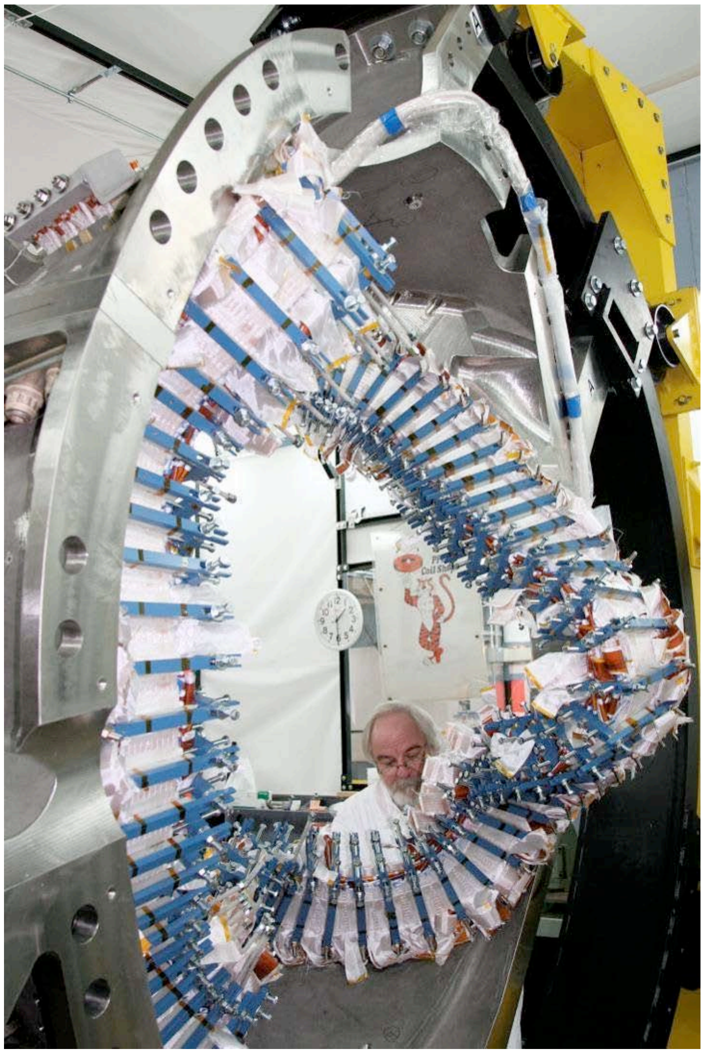
# A PHOTO ALBUM
# Of MANUFACTURING
# A MODULAR COIL



**By: James H. Chrzanowski**
**Plus**
**NCSX Team and Industrial Partners**

**April 27, 2007**

# *NCSX TEAM AND MANUFACTURING CONTRIBUTORS ASSOCIATED WITH THE MODULAR COILS INCLUDE:*

*Princeton Plasma Physics Laboratory*

*Oak Ridge National Laboratory*

Energy Industries of Ohio, Inc

Major Tool & Machine, Inc.

C. A. Lawton Co.

MetalTek International, Carondelet Div

New England Wire Technologies, Inc.

This photo document walks you through the basic manufacturing steps of fabricating a NCSX modular coil. It begins with the arrival of the winding form and ends with the final electrical acceptance tests.**

1. The modular coil winding forms are individually delivered from the manufacturer in Indianapolis [EIO, Major Tool and Machine Inc., C.A. Lawton Co. and MetalTek International] to PPPL via truck transport and are unloaded, uncrated and prepared for processing. [18 total winding forms]

**Uncrated Type C Winding Form**

2. Once uncrated, a thorough inspection of the casting and winding surfaces is made. This includes inspections of the surface finish, review of blemishes and a measurement of the magnetic permeability. A preliminary measurement of the as cast surfaces is often made to determine whether additional grinding may be required.


**Using "Romer" Mechanical Measurement arm to verify surfaces**

3. The winding form is then transported to Station 1a in the coil winding facility where it is mounted into a support ring. This ring assembly will be used for handling [lifting] of the coils and is an integral part of the coil turning fixtures used for winding and processing the coils.

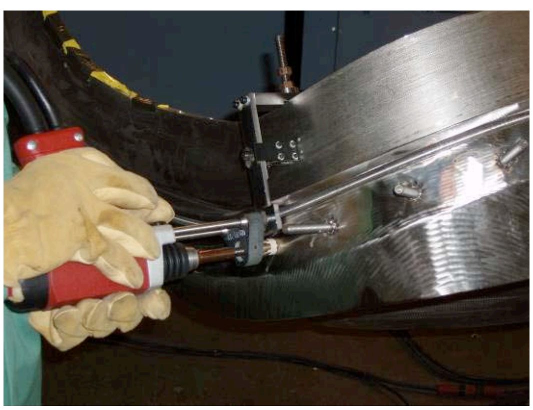

**Loading Winding Form Into Support Ring**

**Transferring Coil to Vertical Position for Transport**

**4.** Once mounted, the ring assembly is repositioned from horizontal to vertical using the repositioning fixture and overhead crane at Station 1A. Once vertical, the coil can easily be transported and loaded into the Casting Preparation station at Station 1B.

**Station 1B- Casting Preparation Activities**

5. At Station 1b the winding form [casting] is prepared for winding activities. Nearly 200 Inconel studs are welded onto the winding form to be used with the winding clamps to support the individual copper turns during winding. These studs will be removed once all manufacturing activities have been completed. In addition, monuments and other hardware components are welded onto the winding form. Those welded items that will remain with the coil after manufacturing, needs to have their magnetic Permeabilty verified. [Requirements < 1.02 μ ]

