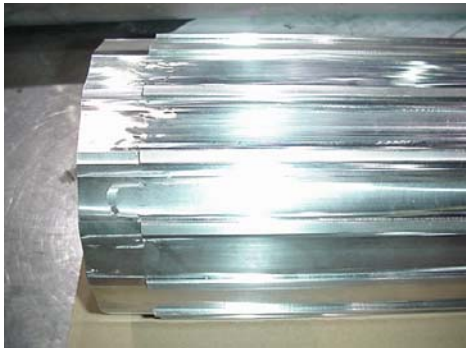
**First Vacuum Test was successful – except for a small leak detected with the Helium leak detection (mass spectrometer) system.**

Terminal Gland Nut Seal

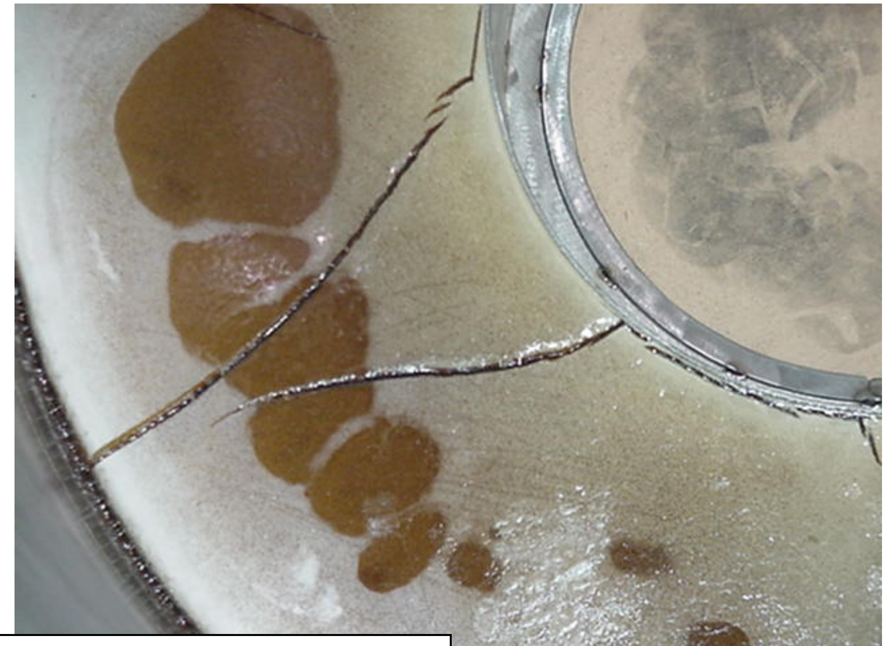

Metallic seals for the cover flange




Spline Tube central magnet support



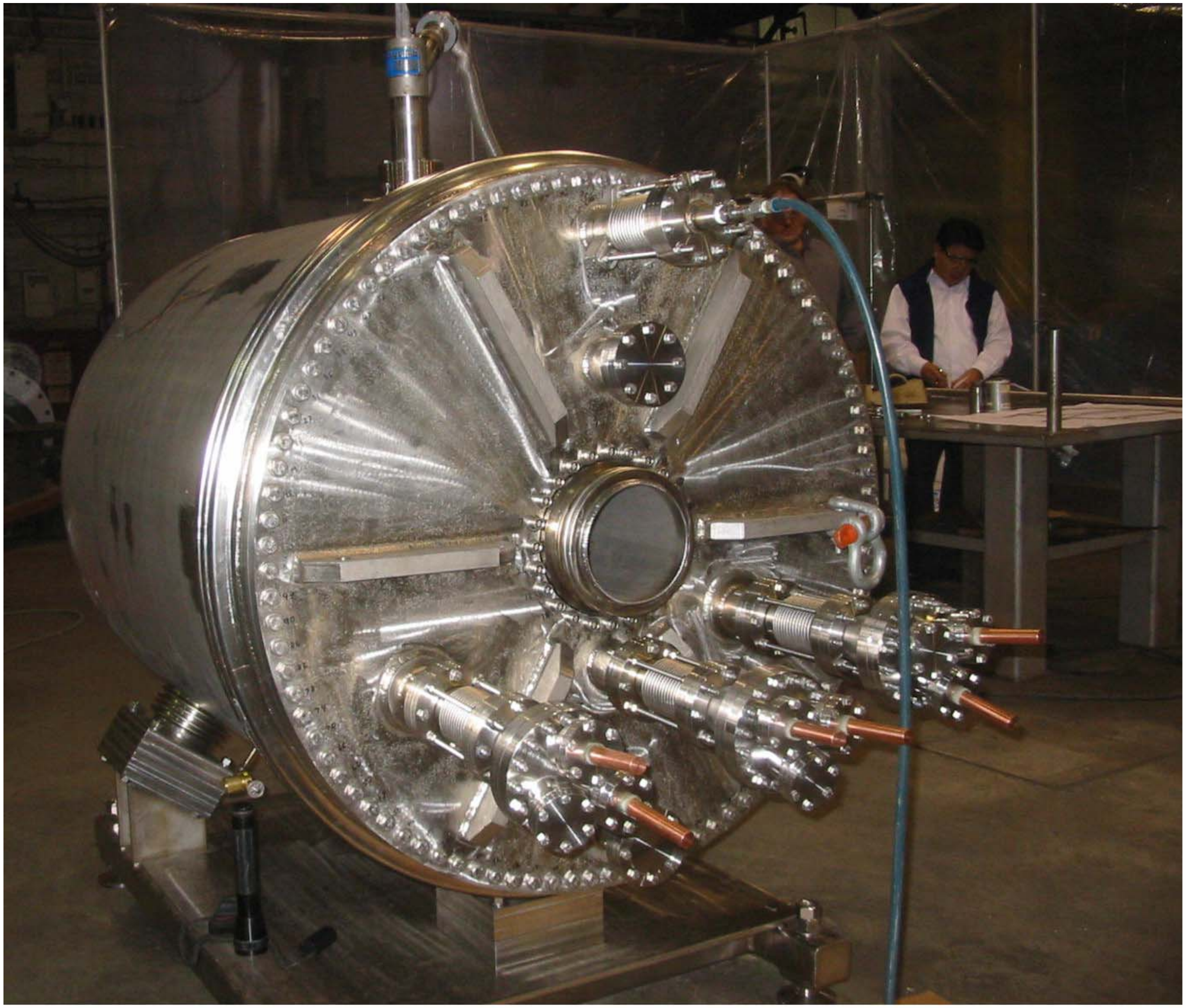
# LN2 Volume Reduction Fillers



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.

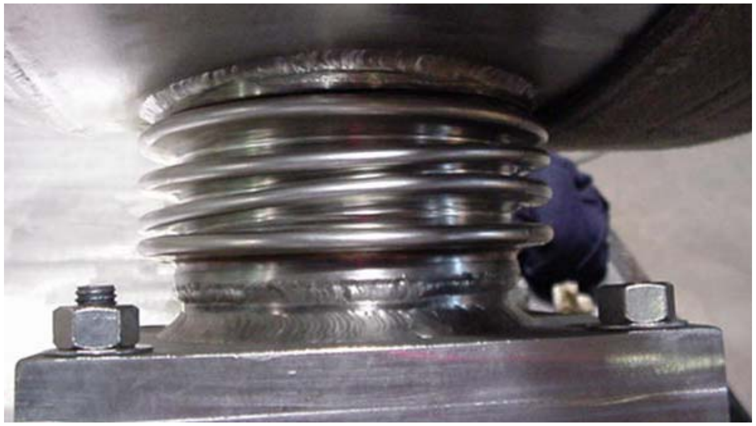
OK- The only problem with deleting the glass bead is that the contraction of the epoxy is about twice that of steel. With the glass bead, the contraction is close to steel. As long as the fillers are not bonded to the steel it will be OK, otherwise we will have some scary noises when we cool down for 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.

## First Vacuum Jacket Test

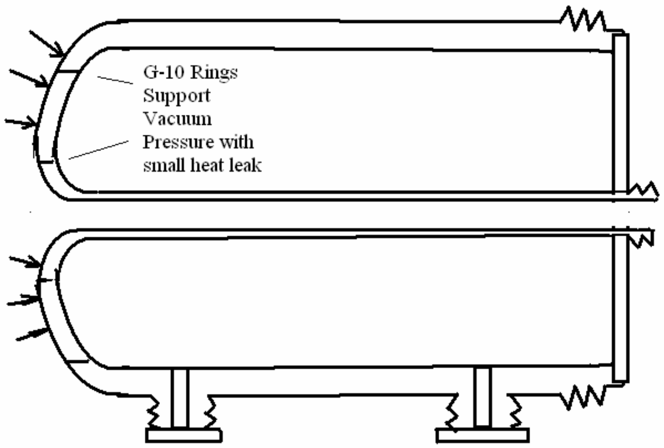


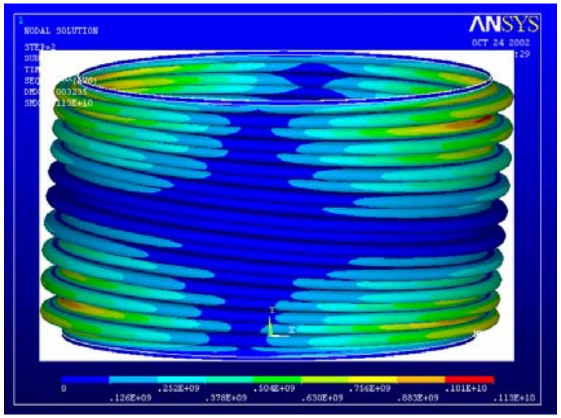
# CVIP Vessel Manufacturing Status – Bellows Problems

Centered bellows after repair attempt. – This one is being replaced. Damage is indicative of occurring with vacuum applied.



Bellows Displacement during second Vacuum Test. Looking from the power lead end, this is the left hand angled bellows. Bellows tilt is indicative of behavior if vacuum boundary was pressurized above 1 atm abs.



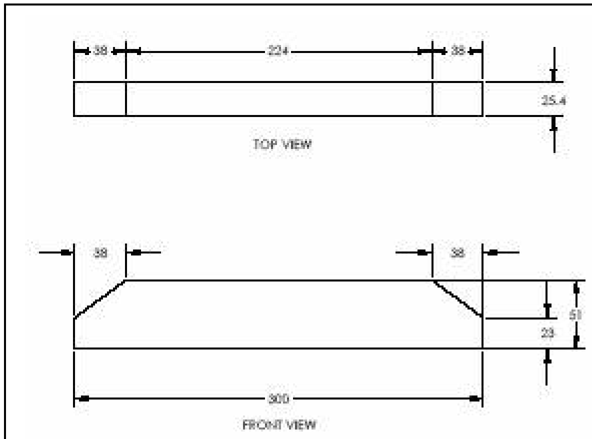




.Gravity support bellows, Stress due to cooldown. 008" thick stock. 4.0 inches in inner diameter, 6mm convolution pitch with 2.5mm flats, 2.2mm lateral displacement due to cryostat cooldown.

