NEW TESTS OF FLUORESCENCE BEAM PROFILERS FOR THE LINEAR IFMIF PROTOTYPE ACCELERATOR (LIPAC) USING 9 MeV DEUTERON BEAMS*

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Abstract

LIPAc prototype accelerator will be a 9 MeV, 125 mA continuous wave (CW) deuteron accelerator, focused on validating the technology that will be used in the future IFMIF facility. In this high power accelerator (1.125 MW), interceptive profilers are forbidden during the nominal operation. In the quest of non interceptive beam transverse profilers required for LIPAc, two prototypes based on the fluorescence of residual gas have been developed by CIEMAT. New experimental tests using 9 MeV deuterons were performed at CNA using the prototypes. Tests include injection of hydrogen, injection of nitrogen for comparison with previous results and a beam steering experiment. Hence, a brief description of the beam transverse profile prototypes together with a summary of the improved new measurements are presented.

INTRODUCTION

The International Fusion Materials Irradiation Facility (IFMIF) [1] aim is to provide a materials irradiation database for the design, construction, licensing and safe operation of the future Fusion Demonstration Reactor (DEMO). IFMIF facility will be a dual 40 MeV deuteron accelerator (2 x 125 mA operating in continuous wave), colliding with a liquid lithium target with the aim to produce high neutron fluxes to test new materials.

In the framework of the "Broader Approach", the Linear IFMIF Prototype Accelerator (LIPAc) project includes the construction of a 9 MeV and 125 mA (CW) deuteron accelerator prototype.

In such high current accelerator, non-interceptive diagnostics are required. Hence, in the following sections, a brief description of fluorescence profile monitor prototypes for the LIPAc, together with new experimental tests using 9 MeV deuterons will be provided.

FLUORESCENCE PROFILING

In general, accelerated particles passing through a vacuum pipe may excite residual or injected gas particles in the beam tube along the beam path, thereby producing photons as a consequence of de-excitation. The resultant light can be used to determine the beam profile. This non interceptive profile technique has previously been tested on other machines, e.g., the relativistic heavy ion collider RHIC [2], the high energy proton synchrotron CERN-PS [3, 4], and the heavy ion GSI-UNILAC [5].

Two prototype fluorescence profile monitors (FPMs), designed and developed at CIEMAT [6], were tested previously at the Centro Nacional de Aceleradores (CNA), Spain [7], where the beam profiling tests were performed with a 9 MeV deuteron beam. Beam current and pressure scans were performed as well as a crosscheck between the prototypes and a rotating wire scanner [8-9].

FPM Prototypes

Two prototype FPMs are constructed 1) based on a custom Intensified Charge Injection Device (ICID) camera 2) second one based on a linear Photo Multiplier Tube (PMT) array and will be referred ICID-FPM and PMT-FPM respectively.

For the first prototype (ICID-FPM) the CID camera selected is a model 8726DX6 by Thermo Sci. coupled to an image intensifier by Proxitronic and a lens. The camera and the intensifier are controlled by external control units. The second prototype is based on a linear multianode PMT coupled to a lens. The 32 channel PMT H7260 from Hamamatsu Photonics with a Bialkali photocathode and quartz input windows was selected. For the charge integrator and data acquisition a PhotoniQ IQSP482 from Vertilon Corp. was chosen. The PMT array is mounted in an interface board together with the lens objective in a custom design and compact assembly for a safe handling interface. Specifications and additional details can be found in [9].

EXPERIMENTAL SETUP

Both profile monitors were installed at the end of the experimental line, one in front the other looking at the vertical projection of the beam. A 25 mm focal length lens was chosen for the ICID-FPM whereas a 50 mm lens was selected for the PMT-FPM. That results in a field of view (FOV) of 181 mm and 250 mm, with a total scale factor (β^y) of 0.55 and 0.79 respectively.

A triplet is installed in the experimental line to final shape the beam. A fixed (15 mm diameter) collimator is located downstream this triplet. This collimator is responsible of a beam intensity cutting during a beam steering experiment and reported hereafter.

The vacuum chamber was blackened and baked during 5 hours at 220ºC, including a soft cooling during 24 hours. This helped to minimize light reflections off walls and certainly improved the quality of the measurements.

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MEASUREMENTS WITH DEUTERONS USING ICID-FPM

Beam Profiles Using N_2

The linear relation between the gas pressure inside the vacuum chamber and the photon yield (checked experimentally previously [8-9]), is used here to recreate higher current scenarios in terms of signal intensity. Although the present monitors have been designed for high current beams, the tests were performed using beam currents of tens of microamperes. Thus, the pressure was raised to compensate the lower beam current.

