Overview of JT-60SA HTS current lead manufacture and testing

Introduction
- HTS current leads (CL) reduce power consumption for refrigeration by a factor 3 to 5
- HTS CL Demonstrator by KIT up to 80 kA
- For ITER: Approx. saving of >1 M€ operating cost/year

JT-60SA HTS current leads
- KIT responsible for design, manufacturing and testing of
  - 20 HTS CL for PF/CS (20 kA) and
  - 6 HTS CL for TF (26 kA)
- Design agreed with JAEA in early 2012
- Design checked by testing W7-X current leads under JT-60SA relevant current scenarios

Design
Copper heat exchanger
- Meander flow type
- Temperature range: 300 K → 60 K
- Cooled with 50 K He
HTS module
- Temperature range: 60 K → 4.5 K
- Conduction cooled from 4.5 K end
- HTS material is Bi-2223/AgAu
Cold contact to superconducting coil
- Copper bar with Nb₃Sn insert
- Clamp contact with Au plated surface
HV insulation
- Glass + epoxy insulation
- Paschen tightness

Manufacturing, assembly and cold test
- Half pieces manufactured in main workshop of KIT
- Assembly carried out in ITEP
- Acceptance test at cold conditions performed in test facility CuLTKa

Acceptance test results
- The cold acceptance test provides information about the operation parameters
  - He mass flow rate for the heat exchanger
  - the heat load at 4.5 K
  - the safety margin in case of a loss of flow accident
- Furthermore, the TF CLs were subject to a six hours’ test at 25.7 kA to prove their long-time stability
  - One PF CL pair was also tested in pulsed operation

Parameter Specification Test results
<table>
<thead>
<tr>
<th>TF current lead</th>
<th>Specification</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation current</td>
<td>25.7 kA</td>
<td>25.7 kA</td>
</tr>
<tr>
<td>He mass flow rate at 25.7 kA</td>
<td>&lt;2.37 g/s</td>
<td>(1.94±0.04) g/s</td>
</tr>
<tr>
<td>He mass flow rate at 0 kA</td>
<td>&lt;0.78 g/s</td>
<td>(0.65±0.03) g/s</td>
</tr>
<tr>
<td>Heat load at 4.5 K end</td>
<td>3 W</td>
<td>(3.15±0.57) W</td>
</tr>
<tr>
<td>Joint resistance at clamp contact</td>
<td>&lt;6 mΩ</td>
<td>&gt;1 mΩ</td>
</tr>
<tr>
<td>Transition resistance at cold and warm end of HTS part</td>
<td>(19.77±0.95) mΩ</td>
<td>(17.4±0.3) mΩ</td>
</tr>
<tr>
<td>Current sharing temperature</td>
<td>-</td>
<td>(74.3±0.9) K</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PF current lead</th>
<th>Specification</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum current</td>
<td>20 kA</td>
<td>20 kA</td>
</tr>
<tr>
<td>He mass flow rate at 20 kA</td>
<td>&lt;1.8 g/s</td>
<td>(1.62±0.08) g/s</td>
</tr>
<tr>
<td>He mass flow rate at 0 kA</td>
<td>&lt;0.78 g/s</td>
<td>(0.49±0.02) g/s</td>
</tr>
<tr>
<td>Heat load at 4.5 K end</td>
<td>3 W</td>
<td>(2.12±0.04) W</td>
</tr>
<tr>
<td>Joint resistance at clamp contact</td>
<td>&lt;8 mΩ</td>
<td>&gt;2 mΩ</td>
</tr>
<tr>
<td>Transition resistance at cold and warm end of HTS part</td>
<td>(17.4±0.3) mΩ</td>
<td>(14.7±0.3) mΩ</td>
</tr>
<tr>
<td>Current sharing temperature</td>
<td>-</td>
<td>(74.3±0.9) K</td>
</tr>
</tbody>
</table>

Conclusion
- KIT designed, manufactured and tested 26 HTS CLs for the satellite tokamak JT-60SA
- The design is based on that for the HTS CLs procured for the Wendelstein7-X stellarator which is under operation at IPP in Greifswald, Germany
- All acceptance tests of the TF- and PF-CL were conducted without any problem and the results were within the expectations; all current leads behave very similar
- The experience of the personnel at KIT ensured a smooth execution of the project within the envisaged time and budget