Qualification Program of Lap Joints for ITER Coils

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ITER Organization

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Contents

- Design
- Materials, Interfaces, Welds
- Mechanical tests
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Twin-Box Joint

- In every coil/feeder of ITER
- Compaction to 18-22% voids
- Copper 12200/10200, ASTM B152
- RRR 6 (PF), 150 - 500 (other)
- ITER grade SS 316L/ 316LN
- Cu and SS explosively bonded
- Cable-Cu: soldered or pressed
- Box-Box: soldered or In wires

photo courtesy of CERN
## Approved Material Manufacturers

<table>
<thead>
<tr>
<th>Coils</th>
<th>Copper</th>
<th>Stainless Steel</th>
<th>Cladding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PF1 (RF)</strong></td>
<td>MKM, GmbH, Germany</td>
<td>Forgiatura Morandini Srl, Italy</td>
<td>Energometall, Russia</td>
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<tr>
<td><strong>PF2-5 (EU)</strong></td>
<td>KME Germany AG &amp; Co KG</td>
<td>Fomas Group, Italy</td>
<td>High Energy Metals, USA</td>
</tr>
<tr>
<td><strong>Feeder, CC, PF6 (CN)</strong></td>
<td>Aurubis, Finland</td>
<td>Guizhou Aerospace Xinli Forging&amp;Casting, China</td>
<td>Nanjing LeiHui New Material China</td>
</tr>
<tr>
<td><strong>TF EU</strong></td>
<td>Aurubis, Finland</td>
<td>316L, Outokumpu Stainless AB, Sweden</td>
<td>High Energy Metals, USA</td>
</tr>
<tr>
<td><strong>TF JA</strong></td>
<td>Mitsubushi Shindoh, Japan</td>
<td>316LN, Daido Steel Co. Ltd., Japan</td>
<td>Asahi Kasei Corp., Japan</td>
</tr>
<tr>
<td><strong>CS (US)</strong></td>
<td>CSN Carl Schreiber, Germany</td>
<td>VDM Metals GmbH, Germany</td>
<td>Nobelclad, France</td>
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Material Acceptance

photo courtesy of ASIPP

UT of Feeder plate: the hatched part is acceptable with 1.6 mm FBH as reference.

photo courtesy of CERN

Samples for tensile and shear test of the interface. Acceptance: interface stronger than copper.
Quality of Interfaces

Cable – Cu sole

Peel-off test on soldered strands (top) failing in cohesion. CT image (bottom) to visualize solder quality.

Box-Box

Qualification of box-box soldering process. The samples cut and tested in shear. Acceptance: >5 Mpa and below 20% void (by RT).
Welds

Quality level B per ISO5817. Weld process qualified to ISO15614-1. VT, LT, PT of all welds. UT of all full-pen welds down to 1mm diam. defect.

When UT is not practical: fatigue test of 4 weld samples at 77K to 220,000 cycles (7x machine life time) at nominal load. During production: periodic welding of PPS.
Full Size Joint Test in Fatigue

PF joints cycled at 77K from $7 \times 10^{-5} - 14 \times 10^{-4}$ linear strain on the conductor jacket ($F_{peak} = 500$ kN) for 30,000 cycles. LT and destructive test afterwards to check the welds’ cross-sections and void fraction.
Electrical Resistance

Full size joint samples tested in SULTAN and NIFS.
(AB=short Vtaps CD=long Vtaps.)
In NbTi joints weak dependence on cyclic load: saturation of resistance after 100 cycles.

Cyclic load for PF joints: 1000 cycles, 5T, 0/+33kA, for MB: 1000 cycles, 7T, -38/+38 kA,
AC loss, Stability

No acceptance criteria. Measured for modeling. Somewhat higher $\pi_\tau$ than expected in PF joints. Significant contribution from cables.

NbTi joints are stable at plasma initiation: 0.4 T/s, 3T and 55kA (field transvers to box-box interface plane)
8 mbar is 3% of the total pressure drop on the (smallest) PF1 Coil.
Conclusion

• Prior to start fabrication of the lap joints on the windings/leads, a broad program of qualification of the materials and manufacturing steps was set-up to the coil suppliers.

• The electrical performance is qualified by testing the full size joints in nominal operating conditions and above. All samples have passed the acceptance criteria.

• The mechanical robustness is qualified by testing the full size joints or the samples of the critical welds in fatigue at 77 K. No failure of the welds or soldered interface was detected in any of the samples.

• The core qualification program has been successfully completed by all coil suppliers with few remaining items to be finalized in 2017.
Acknowledgement

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