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PFC tender: technical issues, planning and logistics

Andrea Augieri
ENEA and DTTS.c.a r.l.

DTT INFO DAY – Superconducting Poloidal Field Coils Procurement
Introduction to DTT Poloidal Field Coils

Focus on some critical aspects of the procurement:

- Internal Joints
- He inlet and outlet
- Nb₃Sn thermal treatment
- Nb₃Sn turn insulation after thermal treatment
- Provisions for coils integration in DTT
- Process Qualification
- Acceptance tests
- Transportation and logistic

Delivery and payment Schedule
6 coils
almost identical in pairs (small deviations will be highlighted)
to fulfil the full top-down symmetry

All coils relying on pancake winding technique

**PF1-PF6**: Nb$_3$Sn
**PF2-PF5** and **PF3-PF4**: NbTi

The procurement will be for:

Impregnated winding packs with:
- He inlet and outlets (with related breakers and pipelines);
- Insulations (turn, pancake, winding pack);
- Internal joints and terminations;
- Instrumentation.

Temporary mechanical structures for handling and transportation
and provisions for coils integration in the DTT machine will be also part of the procurement (more details in the next slides)
## COILS main Features and parameters

<table>
<thead>
<tr>
<th>Coil</th>
<th>PF1/ 6</th>
<th>PF2/ 5</th>
<th>PF3/ 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_{\text{max}}$ (T) (input data)</td>
<td>9.1</td>
<td>4.2</td>
<td>5.3</td>
</tr>
<tr>
<td>MA turns max (input data)</td>
<td>10.19</td>
<td>4.34</td>
<td>5.61</td>
</tr>
<tr>
<td>Inter-Pancake Insulation</td>
<td>1mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_{\text{in}}$ (mm, @RT)</td>
<td>1140</td>
<td>2940</td>
<td>4150</td>
</tr>
<tr>
<td>$R_{\text{out}}$ (mm, @RT)</td>
<td>1660</td>
<td>3220</td>
<td>4550</td>
</tr>
<tr>
<td>$Z_{\text{mean}}$ (mm, @RT) (0 = eq. plane)</td>
<td>±2760</td>
<td>±2534</td>
<td>±1015</td>
</tr>
<tr>
<td>$\Delta Z_{\text{tot}}$ (mm, @RT)</td>
<td>582.4</td>
<td>516.8</td>
<td>452.2</td>
</tr>
<tr>
<td>Ground Insulation (to be added to $\Delta R$ &amp; $\Delta Z$)</td>
<td>5mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td># Quadri/Double pancakes</td>
<td>4 QP + 1 DP</td>
<td>8 DP</td>
<td>7 DP</td>
</tr>
<tr>
<td># turns (radial)</td>
<td>20</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td># turns (vertical)</td>
<td>18</td>
<td>16</td>
<td>14</td>
</tr>
<tr>
<td>Unit length (m, @RT)</td>
<td>723/361</td>
<td>394</td>
<td>769</td>
</tr>
<tr>
<td>$N$ turns totali</td>
<td>360</td>
<td>160</td>
<td>196</td>
</tr>
<tr>
<td>$I_{\text{op max}}$ (kA)</td>
<td>28.3</td>
<td>27.1</td>
<td>28.6</td>
</tr>
<tr>
<td>$\Delta T_{\text{margin}}$ (Top: 4.5K)</td>
<td>1.8</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>$L$ (H)</td>
<td>0.454</td>
<td>0.298</td>
<td>0.690</td>
</tr>
<tr>
<td>Weight (ton)</td>
<td>15</td>
<td>16</td>
<td>28</td>
</tr>
<tr>
<td>Safety discharge (delay time)</td>
<td>1.5 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety discharge (tau)</td>
<td>6 s</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Conductor main Features and parameters

<table>
<thead>
<tr>
<th>Conductor</th>
<th>PF1/6</th>
<th>PF2/5</th>
<th>PF3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial Ext. Dim. (mm, at RT)</td>
<td>22.7</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Vertical Ext. Dim. (mm, at RT)</td>
<td>29.1</td>
<td>28.6</td>
<td>28.6</td>
</tr>
<tr>
<td>Jacket thickness (mm)</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Inner Corner Radius (mm)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Central Channel (OD/ID; mm)</td>
<td>7/5</td>
<td>7/5</td>
<td>7/5</td>
</tr>
<tr>
<td>Turn insulation (mm)</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td># SC strands (0.82mm)</td>
<td>180 (Nb&lt;sub&gt;3&lt;/sub&gt;Sn)</td>
<td>162 (NbTi)</td>
<td>324 (NbTi)</td>
</tr>
<tr>
<td>Strand Cu no-Cu ratio</td>
<td>1</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td># Cu strands (0.82mm)</td>
<td>216</td>
<td>324</td>
<td>162</td>
</tr>
<tr>
<td>Total strand number</td>
<td>396</td>
<td>486</td>
<td>486</td>
</tr>
<tr>
<td>Cabling sequence</td>
<td>[2x(2sc+Cu)+(sc+2Cu)x (6+Cucore)x6] Cu core: 12 strand</td>
<td>(2Cu+1SC)x3x3x3x6</td>
<td>(1Cu+2SC)x3x3x3x6</td>
</tr>
<tr>
<td>Void fraction</td>
<td>29.8%</td>
<td>27.9%</td>
<td>27.9%</td>
</tr>
<tr>
<td>LBO wrapping</td>
<td>(0.05 ± 0.01) mm x 12 mm, open area 50%, SS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External wrapping</td>
<td>(0.05 ± 0.01) mm x 40mm, 50% overlapping, SS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The tolerances for the cross section dimensions (±0.1mm) apply to the conductor after compaction and prior to spooling. No attempt will be made by the conductor manufacturer to correct any key-stoning or other effect which may result from the spooling process.
4 internal joints for PF1-PF6, 7 for PF2-PF5 and 6 for PF3-PF4
+
2 half terminations for each coil

