Procedures for TPC Field Cage Assembly, Safety, and QA For the sPHENIX Project

Department of Physics
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Revision 1
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sPHENIX Project DETECTOR-SPECIFIC QUALITY ASSURANCE PLAN

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SUBJECT:	Procedures for TPC Field Cage Assembly, Safety, and QA	

REVISION HISTORY		
Revision	Date	Description
1	05/20/2019	Initial Release

NOTE

All procedures undergo revision from time to time. Any reference herein to any other procedure implies the latest revision, unless otherwise stated.

1.0 Purpose and Scope

These procedures are designed to ensure that the assembly of the sPHENIX TPC Field Cage is performed safely and correctly.

2.0 Definitions

- TPC: "Time Projection Chamber"
- OFC: "Outer Field Cage"
- IFC: "Inner Field Cage"
- CM: "Central Membrane"
- HV: "High Voltage"

3.0 Responsibilities

This section describes the responsibilities for two roles, "manager" and "technician".

- Technician: Observance of all rules regarding proper handing and safe operation of the mandrels, tensioner, assembly frame, and test equipment used in the clean rooms, following the documented project-defined procedures, and direct instructions of the "manager". The technician is further responsible for recording and stewardship of the test data obtained for each step in the procedure.
- Manager: leadership of all clean-room operations, ensuring that all "technicians" have been properly trained, operate safely, and use only the approved procedures at all times, ensuring that all test results are recorded and made available to project management, presentation of project status and test results at all appropriate meetings.

4.0 Prerequisites

Qualified operators must be familiar with, and follow at all times, the local ES&H regulations of Stony Brook University as outlined here: https://www.stonybrook.edu/campus-safety/#view-environmental-health . They must maintain up-to-date safety training status as required by the campus rules and all pertinent procedures.

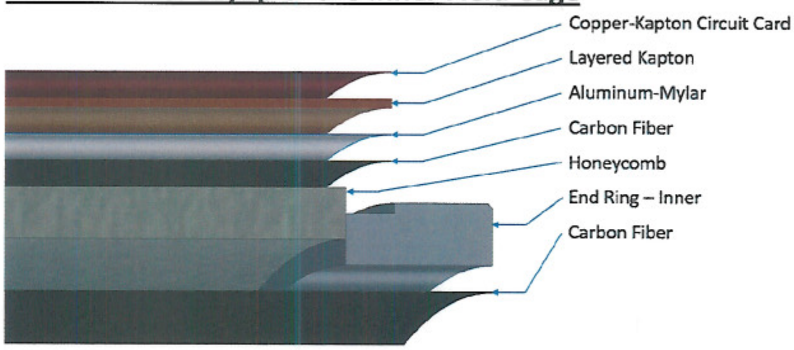
5.0 Precautions and Limitations

This document pertains only to the TPC Field Cage Assembly at Stony Brook University. Additional TPC-related procedures and operations are described in separate SOP documents.

6.0 Procedures

Throughout the procedure discussion, QA procedures and steps will be highlighted in blue and identified hazards and their mitigations will be highlighted in green.

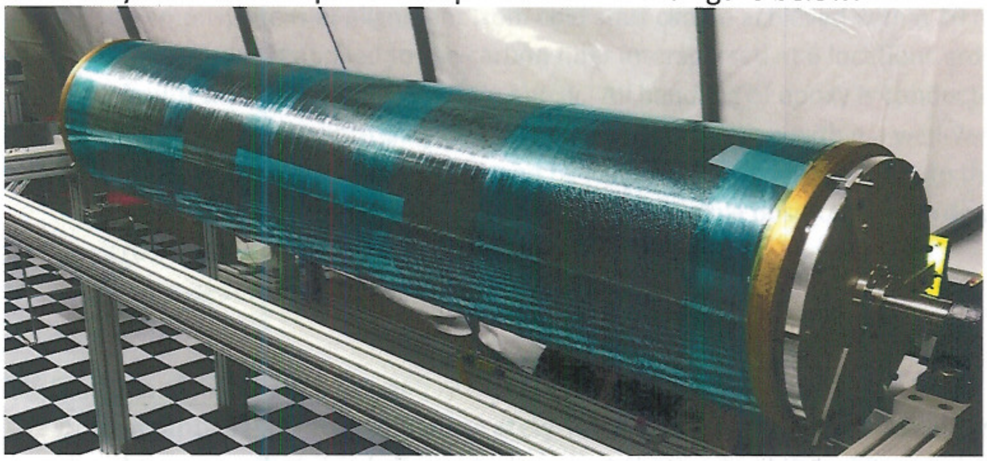
6.1 Procedure for Layup of the Inner Field Cage



The figure above details the multiple layers required for the layup of the Inner Field Cage. These layers are assembled from inside out starting with the innermost Carbon Fiber Layer and ending with the Copper-Kapton circuit card. Because items in the sPHENIX TPC field cage consists of multiple units that are single units (e.g. IFC, OFC, CM), each step in the layup must be preceded by at least one dry run. Any dry run that produces results out of specification or nearly so will be repeated until the dry result is routinely within specification.

