BEAM PROFILE MONITORS FOR THE HERA PROTON ACCELERATORS

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Abstract: Residual gas ionization beam profile monitors are used in DESY III and PETRA II to measure the transverse distribution and the width of the proton beams. First measurements indicate that a good spatial resolution is achieved. With the PETRA type of monitor profiles of beams with currents of 10 μA (in a pressure of 2.5×10^{-8} $mbar$) have been measured.

Introduction

The complex of the HERA proton accelerators consists of the linear accelerator LINAC III (310 MeV/c), the synchrotron DESY III (7.5 GeV/c) and the storage rings PETRA II (40 GeV/c) and HERA (820 GeV/c). All circular accelerators will have non destructive beam profile monitors for emittance measurements and for observation of dynamic beam size behavior.
Presently, in DESY III and PETRA II are working two residual gas ionization beam profile monitors, one for horizontal and one for vertical profile measurements. Foreseen for HERA are the PETRA II type monitors plus one synchrotron radiation monitor and wire scanners.

Residual Gas Ionization Profile Monitors at DESY III

The principal design and functions of the monitors are well discussed in [1, 2]. A schematic drawing of the monitor is illustrated in fig. 1. Its vacuum assembly insertions are shown in fig. 2. The assembly is mounted on a vacuum flange. Every electrode is exactly positioned by Macor-rod spacers, so that the electric fields are precisely homogeneous in the active volume of the monitor.

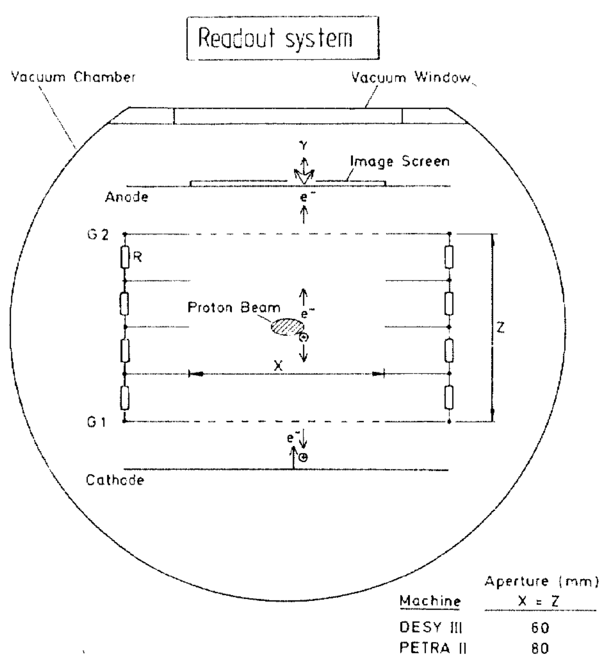

Figure 1: Cross sectional schematic of the proton beam imaging component of the residual gas ionization profile monitor. From [1]

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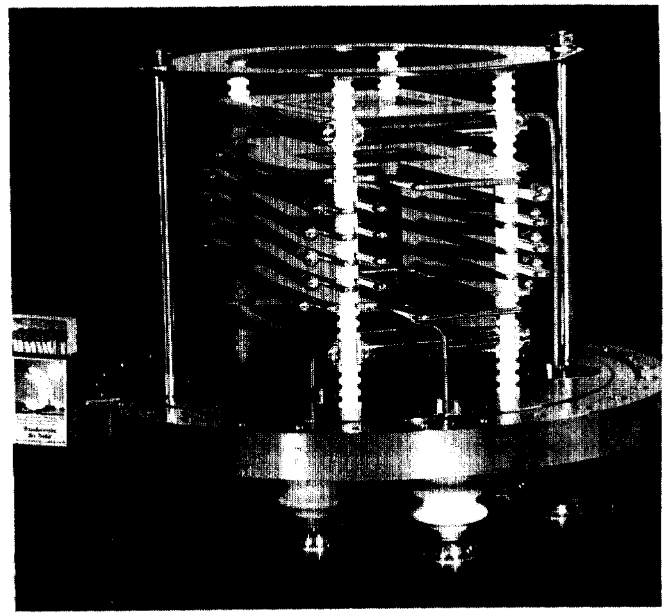

Figure 2: Photo of the vacuum assembly insertions of the DESY III profile monitor

The phosphor screen consists of a glass plate (6.5×6.5 cm^2) with a layer of P31 phosphor on one side. The phosphor is covered with a 10 nm layer of aluminium. This aluminium layer provides a homogeneous electric field in front of the screen and a conductive surface for the charge hitting the screen. A sensitive SIT-Videocamera is used for viewing the screen. The camera is conected to a TV monitor placed in the main control room. A given line of the TV signal can be displayed on an oscilloscope and analyzed for more quantitative informations. The sensitivity of the combination of the phosphor screen and the SIT-camera was determinated as $S = 2.7 \times 10^5$ $e^-/s/mm^2$. This value was confirmed by the first measurements at DESY III [2]. As a result, profiles can be measured for beam currents below 10 mA in a vacuum of about 2×10^{-8} $mbar$.

