OH Coil Design Description

L. Dudek

and the NSTXU Engineering Team

OH Circuit Fault External Review
B318
5/28/2015

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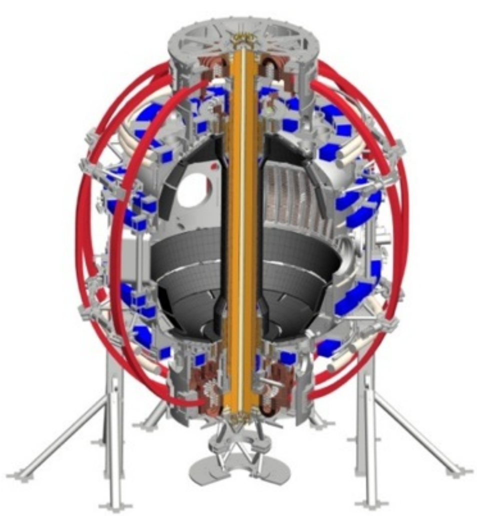

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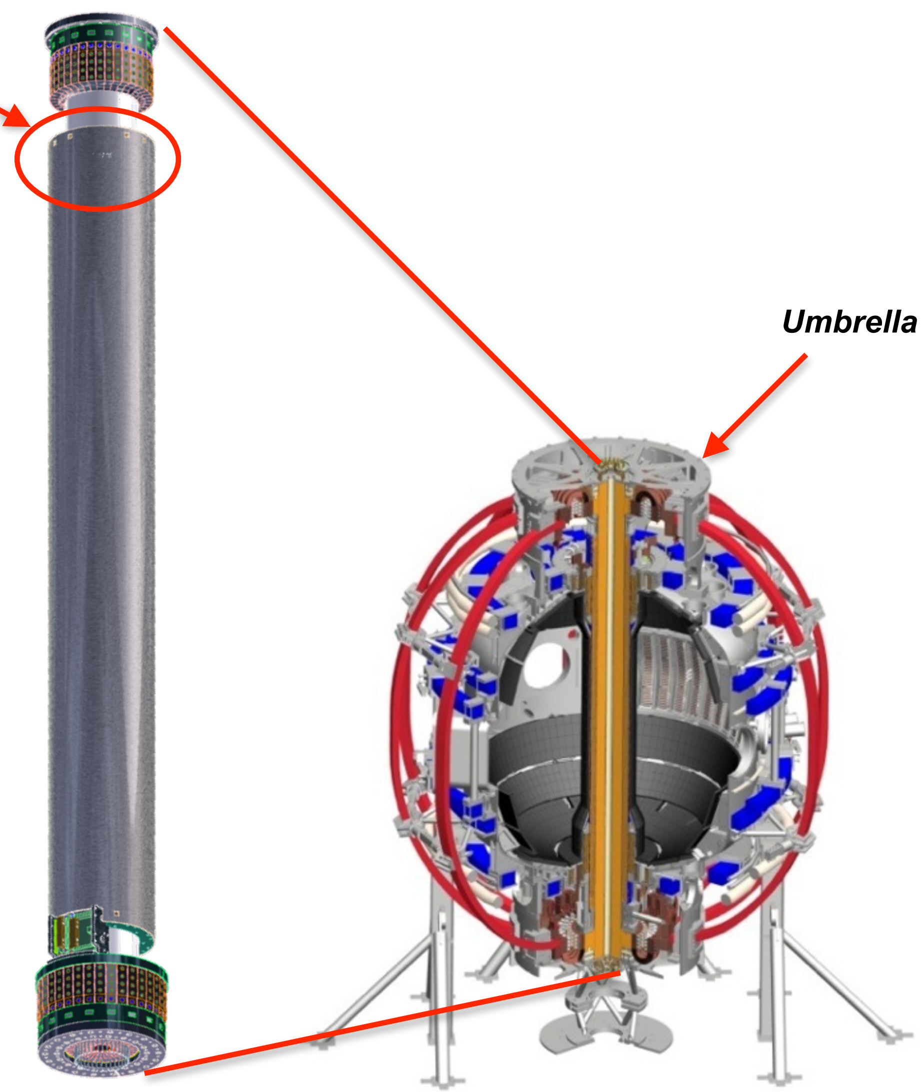
OH Solenoid Parameters

Location of the arc fault

Description	OH Parameters
Operating Voltage	6077 volts
Number of turns	884
Number of layers	4
Cooling hole diameter	0.2250 in
Operating current	24,000 amps
Groundwall insulation	0.1080 in.
Turn insulation	0.0480 in
Outside diameter	22.10 in
Copper mass	6184 lbs
Cooling paths	8
Coolant	DI Water @ 430 psig



