DESIGN AND TEST OF THE LIPAc IPM

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Abstract

The *Linear IFMIF Prototype Accelerator (LIPAc)* will be commissioned in Rokkasho, Japan, shortly. Due to its high beam power of over 1 MW and its tremendous continuous wave beam current of 125 mA, non-interceptive profilers are required. We present the design and test of the LIPAc ionization profile monitor.

Due to the very high space charge, LIPAc is designed in a very compact manner which hardly leaves any room for diagnostics. The IPM was designed using FEM simulations to achieve the optimal electric field keeping the tight space requirements of LIPAc. Due to the limited space available, we had to abstain from using a magnetic guidance field and collect ions instead of electrons. To cope with the strong space charge forces of the beam, we have developed a software algorithm that aims to not only scale the distorted measured profile to its original size, but to fully reconstruct the original beam profile. This algorithm has been tested at SILHI, a high intensity ion source at CEA Saclay, France, where highest space charge forces can be achieved, and the results will be presented as well.

INTRODUCTION

The *International Fusion Material Irradiation Facility (IFMIF)* accelerator will serve as intense neutron source by accelerating two 125 mA *continuous wave (cw)* deuteron beams up to 40 MeV and then having them collide with a liquid lithium target. In the resulting nuclear reactions, neutrons are created. The *Linear IFMIF Prototype Accelerator (LIPAc)* will be a prototype for IFMIF with the very same beam characteristics, but limited to a single 125 mA cw deuterium beam of 9 MeV [1] only.

A major challenge resulting from such beam conditions is the very high beam current at rather low energies that makes non-interceptive diagnostics mandatory and requires a very compact accelerator design leaving only little room for beam diagnostics. An additional challenge is the increased radiation level due to the lithium target at IFMIF / the beam dump at LIPAc which makes high demands on the instrumentation in terms of radiation tolerance.

The development and experimental characterization of a prototype for the LIPAc *Ionization Profile Monitor (IPM)* is already described in earlier publications [2, 3]. Detailed tests were performed at CEA Saclay, France, and GSI, Germany.

When the accelerator beam passes through the residual gas, it will partially ionize the residual gas present in the beam pipe. By applying an electric field, one can extract the ionization products, read the ionization current profile and thereby derive the beam profile. For this technique, it is of utmost importance to ensure that the ionization current keeps its profile during the drift to the read-out plate. This requires a highly uniform extraction field. In addition, a magnetic guidance field is commonly applied to confine electrons along their drift pass to counteract space-charge effects from the beam. Due to a lack of space however, we had to abstain from a magnetic field guidance for the IFMIF-EVEDA IPM and will therefore collect only ions and no electrons.

PROTOTYPE TEST

The IPM prototype was tested in detail at GSI, Germany. There, it was shown that the electric extraction field is uniform, that it dominates any other distortion mechanism at nominal field strength and that the measured profile therefore should be the real beam profile. To test this in a more direct manner, we have compared profiles of 1 mA Xe^{21+} beams acquired by our IPM with profiles from a BIF monitor of GSI.

In Fig. 1, an IPM profile is given in blue and a BIF profile in red. The profiles match nicely as indicated by the calculated standard deviations of 4.72 mm for the IPM and 4.73 mm for the BIF profile. Additional IPM and BIF profiles have been compared for various residual gas types and pressures. The RMS width of IPM and BIF profiles commonly match well within 100 μm. Details on all the prototype tests performed at GSI are presented by Egberts et al. [3].

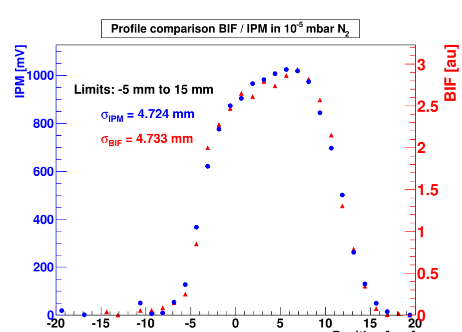

Figure 1: IPM profile (blue) and BIF profile (red) are in good agreement.