The production of images on the the phosphor screen can be realized in different ways depending on the applied voltages on the electrodes. For example:
a)

$$U_{G1} = -1\ kV,\ U_{G2} = +1\ kV,$$
$$U_{anode} = -1\ kV,\ U_{cath} = -18\ kV$$

The positive ions from the ionization strike the cathode where 2 - 3 secondary electrons are be emitted. They will reach the phosphor screen with an energy of $E_{e^-} = 17\ keV$ to produce an image.
b)

$$U_{G1} = -1\ kV,\ U_{G2} = -1\ kV,$$
$$U_{anode} = +18\ kV,\ U_{cath} = -18\ kV$$

Primary electrons from the ionization and secondary electrons (from the positive ions striking the cathode) will reach the screen with an energy of 18 and 36 keV respectively.

c)

$$U_{G1} = -1\ kV,\ U_{G2} = +1\ kV,$$
$$U_{anode} = +18\ kV,\ U_{cath} = 0\ kV$$

Only the primary electrons will reach the screen with an energy of $E_{e^-} = 18\ keV$.

d)

$$U_{G1} = +1\ kV,\ U_{G2} = -1\ kV,$$
$$U_{anode} = -10\ kV,\ U_{cath} = 0\ kV$$

Only the ions will reach the screen.

The resulting profiles are presented in fig. 3 (traces a - c respectively). With d) no signal is measured because the positive ions are stopped in the aluminium layer of the screen.

c) gives a much broader profile than a). A preliminary explanation of this effect could be, that the kinetic energy of the electrons coming from the ionization smear out the true width of the beam. This effect and its reason will be explored more fully later [3].

In a) the ions reach the cathode with little disturbance because of their large mass. The emitted secondary electrons have only a small kinetic energy (1-2 eV) within a given angle distribution. Of course, this will broaden the width of the beam image, but the influence becomes neglible at high voltages on the cathode (see fig 4.).

b) is a simple addition of the effects of a) and c). The signal is not proportional to the electron energies because the thin phosphor layer is optimised for 20 keV. Electrons with higher kinetic energy do not deposit much more than 20 keV in the phosphor.

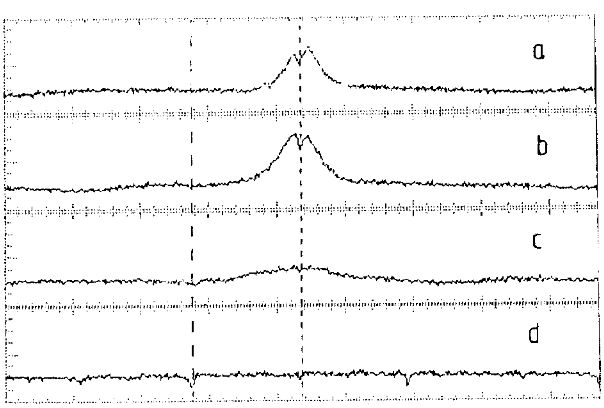

Figure 3: Horizontal profiles at 5 GeV/c, I = 20 mA, $P = 10^{-8}\ mbar$. One line from the video signal is shown. The trace d) shows the calibration markes which are painted every 10 mm on the phosphor screen. The dip in the profiles of traces a - c is a result of this marks.

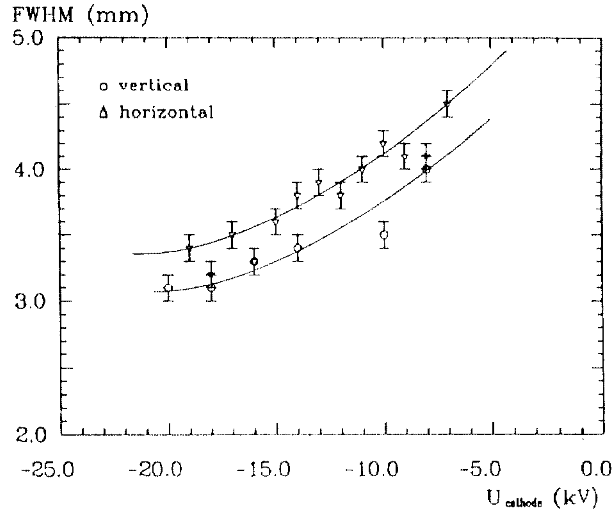

Figure 4: Measured beam width with the horizontal and the vertical profile monitor in dependence of the cathode voltage

Best initial results were yielded by using only the secondary electrons. An advantage of this mode of operation is expected at high proton currents (up to 100 mA). Electrons may be more strongly affected by the electric field of the proton bunch. Because of their larger mass, the dispersion of the ions is expected to be much less than 1 mm.

