RESIDUAL GAS IONIZATION BEAM PROFILE MONITORS FOR THE HERA PROTON MACHINES

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Abstract

Described are beam profile monitors designed for the proton accelerators of the HERA project, namely, the 7 GeV DESY III, the 40 GeV PETRA II and the 820 GeV HERA P machines. Utilizing residual gas ionization (as has been used in many proton accelerators [1-7]), all profile monitors are of a similar basic design offering three main features: 1) "separated function" design, 2) optical sensing of the proton beam image, and 3) selectable modes of operation.

The "separated function" feature allows the most critical components to be outside the vacuum. Optical sensing provides a wide field of view with good spatial resolution and allows multiple, simultaneous, but independent readout systems, such as a television camera, a linear array of photodiodes and an image dissector. Remotely selectable modes of use allow the beam profile to be derived from ionized electrons, ions, or both. The proton beam imaging component may be optionally operated with a magnetic field to increase the resolution. Sensitivity of the system can be increased by the use of an external image intensifier or by increasing the internal partial pressure of the monitor by a remotely controlled leak valve.

Introduction

Described here are the gas ionization profile monitors for the following HERA proton accelerators at DESY:

Accelerator	Energy Range (GeV)	Beam Currents (mA)	Beam Protons
DESY III	0.05 to 7	50 to 160	$[1.1(10)^{12}]$
PETRA II	7 to 40	160	$[7(10)^{12}]$
HERA P	40 to 820	160	$[2(10)^{13}]$

The profile monitors are all of the same basic design having the following features:

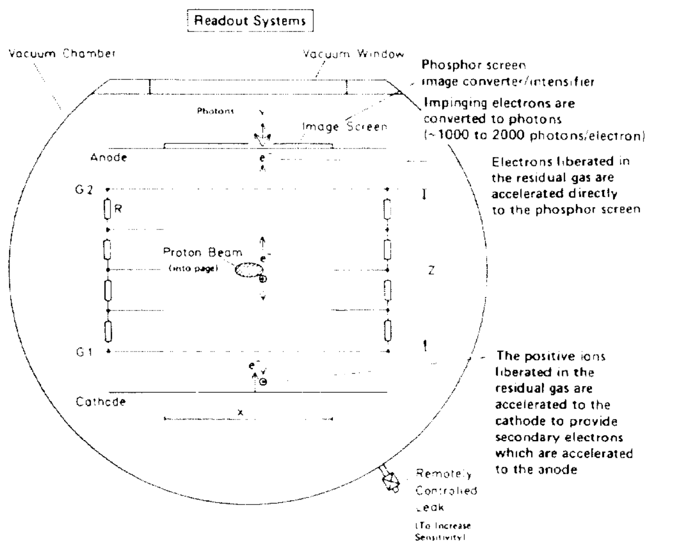
"Separated function" design in which the proton beam imaging function (inside the vacuum chamber) is separated from the readout function (outside the vacuum). This arrangement minimizes the number of active elements inside the machine vacuum, greatly reduces the number of vacuum feedthroughs, and allows convenient access to the readout devices.

Optical readouts combine a wide field of view (several cm) with good spatial resolution (<< 1 mm); provide demagnification of the beam image so that conveniently available commercial optical components may be used; and allow a multiplicity of readouts for simultaneously viewing the image.

Selectable modes of Operation allow the magnitudes and polarities of biasing voltages to define the signal source as 1) liberated electrons (used directly); or 2) liberated positive ions used indirectly; or 3) both used collectively for maximum sensitivity. The profile monitor may also be operated with a magnetic field parallel to the electric field for enhanced resolution, and finally, the sensitivity is adjustable by a piezolectric precision leak valve.

Beam Imaging

Fig. 1 is a cross sectional view of the beam imaging component inside the vacuum chamber. This component has four electrodes consisting of a cathode, grids G1 and G2, and an anode containing a (P-31) phosphorized imaging screen. Gradient electrodes linearly biased between G1 and G2 maintain a homogenious electric field. A vacuum window allows the imaging screen to be viewed by readouts above.



