Technical Issues for Modular Coil Winding Form Procurement

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NCSX Project Meeting

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Issues – Mod coil winding forms

- **Winding form time constant:**

  poloidal electrical break added to winding forms, but PAC wants to know if it is really required

- **Cooling configuration:**

  need copper conduction layer on winding form, connected to cooling lines, but how do we pick the manfacturing method (thermal spray, copper strips, electroforming, etc.)?

- **Tolerances:**

  Winding form machining tolerances drive cost and represent feasibility issue at some point. Our present plan is to develop final requirements in conjunction with R&D vendors and prototype fabrication

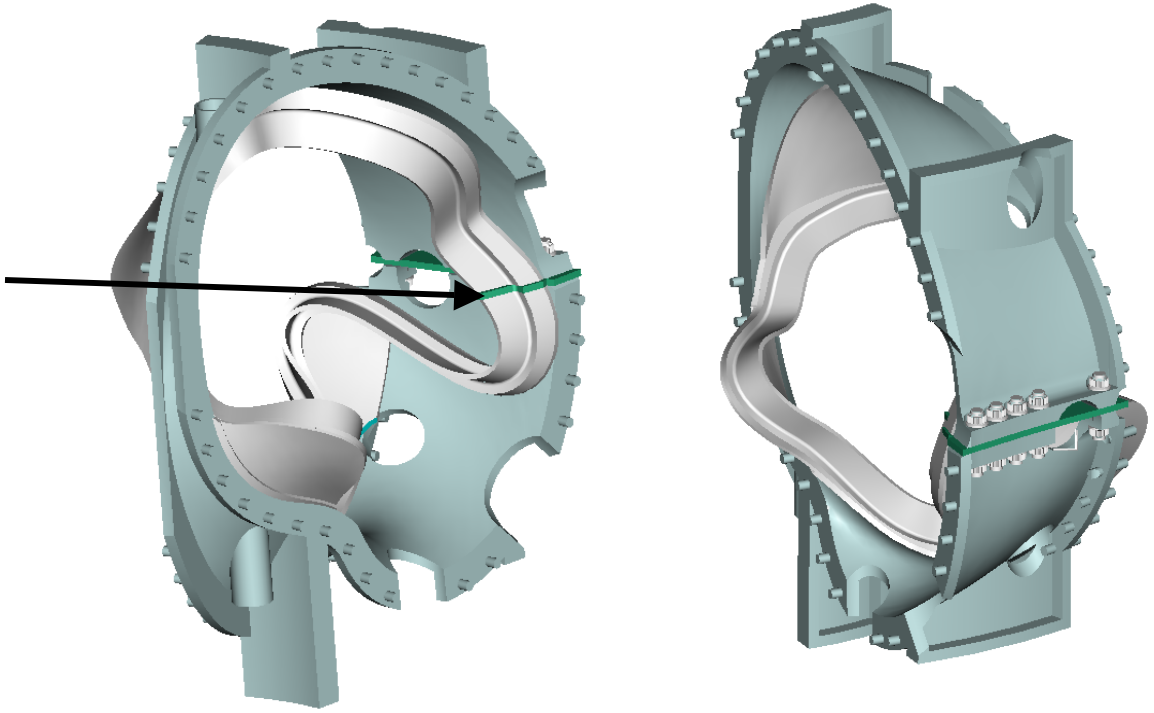
- **Pro-E models:**

