Manufacture of the ITER Central Solenoid Components


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“The views and opinions expressed herein do not necessarily reflect those of the ITER Organization”
Manufacture of the ITER Central Solenoid (CS) Components

- CS Components
- Manufacturing Routes
- Qualification Program
- Manufacturing Plan
- Conclusion

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ITER Central Solenoid
CS Components

- 6 modules
- 9 structure subsets:
  - 1 centering subset
  - 1 UKB + 1 LDP
  - 5 tensioners
  - 1 inner tie-plate
  - 2 outer tie-plates
  - 1 isolation plate
  - 1 LKB
  - 1 Lower Support
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Modules Production Route

CS Modules manufacturing line at GA (Poway, CA)

10 work stations
Structure Manufacturing Routes

XFM-19 Melting → ESR → Forging → Machining

Forging steps

First of series UKB and LDPs

First of series Tie-plate

First of series LKB
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Modules Qualification Program

2 He inlets in one single sample

Fatigue tests of samples at 77 K at NHMFL: 540,000 cycles

Ultrasonic peening

Maraging C250 rod

> 300 MPa
## Modules Qualification Program

### Tests at NHMFL

- Tested in June 2017

<table>
<thead>
<tr>
<th>Sample</th>
<th>Number of cycles</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-P</td>
<td>540,000</td>
<td>✓</td>
</tr>
<tr>
<td>3-P</td>
<td>850,660</td>
<td>✓</td>
</tr>
<tr>
<td>1-AW</td>
<td>158,000</td>
<td>x</td>
</tr>
</tbody>
</table>

### Residual stress measurement

- Depth (mm)
- Residual stress (MPa)

### Examination at CERN

- **Weld micrography**

- 7049.481 µm
Modules Qualification Program

CSUS1 SULTAN sample

- 3 types of joints in one single sample
- Tested in June-July 2017

<table>
<thead>
<tr>
<th>Joint</th>
<th>Resistance (nΩ)</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin-box</td>
<td>0.6- 0.9</td>
<td>✔</td>
</tr>
<tr>
<td>Splice</td>
<td>0.1</td>
<td>✔</td>
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<tr>
<td>Coaxial joint</td>
<td>22-56</td>
<td></td>
</tr>
</tbody>
</table>

See **Wed-Af-Or26: Performance of the ITER CS joints and Qualification Program of Joints for ITER Coils**
3x3 VPI samples

AC High voltage testing of turn-to-turn insulation (50 Hz)

Inception at 4.5 kV (6 times nominal fault voltage), breakdown at 8.8 kV (12 times U nom x 10 times CS lifetime)

Tested in September 2016

ITER Central Solenoid design fulfils the electrical requirements

Results presented at 35th IEEE DEIS Electrical Insulation Conference, Baltimore, June 2017
## Modules Qualification Program

<table>
<thead>
<tr>
<th>Wire</th>
<th>Insulation at 6 kV (TΩ)</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire 1 / wire 2</td>
<td>1.59</td>
<td>✓</td>
</tr>
<tr>
<td>Wire 1 / pipe</td>
<td>2.03</td>
<td>✓</td>
</tr>
<tr>
<td>Wire 2 / pipe</td>
<td>2.34</td>
<td>✓</td>
</tr>
<tr>
<td>Wire 1 + wire 2 / pipe</td>
<td>1.36</td>
<td>✓</td>
</tr>
</tbody>
</table>

**HV wire extraction sample insulation test**
Modules Qualification Program

Turn insulation application on module mock-up
Cryogenic He cooling Piping manifolds system installation on module mock-up
Structure Qualification Program

XFM-19 qualification

Mock inner tie plate

Mock outer tie plate

Mock spring

Tensile properties

Cooling pipe weld assessment

Precompression test (coming soon)

See Wed-Af-Po3.10: Investigation of Materials and Welds for the Precompression Structure of the ITER Central Solenoid
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Manufacturing Plan

First $13 \text{T Nb}_3\text{Sn}$ Module after heat treatment
Manufacture of the **first 4 modules** is ongoing

**CS Modules Manufacturing Plan**

Starting dates

<table>
<thead>
<tr>
<th>Module 1</th>
<th>Module 2</th>
<th>Module 3</th>
<th>Module 4</th>
<th>Module 5</th>
<th>Module 6</th>
<th>Module 7</th>
</tr>
</thead>
</table>

Start of CS Assembly

- **Module mock-up**
- **Module 1**
- **Module 2**
- **Module 3**
- **Module 4**
- **Module 5**
- **Module 6**
- **Module 7**

<table>
<thead>
<tr>
<th>Time (days)</th>
<th>Module 1</th>
<th>Module 2</th>
<th>Module 3</th>
<th>Module 4</th>
<th>Module 5</th>
<th>Module 6</th>
<th>Module 7</th>
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<tbody>
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<td>732 days</td>
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</tr>
</tbody>
</table>

P. Libeyre, Manufacture of the ITER Central Solenoid Components, MT-25, Amsterdam, 28 August-01 September 2017
First components of structure are near completion

CS Structure Manufacturing Plan

Starting dates


2014

LKB and Isolation Plates

UKB, LDP, Precompression Components

Lead Support Brackets/Module Alignment System

Components for Precompression Testing

Lower Components

Precompression Verification Test

Small Fab Components

Tensioning Components

Today

First components of structure are near completion
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Conclusion

• **Manufacture** of the ITER CS components is ongoing, in line with schedule

• **Qualification** of the manufacturing procedures is mostly achieved (no major issue)

• **Manufacturing plan:**

<table>
<thead>
<tr>
<th>modules</th>
<th>2018</th>
<th>first module completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>structure</td>
<td>2017</td>
<td>first components completed</td>
</tr>
</tbody>
</table>

• **Delivery plan**

<table>
<thead>
<tr>
<th>modules</th>
<th>2019 - 2021</th>
<th>one module / 6 months</th>
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</thead>
<tbody>
<tr>
<td>structure</td>
<td>2017 - 2020</td>
<td>by batches</td>
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</tbody>
</table>
Conclusion

Obvious progress in CS components manufacture