TWO-DIMENSIONAL IONIZATION BEAM PROFILE MEASUREMENT*

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Abstract

Equipment for non-destructive, two-dimensional beam profile measurement was developed for the high intensity beam project foreseen at INFN, Legnaro and the K200 variable-energy, separated-sector cyclotron at iThemba LABS. Ions, produced by the interaction of the beam with residual gas, are accelerated in an electrostatic field towards microchannel plates (MCP) for signal amplification. With the first of the two prototypes that were built, ions are accelerated in an electric field between two parallel plates and after passing through an aperture in one of the plates, move through the electric field between two curved plates and consequently bent through ninety degrees before reaching the MCP. The aperture in the plate provides one profile dimension and the spread in the energy of the produced ions the other dimension. In the second prototype two one-dimensional systems, rotated through ninety degrees with respect to each other, were installed in close proximity of each other. The beam profiles measured with both prototypes were compared with those measured with a nearby profile grid. Measurements were made on various beams and with intensities between 10 nA and 1μA.

BACKGROUND

One-dimensional residual gas beam profile monitors (RGBPMs) are already used successfully. Space limitations and the need to measure both dimensions of the beam at the same location, initiated the investigation of two-dimensional systems. iThemba LABS designed the first prototype, RGBPM-1, and was tested at the 6 MV Van der Graaff accelerator on site. It is based on the energy spread analyses method [1].

THE DESIGN OF RGBPM-1

In order to improve on previous designs, a different geometry, shown in Fig. 1, was developed for the analyzing field. Only electrostatic fields are used. Residual gas ions are accelerated in the collecting field and pass through a 1 mm extraction slit. The curved electrodes produce the analyzing field that bends the trajectory of the ions by approximately 90 degrees. Curved electrodes are chosen to assure that the electrostatic field remains perpendicular to the ion path. The aim is to obtain a linear projection of the two dimensional profile on the MCP surface. Ions created further from the slit obtain additional acceleration, and because of their higher energy will be deflected less in the analyzing field. Those that are created in the collecting field at position *a* in Fig. 1 are deflected more than those created at position *c*. The vertical position information can therefore be recovered on the MCP. The horizontal information gathered in the collecting field is maintained in the analyzing field and is therefore also available on the MCP, as in the case of a one-dimensional system.

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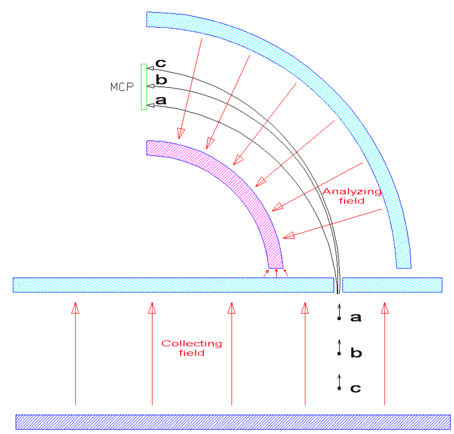

Figure 1: The electrostatic field in RGBPM-1.

Electric field calculations and particle orbit simulations were done with the program TOSCA [2], to determine the geometry as well as the potentials required on the electrodes. The calculations confirmed that beam profile information in both the horizontal and vertical directions can be obtained with this method as shown in Figures 2 and 3. For the current design, with central radius of the

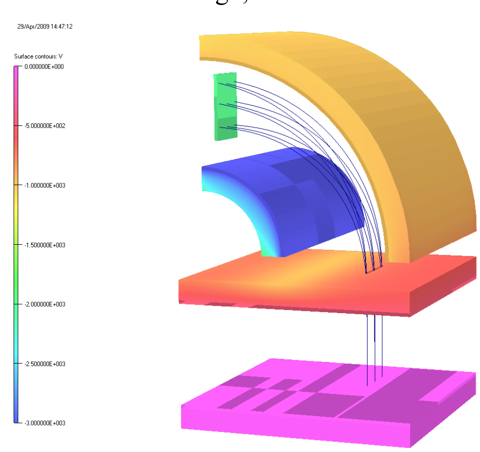
Figure 2: Calculated ion paths in the electrostatic fields of RGBPM-1.

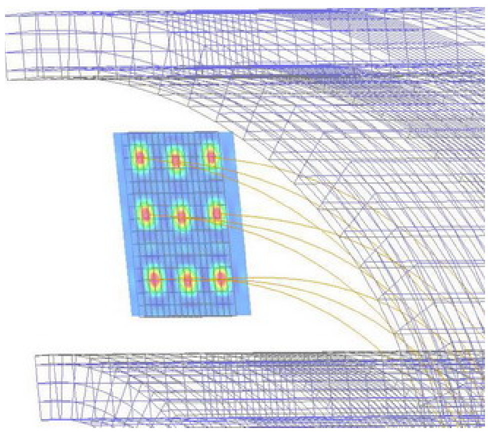

Figure 3: Projection of different beam positions onto the MCP of the RGBPM-1.

analyzing field of 40 mm, the magnification is 0.75 with respect to the measured profile in the vertical plane.

