Cu cladding problem

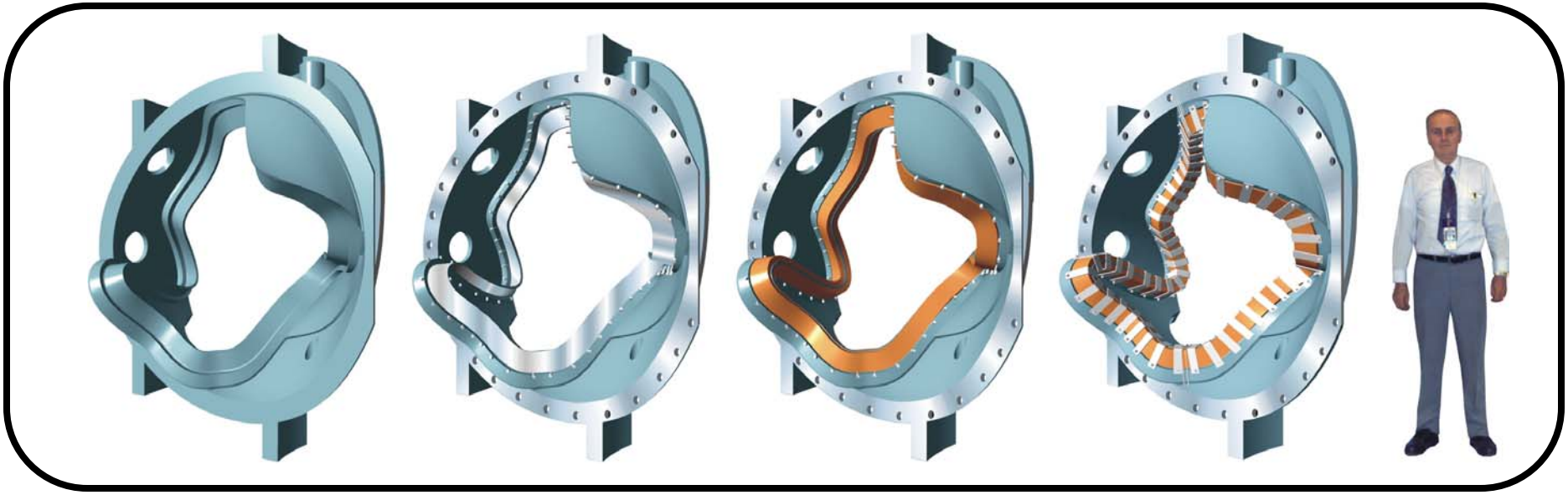
B. Nelson, D. Williamson, A. Brooks, HM Fan, M. Cole and the WBS-1 Design Team

NCSX WBS-1 meeting

January 29, 2003

Modular coil manufacturing sequence

- **Continuous support for strength and accuracy of windings**
- **Single machined part provides winding form and assembly features**
- **Winding never removed from coil form**



