

Experience with the Residual Gas Ionisation Beam Profile Monitors at the DESY Proton Accelerators

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Abstract

The first ionisation profile monitor (IPM) at DESY was installed at the end of 1988 shortly before the first run of the DESY III proton synchrotron. Extended versions of the IPM with amplifications from micro channel plates (MCP) were installed in PETRA II in 1989 and in HERA in 1991. These nondestructive monitors are working in vacuum conditions better than 10^{-8} mbar. Profiles are aquired at beam energies between 50 MeV and 480 GeV and current from $0.01 \mu\text{A}$ to 70 mA. The spacial resolution has been studied and is described in detail in this report. Readout is performed using phosphor screens viewed by various video cameras. The continuous video display at the operator console is very useful for beam studies and emittance measurements.

1 INTRODUCTION

The circular proton accelerators at DESY cover a wide range of energy (50 MeV - 820 GeV) and also a wide range of beam currents due to different operating conditions. It is desirable to measure the beam dimensions under all conditions in a non destructive way without modifying the monitor. The IPMs satisfy this requirement for the most conditions.

The first devices using the residual gas ionisation for non destructive profile measurements were proposed in [1] and the first use of a MCP inside such a monitor was reported in [2]. We have build, based on these ideas, IPMs for the proton accelerators DESY III, PETRA II and HERA. The readout is performed by phosphor screens viewed by video cameras. This concept offers some advantages: 1) There is no noise induced by the electromagnetic field of the bunches. 2) The resolution is not limited by the mechanical dimensions of anode stripes. 3) Only one optical feedthrough (a radiation harded vacuum window) is needed. The data analysis is performed by commercial systems such as TV-screens, TV-triggerable scopes or frame grabber cards for personal computers.

The design of and first results from the IPMs at DESY III and PETRA II are described in [5]. This report presents some new results from the monitors and discusses in detail the spatial resolution.

2 SENSITIVITY

In [5] we have reported that profiles at about 10 mA beam current at DESY III (corresponding to the first multi bunch operations) are easily detecable. This IPM does

not require a MCP; a proximity image intensifier (Proxi-fier Typ BV2502MG15, Proxitronic) in front of the SIT video camera improves the sensitivity by a factor of about 5. This is adequate for single bunch operation of DESY III.

Since the better vacuum conditions the monitors installed in the HERA and PETRA rings require greater sensitivity. Both include a MCP (Hamamatsu Type F2805-03, $60 \times 60 \text{ mm}^2$) positioned in the vacuum chamber in front of the phosphor screen which provides a gain factor of up to 3×10^4 . The readout for PETRA uses a Newvicon video camera and for HERA an SIT camera which is 200 times more sensitive. With this configuration the first circulating beam in HERA with a current of about $0.01 \mu\text{A}$ was 'seen' by the IPM. When HERA operates with nominal currents (160 mA) the SIT camera will be replaced by a normal video camera.

To avoid saturation of the video signal an automatic gain control is forseen. It controls the voltage across the MCP (gain) depending on the brightness of the video signal.

3 RESOLUTION

The precision of the measured beam profile depends on various effects which are discussed in the following. Since it is well known that collection of the electrons gives a very poor resolution [4], [5], we will concentrate on measurements using the ions.

3.1 Noise

The noise in the readout system is produced mainly by the video camera. It can be drastically reduced by adding a few video lines of the same picture or the same line of a few pictures. Cooling of the sensitive SIT camera by Peltier elements is helpful for reducing the dark current of the camera.

Up to now the data of the IPMs have been stored on a digital scope. The fits to the data are done by eye and by cursors. The uncertainty of this procedure is about $\pm 100 \mu\text{m}$; the error bars in the figures correspond to this value. In the future a personal computer will analyse the data so that a standard fit will reduce this readout error to a negligible value.

3.2 Optics

The video camera has to be focused on the phosphor screen. This can be checked by lighting the screen by a small lamp. $200 \mu\text{m}$ wide calibration marks are painted every 10 mm on the screen. These lines give a sharply defined picture which is also used to calibrate the measured

profile.

The grain size of the phosphor ($\leq 4 \mu\text{m}$) gives no contribution to the resolution.

Therefore the uncertainty due to the optic is much less than $200 \mu\text{m}$.

3.3 Field shaping

The ionisation products are guided by the electric 'extraction' field to the anode or cathode. Therefore parallel equipotential lines are necessary to produce a valid image of the beam. Fig. 1 shows the calculated lines for the IPM in DESY III.

