EC Launchers and IC Antennas for ITER

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Content

1. Outline planning for EC upper launcher and IC antenna projects

2. Design and manufacturing solutions for EC upper launcher and IC antenna

3. Overview of required testing activities

4. Current design of port plug test facility

5. Possible additional scope: diagnostic port plug assembly and testing

Main purpose: identify suitable companies for assembly and testing of IC antenna and EC Upper Luncher

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EC Upper Launcher - Overview

**Main Function of the EC UL**
Provide localized current drive for plasma stabilization → required directivity & focusing of the injected EC beams → Optical system + steering mechanism

**Derived functions**
- Confinement of radioactive gas (T)
- Vacuum boundary
- Neutron shielding (surrounding components + dose in port cell)
- Belongs to the cooling/baking system of the Tokamak

EC Upper Launcher – Overall design

- Overall port plug length = 6m
- Rear flange width = 1.3m
- Wall thickness mid section = 90mm
- Total weight ≈ 18t (no water)
- Internal layout designed to allow free propagation of mm-wave beam
Main frame single wall + back end
• stainless steel welded plates (current proposal is TIG for radial welds and EB for longitudinal welds)
• Currently investigating option to deep drill top and bottom plates for cooling channels
• Back-end: actively cooled section +
• Weight ≈ 6t (single wall) + 5t (back end)

Main frame double wall
• Deep drilled bores 30mm diameter
• Cooling lines to be sealed by welded plugs
• Weight ≈ 1t

Blanket Shield Module
• Deep drilled walls with welded plugs
• First wall panel: multilayer structure with cooling pipes between copper plates (HIPping/diffusion bonding?)
• Front wall stainless steel or beryllium
• Weight ≈ 1t

Diagnostic, services & feedthroughs
• Standard: cooling pipes, gas lines, cabling, sensors, etc.
• Non-standard: electrical and signal feedthroughs, some diagnostic devices
• Weight ≈ 1t

Neutron shields
• Stainless steel machined block with drilled channels.
• Welded plug design to be optimized
• Weight shield assemblies ≈ 3.5t

Fixed mirror assembly
• Two machined plates joined together (stainless layer with milled channels + copper layer)
• Joining technique to be defined (e.g. EB welding, diffusion bonding?)
• Weight mirror assemblies ≈ 0.5t

Steering mirror assembly
Ex-vessel waveguide assembly
• waveguides, miter bends, couplings, etc.

EC Upper Launcher – Backend assembly
(first confinement barrier)

• Welding / machining of outer contour of Support Flange/CP, Socket and Stiffener plate
• Machining of socket cooling channels and cut-outs for WG assembly and Cooling Feed-throughs at stiffener Plate
• Loose insertion of pipes
• Welding of Flange, Socket and Stiffener plate.
• Weld to main Frame
• Re-machining of Reference planes / points
• Machining of pipe feed-throughs at CP
• Welding of pipes at CP
• Final machining of WG-feedthrough cut-out, seal grooves and reference planes
Introduction of the ICH Antenna

 Ion Cyclotron (IC) Heating and Current Drive (IC H&CD)

- This system is required to provide ion cyclotron heating (20MW) and current drive into the plasma.
- The antenna will also be used for wall conditioning between pulses.
- The IC power shall be coupled to the plasma through two antennas in two equatorials ports (one antenna in EU procurement, one TBD)
- The IC system shall be capable of operating at any frequency in the range of 40-55 MHz
- The pulse lengths will be up to 3600s and a duty cycle of 25%

Antenna Overview: Parts description

- Antenna Port Plug, 43 t
- Transition Frame, 5 t
- Straps housing & Faraday Screen
- 4 Port junction & Straps
- RVTL
- Port Plug Bulkhead

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### Main sub-assemblies

<table>
<thead>
<tr>
<th>Sub-assembly</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Front Module Assembly (FMA)</strong></td>
<td>Dimensions: 3.3m x 0.82m x 1.02m, mass: ≈ 8T</td>
</tr>
<tr>
<td><strong>Port Plug Body (PPB)</strong></td>
<td>Dimensions: 3.3m x 2.0m x 2.4m, mass: ≈ 18T</td>
</tr>
<tr>
<td><strong>Removable Vacuum Transmission Line (RVTL)</strong></td>
<td>Dimensions: 2.66m x 0.35m x 0.27m, mass: ≈ 400Kg</td>
</tr>
</tbody>
</table>

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### Overall Assembly sequence (proposal)

1. **Front Module Assembly**
2. **Removable Vacuum Transmission Line (RVTL)**
3. **Port Plug Body**
4. **Front Housing**
5. **Rear Shield Cartridge**

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First the port plug body is attached to the frame, then the PPB frame is anchored to the reference frame.

