Winding Pack Height Management during Fabrication of the ITER CS Module

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ITER Central solenoid and CS Module
40x14 array

- To qualify the VPI procedure and selection of insulation, USIPO carried out VPI of the full cross section 40 conductors tall by 14 conductors wide
- Process of resin mixing, degassing, transfer, mold preparation, VPI, gelling and cure cycle— all established
- Quality of impregnation is very good
- However one problem surfaced the vertical stack dimension reduction by about 1% or 20-25 mm, which is not acceptable
Turn insulation
Top and Bottom Design

[Diagram of Top and Bottom Design with detailed layers and specifications]
Vertical spacing (between rows) in 14x40

Average vertical spacing (z distance between conductors) turned out to be 3.5 mm vs advertised thickness of 2.7 mm. Linear with the load, no sign of saturation.
Top of Stack Post-VPI
Top of Stack Post-VPI

Sagging in the middle relative to the ends – 6 mm

G-10 Modular Channel Plate

G-10 Panels and 7500 Glass Cloth

Kapton and 1080 Glass Cloth with 1581 Glass Wrap

NEAT EPOXY

G10/GLASS

NEAT EPOXY
Top of Stack Post-VPI (left side)
Summary of stack dimensional change

- About 17 mm at the outer layers (bars 1 and 14)
- About 23 mm in the middle of the stack (bars 7 and 8)
Bottom of Stack Post-VPI (after sawing)
Post-disassembly Measurements

Average Vertical Spacing Between Bars

Measurement Location

Note: Block 1 data from direct measurement of gap after sawing sample
Why this happened

Possible speculative reasons:

1) Dry glass creep: the stack was 3+ months under natural dead weight load
2) Settling under lubrication by resin
3) Insulation creep at elevated temperatures and dead load
4) Other magnets: either people did not pay attention or always had enough precompression. Tall stacks are rare.
Study at MDL and GA

Test Setup: Test Mold

- Linear Voltage Displacement Transducers (LVDT)
- Pneumatic Actuators
- Linear Voltage Displacement Transducers* (LVDT)
- Load Distribution Bar
- 7x1 Bar Stack
- Resin Distribution Plate

*Clearance prevents bar ends/sides from binding and racking
→ Free floating bars

*LVDT’s are spring loaded to maintain contact on bars and overcome 30 PSI internal pressurization during VPI injection.
Load and unload cycles on 12x1 array
Evolution of the height stack during bakeout, injection and cure cycles
GA studies on 7x1 arrays

Shrinkage at Specified Events during Testing

- Test Results: Observations

<table>
<thead>
<tr>
<th>Shrinkage [mm]</th>
<th>TEST1</th>
<th>TEST3</th>
<th>TEST4</th>
<th>12x1*7/12</th>
<th>TEST2</th>
<th>TEST5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 psi Active, 0 psi Preload</td>
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<tr>
<td>0 psi Active, 18 psi Preload</td>
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<td>5 psi Active, 10 psi Preload</td>
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<tr>
<td>17 psi Active, 35 psi PreLoad (12x1 data X 7/12)</td>
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<tr>
<td>18 psi Active, 0 psi Preload</td>
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<tr>
<td>23 psi Active, 28 psi Preload</td>
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- At Peak Preload
- After Preload Springback
- After Active Loading
- After VPI
GA studies on the wet glass layers

Test Purpose:
• Define the amount of vertical shim shrinkage as a function of CSM layer and number of vertical shims
• Determine the optimal number of vertical shims in between each conductor layer that will:
  1. Achieve 3.5 mm nominal gap thickness
  2. Reduce shrinkage during the VPI Process
Conclusions

• Dry glass compaction is the main reason for sagging of heavy winding packs
• Bakeout, VPI, gelling, curing and cooldown effects are much smaller
• Uncertainty of the coil height can be overcome by compaction of the glass while dry and during impregnation.
• We developed a credible height management scenario, which will be verified on a full scale prototype in the nearest future.