IMPLEMENTATION

A special X-Y matrix multilayer printed circuit board was designed as a position-sensitive collecting anode behind the MCP. This anode is at virtual earth potential. Current measurement electronics, using the ACF2101 integrating current to voltage converter, measures the amplified signal from the MCP. The printed circuit board has a resolution of 40 horizontal and 40 vertical channels with a pitch of 0.75 mm. A profile grid with a wire spacing of 1 mm was installed 7 cm downstream from the MCP to verify the measurements. The RGBPM-1 is installed in a beam diagnostic vacuum chamber in the beam lines and fits into the available space, without interfering with a nearby installed profile grid monitor.

Fig. 4 shows the profiles measured with the RGBPM-1 and a harp. The measured profile of the RGBPM-1 is nearly a factor 2 larger than the measured profile on the grid profile monitor, both in the vertical and the horizontal planes. TOSCA calculations indicate that this broadening effect is not due to distortion of the analyzing and collecting fields, as shown in Fig. 3, but could possibly be owing to space charge effects, or because the

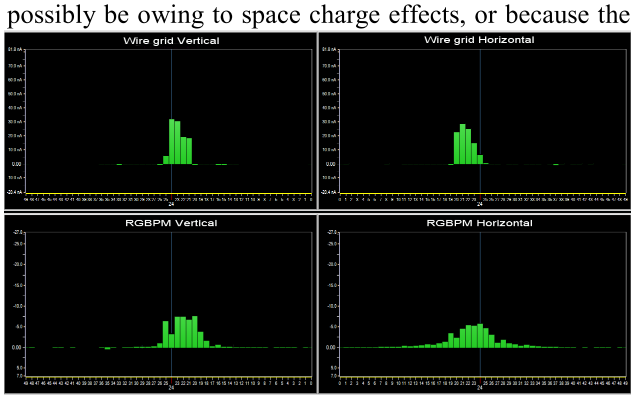

Figure 4: The horizontal and vertical RGBPM-1 profiles, bottom, compared with the profiles measured with a wire grid on top.

ions produced in the rest gas are not completely at rest. This has to be investigated

THE DESIGN OF RGBPM-2

The second design, developed at INFN at Legnaro, Italy, is based on the combination of two one-dimensional systems, rotated through ninety degrees with respect to each other, installed in close proximity as shown in Fig. 5. It was tested on the 15MV tandem at INFN, Legnaro as a

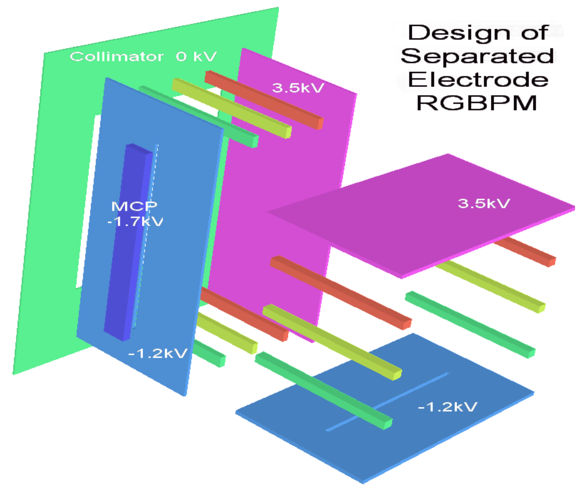

Figure 5: Calculated construction of the RGBPM-2 with the relevant voltages shown on the electrodes.

non-interceptive beam profile monitor for the high intensity beam project foreseen at INFN. The mechanical arrangement comprises two parallel plates for each plane, 50 mm apart with a collection voltage and extraction slit. A pair of rectangular MCPs followed by a position sensitive collecting anode is facing the slit, for each plane. The opening for the beam is 50 x 50 mm^2.

A photo of the monitor is shown in Fig. 6. The operating principle of the detector is described comprehensively in reference [3]. The copper bars, visible on the photo, keep the collecting field more uniform. The signal from the MCP is measured on a position sensitive anode, with a pitch of 1.25 mm (40 channels covering 50 mm). The electric fields of this monitor were also

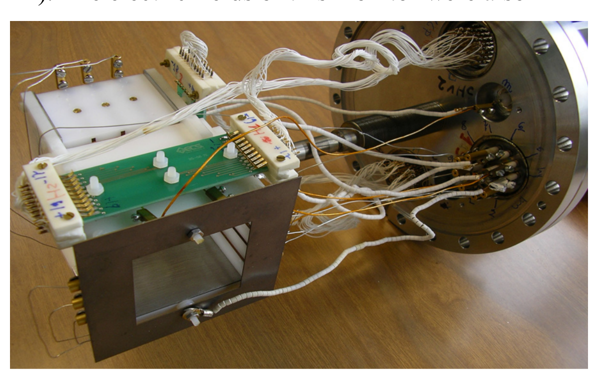

Figure 6: The residual gas beam profile monitor RGBPM-2. The 50 x 50 mm^2 opening for the beam is defined by a square tantalum protection screen in front of the monitor.