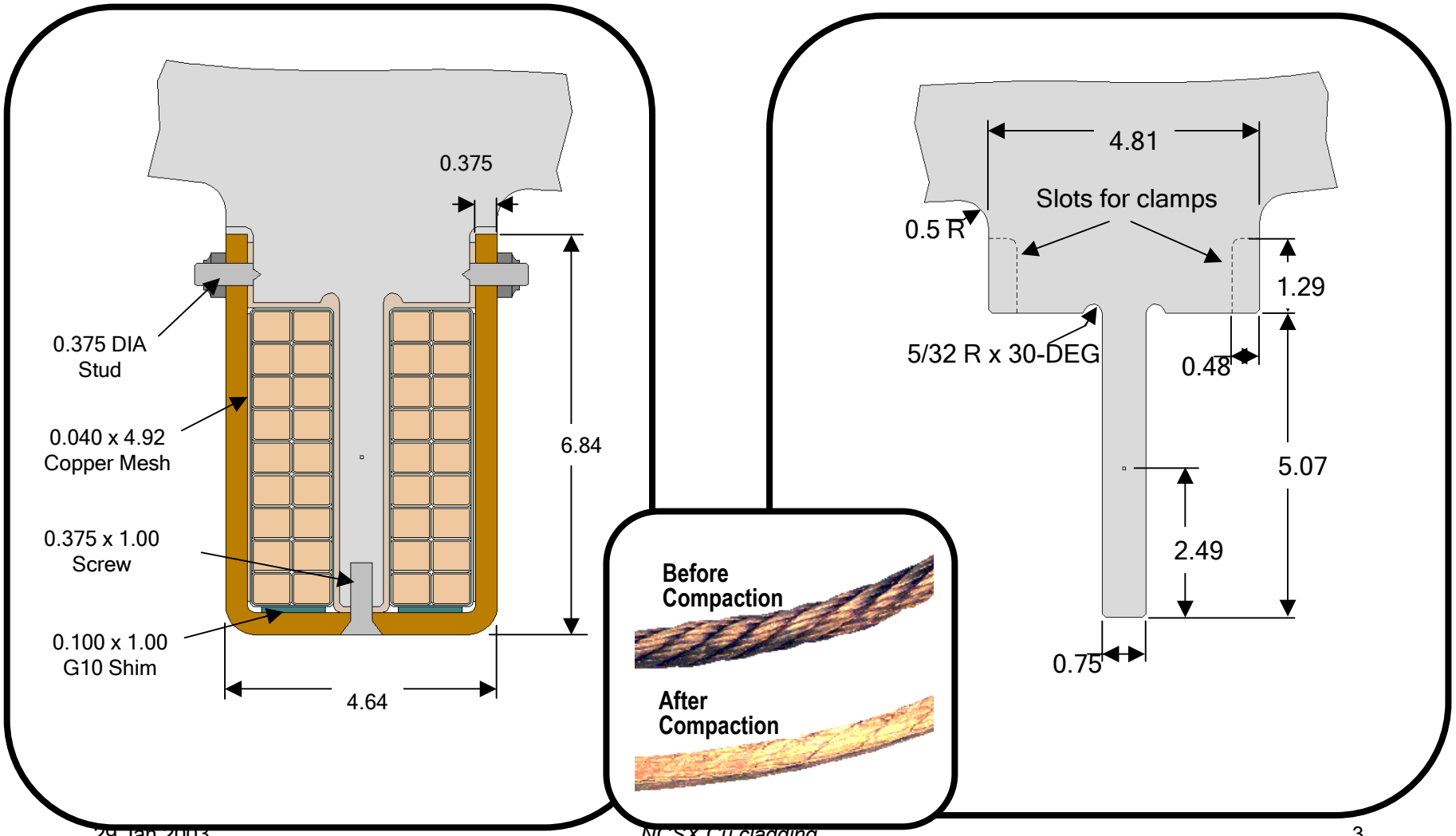
Rough casting

Features are machined

Conductor wound directly into structure

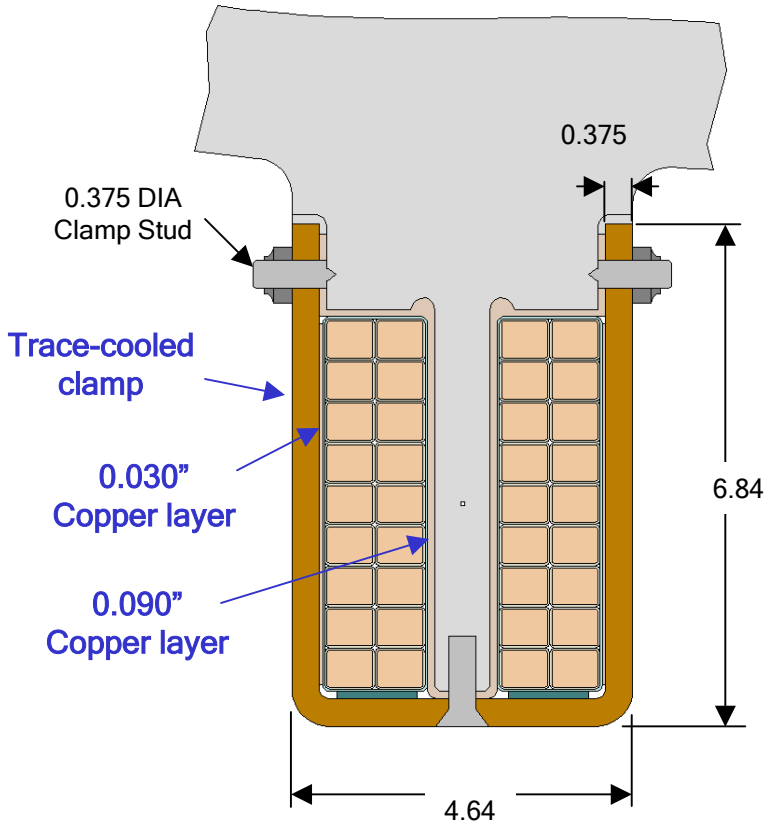
Auxiliary support clamps are installed

NCSX Modular coils wound with flexible cable directly on coil structure



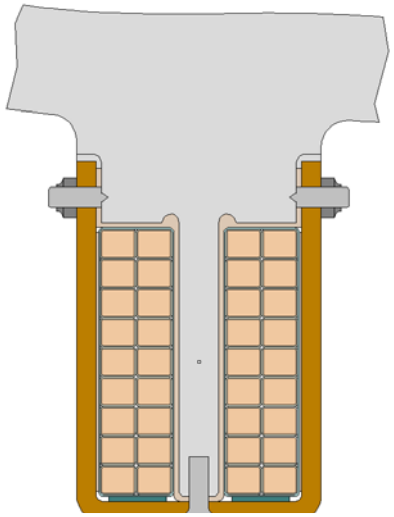
Thermal conducting layer

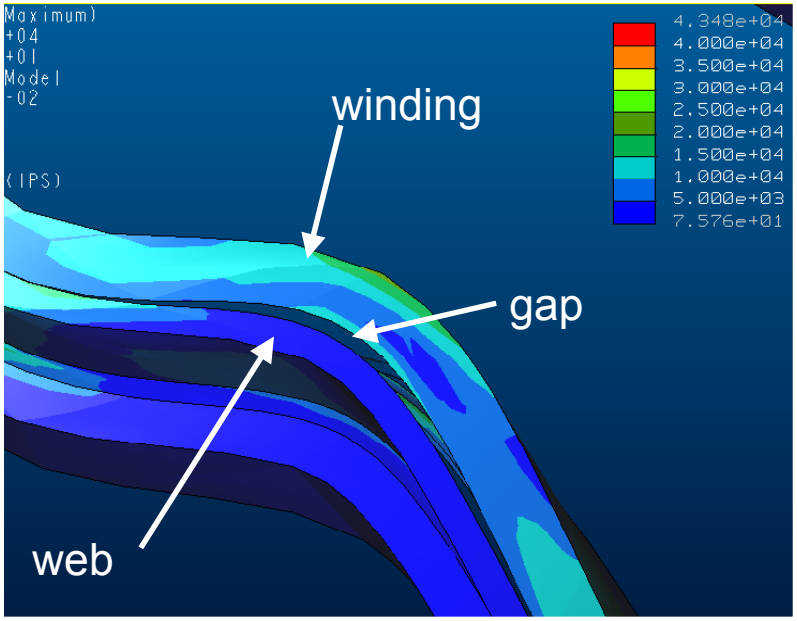
- Modular coil winding cooled by conduction to copper layer on winding form
- Copper layer is insulated from winding form electrically and is divided into ~ 2 inch lengths to minimize eddy currents
- Copper layer is connected thermally to trace-cooled clamp
- Analysis indicates this approach works, with cool-down time between shots of about 15 minutes



