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DEVELOPMENT OF LOW LEVEL BEAM DIAGNOSTICS FOR POLARIZED PROTON OPERATION IN THE ZERO GRADIENT SYNCHROTRON*

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Summary

Two systems are described which operate in high noise environments and detect weak (nanoampere to microampere) signals. Polarized beam[1] is injected in the Zero Gradient Synchrotron (ZGS) and stopped just downstream of long straight section three (L-3). The L-3 section contains a vertically segmented Faraday screen[2] from which a radial profile of injected beam is obtained. The microampere currents are sensed by a bank of 44 operational amplifiers, multiplexed and displayed by a computer.

The resonantly extracted polarized proton beam requires good control[3] for a successful physics program. An ion chamber and associated electronics are described which provide three control parameters. Extracted beam intensity, instantaneous spill rate, and horizontal position information are generated and provided for feedback control of the extracted beam.

Introduction

The signal to noise ratio of beam diagnostics and feedback systems is of prime concern. Characteristically, accelerators are noisy devices with megawatts of power contributing electrical noise throughout the passbands of diagnostics devices. Polarized proton operation meant that diagnostics have to work with beam intensity levels much lower than associated with H^- injection.[4] Beam intensity would be down by a factor of 100→200 during polarized operation. Particular attention is paid to detection and signal transmission techniques, otherwise noise would overpower the weak beam signals. Both systems described follow good engineering practices for maximum noise rejection.

Polarized Proton Injection Diagnostics

Polarized 50 MeV protons are injected in the ZGS ring and then stopped after passing through a 50% transmission, segmented Faraday screen. The screen is positioned at a point in the orbit such that the radial profile of injected beam gives a relative indication of energy spread. Fig. 1 shows a portion of the segmented Faraday screen. Beam is shown hitting the screen with corresponding segment currents plotted below. High performance differential operational amplifiers are used to convert segment currents to voltage levels. Fig. 2 shows the configuration of Faraday screen segments and operational amplifiers. A total of 44 amplifiers are used, one for each screen segment. Currents from the segments flow into amplifier summing junctions. Noise pick up is reduced because of the low impedance each segment sees. Operational amplifier theory provides that the current flowing into a summing junction is equal but opposite to that flowing out. Therefore, equation (1) is true

$$V_o = I_n R_f \tag{1}$$

where

V_o = amplifier output voltage
I_n = current from screen segment
R_f = feedback resistor.

The current to voltage scaling factor is simply equal to feedback resistor "R_f". Noise is effectively nulled by connecting all the non-inverting amplifiers inputs together and grounding them on the L-3 vacuum vessel. The differential common mode rejection of these amplifiers is used to advantage in this application. Noise components on the screen segments are common to those in the vacuum vessel which allows cancellation in the amplifiers. The only problem encountered was overloading of the amplifiers due to the 200 MHz structure of injected beam. The solution was to put some resistance in series with each amplifiers summing junction. This resistance in combination with the amplifiers input capacitance effectively filters out the 200 MHz structure while preserving the average value of segment current. Even though the amplifiers frequency response is orders of magnitude below 200 MHz, they did, in fact, overload because of the beam's RF structure. Using $1 \times 10^6\ \Omega$ feedback resistors, the rise time was measured at 20 μs. To test the amplifiers response a current source was constructed using photodiodes. A reverse biased silicone photodiode approximates a current source. A light emitting diode was modulated and the light pulses projected on to the photodiode. Reverse current through the photodiode is proportional to the incident light, thus it is used to drive the amplifier under test. Fig. 3 shows the photodiode-amplifier test set up. Fig. 4 is a polaroid of an actual computer scan of 50 MeV polarized protons hitting the L-3 screen. Fig. 5 shows another scan with injected beam turned off. There is very little noise present even though the ZGS ring magnet power supply is pulsing.

Ion Chamber Diagnostic Device For The External Polarized Proton Beam

An ion chamber based system has been developed which provides spill rate, beam position and spill intensity information. The device is located immediately adjacent to the External Proton Beam I (EPBI) extracted beam port (L-2) in the ZGS ring. The noise environment is severe due to the proximity of pulsed magnets and ZGS octant 3. Typical slow spill beam current through the ion chamber would be about 2×10^{-9} ampere. Fig. 6 shows a block diagram representation of the system. Because of the noise environment, differential signal transmission is used

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where possible. The ion chamber itself is totally shielded along with the current sensing amplifiers. These amplifiers are located within three feet of the ion chamber to further reduce noise pick up possibility. The center electrode of the chamber is in two electrically isolated halves. Output current from the electrode pair is related to spill intensity and beam spot position. Labeled "right" and "left," these channels are combined algebraically to produce a sum signal and a difference signal. The sum is used for spill rate measurement, then integrated for spill intensity. The difference signal is used for sensing position variations of extracted beam.

