Overview of Ion Source Characterization Diagnostics in Indian Test Facility (INTF)


ITER-India, Institute for Plasma Research, A-29, GIDC-sec-25, Gandhinagar, Gujarat, 382016, India.

16th International Conference on Ion Sources, 23-28 August 2015, New York USA
Contents

• Introduction to INTF
• Diagnostics for INTF to characterize Beam Source and corresponding beam
  – Cavity Ring Down Spectroscopy
  – IR Thermal imaging
  – Probe based diagnostic in Ion source
  – Plasma characterization by RF
  – Doppler Shift Spectroscopy
  – Beam profile with Calorimeter
  – Optical Emission Spectroscopy
  – Beam Tomography.
  – Tungsten Wire Mesh
• Summary
Negative Hydrogen Ion source of dimensions ~1.6m * 0.6m, beam energy of 100kev & 60A of extracted & accelerated current.

Beam has to travel 20.67 m with compatible beam line components. with pulse length of 3s ON-20s OFF with 5Hz modulation for 1 Hr.

The mandate of INTF is to characterize the ITER-DNB beam with full specification.
INTF is a serious effort from IN-DA to test DNB and to explore in the R&D, one of the most important challenges in ITER.

- NBI test bed (~ 24 m) with longest beam length = 20.67 m
- BS (to be characterized before sending to ITER) operation.
- Test power supplies using CODAC type platform.
- Floor area: ~ 350 m² (Excluding PS area)
- 1:1 sized BLCs are prototype.
- Vacuum vessel: Cylindrical φ ~ 4.5m, L ~ 10 m
- Duct size: Conical cylindrical L ~ 13 m
- Pumping system: 12 modular cryo-sorption pumps.
The challenges involved in DNB delivery include,

1) **60A** extracted and accelerated H- ion current.
   → **Efficient H- source; Low Stripping**

2) Transport for **20.665 m** from the grounded grid of the ion source with low divergence.
   → **Excellent accelerator system.**

Transport also depends on,

a. **Filter field** effects on beamlet dispersion and deflection.

b. **Bending of grid segments due to expansion** under heat loads.

c. **Beam focussing mechanism** using geometric aiming and aperture offset in presence of PG filter field and space charge repulsion.

3) Integrated beam operation with **Power supplies** using **CODAC** type platform.

4) **Minimum diagnostics to reduce maintenance in nuclear environment** in ITER.
Role of INTF Diagnostics

• Objective of INTF diagnostics:
  – To identify optimized operational window of the Beam Source through Control and Characterization
  – Monitor for safe operation through interlocks.
• Main systems to control for safe operation (*not discussed in the talk*)
  – Vacuum and Gas feed system, Cooling water, Power supply, Cryogenic system.

Minimum Diagnostics in DNB (*To reduce Maintenance downtime in ITER*) → only for protection purpose (electrical, calorimetric and thermocouple based)

➤ Beam characterization need to carried out in test bed before being delivered to ITER.

1. R&D is required for big negative ion source operation and optimization.
2. The ion optics for DNB is too complex and its performance @20.67m need to be checked under various operating conditions.
3. Same would be for the power supplies for integrated operation.

Diagnostics play a big role in INTF
1280 beamlet (4 x 4 beam groups)
Diagnostic line of sights – Beam Source characterization

- 4 OES LOS ports & 4 CRDS LOS ports
- 16 CFC plates for 16 beam groups
- 4 DSS ports
- Ion Source
- 4 OES LOS ports & 4 CRDS LOS ports
- IR Camera LOS ports
## Diagnostics for Characterization