Umbrella Structure

OH Solenoid Materials

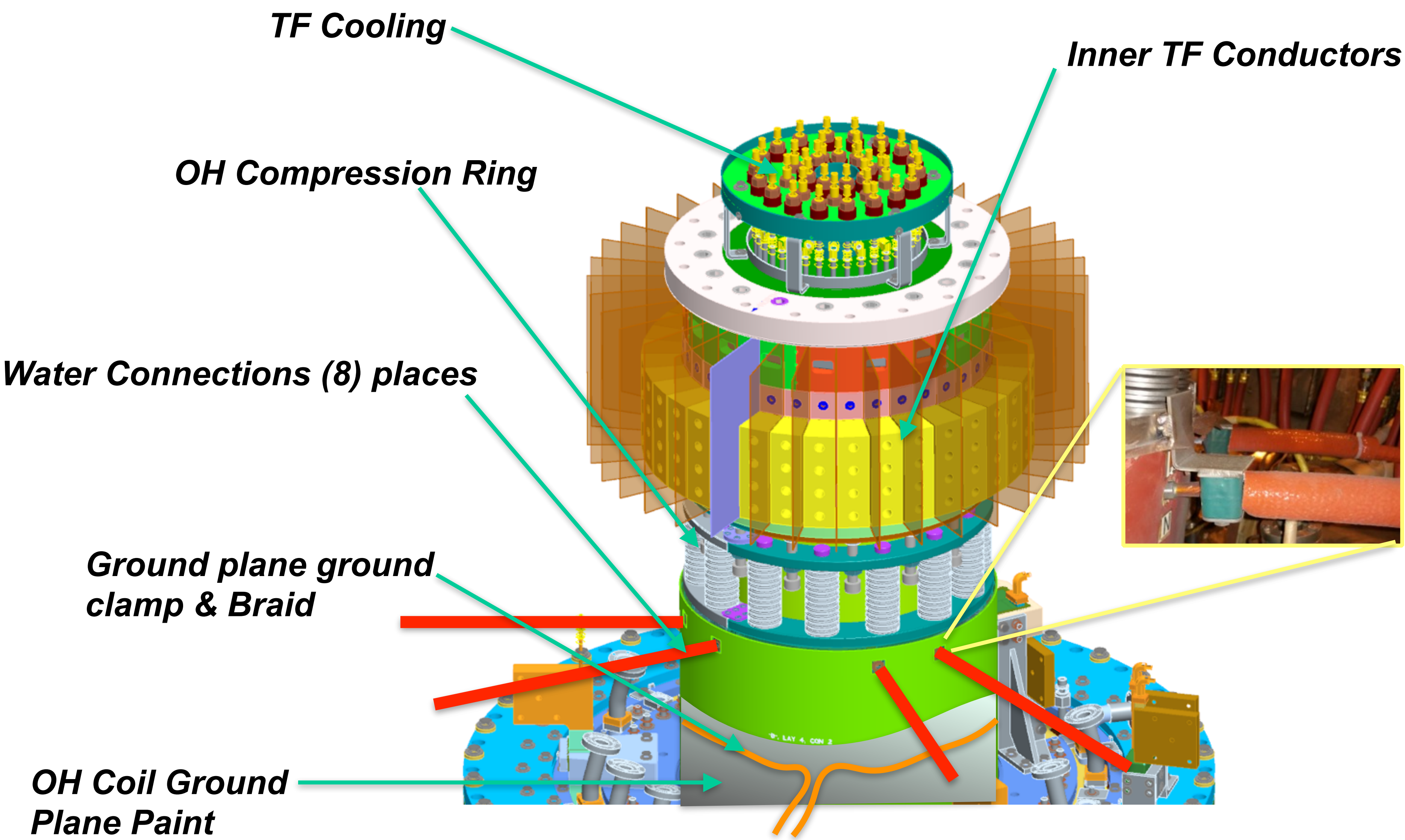
- **Conductor :** C10700 –Oxygen free-silver bearing copper conductor
  Insulation:
  - **Turn Insulation:** Co-wound Kapton/S2 glass tape
  - **Ground wrap Insulation:** Half-lapped layers- 0.006 inch thick S-2 (satin weave) standard silane finish glass tape- (Temperature class- 180 degrees C)