6.1.1 Inner Carbon Fiber Stiffener

The inner carbon fiber stiffener is held in place by a shrink wrap technique that is easily reversible. This layer is required to be placed with an accuracy of 0.100" along the mandrel. It is held in place and air pockets are eliminated by wrapping the setup with at least 4 layers of stretch plastic wrap as shown in the figure below:

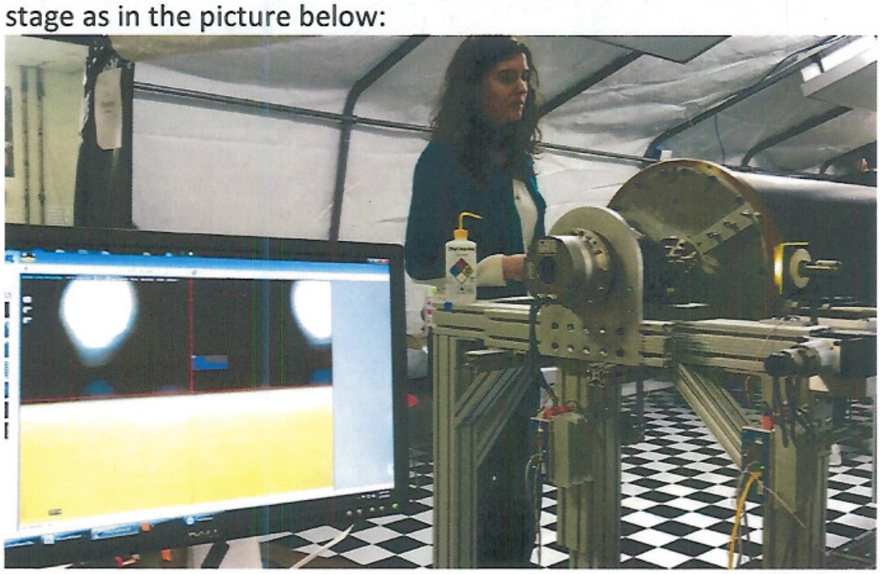


The following steps ensure proper layup:

- Visual inspection of the gap between carbon fiber sheets and pressure applied to points at a minimum of 5 Zed-location and 4 phi locations is used to demonstrate that there are no visible gaps between the carbon fiber sheet and the mandrel.
- The microscope is used to assume that the Zed-location of the sheet is within 0.100" of the ideal location.

6.1.2 End Ring Placement

The end ring alignment is a critical parameter to the TPC since this sets the overall length of the inner field cage. This overall length must match the overall length of the outer field cage to within 0.010". The end ring is held in position by three brackets that also serve to align the ring to high precision using a microscope on a precision moving stage as in the picture below:

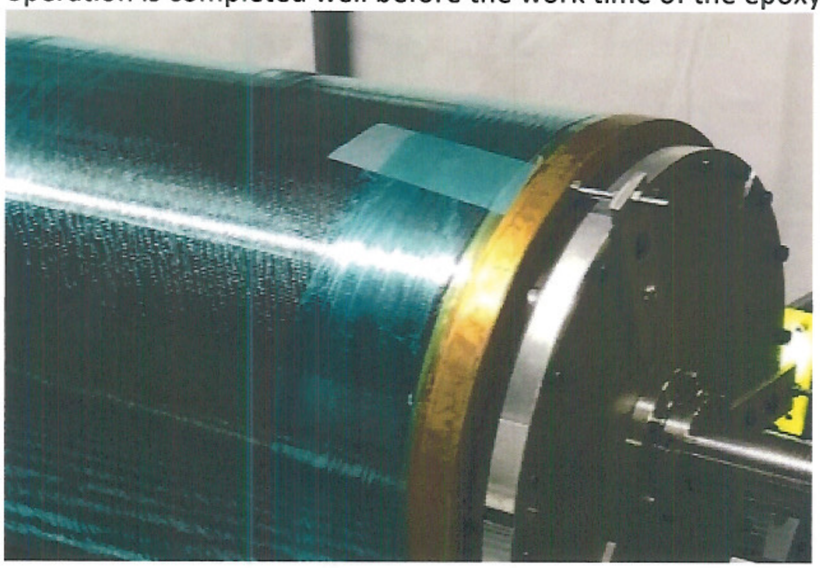


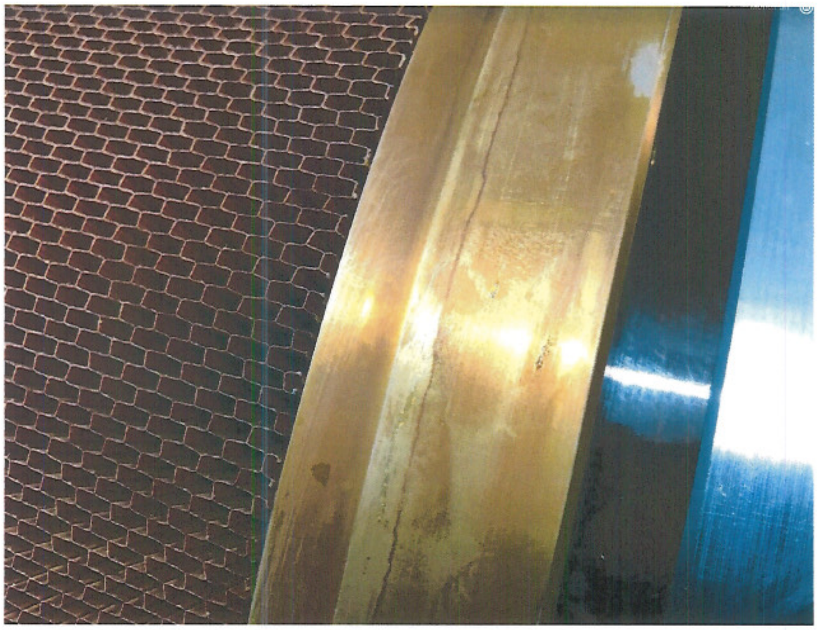
The following steps ensure proper layup:

- The microscope is used to check the alignment of the end ring at or close to each of the three hold points. Adjustment is made until the alignment at each point is within 0.005"
- A team with a minimum of three people performs a dry run of positioning the end ring to demonstrate that alignment from cold start can be achieved within 20 minutes.
- DP-460 epoxy is applied to the carbon fiber interspersed at 6 locations around the azimuth with 90 minute cure time epoxy. All handling of epoxy is conducted with proper procedures including PPE (gloves), and application within a well-ventilated area.
- Once placed, the end ring is surveyed by rotating the mandrel to ensure that the location tolerance is within specification (0.005"). The position is recorded by movie screen capture of the microscope image and properly archived.
- The procedure is repeated for the second end ring.

6.1.3 Honeycomb Placement

The honeycomb is easy to place accurately since it is quite pliable. However, care must be taken to ensure that it is fully seated against the inner carbon fiber and that the operation is completed well before the work time of the epoxy is reached.



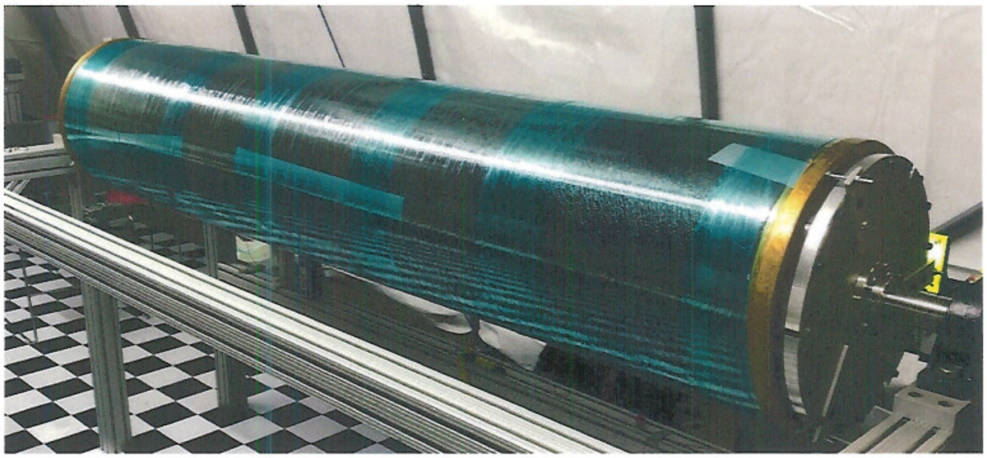


The following steps ensure proper layup:

- A minimum of 7 people is required to apply the honey comb with assignments:
  2 Gunners—Operate glue gun applying beads of one squeeze of epoxy per ½ mandrel
  3 Smooth Operators—Use rollers to smooth epoxy layer to uniform thickness
  1 computer operator—Rotates mandrel as required during all steps, keeps time
  1 supervisor—Oversees the operation and manages motions.
  2 carriers—Gunners become carries to bring the honeycomb to place.
  3 tensioners – Smooth Operators become tensioners after the honeycomb is in place.
- Two successful dry runs are required before beginning.
- All gluing operations follow posted procedures/requirements for PPE and ventilation.
- After placement but before drying a "push test" is performed to verify that the honeycomb is fully seated at all locations.
- When the operation is completed, the mandrel is set to slowly turn for a time period no less than twice the epoxy work time.

6.1.4 <u>Outer Carbon Fiber Stiffener</u>

The outer carbon fiber stiffener is held in place by the same shrink wrap technique as other layers. The carbon fiber stiffener is applied in two separate halves in two operations.

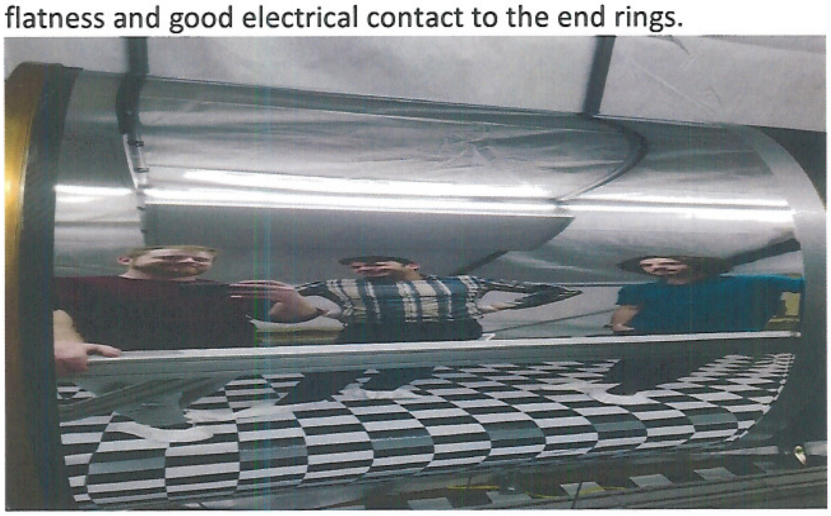


The following steps ensure proper layup:

- A minimum of 7 people is required to apply the carbon stiffener with assignments:
  2 Gunners—Operate glue gun applying beads of one squeeze of epoxy per ½ mandrel
  3 Smooth Operators—Use rollers to smooth epoxy layer to uniform thickness
  1 computer operator—Rotates mandrel as required during all steps, keeps time
  1 supervisor—Oversees the operation and manages motions.
  2 carriers—Gunners become carries to bring the carbon fiber to place.
  3 tensioners – Smooth Operators become tensioners after the carbon fiber is in place.
- Two successful dry runs are required before beginning.
- At the end rings, both structural (DP-460) and conductive epoxy are used.
- All gluing operations follow posted procedures/requirements for PPE and ventilation.

6.1.5 Aluminized Mylar

The aluminized mylar layer is used to smooth the field. Its principle properties are flatness and good electrical contact to the end rings.



The following steps ensure proper layup:

- A minimum of 4 people is required to apply the Al mylar sheet(s) with assignments:
  1 Gunners—Operate glue gun applying beads of one squeeze of epoxy per ½ mandrel
  2 Smooth Operators—Use rollers to smooth epoxy layer to uniform thickness

1 computer operator—Rotates mandrel as required during all steps, keeps time
2 tensioners – Smooth Operators become tensioners after the carbon fiber is in place.

- Two successful dry runs are required before beginning.
- All gluing operations follow posted procedures/requirements for PPE and ventilation.
- After three sections of Al-mylar are placed, Aluminum tape with conductive adhesive is applied to make full electrical contact.
- An Ohm-meter is used to demonstrate a value of less than ~~below~~ 2 Ohm between either end ring and any point on the Al-Mylar.

6.1.6 Kapton Layers

The Kapton layers provide insulation between the grounded Al-mylar sheet and the high voltage of the striped circuit cards. The kapton is applied in three sections along Zed at a thickness of 6-layers. The three sections are of length 19"-44"-21". Following a 6-layer application in three lengths two similar layers are added. The full set of layers is 19-44-21; 21-44-19; 19-44-21 resulting in a staggered seam to improve voltage stability.