Vacuum Connection

**Fixes? We May have to Constantly have a Vacuum Pump Running ….**

# CERN Magnet/Vessel Qualification Questions :




From: Adrian Fabich [mailto:Adrian.Fabich@cern.ch]
Sent: Wednesday, December 07, 2005 1:25 AM
To: titus@psfc.mit.edu
Subject: FW: MERIT vessel safety (review by Andrea)

Hello Peter,
Yesterday I had a chat with our safety colleague concerning pressure vessels (=cryostat). Below you cand find the few comments/questions, he
stated. Most critical, he told, is the issue of page 10.0-1. I hope we find half an hour at BNL next week to go through. Sorry for the miserable notes, my style of writing. I will discuss with you in detail.
We should provide him response on the few topics, such that he can approve the system for CERN.
Adrian

-----Original Message-----
From: Adrian Fabich
Sent: Tuesday, December 06, 2005 11:25
To: Adrian Fabich
Subject: MERIT vessel safety (review by Andrea)

Page 10.0-1
15 bar or 20 bar?
exceeds 300 bar ; limit exceeded!
How to overcome pressure overload?
PHT: The issue was a local stress beyond 300 MPa with a 2 cm rib. The ribs are actually 1 inch thick. I need to update the calculations, but the stiffer ribs will improve the cover flexure and resulting stresses at the flanges.

The cold vessel was pneumatically tested to 245 psi or 16.66 atm. This was in accordance with ASME div I Pneumatic test requirements for 1.10 times the design pressure- however we made no attempt to take credit for the lower temperature allowables. So we have a larger margin at 80K

CODAP

risk category 3 (of 4)

-> construction category A (strongest)

acceptance type

definition of delivery

AA will send document

Page 10.0-5

results for 1 cm or 2 cm ribs given? If not, please provide!

PHT: See above

Page 10.0-7 (and 8)

bolt calculations

safety factor of only 1.3 or even 0.84 (at 20 bar)

This will break or not?

PHT: Inner flange bolts are limiting. Additionally, M12 bolts were substituted for ½ inch bolts. The M12's still meet the stress allowables for 15 atm. The load on this bolt circle was calculated two ways. First the loads were estimated from pressure centroid location, and second, the finite element model was used. The most limiting bolt loading was used for evaluation of bolt tension and thread shear. We can only qualify 15 atm based on the RT allowable for the bolts. The bolts also must compress the metal "C" seals, which they did successfully during the pneumatic test.

Page 11.0-1

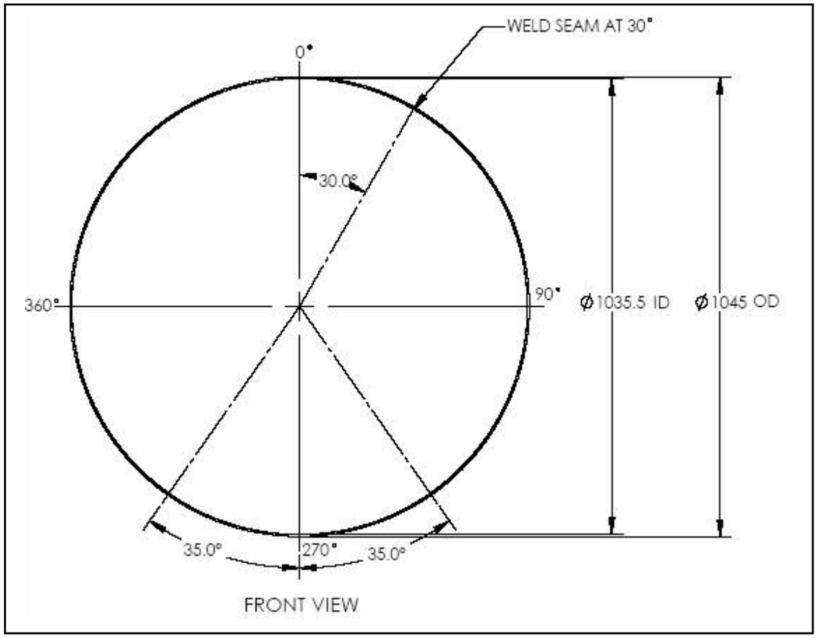
Buckling

safety factor 3/5 stated. Fine

are the calculations given for 1 or 5 mm?

if not 5 mm, please provide!

PHT: the Vacuum Vessel is 4.75mm thick. It has been structurally tested under vacuum, but the strains appear excessive at the bellows and there are a couple of vacuum leaks to resolve.

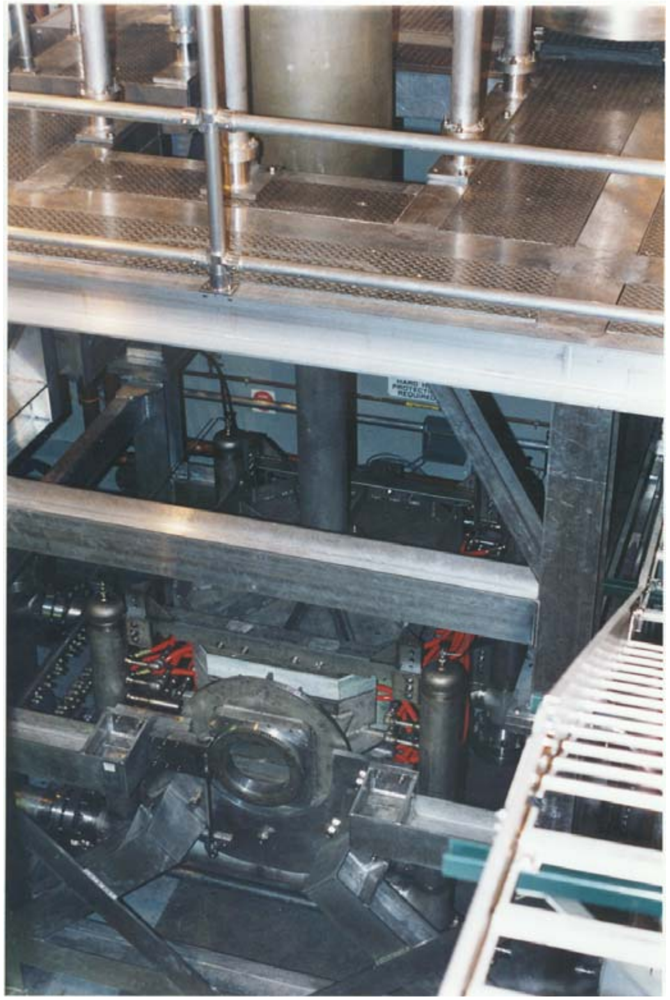



This safety issues are raised by Andrea, not discussed with Alberto.

## Plans for Testing at MIT:

## The tests performed at MIT are intended to:

- **Confirm high pressure seal, and vacuum retention after shipping and receipt.**
- **Exercise the magnet to its design field of 15T. Benchmark linear field/current dependence**
- **Quantify deviations from the expected solenoidal field configuration. (lead break-outs, end ramps and fillers and slight ferromagnetic behavior of 304/316 SST are possible issues)**
- **Quantify the dimensional; stability of the bore geometry at cryogenic temperature. (The bore is part of the vacuum boundary which has exhibited some uncertain, and not yet understood tendency to move during tests at CVIP)**
- **Demonstrate repeatability of bore position at cooldown.**
- **Confirm adequate mechanical and electrical performance of terminal gland nuts.**
- **Verify that the cryogenic system can provide a 20 minute cooldown time between experimental pulses.**
- **Quantify a flow rate vs. time procedure to obtain the 20 minute cooldown.**
- **Vent LN2 through drain extension back into dewar, and quantiy residual LN2 in tilted magnet.**
- **Prepare to perform mercury jet tests in the magnetic field (exclusive of the proton beam)**



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.

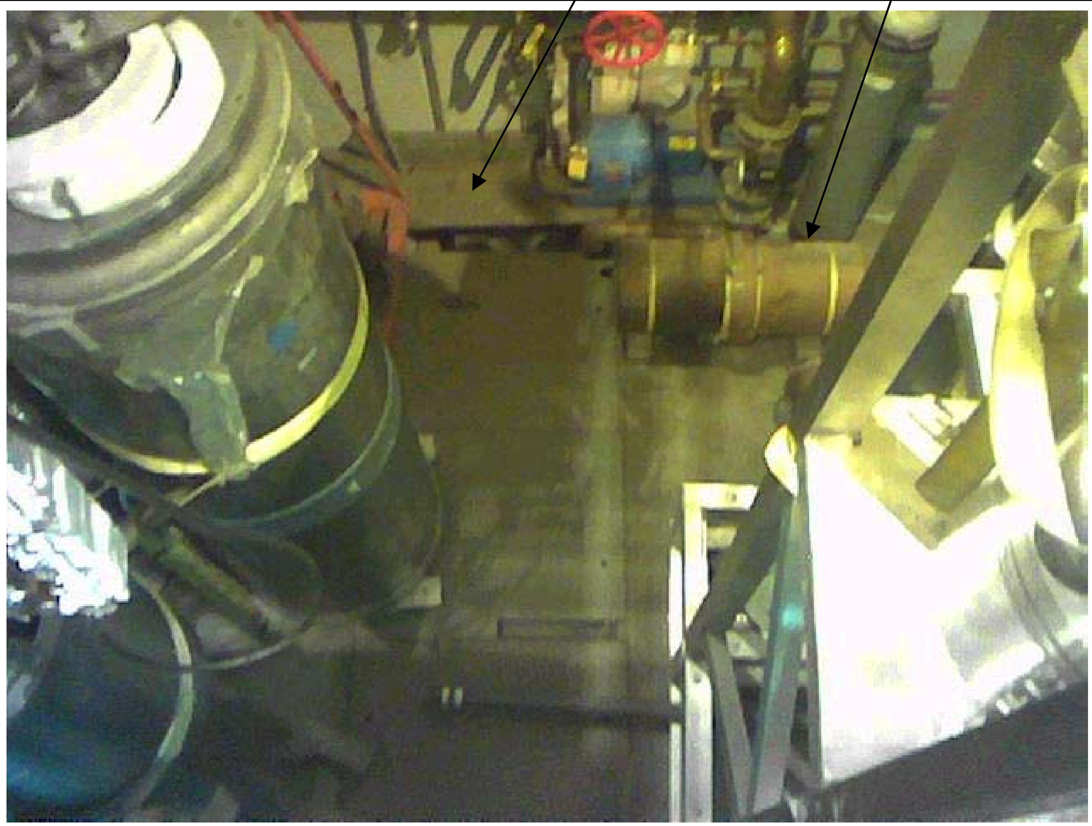
**The test location is the Pulsed Test Facility (PTF) at MIT-PSFC primarily used for testing of superconducting joints in a transient high field background. The test area will need to be cleared of extraneous equipment. Magnetic materials and tools will be removed.**

PTF Upper Cryostat

**View of test area at floor level**

Iron Return yoke for split pair will be moved.