Ion Chamber Consideration

All calculations for the chamber were carried out using air as the gas at one atmosphere of absolute pressure. The chamber electrodes and windows are made of 0.010 mm thick aluminum. Since low intensity proton beams are to be measured, no attempt to pressurize the chamber with a noble gas was made. Recombination effects are strongly related to plate spacing and beam density within the active volume of the chamber. Estimates of the extracted beam intensity, spill time and spot size were made, and the recombination[5] percentage of chamber current calculated.

$$-\left[\frac{\delta I_s}{I_s}\right]_{rec} = \frac{aN_o d^2}{6W_+ W_-} \qquad (2)$$

where

a = recombination coefficient with positive ions

N_o = number of ion pairs produced per unit volume per unit time

d^2 = plate spacing in cm^2

W_+ = drift velocity of positive ions

W_- = drift velocity of negative ions.

The results were that 0.0028% of the chamber current would recombine for the following slow spill example:

$Q = 3 \times 10^9$ protons

$T = 0.5$ seconds

Spot Size = $6.0\ cm^2$.

Calculations of ion current multiplication and diffusion losses were in the 0.1% range. To the first order, an expression for the total system sensitivity was generated as follows: the chamber will collect ions in numbers related to beam intensity and the gas gain (G). The energy lost by a 6 GeV proton passing through the chamber is:

$$\frac{de}{dx} = 3.908 \times 10^{-9} \frac{\text{erg}}{\text{cm - proton}} \qquad (3)$$

If the average energy required to produce an ion pair in the gas is "I", then the gas gain "G" can be written:

$$G = \left(\frac{de}{dx}\right)\left(\frac{1}{I}\right) L \qquad (4)$$

where

L = plate spacing of ion chamber in cm.

The chamber under discussion has a calculated gas gain of

$$G = 88.5 \ \frac{\text{ion - pairs}}{\text{proton}} . \qquad (5)$$

Chamber output is scaled by feedback resistors "R_f" of the current to voltage converters, then the summed left and right channels integrated for spill intensity. Fig. 6 should be referenced for the following derivation:

$$V_o = \frac{1}{RC} \int V_1 dt = \frac{V_1 T}{RC} \qquad (6)$$

where

RC = integration constant

V_1 = current to voltage converter output

T = spill time

substituting

$V_1 = iR_f$

$Q = iT$

and solving for coulombs gives

$$Q = \frac{V_o RC}{R_f} . \qquad (7)$$

Since one coulomb is 6.281×10^{18} electronic charges, equation (7) can be expressed in terms of numbers of protons (#P) per volt of integrator output. Gas gain "G" scales the final expression of sensitivity.

$$\frac{\#P}{V} = \left[\frac{RC}{R_f G}\right] 6.281 \times 10^{18} \qquad (8)$$

References

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4. E. Crosbie, et al., "Injection and Acceleration of Protons in the Zero Gradient Synchrotron by Stripping H^- Ions," IEEE Transactions on Nuclear Science (June, 1975), Vol. NS-22, No. 3, p. 1056.

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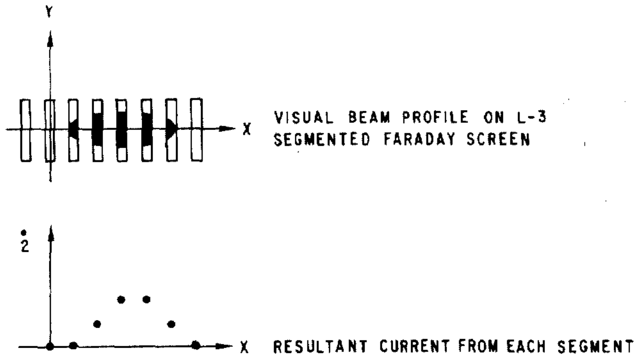

Fig. 1.