- **Fillers:** All G-11 laminate material

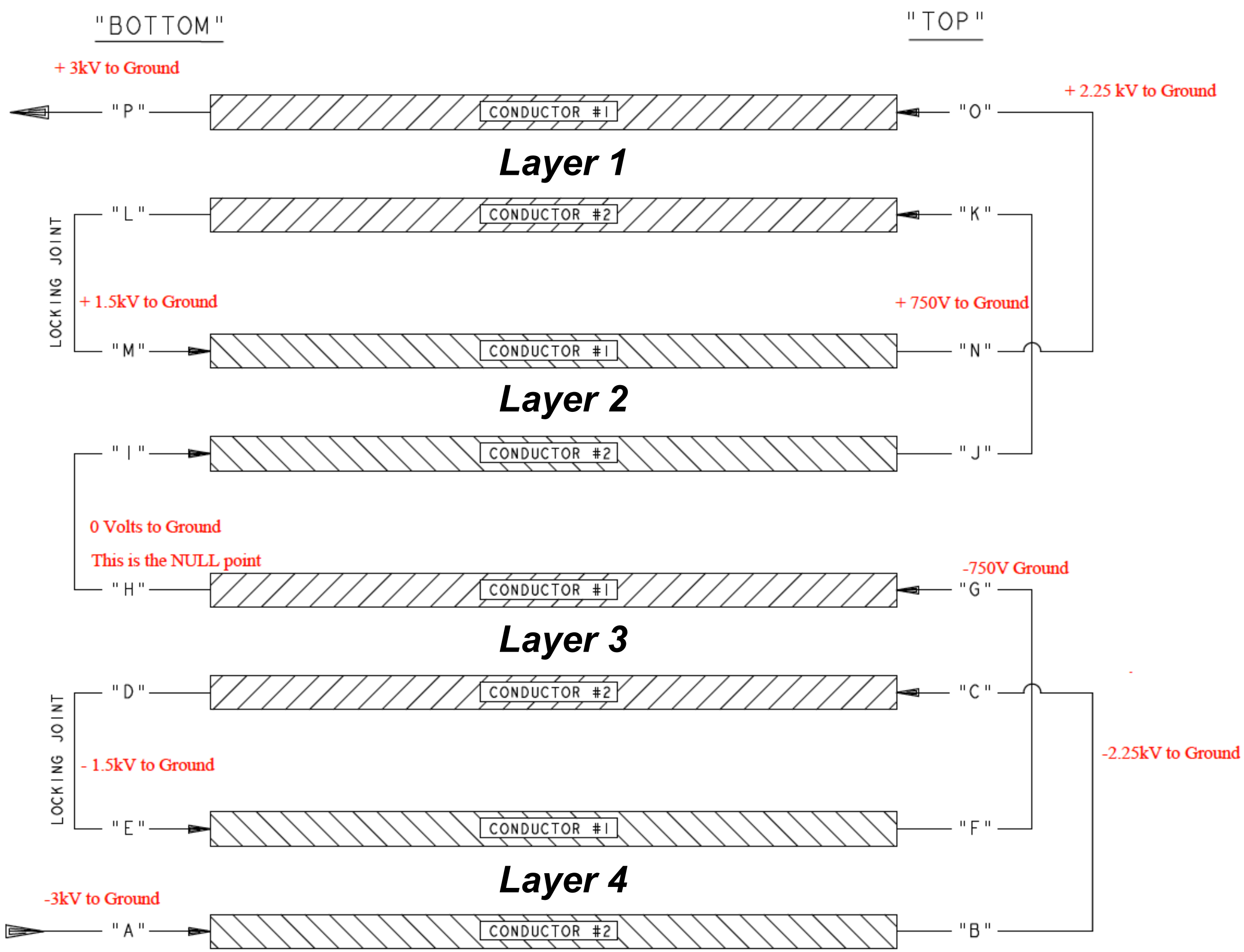
- **Cooling Fittings:** Custom cast copper components C10200

- **VPI System-** CTD-425 Cyanate-Ester Hybrid system
  - **Cure cycle:** 22 hours @ 100 degrees C
  - **Post Cure Cycle:** 24 hours @ 170 degrees C

