# A DIAGNOSTICS PLATE FOR THE IFMIF-EVEDA ACCELERATOR

I. Podadera*, B. Brañas, J.M. Carmona, A. Ibarra, C. Oliver, CIEMAT, Madrid, Spain
PY Beauvais, J. Marroncle, A. Mosnier, CEA-Saclay, Gif-sur-Yvette, France

### *Abstract*

The IFMIF-EVEDA accelerator [1] will be a 9 MeV, 125 mA Continuous Wave (CW) deuteron accelerator which aims to validate the technology that will be used in the future IFMIF accelerator [2]. It is essential then to implement the necessary instrumentation for the commissioning and operation of the accelerator, as well as for a correct characterization of the main beam properties. To meet these requirements, a complete set of instrumentation will be installed in the last part of the accelerator, just before the beam dump, in the so-called Diagnostics Plate (DP). In this contribution, the requirements imposed to the instrumentation, the type of techniques that will be used and a first conceptual design will be presented.

## INTRODUCTION

In the quest for materials fulfilling the specifications of future fusion reactors, there has been proposed a facility which can reproduce the irradiation conditions at these machines, the International Fusion Materials Irradiation Facility (IFMIF). As this is a very high deuteron current accelerator with outstanding requirements in terms of accelerator technology, the construction of a prototype accelerator, IFMIF-EVEDA, in Rokkasho -Japan- was launched within the frame of the Broader approach agreement.

IFMIF-EVEDA will be designed, constructed, tested and characterized to validate the feasibility of the construction of IFMIF. The main parameters of the prototype accelerator are a continuous operation with deuterons at 125 mA. The beam energy is 5 MeV at the exit of the RadioFrequency Quadrupole (RFQ) and at the Medium Energy Beam Transport line (MEBT), between the RFQ and the superconducting HWR cavity (scHWR), which accelerates the deuterons up to 9 MeV. Further details can be found in [1].

To achieve the goals of IFMIF-EVEDA, it is required the implementation of a complete set of diagnostics to characterize each important parameter of the beam and the accelerator. For this reason, the Diagnostics Plate (DP) will be placed downstream the scHWR, in the High Energy Beam Transport line (HEBT) up to the Beam Dump [3]. The main parameters of the beam will be measured in the DP: current, phase, position, transverse and longitudinal profiles, transverse halo, mean energy and energy spread, transverse and longitudinal emittance and beam losses. The specifications, the limitations and the challenges of each device are discussed hereafter.

## TECHNICAL DESCRIPTION

### *Mechanical layout*

The DP will consist of a set of diagnostics devices which will be assembled together (around 3 m length) and placed on an independent trolley. The system can be moved at several locations of the accelerator without major modifications. The chassis will be designed to minimize the vertical deformation and avoid mechanical resonances. The order of the diagnostics on the assembly could be changed during the commissioning or the tests to adapt the plate to new devices or to optimize the performance of some of them. In the middle of the plate there will be a reserved area prepared to install prototype monitors to cross-check the measurements.

The DP should be an independent high vacuum section (inner beam pipe diameter 100 mm) which could be pumped down independently to fit the requirements of the accelerator ($10^{-7}$ mbar) without perturbing the neighbor scHWR.

### *Beam specifications and operation*

The DP will have to be adapted to be installed at least at two different locations of the accelerator for commissioning of the different elements: 1) At the extraction of the MEBT (5 MeV), 2) At the extraction of the scHWR (9 MeV). In both places the accelerator can be operated in continuous or pulsed mode. The main properties of the beam along the DP are summarized in Tab. 1. The monitors in the DP must be designed to operate with all these working conditions.

Table 1: Range (approx.) of the beam properties at the DP.

| **Beam parameter** | **Min. Value** | **Max. Value** |
|---|---|---|
| Energy $E$ (MeV) | 5 | 9 |
| $\beta$ | 0.0727 | 0.0975 |
| Mean current $\langle I_b \rangle$ (mA) | 0.5 | 125 |
| Pulse length $T_p$ ($\mu$s) | 100 | CW |
| Duty factor (%) | 0.1 | CW |
| Bunch length $\sigma_z$ (ns) | 0.15 | 0.7 |
| Transverse size $\sigma_{x,y}$ (mm) | 1 | 10 |

### *Measurement challenges*

**High beam current at low beam energy** IFMIF-EVEDA will be the first accelerator in achieving such high deuteron current. In combination with the CW operation or with long beam pulses (down to 100 $\mu$s), any interceptive

---

* ivan.podadera@ciemat.es

diagnostics device could be destroyed. In addition, even though the low energy of the deuterons at IFMIF-EVEDA limits the beam power of the accelerator, it will also decrease the range of the deuterons in the materials. That means all the power will be deposited in a very small area, limiting as well the use of such interceptive diagnostics [4].

