BEAM TRANSVERSE PROFILE MONITORS
FOR IFMIF-EVEDA

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Abstract
In the framework of the IFMIF-EVEDA project, a high deuteron beam intensity (125 mA - 9 MeV) prototype accelerator will be built and tested at Rokkasho (Japan). CEA-Saclay group and CIEMAT-Madrid (Spain) are responsible for the beam instrumentation from the ion source to the beam dump. One of the most challenging diagnostic is the Beam Transverse Profile Monitor. Two kinds of monitor are investigated: one based on residual gas ionization developed at CEA Saclay and the other one based on residual gas fluorescence studied at CIEMAT Madrid. Emittance measurements through quad-scans will be performed using transverse profiles. In this paper, the principal aspects as well as a brief description of these profilers (for IFMIF-EVEDA prototype accelerator) are reported.

INTRODUCTION
The International Fusion Materials Irradiation facility (IFMIF) aims at producing an intense flux of 14 MeV neutrons, in order to characterize materials envisaged for future fusion reactors. The primary mission of IFMIF is to provide a materials irradiation database for the design, construction, licensing and safe operation of the future Fusion Demonstration Reactor (DEMO) [1]. In such a reactor, high neutron fluxes may generate up to 30 dpa/fpy (displacements per atom / full power year). IFMIF facility is based on two high power continuous drivers (175 MHz) delivering 125 mA deuteron beams at 40 MeV each, colliding with a liquid lithium target.

In the framework of the “Broader Approach”, the IFMIF-EVEDA (Engineering Validation and Engineering Design Activities) project includes the construction of an accelerator prototype with the same characteristics as IFMIF, except a lower energy of 9 MeV instead of 40 MeV for the incident deuteron energy. Most of the components of the accelerator are developed by France, Italy and Spain. Accelerator parameters are

- 125 mA cw deuteron beam at 175 MHz (5.7 ns)
- Vacuum pipe pressure level: $10^{-5}$ mbar (at target region) and below $10^{-7}$ mbar elsewhere.

In such high current accelerator, non-interceptive diagnostics are required. Hence, in the following sections, a brief description of the different beam transverse profile monitor prototypes will be provided. Such monitors are actually in design and prototyping phases.

RESIDUAL GAS IONISATION PROFILER
This monitor is based on the ionizations induced by the beam particles on the residual gas contained in the beam pipe of the accelerator.

Figure 1: First prototype drawings
A first prototype was built [2] (figure 1), where an electric field is applied between two parallel plates, which drives ions and electrons towards them. A voltage is applied to the upper plate whilst the lower plate is grounded. The lower plate consists of 32 conductive strips covering a 4x3 cm$^2$ surface. On each side of the active area 9 thin pads are set regularly in order to insure the electric field uniformity (each resistor is 60 MΩ). This monitor is fixed on a
flange (DN100), which is held on the accelerator beam pipe.

**Front-end electronic**

The currents induced by the ionized particles motions are read-out by a front-end electronic card developed in our CEA group. The 32 channels are connected, via a kapton bus, to this card (Figure 2).

![Figure 2: Front-end electronic sketch.](image)

A transimpedance circuit converts all strip currents in voltage at 33 MHz. After the amplifiers, multiplexer and sequencer stages, a profile of the beam is given every 1060 ns.

![Figure 3: Beam profile seen on an oscilloscope every 1060 ns, which correspond to the 32 strips, lay out over 40 mm.](image)

The oscilloscope picture of such a profile can be seen on figure 3. This card reads the strip currents with a bandwidth below 3 MHz and has sensitivity down to 1 nA due to a high gain of 1.2 mV/nA. The equivalent input noise is around 0.8 nA.

**Monitor beam test**

This monitor was tested in July 2008 at Saclay, on the IPHI (Injector of Proton at High Intensity) source accelerator [3]. A continuous proton beam of 75 and 95 keV was delivered at beam intensity up to 12 mA for our test. Firstly we have checked that we observed an ionization signal by varying the residual gas pressure at constant beam intensity (1.2 mA). The pressure ratio is about 3.5 and this is what we got from data reported on figure 4 for different HV values.

![Figure 4: Maximum amplitude response for a 1.2 mA beam intensity at 2 vacuum pressures.](image)

Extrapolating our data to IFMIF conditions at the beam dump level [4], have shown that enough signal can be picked up with such a monitor. So, no ionization amplifiers, like MCPs (Multi Channel Plates) which are radiation sensitive, are required in this hard radioactive environment (γ and neutrons). Some other lessons were withdrawn from these tests, which have been taken into in account to build a second prototype.

They concern mainly:

- Electric breakdown and short cuts: ceramic will be used to avoid breakdowns and charging.
- Water-cooling system conditioned for higher beam intensity.
- Beam profile resolution: possibility to measure it with a grid profiler (SEM) at the same place. The required resolution is around 0.25 mm rms.
- Good behavior of the electronic Front-end, but integration charge mode has to be investigated for very low vacuum pressures, for which currents are too weak to be measured.

With the second prototype (figure 5), two campaigns of tests are foreseen, one on IPHI during mid 2009, and later, at higher beam energy.
Figure 5: In horizontal, the monitor mounted on a piston, with its front-end electronic card on the left (green). In vertical, the grid profiler is shown.