<table>
<thead>
<tr>
<th>Diagnostics</th>
<th>Location</th>
<th>Measured quantity</th>
<th>Controlled / Monitored parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical</strong></td>
<td>• Ion source • RID</td>
<td>• PG current • Bias current. • Probe current. • RID current</td>
<td>• PG filter field. • Co-extracted electron • Plasma density – uniformity • Neutralization efficiency</td>
</tr>
<tr>
<td><strong>Optical (Emission, Doppler Shifted, Cavity Ring down)</strong></td>
<td>• Ion source • Beamline</td>
<td>• Balmer lines, Cs line • H-alpha line intensity • CRD signal</td>
<td>• Plasma density and temperature, -ve ion density, Cs density. • Beam energy, div. &amp; stripping</td>
</tr>
<tr>
<td><strong>Thermo-couple</strong></td>
<td>V-target</td>
<td>• Surface temperature</td>
<td>• Beam profile</td>
</tr>
<tr>
<td><strong>Calorimetry</strong></td>
<td>V-target</td>
<td>• Water temperature</td>
<td>• Beam power</td>
</tr>
<tr>
<td><strong>IR Imaging</strong></td>
<td>Perpendicular target</td>
<td>• IR imaging</td>
<td>• Beam profile, beam Divergence &amp; stripping losses</td>
</tr>
<tr>
<td><strong>Tomography</strong></td>
<td>• Near Duct</td>
<td>• H-alpha intensity from the beam</td>
<td>• Beam profile Near Duct.</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>Location</td>
<td>Measured quantity</td>
<td>Controlled /Monitored parameter</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------</td>
<td>------------------------------------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>Vacuum</td>
<td>• Ion source</td>
<td>• Gas Press &amp; Flow</td>
<td>• Source plasma parameter.</td>
</tr>
<tr>
<td></td>
<td>• Vessel</td>
<td>• Gas composition</td>
<td>• Neutralization efficiency.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td>• HV deck</td>
<td>• Volt. &amp; Current</td>
<td>• Beam power, uniformity, electron current, focus.</td>
</tr>
<tr>
<td></td>
<td>• Ion source</td>
<td>• RF power &amp; matching</td>
<td>• Power on RID panel</td>
</tr>
<tr>
<td></td>
<td>• RID</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calorimetry</td>
<td>All BLCs, Ion source</td>
<td>• Water temp.</td>
<td>• Power density.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water flow rate.</td>
<td>• Beam alignment &amp; uniform</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Water quality</td>
<td>• Breakdown level.</td>
</tr>
<tr>
<td>Cryo</td>
<td>Cryopump</td>
<td>• Cryogenic flow, temp &amp; Pressure</td>
<td>• Cryopump temp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Heat load on cryo system</td>
</tr>
<tr>
<td>Optical</td>
<td>• Ion source</td>
<td>• H-alpha intensity</td>
<td>• RF power coupling.</td>
</tr>
<tr>
<td></td>
<td>• Beam line</td>
<td>• Cs lines.</td>
<td>• Cs amount in plasma.</td>
</tr>
<tr>
<td>Thermal</td>
<td>• All BLCs</td>
<td>• Surface temp.</td>
<td>• Beam alignment &amp; profile.</td>
</tr>
<tr>
<td></td>
<td>• Cs oven</td>
<td>• Cs oven temp.</td>
<td>• Cs inventory.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# DACS Interface with Diagnostics

<table>
<thead>
<tr>
<th>Category of Diagnostics</th>
<th>Interface Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Slow Signals &lt; 20 Sps (e.g. Thermocouples, Pressure transmitters)</td>
<td>Through Siemens S7 plcs, software integrated with EPICS and NI 6225 digitizer cards</td>
</tr>
<tr>
<td>2 Fast Signals, in range of KSp s (Probe diagnostics, Power supply)</td>
<td>NI 6225 Digitizer cards with Labview RT</td>
</tr>
<tr>
<td>3 High Speed Event based DAQ in range of 100 MSp s (e.g. CRDS)</td>
<td>Specific hardware from CAEN, integrated with central DACS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diagnostics System</th>
<th>Acquisition Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Spectroscopy</td>
<td>8</td>
</tr>
<tr>
<td>Beam Spectroscopy</td>
<td>12</td>
</tr>
<tr>
<td>IR Beam dump</td>
<td>40</td>
</tr>
<tr>
<td>IR Camera</td>
<td>4</td>
</tr>
<tr>
<td>CRDS</td>
<td>8</td>
</tr>
<tr>
<td>Beam tomography</td>
<td>8</td>
</tr>
<tr>
<td>Probes</td>
<td>10</td>
</tr>
</tbody>
</table>

![Diagram of DACS Interface with Diagnostics](image)
Cavity Ring Down Spectroscopy

Based on Laser Photo-Detachment Principle

\[ H^- + \text{photon} = H + e^- \]

4 LOS on a vertical plane between Bias-plate and PG. Each cavity length ~ **5m** with plasma column **0.5m**.
Single **NdYAG** laser beam will be divided into 4 cavity using beam-splitter & bending optics.