Aperture Requirements

Machine	Aperture (mm) X = Z
DESY III	60
PETRA II	80
HERA P	60

Fig. 1: Cross Sectional Schematic of the Proton Beam Imaging Component of the Residual Gas Ionization Profile Monitor

In operation, G1 may be biased at, say, -1.5kV and G2 at +1.5kV with the cathode at -12kV and the anode at +12kV. As depicted in Fig. 1, the proton beam travels into the paper between G1 and G2 liberating electrons and ions. The electrons are accelerated toward G2 and the ions toward G1. On passing through their respective grids, the electrons and ions are post accelerated to the anode and cathode. The electrons arrive at the anode with an energy in eV equivalent to the anode voltage where they excite the phosphor in proportion to their intensity to form an optical image of the proton beam cross section.

Similarly, the positive ions strike the cathode with an energy in eV equivalent to the cathode voltage, and, for the illustration here, their energy is 12 keV. At this energy, and if the cathode is aluminum, the secondary electron coefficient for positive ions is about unity. The resulting secondary electrons are in an electric field that accelerates them to the anode; furthermore, for the voltages indicated, these electrons arrive at the anode with an energy of twice that of the primary electrons. If the image screen is responding linearly to incident electron energy and intensity, then the light output with ions and electrons is three times that with the primary electrons alone.

Obviously the magnitudes and polarities of the biasing voltages can be manipulated so that only primary electrons or only positive ions, or arbitrary contributions thereof, are effective in producing signal.

The bottom portion of Fig. 2 is a longitudinal sectional view of the imaging component. The tangible item here is that electrodes G1 and G2 must extend, as indicated, so as to maintain a homogeneous electric field in the active volume of the detector and to avert externally produced electrons and ions from entering the active volume of the monitor and perverting the beam image.

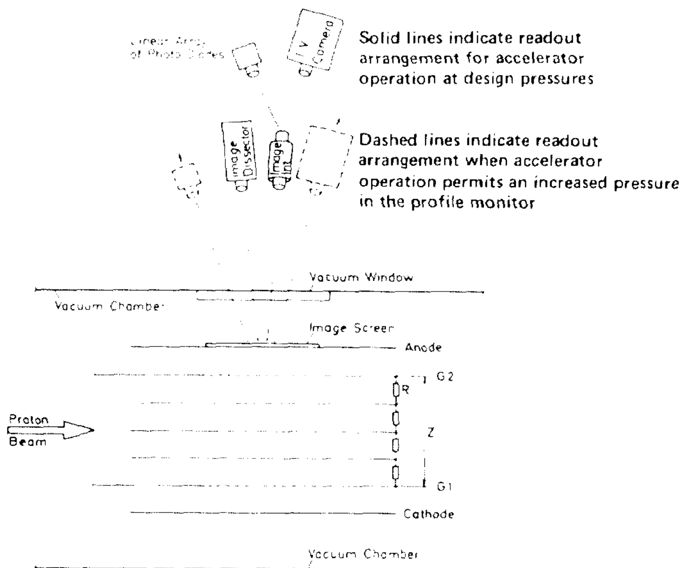


Fig. 2: Schematic of Profile Monitor System with Multiple Readouts

Optical Systems

Each optical system consists simply of a single Fresnel F0.65 lens with a focal length of 21.6 mm that relays the image to the readout device. This optical system provides a demagnification of five (5) and an optical transmission quotient of 0.19, i.e., the light intensity at the readout is 19 percent of that at the proton beam imaging screen.

Readouts

The upper portion of Fig. 2 shows two arrangements of readouts. The arrangement illustrated in solid lines may be used at the design pressures of the accelerators. As will be seen later, the light levels at the readouts in this mode of operation are too faint for the T.V. camera or the photodiode array to detect directly; therefore, an intervening image intensifier, which boosts their sensitivity $>(10)^4$, is required. However, if accelerator operation permits, a (localized) pressure increase in the monitor provides light levels sufficient for direct viewing by the T.V. camera and the diode array.

The following is a tabulation of some readout options and their attendant merits:

Device	Merits
Television Camera	Simple to implement; provides convincing display.
Photodiode Array	Also uncomplicated but more amenable to automated quantitative analyses; more linear response; scan rate can varied.
Image Intensifier	Increases sensitivity of T.V. camera and diode array by $> (10)^4$
Image Dissector	Same merits as photodiode array but with much higher sensitivity. Also offers random access to, and unlimited dwelling on, any portion of the image.

Summary of Luminous Emittances

Table 1 is a tabulation of luminous emittances (light levels), computed at the readouts, for the three proton accelerators, at their design pressures, during injection and at ejection. The beam widths in the machines differ from those at the readouts by a factor of five owing to the demagnification of the optical systems. The indicated luminous emittances are those expected from anode and cathode voltages of ± 12 kV and are adequate for detection by the image dissector; however, in general, the light levels must be increased to a level of about one lux for detection with a T.V.