**Debunching** The expansion of the longitudinal bunch width along the HEBT will make difficult the use of electromagnetic pickups in the DP. As explained in [5, 6], at low $\beta$, the electromagnetic field accompanying the beam cannot be longer assumed as a TEM, since it contains a longitudinal field component. For a given angular frequency $\omega$, a beam pipe of radius $b$, and a beam placed at the polar coordinates $(r, \theta_0)$, the total image (wall) current $I_W$ can be expressed as:

$$I_W(t) = -2\langle I_b\rangle \sum_{n=1}^{\infty} A_n \frac{I_0(gr)}{I_0(gb)} \cos(n\omega_0 t), \qquad (1)$$

where $\langle I_b\rangle$ is the average beam current, $I_0$ represents the modified Bessel function of order 0, and

$$g = \frac{\omega}{\beta\gamma c} = \frac{n\omega_0}{\beta\gamma c}, \qquad (2)$$

where $\omega_0$ is the fundamental bunch angular frequency, and $A_n$ represents a bunch-shape factor. Due to the penetration of the magnetic field into the vacuum chamber, the DC component of the beam current is not included in the wall current. It is clear that the high frequency components of the beam will decrease for lower energies and for big beam pipe radius. Therefore, it is important to determine with sufficient precision the value of these components. An example is given in Fig. 1. The total wall current at several locations along the DP (input, middle and end) is given in time domain for a train of gaussian bunches. Since the beam pipe radius is constant along the DP -$b = 50$ mm-, only the increase of the bunch width $\sigma_z$ [3] is responsible of the lower high frequency components at the end of the device.

**Radiation damage** At the final IFMIF accelerator the diagnostics located into the target area will support very high levels of radiation. In the case of IFMIF-EVEDA, due to the proximity of the beam dump, there will be high radiation levels mainly in the beamline after the magnetic dipole. The diagnostics placed in this area will support high neutron and gamma fluxes. Although this is an issue for the diagnostics located there, this area can be used to test a prototype of the transverse beam profiler for the target area at the final IFMIF. However, the DP will be located out of the hot area and will not have to stand such high radiation. Nevertheless, the radiation will still be a problem for sensitive devices like the fluorescence monitors.

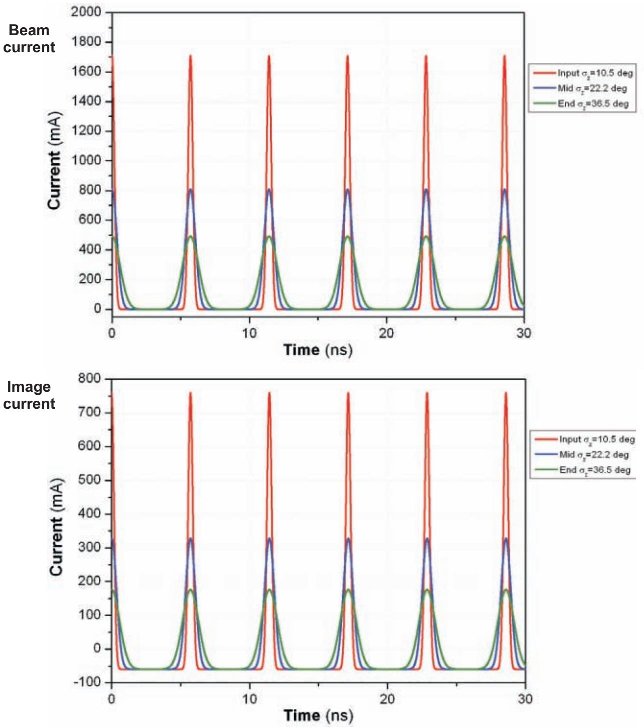

Figure 1: Comparison of the beam and image current at different locations of the diagnostics plate.

Table 2: Summary of the monitors used in the IFMIF-EVEDA accelerator for the measurement of several beam parameters.

| **Beam parameter** | **Monitor** |
|---|---|
| DC current | DC current transformer (DCCT) |
| AC current | AC current transformer (ACCT) |
| Position | Shorted stripline (SBPM) |
| Transverse profile | Gas fluorescence (FPM)<br>Gas ionization (BTPM) |
| Transverse halo | Segmented ring (SHM) |
| Transverse emittance | Quadrupole scan |
| Longitudinal emittance | Buncher scan |
| Energy spread | Magnetic dipole (MD) |
| Mean energy | SBPM |
| Longitudinal profile | SBPM spectra |
| Beam losses | Under investigation (BLM) |

## MONITORS DESCRIPTION

The list of the main diagnostics devices to be installed in the DP is given in Tab. 2. It is important to point out that due to the mechanical flexibility of the DP, another devices could be installed in the future for further tests. For example, transverse profilers, like Secondary Emission Monitors or Wire Scanners, could be installed to cross-check or complement the non-interceptive profilers at low current or low duty cycle. In the same way, fast faraday cups or particle detectors could be studied.