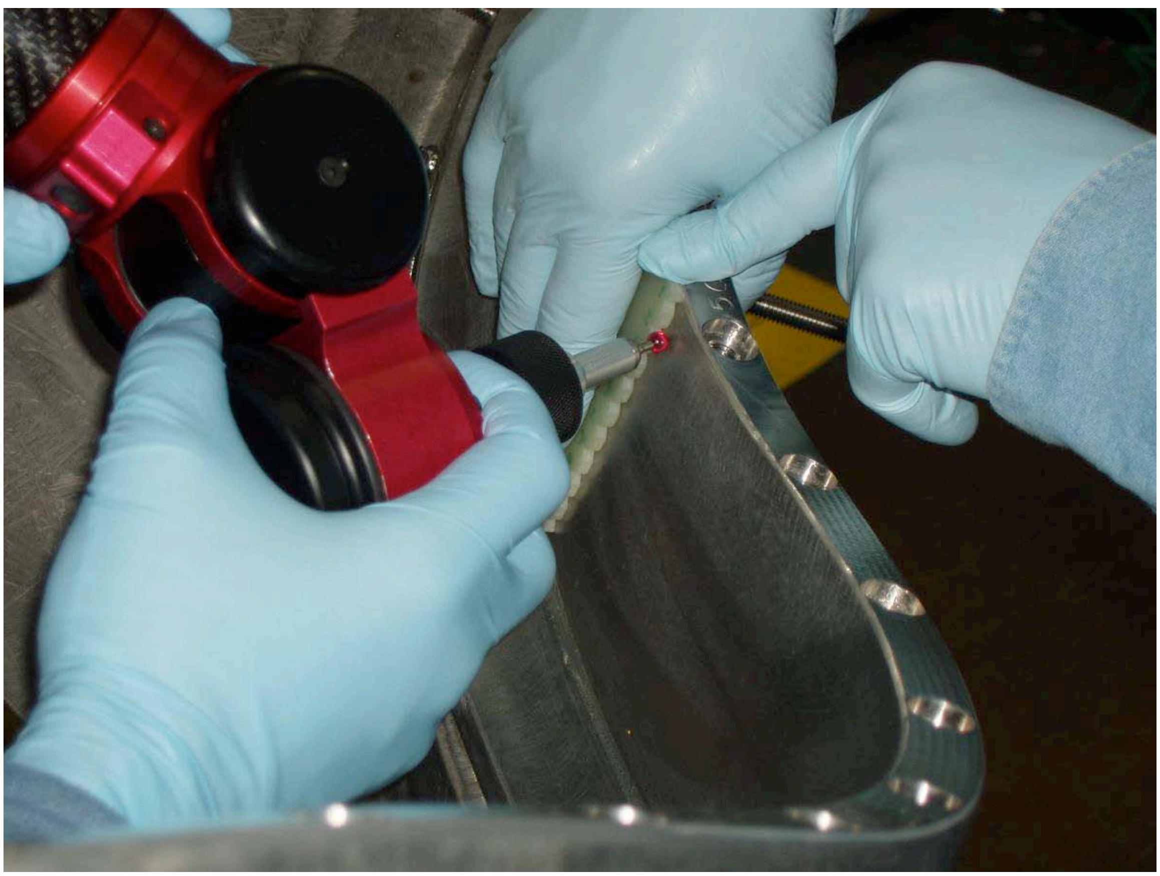


**Using a Stud Gun, Studs are welded Onto the Winding Form**

**Quality Control Representative is measuring the Magnetic Permeability Using a Severn Gauge**

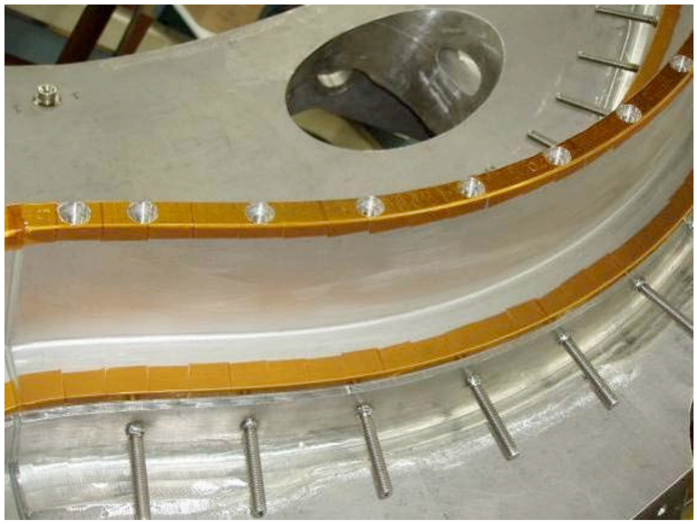
6. The winding surfaces are measured using the “Romer”arm. This information is then used to shim the side bars of the winding clamps to help maintain the width and height of the coil bundles.


**These figures show surface measurements being taken using the “Romer” arm**



**Measuring the winding surface using a template and Romer**

7. A layer of Kapton adhesive back insulation is applied to the top and bottom edges of the winding surface septum. This layer of insulation provides additional electrical standoff between the copper cladding and winding form during assembly.

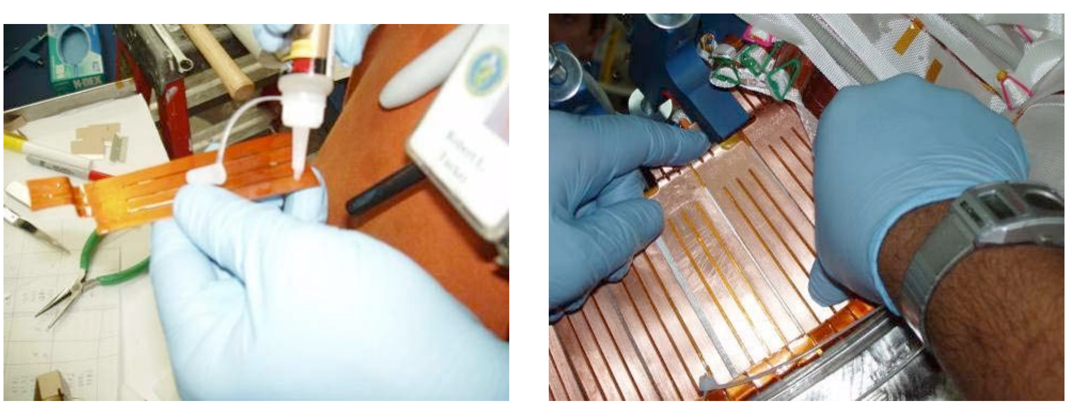


**Kapton Insulation Applied to the Edges**

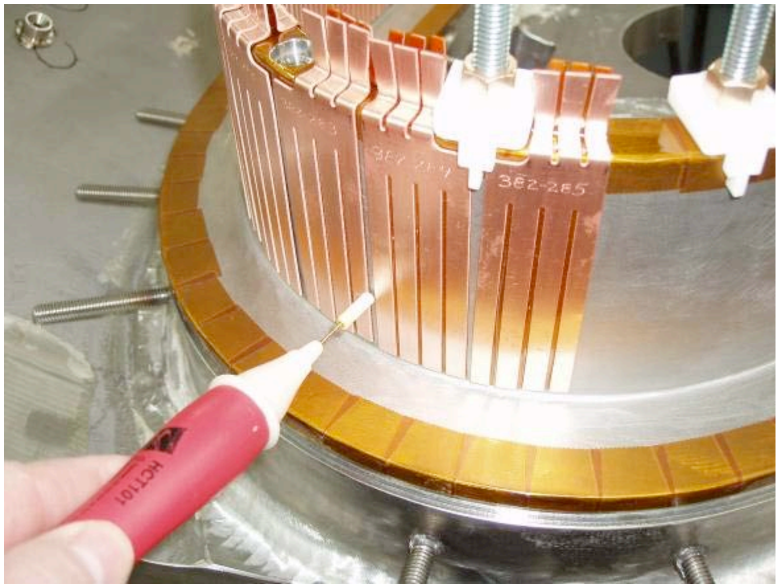
8. Several layers of mold release are then applied to the winding surfaces to minimize the bonding between the coil bundle and winding form during the epoxy fill [VPI] of the coil.

9. Individual pieces of Kapton backed copper cladding are then positioned onto the winding surfaces. Once completed, this will provide the inner wall cooling for the coils.

10. Approximately [750] copper cladding components are temporally held in position using a 2-part 3M-adhesive.

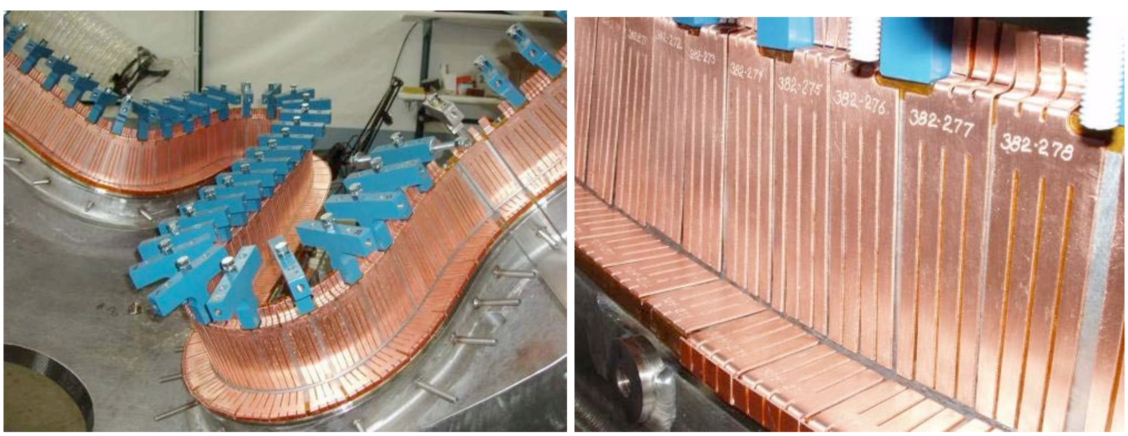


**Application of 3M Adhesive to Kapton**



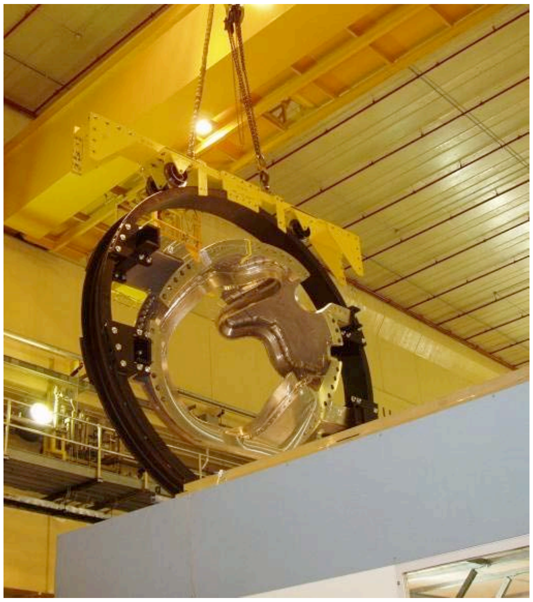

**Testing of Cladding Depth**

11. The individual pieces of cladding must be electrically isolated from each other as well as from the winding form. In the figure above the height of the cladding from the winding form is being checked. It is essential that the cladding pieces fit tightly to the winding form to ensure accurate tolerances and positioning of the copper conductor.



