COMPLETION OF THE FRENCH JT-60SA TOROIDAL FIELD MAGNET CONTRIBUTION

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Introduction
The JT-60SA toroidal field coils (TF) magnet procurement is a part of the broader approach (BA) agreement. After preliminary and detailed design studies as French voluntary contributor, CEA has contracted in July 2011 with Alstom (now GE) for the manufacture of 9 + 1 winding and its integration in the casing. The conductors, as well as the casing being free components provided by F4E. The different production phases as well as the manufacturing status and achieved schedule are presented. A focus on the main issues during the qualification as well as production phases is made.

Global work execution and status
Workshop organization in 12 Workstations: global target < 40 days/ WSt

<table>
<thead>
<tr>
<th>Phase 1: 07/2011 to 02/2012</th>
<th>Phase 2: 01/2012 to 12/2013</th>
<th>Phase 3: 01/2014 to end 2017?</th>
</tr>
</thead>
<tbody>
<tr>
<td>manufacturing drawing</td>
<td>Processes qualification</td>
<td>Coils production</td>
</tr>
<tr>
<td>Manufacturing process according PBS</td>
<td>Tooling procurement</td>
<td>• 7 coils validated</td>
</tr>
<tr>
<td>Tooling definition</td>
<td>QA documentation definition</td>
<td>• 3 coils at final manufacturing stage</td>
</tr>
<tr>
<td>Workshop organization</td>
<td></td>
<td>Planning mainly driven by casing elements delivery</td>
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</tbody>
</table>

Important impact of additional requirement and NCs on delivered components (conductor, casing) w. r. t. initial specification

Main qualification phase issues

<table>
<thead>
<tr>
<th>Conductor insulation shear strength</th>
<th>40 MPa and 20 MPa x 36000 cycles</th>
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<tbody>
<tr>
<td>Particular preparation highlighted</td>
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</table>

Winding
Full elastic-plastic conductor characterization
D shape reference and clamping needed

Impregnation
Resin injection

Helium inlets
Stress release

Casing welding
Welding process qualification
100% UT checks on relevant defects and geometry

Production phase issues
Conductor cross section
NC on delivered conductor spools + successive straightening and bending (unspooling, straightening, bending)

26 x 22 ±0.1 mm theoretical to 26.4 x 21.8 ±0.1 mm

DPs winding
Local defect at transition between smaller radius and straight part

Pancakes D shape:
use of continuous inner references and outer clamping system
Induce WP cross section deformation of trapezoidal shape

Integration in casing

Coil no. | Countered bending | Final straight leg bending |
---------|-------------------|---------------------------|
10       | 4.8               | -2.29                     |
11       | 4.4               | -2.75                     |
12       | 4.2               | -0.42                     |
13       | 4.1               | -1.03                     |
14       | 3.2               | 0.93                      |
15       | 2.1               | -0.64                     |
16       | 1.0               | -0.23                     |
17       | 1.0               | t.b.c.                    |
18       | 1.0               | t.b.c.                    |
19       | 1.0               | t.b.c.                    |
20       | 1.0               | t.b.c.                    |

Conclusion
The procurement of the 9 + 1 French JT-60SA TF coils is done by GE and followed by CEA. After preparation and qualifications phases, the coils production should be completed end 2017. 7 coils are already delivered and installed in the tokamak and 3 remaining coils at final stage of manufacturing. The coils production planning is driven by casing elements delivery. The learning curve demonstrate a reduction from 280 calendar days for the first coil to a nearly stabilized time of about 170 days after the 4th coil. The qualification phase demonstrate the need for a strong qualification program helping identification of unforeseen issues and limiting the associated risks. During production, unexpected issues linked to the winding operation of large D shaped coils and integration of the WPs inside their casing were experienced. Finally, all these issues were successfully faced by GE team, thanks to their business and technical agility helped by strong CEA support. The JT-60SA French TF coil manufacture is now near to be completed and the 10 coils set should be delivered without further significant delay and fully compliant with the requested performances.