Thermal conducting layer requirements

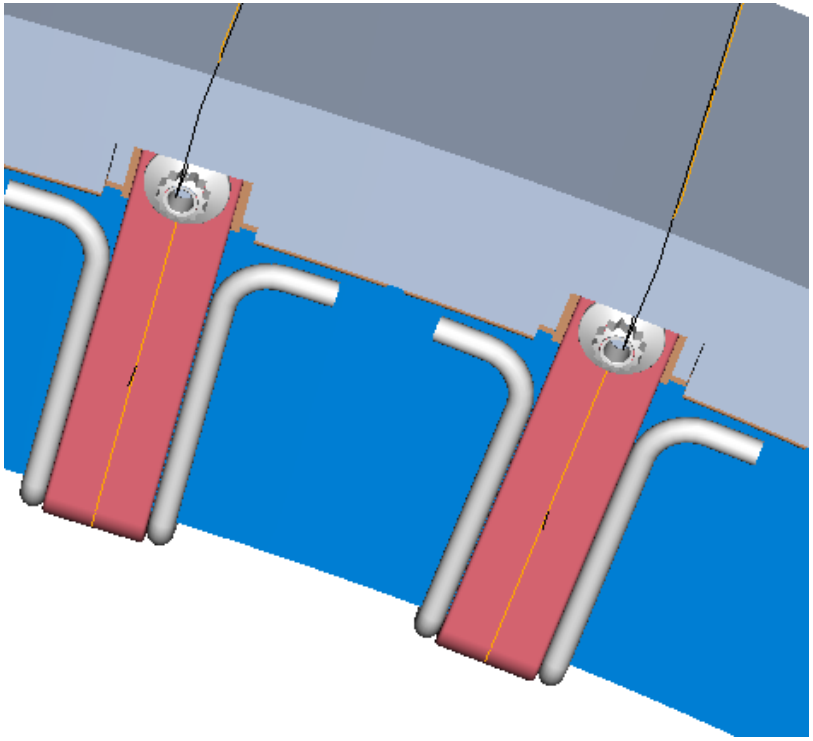
- **Conducting layer must stay with winding, not winding form, during operation.** *(Winding pack heats up rapidly during a shot and may move away from winding form or slide along winding form, winding may also shift during VPI)*
- **Conducting layer must stay in intimate contact with heat sink (e.g. cooling lines)**
- **Conducting layer is required on both sides of winding, i.e. both pies of a winding cannot be cooled from one side**
- **Conducting layer must be provide accurate surface for winding turns.**

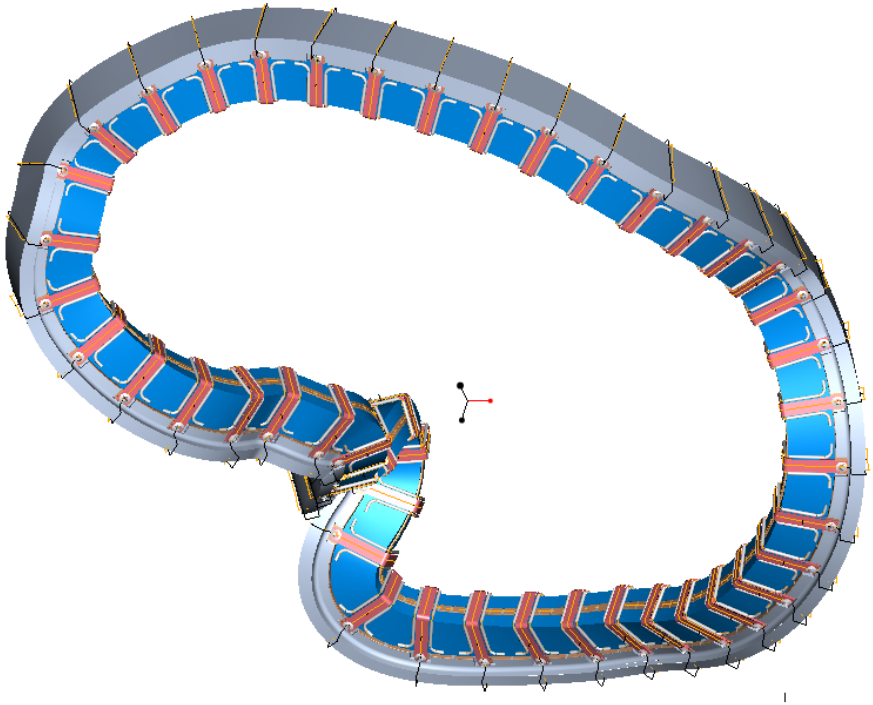




Coil assembly with clamps

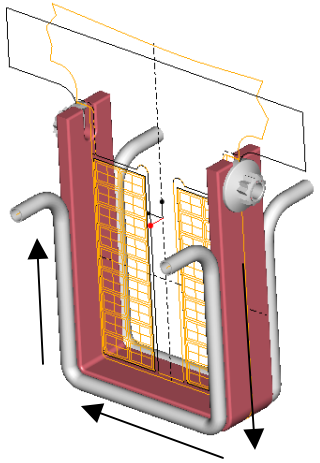
- Clamps required to pre-load winding against tee (48 shown)
- Baseline design puts cooling tubes on clamps