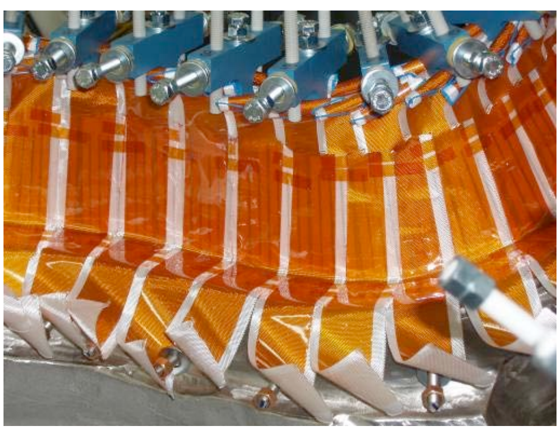

**Copper Cladding Installed**

12. The modular coil is then transferred to one of the two coil winding stations.




**Transferring Coil Assembly to Winding Station**

13. Since the coil is wound directly onto its structure, pre-cut layers of glass and Kapton insulation need to be applied on top of the copper cladding to form the inner electrical groundwall. Approximately 1000 individual lengths of the insulation are applied on both sides of the winding form. In addition, strips of glass tape [Lacing] are pre-positioned on top of the ground wrap. These will later be used for securing the coil bundles.

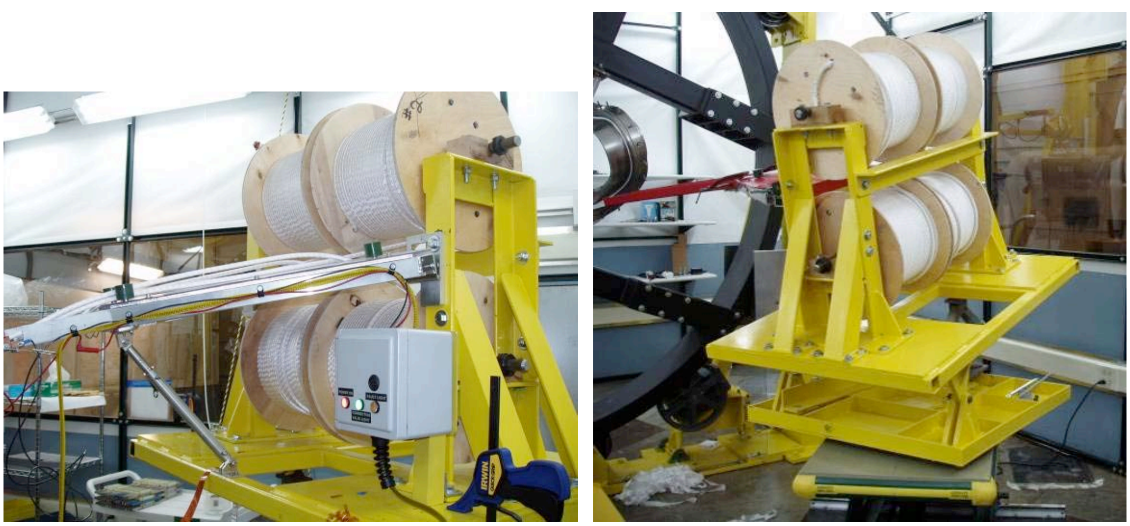



**Applying Ground wrap insulation**

14. Once the ground wall insulation and lacing strips have been positioned, the copper conductor can be wound onto the winding form.

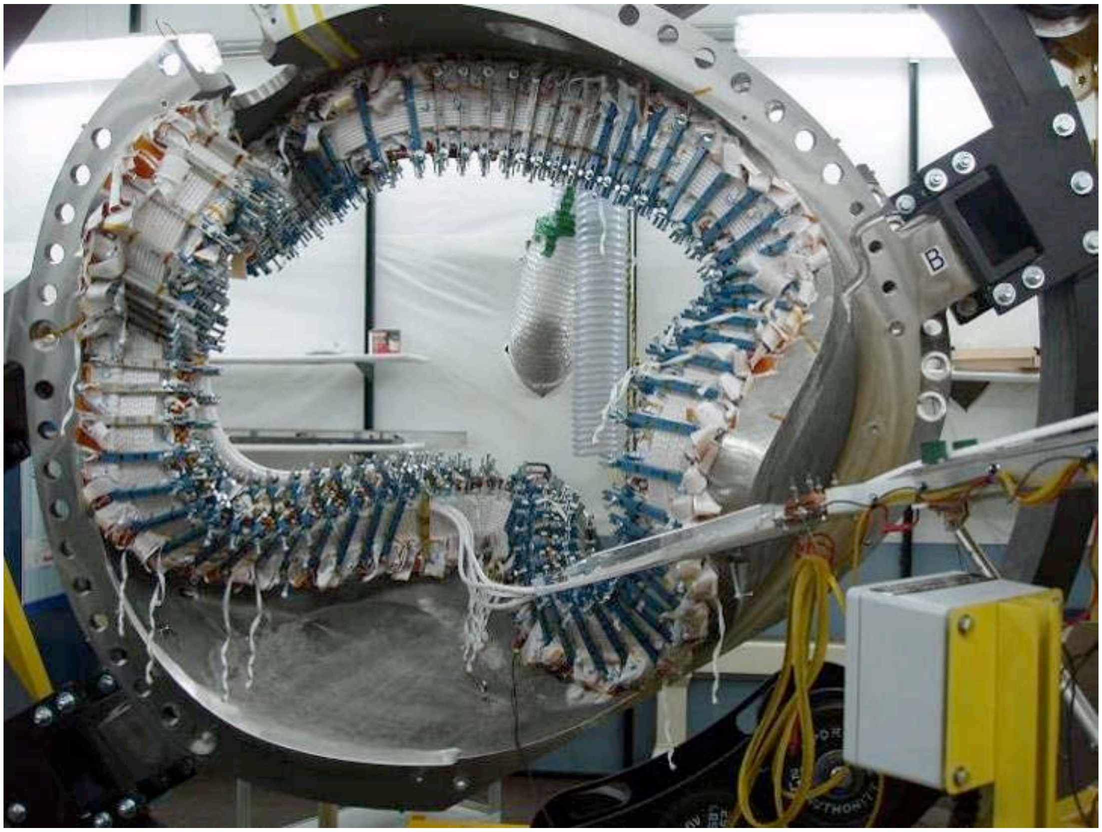
15. **Copper Conductor Description:**
The rectangular compacted copper conductor will be fabricated using 34-gauge oxygen free copper wire. Its rope construction is [12 x 5 x 44 x 34] with an external 0.004-inch thick nylon serve. Once cabled, the copper rope was compacted to dimensions of 0.350 in. x 0.391 in. +/- 0.010 inches. [Note: dimensions include the nylon serve]. The vendor then applied (2) half-lapped layers of dry S-2 glass insulation around the completed conductor. [Conductor supplied by New England Wire Technologies, Inc.]

16. The copper conductor is wound onto the winding form 4 conductors-in-hand. The conductors are fed from (4) spools on a payout spool system that allows for changes in height, rotation and angle to accommodate the complex geometry of the winding form.