**FLUORESCENCE PROFILE MONITOR**

This non interceptive transverse profile monitor is based on the interaction between the beam particles and the residual (or injected) gas inside the vacuum chamber of the accelerator. Photons are produced due to the excitation and de-excitation of the gas molecules or atoms (in the case of injected atomic gas).

The light emitted, can be collected and used for the determination of the beam profiles. Due to the low cross sections between the beam and the gas at those energies (9 MeV), the diagnostics will require a sufficient long integration time and optics optimization. This technique is under development in the heavy ions accelerator complex GSI [5-6].

A set of collection optics will be installed to obtain the X and Y projections of the beam in the same location. Each consists of a special optical window (see figure 6), lens, and a coherent fibre bundle. A movable calibration lamp and a gas valve will be installed in order to provide spatial calibration and to increase the pressure locally, respectively. Finally, a filter wheel to select different transitions and a set of MCP plus a detector will be installed inside of a shield box.

**Goals for IFMIF-EVEDA BIF monitors**

The high neutron and gamma fluxes can lead into a permanent damage for electronic devices like detectors or MCP’s. Detectors usually lose dynamic range and contrast with radiation and can become inoperative even at low dose rates [7]. The detector which suits better our requirements must be chosen carefully, taking into account quantum efficiencies, readout times, spatial resolution, dynamic range and rad-hard operation if possible. CCD’s and CID cameras from several companies have been considered. To date, the most promising candidate for EVEDA are CID rad-hard cameras because of its high dynamic range and rad-hard resistance operation of some models (up to 3 Mrad). Other detectors like PMT’s or APD’s are rejected due to lack in spatial resolution.

Another drawback is that transmission of optical windows falls with radiation, resulting in decreasing photon counts with time. In order to avoid this issue, the construction optical windows based on with KU1 and KS-4V quartz glasses are proposed. Transmission for these quartz glasses is ~100% and remains constant for wavelengths above 380 nm [8].

**Residual gas and profile reliability**

Typically, molecular nitrogen and hydrogen are the main components of the residual gas present inside a beam pipe. The most intense lines come mainly from N$_2$ and N$_2^+$ with wavelengths between 385-430 nm and lifetimes about 60 ns [9]. In high current accelerators (and especially in low-$\beta$ beams) the interaction between the electric field and excited charged particles of the residual gas, could lead into a profile falsification. For instance, in case of large transition lifetimes, the distance between the points where the excitation and de-excitation of a particle occurs, can be non negligible. In order to avoid the contribution of electric field to beam profiles, transitions coming from non
ionized atoms or molecules can be selected like e.g.. Ne I, Ar I, Kr I or Xe I lines, depending on their lifetimes and intensities.

Thermal motion could be also a source of profile widening also, but even for long lifetimes (~60 ns), the distance between excitation and de-excitation (photon emission) due to this effect is negligible (e.g. 2.5E-3 mm for N$_2^+). See table 1.

<table>
<thead>
<tr>
<th>Candidate Gas</th>
<th>$v_{th}$</th>
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<tbody>
<tr>
<td>N$_2$</td>
<td>4.15 x 10^{-4} mm/ns</td>
</tr>
<tr>
<td>Ne</td>
<td>4.92 x 10^{-4} mm/ns</td>
</tr>
<tr>
<td>Ar</td>
<td>3.48 x 10^{-4} mm/ns</td>
</tr>
<tr>
<td>Kr</td>
<td>2.39 x 10^{-4} mm/ns</td>
</tr>
<tr>
<td>Xe</td>
<td>1.92 x 10^{-4} mm/ns</td>
</tr>
</tbody>
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Table 1: Velocities due to thermal motion for different candidate gases

Unlike other accelerators, hydrogen is expected to be the dominant residual gas in EVEDA due to superconducting cavities (at least near them). Thus, injection of another gas could be desirable because of hydrogen low mass and weak transitions in the region of interest. In the quest of the best gas, high mass, high cross sections, a short lifetimes (~1ns) and transitions in the visible region are desirable. Neon, Argon, Krypton and Xenon are gases with similar cross sections, with transitions in the visible region and in the case of Xe, a large mass (131 amu), and some Xe II transitions with short lifetimes (~6 ns) [9].

**Shield concept and BIF prototype**

High neutron and gamma fluxes are expected during operation of the accelerator inside the vault. In such hostile environment, is essential to design a local shield for the sensitive elements. Looking for a cost reduction and a better shield approach, estimations of the neutron and gamma spectra are being made (see figure 7). For monitors that will be located in the HEBT, a dual head and single output coherent fibre bundle are being considered. For the BIF-EVEDA prototype monitor, a radiation tolerant CID camera had been selected. Since every pixel in CID cameras is addressable individually, it could be possible to obtain both profile projections with a single camera using the proposed bundle, implying a cost reduction.

**CONCLUSION**

IFMIF-EVEDA prototype profilers based on ionization and fluorescence of residual gas have been presented. At the present design status, both techniques look very promising to characterize the beam transverse profile at such low energies and high deuteron current. Therefore, they could be key devices to carry out non-interceptive transverse emittance measurements by doing quadrupoles scans.

**REFERENCES**

[10] F. Ogando et al., private communication