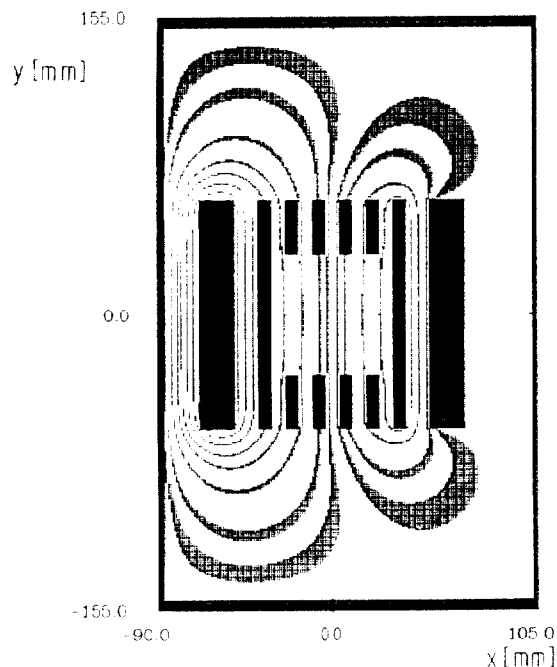


Figure 1: Equipotential lines in the IPM (DESY III type)

The small inhomogeneity of the lines causes a focussing effect for the ions produced in the middle of the monitor; the strength of the effect depends on the beam width. For a 10 mm beam width it supplies a focussing of about $100 \mu\text{m}$ [6]. For the normally smaller beams in the DESY accelerators the influence is less than $50 \mu\text{m}$.

The phosphor screen is covered with a 100 \AA aluminium layer. This prevents field shape distortions due to space charge in the high ohmic phosphor layer.

3.4 Ionisation

A) Initial velocity of the residual gas molecules:

From the kinetic gas theory it follows that the mean transverse speed of the residual gas (H_2) is $|\bar{v}_\perp| \approx 1000 \text{ m/s}$. This value will not change during ionisation and collection of the electrons/ions. The collection time for the H_2 ions is about $0.1 \mu\text{s}$ so that the distortion in space is about $100 \mu\text{m}$.

B) Ionisation-kick and electric potential of the beam:

The ionisation causes a kick to the electron of a residual gas molecule, which receives an energy of a few eV. This is probably the reason for the poor resolution when collecting

electrons. The ionisation-kick is negligible for the heavy ions. For high intensities and small beams the electric potential of a bunch can exceed the extraction field. This will disturb the collection although the ions perceive only the average field of many bunches because of the long collection time.

F. Hornstra [7] has proposed an experiment which measures the strength of these effects. He concludes that the measured beam width (FWHM) depends on the extraction field V_{ext} as

$$FWHM = x_0 + 4\sqrt{\frac{dE_x}{V_{\text{ext}}}}$$

(d is the distance to the image plane, E_x is the transverse energy of the ion and x_0 is the real beam width) if the bunch potential plays no role. In Fig. 2 is plotted the measured beam width (FWHM) versus $\sqrt{1/V_{\text{ext}}}$. It shows that the collected ions have a distortion of less than $100 \mu\text{m}$ at small beam currents and at strong extraction fields. The deviation from linearity at small V_{ext} and at high beam currents indicates the influence of the bunch potential. We have similar results for the IPMs in PETRA and HERA [6].

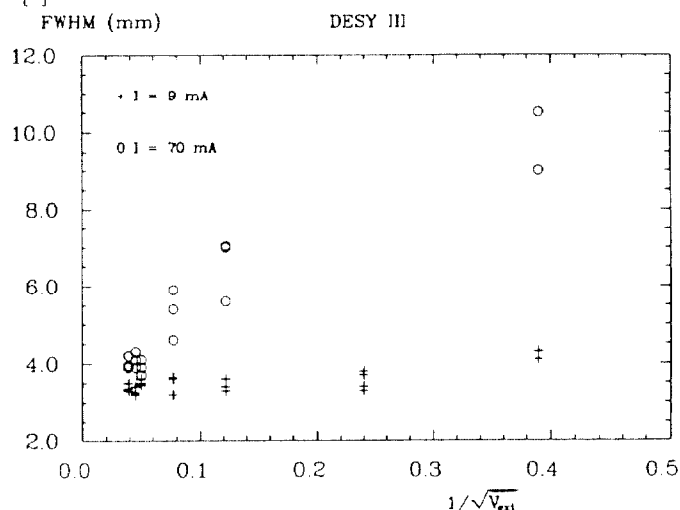


Figure 2: Dependence of the measured beam width (FWHM) from the extraction field V_{ext} and the beam current I at DESY III. The variation of the FWHM at certain V_{ext} is caused in different acceleration cycles with slightly different currents.

This method supplies the maximum acceptable beam current for IPMs as a function of the beam width.

