CONF-790327--99

MASTER

A NONINTERACTIVE BEAM POSITION AND SIZE MONITOR FOR HEAVY IONS

John M. Bogaty

Prepared for

1979 Particle Accelerator Conference

San Francisco, California

March 12, 1979

UofC-AUA-USDOE

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated under Contract W-31-109-Eng-38 for the

U. S. DEPARTMENT OF ENERGY

A NONINTERACTIVE BEAM POSITION AND SIZE MONITOR FOR HEAVY IONS*

John M. Bogaty†

Abstract

The Ion Beam Fusion development program[1] at Argonne National Laboratory requires noninteractive size measurements of a pulsed, 30 mA, Xe^{+1} particle beam. Pulses of 100 μs duration will be produced by the 1.5 MV preaccelerator;[2] therefore, fast response diagnostics are required. Techniques of utilizing residual gas ionization to profile particle beams have been reported before.[3] This paper discusses the development of vertical and horizontal beam profile monitors that are synchronously clocked to interface with oscilloscopes and computers. Modern integrated circuitry is utilized which boosts performance to a point where pulses as short as 20 μs can be analyzed. A small, simple ionization chamber is shown which provides sixteen channels of position resolution over 12 cm of aperture.

Ion Chamber Parameters

Passage of heavy ions through residual gas produces free electrons that are collected on a special ground plane. This ground plane is made up of sixteen isolated metallic strips parallel to the beam axis. Figure 1 shows the ion chamber geometry as positioned for horizontal beam size measurements. Physical aperture, in both planes, is set at 10.0 cm. Detector strips are 5 mm wide by 75 mm long, and set on 8.0 mm centers. Adjacent strips are isolated by a 1.3 mm wide guard strip which is grounded. Overall dimensions for the complete detector assembly are 177 mm wide by 75 mm long. Electrons are driven to the detector by electric fields from a high voltage plate spaced 158 mm away. Electrode width was made as large as possible to minimize field distortion. A fine mesh metallic screen is positioned 6.3 mm above the detector strips. When biased properly, this screen provides suppressor grid action to repel secondaries.

Computer analysis of electric field shapes for various electrode sizes and spacing revealed the magnitude of beam position error to be expected. An electron originating on the vertical midplane will follow local electric field lines and be driven toward ground. Electric field curvature will have the effect of moving the electrons apparent origin closer toward beam center. This produces a position error that increases as a function of field curvature. An electron originating on the vertical midplane but 5 cm either side of center will produce an apparent position error of -14.5%. This is the worst case for a particle at the aperture limit. For a centered 2.54 cm wide beam, the fringe position error will be -6.8%.

Ion Chamber Sensitivity

Electron generation in background gas is given below.[4] For the conditions specified, electron current should be at least what calculation indicates.

$$I_e = \frac{I_b \sigma P}{KT} 1.33 \times 10^3 \text{ A} - \text{m}^{-1} \qquad (1)$$

where

I_e = electron current produced per meter path

σ = cross section for Xe^{+1} ion in Xe background gas = 10^{-16} cm^2

K = 1.38×10^{-16} erg/°K

T = 300° K

P = gas pressure = 10^{-6} Torr

I_b = Xe^{+1} beam current = 30 mA.

$$I_e = 1 \times 10^{-5} \text{ A} - \text{m}^{-1}. \qquad (2)$$

Each strip will collect electrons in proportion to length and width. Strip current will also be inversely proportional to the number of channels shadowed by the ion beam. There is a mechanical sensitivity factor involved because the detector strips must be isolated from each other. Leakage currents could produce errors in beam profile data; therefore, grounded guard strips are placed between adjacent detectors.

Electric field lines from the high voltage electrode will terminate over the entire metalized ground plane surface. Electron current will be lost in proportion to guard strip width. Mechanical sensitivity is, therefore, based on effective detector strip width η_d.

$$\eta_d = \frac{W_d}{W_d + W_g} \qquad (3)$$

where

η_d = detector collection efficiency over width $W_d + W_g$

W_d = detector strip width

W_g = guard strip width.