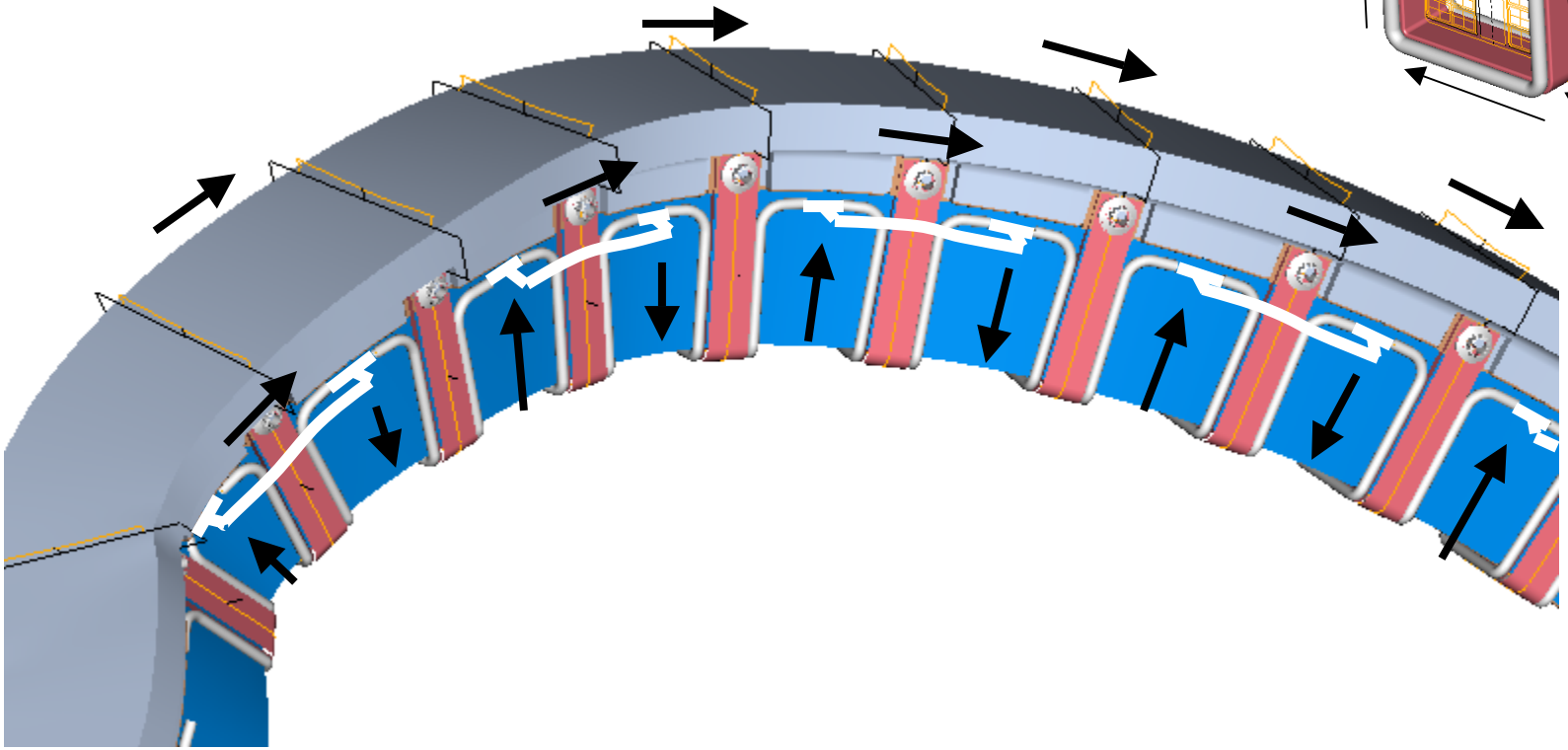




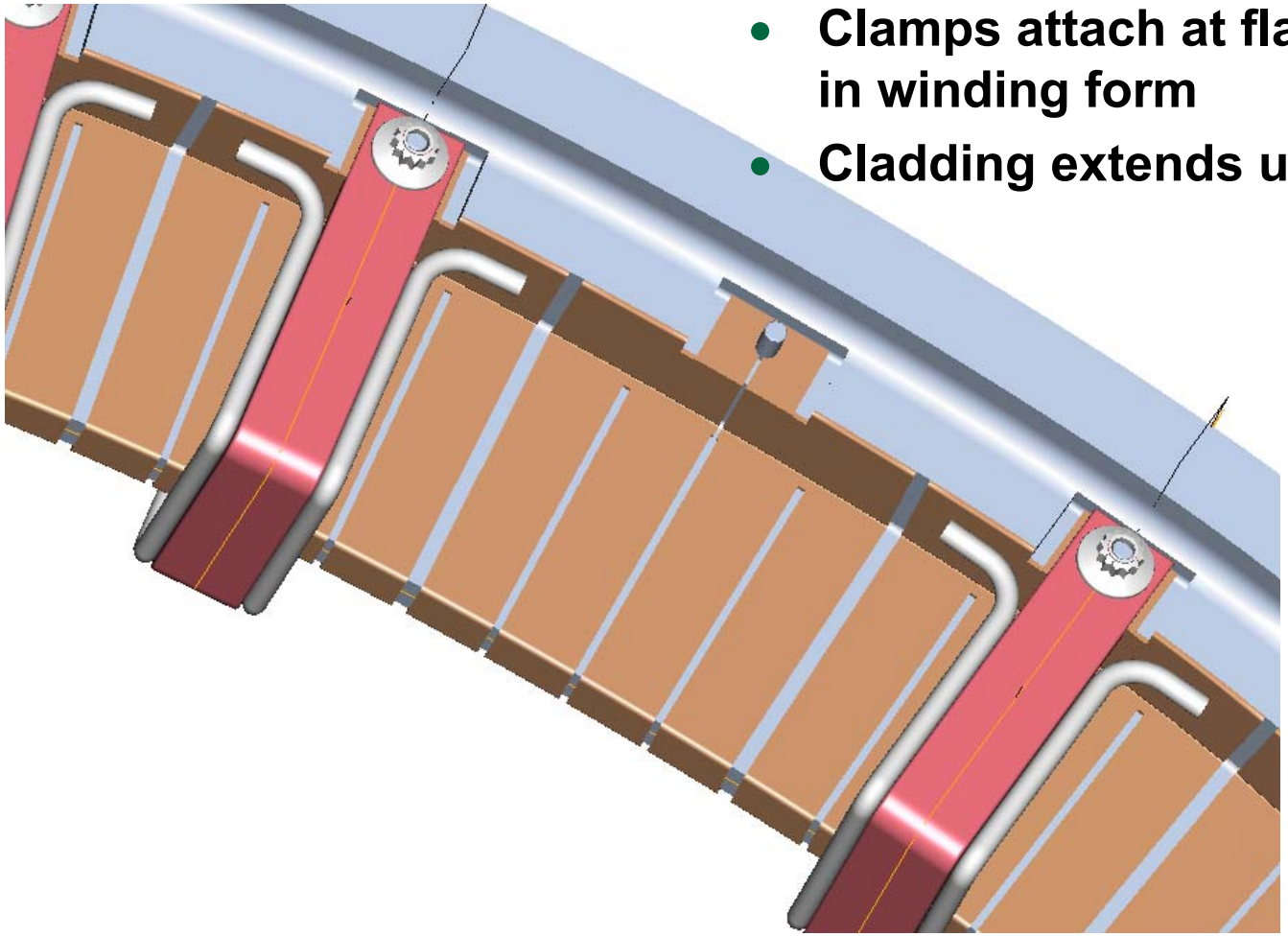
Clamp cooling lines are daisy chained?