Pump Base is ferromagnetic, Unistrut and electrical conduit is ferromagnetic



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

## 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 would allow a further simplification of the system planned for CERN. However LN2 purge will be simulated at MIT**

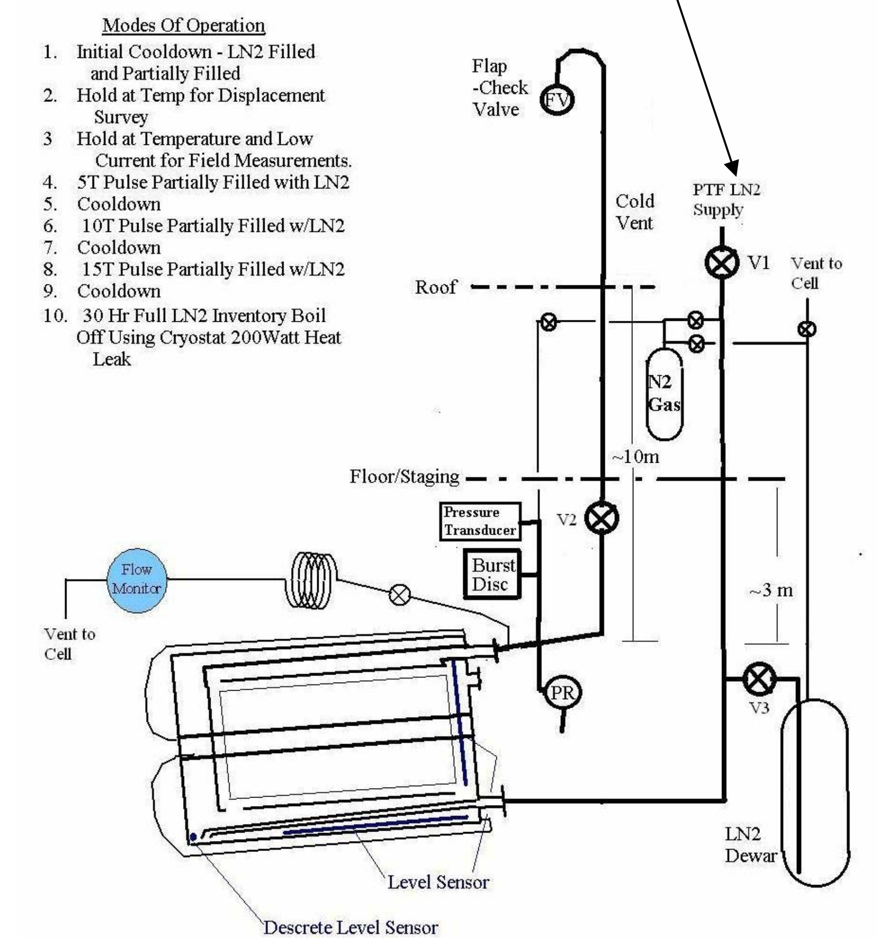
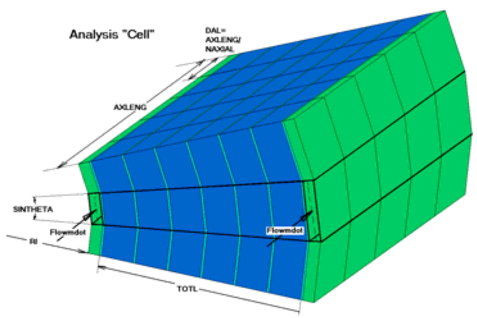
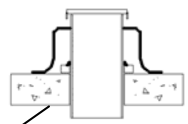


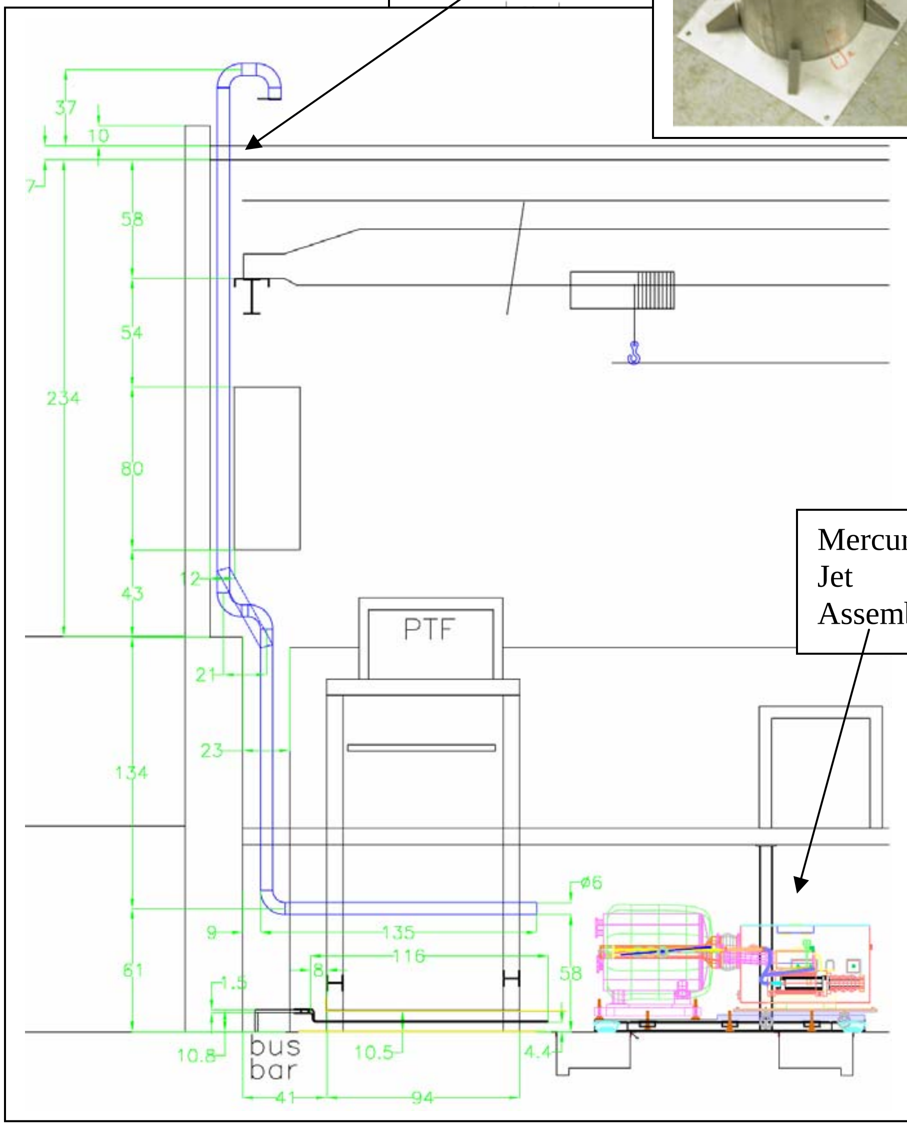

Figure 6.0-3 Cryogenic System Planned for Use at MIT



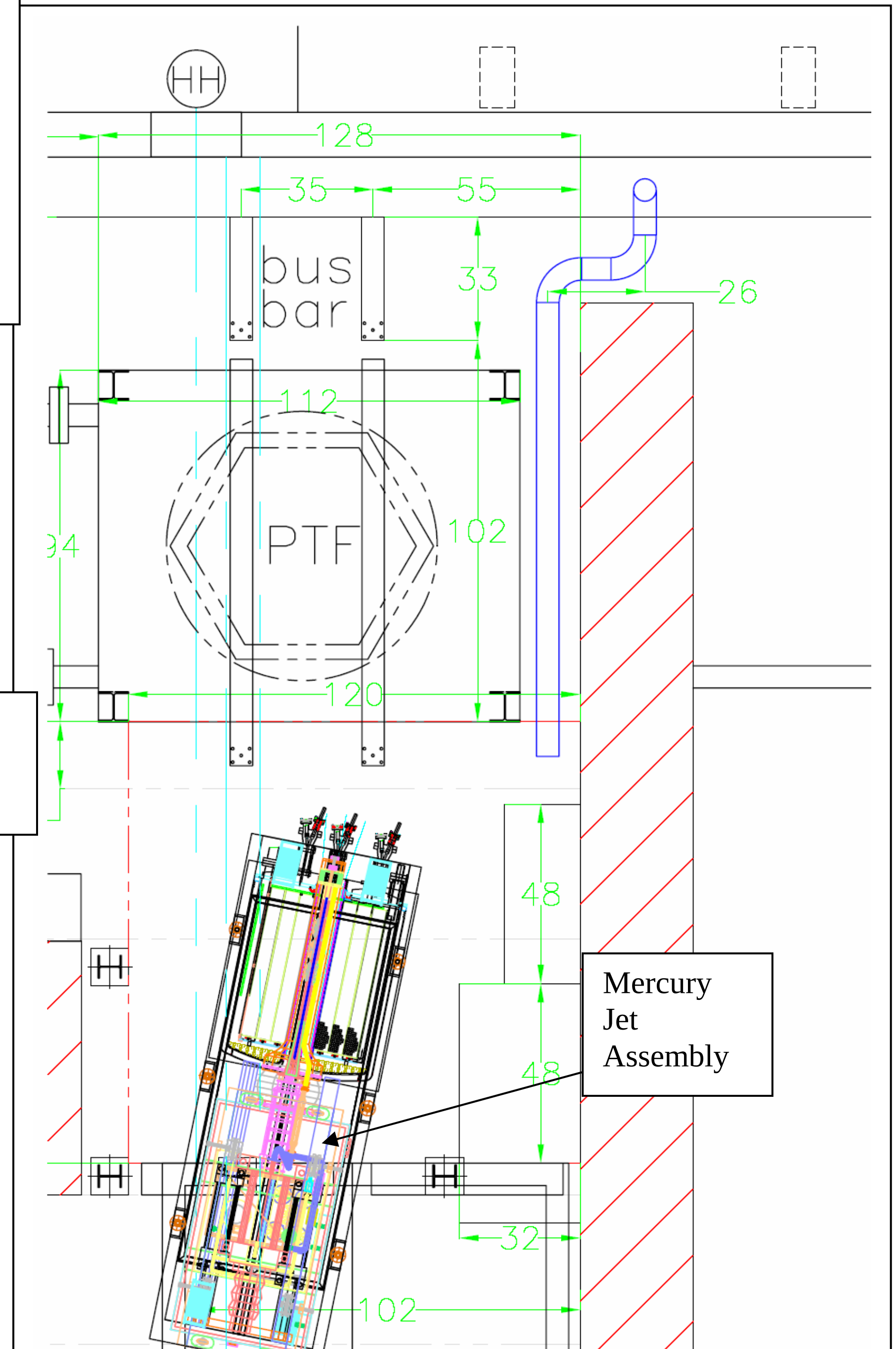

The Simulation originally assumed axial gas flow. Circumferential grooves have been added to allow pool boiling cooling.