For this ion chamber:

$$\eta_d = \frac{5 \text{ mm}}{5 \text{ mm} + 1.3 \text{ mm}} = 79.4\%. \qquad (4)$$

Electrons stopped on the suppressor screen wires account for a further loss of signal. The screen used has a transmission coefficient of 50%, so this factor is used to arrive at an overall efficiency η_o.

$$\eta_o = \eta_d \eta_t \qquad (5)$$

---

*Work supported by the U. S. Department of Energy.

†Argonne National Laboratory, Argonne, IL 60439 USA

where

η_o = overall electron collector efficiency

η_d = detector collection efficiency [Eq. (3)] (79.4%)

η_t = suppressor screen transmission efficiency (50%)

$$\eta_o = 39.7\%. \tag{6}$$

Assume a 4.0 cm wide uniformly distributed ion beam is centered over one strip, the electron current flowing out of this strip will be:

$$I_s = \left[\frac{W_d}{W_b}\right] \eta_o I_e \ell \tag{7}$$

where

I_s = output current of one strip

W_d = strip width (mm)

W_b = ion beam width (mm)

η_o = ion chamber efficiency (39.7%)

I_e = electron current produced due to passage of ion beam [Eq. (1)] (10 μA/m)

ℓ = length of detector strip (m).

Solving Eq. (7) gives:

$$I_s = 3.8 \times 10^{-8}\ \mathrm{A}. \tag{8}$$

Signal Processing

Each detector strip drives the summing junction of an operational amplifier (Fig. 2). This converts the strip currents to voltages which are applied to sample and hold amplifiers. All sixteen sample and hold amplifiers are simultaneously commanded to sample strip data. The combination of operational amplifier rise time, plus follow and hold acquisition time determines how fast data can be collected. Controlling parameters are operational amplifier feedback resistance and storage capacitor value for the follow and hold circuit. This combination, at the present, allows data to be sampled in 20 μs. Signal distribution is held until the next sample command is given. Between samples, a multiplexer is used to scan all follow and hold output levels. The resultant serial data train is sent to a remote location for display. A free running clock controls scanning rate and provides display triggering.

Ion beam profile data is displayed by connecting the multiplexer output to an oscilloscope. Multiplexer clock logic provides a scope trigger at the start of each scanning sequence. Scan rate is adjusted to coincide with a multiple of the oscilloscope's horizontal time base frequency. This allows a convenient relationship between ion chamber strip positions and cm markings on the cathode ray tube. Visually, the data is presented as shown in Fig. 3. The first multiplex channel is grounded for baseline reference. Channel 2 is used to provide a marker pulse which denotes one aperture limit. Channels 3 - 18 display beam profile data. This is followed by another aperture limit pulse and a second grounded channel. One complete scan has now been displayed. However, time must be given for horizontal retrace of the oscilloscope. To provide this time the multiplexer is allowed to scan four more unused ports. These ports are grounded and will not appear if the oscilloscope's time base is adjusted correctly. The scanning techniques described allows continuous display of sampled data. Data may be updated by triggering another 20 μs sample command.

The first tests of this system using heavy ions will not have occurred in time for inclusion here. However, a similar system is used on the Argonne Rapid Cycling Synchrotron which accelerates protons. Figure 4 shows a typical scan of horizontal beam size and position.

Computer Application

Digital conversion of multiplexed strip data is accomplished by using one analog to digital converter. Each time the multiplexer scans through an input port, the analog to digital converter digitizes that signal. When a conversion is completed, the BCD clock state is used to provide an address for computer memory storage. Since the multiplexer scan rate is slow (20 kHz), there is plenty of time to complete each conversion. Once all strip data is in computer memory, beam size and position can be generated through software. Data can come in from several appropriately placed beam size monitors. Beam emittance can then be calculated and displayed via CRT terminal.

References

1. Proceedings of Heavy Ion Fusion Workshop, Argonne National Laboratory, Sept. 19-26, 1978, (to be published).
2. J. M. Watson, et al., "A High Intensity 1.5 Megavolt Heavy Ion Preaccelerator For Ion Beam Fusion,"(to be published this conference).
3. W. H. DeLuca, "Beam Detection Using Residual Gas Ionization," IEEE Transactions on Nuclear Science, Vol. NS-16, No. 3, pp. 813-822, (June 1969).
4. S. Fenster, Argonne National Laboratory, private communication, (June 1978).