- Two lines in parallel
- Connections alternate sides





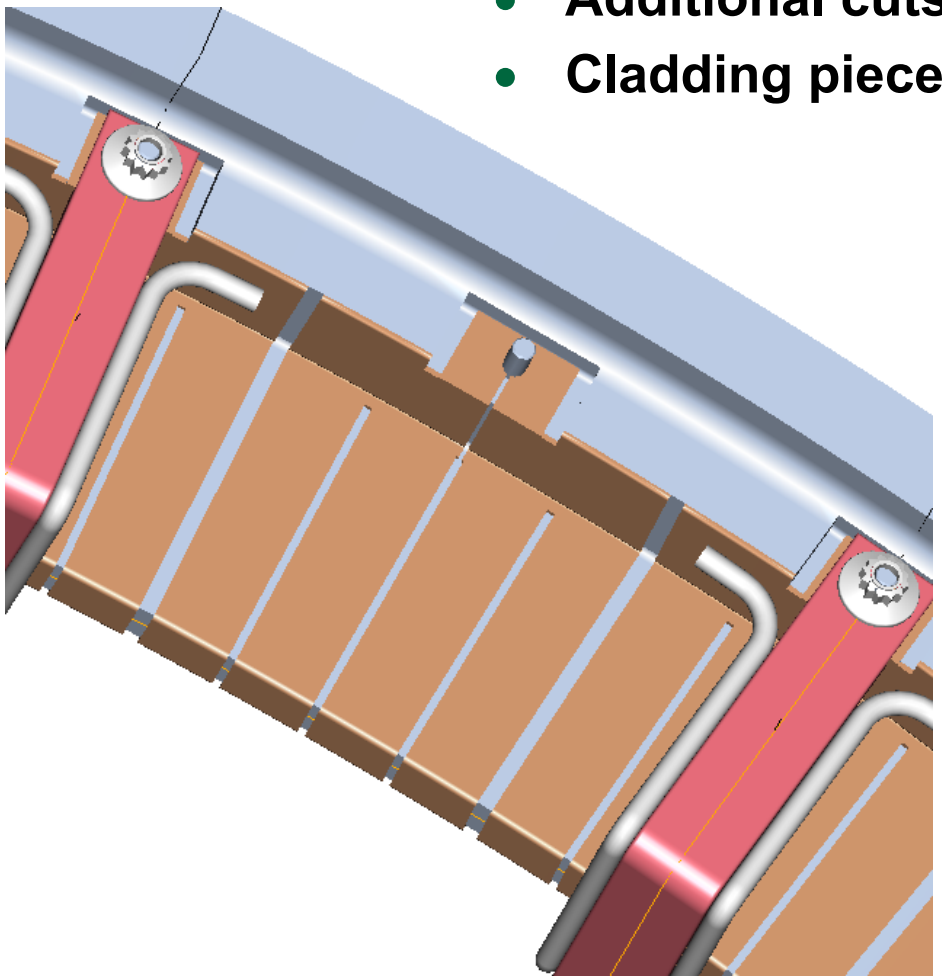
Clamps connect thermally to Cu cladding

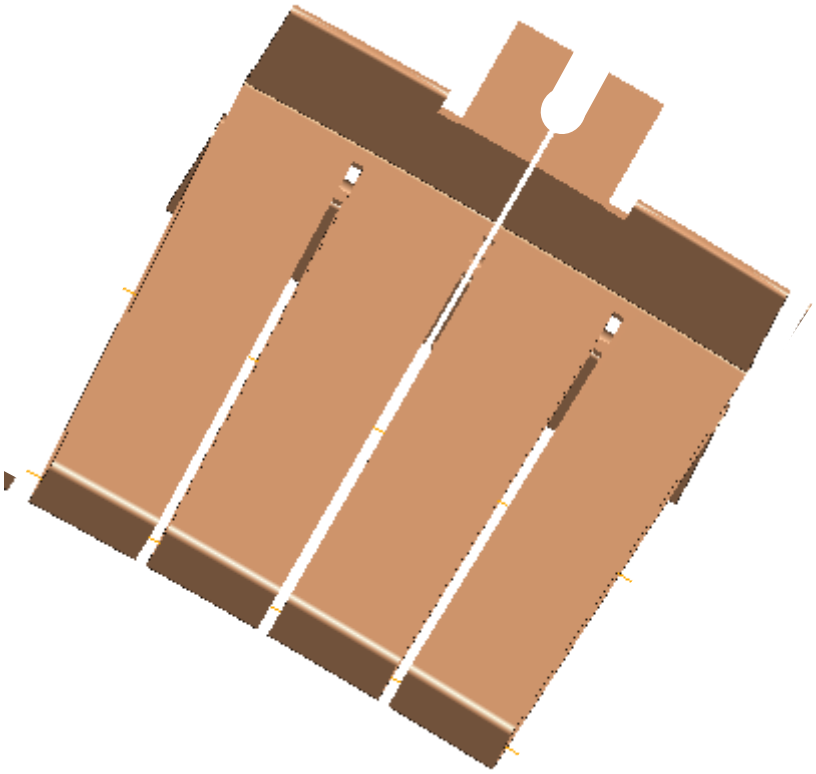


- Clamps attach at flats machined in winding form
- Cladding extends under clamps

Cladding divided into 96 formed pieces, (two pieces per clamp)

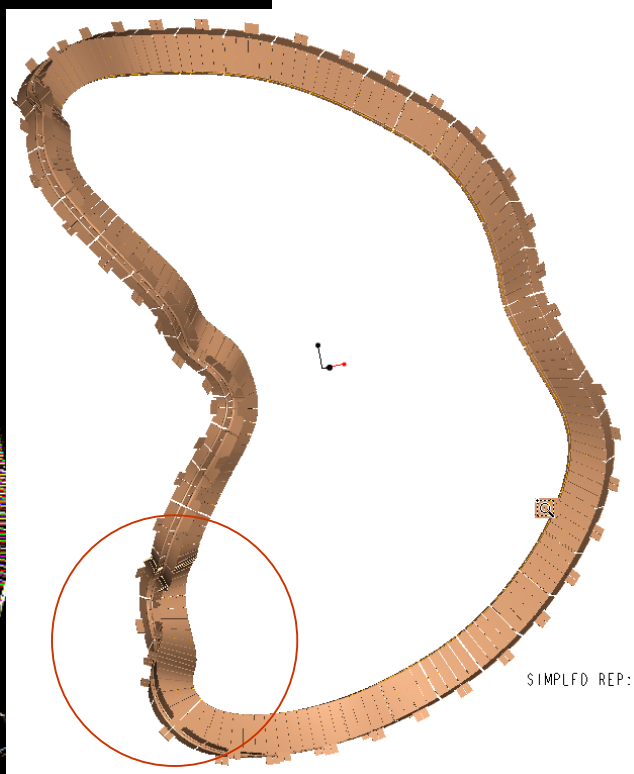
- Additional cuts added for ease of forming
- Cladding pieces register off of stud