The position of the calibration marks on the phosphor screen relative to the nominal beam is measured precisely. So, the monitor can also be used as an absolute position monitor, even without bunched beams. A comparision with a position monitor in the neigborhood of the profile monitor has given an agreement of better than 0.1 mm. In particular, the beam oscillations visible on the TV monitor gives a good indication of the stability of the beam in the ring.

The influence of the electric field from the monitor on the circulating beam in DESY III is small and is only evident at injection (310 MeV/c). Compensation by the correction coils of DESY III is easily effected.

Residual Gas Ionization Profile Monitors at PETRA II

With the second run of PETRA II in May 1990, the first measurements with the profile monitors in that machine were possible. In three ways, the PETRA II monitor differs from the DESY III type as follows:

1) The aperture is $80 \times 80\ mm^2$.

2) A micro channel plate (MCP, $60 \times 60\ mm^2$) is installed 1 mm in front of the phosphor screen. It is used to multiply the incoming electrons by a factor of $\leq 3 \times 10^4$. With such a gain it is possible to measure profiles at very low beam currents. Also one is able to make more detailed examinations of the edges of the beam. By adjusting the voltage across the MCP, its gain can be adjusted from $\approx 10^2$ at 500 V up to $\approx 3 \times 10^4$ at 1100 V.

3) A normal video camera is used, rather than the highly sensitive SIT camera, to readout the phosphor screen.

The first measurements were done with secondary electrons, because of the experience with the monitor in DESY III. The voltage settings were:

$$U_{cath} = -18kV,\ U_{g1} = -1.6\ kV,$$
$$U_{G2} = 1.6\ kV,\ U_{MCPin} = -2\ kV,$$
$$U_{MCPout} = -1.05\ kV,\ U_{anode} = +6\ kV.$$

One of the first profiles measured on a stored proton beam at 7.5 GeV and a current of $\approx 20\ \mu A$ are shown in fig. 5. The dimension of the beam was determinated to be $\sigma = 2.2\ mm$ for the the vertical extend.

Operation of the monitor produced no observable effect on either the injected or stored beam in PETRA II.

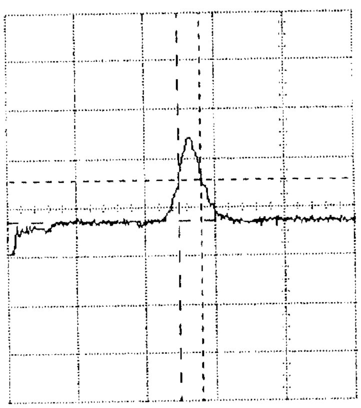

Figure 5: Vertical profile of a proton beam in PETRA II at 7.5 GeV/c. The proton current was 20 μA and the pressure was $\approx 2.5 \times 10^{-8}\ mbar$. The measured beam width is $\sigma = 2.2\ mm$.

Profile Monitors for HERA

The start of the HERA proton ring is planned for the beginning of 1991. At this time will be installed two residual gas ionization profile monitors of the PETRA II type. In the beginning, it is expected that the stored beam current will be small. The high internal gain of the monitor will allow to measure profiles at the expected small currents. The partial pressure, even in the warm parts of HERA, will be 1 or 2 orders of magnitude less than that in PETRA II. This will be compensated by using sensitive SIT video cameras. With such a system beam profiles can be measured down to a current of less than 100 μA. The proton bunches in HERA become very narrow with increasing energies, which results in a very strong electric field of a bunch. At high beam currents this field may have a significant influence on the liberated ions and the returning secondary electrons. With increasing beam energy and beam current the spatial resolution of the monitor may decrease.

The residual gas ionization beam profile monitor will be used mainly during injection studies at 40 GeV and the first acceleration stages. A synchrotron radiation monitor using the "edge effect" will be used to measure beam profiles at high energies [4]. Calculations have shown that profile measurements will be possible at beam energies above about 300 GeV/c [5].

Conclusions

Discussed are the first results of the residual gas ionization proton beam profile monitors of DESY III and PETRA II. The readout is provided by a video camera viewing the phosphor screen. A micro channel plate in behind of the screen gives a sufficient gain to measure profile in good vacuum and at low beam currents. The measurements indicate that the spatial resolution of the monitors is adequate for measuring beam dimensions in the order of a few millimeters (the smallest measured beam size has been $\sigma = 1.3\ mm$). Direct verification of their resolution remain to be done.

In the HERA proton ring two monitors, one for horizontal and one for vertical, will be installed for injection studies. Additional wire scanners for profile measurements are planed for each ring [4]. The spatial resolution of the scanner can be better than a tenth of a micron. Therefore an exact calibration of the residual gas ionization beam profile monitors will be possible in the future. In contrast to a wire scanner, the residual gas beam profile monitor can be used in a continues mode. A continuous visible beam display at the operator consoles in the control room is most helpful.

Acknowledgements

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