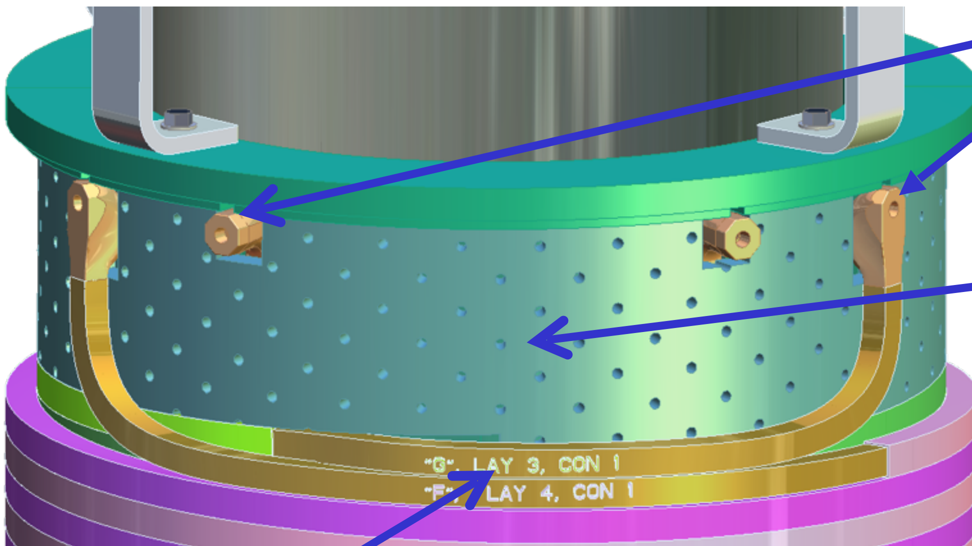
Upper OH Coil Arrangement



OH Coil Winding Potentials



OH Layer to Layer Joints



OH Cooling fittings- torch brazed to copper conductors

G-11 fillers between layers supports turns

S-2 glass between G-11 fillers

Perforations in G-11 will enhance epoxy flow during VPI

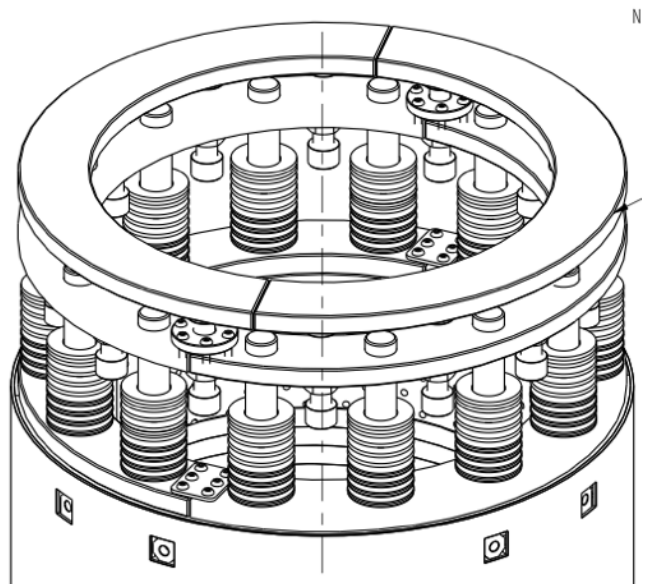
Layer to layer TIG-Braze joint [Typical]

"TIG-Braze"

- TIG-Brazing method minimizes annealing of conductors (use Sil-Fos)
- Provides adequate joint strength
- Qualified method and procedures used in previous OH solenoids

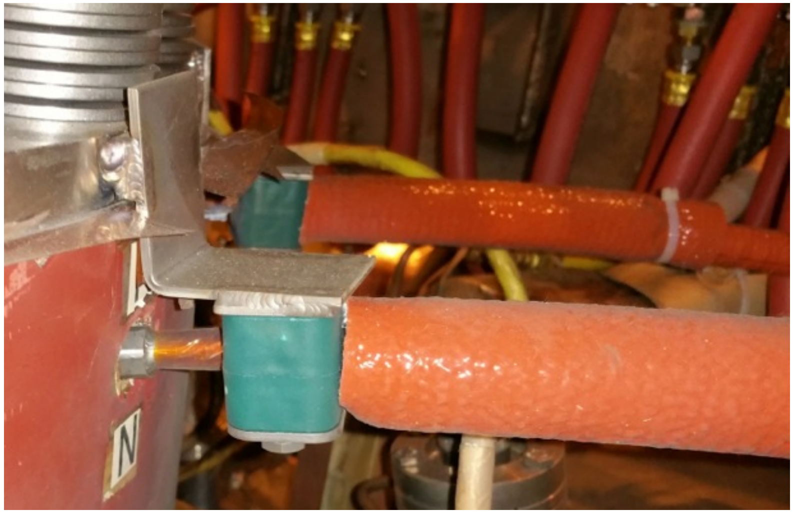
OH Compression Ring

- Purpose to hold OH Coil in place under launching loads and during bakeout thermal expansion
- Consists of a set of six half rings preloaded by belleville springs at the time of installation. Preload is adjustable
- The assembly splits into halves so it can be installed after potting of the OH coil
- Required 14 stacks of 26 bellevilles to maintain a minimum of 20,000 lbs load on the OH.
- This assy was found to be floating electrically.

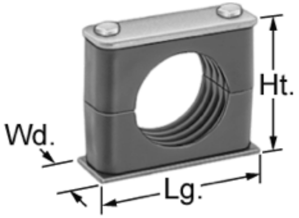


Upper Water Connections

- Design adopted from NSTX OH Water Connections
- Polypropylene clamps serve double duty as supports and insulators.
- Water tubes are overwrapped with 3 mil Kapton before applying clamp. Assy passed 13kv Hipot test (on the bench).
- Fitting where it enters the coil is left bare to allow inspection for water leakage
- Normally the OH hose connections would be non conductive. The (8) upper an lower hoses are 316SS to meet OH Water Heater requirements.
- The SS hoses are double insulated and terminated just outside the Umbrella in G10 Blocks. Were tested successfully to 17 kv on the bench.
- The SS hoses do not appear to have been involved in the event.



High Pressure Polypropylene Vibration-Damping Clamp
Weld-Mount, 1 Line, Type 304 Stainless Steel Hardware, 1/2" ID



