National Spherical Torus eXperiment - Upgrade

NSTX-U

Calculation of TF and OH Gap Electric Field Strength Distribution

NSTXU-CALC-133-21-00

Date: 01/27/2017

Weiguo Que Digitally signed by Weiguo Que Date: 2017.02.02 10:47:28 -05'00'

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Approved By – Responsible Engineer

NSTX-U CALCULATION

Record of Changes

Rev.	Date	Description of Changes
0	01/27/17	Initial Release

NSTX-U Calculation Form

Purpose of Calculation:

A key component of NSTX-U is the fabrication of a new, higher field center stack (CS). To provide robust joints between the inner and outer legs of the Toroidal Field Coils (TF) and minimize radial build, the NSTX-U CS design requires that the Ohmic Heating solenoid (OH) should be wound directly on the inner TF bundle. To protect the OH against thermal expansion stress when the inner TF bundle is hot but the OH is relatively cool, the completed CS will have a 0.1 inch annular gap between the outer diameter of the TF bundle and the inner diameter of the OH solenoid.

A plaster-like ceramic based compound called Aquapour was used to form the gap 0.1 inch above the TF center stack surface. Aquapour is normally easily dissolved by water. The intent was to remove it after the OH winding was completed to create a thermal expansion gap between the OH and TF windings. Unfortunately the Aquapour became contaminated with the CTD 425 resin during the vacuum pressure impregnation (VPI) process. The resin-contaminated Aquapour is impervious to water, and is moderately hard. Attempts to remove it with picks, a variety of saws, and pressurized water were unsuccessful.

Four piano wires were also trapped in the gaps which are intended to help remove the Aquapour. These wires will create electric field stress concentrations and could conceivably shorten the insulator life against micro-discharges.

In order to evaluate the “Aquapour” and four wires effects to the TF and OH coil insulation system, the static electric field analysis using Maxwell has been performed.

References:

1. M. Mardenfeld, J. Chrzanowski, M. Anderson, E. Kearns, C. McFarlane, S. Raftopoulos, W. Reese, R. Tucker “ Novel Use of Water Soluble Aquapour as a Temporary Spacer During Coil Winding for the NSTX-U Center Stack” , 2013 IEEE 25th Symposium on Fusion Engineering (SOFE).

Assumptions:

1. TF coil is treated as a single piece copper conductor at same potential.
2. OH coil is treated as a single piece copper conductor at same potential.
3. Wire with diameter 50 mil is at the center of the TF and OH Gap (100 mil).
4. There is an air bubble with diameter 20 mil inside the Aquapour.
5. Aquapour dielectric constant is 5.0.

Calculation:

Software used: ANSYS MAXWELL 2D and 3D

Some critical dimensions:

1. TF coil radius: 7.68 inch (Based on drawing E-DC1424)
2. TF coil G10 thickness: 0.214 inch (Based on drawing E-DC1424)
3. Aquapour Gap: 0.1 inch (Based on drawing E-DC1554)
4. OH G10 thickness: 0.172 inch (Based on drawing E-DC1554)
5. OH coil thickness: 0.611 inch (Based on drawing E-DC1554)
6. Wire diameter: 0.05 inch, air bubble diameter: 0.02 inch

Case 1: TF at 1kV, OH at -3 kV and Wire at 0 V (Maxwell 2D)