Vent Status:
Roof Penetration has been cut – Vent Pipes Arrive Nov 1





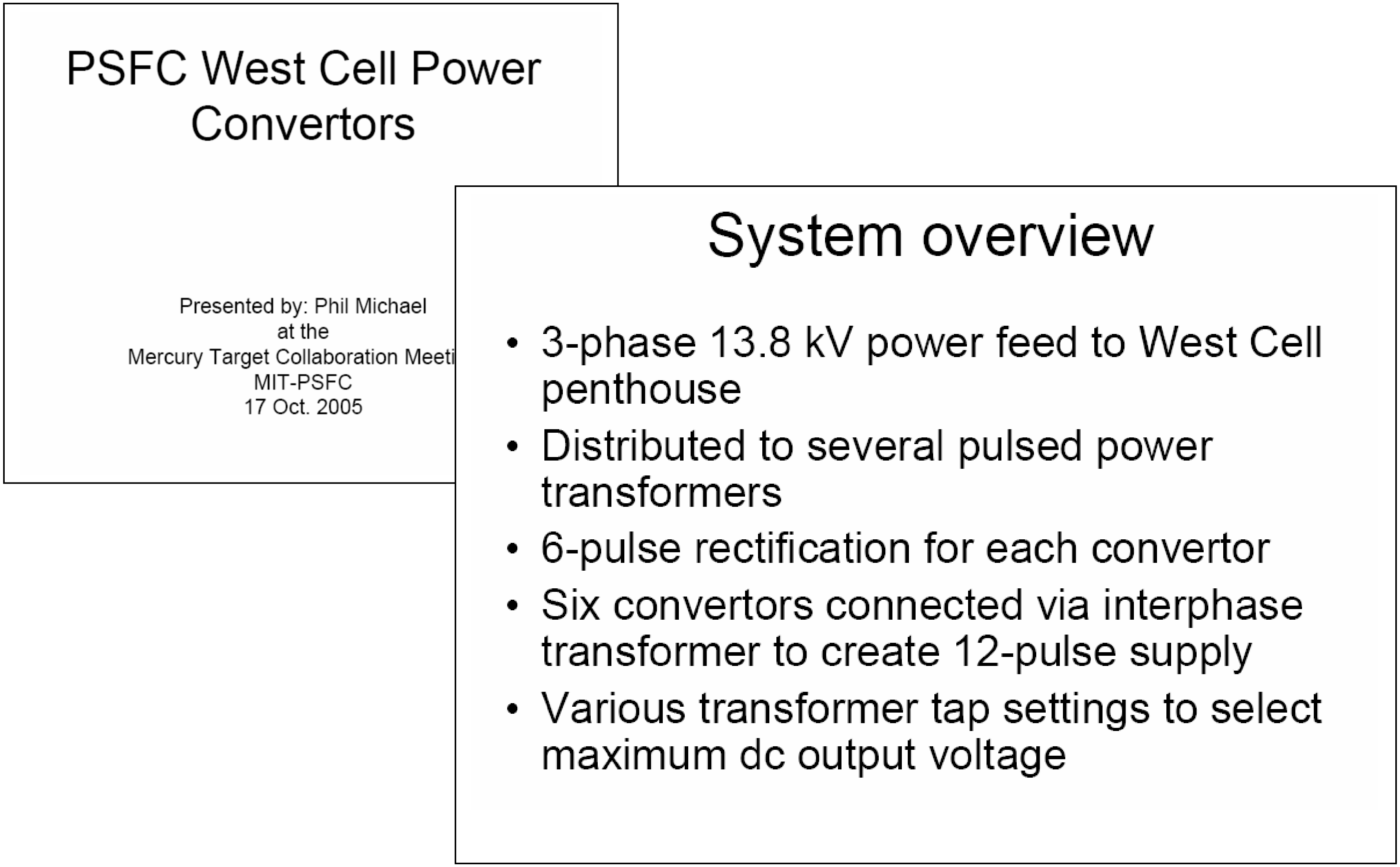

Mercury Jet Assembly




Mercury Jet Assembly

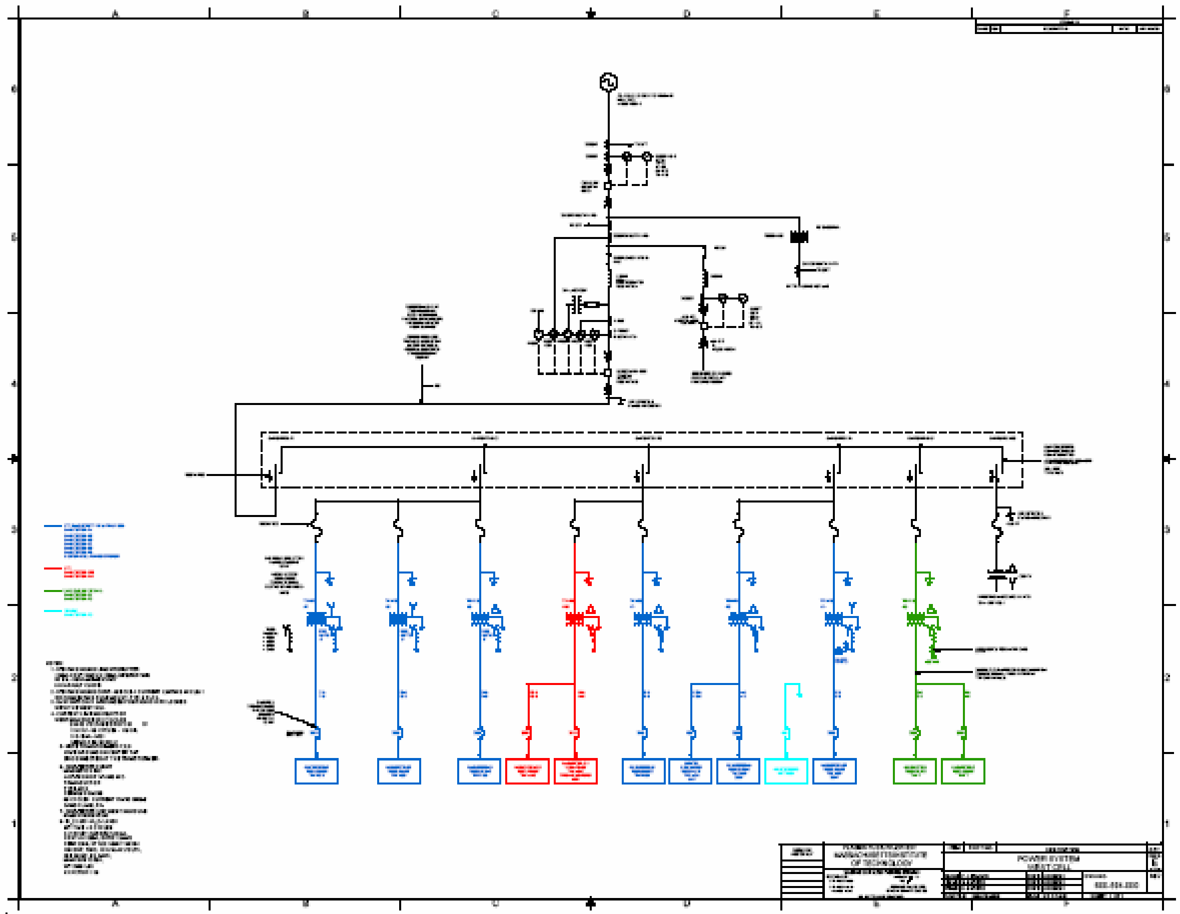
**Power Supply Upgrades and Modifications**

**At the MIT MERIT Collaboration Meeting, Phil Michael of MIT presented plans for Power Supplies and Upgrades. http://www.hep.princeton.edu/mumu/target/MIT/West_Cell_Power_Convertors.pdf**



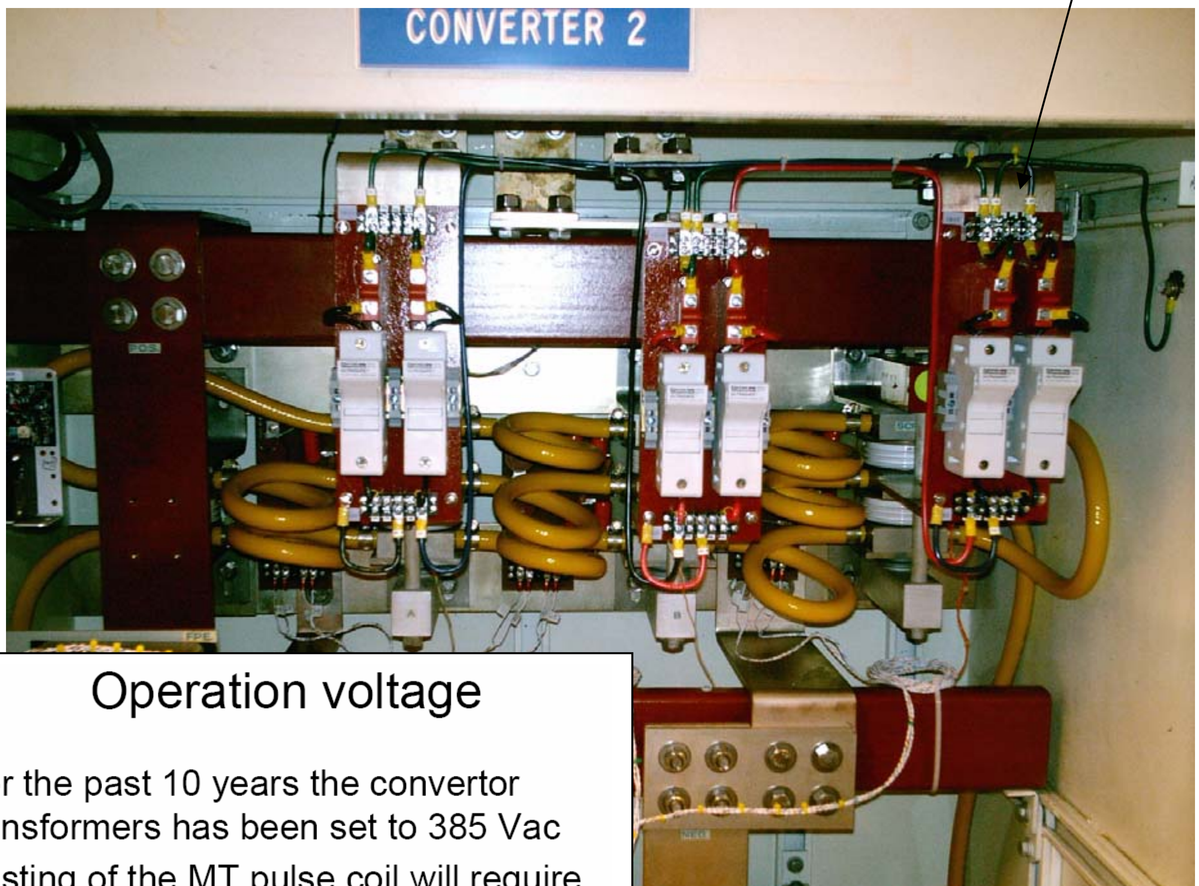
PTF Power Supplies

# System schematic



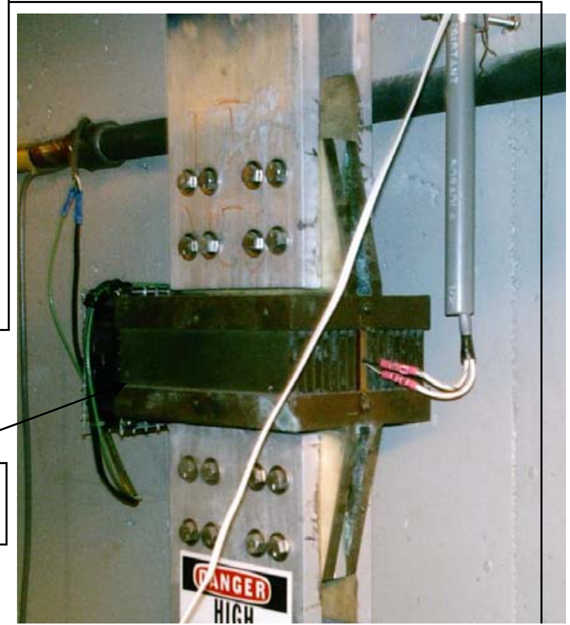
# Power Supply Upgrades and Modifications