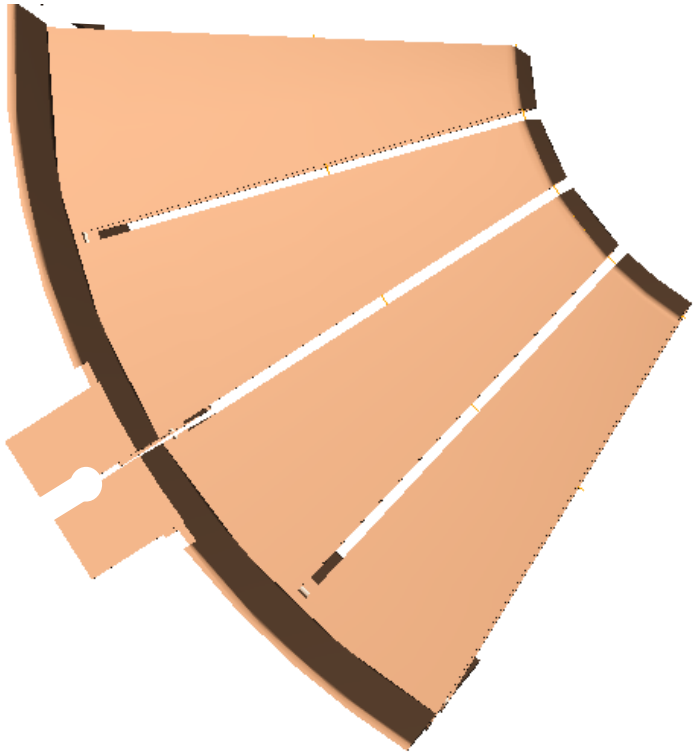




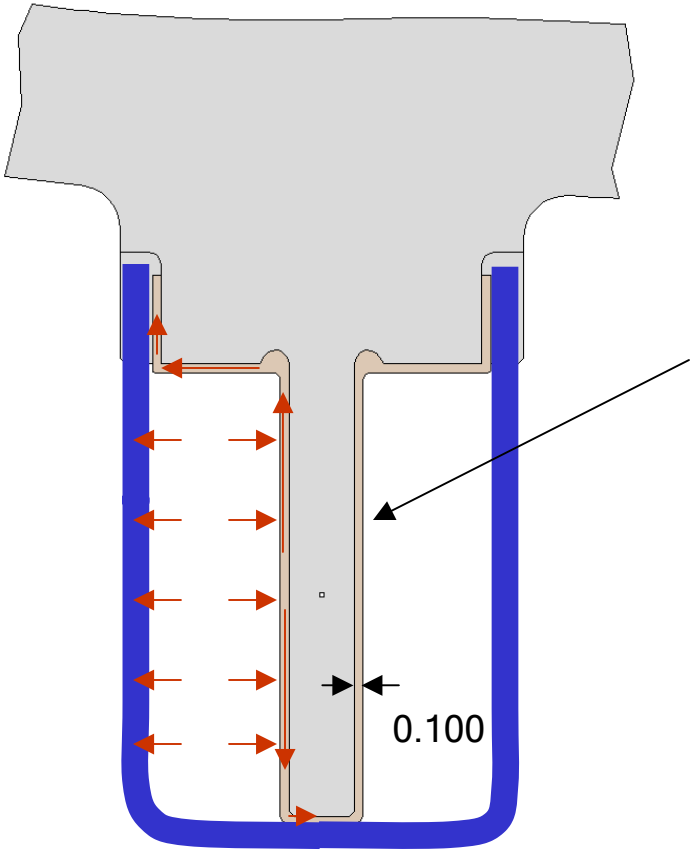
Cladding geometry is not simple

- Developed shapes will be a little bit complicated
- Simple shapes would leave large gaps





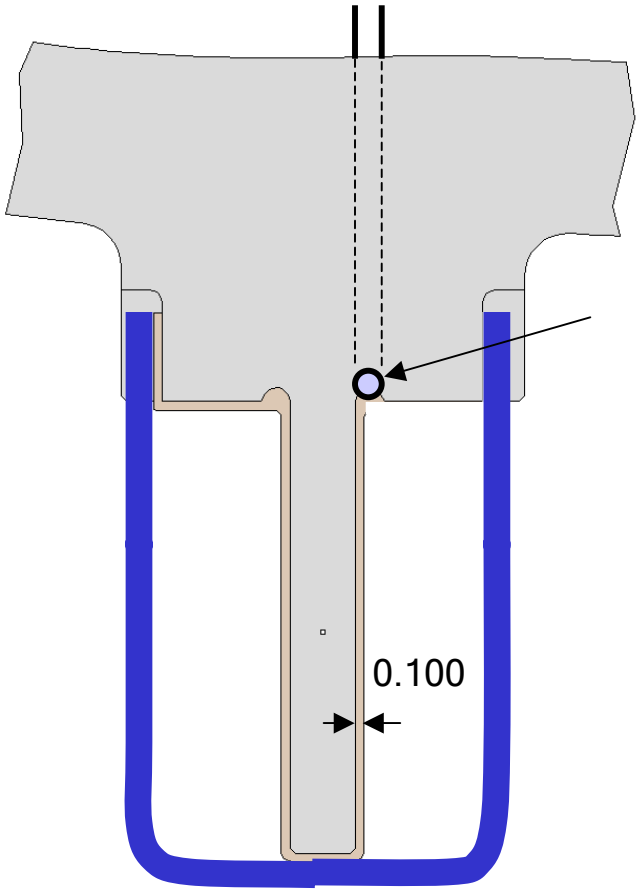
Baseline cooling concept: Cu on tee plus cooled clamps