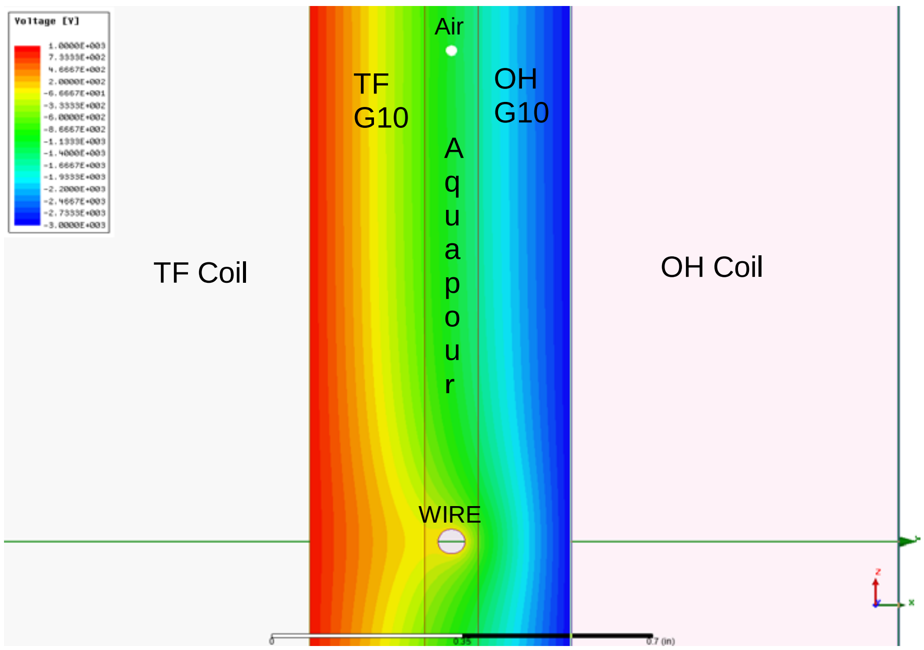

Figure 1: Voltage distribution between TF and OH coil.

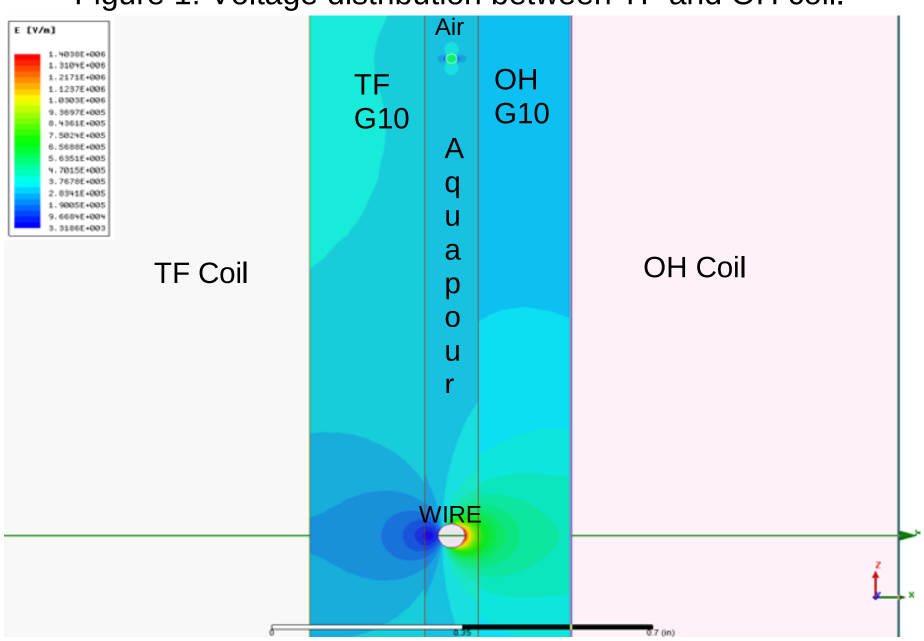

Figure 2: Electric field strength distribution between TF and OH coil.

The maximum electric field strength 14.0 kV/cm is at the side of the wire close to OH coil. It is about half of the air break down electric field strength 30 kV/cm. The maximum electric field strength inside the air is about 7.0 kV/cm.