Over Voltage Protection


## Operation voltage

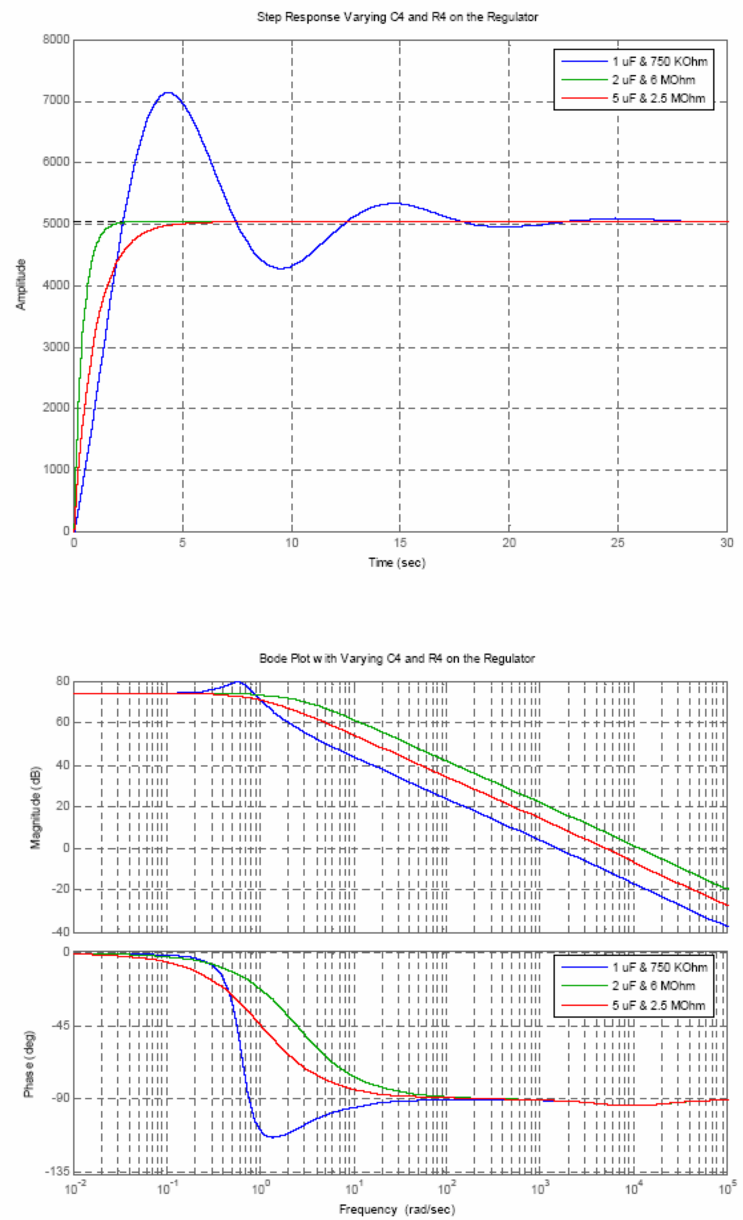
- For the past 10 years the convertor transformers has been set to 385 Vac
- Testing of the MT pulse coil will require resetting the taps to roughly 590 Vac
- The fault protection circuitry in the covertors is ~20 yr old
- Several fault protection components are being upgraded for higher us voltage

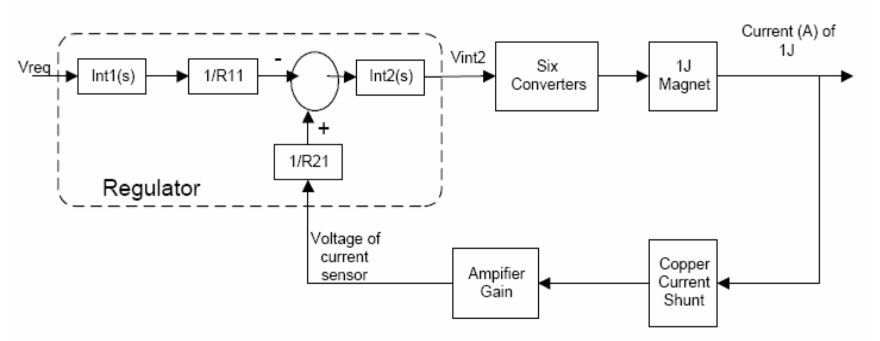


Current Shunt

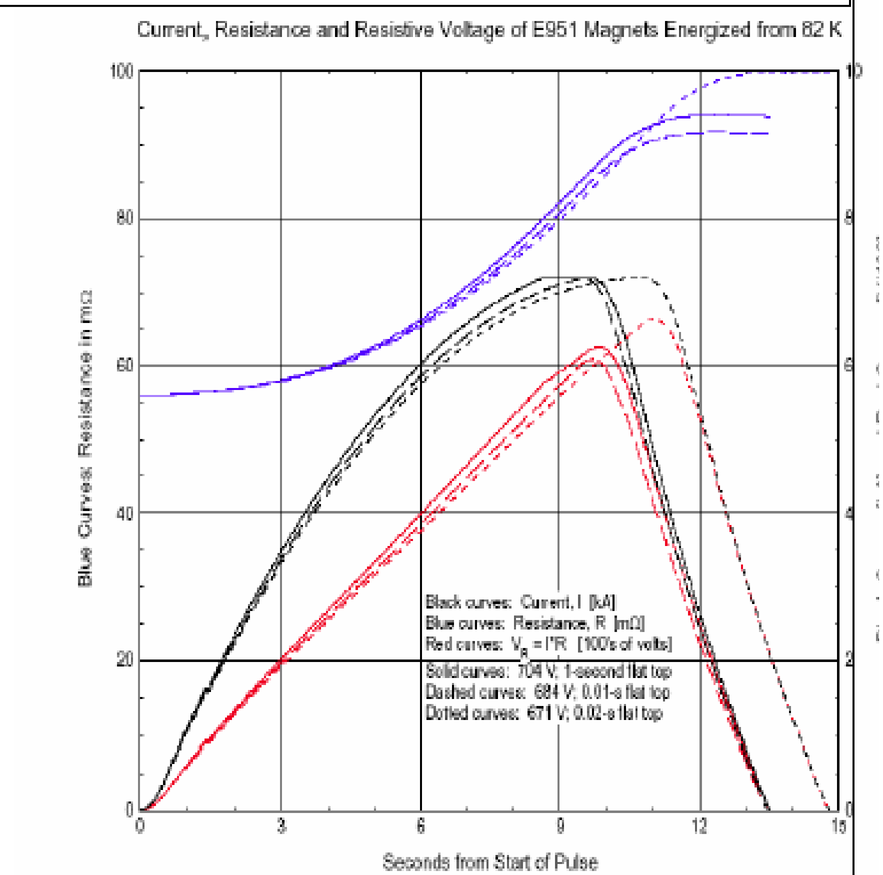
# West End Converters Feedback

Gary Dekow ran his  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.

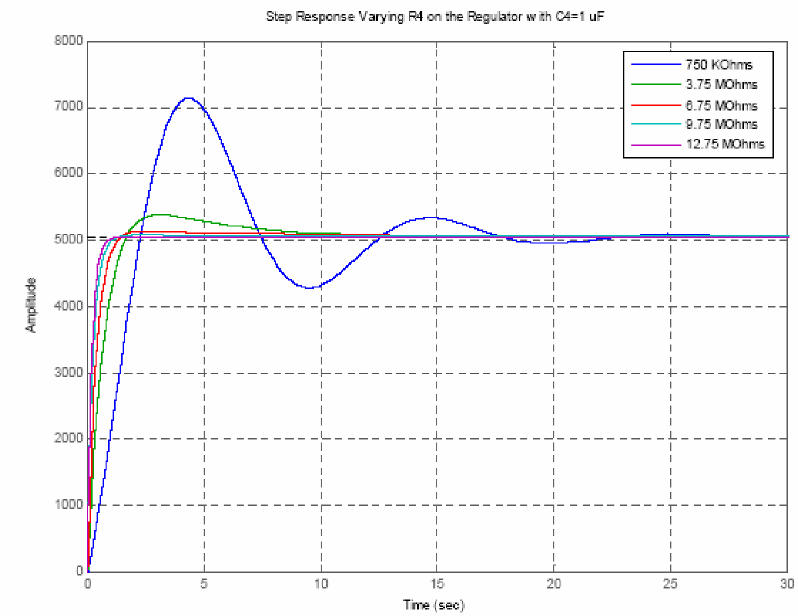


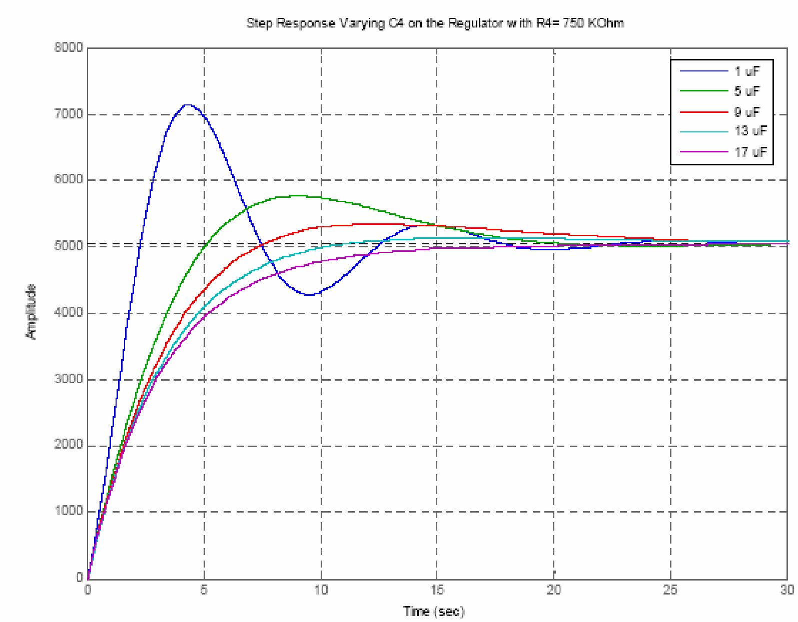



Gary Dekow’s Simulation Model




Current Trace used in the Simulation



## Status of Bus Bars / Leads

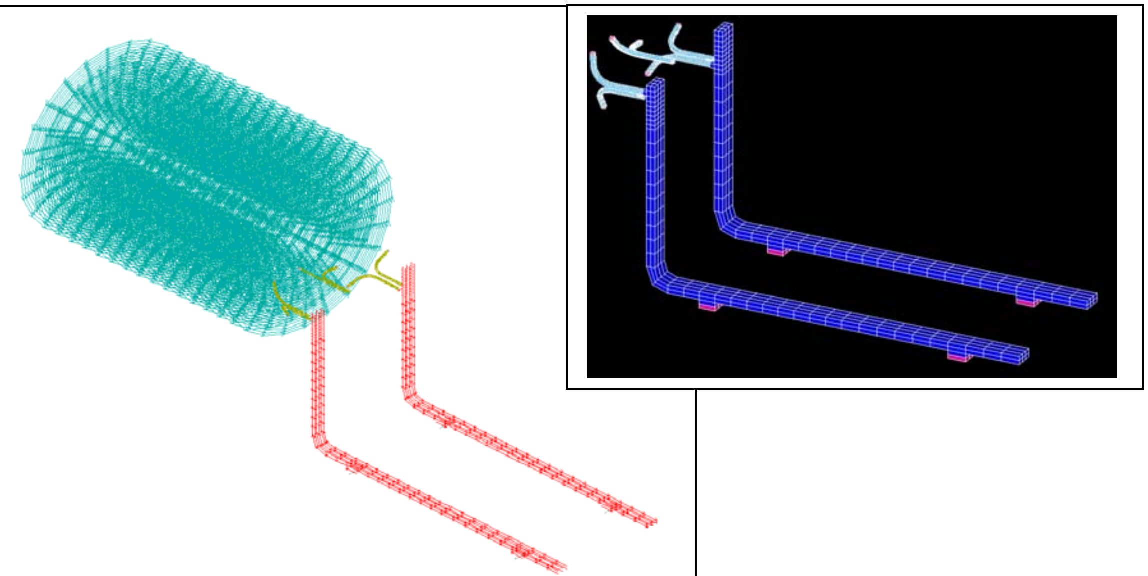
The leads are modeled as 1 X 3 inch bar/strap.

