TRANSVERSE BEAM PROFILE MEASUREMENTS USING OPTICAL METHODS

A. Peters, P. Forck, A. Weiss, A. Bank
Gesellschaft für Schwerionenforschung (GSI), Darmstadt, Germany
e-mail: A.Peters@gsi.de

Abstract

Two different systems are currently under development at GSI's heavy ion facility to measure transverse beam profiles using optical emitters.
At the GSI-LINAC for energies up to 15 MeV/u residual gas fluorescence is investigated for pulsed high current beams. The fluorescence of N_2 is monitored by an image intensified CCD camera.
For all ion species with energies above 50 MeV/u slowly extracted from the synchrotron SIS a classical viewing screen system is used. Three different target materials have been investigated and their behavior concerning efficiency, saturation and timing performance is evaluated.
Both systems (will) use CCD cameras with a digital readout using the IEEE 1394 standard.

1 RESIDUAL GAS FLUORESCENCE MONITORS

The traditional determination of transverse beam profiles by secondary emission grids can not be applied at the high current heavy ion LINAC at GSI [1] due to the high beam power. Alternatively a non-intersecting residual gas monitor can be used or the fluorescence of the residual gas can be detected. The latter has the advantage that no mechanical parts and therefore no extra apertures are installed in the vacuum pipe, leading to a compact and cost efficient design. The method of residual gas fluorescence was applied to a proton LINAC [2] and recently also at a synchrotron [3]. Here a first test at a pulsed heavy ion LINAC is done.

The residual gas at the LINAC has a typical pressure of 10^{-7} mbar containing mainly Nitrogen. We use an additional gas inlet to increase the pressure up to 10^{-4} mbar. The N_2 is excited by the accelerated ions and the fluorescence from neutral or ionized molecules at wavelengths between 350 and 470 nm is dominant [2, 4]. The excited states have lifetimes of 40 ns and 60 ns, short enough to prevent broadening due to the movement of N_2^+ in the space charge potential of the beam.

For the detection we used an intensified camera (Proxitronics NANOCAM HF4 [5]), yet with a video signal output which is digitized using a PC frame-grabber. The photo-cathode is made of S20/Quartz, having a quantum-efficiency of $10 - 15\%$ at the interesting wavelength interval and a low dark current. A two-fold MCP amplified the photo-electrons with a gain of 10^6 and a P46 fast phosphor screen is used. The gating of the camera is done by switching the voltage between photo-cathode and the MCP within 5 ns.

A first test was performed with an 5.8 MeV/u Ar^{11+} beam with an electrical current of 700 μA and a pulse length of 200 μs. This corresponds to $\sim 10^{11}$ particles per macro-pulse passing the 35 mm diameter view-port for the camera. An example is given in Fig. 1 for one macro-pulse recorded at a pressure of 10^{-5} mbar having a relatively large vertical width of 13.6 mm FWHM. The projection of the 2-dim. plot with the 'single photon counting' pixels onto the axis of interest shows sufficient statistics. This can by easily improved by binning, in particular for a large width. The measurement is background-free, even without using any optical filters.

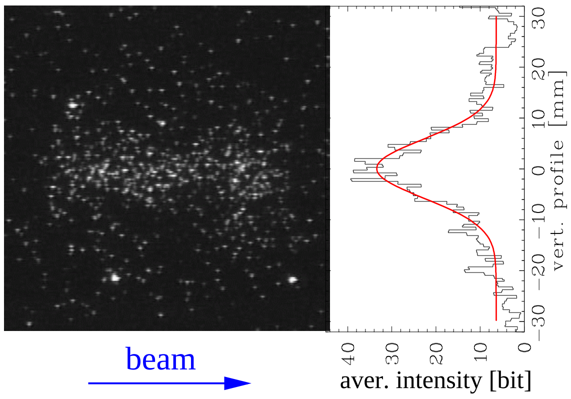

Figure 1: Fluorescence image and projection of a 5.8 MeV/u Ar^{11+} beam

It is shown, that for beams behind the stripper, like tested here, the method can be applied with a moderate pressure bump. While for beams at the first section of the LINAC, before the stripper, the particle current is an order of magnitude higher as well as the energy deposition, therefore a pressure bump is not needed. Using the switching of the photo cathode voltage, movement of the beam within the macro-pulse can be detected easily.

2 IMPROVEMENT OF VIEWING SCREEN SYSTEM

Up to now the viewing screens used at GSI to observe the slowly extracted ion beams from the heavy ion synchroton are equipped with Chromox targets [6], which have a good sensitivity, a high radiation hardness and are UHV-compatible as well. But a major disadvantage is their longlasting afterglow up to some minutes. Therefore they can not be used for exact measurements of beam movements in the millisecond region as well as changings of beam profile widths from spill to spill. Because of these facts multi-wire proportional chambers (MWPCs) are mainly used when precision measurements are necessary. But these MWPC systems are rather expensive due to the large number of analog electronics. Especially for a commercial therapy facility planned at the university clinicum in Heidelberg [7] an improvement of the GSI viewing screen was aspired leading to an inexpensive alternative to MWPCs.