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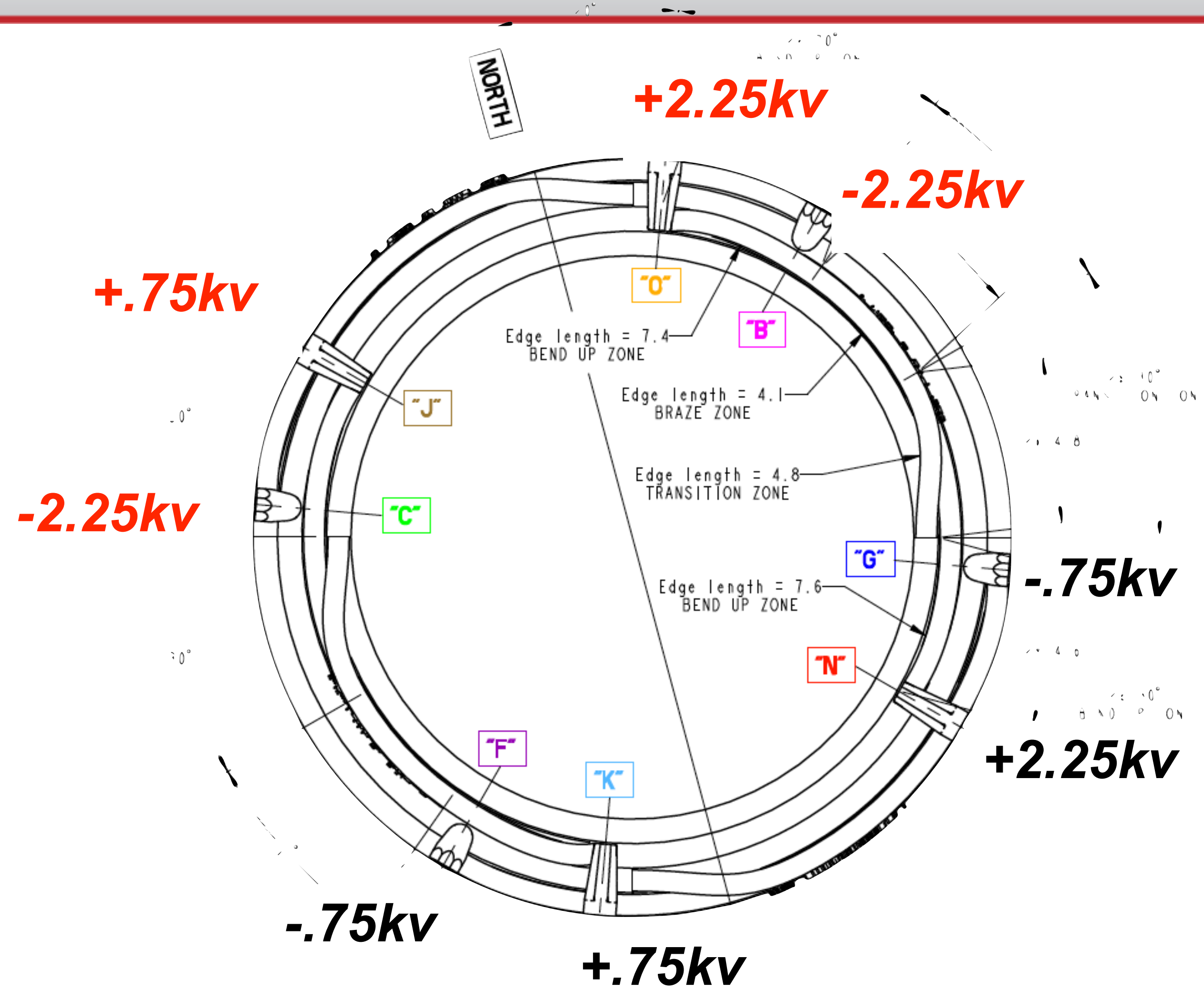
For OD	1/2"
For Tube/Pipe Size	1/2"
Length	2 7/8"
Width	1 1/4"
Height	2"
Additional Specifications	High-Pressure Single-Line Polypropylene Clamps Type 304 Stainless Steel Hardware For Tube

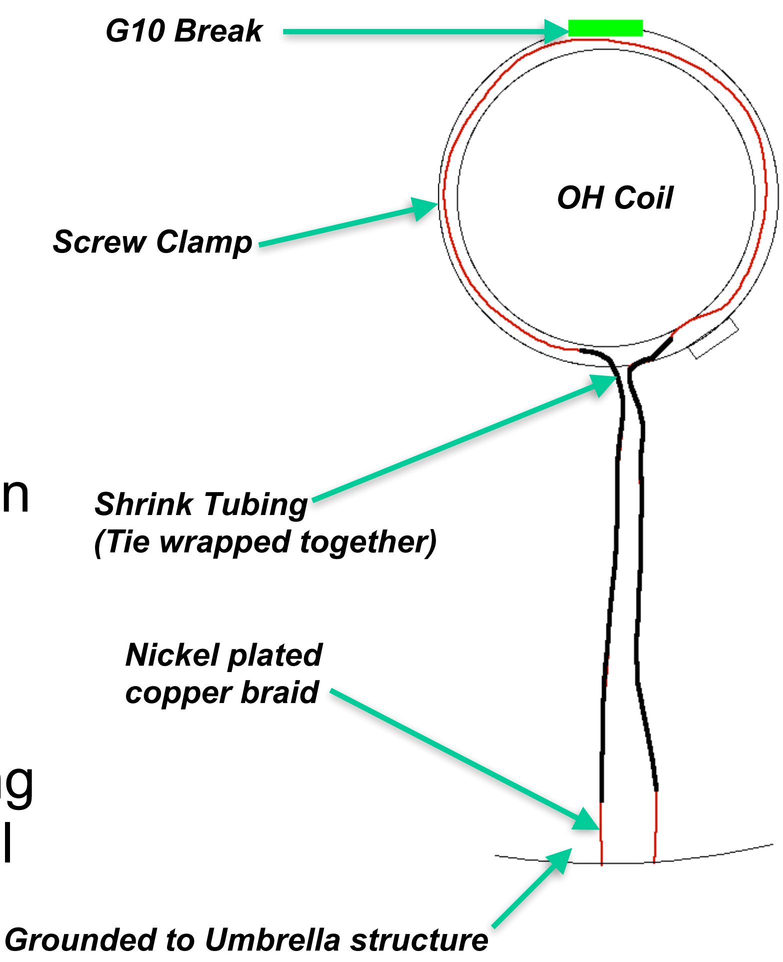
Upper Water Conn



TOP VIEW
LAYER 1 & 2
"J" & "K"
"N" & "O"