### Loads on the Bus Bar Extensions

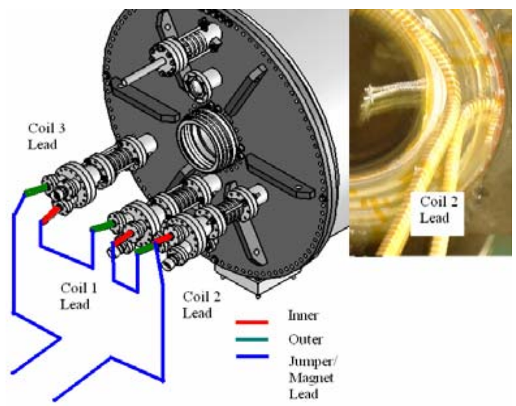
The total reaction for the 2 pads on the rear lead are:

**FX 113.73N**
**FY 1982N**
**FZ –24.5N**

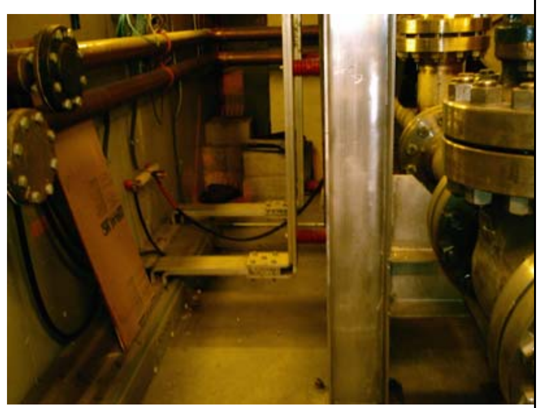
The total reaction for the 2 pads on the front lead are:
**FX 627N**
**FY 1714N**
**FZ –17.25N**



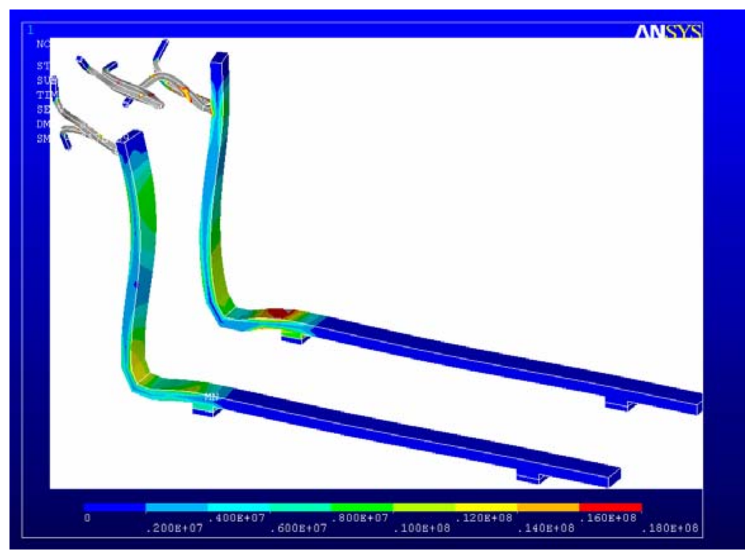
Biot Savart Model of leads and Bus Bar Extensions




MIT-PSFC will Fabricate Jumpers ,Leads and supports.



Bus connection to the PTF Split Pair




Strap Stress is only 18 MPa.

# Preparation activities

- Modifications can start during APS fall meeting - Oct. 24~28, 2005
- Installation of over voltage protection components
- Retest of system using PTF coil as reference

***( We may have to wait until Jan Egedal' VTF Magnetic Reconnection Experiments, and C-Mod's WASP Probe Tests Complete. We are looking into power supplies for low current tests – Inductance, field mapping etc. )***

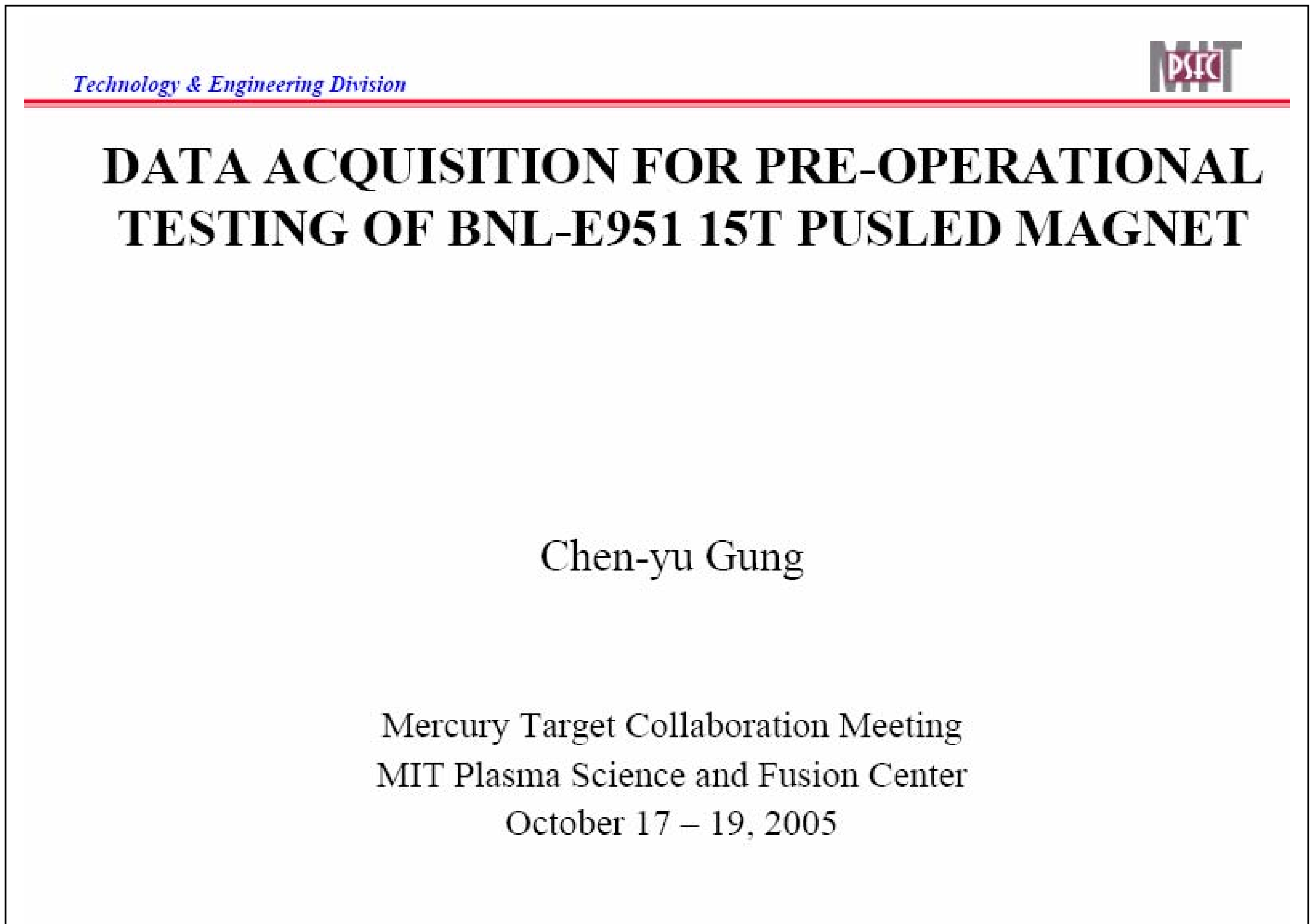
- Completion of bus work to pulse coil

- Tuning of regulator
- Implementation of test program

**MIT-PSFC Data Acquisition System Plans**

At the MIT MERIT Collaboration Meeting Chen-yu Gung of MIT presented plans for data acquisition.