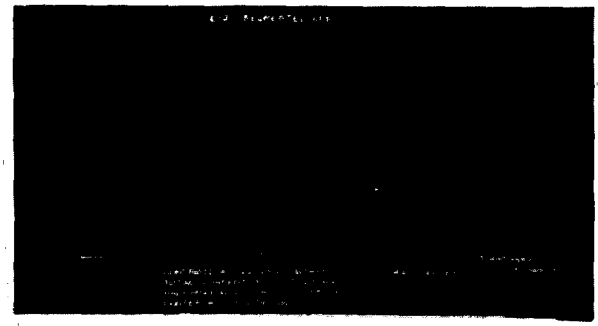

Fig. 4.

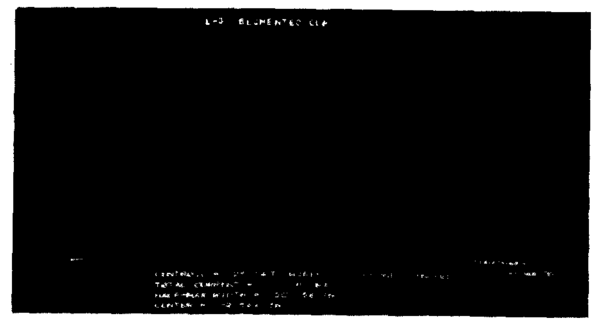

Fig. 5.

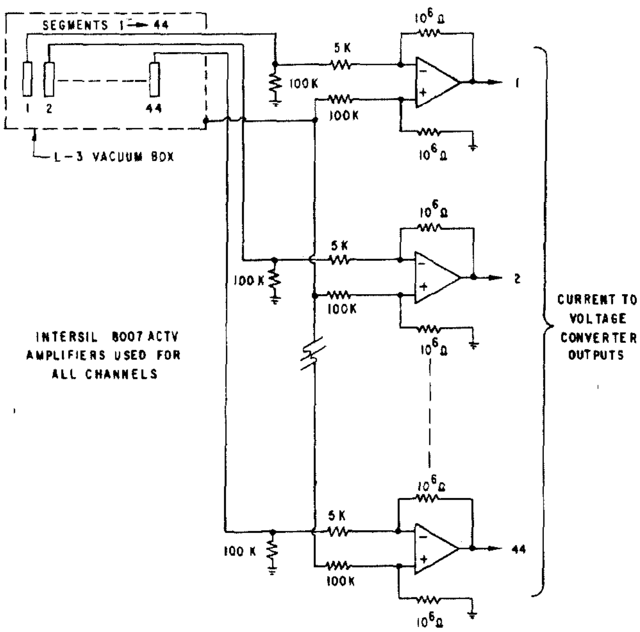

Fig. 2.

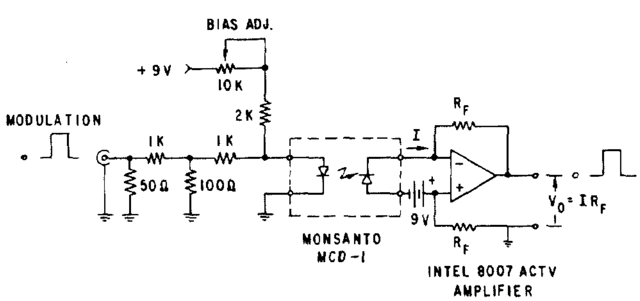

Fig. 3.

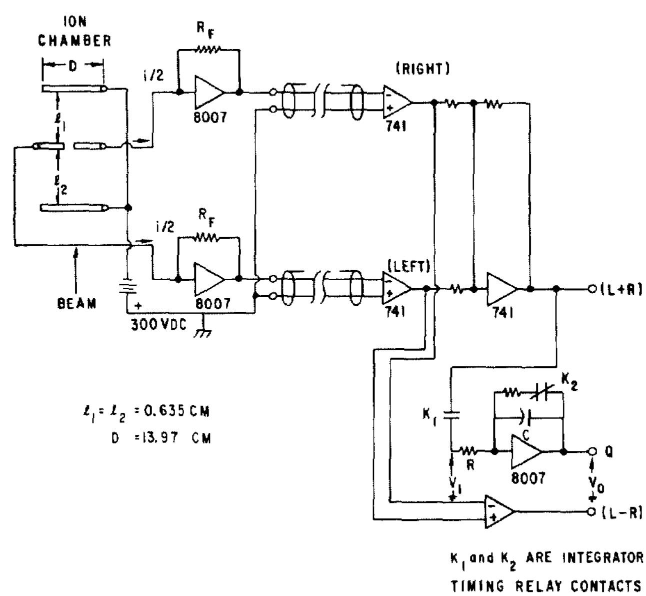

Fig. 6.