Figure 1 shows a series of transverse beam profiles (Fig. 1a to Fig. 1f) during a beam current scan (from 0.45 μA to 7 μA) using a fixed N_2 pressure (1.7×10^{-4} mbar) and intensifier gain (91%) for proper comparisons. The peak profile intensities (valid as signal strength estimator for Gaussian profiles) and the full width half maximum (FWHMs) for these profiles are shown in Fig. 1g and Fig. 1h.

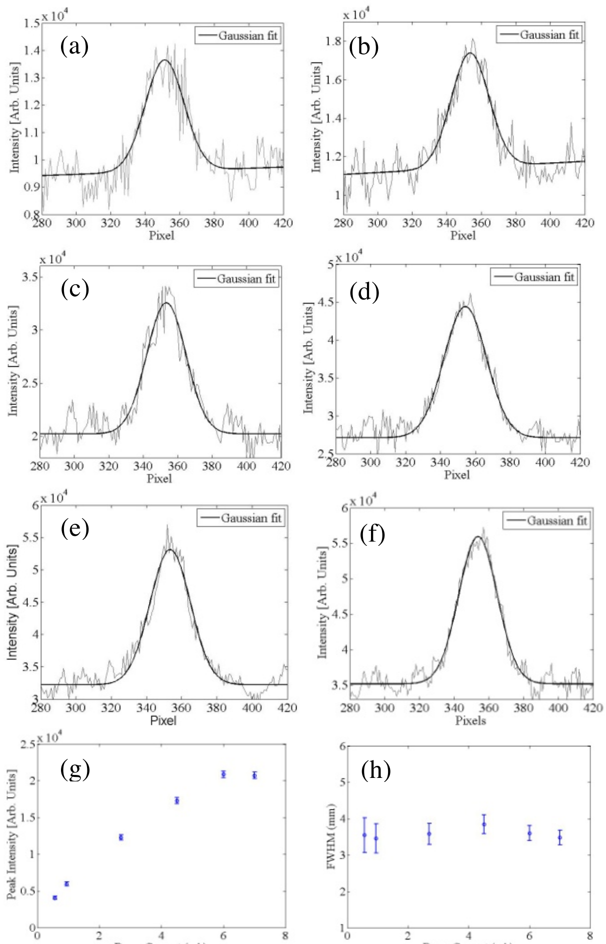

Fig. 1: Beam profiles acquired with the ICID-FPM prototype during a beam current scan are plotted for comparison. The gamma dose rates during the profile recording were from 6 mSv/h (a) to 23 mSv/h (f). Evolution of peak profile intensities (g) and beam widths (FWHMs) (h) are plotted versus the beam current for each profile.

The image saturation is apparent for higher signal levels (Fig. 1g) being recommended to change the gain settings in the intensifier for higher signal levels during normal operation to maintain the dynamic range (and linearity). This behaviour was not found with the PMT-FPM prototype during a larger beam current scan (from 0.4 μA to 40 μA) [9]. It should note that profiling with the ICID-FPM is easier now after the improvements described in the *experimental setup* section when compared with previous results [9].

Beam Profiles Using H_2

Commonly N_2 is the major component of the residual gas in the accelerator lines. An exception could be found in areas close to superconducting cavities where the major component is expected to be H_2.

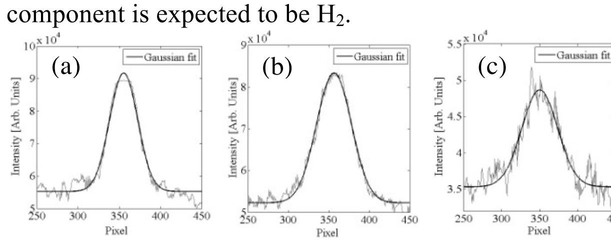

Fig. 2: Beam profiles using injected H_2 (a, b) for two different beam sizes, and one profile using N_2 (c) is shown for comparison. Beam widths are $\sigma^{(rms)}=5.4\pm0.1$ mm for (a), $\sigma^{(rms)}=6.8\pm0.1$ mm for (b) and $\sigma^{(rms)}=7.3\pm0.3$ mm for (c). Deuteron beam currents were 8 μA, 6 μA and 7 μA respectively.

Figure 2 shows beam profiles acquired using injected H_2 (Fig. 2a and 2b) together with a similar profile obtained using N_2 (2c). The hydrogen pressure for Fig. 2a and 2b was 1.3×10^{-4} mbar whilst the intensifier gain was set at maximum. The nitrogen pressure for Fig. 2c was 1.7×10^{-4} mbar while the intensifier gain was set at 91%. The beam widths are shown with errors coming from the fit in Fig. 2 caption.

A good consistency has been found between the profile shapes and beam widths along the experiment. Hence, the beam profiles recorded in a H_2 dominated vacuum, points to reliable operation when installed in areas close to superconducting cavities (Sc) although high beam currents will be required (due to intrinsically low vacuum pressures without option for gas injection).