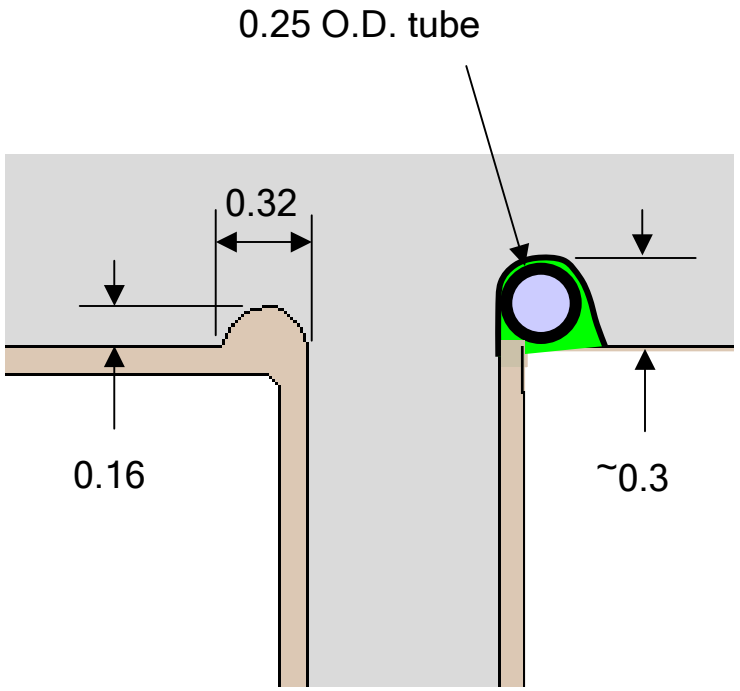


Thermal Conduction Layer Options:

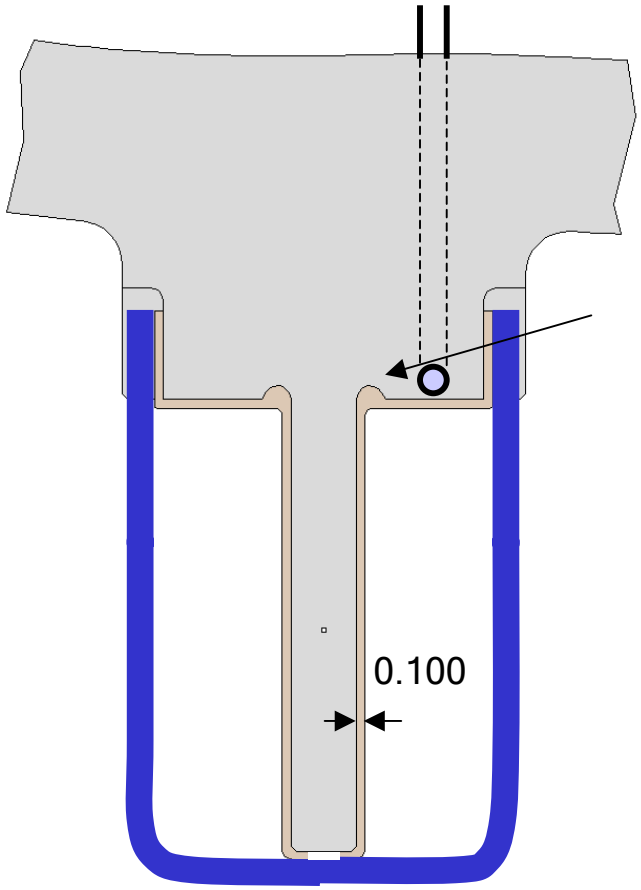
1) Varnish SS, electroform with copper
2) Flame spray ceramic/copper, full thickness
3) Flame spray 0.010”, then electroform
4) Copper strips, developed shapes

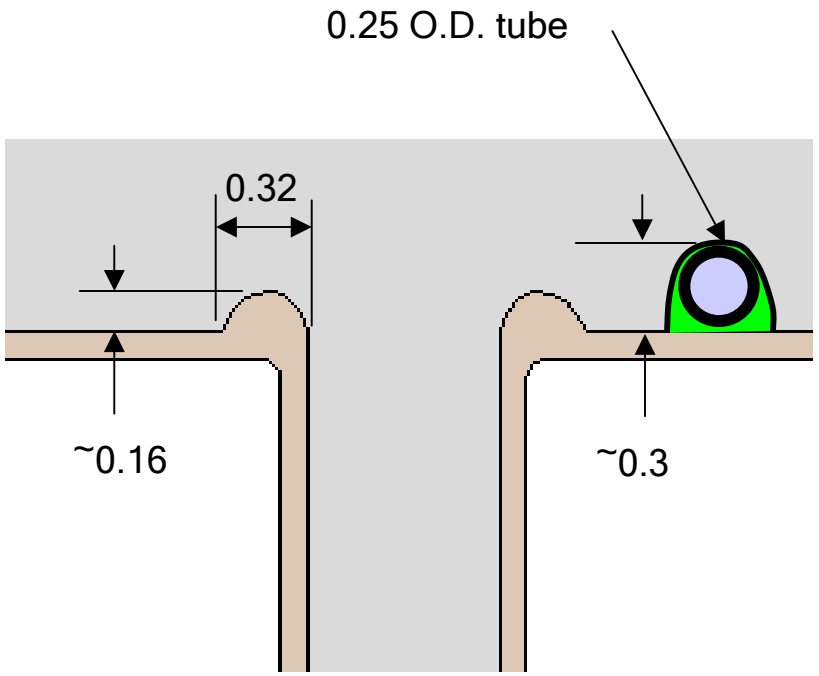
Alternate concept should be easier for Cu strip geometry, but requires deeper groove for tube, clamp still cooled





Alternate concept 2 moves tube away from corner for easier groove machining, clamp not actively cooled





Issues with Cu cladding options:

- **Flame spray**
  - **Requires ceramic substrate for electrical insulation**
  - **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. **Internal R&D Program will be conducted over next three months to develop process**