Detailed design is left to supplier

It must be compliant with requirements in terms of:
• Maximum allowable resistance
• Geometrical constraints

Each coils internal joints concept MUST pass the following qualification test:
• @RT
  ▪ welds mechanically tested
  ▪ He leak test at 3 MPa for 3 hours
• @4.5 K
  ▪ electrical test (maximum resistance specification)
Internal Joints and half terminations MUST be in radial direction (interference with other structures)

Possible method: twin box – praying hands

A supporting structure (G10) embedded in the WP body MUST be designed and realized to ensure mechanical stability of the joints and termination structures

In PF1-PF6, half joint should be prepared before heat treatment
Joint finalized after heat treatment
INTERNAL JOINTS AND TERMINATIONS

PF2 – PF3 – PF4

A supporting structure (G10) embedded in the coil body **MUST** be designed and realized to ensure mechanical stability of the joints and termination structures.

Reduced space between joints could be an issue: joint process must be possible with all the DP stacked.

Internal Joints and half terminations **MUST** be in tangential direction.

Possible method: twin box – shacking hands.
He inlet and outlet

He inlets must be located always in the inner surface of the coils.

In DPs, the inlets will be welded in the inter-pancake transition region
In QPs, the inlets will be welded in the 1->2 and 3->4 inter-pancake transition region

He outlets must be located always in the joint or half termination region
In QPs, outlets will be welded in the 2->3 inter-pancake transition region

The He inlet and outlet manufacture could be critical with respect to:
• strand integrity
• pipeline complexity

The proposed manufacturing process MUST be approved by DTT and MUST be qualified (He leak, pressure test and strands properties)
**PF1 - PF6**

Complex pipeline structure (due to geometrical constraints)

Electrical isolators on He line will be re-installed after integration with mechanical supports

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**PF1 - PF6** coils will be tested in the DTT Cold Test Facility

Coil acceptance after test results

connection with He circuit will be removed during the assembly, connection with He circuit will be restored (step 2)

Supplier **MUST** define a proper procedure to perform step 1 and step 2 to be sure that insulation and He circuit will be safe (warranty still valid)
The temperature and Ar gas pressure MUST be accurately monitored and their readings recorded during the entire cycle.

The correctness of the heat treatment will be proved on one or more strand (provided by DTT) witnesses placed inside the furnace.

The required temperature uniformity inside the working volume (including the thermal load mass) is ± 5 °C.
**Nb$_3$Sn insulation** (after thermal treatment)

TURN INSULATION include:
- the positioning of the co-wound tape for the QDS, and the insulation of the He Inlet region
- and
- does not include the inter-pancake insulation (additional step)

NbTi coils (**PF2-PF3-PF4-PF5**): turn insulation can be performed during the winding process
(supplier can choose to perform this step in a different stage)

Nb$_3$Sn coils (**PF1-PF6**): turn insulation **MUST** be performed after the thermal treatment

- Lifting each turn of DP and QP
- Wrapping the complete conductor length (hybrid Polymide and Fiber glass)

Longitudinal and transverse strain on the conductor must be considered
Coils are expected to move in radial direction (cooldown and energization) Slides to allow joints and termination radial movement

Provisions for coils integrations in DTT

Each PF winding pack will be integrated with 18 mechanical supports

Mechanical support purpose: pre-compression of the coil mounting of PF coils on TF structures

The integration will be made by DTT but...