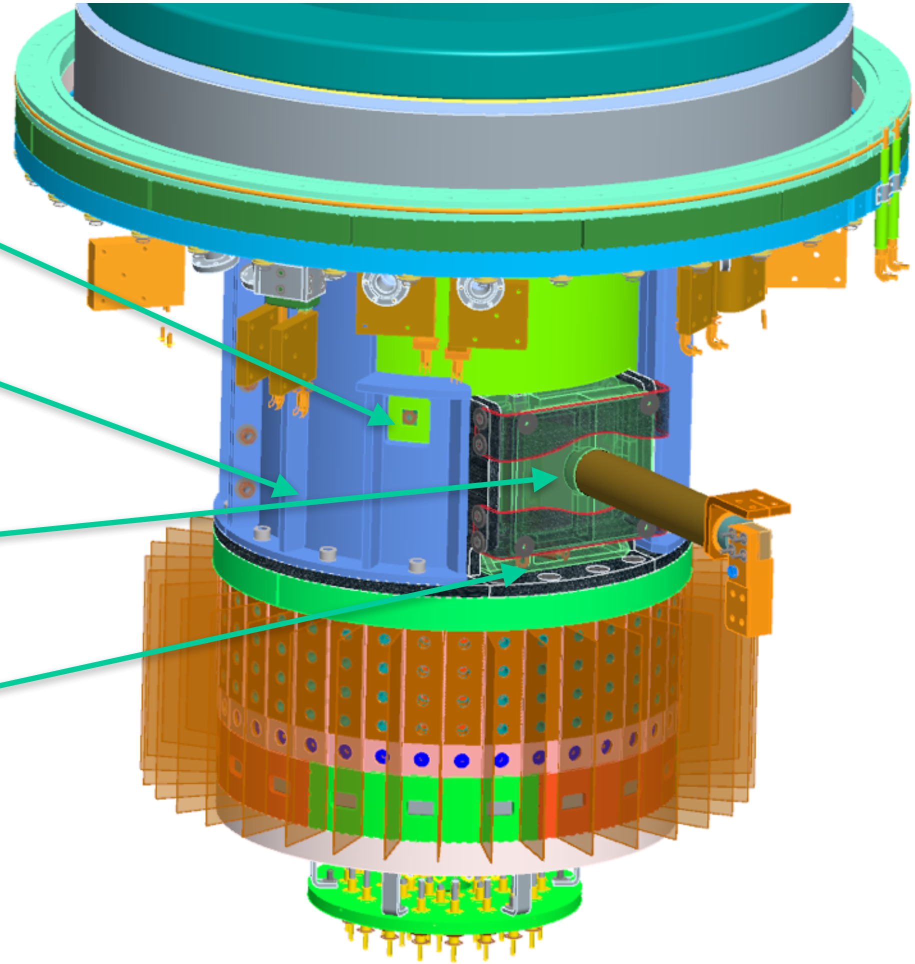
Ground Plane Grounding Clamp

- Grounding clamp is documented on B-4F1005, however it was not updated for NSTXU.
  - Note: “1/2” Wide Braided copper straps insulated on one side”
- Was installed by a machine tech per verbal instructions from electrical engineer. The installation is confirmed in IP-3572.
- Engineer instructed technician to avoid loops.
- Technician interpreted as not connecting ends together as they came around coil