In addition to the modernization of the image acquistion system (see next section) the main task was to test more suitable target materials. A comprehensive study [8] showed that commercially available phosphor screens [5] - prepared by sedimentation of phosphor grains on a glass or metal substrate - should have the right parameters. Therefore, the following two screens were chosen and compared to Chromox.

Name	Composition	Max. Light Emission	Decay Time (90% to 10%)	Decay Time (10% to 1%)
Chromox	Al_2O_3:Cr	700 nm	some ten ms	~ min.
P43	Gd_2O_2S:Tb	545 nm	1 ms	1.6 ms
P46	$Y_3Al_5O_{12}$:Ce	530 nm	300 ns	90 μs

Both phosphor screens have reasonable decay times as well as their maximum light output lies in the green region (about 540 nm) which fits ideally to the sensitivity of monochrome CCD sensors.

All screens were tested in two short beam times with protons and carbon ions, the main beam species foreseen for the cancer therapy facility.

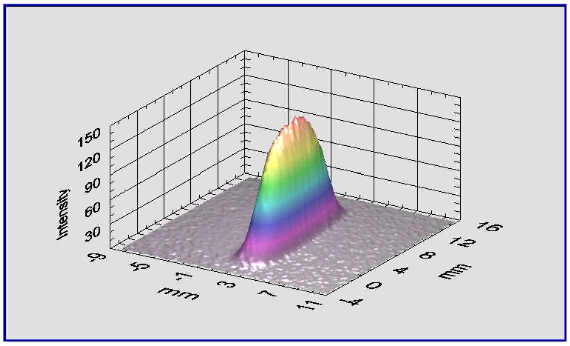

Figure 2: 3D profile of a 356 Mev/u $^{12}C^{6+}$-beam on a P43 target

Fig. 2 shows a typical example of a beam spot image. No differences in size are observed due to the target material, but the yield of light differs by a factor of about 7. The following table shows the values of the summarized surface luminosity relative to Chromox. All measurements were taken with the same camera settings with a 356 MeV/u $^{12}C^{6+}$-beam, a proton beam of 200 MeV shows similar results.

Target material	Rel. yield of light
Chromox	1.0
P43	1.46
P46	0.2

In Fig. 3 the summarized surface luminosity of the target images is compared to a current measurement with an ionization chamber (the last 200 ms of the spill were not measured due to a wrong camera setup). The data are not directly correlated because of the necessary target changes but P43 and P46 show the same time distribution with fluctuations in the ms as the IC. The different yield of light corresponds to the above given table. Differing is the offset and the smaller slope of the Chromox curve which shows directly the longer decay times of this target material.

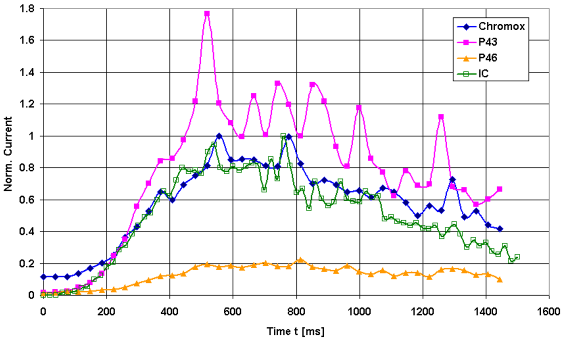

Figure 3: Summarized surface luminosity of the three different targets in comparison to a current measurement with an ionization chamber

No saturation was found in our experiments with up to 4×10^8 carbon ions per second, even at lower energies (80 MeV/u), which lead to higher energy loss in the target. But further studies have to be carried out.

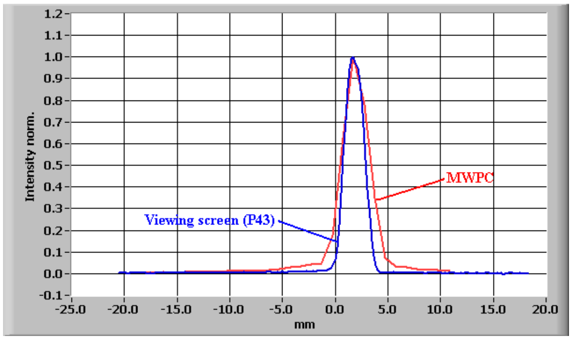

Figure 4: Horizontal profile of a 356 Mev/u $^{12}C^{6+}$-beam on a P43 target in comparison to a MWPC measurement

In comparison to MWPCs smaller profile widths are found by using viewing screens, see Fig. 4. This effect was yet observed by irradiation of films to verify the homogenity of area scans for therapy [9]. From these measurements it can be deduced that viewing screen images generate a more realistic picture of the beam spot size.