Case 2: TF at 1kV, OH at -3 kV and Wire at 0 V (Maxwell 3D)

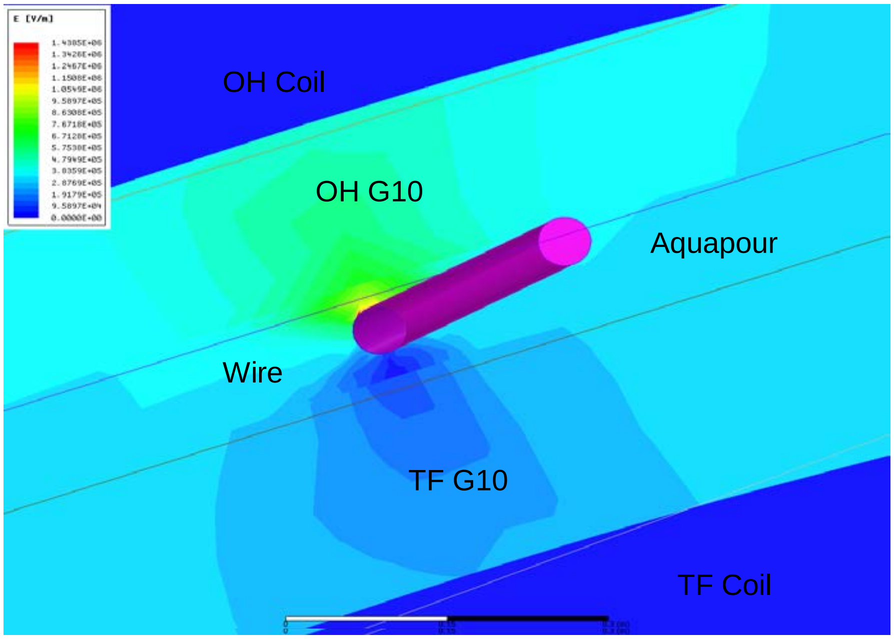

Figure 3: Electric field strength distribution between TF and OH coil.

Since the wire is hanging from top of the TF G10 insulation layer to the bottom, 3D models can accurate represent the real case by using the Maxwell 3D software. The electric field calculation result is shown in Figure 3. The maximum electric field strength 14.4 kV/cm is at the side of the wire close to OH coil. It is about half of the air break down electric field strength 30 kV/cm. There is only a little difference between the 3D and the 2D case calculation results.

Case 3: TF at 0kV, OH at 3 kV and Wire at 0 V (Maxwell 2D)

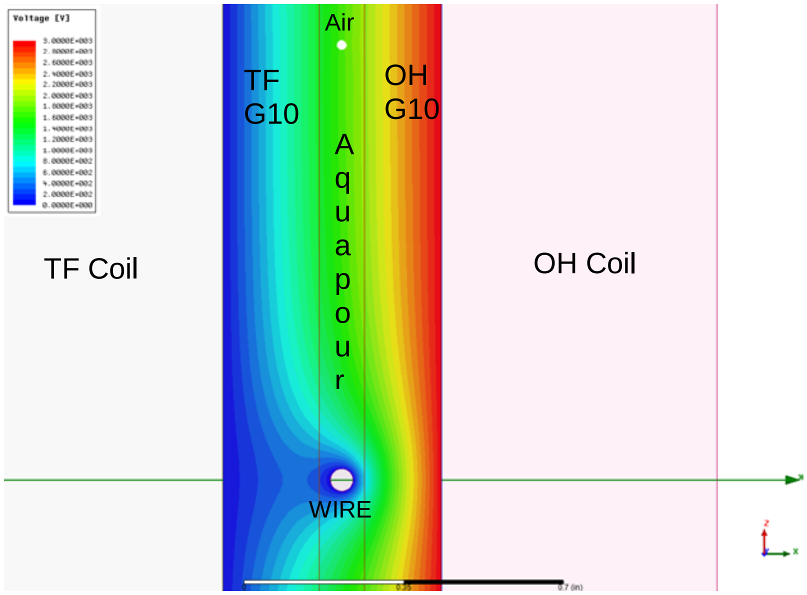

Figure 4: Voltage distribution between TF and OH coil.