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FINAL IPM DESIGN

Based on the findings of the tests at the UNILAC and the SILHI source of the IPHI project, the final versions of the LIPAc IPMs have been developed, with an apertures of 103 mm and 153 mm. For the IPMs, only radiation hard materials have been used, like metals, ceramics, epoxy glass, etc. A sketch of the final IPM with 153 mm aperture is given in Fig. 2. On LIPAc, two of each IPM type will mounted for x and y.

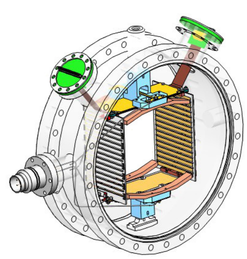

Figure 2: Design of the final LIPAc IPM.

The internal aperture of the IPM is a few mm larger than the internal beam pipe diameter. This way, the IPM is well protected from the beam by the beam pipe itself. This approach however places the circular beam pipe in close proximity to the rectangular field box. To counteract any distortions of the electric extraction field caused by the grounded beam pipe, curved electrodes on both sides of the IPM set appropriate voltages are added, as can be see seen in Fig. 2 in a brass-like color.

The IPM field box was designed to optimize the electric field uniformity based on FEM simulations by Lorentz-E [4] while keeping the IPM depth within reasonable limits. This process includes the adjustment of size, position and voltage of each degrader pair and optimization of the curvature, size and voltage of the correction electrodes.

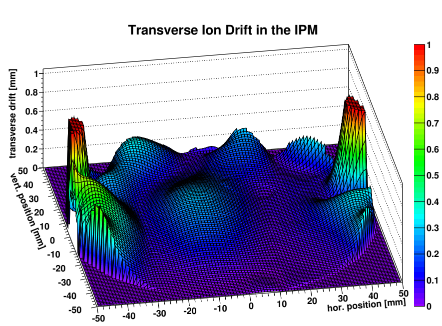

Figure 3: Transverse ion displacement during their drift towards the read-outstrips in the extraction field only.

For a better understanding of the extraction of the ionization particles by the electric field, a particle tracking of the ions was performed. The transverse displacement of the extracted ions in the central IPM plane is plotted in Fig. 3. Since no particles are expected outside the beam pipe diameter, the drift is set to zero in this region. One can see that in the center of the beam pipe, where the beam is to be expected, the transverse ion drift is constantly well below 500 μm. For the tracking, the high voltage of the second IPM has been taken into account which results in the asymmetry seen in Fig. 3.

SPACE CHARGE EFFECT

This particle tracking, however, only takes into account the effect of the electric extraction field, but not the space charge field. Using a "point summation" technique the space charge field of a 125 mA cw beam has been calculated for a beam distribution provided by our beam dynamics group. The resulting space charge field was superimposed with the field of the IPM field box, and the particle tracking was repeated. The resulting ion displacement in a different scale is given in Fig. 4.

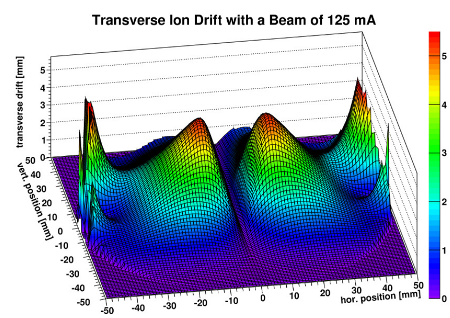

Figure 4: Transverse ion displacement during their drift towards the read-outstrips in the extraction and the space charge field.

The extraction field does not longer dominate the extraction process, but the space charge field results in an ion displacements of over 5 mm. The IPM will therefore measure a profile which is much broader than the actual beam profile. A simulation of a measurement of the LIPAc beam at nominal conditions is given in Fig. 5.

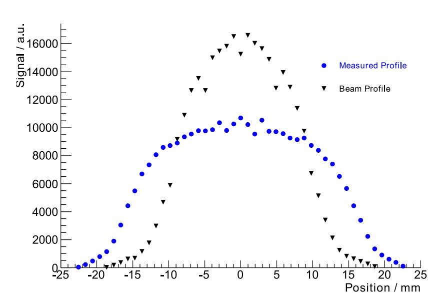

Figure 5: Simulation of a measured profile (blue) of a 125 mA beam at 9 MeV in comparison to the actual beam profile (black).