**G10 filler** and **SS sheets** for finer spacing must be provided by the supplier

DTT will provide detailed information on this topic

In **PF1 - PF6 + PF5** joints and term. are in radial direction
Qualification of the Manufacturing process

The definition of most of the manufacturing processes are left to supplier

**BUT**

All the special processes **MUST be qualified** and approved by DTT

- **Internal joints and half terminations**
  - Geometrical: 3D modelling
  - Electrical: test on mock-up (@ op. cond)

- **He inlets and outlets**
  - Strand integrity
  - He leak and pressure tests
  - Insulation

**Winding**

SUB-size or Mock-up
Straight beam Sample

**Impregnation**

Geometrical survey
Sizes check
Impregnation quality
Electrical test

minimum set of the QUALIFICATION TESTS will be defined by DTT

Courtesy of JT-60SA
Qualification of the Manufacturing processes

Qualification of Insulation

A dedicated procedure, to be submitted and approved by DTT has to be prepared and qualified by testing a significant WP mock up

HIGH VOLTAGE TESTING

D.C.
- $V_{dc} = 1.2 \text{ kV (turn insulation)}$
- $V_{dc} = 10 \text{ kV (insulation to ground)}$

A.C.
- $V_{ac} (\text{RMS}) = 0.1/\sqrt{2} \text{ kV (turn insulation)}$
- $V_{ac} (\text{RMS}) = 3/\sqrt{2} \text{ kV (insulation to ground)}$

Example values. Exact voltage values will be provided with technical specifications

Simplified PASCHEN test (@RT)

High Voltage testing in Vacuum and selected step of He pressure
## Qualification of the Manufacturing processes

### Conductor lengths provisions

<table>
<thead>
<tr>
<th>Item</th>
<th>Length (m)</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>PF1-PF6 Cu Dummy</td>
<td>368</td>
<td>1</td>
</tr>
<tr>
<td>PF1-PF6 SuperDummy</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>PF1-PF6 DP</td>
<td>368</td>
<td>8</td>
</tr>
<tr>
<td>PF1-PF6 QP</td>
<td>730</td>
<td>2</td>
</tr>
<tr>
<td>PF2-PF5 Cu Dummy</td>
<td>401</td>
<td>1</td>
</tr>
<tr>
<td>PF2-PF5 SuperDummy</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>PF2-PF5 DP</td>
<td>401</td>
<td>16</td>
</tr>
<tr>
<td>PF3-PF4 Cu Dummy</td>
<td>776</td>
<td>1</td>
</tr>
<tr>
<td>PF3-PF4 Cu SuperDummy</td>
<td>200</td>
<td>1</td>
</tr>
<tr>
<td>PF3-PF4 DP</td>
<td>776</td>
<td>14</td>
</tr>
</tbody>
</table>

Any other material required for the qualification of the manufacturing processes must be purchased by the supplier.
Acceptance Tests

There will be acceptance tests during each manufacture step of a single coil

- He inlets
- Winding
- Internal Half joints and terminations
- Heat treatment
- Insulation of DP and/or QP
- Internal joints
- Impregnation
- Instrumentation
- WP grounding

Mechanical tests of welding
Pressure tests
He leak test

Geometrical measurements
Strands witnesses verification

Prior to:
He leak and pressure test
Flow measurement

After:
Geometrical and visual check
HV tests
Final Acceptance tests: COIL

Tests at Room Temperature

Visual checks (integrity of wiring and hydraulic circuit, geometrical survey)

Electrical tests (RT resistance, HV tests, V taps connections, turn insulation tests)

Simplified PASCHEN test

Leak test

Pressure test

Pressure drop test

Tests at Cryogenic Temperature

Hydraulic tests

Evaluation of joint resistance

PF1-PF6 will be tested in the COLD TEST FACILITY

$I_c$ test

QDS test

(final acceptance released only after tests)
Transportation of the coils could be an issue

- Total weight (> 15 tons)
- Total dimensions (~10 m)

<table>
<thead>
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<th>Coil</th>
<th>PF1/6</th>
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<th>PF3/4</th>
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<tbody>
<tr>
<td>$R_{in}$ (mm, @RT)</td>
<td>1140</td>
<td>2940</td>
<td>4150</td>
</tr>
<tr>
<td>$R_{out}$ (mm, @RT)</td>
<td>1660</td>
<td>3220</td>
<td>4550</td>
</tr>
<tr>
<td>Weight of WP (tons)</td>
<td>15</td>
<td>16</td>
<td>28</td>
</tr>
</tbody>
</table>

The transportation strategy is left to the supplier

For all the 6 coils a transportation structure must be designed and realized

For PF1-PF6 the transportation structure must be designed to work in the Cold Test Facility

Courtesy of JT-60SA

Courtesy of ITER
Some possible hypotheses

Supplier **MUST** manage all the logistic for transportation from the factory to the DTT Hall.
Delivery and Payment Schedule

There are two main constraints:

1. **PF6, PF5 and PF4** MUST be delivered, tested (PF6 only) and ready to be assembled before September 23;
2. Conductor delivery schedule already defined.

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**Main consequences**

Although coils are identical in pairs, the production plan MUST proceed in this order:

**PF6 – PF5 – PF4 – PF3 – PF2 – PF1**

Due to conductor production schedule (fixed by other magnets requirements): there could be a pause in the PF coils production (some months)

About payments: a 20% of the total amount can be pre-paid
THE END

Thanks to:
S. Turtù, G.M. Polli, A. Di Zenobio