Kapton is applied by a specially made tensioner system that used closed-loop feedback to deliver uniform tension independent of the speed at which the kapton is drawn from the roll. The tensioner system is shown in the photograph below:

The following steps ensure proper kapton application:

- A fresh calibration of the tensioner system is performed using a hanging weight of 10% or greater of the final tension.
- Tensioner system rollers are aligned to a tolerance of 0.003" WRT the field cage and each other.
- The kapton roll is aligned to the mandrel using a reference straight edge.
- A minimum of 5 turns of kapton take-up is used (paper on) to ensure that the kapton application does not "spiral" by more than 500 microns during 5 turns.
- Kapton is positioned with a small (~20 cm) initial length with paper backing still in place.
- During rolling, a Helium jet is sprayed below the kapton to ensure that any trapped gas is Helium, which can diffuse through the kapton over time.
- Visual inspection is used to ensure no bubbles.
- Gaps between adjacent winds are filled with DP-460 epoxy.
- All gluing operations follow posted procedures/requirements for PPE and ventilation

6.1.7 Striped Circuit Card Placement

The striped circuit cards provide the electric field shaping of the field cage. These must be placed precisely to ensure field uniformity of the final device.

6.1.7.1 Preliminary Electrical Tests

Each striped circuit card is tested thoroughly prior to installation on the mandrel. Both High Voltage and resistance tests are performed. The device shown in the picture below ensures safe operation of the HV test:

The follow procedure ensures safe and effective testing of each striped circuit card.

- All personnel are required to be familiar with posted procedures and safeguards built into the high voltage system via a signed acknowledgement.
- The striped circuit card is inserted into the test jig while the jig is disconnected from the HV supply.
- The HV source is set to have minimum trip current.
- Personnel wear appropriate PPE during the tests.
- Each strip is tested to 1200V without sparking in air.

- After HV testing each strip is tested to have a neighbor resistance of 4 M-Ohm with 0.1% tolerance.
- Any since strip failure must be corrected and the full card re-tested prior to installation in the TPC.

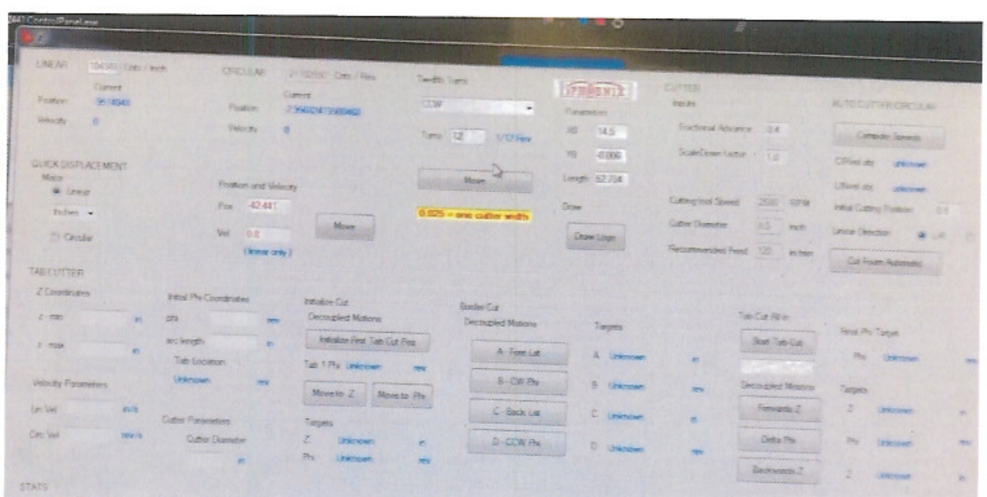
6.1.7.2 Circuit Card Placement

Striped circuit card placement is the most important factor in ensuring electric field uniformity of the TPC. The microscope on the precision stage is used to ensure accurate placement.

- Using the microscope, a dry fit is performed to place a single car to a precision of +/- 100 microns along Zed at all azimuthal angles.
- A minimum of three dry fits achieving the required precision are required before any wet run can be attempted.
- A minimum of 4 people is required to apply the circuit cards with assignments:
  1 Gunners—Operate glue gun applying beads of one squeeze of epoxy per 1/5 mandrel
  2 Smooth Operators—Use rollers to smooth epoxy layer to uniform thickness
  1 computer operator—Rotates mandrel as required during all steps, keeps time
  2 tensioners – Smooth Operators become tensioners after the card is in place.
- All gluing operations follow posted procedures/requirements for PPE and ventilation.
- Electrical connections are completed using hand-soldered HVPW resistors.