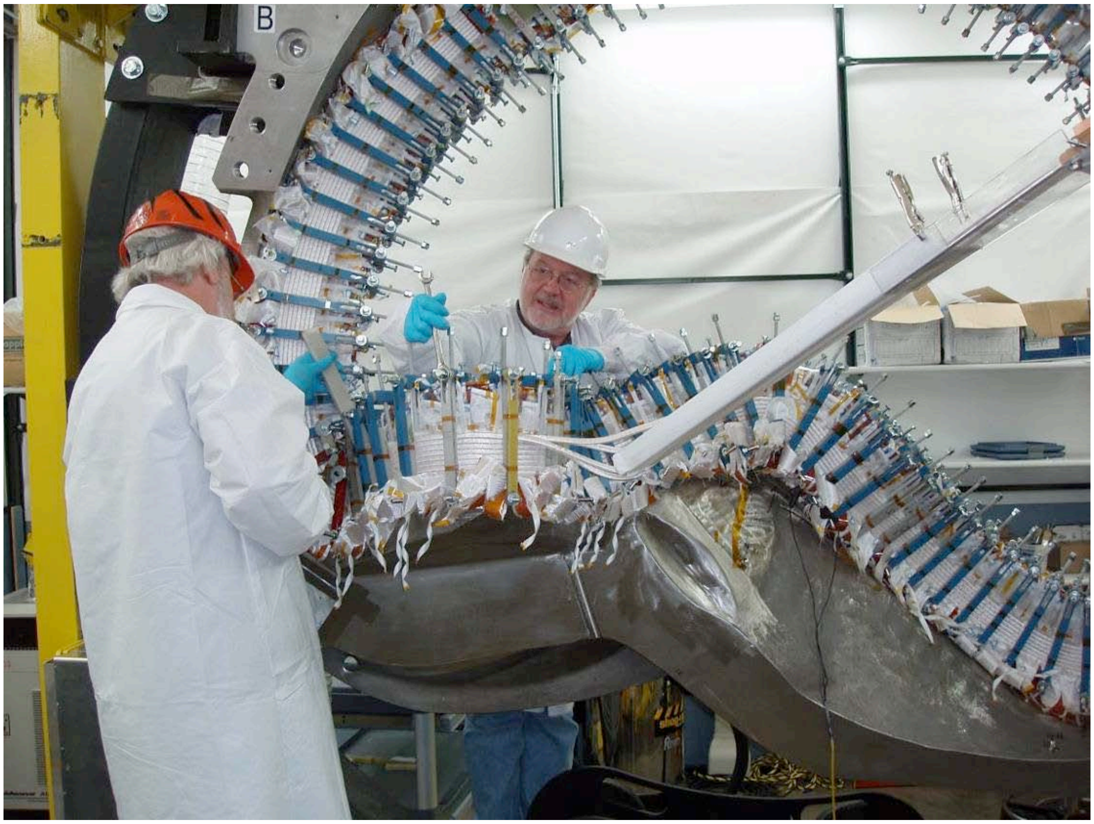


**Conductor Payout Spool**


**Conductor Winding Operation Photographs**

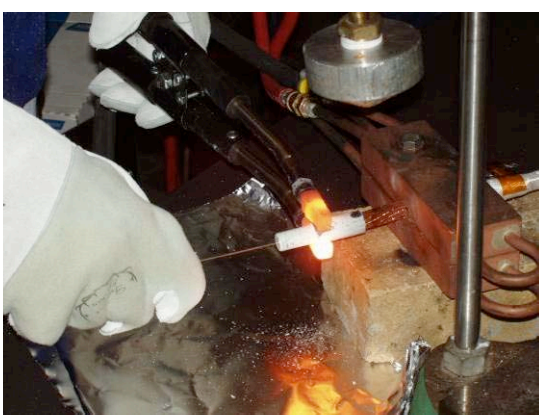



**Winding Type-C Coil**




**Modular Coil Winding Operation**

17. Once the coil is wound copper lugs are brazed onto each of the conductor ends.

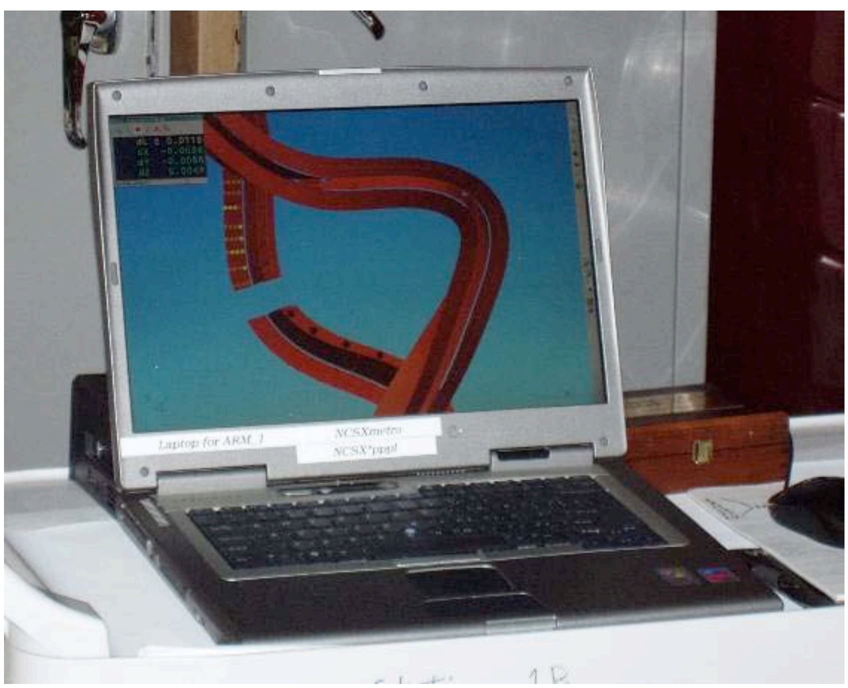


**Brazing Copper Lugs onto Conductor**

**Modular Coil Lead Area**

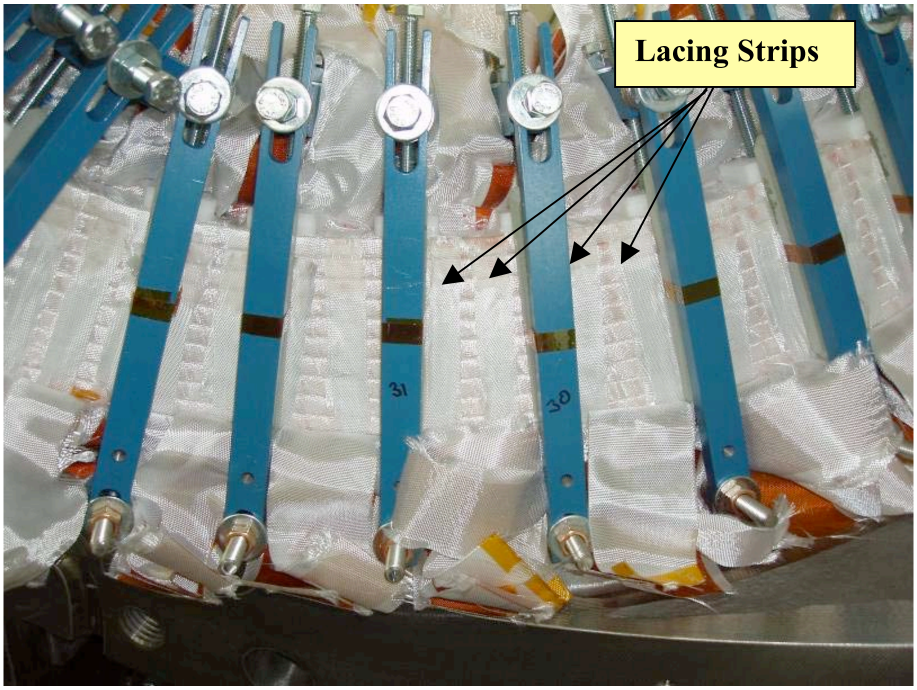
18. Once wound, the locations of the coil bundles are measured using the ROMER measuring arm. The data is analyzed and the turns are then repositioned by pushing or loosing the coil clamps to achieve the best possible location of the coil current centers. [Tolerance is ± 0.020 inches]


**Technician measuring the location of the coil turns**



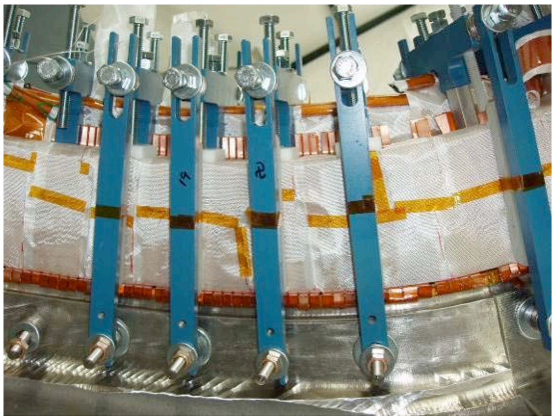
**Model of coil showing measurements taken with the Romer arm**

19. Once the coil bundles are in their final position the glass tape lacing that was installed prior to the winding is secured around the bundles to hold the coil turns in place during the installation of the ground wrap, chill plates and bag mold.