TABLE 1: SUMMARY OF DESIGN PRESSURES; BEAM WIDTHS, AND LUMINOUS EMITTANCES (LIGHT LEVELS) FOR THE THREE HERA PROTON ACCELERATORS AT INJECTION AND EJECTION ENERGIES

IN THE ACCELERATORS					AT READOUTS		
ACCELERATOR	DESIGN PRESSURE (mbar)	PHASE OF OPERATION	ENERGY (GEV)	BEAM WIDTH (2σ, mm)	IMAGE* WIDTH (2σ, mm)	LUMINOUS EMITTANCE (IN LUX) FOR BEAM: CENTER 5%	EDGE 5%
DESY III	$1.5\ (10)^{-8}$	INJECTION	0.05	12	2.4	$9.2\ (10)^{-1}$	$9.2\ (10)^{-3}$
		EJECTION	7	3	0.6	$1.9\ (10)^{0}$	$1.9\ (10)^{-2}$
PETRA II	$1.5\ (10)^{-8}$	INJECTION	7	11	2.2	$5.4\ (10)^{-1}$	$5.4\ (10)^{-3}$
		EJECTION	40	5	1.0	$2.4\ (10)^{0}$	$2.4\ (10)^{-2}$
HERA P	$1.0\ (10)^{-9}$	INJECTION	40	10	2.0	$7.6\ (10)^{-2}$	$7.6\ (10)^{-4}$
		STORE	820	2	0.4	$5.4\ (10)^{-1}$	$5.4\ (10)^{-3}$

* Optical system provides demagnification of five (5).

camera or a photodiode array. As mentioned in the previous section, increases in light levels are afforded by an intervening image intensifier, as illustrated in Fig. 2, or by the simple expedient of locally increasing the gas pressure by the use of a piezoelectric precision leak valve.

Displays

The display produced by a T.V. system shows, in real time and real space, a ribbon of light for which the position and width are changing during acceleration. When the beam position is stable, quite accurate beam position and widths can be measured as the beam image is directly referable to graticule marks on the image screen. As indicated in the Readout section above, a television system presents a convincing display to which humans relate quite well.

The output expected from the photodiode array is illustrated in Fig. 3 and that from the image dissector in Fig. 4. With the addition a simple hardware, either profile may be used to provide a plot of beam width during acceleration as illustrated in Fig. 5. Such displays are most useful in monitoring and tuning accelerators particularly during commissioning.

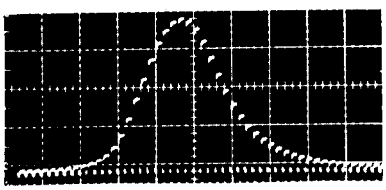


Fig. 3: Expected Profile from Linear Array of Photodiodes

Fig. 4: Expected Profile from Image Dissector

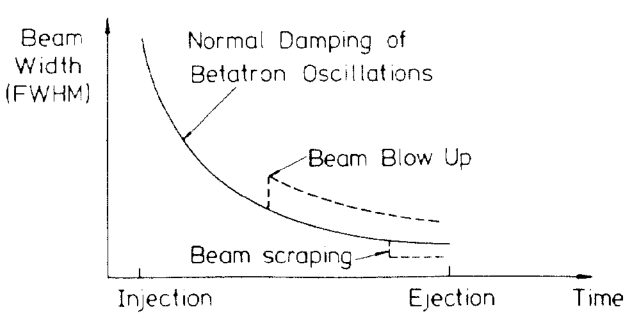


Fig. 5: Illustration of Beam Width During Acceleration (Display is obtainable from either of above types of profiles)

Conclusions

The profile monitors described in this paper derive information from a simple beam imaging device that has no critical elements in the machine vacuum. Either electrons, or positive ions, or both, liberated by the incident beam may be used as signal. Optical readout combines high resolution with a wide field of view and permits multiple readouts that are easily accessible. The overall system is uncomplicated, sensitive, and reliable.

Finally, supplementary profile monitors foreseen for the HERA proton storage ring are listed below:

1) Flying wire scanner (intermittent use)
2) Synchrotron radiation (E > 300 GeV)
3) Gas scintillation (continous use).

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