The front module is manipulated by a crane and positioned on the front frame. The module slides on 4 rails inside the Port Plug structure.
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Complete Assembly

Extensive testing foreseen during assembly

- Testing of sub-components during fabrication and assembly:
  - Welds and joints inspections
  - Dimensional checks (metrology)
  - Vacuum and leak tightness
  - Hydraulic
  - High voltage tests of IC quadrants (TBD)
  - Others (kinematic, pressure test, electrical, sensors and signals, etc)

- Test performed using test rigs, vacuum chambers, baking facilities, specific instrumentation

- Cleaning and vacuum conditioning are also required for some components (at specific stages of production) to ensure compliance with vacuum requirements + thermal cycling

- The assembled port plug is also tested for compliance with specifications (environmental tests) and for ensuring basic functionality (EC and IC high power transmission excluded) – see next slide
Final assembly acceptance tests

3 types of tests performed as part of the acceptance test of the port plug assembly:

- **Environmental**: common to all port plugs in ITER, aimed at ensuring compliance with vacuum requirements, pressure test, leak tightness, “bakeability”, etc.
- **Alignment and dimensional tolerances**
- **Functional**: this is a limited set of tests (aimed at verifying compliance and not full functionality of the plug) and may include tests of the local control system, steering mechanism rotation, etc.

Most of the tests shall be carried out using the Port Plug Test Facility (PPTF) – next slide.

Port plug Test facility today

- Preliminary layout. Dimensions: 21x19 m
- 25 t for the Test Tank
- 18 t for the upper adapter
- 10 t for each Port Plug handling equipment (upper and eq.)
- PP + water loads must be added
Environmental tests provided by PPTF

- **Thermo-mechanical strain of the port plugs**
  Ports plug are heated up to 240°C (internal component baking temperature) and cooled down three times. Heating and cooling rate of 5°C/h is considered optimal.
- **Regulatory pressure tests**
  The PPTF is able to pressurize port plug circuits, to ensure compliance with the French pressure equipment directive (ESP). Different test pressure may be required depending on the final ESP(N) classification of the port plug internals & circuits (as well as selected Codes & Standard) and could be up to 7.8MPa.
- **Leak test the port plugs**
  The PPTF is capable of measuring that the port plug leak rate is under $5 \times 10^{-10}$ Pa.m$^3$/s, air equivalent. The windows and penetrations of the port plug back flange shall be tested as well as the port plug cooling circuits.
- **Hydraulic flow tests**
  The pressure drop of the cooling circuits shall be measured and compared to the maximum allowable value.
- **Port plug out-gassing**
  The PPTF is capable of checking that the port plug outgassing rate at 100°C is below $10^{-5}$ Pa.m$^3$/s for hydrogen isotopes and below $10^{-7}$ Pa.m$^3$/s for impurities.

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Functional tests (examples)

The tests to be performed depend on the specific port plug. Definition of these tests is ongoing.

- **Steering mechanism** tests (EC Launcher)
- **Internal alignment** (EC and IC) – laser alignment and/or low power mmw (for EC)
- **Diagnostics & sensors**, control & interlocks (electrical and functionality)
- **High-voltage** tests for IC (TBD)

Additional testing equipment may be required and some may need integration in the PPTF itself.

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5 additional port plugs (mix of equatorial and upper) in the EU scope of procurement

Possible option being considered by F4E is to assemble and test all port plugs (up to 6 heating and 5 diagnostics) with a single assembler.

A tentative and integrated time schedule is shown in the next slide.
Technical expertise and capabilities

Procurement
- materials (316LN, copper alloys, Inconel, Ti, etc.)
- components (pipes, bolts, cabling, sensors, etc.)

Manufacturing
- precision machining of large components
- deep drilling
- tubes bending
- Heat treatments, surface cleaning

Joining & Inspection
- EB / TIG welding, diffusion bonding, HIPping, etc.
- NDT (visual, x-ray, UT, dye pen, etc.)

Design and reporting
- Design adaption for manufacturing
- Production of manufacturing drawings
- Manufacturing reports

Metrology
- positioning, dimensional, alignment, etc.
- Tolerances: e.g. few mm for fabrication/assembly tolerances

Code and Standards
- ASME, RCC-MR
- National and regulatory (e.g. PED)

Acceptance testing
- leak testing, pressure testing, flow testing, hardness, etc.

Resources, tools and processes

Resources
- Team size, expertise, etc.
- Management of subcontractors
- Access to external experts
- Design office

Plant & Tools
- Production capacity
- Machinery
- Tools, cranes, jigs & fixtures
- Clean areas, storage, etc.
- Software, etc.

QA & Processes
- Traceability of documents, records, data, WPS, etc.
- Control plan
- Internal processes
- Internal and external audits
- Control of non-conformities and corrective/preventive actions