### *Beam current*

The main operation mode of the accelerator is CW, thus an DC current transformer (DCCT) will be installed in the DP to measure the DC beam component. Transmission losses out of the scHWR and current fluctuations can also be observed. In addition, an AC current transformer (ACCT) will be installed to measure the pulse current and the noise coming from the accelerator equipment.

### *Centroid transverse position*

Although it is not a fundamental measurement for the beam characterization, the transverse beam position is an important parameter for the control of the accelerator and the beam transport through the DP. In addition, as seen later, the Beam Position Monitors can be used to give information about other beam parameters for characterization. Three four-stripline monitors shorted in one side (SBPM) [7], will be installed. They will provide information about the position and phase at each SBPM at the fundamental bunch frequency (175 MHz).

### *Transverse profile*

Two non-interceptive alternatives based in the interaction of the beam with the residual gas will be tested in the DP. Both will be developed and installed in the DP for comparison of the behaviour in the IFMIF-EVEDA hard radiation environment.

**Ionization Profile Monitor** The main details of this device, in development at CEA, were presented in [8]. It will measure the current created by the residual gas ionization pairs at several microstrip lines around the beam axis.

**Fluorescence Profile Monitor** The interaction between the beam and the residual gas produces photons due to the excitation and de-excitation of the gas molecules. The light emitted can be observed and used for the determination of the beam profiles [9]. Due to the low cross sections of the excitation reactions between the beam and the gas at those energies, the diagnostics will require a sufficient long integration time and optics optimization.

### *Transverse halo*

In a high current hadron LINAC, the transverse halo has to be monitored to minimize the beam losses and ensure a safe operation of the accelerator. Due to the high power of the IFMIF-EVEDA beam, segmented rings will be placed at the outer region of the beam pipe in the DP to check the halo growth. The device could also serve as a fast interlock in case of beam displacement.

### *Transverse and longitudinal emittance*

Quadrupole and buncher scans will be used in combination with the transverse and longitudinal profilers, respectively, to check the transverse and longitudinal emittance. The method will consist in varying the strength of the first quadrupole (or the buncher). In principle, it is limited by the high space charge of the deuteron beam at the HEBT. However, with the use of the method in combination with a particle tracking code, able to handle the beam space charge, the emittance could be obtained with a certain accuracy. Further details of the present status of the simulations can be found in [3].

### *Mean longitudinal energy*

The mean energy of the deuterons will be determined by using the Time of Flight technique. In this case, the sum signal from three BPM's will be used. The BPM's are expected to provide sufficient phase accuracy (1 °) [7] which, in combination to the distance between BPM's, will provide the necessary resolution.

### *Energy spread*

Although it is not directly included in the DP, a magnetic dipole is installed downstream the DP in the HEBT [3]. The high dispersion in the dipole could be used to calculate the energy spread of the beam, using the beam transverse profilers before and after the dipole [10].

## CONCLUSIONS

The DP for IFMIF-EVEDA will be essential to accomplish the objectives of the accelerator. It will contain many challenging instrumentation which pushes up the present requirements at the hadron linacs. In this paper, the main instruments that will allow the beam characterization have been discussed and identified. The DP will be flexible and permit the addition of future diagnostics techniques.

## ACKNOWLEDGEMENTS

We would like to acknowledge the great help from all the institutes and diagnostics experts who participate in the IFMIF-EVEDA diagnostics miniworkshop at CIEMAT during summer 2007.

## REFERENCES

[1] A. Mosnier, A. Ibarra, A. Facco, these proceedings.

[2] P. Garin, these proceedings.

[3] C. Oliver et al., these proceedings.

[4] P. Ausset et al., DIPAC'05, p. 173 (2005).

[5] J. Cuperus, Nucl. Inst. Methods, 145, 2, p. 219-231 (1977).

[6] R. Shafer, AIP BIW'93,319, p. 303 (1994).

[7] S. Kurennoy, LINAC'00, p. 172 (2000).

[8] J. Marroncle et al., BIW'08, to be published.

[9] F. Becker et al., BIW'08, to be published.

[10] R. Shafer et al., PAC'97, p. 83 (1998).