6.1.7.3 Circuit Card Survey

After all striped circuit cards are placed, the stripe locations are surveyed and archived. This is done using the precision stage and microscope driven by custom software. The survey software takes a series of snapshots from the microscope looking at the field cage stripes. Given the known location of the microscope features such as stripe edges are expected to land at known locations. The software runs by taking a user-defined number of survey points along Zed and phi, storing the images, and fitting the screen-location of the edges. This information is stored as the "as-built" field cage dimensions.



6.1.7.4 Final Electrical Tests

After the circuit cards are surveyed the same electrical test (HV) are applied to ensure that all boards survived the installation process. Any and all necessary repairs are made.

6.1.8 Final Mechanical Survey

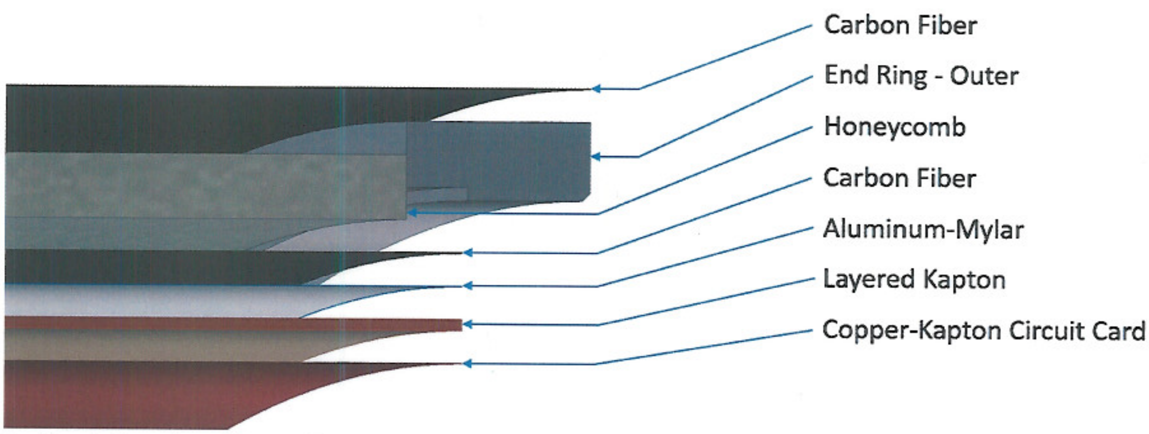
The end ring positions are surveyed a final time. Variations from ideal are recorded at each bolt hole. These variations will be compensated with precision thickness washers at final assembly.

6.1.9 Inner Field Cage Removal

The mandrel is designed with a collapsible inner wall. When the field cage is complete, these walls are collapsed to remove the final ~~pirce~~ piece.

6.2 Procedure for Layup of the Outer Field Cage

The outer field cage is extremely similar conceptually to the inner field cage. The main differences are size (80 cm radius instead of 20 cm) order of layers (striped cards are the inner-most layer rather than the outermost layer as shown in the figure below). For those reason most of the steps of assembly are identical to that already specified for the inner field cage.



In the following discussion(s) only deviations from the inner field cage procedures are listed.

6.2.1 Mandrel Dimensional Integrity Measurement

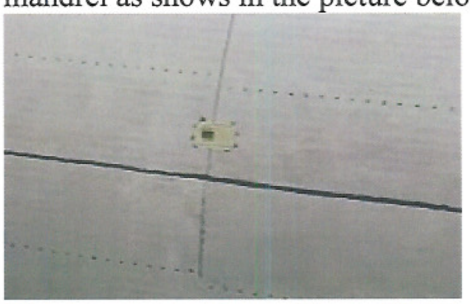
Because of its size, the outer field cage mandrel is not cut from single-piece pipe, but rather constructed from machinable foam. The quality of the cut is verified by taking multiple precision circumference measurements along the length. The radius of the machinable foam must be to specification within +/-0.010".

6.2.2 Mandrel Vacuum Certification

With the striped circuit cards as the inner-most layer a special means must be devised to hold them in place. We have chosen a "vacuum-head" technique in which channels on the backside of the machinable foam are used to distribute vacuum under the striped circuit cards. The integrity of the vacuum system is proved by pumping on "blank mylar" cut to the same size as the striped circuit cards. We require a pressure of no more than 150 Torr as measured in the vacuum distribution box.