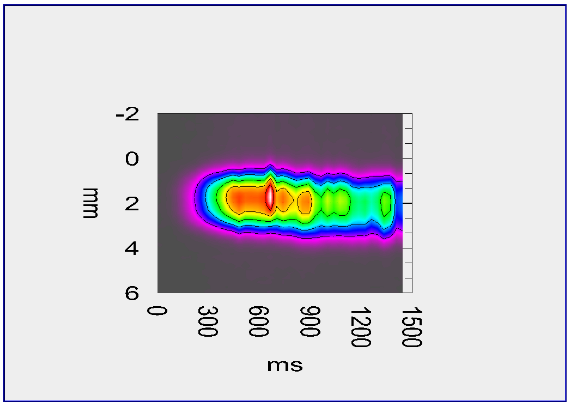

Figure 5: Evolution of the horizontal profile of a 356 Mev/u $^{12}C^{6+}$-beam on a P43 target during the spill

The contour plot in Fig. 5 shows the beam profile evolution during one spill. Even with a frame rate of only 30 images per second the good stability of the beam position - independently from the fluctuating intensity - is verified.

Recapitulating the first results of the target improvements one can state that with restricted parameters in ion species, energy and intensity as foreseen for therapy project viewing screens seem to be a good alternative to MWPCs with the same or even better properties for beam profile measurements.

3 DIGITAL IMAGE DATA ACQUISITION USING IEEE 1394

Until today most CCD cameras transmit the captured images as an analog TV-signal which is digitized afterwards with a framegrabber. This technique has two main disadvantages: the multiple AD-conversions and vice versa and the signal-loss due to noise and reflections on the analog cables. Direct digital readout of CCD cameras came up in the last years, but mostly each company uses its own protocol on different hardware, the cable length between camera and interface is limited to some meters or only point-to-point solutions are offered like “Channel Link”.

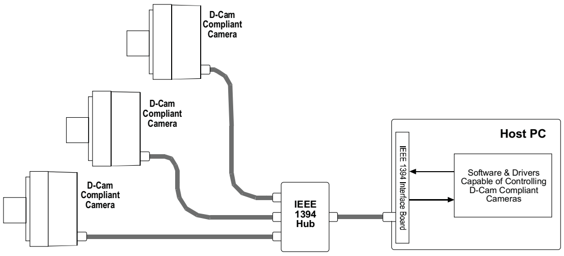

Figure 6: An example of an IEEE 1394 camera network

A new approach in industrial automation is to use the IEEE 1394 high-speed serial bus [10, 11], also known as “FireWire (Apple)” or “i.link (Sony)”. Unlike normal camcorders, which send highly compressed video data, industrial digital cameras for image processing must deliver uncompressed data. For this purposes the DCAM specification [12] was set up. This standard has several advantages for beam diagnostic measurement systems:

- a complete digital data path without any loss of image quality,
- a single bus with up to 63 nodes (see Fig.6 as an example), which can be brigded to other segments,
- multiple cameras with different properties, e.g. resolutions on the same bus,
- isochronous and asynchronous data transfer, with a throughput up to 400 Mb/s (and up to 3.2 Gb/s in the future),
- standardized and inexpensive PC interfaces, cables, hubs and repeaters for the bus infrastructure.

Up to now the cable length is limited to 4.5 meters between the individual nodes without repeaters, but bus extenders using glass optical fibers for longer distances exist [13], and the next IEEE 1394b specification will include standards for longer cable lengths.

For the above mentioned target measurements a prototype camera (type A302fs from Basler, [14]) was used which is capable to take 30 frames per second (maximum) with exposure times of up to 80 ms. The software package was written in LabVIEW using the IEEE 1394 driver for IMAQ to acquire the images and IMAQ Vision for image processing. For the viewing screen tests the camera works reliable and with the pronounced parameters. An intensified version of a similar camera will be built in the next months together with Proxitronic (see more information on [5]) for the residual gas fluorescence monitors.

4 REFERENCES

[1] W. Barth, *Proc. 20th LINAC Conference, Monterey*, p. 1033 (2000)
[2] D.P. Sandoval et al., 5th *BIW, Santa Fe, AIP Conference Proceedings 319*, pp. 273-282(1993)
[3] G. Burtin et al., *Proc.* 6th *Euro. Part. Acc. Conf. EPAC, Vienna*, p. 256 (2000).
[4] L.W. Dotchin et al., *J. Chem. Phys.* **59**, 3960 (1973).
[5] http://www.proxitronic.de
[6] R. Jung, *Proceedings of the* 1st *DIPAC, Montreux, Switzerland*, pp. 54-63 (1993)
[7] A. Peters, P. Forck, 9th *BIW, Boston, AIP Conference Proceedings 546*, pp. 519-526 (2000)
[8] A. Weiss, *“Neues Leuchtschirm-System für hochenergetische Ionenstrahlen”*, diploma thesis, to be published
[9] Th. Haberer, U. Weber, priv.comm.
[10] D. Aderson, *“FireWire systems architecture: IEEE1394a”*, www.mindshare.com
[11] Basler Vision Technolgies, *“IEEE 1394 Technology Brief”*, March 2001, www.basler-mvc.com
[12] 1394 Trade Association, *“IIDC 1394-based Digital Camera Specification, Version 1.30”*, www.1394ta.org
[13] NEC MX/GF4 IEEE 1394 Network Adapter, see http://www.1stt.at
[14] Basler Vision Technolgies, *“Basler A302fs camera manual”*, Nov. 2000, www.basler-mvc.com