ITER cryopumps – Challenges to industry for Built-to-print Packages

Cryogenics

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ITER and its main cryovacuum systems

3 Large cryopump systems

- Cryostat HV pumping system
- Neutral Beam (NBI) HV pumping system
- Torus exhaust HV pumping system

Major plasma radius 6.2 m
Plasma Current: 15 MA
Typical Temperature: 20 keV
Plasma Volume: 840 m$^3$
Typical Density: $10^{20}$ m$^{-3}$
Fusion Power: 500 MW

Europe is responsible for the procurement package ‘Cryopumps, related cryolines And valve boxes’ (in-kind)
Function of the main cryovacuum systems

Function of the torus cryopumping system
- During pulses: Pump the torus exhaust gas (all variety of gas species) against high gas throughputs; Keep the divertor vacuum at 1-10 Pa.
- In between the pulses:
  Pump down the torus chamber (1350 m³) from 10 Pa to $5 \times 10^{-4}$ Pa.

Function of the neutral beam cryopumping system
- Provide the operational vacuum (of the order of 0.02 Pa in 160 m³) against high gas throughputs (only hydrogen or deuterium).

Function of the cryostat cryopumping system
- Maintain the insulation vacuum system (8500 m³ @ $10^{-4}$ Pa) against leakage gas, outgassing (walls, magnet epoxies,...).
Cryopumps are cooled by supercritical helium (4 bar@~4.5 K; 18 bar@80 K) from a supply which is integrated with the ITER superconducting magnets;

Cryopumping system regeneration schemes (at different temperatures in the range 80-475 K for the different gas species) are based on sequential regeneration of individual pumps to:

- minimise gas inventories (hydrogens, including tritium),
- for oxy-hydrogen explosion safety and tritium limitation,
- smooth demands on cryodistribution system;

NBI, torus exhaust and cryostat pumps share the same pump concept: Cryosorption on charcoal for light gases ($H_2$, $He$) and cryocondensation for all heavier gases;

All cryopumps have to be designed for tritium compatibility;

The cryopumps are tailor-made devices.

Industry to manufacture according build-to-print! The design is being elaborated in the fusion labs.
Development path towards the cryopumps

Stage I
1990-1995
Qualification of the sorbent and the panel technique

Stage II
1995-2000
Test of complete sorbent coated panels

Stage III
1999-2006
Investigation of the scaled cryopump

Stage IV
2002-2006
Sorbent panels test under tritium (JET)

Prototypes and serial pumps
Torus system configuration

- Entrance from the plasma
- Installation points of the torus cryopumps
- Pumping duct
Torus/Cryostat cryopump design

Geometry

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prototype</th>
<th>800 mm</th>
<th>500 mm</th>
<th>2054 mm*</th>
<th>1560/1776* mm</th>
<th>11.2 m²</th>
<th>28</th>
<th>1000 mm</th>
<th>2.9 m³</th>
<th>8 tons</th>
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<tbody>
<tr>
<td>Valve Diameter</td>
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<td>800 mm</td>
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<td>Cryopanel Area</td>
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Design pumping speed: 80 m³/s, No of pumps needed: 11 = 8 (Torus) + 2 (cryostat) + 1 (spare)

1:1 scale prototype currently under manufacturing
Neutral Beam systems configuration

Design pumping speed: 2500 m³/s, No of pumps needed: 2 per NBI → 10 = 6 (H-NBI) + 2 (NBTF) + 2 (D-NBI)

Size: 8-9m long, 2.6m high
Weight: 9 tons

8 modules in series
General approach to procurements

- Complete R&D to define the design specifications (detailed design)
- Review with ITER IO of the R&D outcomes
- Finalisation of the Design
- Review with ITER IO of the design
- Preparation of the manufacturing drawings and launch the Call for Tender (Europe to worldwide, separate)
- Manufacture of the components
- Test at Supplier site
- Test at Association site (TIMO-2 @ FZK; NBTF @ RFX)
- Shipment to ITER Site
- Participation to installation and commissioning

Torus: Oct 2010
NBI: Mar 2011

Torus: completed Mar 2013
NBI: completed Feb 2013
Expertise needed for cryopump manufacturing

- **Contractual manufacturing according build-to-print**

- **Only minor changes to the design – if at all – are expected** (primarily given by adaptation to chosen final manufacturing procedures)

- **Leading edge expertise in UHV vacuum technology**
  - Cleanliness requirements
  - Material handling
  - Compatible welding and expertise behind
  - Leak testing expertise and equipment

- **Broad expertise in cryogenic technology**
  - Hydroformed cryopanels

- **Skills in procurement of materials**

- **Handling and precision machining of large components**

- **Experience with pressure vessel equipment / Notified Bodies**

- **Digital formats of the ITER IO / F4E:**
  - 3D Drawings in CATIAV5R17 in ENOVIA / SMARTEAM environment
  - Project planning in PRIMAVERA (?)
Soft expertise needed (2)

- Demonstration of project management skills and commitment to the project
- Convincing sub-contractor philosophy and mitigation strategies
- Acceptance of supervision, QA control and extensive documentation