**Glass Tape Lacing Strips Secured**

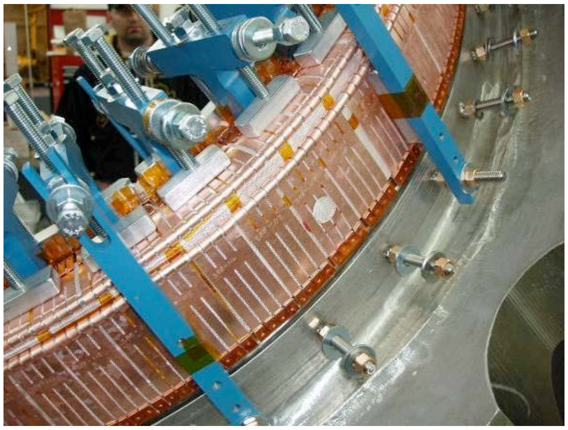
20. The Ground wrap insulation is then finalized to complete the outer insulation wall of the coil.

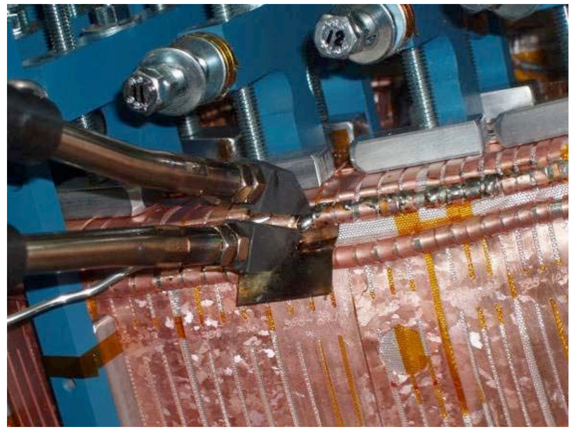


**Finalizing the Groundwrap insulation**

21. Copper chill plates [750] are then installed over the completed ground wrap wall. This forms the outer wall of coil cooling. The chill plates connect to the inner wall cladding that was installed prior to the groundwrap insulation. Pre-tinned copper

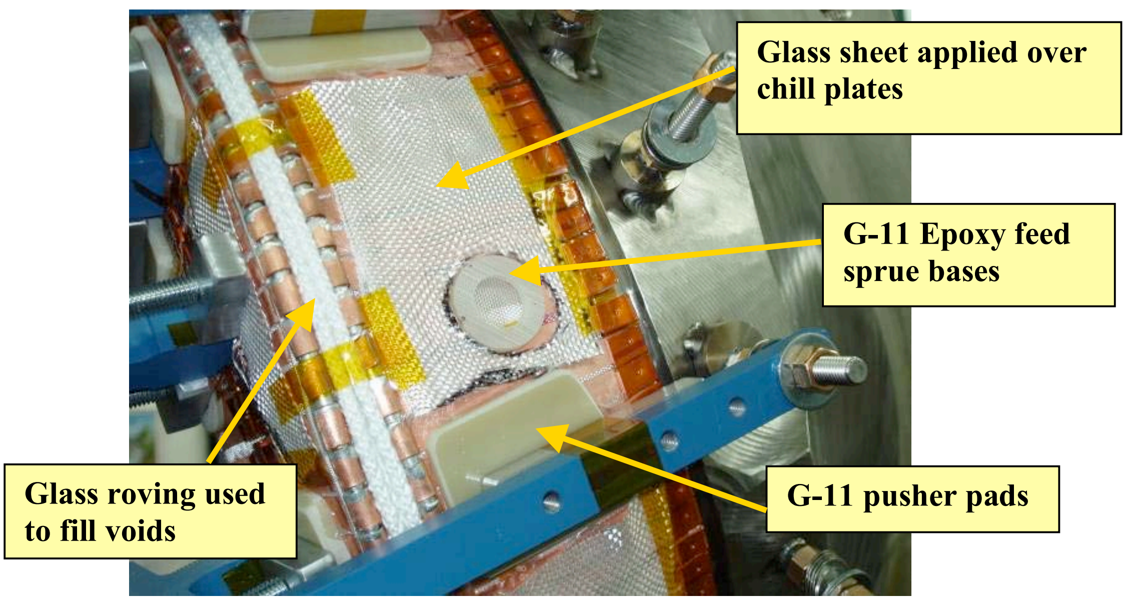
tubing is then positioned and soldered to the chill plates providing a flow path for the liquid Nitrogen used to cool the coils.





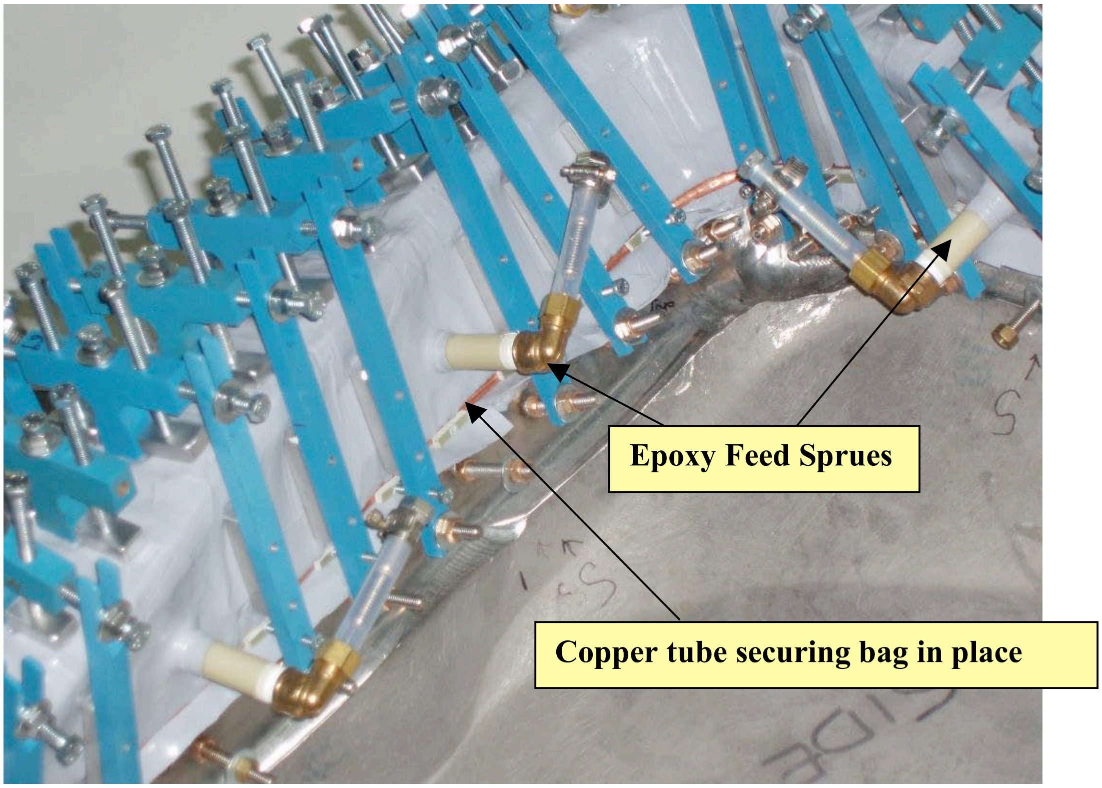
**Installation of Copper Chill Plates and Tubing**

22. G-11cr pusher pads are then installed directly onto the copper chill plates in locations where the final coil clamps are to be installed. In addition a layer of 0.010 inch thick glass tape is applied over the surface of the chill plates to provide additional support for the chill plates once the coil has been filled with epoxy.