http://www.hep.princeton.edu/mumu/target/MIT/DAQ_for_BNL_pulsed_magnet-1.pdf

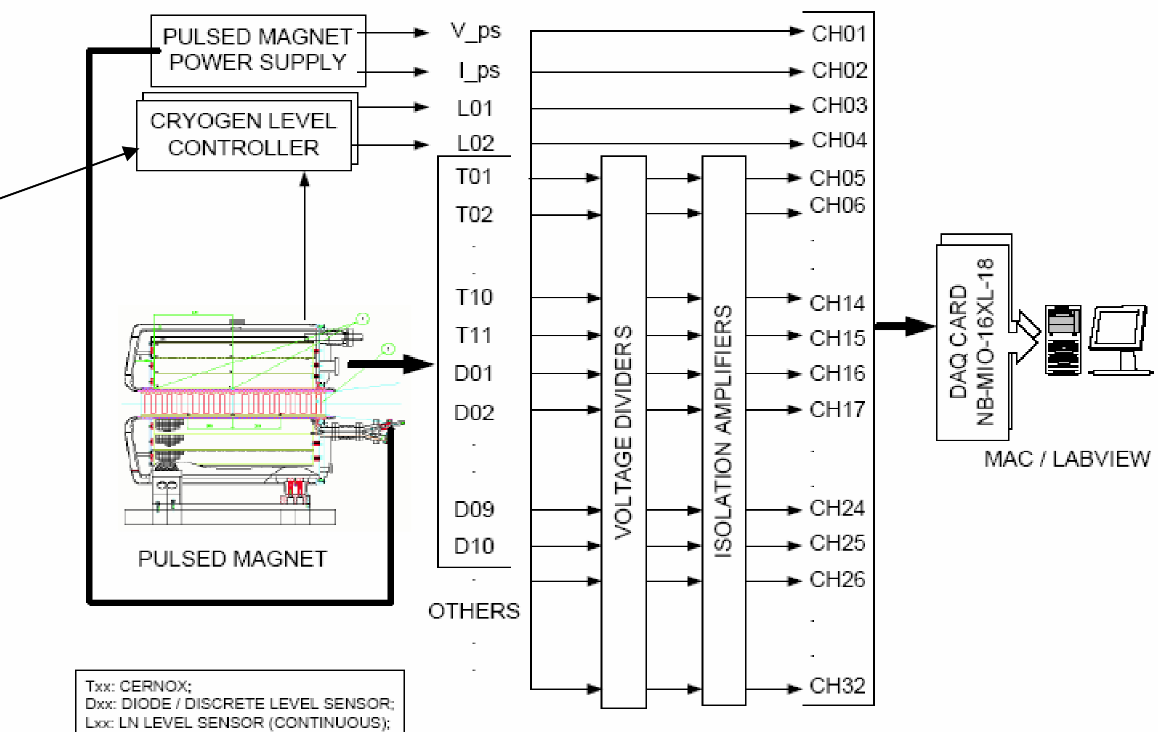


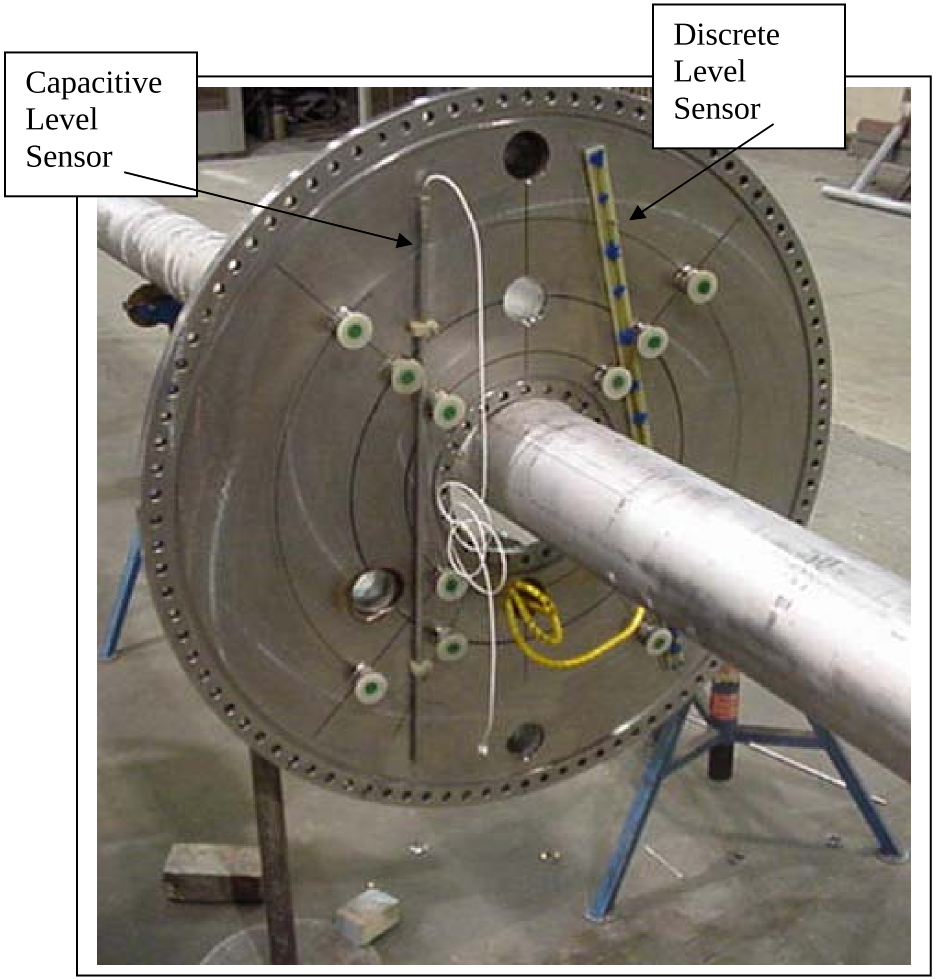
# Instrumentation and Signal Level

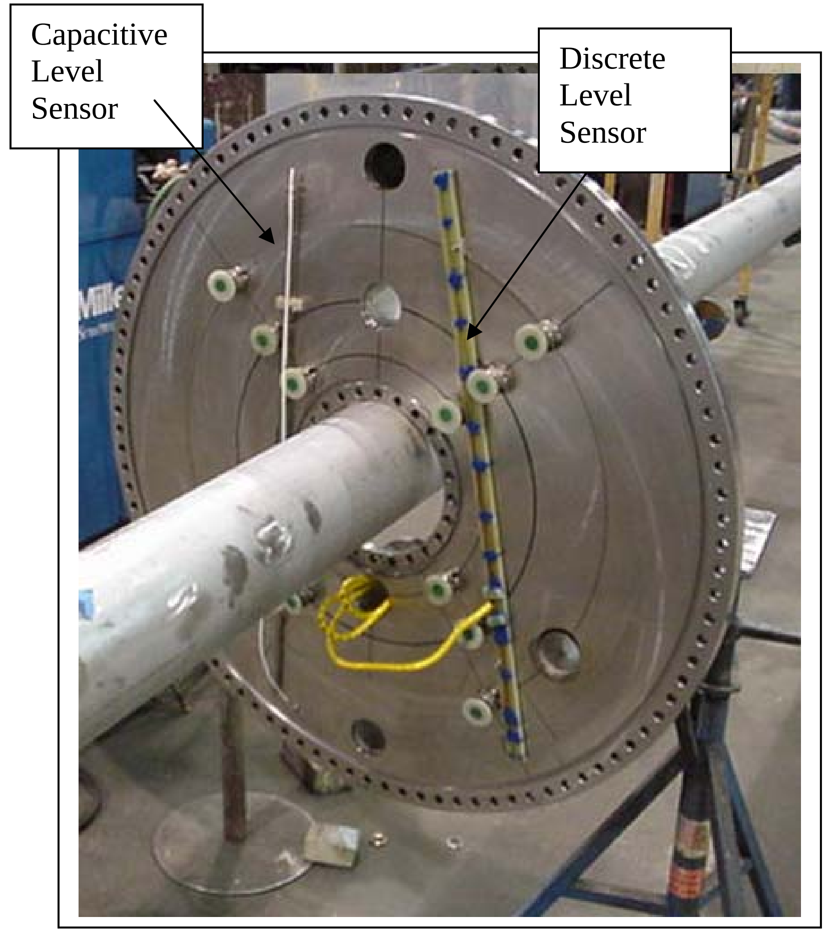
| Instrumentation Name | Number of Signals | Signal Level |
|---|---|---|
| Power Supply | 2 ($V_{magnet}$ & $V_{shunt\ resistor}$) | 0 – 10 V |
| AMI LN level sensor | 2 | 0 – 10 V |
| CERNOX | 11 | Varies with temperature |
| Discrete level sensor diode | 10 | Unknown |
| Others, such as TC's, Hall probe, etc. | TBD | TBD |

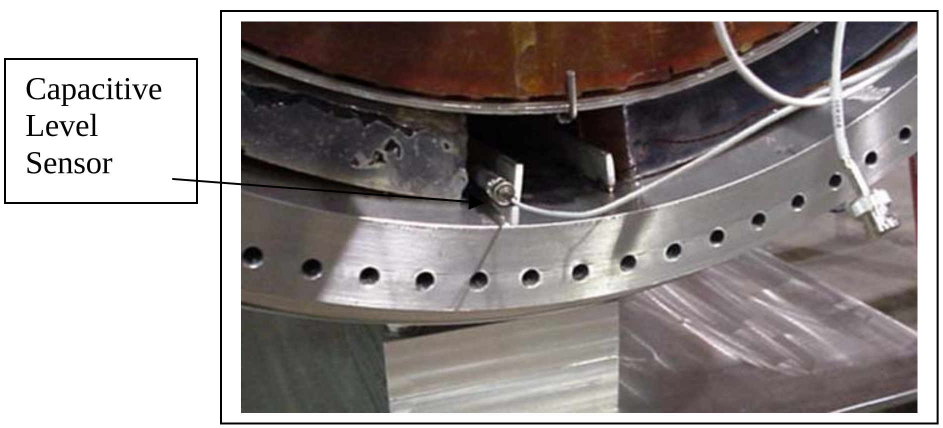
- Use 2 National Instrument NB-MIO-16XL-18 in one Macintosh computer.
- DA is programmed in Labview.
  - Thing to do – modify existing program.
- Precision at 16 bit for bipolar DA between ± 10 V: ~ 0.3 mV.
- Maximum (damaging) input voltage: ± 35 V.
- Max. sampling rate for single channel DA: 55 Ksamples/sec.
- Max. sampling rate for multi-channel DA: 20 Ksamples/sec.