3.5 Secondary Electrons

A very sensitive mode of operation of the IPMs was necessary during the first runs of the proton rings. Therefore the ions were accelerated onto the cathode, where they emitted secondary electrons. These electrons were accelerated onto the MCP (PETRA/HERA) or directly onto the phosphor screen (DESY III). The primary electrons were decelerated so that they didn't contribute to the signal. The secondary electrons have an energy and angular distribution when they are emitted from the cathode. This

results in a spread of the measured profile. With the same idea used in 3.4 it is possible to determine this effect by plotting the measured beam width versus $\sqrt{1/V_{\text{cath}}}$. The extrapolation at $V_{\text{cath}} = \infty$ gives the real beam width. This measurement is shown for HERA in Fig. 3. The two data points at $\sqrt{1/V_{\text{cath}}} = 0$ are the beam width measured by changing the polarity and accelerating the ions directly onto the MCP. The extrapolated and the measured width are in good agreement. The decrease of the measured values at low V_{cath} is caused by a change of the energy and angular distribution of the secondary electrons at low impact energy.

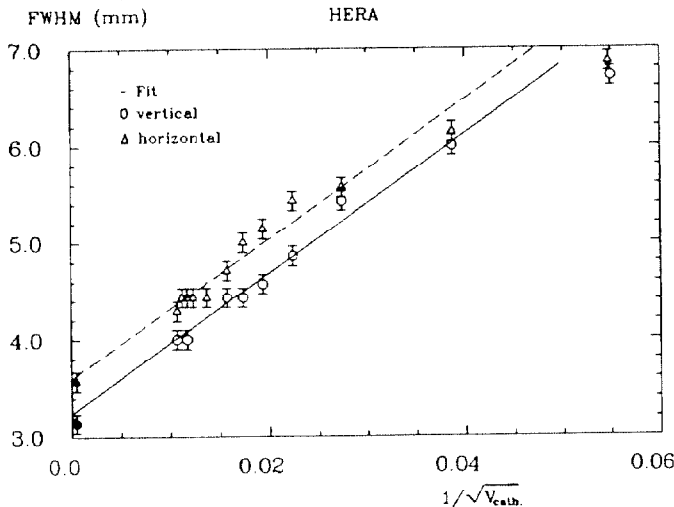


Figure 3: Dependence of the measured beam width (FWHM) in HERA on the cathode potential V_{cath} .

We have results consistent for PETRA and DESY III [6]. Measurements with a wire scanner in DESY III agree within $100\mu\text{m}$ with the extrapolated beam width. In the future the collection of ions will be the usual mode of operation. Unfortunately this is not possible in DESY III because of the missing MCP; the aluminium layer in front of the phosphor screen would prevent the ions from reaching the phosphor. But the additional term can be easily subtracted.

3.6 Micro Channel Plate

A MCP consists of thousands of small glass tubes coated by a highly efficient secondary electron emitter. The small channel diameter and the spacing of the channels of less than $10\mu\text{m}$ are negligible for the resolution. But the multiplied electrons at the output of a channel have again an energy and angular distribution [8]. The distance between the MCP output and the phosphor screen in our IPMs is 4 mm because of the need for a high acceleration voltage ($\approx 10\text{ kV}$). The maximum diameter of the charge cloud under these conditions is calculated to about $300\mu\text{m}$. The same trick used in the previous sections can be used to measure the net effect at the IPMs but the potential between MCP and screen is limited to a small region between 8 – 12 kV, so that the interpolation to an infinite acceleration voltage gives a big uncertainty (the measurements give an effect consistent with $0 \pm 400\mu\text{m}$). Additional measurements in

the laboratory are foreseen to obtain the correct value.

For future operation the age of the MCP must be taken into account. The gain of the channels most used will decrease after a time [3]. Since our IPMs have a large aperture exact profile measurements will be done with a small local beam bump which moves the image onto unused channels of the MCP. This also will work against inhomogeneous aging of the phosphor screen.

4 CONCLUSIONS

The IPMs for the proton accelerators at DESY have worked for 2 years with a good reliability. Their continuous video display of the beam width give a quick picture of the beam behaviour after injection and during acceleration and storage. The sensitivity of the IPMs is adequate to measure profiles down to a beam current of $0.01\mu\text{A}$. The use of the primary ions is necessary to achieve a good spacial resolution. Nevertheless one has to take into account the energy and angular distribution of the secondary electrons from the cathode and from the MCP. Having done this, the profiles (FWHM) of the IPM and the wire scanner at DESY III agree to within $100\mu\text{m}$. The IPM-profiles in HERA are about $500\mu\text{m}$ wider than those from the wire scanners; this may be the result of residual beam optics errors in HERA, since the IPMs and wire scanners are at different positions in the ring.

Acknowledgement

I would like to acknowledge A. Lazos, M. Miat and H. Schultz for their contributions to the electronics, construction and installation work.

5 REFERENCES

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