6.2.3 Challis Placement

The outer field cage provides the sole mechanical support for the central membrane and has so-called "Challis & Tab" structures machined from Butterboard (a low out-gassing lightweight fine cell polymer foam). These must be placed into "negative cutouts" in the mandrel as shows in the picture below:



The microscope is used to verify the challis location to +/-100 microns.

6.2.4 Striped Circuit Card Placement

Identical to inner mandrel.

6.2.4.1 Preliminary Electrical Tests

Identical to inner mandrel.

6.2.4.2 Circuit Card Placement

Identical to inner mandrel.

6.2.4.3 Circuit Card Survey

Identical to inner mandrel.

6.2.5 Kapton Layers

Identical to inner mandrel.

6.2.6 Aluminized Mylar

Identical to inner mandrel.

6.2.7 End Ring Placement

Identical to inner mandrel.

6.2.8 Honeycomb Placement

Identical to inner mandrel.

6.2.9 High Voltage Lead Placement

In addition to providing the mechanical support for the central membrane, the electrical contact to the central membrane is made through the outer field cage. The striped circuit cards provided a triplet (redundancy) of plated-through holes that transfer the potential inward to the central membrane. The cable leading to these feedthroughs runs through the end ring and along a purposeful gap in the honeycomb. The following procedures are used to properly place the HV Lead:

- The cable used for Central Membrane HV shall be approved for use by BNL safety prior to installation onto the TPC.
- Connectors shall be commercial standards rated appropriately for the cable.
- The cable shall be certified by the manufacturer prior to assembly into the TPC.

6.2.10 Outer Carbon Fiber Placement

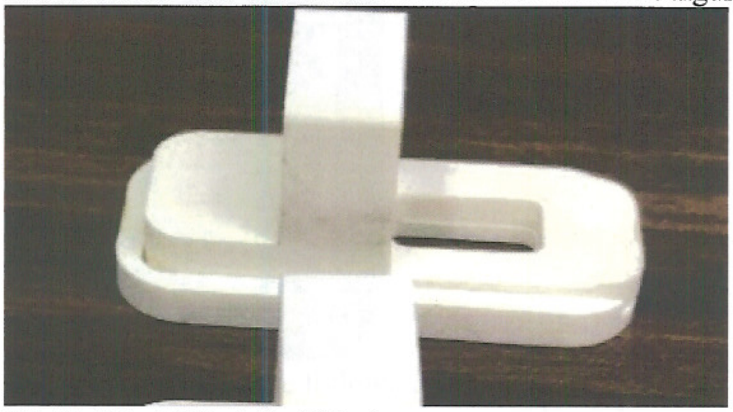
Identical to inner mandrel.

6.2.11 Outer Field Cage Removal

The outer field cage mandrel is comprised by a series of independent foam boards held in place by 8020 T-slotted framing as shown in the figure below. When the field cage is complete the spokes of the end wheels are removed one-by-one, allowing the foam to leave and freeing the Outer Field Cage.

6.2.12 Central Membrane Tab Application

The tab piece is inserted into the challis and held using DP-460 epoxy. The Challis is designed as a 3-sided cup. Because the Zed-position of the tab is critical, no glue shall be placed in the Zed-facing edge of the Challis, thereby assuring the require alignment of 250 microns. Tab and Challis sets are shown in the figure below:

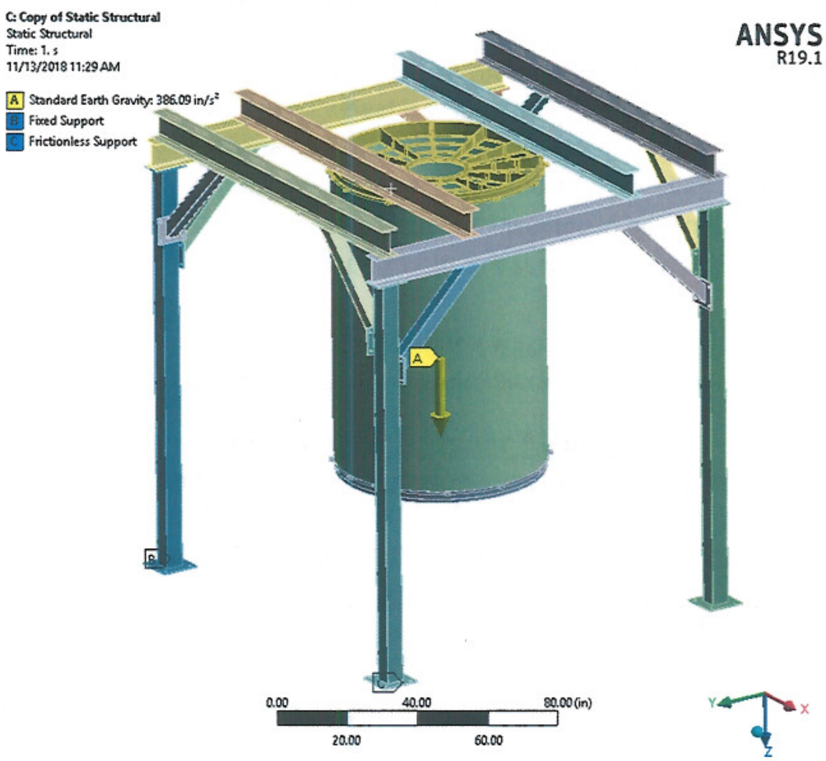


6.2.13 Final Electrical Tests

Identical to Inner Field Cage.

6.3 Procedure for Field Cage Assembly

In order to avoid stresses on a partly-assembled field cage, the field cage will be constructed in a vertical orientation as shown in the figure below.



6.3.1 Construction of the Assembly Frame

The Assembly Frame is comprised from a series of steel I-beam and box beams with welded plates on the ends. This frame was mechanically modeled by BNL engineers to be much sturdier than needed. It is assembled inside the SBU clean tent.

Assembly involves the following key steps.

- All pieces certified to tolerance by SBU machine shop personnel.
- Assembly utilized lifts specified and test to 125% of the required capacity.
- Assembly performed only by certified riggers.

6.3.2 Hoisting of the Top Wagon Wheel

The wagon wheel is lifted into position using a hoist attached to an A-frame. Prior to this lift the wagon wheel must be prepared in the following ways:

- The wagon wheel is inspected to demonstrate compliance with tolerances in the original drawings and Statement of Work.
- The spring-energized seals must be installed in advance.
- The roller wheel must be installed in advance.
- Downward facing bolts are staged in advance for engagement of the inner and outer field cages.
- The bolts suspending the wagon wheel provide a gap between the wheel and the assembly frame to avoid distortions in the wagon wheel shape.

6.3.3 Installation of the Inner Field Cage

The inner field cage is equipped with precision washers at each bolt hole to bring the length tolerance to 0.002". The inner field cage is lifted up to engage the spring-loaded seal and pulled into final position using the pre-staged bolts in the wagon wheel.

6.3.4 Installation of the Outer Field Cage

The outer field cage is equipped with precision washers to bring its length into tolerance and then lifted into position and bolted to the wagon wheel.

6.3.5 Installation of the Central Membrane

The central membrane is lifted into position and secured to the tabs on the outer field cage. Electrical connections to the outer and inner field cage are made and tested with a volt meter.

6.3.6 Installation of the Carbon Fiber Tie Rods

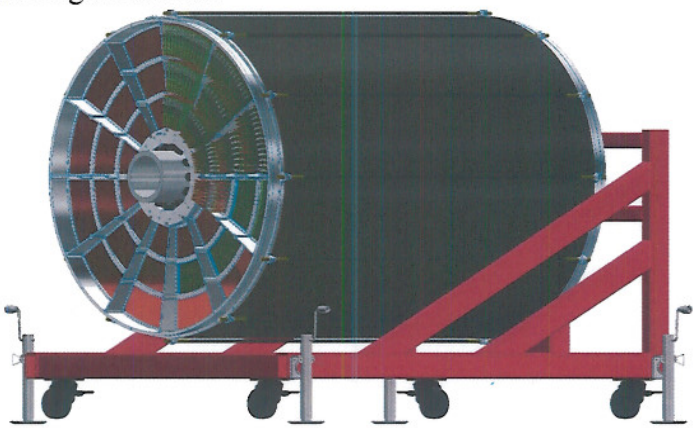
The carbon fiber tie rods must be pre-positioned on the top wagon wheel.

6.3.7 Hoisting of the Second Wagon Wheel

The bottom wagon wheel is lifted into position and secured to the inner and outer field cages as well as to the tie rods. Precision shim washers are used to compensate for any variation for the inner and outer field cages from an ideal length.

6.4 Movement of the Field Cage to the Transport Cart

Lastly the TPC Field cage must be transferred to the transportation and installation cart shown the figure below.



The TPC is suspended from the roller rings that had been pre-installed into the TPC wagon wheels during the prior steps. Movement of the TPC from the assembly frame to the transport cart will involve professional personnel.