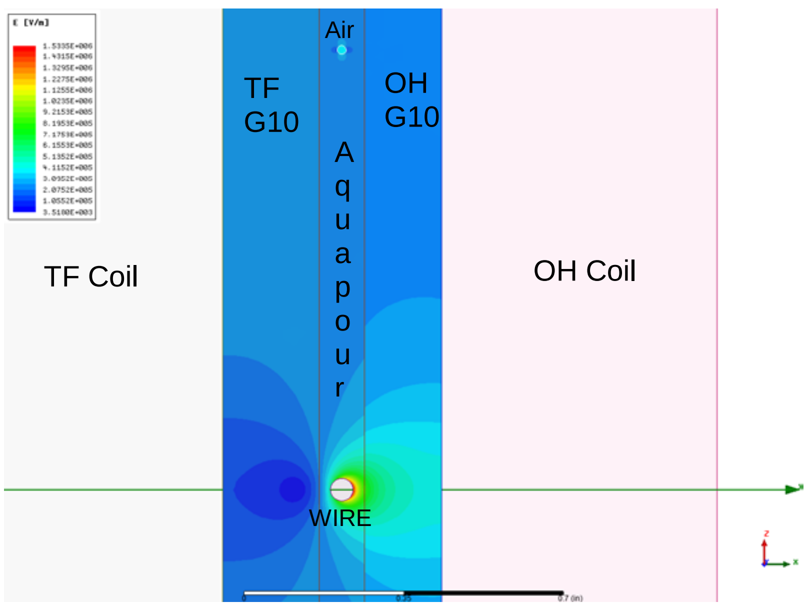

Figure 5: Electric field strength distribution between TF and OH coil.

The maximum electric field strength 15.3 kV/cm is at the side of the wire close to OH coil. It is about half of the air break down electric field strength 30 kV/cm. The maximum electric field inside the air is 4.0 kV/cm.

Case 4: **TF at 0kV, OH at 3 kV and Wire is floating. (Maxwell 2D)**

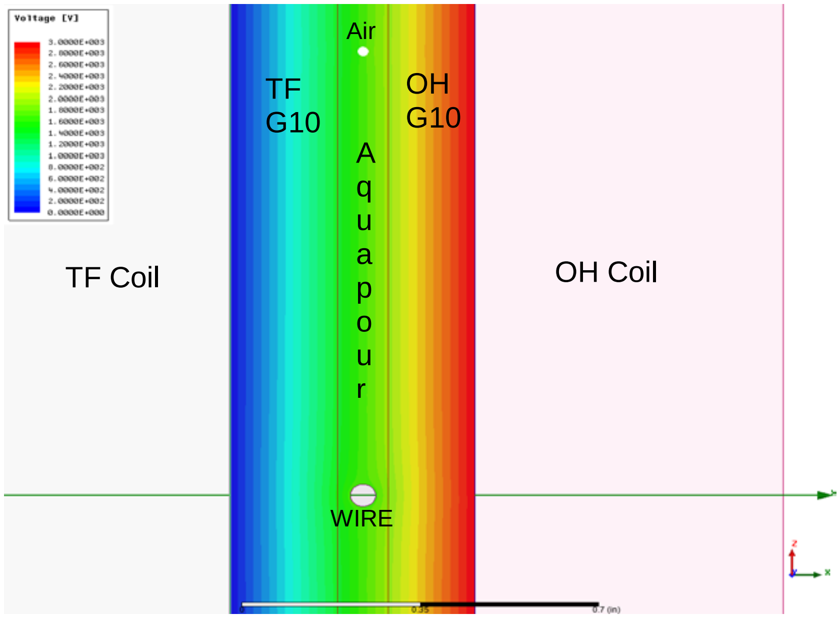

Figure 6: Voltage distribution between TF and OH coil.