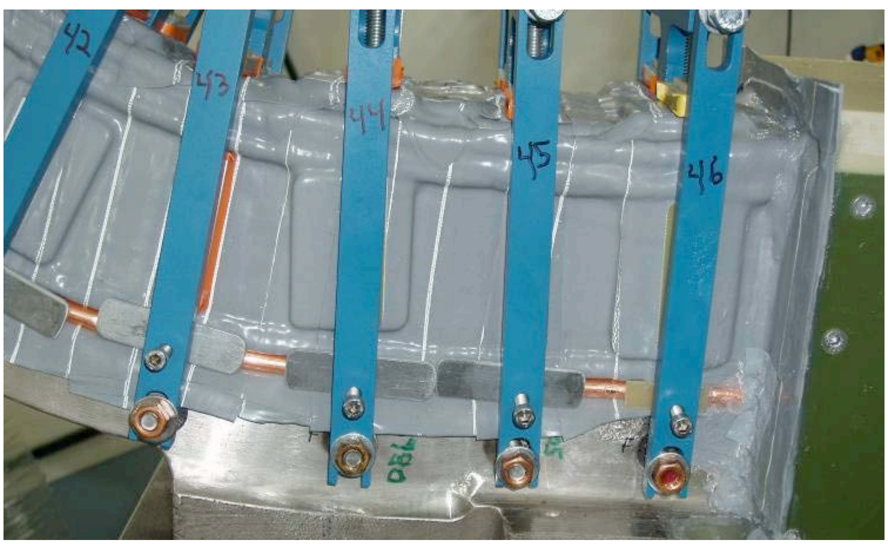



**Outer Layer over Chill Plates**

23. The "Bag" mold is now ready to be installed. Two layers of silicone vulcanized rubber tape are applied over the coil bundles. The ends of the bag are held in place using silicone RTV and copper tubing that is pushed into a pre-machined grove in the winding form. The copper tubing works similar to a spline that is used to hold screening in place.

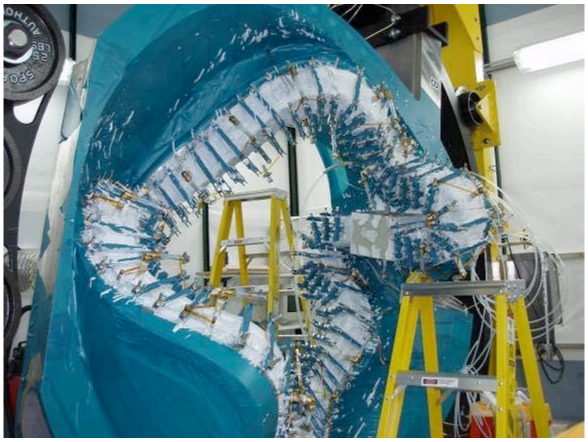
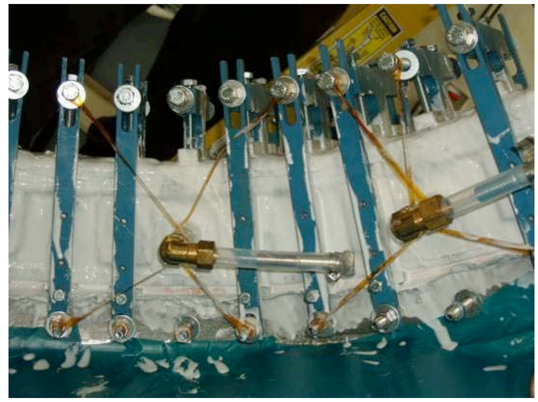



**Silicone Bag Mold in Position**



**Bag Mold under Vacuum**

24. Once installed, the bag mold is pumped down using a vacuum pump. A layer of RTV is then painted onto the outside surface to fill any small leaks.

**RTV over paint of the bag mold while under vacuum**

25. A mixture of chopped fiberglass and 2-part room cured epoxy is then mixed and applied over the bag mold, providing the structural element of the mold design.

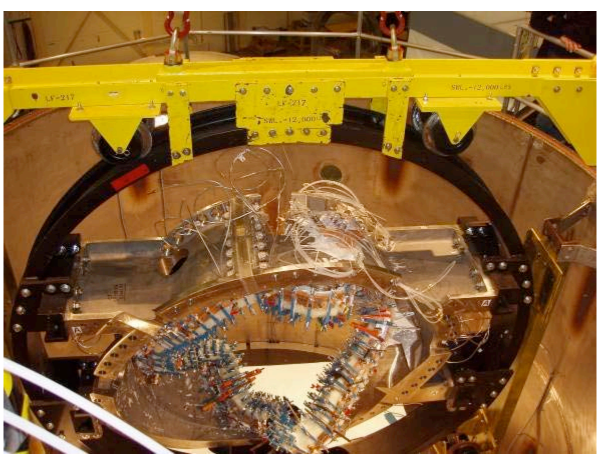

**Epoxy/Chopped Glass Structural Shell**

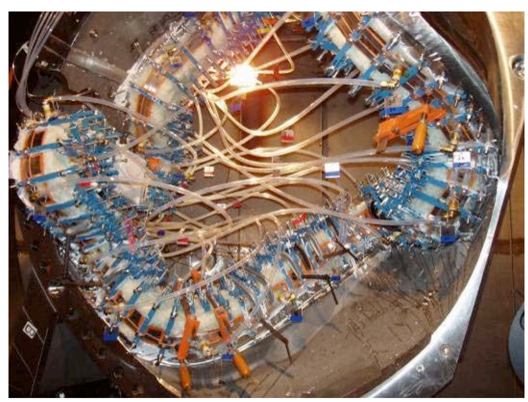
26. Once the epoxy shell has cured, the entire coil and ring assembly is then lifted from the winding station and positioned inside of the autoclave [vacuum-pressure-oven] for preparation of the epoxy filling [VPI] operation.

27. The coil is then plumbed to the epoxy delivery system using heat resistant tubing. Nearly 40 epoxy lines and thermocouples are connected to the coil assembly.

28. The autoclave has the capability of providing either vacuum or positive pressure atmospheres during the epoxy filling and oven curing operations.

**Modular Coil being lifted into the Autoclave**





**Modular Coil in the Autoclave**

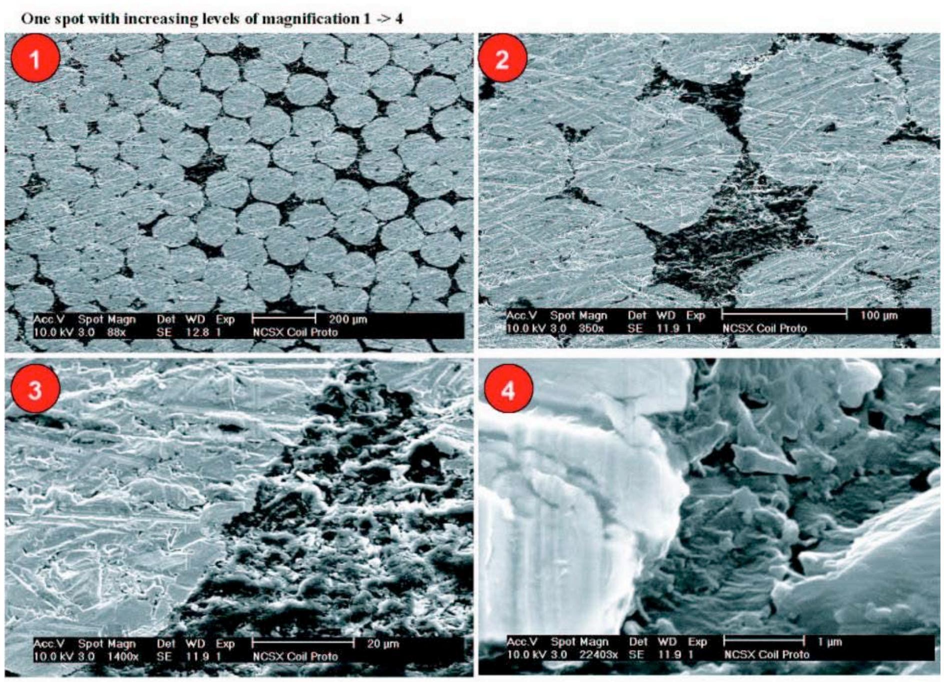
29. Twenty four gallons of epoxy are weighed and prepared for the VPI operation. Only eleven gallons of the total epoxy mix actually fills the coil. The remaining epoxy is for filling the feed lines and maintaining some overage in case it is needed during the VPI filling operation.