  ***Problems need to be fixed and new coil shape incorporated as soon as possible*.**

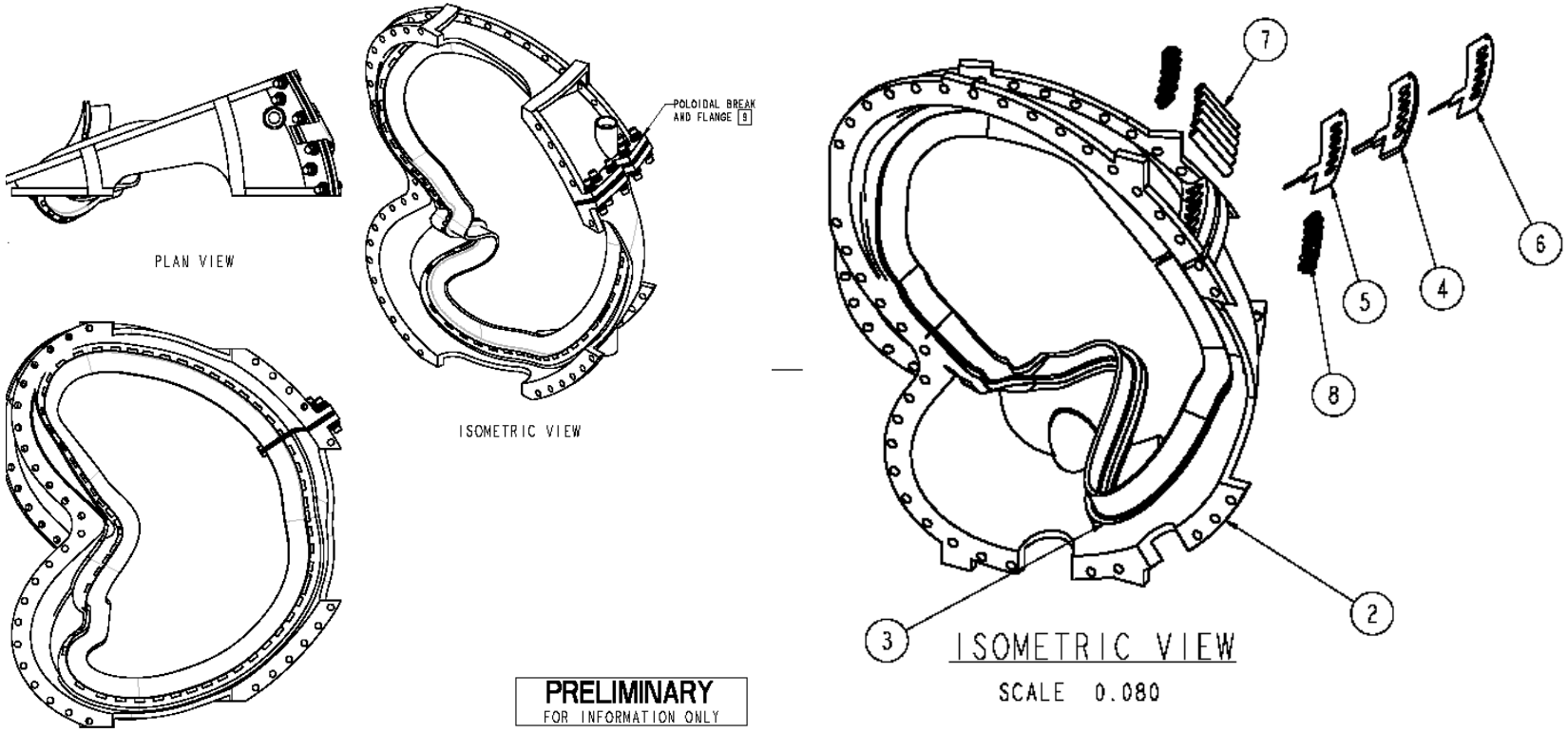
Poloidal break – shell L/R

- Time constant of shell whittled down to ~ 20 ms
  - Cut, insulate and bolt poloidal break prior to final winding path machining
  - Copper chill plates insulated from casting
  - All toroidal flanges except final field joints insulated

Connection at “tee” still a problem



Poloidal break – prototype coil



Poloidal break – issues

- **PAC comment:** **"Engineering design to accommodate electric breaks in the coil support castings is a critical item for the PDR. The electrical break may introduce significant complexities in the design and manufacturing process, and may have implications in machine operation and longevity. Issues need to be identified and a plan formulated for addressing them. The need for these breaks should be fully justified for the PDR."**