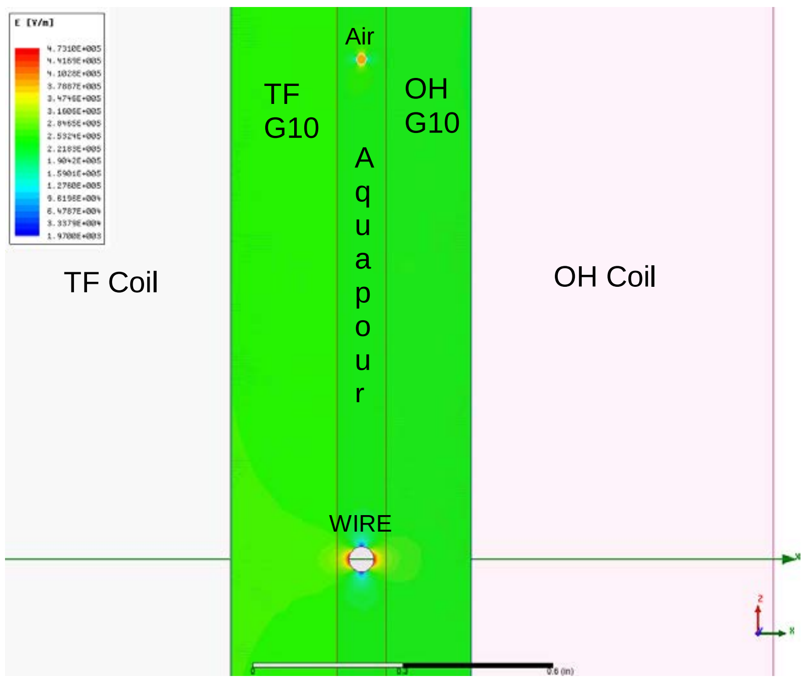

Figure 7: Electric field strength distribution between TF and OH coil.

The maximum electric field strength 4.73 kV/cm is at the both side of the wire. It is only about 16% of the air break down electric field strength 30 kV/cm. The maximum electric field inside the air is 4.0 kV/cm.

Conclusion:

G10 dielectric strength is 315 kV/cm. Air dielectric strength is 30 kV/cm. The maximum electric field strength inside the TF and OH gap is only 15.3 kV/cm when the wire is grounded. If the wire is floating, the maximum electric filed strength inside the TF and OH gap is only 4.73 kV/cm. Based on the calculation results, the existence of Aquapour and the wire will not affect the normal operation of NSTX-U.

Attachment:

Some info about the material Aquapour.

ADVANCED CERAMICS MANUFACTURING

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MATERIAL SAFETY DATA SHEET

SECTION 1 — PRODUCT AND COMPANY IDENTIFICATION

Date	April 18, 2012
Manufacturers Name	Advanced Ceramics Manufacturing, LLC.
Address	7800A South Nogales Highway • Tucson, AZ 85756
Hazard Ratings	Health — 1 Flammability — 0 Reactivity — 0
Product Name	**AQUAPOUR™**
Formula	Not available
Synonyms	None
Chemical Name	Refer to Section 2

Product Information Telephone Number: 520.547.0850
Hazardous Materials Support Center: 800.554.9964
Chemtrec (Spill Related Emergencies): 800.424.9300

SECTION 2 — INGREDIENTS

Notes Aquapour™ has no known hazardous properties. The formula is proprietary information and is the property of Advanced Ceramics Manufacturing.

Materials:	WT%	TLV (mg/m³)	PEL (mg/m³)	CAS Number
Water Soluble Binder	1%-30%	NE	NE	
Plaster of Paris	1%-50%	10	15 (T) / 5 (R)	26499-65-0
Ceramic Microspheres	10%-90%	10 (I) / 3 (R)	15 (T) / 5 (R)	66402-68-4
	(T) - Total	(R) - Respirable	(I) - Inhalable	(NE) - Not Established

SECTION 3 — PHYSICAL DATA

Boiling Point	N/A
Specific Gravity	(H_2O = 1): 0.57
Vapor Density	N/A
Appearance & Odor	Gray powder with no detectable odor.
% Volatiles by Weight	N/A

SECTION 4 — FIRE AND EXPLOSIVE DATA

Flash Point	N/A
Special Fire Fighting Procedures	N/A
Stability	N/A
Conditions to Avoid	N/A
Autoignition Temperature	N/A
Unusual Fire & Explosion Hazard	None

SECTION 5 — HEALTH HAZARD INFORMATION

Eye Contact	Direct contact may cause irritation.
Skin Contact	Direct contact may cause irritation.
Inhalation	Repeated exposure to dust may cause delayed lung injury.