**ISSUES:**
- Deterioration of mirror reflectivity.
- Cavity Misalignment (Vibrations, thermal)
- Electrical noise on detection system
- Significant deviation from exp. decay

Line Integrated H-ve Ion density measurement

**Graph:**
- Empty cavity
- With H-ve Ions

16th International Conference on Ion Sources, 23-28 August 2015, New York USA
The beam dump is supposed to handle ~ 6MW of ion beam power with peak power density ~ 20 MW/m² without active cooling.

The beam dump is proposed to be made of 16 carbon fibre composite (CFC) plates.

Equipped with:
- IR camera,
- Thermocouple
- Electrostatic Probe

Beam profile will be seen from rear side by set of IR cameras → Overlapping Line of Sight (LOS) for cross-calibration.

Particles impact to dump → Secondary electrons emission → Bias CFC plates

Beam interaction with background gas
→ Plasma formation near plate → Radiating sheet on front of plate → Impact on visibility → Rear side observation using IR camera (100 to 1500 deg C)

Diagnostics beam dump is optimized using designed by analysis approach, Simulated thermal response of the material under given variable load & material properties.
Electrostatic probes in BS

- ES probes (Single or Double probe) are separate detachable attachments on Bias plate.

![Diagram of Bias plate and PG frame with annotations](image)

- PG plate
- PG frame maintains gap ~ 7mm between Bias plate and PG.
**Preliminary Numbers**

Number of Ports & LOS
36 LOS from 12 ports

Doppler spectral shift
for 100 kev beam its ~ 5 nm from 656nm.

Temporal resolution
~1 sec for 1 MHZ ADC and 1024*1024 CCD,
Planned to enhance up to 10Hz with binning

Lens Optical Throughput
$7.23 \times 10^{-10} m^2 Sr$ at collecting lens of
10mm at 2800mm from source.

Spectrometer throughput
$\sim 3.7 \times 10^{-10} m^2 Sr$ for F no is nearly 750mm
it has an entrance throughput that matches
reasonably well that of the optical head.

**Objectives**

*Stripping loss of ions* - from stripped ion peak
*Beam divergence* - from line broadening
*Beam uniformity* - intensity comparison from LOS
*Energy distribution of species present* - Doppler shift
*Fraction of species* - Intensity comparison

View angle w.r.t beam optimized, keeping in mind
error in divergence calculation & peak resolution.
After trade off angle of 60 degree finalized for DSS.
Plasma characterization by RF electrical parameters

• **Plasma density estimation using electrical parameter in RFG circuit for Inductively coupled plasma sources.**

  Plasma loading assuming plasma as single turn secondary to coil.

  (Air core transformer model)  ➔ plasma density estimation through conductivity tensor

  ➔ Current in coil from calorimetric data of cooling circuit.

  

  Ref- Plasma density estimation of a fusion grade ICP source through electrical parameters of the RF generator circuit


• **Physics-Electrical Hybrid Model for Real Time Remote Plasma Characterization & Impedance Matching in RF Plasma Source**

  Plasma load using HELIC Code from Dr. Arnush(UCLA)  ➔ Power transfer using air core transformer model-

  ➔ Plasma Density though Power Balance

  *(Poster presentation in Evening)*

  Good agreement of calculations with experimental results, Work in Enriching the physics of coupling & minimizing source of possible error on going.
1. **Tungsten Wire mesh calorimeter for qualitative beam profiling.** Tungsten wire thickness design data base created for multiple range of operating power load using thermal analysis.

2. **Neutral Beam Tomography for Beam profiling at duct.** Selection of Inversion algorithm under study.

INTF is an opportunity to explore and overcome the issues and challenges in ITER - DNB.

Role of Diagnostic in INTF is very important because ITER does not allow enough diagnostics for characterization.

Multiple Diagnostics are provisioned for INTF to characterize Beam Source and corresponding beam.

In INTF, DNB system including Power supplies and CODAC based control system will be tested.

Thank you