Epoxy Being Weighed prior to VPI

Viscometer


Epoxy Delivery Control Station

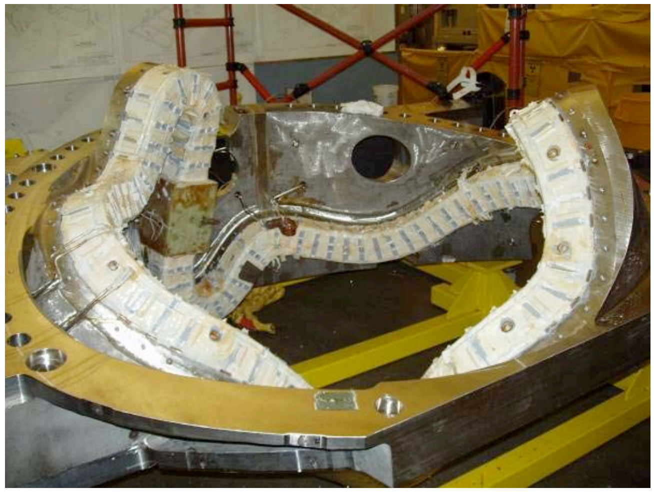
30. The VPI operation takes nearly 60 hours to complete the cycle. This includes the epoxy mixing operation, filling the coil, plus the heat cure cycle [110º C for 5 hours and 125º C for 15 hours] and cool down steps.



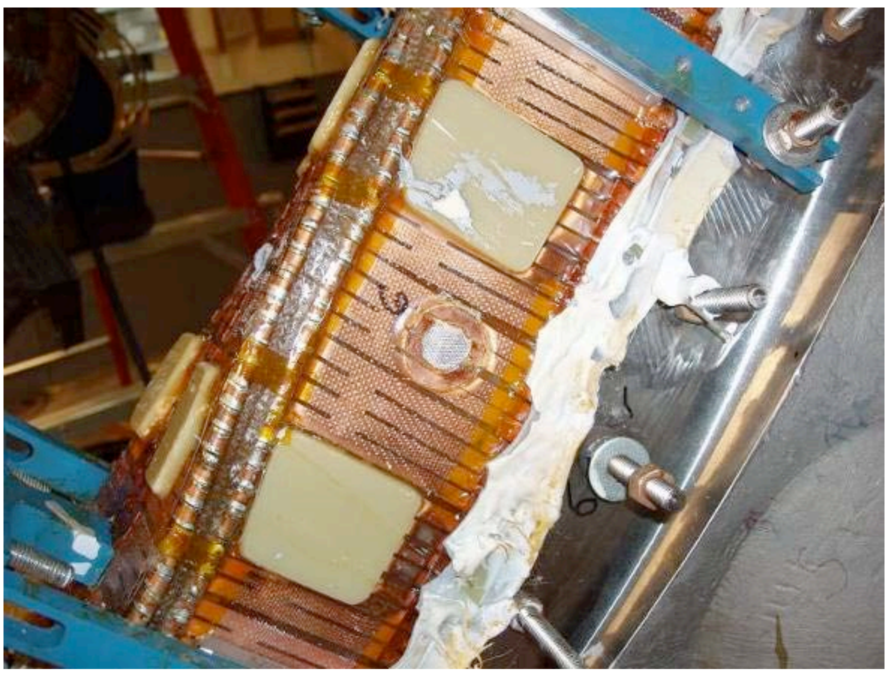

**Electron Microscope photo's showing epoxy fill between then individual copper strands.**

31. Once the VPI process has been completed [coil is filled and epoxy cured] the coil is removed from the autoclave and prepared for final testing and assembly.

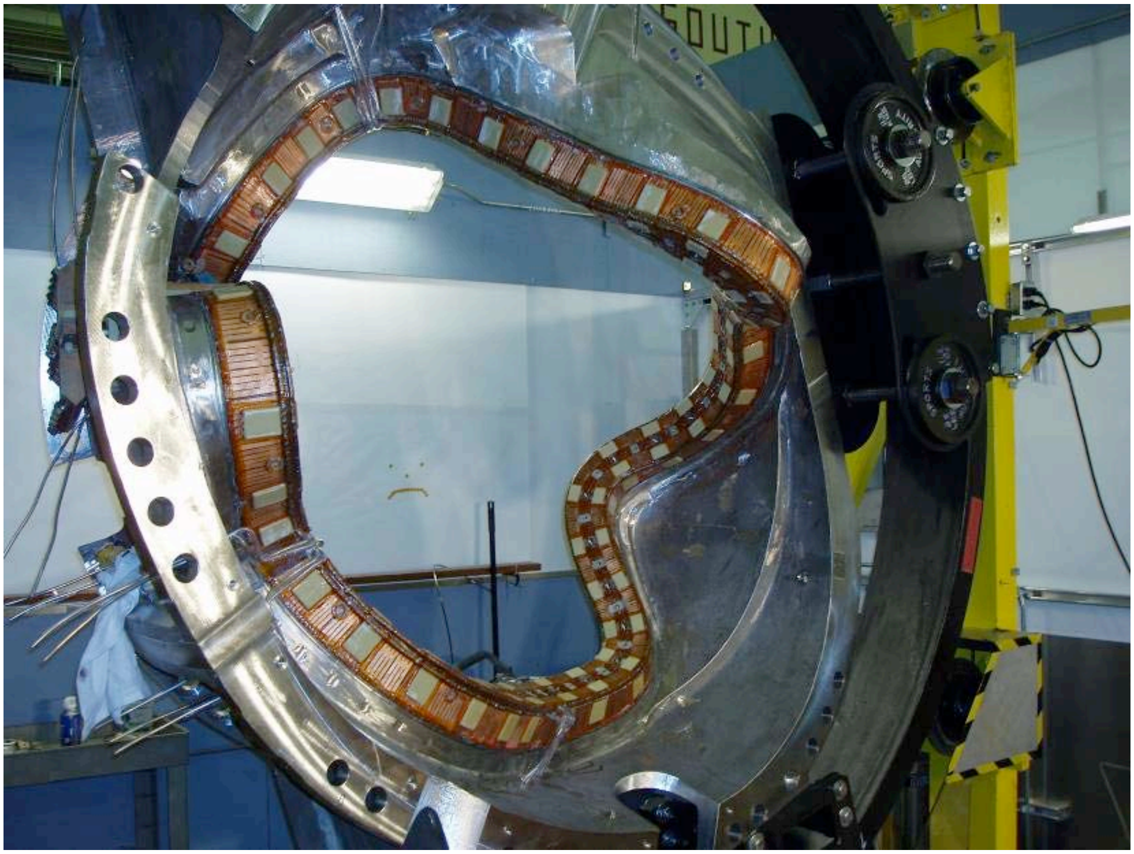
32. The epoxy shell mold and bag are removed and the final coil clamps are installed.