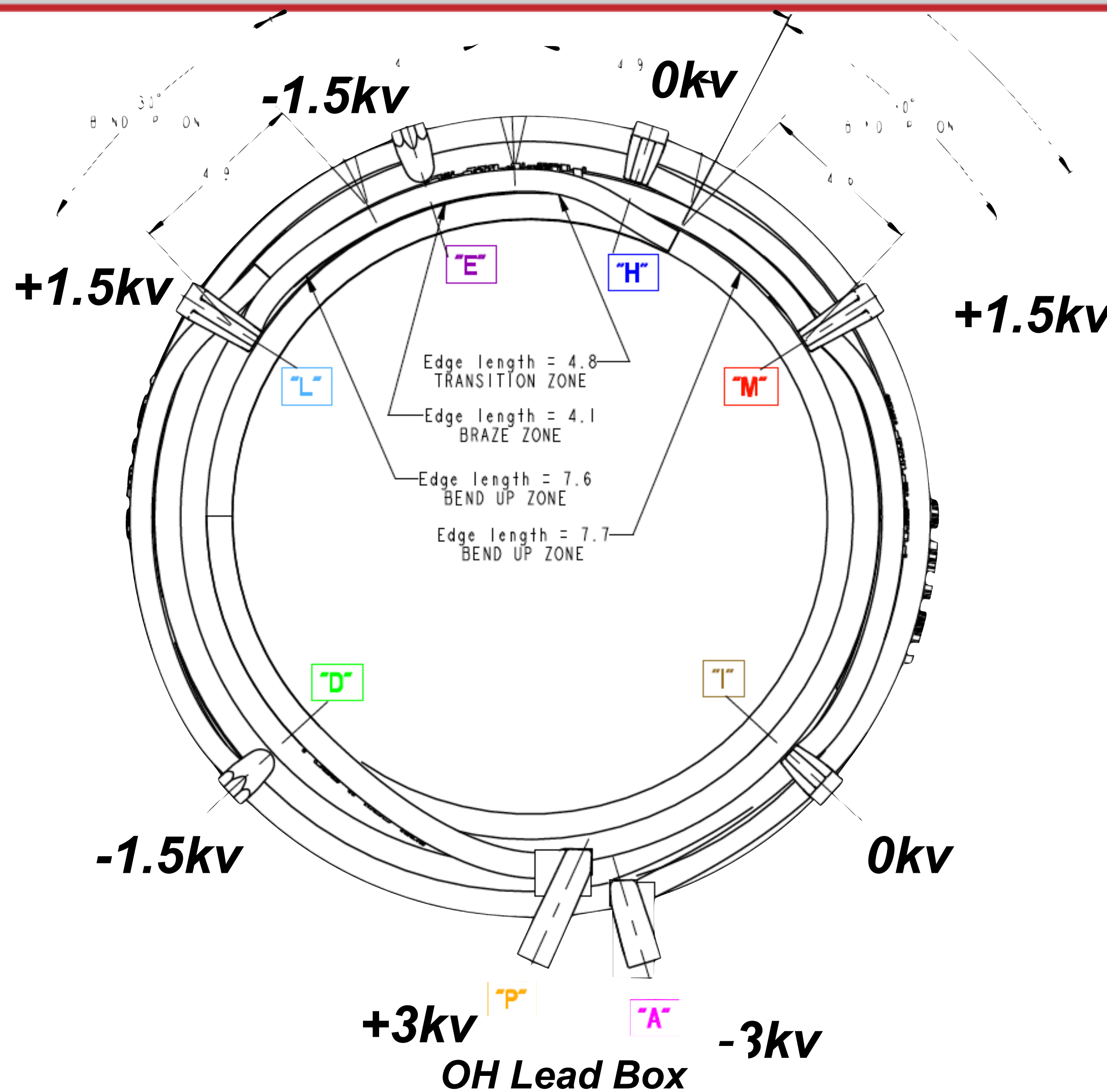


Lower OH Coil Arrangement

- Layer-Layer Water Conns
- Grounded Support Structure
- Coaxial OH Connector
- OH Lead Water Conns



Lower Water Conn

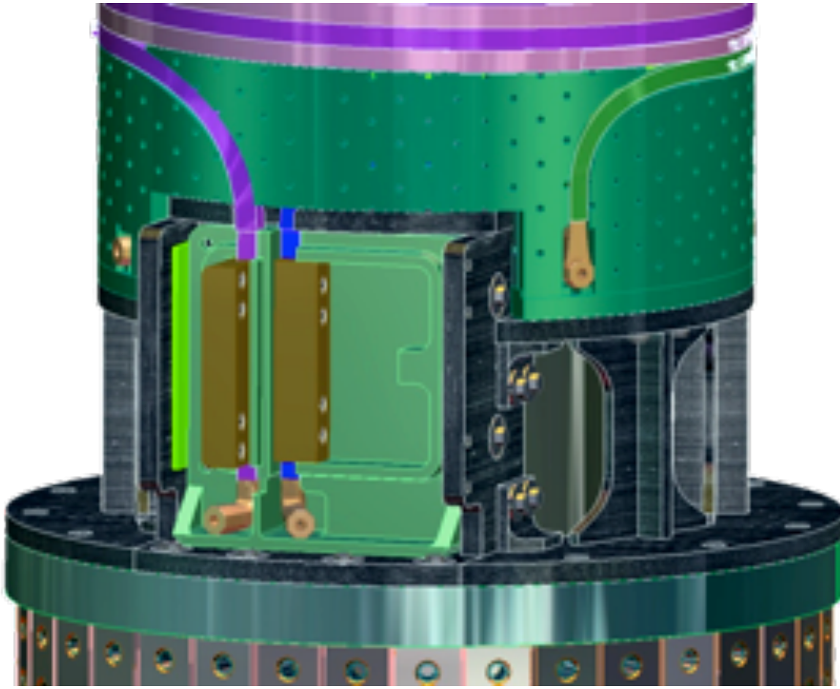


Lower Water Connections

- At 6 locations, the design utilizes the same polypropylene clamp in the upper connections.
- The 2 connections at the leads coming into the coil are clamped by solid blocks of G10.
- The brackets are welded to the OH support structure which is grounded to the CS casing.
- All of these connections have passed the 9 kv field Hipots without any issues.