- **Some Issues:**
  - **Distortion of casting when break is machined**
  - **Discontinuity in winding support causes excessive local deformations and/or fault in insulation**
  - **Bolts get loose over time, tee-to-tee connection not accessible**
  - **Costs more to include break than to not include break**

Poloidal break – recommendation

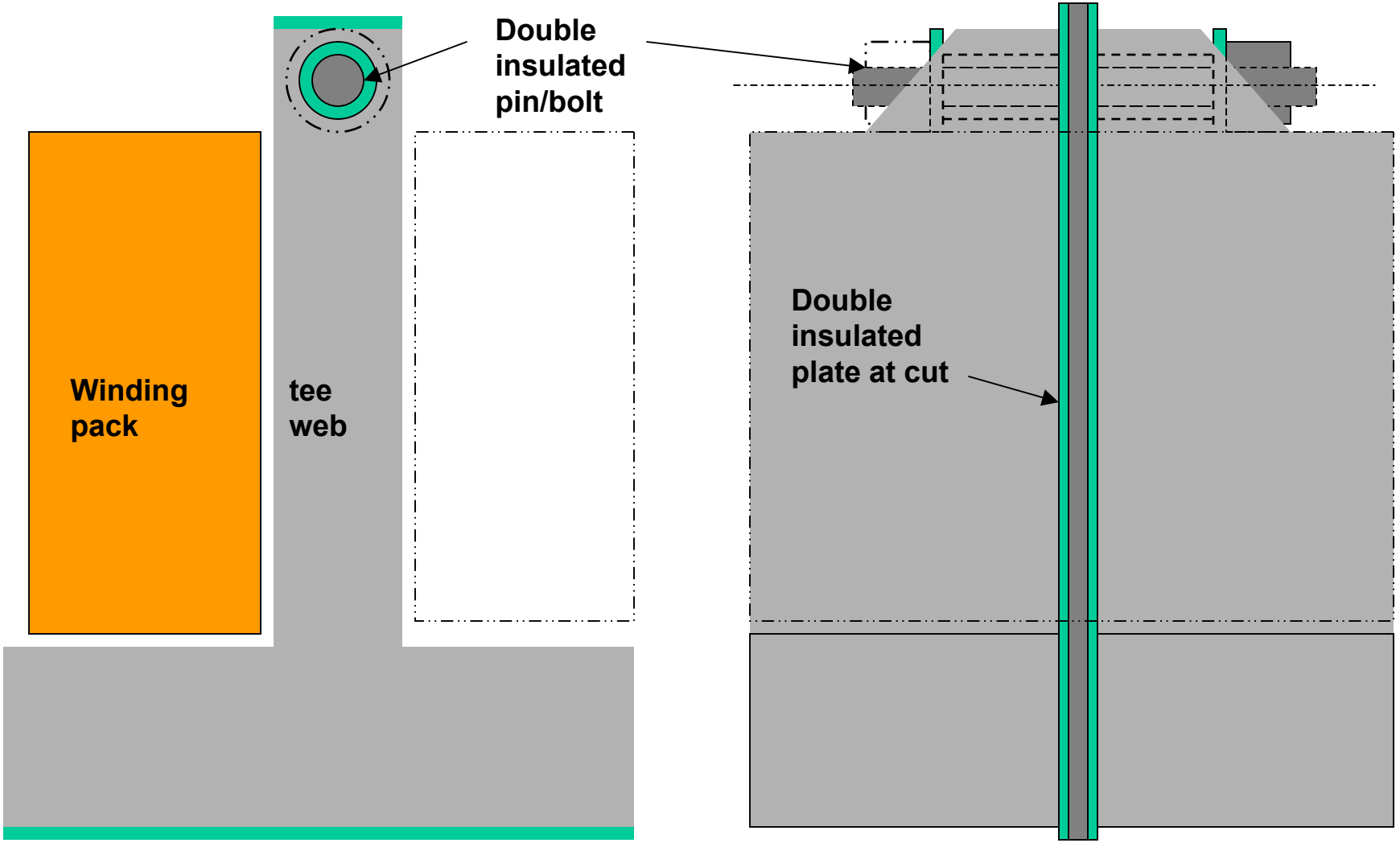
Since:

1. ***We can't calculate the EM effects of not having the break, and this could affect operation significantly, and***
2. ***We won't be able to add the break if later analysis says we have to have it, and***
3. ***We need to get on with the design and R&D, so:***

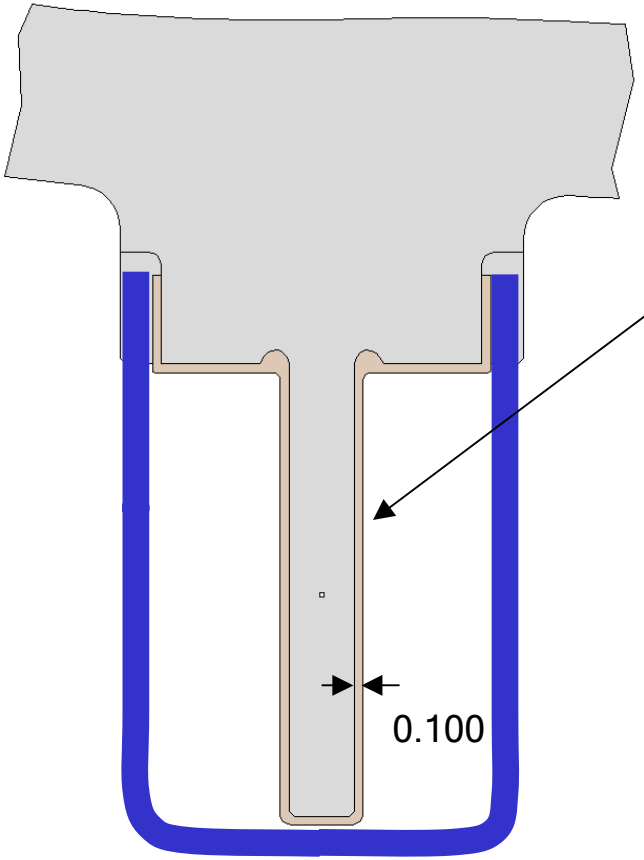
Therefore: Keep the breaks

1. **Refine the tee-to-tee connection, in conjunction with machining advice from vendors and a desire to avoid inaccessible bolts**
2. **Analyze the lateral loads and local stresses and deformations.**
3. **Modify the models and drawings as needed**

Baseline option for connection of tee web across poloidal electrical break



Baseline concept: Cu on tee plus cooled clamps, conducting layer on winding pack



Heat Conduction Layer Options:

1) Varnish SS, electroform with copper
2) Flame spray ceramic/copper, full thickness
3) Flame spray 0.010”, then electroform
4) Copper strips, developed shapes

Copper surface must meet accuracy requirements:

profile within .020 inches , (bilateral tolerance, +/- .01 inches from ref.)

Issues with options:

- **Flame spray**
  - **Requires ceramic substrate for insulations**
  - **Must be machined after spray or applied with robot**
  - **Surface must be hand worked for decent finish**
  - **Thermal conductivity may not be very good**
  - **Difficult to do in-house**

- **Electro-form (plating)**
  - **Must be shipped to specialized vendor, who has equipment**
  - **Slow, about 1 mil per hour max**
  - **Must be machined, possibly twice, to retain surface tolerance**
  - **Probably not compatible with insulating break due to immersion in copper sulphate solution**

- **Mechanical bonding of copper strips**
  - **Very difficult to achieve proper shape if formed from single sheet**
  - **Narrow, simple shapes leave large gaps between pieces**
  - **Bonding process not defined yet**
  - ***But, we can do it in house!***

Cu Cladding Recommendation:

1. Remove copper cladding from winding form task

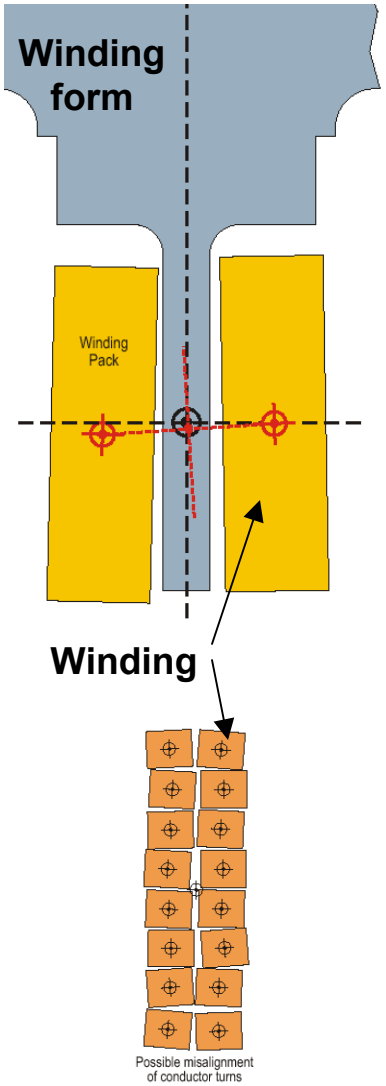
2. Apply copper strips at PPPL prior to winding
   - Write software to make developed shape patterns
   - Cut patterns with water jet cutter from dxf files
   - Stack of 3 or 4 0.02 inch sheets should make forming easier
   - Bonding can be done with hot melt adhesive
   - Inspection via faro arm and ohm meter
   - Re-work accommodated by hot melt adhesive
   - Process can be tried very soon on partial full scale “tee” castings recently procured by PPPL (due end of Jan)

3. This option should be feasible and removes another obstacle to progress

Winding form tolerances

- **Tolerances must be divided among various elements:**

Element	Tolerance budget	Comment
Winding form	+/- 0.01 in.	Baseline on drawing
Copper cladding	TBD	Could be used to improve winding form tolerance if shims are allowed
Insulated conductor size	+/- 0.01 in.	Based on NEEWC input
VPI process	TBD	Assumed to be small, but not known
Assembly of coil in field period	TBD	Adjusted to best fit, coil-to-coil with custom shims
Assembly of field periods	TBD	Adjusted to best fit with custom shims
Total tolerance	+/- 0.06 in. (+/- 1.5 mm)	Minimum value, may be relaxed according to location around winding



- **Baseline winding concept assumes winding form will be used as-is and not be custom shimmed or adjusted**

Tolerance Recommendations

- **Divide tolerance equally between**
  - **winding form / copper conduction layer**
  - **Conductor winding packs / VPI, and**
  - **Assembly**

- **Winding form and Cu would thus have a total of +/-0.02 inches from theoretical profile, or 0.04 inch bilateral profile tolerance relative to component coordinate system**

- **Leave prototype drawing tolerance as-is pending further discussions with vendors**

Pro-E modeling status

- New M50 coil model geometry has been massaged via twisting, envelope definition
- New shell model is not available yet
- Pro-E is a continuous headache

Recommendation:

Try to avoid what-if studies to the extent possible until we solve the immediate modeling problems

Peer review of winding form issues

- Rich Hawryluk has requested peer review of modular coil winding form issues
- Larry Dudek will chair review, January 23 from 1:00 to 3:30
- Reviewers will include:
  - L. Dudek, J. Chrzanowski, G. Gettlefinger, S. Raftopoulos, PPPL
  - Tom McManamy, ORNL
- We will need to pull together information on:
  - Poloidal break req. and loads: Dave Williamson, Art Brooks, HM Fan
  - Copper cladding performance: HM Fan, Paul Goranson
  - Tolerance budget: Jim Chrzanowski
  - Latest drawings and models: Mike Cole
- Suggest dry run next Wed at 1:30

Summary of recommendations

- Leave poloidal break in design
- Apply copper conduction layer at PPPL in the form of copper strips
- Assign 0.020 inches of tolerance to winding form plus copper conduction layer
- First design priority is Pro-E model of new coil set
- Input for Peer Review is requested from various folks