HEBT Diagnostics for Commissioning, Control and Characterization of the IFMIF-EVEDA Accelerator

PY. Beauvais², B. Brañas¹, J.M. Carmona¹, N. Chauvin², A. Ibarra¹, J. Marroncle², A. Mosnier², C. Oliver¹, I. Podadera¹

¹CIEMAT
²CEA-Saclay
Characterization of materials envisaged for future fusion reactors.

Study and analysis of the behaviour of materials under a high flux of neutrons ($10^{18}$ n/m$^2$/s).

IFMIF design

Facility availability >70%

Neutron flux density

Beam footprint at interaction point

IFMIF Accelerator

Deuterons, 2 x 125 mA, CW, 40 MeV.
Target region: 20 cm horizontal x 5 cm vertical.

Accelerator challenges
• Space charge.
• Beam instabilities.
• CW operation.
• Beam interception (activation).
• Shape of the beam footprint at the target.

Superconducting HWR
CW 175 MHz, HWR, 4 cryomodules, 40 MeV

RF Power System
175 MHz

High Energy Beam Transport (HEBT)
Large Bore Quad & Dipoles

Radio Frequency Quadrupole (RFQ)
CW 175 MHz, water cooled, 5 MeV

Ion Injector
CW ECR, Source, 140 mA D⁺, 95 keV, Magnetic LEBT to RFQ

26-8-2008
I. Podadera- IFMIF-EVEDA HEBT diagnostics- HB2008
EVEDA phase
Engineering Validation and Engineering Design of the IFMIF project

Goals
• to validate the technical options with the construction of a prototype accelerator.
• to produce the detailed integrated design of the future IFMIF accelerator.

Main specifications
• Installation in Rokkasho-Japan 2012-2013.
• Manufacturing and tests of a prototype accelerator (1:1) with 9 MeV final energy.
• Deuterons, 125 mA cw, 9 MeV.
• Commissioning phase: 0.5 mA-125 mA, pulsed mode down to 200 ms, 0.1% duty cycle.

### IFMIF-EVEDA Accelerator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion species</td>
<td>D⁺ / H₂⁺ (tests)</td>
</tr>
<tr>
<td>CW current (min/max)</td>
<td>0.5/125 mA</td>
</tr>
<tr>
<td>RFQ output energy</td>
<td>5 MeV ( (\beta=0.0727) )</td>
</tr>
<tr>
<td>HWR output energy</td>
<td>9 MeV ( (\beta=0.0975) )</td>
</tr>
<tr>
<td>RF frequency</td>
<td>175 MHz</td>
</tr>
<tr>
<td>Bunch width (min/max)</td>
<td>0.1-3 ns</td>
</tr>
<tr>
<td>Duty factor (min/max)</td>
<td>0.1%/CW</td>
</tr>
<tr>
<td>Pulse length (min/max)</td>
<td>~100 ( \mu )s/CW</td>
</tr>
<tr>
<td>Beam power</td>
<td>1.125 MW</td>
</tr>
</tbody>
</table>

Mockup courtesy of T. Trublet
Commissioning

• **5 MeV for RFQ commissioning:**
  - From 0.5 mA to 125 mA.
  - Pulsed and CW operation.

• **9 MeV for HWR commissioning and beam characterization:**
  - From 0.5 to 125 mA.
  - Pulsed and CW operation.
HEBT beam diagnostics

**Characterization diagnostics:** Diagnostics Plate + spectrometer.

**Beam Dump control:** Halo, BLM’s position and transverse profile to control losses and power density profile on the cone (~200 kW/cm²).

**Beam Losses:** BLM’s + DCCT and BPM’s transmission monitoring.

**Spectrometer:** Beam characterization (profilers), reduction radiation impact on the accelerator, controlled with BPM’s, DCCT’s transmission and BLM’s.
High Energy Beam Transport Line (HEBT)

![Diagram of HEBT with labeled components: Magnetic dipole (spectrometer), BPM5, BPM6, TPMS-IFMIF, TPMS, SHM2, DCCT3, TraceWin, CEA/DSM/DAPNIA/SACM, Diagnostics plate, QD2, QT1, HWR, BPM4, TPM1, TPM2, TPM3, QT3.]

**Beam dynamics**

rms beam envelope along the HEBT (from HWR up to Beam Dump)

C. Oliver et al., *HEBT for the IFMIF-EVEDA accelerator*, EPAC’08, p. 3041 (2008)

26-8-2008  I. Podadera - IFMIF-EVEDA HEBT diagnostics - HB2008
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC current</td>
<td>ACCT</td>
<td></td>
</tr>
<tr>
<td>DC current</td>
<td>DCCT</td>
<td></td>
</tr>
<tr>
<td>Position</td>
<td>Stripline BPM</td>
<td></td>
</tr>
<tr>
<td>Transverse Profile</td>
<td>Gas fluorescence (FPM)</td>
<td>Gas ionization (BTPM)</td>
</tr>
</tbody>
</table>

Essential for initial commissioning (HB2006):
- Current
- Position
- Profile
Characterization of each important beam parameter for validation of the accelerator and commissioning of the RFQ and the HWR cavities.