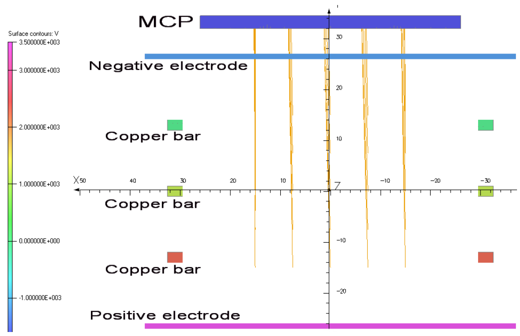

Figure 7: Twenty five particles, starting on a 30 mm x 30 mm XY-grid are tracked through the calculated electric field of the vertical profile monitor of RGBPM-2. The distortion of the profile is about 1mm due to non homogeneity of the electric field.

calculated with the program TOSCA. Particles were tracked in a plane perpendicular to the beam direction at the position of the vertical and horizontal micro channel plates to determine the distortion of the measured beam profile at the microchannel plates, due to the non-homogeneity of the electric field and likely influence between the horizontal and vertical collecting fields. The calculation, Fig. 7, shows that the beam profile in the vertical is distorted with less than 1 mm.

The collecting electrostatic field is approximately 1 kV/cm and the MCP side facing the collecting plane is at -1700 V, with about 800 V on each MCP. A grid system was installed 15 cm downstream from the RGBPM-2 detector to compare the profiles, in both the horizontal and vertical directions. The pitch of the grid is 0.75 mm. Several tests were made using various ion beams at different beam intensities. The profiles measured with the RGBPM-2 are strongly influenced by the presence of the profile grid intercepting the beam. When the grid is inserted to intercept the beam, the scattered electrons from the wires produce a lot of noise on the RGBPM-2. It

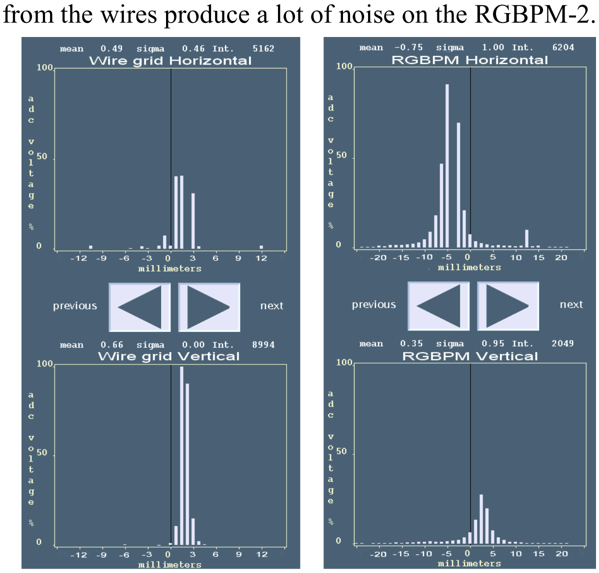

Figure 8: The profile of a 60 nA beam of 99 MeV oxygen ions measured with the grid is shown on the left. The profile measured with the RGBPM-2 is shown on the right.

is evident that the RGBPM-2 profiles are wider than those measured with the profile grid by approximately a factor of two as can be seen in Fig. 8. To explain this, four hypotheses are investigated: cross talk between the anode strips, transversal velocity of the produced ions, additional ionization caused by fast electrons produced by primary ionization and space charge effects. Work is in progress to improve the ion collecting field by experimenting with higher collector voltages.

CONCLUSION

The RGBPM-1 is a more compact and cheaper monitor compared to RGBPM-2, since it uses only one set of MCPs. It is however more difficult to operate, because the beam position display in the analyzing plane has to be calibrated against another beam position monitor. The RGBPM-1 monitor is also less sensitive than RGBPM-2 since the ionized rest gas is distributed over a larger area on the MCP. Even though the RGBPM-2 consists of two sets of electrodes, it still fits into a single vacuum chamber with insignificant mutual electrical influence. The calculations confirm these marginal distortions as shown in Fig. 7. It is possible to get good beam profile information with beam intensities from 10 nA at a pressure of 10^{-6} mbar without the addition of external gas. As a non-intercepting device, both RGBPM-1 and RGBPM-2 are useful beam position monitors. In both cases the RGBPMs were compared with a nearby profile wire grid system to determine their accuracy. The measured beam profile of both the RGBPM-1 and RGBPM-2 is about a factor of two larger than the beam profile measured with profile grid monitor. If the increase in the measured beam profile could possibly be due to space charge effects and because the ions produced in the residual gas are not really at rest, a higher collector voltage and mathematical methods [4] could possibly resolve this problem, and is the subject of future development.

REFERENCES

[1] J. C. Muller, et al, s, “Beam profile measurements using residual gas in the beam line”, http://www.kvi.nl/~annrep/ar1997/node61.html.
[2] http://www.vectorfields.co.uk/.
[3] B. Hochadel et al., “A residual-gas ionization beam profile monitor for the Heidelberg Test Storage Ring TSR”, Nucl. Instr. and Meth. A343 (1994) p 401.
[4] R. E. Williamson et al, “Analysis of measurement error in residual gas ionization profile monitors in a high intensity proton beam”, EPAC ’08, Genoa, TUPC109.