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SPACE CHARGE CORRECTION

Since no magnetic field can be applied due to a lack of space to confine electrons, other techniques have to be developed to overcome the space charge effect. Increasing the electric field will reduce the effect of the space charge, but this was found to be not sufficient for a proper profile measurement. Another approach that shows more merit is a correction algorithm that folds back the broadened profile to correct for the space charge effect.

Such a space charge correction algorithm requires the beam distribution as input to calculate the space charge field. The algorithm is implemented such that it assumes a random beam particle distribution to perform a particle tracking for this distribution and to determine the probability for each ion collected on the strips where it might have been created. Based on these probabilities, a correction matrix is calculated that can be multiplied on the vector of the measured profile to derive the actual beam profile.

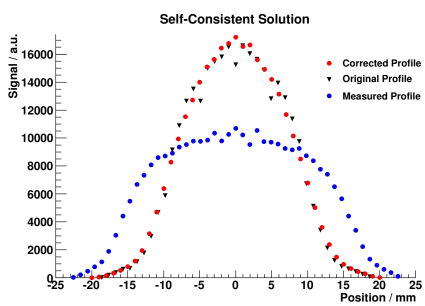

Figure 6: A space charge correction algorithm applied on a simulated profile measurement (blue) can grant a corrected profile (red) which is in good agreement with the original beam profile (black).

If the resulting corrected profile differs from the profile of the beam particle distribution used as input, the calculation is not self-consistent and a new beam particle distribution is tested. This can be repeated until a self-consistent solution is found. By generating a database of correction matrices for possible beam particle distributions, such a correction algorithm can be applied on-line.

When the final IPM version was tested in December 2011 the the SILHI source at CEA Saclay, the correction algorithm was tested as well. The SILHI source delivers high current proton beams of 90 keV. In contrast to simulations, the actual beam distribution is unknown in a real experiment. A simple evaluation of success or failure of the algorithm is therefore not possible. If the space charge effect is varied, while the beam shape is kept constant, the algorithm can be applied for each various different space charge settings and if the algorithm succeeds in reconstructing the beam profile, the resulting corrected profiles will match as the beam shape is kept constant.

Practically, it is impossible to vary the beam setting without changing the beam shape as well. It was therefore decided to vary the extraction voltage of the IPM instead. At lower extraction voltages, the collected ions will remain longer in the beam region and the effect of the space charge is increased.

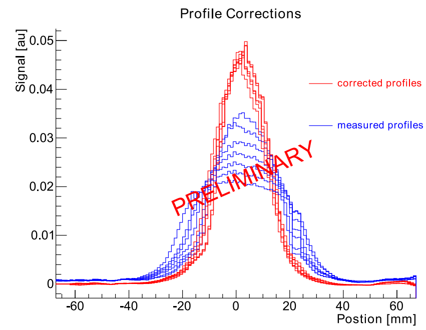

Figure 7: Test of the space charge correction algorithm at SILHI at 6 mA. Profiles measured of the same beam at different extraction voltages (blue) and the corresponding correction profiles (red).

A preliminary result of this test is presented in Fig. 7. The corrected profiles match nicely which indicates a successful profile reconstruction.

CONCLUSION AND OUTLOOK

We have designed and built a prototype for the LIPAc ionization profile monitor. It was tested in detail at the UNILAC at GSI. Based on our findings, we have designed the final LIPAc IPMs, out of which one is already manufactured and has been tested at SILHI in December 2011.

A major issue for an ionization profiler that has to abstain from a magnetic field guidance, is the space charge effect that distorts the measured profiles. To correct this distortion, a software algorithm has been written, which aims at fully reconstructing the beam profile. In simulations, it works very well and also experimental tests look promising. The data analysis is, however, still ongoing.

ACKNOWLEDGMENT

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