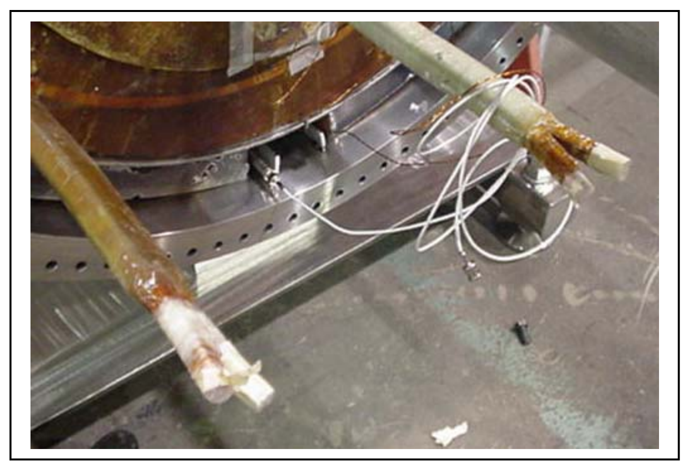
## SIGNALS AND DATA ACQUISITION FOR PULSED MAGNET TEST




Capacitive Level Sensor
Discrete Level Sensor

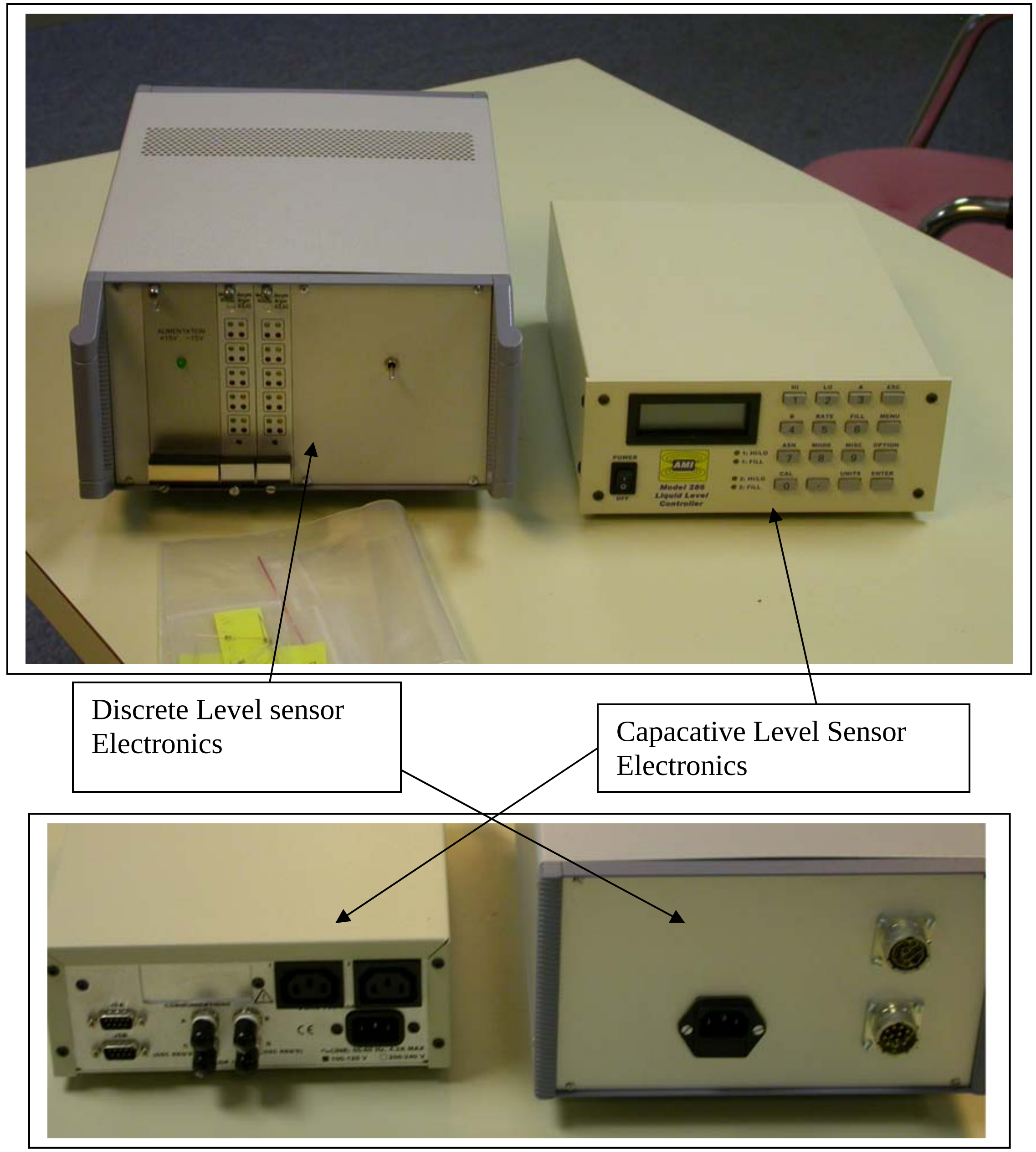

Capacitive Level Sensor
Discrete Level Sensor


Capacitive Level Sensor

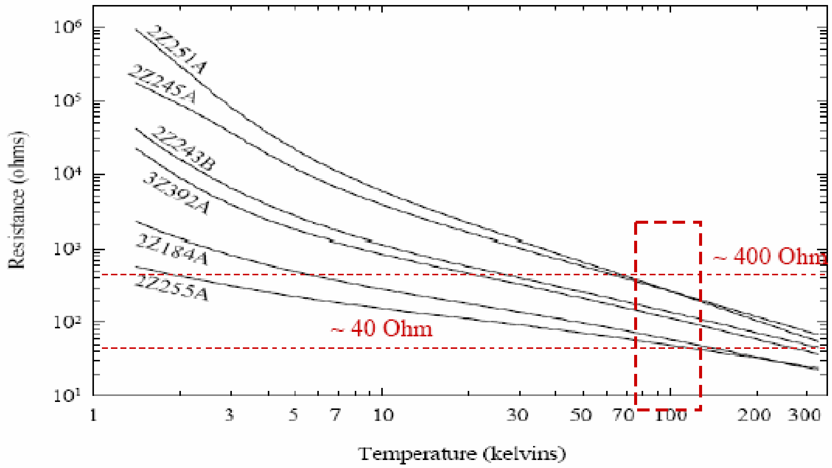


## Level Sensor Electronics

## Discrete sensors and Electronics have been received from Friedrich Haug/CERN

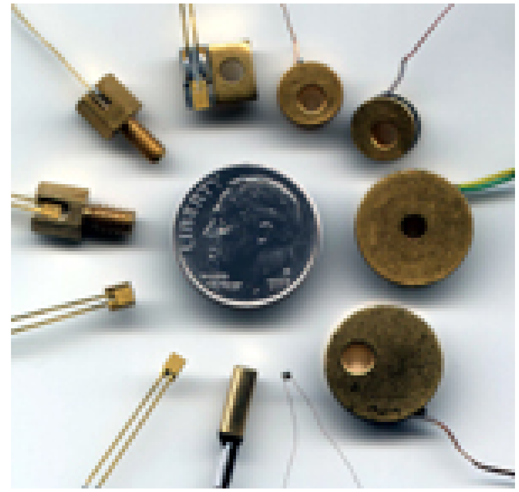


## CERNOX Temperature Sensor




. Typical resistance versus temperature characteristic for each wafer tested for stability.
Ref: Courts, S.S and Swinehart, P.R., 'Stability of Cernox Resistance Temperature Sensors', Adv. in Cryogenic Eng., Vol. 45, 2000.

Typical resistances of CERNOX are between 40 Ohm and 400 Ohm at respective temperatures of 120 K and 80K. The sensor voltage signals are between 0.4 V and 4 V if an excitation of 10 mA is used.



***We are investigating using voltage taps at the terminals to check resistance of the three coil segments, and thus their temperature. CERNOX sensors are intended as a diagnostic at MIT and may not be needed at CERN***

## Excitation Source for CERNOX

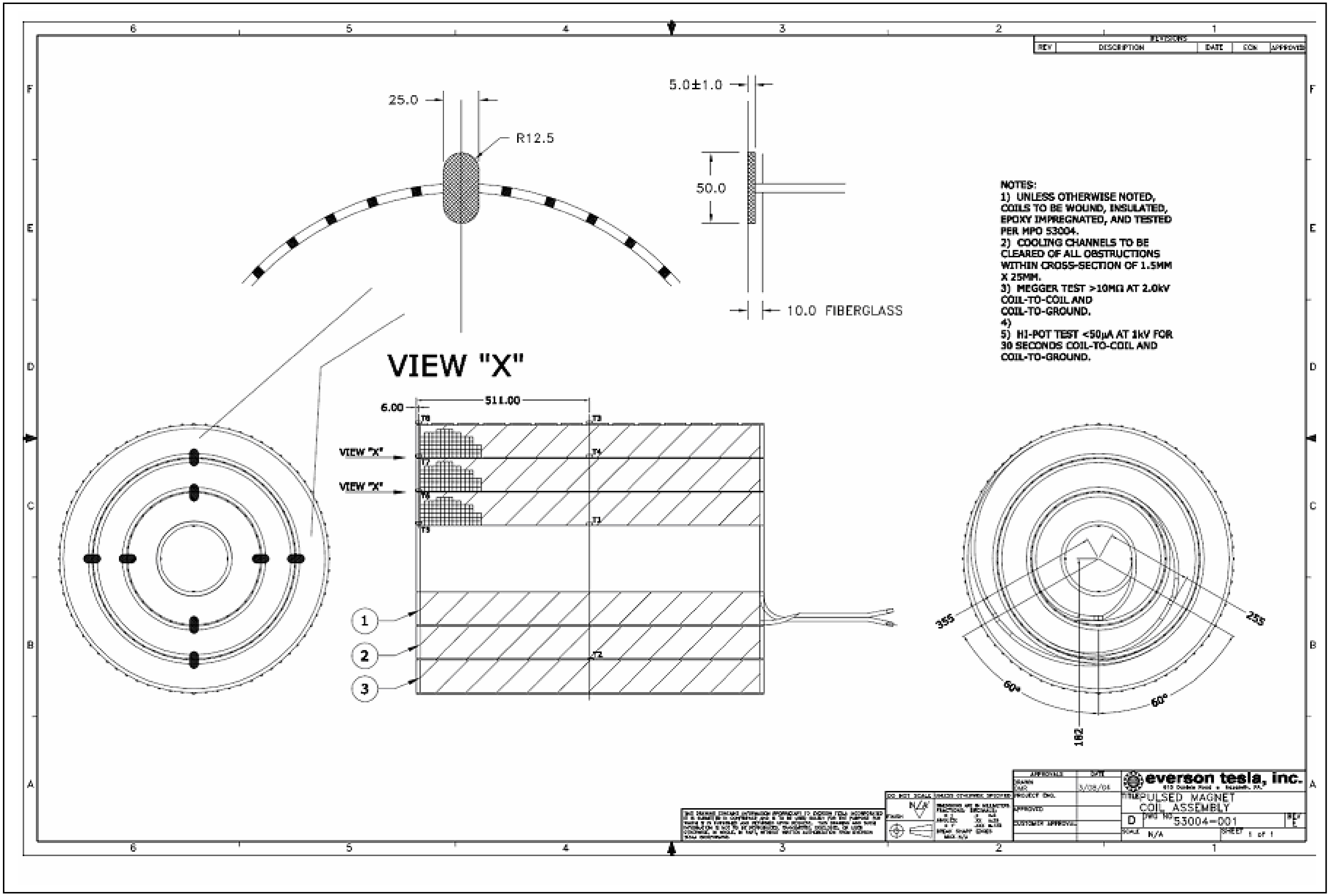
Lake Shore Model 120CS Current Source

| | |
|---|---|
| Output Current | 1 μA to 100 mA |
| Accuracy | 0.1% on fixed ranges |
| Stability | Better than ± 0.01% |
| Compliance Voltage | 11 Volts up to 50 mA |

- Each current source will be used to drive 4-5 CERNOX's connected in series with an excitation current set at 10 mA. Connections of the current leads will be made outside the magnet vessel.
- Four lead measurement will be used. The voltage leads will be tapped to the current leads outside the magnet vessel.
- The voltage drop along the lead wires needs be corrected.

- The same type of current source will be used to drive the discrete LN

# CERNOX Sensor Locations



# 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**

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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

# Main Elements of the Planned Test Procedure (Needs Revision to Reflect LN2 Purge)

**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

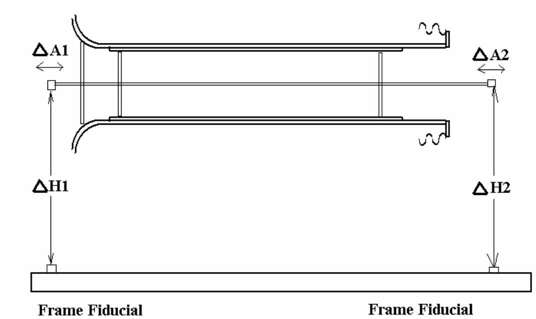
**Record Cold Dimensional Changes**

Map bore dimensional changes due to cooldown.

**Inductance Measurement**

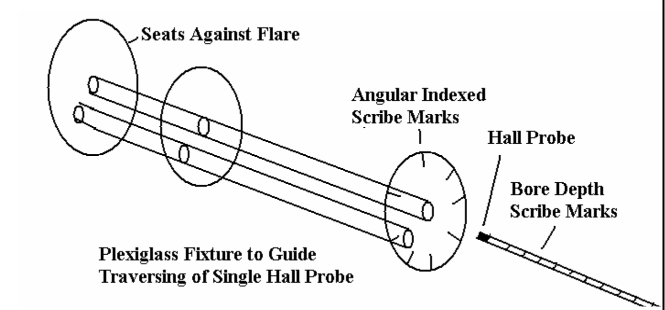
Measure 3 coil low current static resistance. Measure constant-Low Voltage current ramp

**5T Test**




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

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.
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**

**Closing Remarks**

**Schedule :**

**We begin testing as soon as we receive the magnet. We should complete by the end of January, but we are requesting a no cost extension until end of Feb.**

**Costs:**

**We have absorbed costs of extended fabrication follow, addition of discrete level sensors, LN2 drain,  residual LN2 measurement, change order prep and negotiation, and others I am not remembering now.**

**We will "sharpen our pencils" on estimates for Mercury Jet Experiments here at MIT – Noted additions:**

**Hg system is now "open" – if only for initial filling. We need to have some of our safety people and technicians trained in the handling of Hg.**

**Nozzle adjustments are now anticipated at MIT? – at least the contingency should be considered. This may have a schedule impact on other PTF experiemtns.**