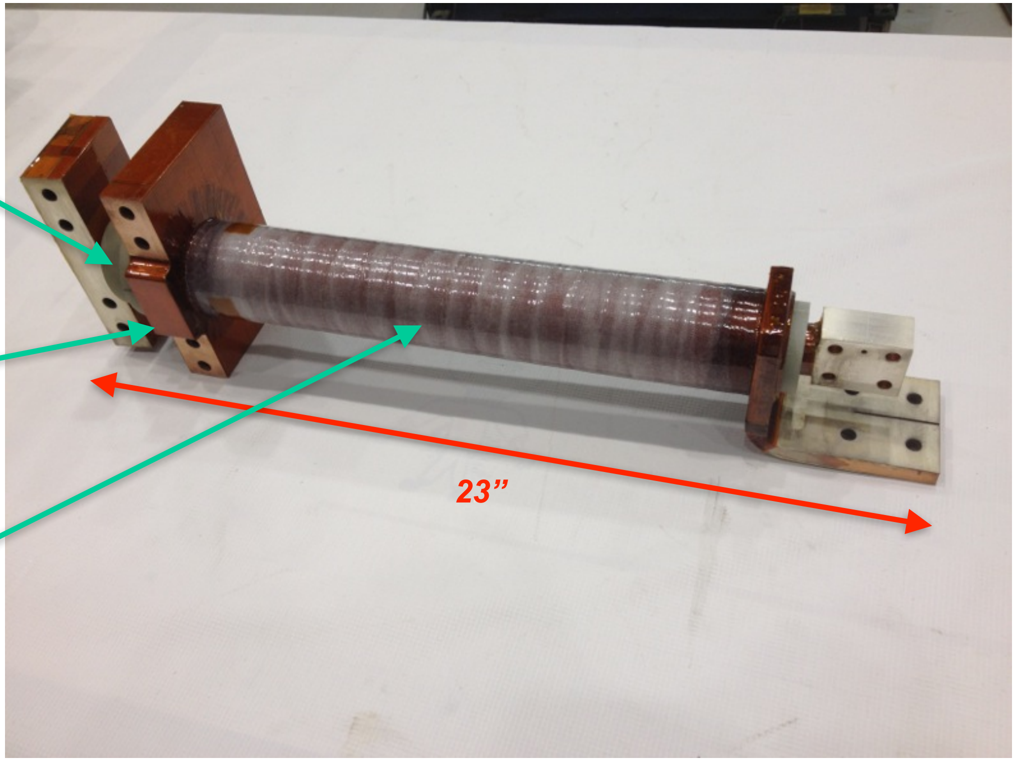
OH Lead Box & Water Conns

- OH Features a coaxial input connector to minimize forces between conductors.
- The two leads are brazed to copper flags that are wrapped in Kapton tape and are supported by a G10 enclosure wrapped in a heavy 316SS Box.
- The water connections are also wrapped in Kapton and are separated by a G10 partition at their closest point.

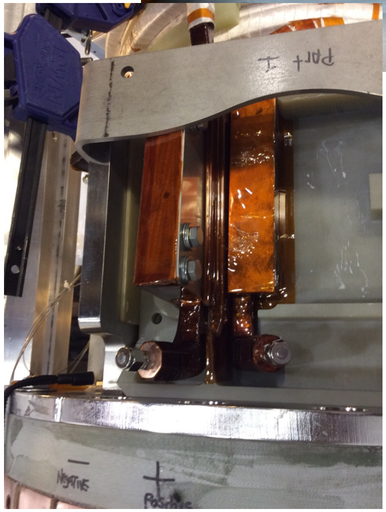


OH Coax Connection

- G10 Insulating tube between inner and outer conductor
- Kapton on exposed copper connector flags
- Outer conductor insulated with Kapton and over wrapped with fiberglas and Hysol RT cure epoxy.
- This assy was hipotted to 13kv on the bench.
- This piece is being reinforced by epoxy injection between G10 and outer conductor to eliminate bending (See Raftopoulos talk)



OH Lead Box Detail



- All metal lead box surfaces that faced conductors were insulated with Kapton.
- Any non-contact surfaces of the OH lead flags were insulated with Kapton
- After installation of the water connections in the field tubes were Kapton wrapped and G10 support blocks were installed.
- The lower OH water connections have hipotted in the field to 9kv.
- SS Hose assembly was hipotted on the bench to 17kv.

Electrical Testing

- Acceptance test in the Coil Winding Facility:
  - 12 microamps @ 13 kV
  - 23 microamps @ 9 kV
- OH installed in NSTX-U. Hi-Potted from the PCTS in the NTC:
  - 27 microamps @ 9 kV
- OH installed in NSTX-U. Hi-Potted from the SDS in FCPC:
  - 42 microamps @ 9 kV

Summary

- The OH Coil is a robust design
- Attention to detail was paid to ensure the conductors are well insulated from each other and in the OH connector box.
- The water fittings in the upper end of the coil are well away from the OH turns making damage to the coil unlikely
- Hipot Testing of individual components was performed at 13 Kv (2E+1) to ensure reliability.
- Since the arc fault the OH coil has been inspected and retested successfully:
  - Cooling Passage connections inspected for damage
  - Hydrotest of cooling channels passed successfully
  - Pneumatic flow test of passages passed
  - Repeated Megger tests have passed for the OH insulation
- All indications are that the OH coil has been undamaged by this event.