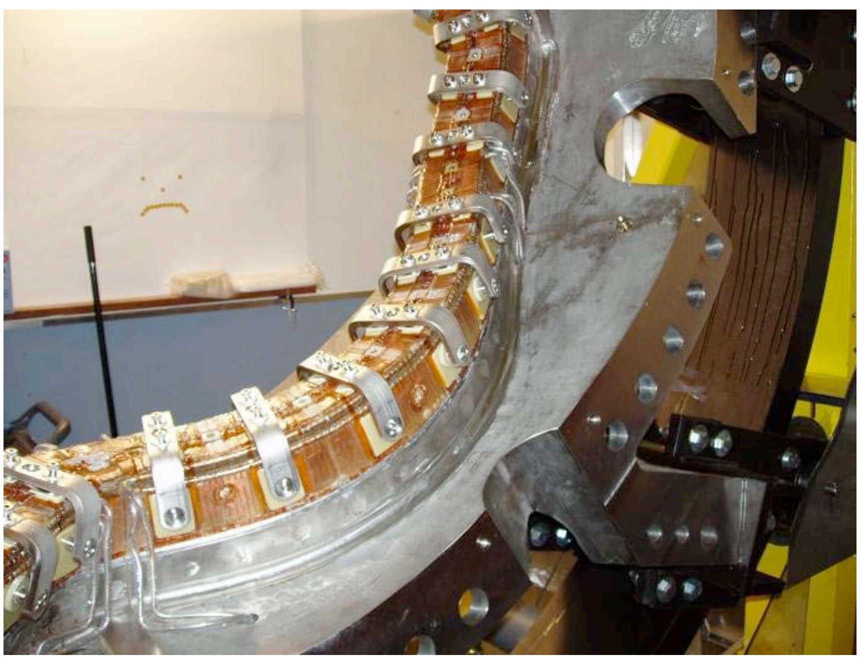
**Modular Coil without the Epoxy Shell**



**Bag Mold Removed**



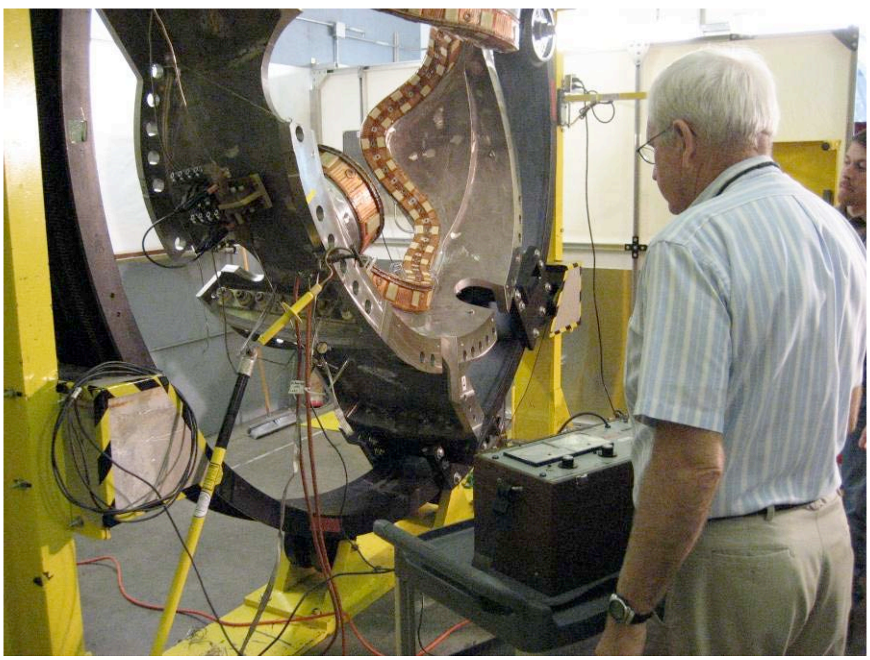
**Final Coil with Bag mold removed and Prior to Clamp Installation**



**Installation of Final Clamps**

**Pneumatic Test Setup for checking cooling tube system**

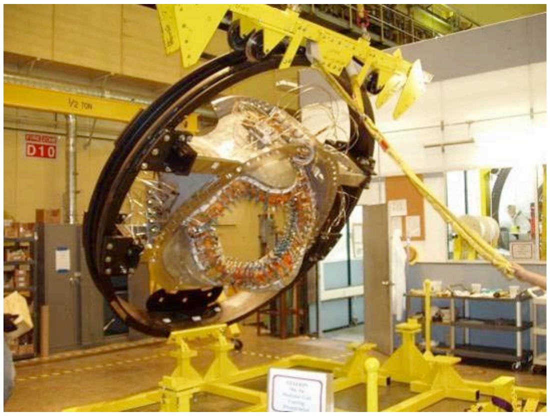
33. Pneumatic and electrical tests are performed to verify the integrity of the completed coil.



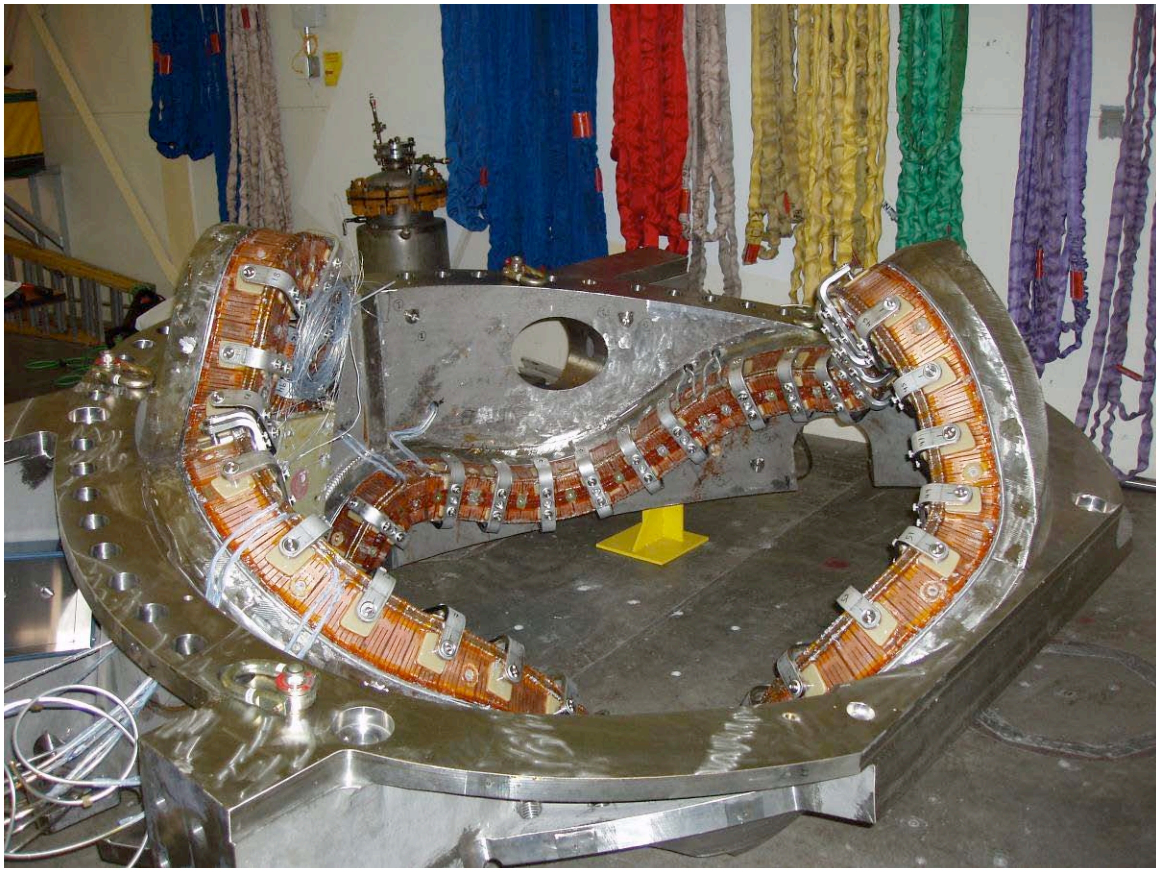
**Measuring the Insulation Resistance**

**Measuring the Coil Resistance**

34. The finished coil is then transferred to station 1a and removed from the ring assembly. Temporary coil legs are then added for storage until the coils are needed.




**Coil Being Removed from Ring Assembly**



Final Coil after Testing- Ready for Installation

THE END