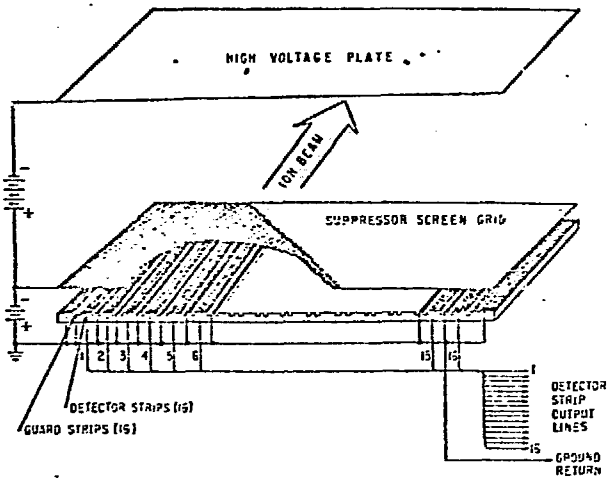

Fig. 1. Ion chamber positioned for horizontal beam size measurements

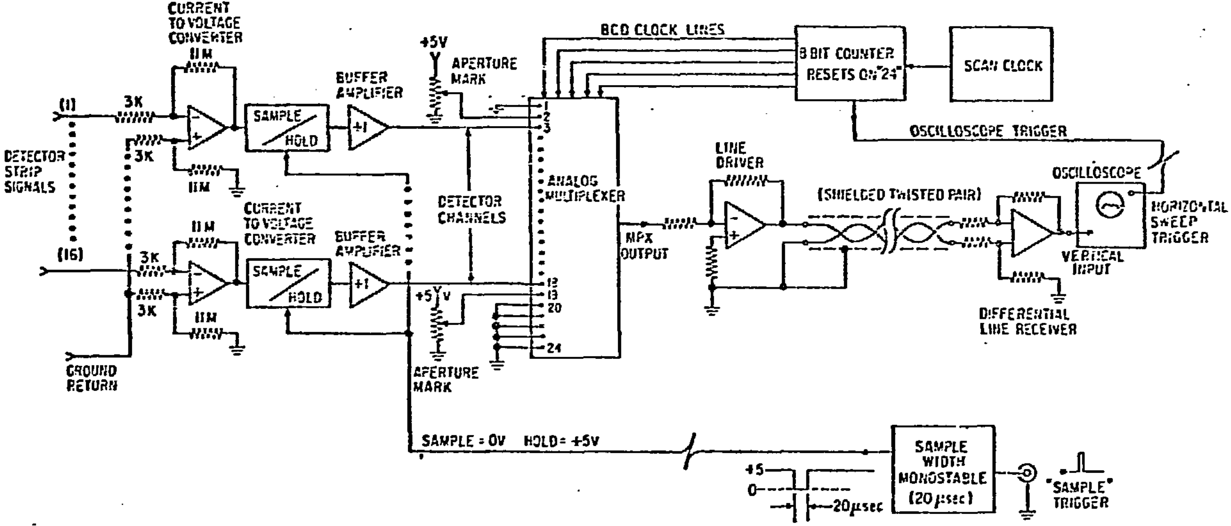

Fig. 2. Signal processing

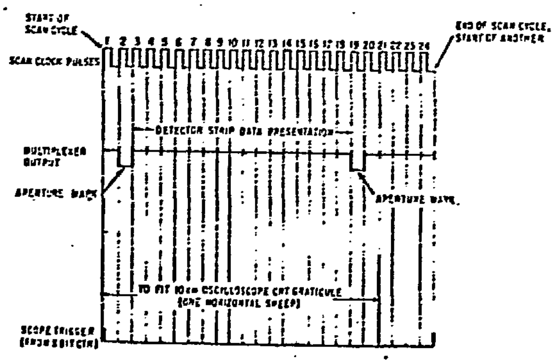

Fig. 3. Scanning sequence for data presentation

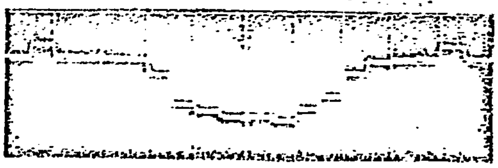

Fig. 4. Display of horizontal beam size