MEASUREMENTS WITH DEUTERONS USING PMT-FPM

Systematic beam current and pressure scans were presented previously using the PMT-FPM monitor (contrary to ICID-FPM) [9]. Instead of presenting a similar scan with PMT-FPM (with the same conclusions) we will focus on the improvement factor found in the new measurements. In addition, an experiment in which the beam was steered transversally to analyze the capability of the monitor to track the beam centroid, the beam width and the displacement is presented.

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Comparison With Previous Results

A comparison with previous measurements can be performed to evaluate the improvement in the profile measurements. As noted in [8-9], the linear relation between the signal strength versus the beam current, beam pressure and integration time can be used for extrapolation (the same gas species was used here, i.e., nitrogen). Figure 3 shows contour plots (beam profile evolution in time) for a previous measurement (Fig. 3a) at very low current (to determine the minimum conditions), and two additional contour plots taken during the present experiments (Fig. 3b and 3c).

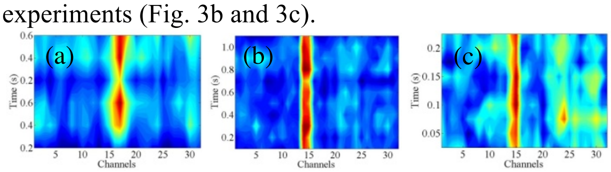

Fig. 3: Beam profile evolutions for comparison. Beam currents, pressures and acquisition times are 0.45μA, 3.6x10^{-4} mbar and 100ms (a), 0.45μA, 4x10^{-5} mbar, 100ms (b) and 5μA, 8x10^{-6} mbar, 50ms (c).

Given similar beam profiles, a simple comparison can be done by multiplying the beam current, pressure and integration times. If Fig. 3a is taken for reference, the improvement factor for data shown in Fig. 3b and Fig. 3c are 9.0 and 8.1 respectively. It should be noted that the pressures used in previous experiments were typically around 4x10^{-4} mbar, whereas the pressures in the new experiments are typically in the 4x10^{-5} mbar region (Fig. 4) and lower i.e., 8x10^{-6} mbar (see Fig. 3c).

Beam Steering Experiments

The deuteron beam was steered to check the availability of the non-interceptive profiler to track the beam and its main parameters i.e., beam centroid, beam width, intensity and total displacement.

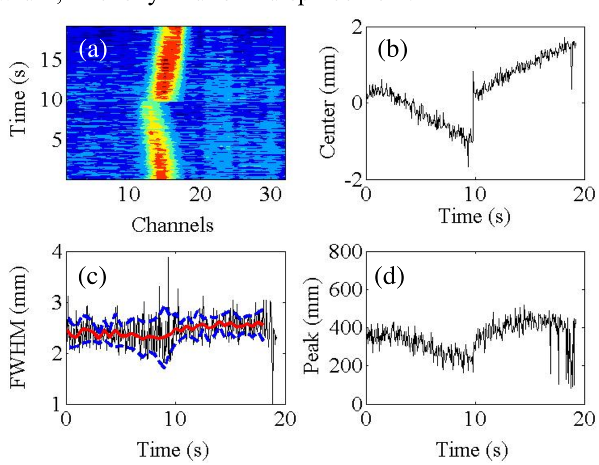

Fig. 4: Temporal evolution of the beam transverse profiles (a), the beam center position (b), the FWHM (c) and peak profile intensity (d) during a steered beam. The measurement was done using a beam current of 1.4 μA, N_2 pressure of 4x10^{-5} mbar and an integration time of 50 ms. Higher currents improve the measurements [10].

Figure 4 shows the temporal evolution of the main beam transverse parameters. The beam current is very low in this example, resulting in measurements with higher standard deviation (STD) values (e.g. blue curves shows 1σ confidence interval in Fig. 4c). Although better measurements have been carried out [10], the selected example shows better the beam-cut effect of a 1.5 cm fixed collimator installed upstream the experimental line. Due to a misalignment, when the beam was steered downwards the beam is cut and the peak profile intensity falls (beam current cut), see Fig. 4a and 4d. On the contrary, when the beam is steered upwards the beam current increase, thus the peak profile intensity increase. As a consequence of the signal strength variation, the STD of the fitted FWHM changes during the experiment i.e., 0.1<STD (mm)<0.62 for 0.5 s of averaging time and 0.09<STD (mm)<0.5 for 1 s.

CONCLUSIONS

New experimental tests have been performed using two prototypes of non-interceptive beam profilers designed for high current beams. Experiments consist in comparisons with previous measurements using injected N_2, validation of the FPM technique in H_2 dominated vacuums and a tracking of the main beam transverse parameters during a steered beam steering experiment. In addition, due to the absence of shielding between the beam target and the location of the profilers, the radiation levels during the measurements were not negligible.

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