Parameters:
- DC current
- AC noise
- Centroid jitter
- Transverse profile (size and distribution)
- Halo
- Mean energy
- Bunch width

Challenges:
- Low $\beta$
- Debunching
- Radiation damage

I. Podadera et al., EPAC’08, p. 1248 (2008)
The fundamental harmonic is reduced almost 5 times from the beginning to the end of the line. The higher harmonics disappear...
Stripline Beam Position Monitors

- Shorted stripline Beam Position Monitors along the HEBT (x6).
- $\beta=1$ approximation not longer valid (Shafer criteria)$^1$
- Use for beam position measurement (probably at the fundamental harmonic due to the low signal at higher harmonics).
- Time of flight measurement (better accuracy than capacitive pick-up for offset beams)$^2$.
- Bunch width measurements at DP using higher harmonics.

1R. Shafer, AIP BIW'93,319, p. 303 (1994)

Energy: 5/9 MeV
Position resolution: 10 $\mu$m
Absolute precision: 100 $\mu$m
Dynamic range: 0.5 mA- 150 mA
Position range: ± 30% aperture.
Linearity error: ±1%.
Phase accuracy: 1°-2°.
Phase resolution: 0.1°.

Example for $\beta=0.4$
Stripline Beam Position Monitors

Four-strip geometry optimization

Optimization of the geometry parameters using the matching of the four strips with the electronics.

\[ Z_{dip} = Z_0 = \sqrt{Z_{sum} Z_{quad}} \]


Length optimization

Optimum for 175 MHz narrowband measurement

\[ l_{opt} = \frac{c}{2f} \left[ \frac{1}{\beta_w} + \frac{1}{\beta_s} \right] \approx 78 \text{ mm} \]
MPS and thermal shock

IFMIF accelerator stop limit (CDR): 10 \( \mu \)s

Maximum time before failure for 90\(^\circ\) total beam impact:\(^1\)

\[ \Delta t = \frac{2\pi \sigma_x \sigma_y}{I_0 R_{\text{max}}(E_0)} q_{\text{max}} \]

Formula for evaluation maximum heat density:\(^2\)

\[ q_{\text{max}} = \frac{2}{\sqrt{3}} \cdot \frac{c_v}{\alpha E} \sigma_y \]

According to the models, at SNS and J-PARC LINACs, the whole pulse injection would not be allowed.\(^1,^2\)


But a 90\(^\circ\) beam impact in the vacuum pipe is not realistic under normal operation conditions...
Two non-interceptive methods based on interaction between gas in the chamber and deuteron beam are under design and will be installed at IFMIF-EVEDA.

**Ionization (BTPM)**
(CEA-Saclay development)

**Fluorescence (FPM)**
(CIEMAT development)

**Preliminary calculations:**
$10^{10}$ photon/s at 9 MeV, 125 mA

Detector assembly in the vacuum pipe

J. Marroncle et al., proceedings BIW’08, 2008

First experiments carried in Saclay with protons at 95 keV, 100 mA
IFMIF profiler

- Key device for operation of the IFMIF accelerator.
- Control the overlap between both accelerators and the flat transverse profile.
- Several techniques have been already analyzed.\(^1\)
- IFMIF profilers will be tested near the BD region at IFMIF-EVEDA (high neutron flux).

\(^1\)E. Surrey et al., A beam profile monitor for IFMIF reference, EFDA TW5-TTMI-001 (2006)
Transverse emittance

- Quadrupole scan in a free dispersion region (before spectrometer).
- Resolution affected by space charge (non-linear optics).
- Compromise between maximum size (beam losses) and minimum size (halo creation).

C. Oliver et al., *HEBT for the IFMIF-EVEDA accelerator*, EPAC’08, p. 3041 (2008)
Conclusions

- **HEBT diagnostics** will have to permit the safe transport of the IFMIF-EVEDA high-intensity deuteron beam from the HWR up to the beam dump.

- The beam will be fully characterized with a movable **diagnostics plate** and a spectrometer.

- **Low beam energy and high intensity** precludes the use of any interceptive diagnostics.

- The instrumentation placed near the BD will receive **high radiation**, it will be a good place to test the future IFMIF profiler.

- **Electromagnetic pick-ups** are challenging due to the low beta effect, the debunching process and the relatively high beam pipe diameter.

- An intensive R&D programme about the use of non-interceptive gas diagnostics (**fluorescence & ionization**) to monitor the transverse profile has started and its success is almost mandatory for the accelerator operation.

- Due to the high intensity, non-linear **space charge** forces make difficult the implementation of non-interceptive methods for the measurement of emittances and energy spread.
We want to thank the support and help of all the ASG

Thanks for your attention!!!