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AIR-FILLED ION CHAMBER BEAM LOSS MONITORS FOR THE ZERO GRADIENT SYNCHROTRON (ZGS)*

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Abstract

Small, air-filled, ion chambers have been constructed to serve as localized beam spill monitors. They are mounted at the downstream end of each straight section of the ring and are useful for locating beam obstructions and for finding spills due to abnormal machine adjustment. The chamber is made up of thin aluminum sheets with mylar insulation and is enclosed in a lucite box. No preamplifier is used, but the signals are transported to the Main Control Room (MCR) via RG-22/U shielded pair to maintain good SNR. A central 300 V power supply provides ion collection potential for all eight chambers. The signals are processed for individual and multiplexed monitoring.

Introduction

A simple radiation monitoring system was desired to make comparative tests of beam spills for determining accelerator behavior. Radiation safety monitors which were on the outer wall of the Ring Building were too nondirectional in their reception to localize losses. Ion chambers filled with air at atmospheric pressure were selected because they are easily constructed and are maintenance-free. Close spacing between the plates keeps the transit time low so that the chambers are useful for monitoring beam structure and fast spills.

Ion Chamber Description

Physical

A diagram of the ion chamber is shown in the lower left section of Fig. 1. The mylar is 1/2 in wide and leaves 3.5 x 3.5 in^2 of the 4 x 4 in^2 plate area uncovered, except with air. Four chamber sections are formed with an active volume of 3 cm^3 each, or 12 cm^3 total. Additional sections can be added to proportionally increase sensitivity. The metal-mylar stack is mounted inside a lucite box which provides insulation and a mount for the RG-22/U cable connector. A view of the assembled chamber is seen in Fig. 2.

Electrical

Loss of ion current due to recombination and diffusion would be reduced by using appropriate gases to replace air. It will be shown later that these errors contribute little because the space between plates is so small.

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Sensitivity

A quick estimate of the sensitivity can be made by assuming uniform radiation flux over the chamber. Ion chamber sensitivity (S) is then defined as

$$S = \frac{\text{Volume}}{3 \times 10^9} \text{ A/R/s}.$$

The total chamber volume is 12 cm^3.

$$S = \frac{12}{3 \times 10^9} = 4 \times 10^{-9} \text{ A/R/s}.$$

A current of 10^{-8} A is the threshold of detection by the electronics for a reasonable SNR. This then sets a minimum radiation level of

$$\frac{10^{-8}}{4 \times 10^{-9}} = 2.5 \text{ R/s}.$$

At first glance, this appears to be an insensitive system, but where intense accelerator beams are concerned, 2.5 R/s is relatively small. By assuming that minimum ionizing radiation is involved, we can determine the rate of particles scattered through the ion chamber.

For air:

$$\frac{dE}{dx} = 0.0022 \frac{\text{MeV}}{\text{cm}} \quad \text{(energy lost per unit distance)}$$

$$d \text{ (total)} = 4 \times 0.038 \text{ cm} = 0.152 \text{ cm}.$$

$$\text{Energy lost/particle} = 0.0022 \times 0.152$$

$$= 3.3 \times 10^{-4} \text{ MeV or } 330 \text{ eV}.$$

$$\text{Number of ion pairs/particle} = \frac{330 \text{ eV}}{32.5 \text{ eV/ion pair}} = 10.2 \text{ ion pair/particle}.$$

$$\text{Particle rate} = \frac{10^{-8}}{10.2 \times 1.6 \times 10^{-19}} = 6.1 \times 10^9 \text{ particle/s}.$$

At energies > 1 GeV, this flux will occur mostly as scattered protons.

Recombination and diffusion effects will reduce ion chamber current. Values for these effects can be determined by expressions derived by Rossi and Staub.[1] For worst case, we assume that all negative charges occur in air as negative ions, instead of electrons. Recombination error then is

$$\left(\frac{\Delta I}{I}\right)_{rec} = - \frac{\alpha N_o d^2 R_i}{6 \nu_+ \nu_-}.$$

α is the recombination coefficient = 2×10^{-6} cm^3/s. (Worst case.)

N_o is the number of ion pairs/cm^3/R/s.

d is the spacing between plates = 0.038 cm.

R_i is the radiation level = 2.5 R/s.

ν_+ is the drift velocity for the positive ion

$$= 1.11 \times 10^4 \text{ cm/s}.$$

ν_- is the drift velocity for the negative ion

$$= 1.35 \times 10^4 \text{ cm/s}.$$

$$\left(\frac{\Delta I}{I}\right)_{rec} = -\frac{(2 \times 10^{-6})(2.08 \times 10^9)(0.038)^2 (2.5)}{(6)(1.11 \times 10^4)(1.35 \times 10^4)}$$

$$= -1.7 \times 10^{-8}.$$

It is apparent that recombination error is of no consequence, even if the spill rate were 1,000 times greater.

Diffusion error is given by

$$\left(\frac{\Delta I}{I}\right)_{diff.} = -\frac{e\, 2.5 \times 10^{-2}}{V}.$$

e is the ratio of mean energy of ions with and without electric field on. e is approximately four for this ion chamber.

V is the voltage applied to the plates = 300 V.

$$\left(\frac{\Delta I}{I}\right)_{diff.} = -\frac{(4)(2.5 \times 10^{-2})}{300} = -3.3 \times 10^{-4}.$$

Diffusion error is also of little consequence.

Transit Time

Longest transit time is due to the positive ions and is determined by

$$t = \frac{d}{\nu_+}$$

$$t = \frac{0.038}{1.11 \times 10^4} = 3.4 \times 10^{-6} \text{ s or } 3.4 \text{ μs}.$$

Electronics Unit Circuit Description

The circuit diagram is shown in Fig. 1. Complexity is reduced by not having preamplifiers and their associated power supplies. The operational amplifier current-to-voltage converters are operated in a differential-input mode to reject common mode noise. Further simplification results from using a common power supply for all eight chambers. This power supply is decoupled from the amplifiers by an RC network to reduce introduction of noise. The balance control, which is common to all the inputs, is adjusted for minimum noise output.

The ion chambers can be monitored individually by the octant selector. The time constant of the electronics for this monitor is 20 μs, so that ion chamber transit time contributes little to the rise time.

All eight chambers can be monitored in a time multiplexed mode for comparative losses. Each multiplexer channel output is offset by a different dc voltage to separate the data.

Chamber Environment

Care must be taken that the ion chamber is not located near electrically noisy equipment. This precaution is needed because the chamber plates are not shielded. A grounded shield was placed around a chamber when a noise problem arose. The noise level was greatly reduced, but operation was altered. The shielding forms another ion chamber which is connected in parallel with the original one, but which has different ion collection characteristics. It took some investigation time before the problem of strange waveforms was diagnosed.

Results

The utility of this system comes from being able to distinguish abnormal from normal spill signals. A catalog of normal operating waveforms is maintained for comparison. Figure 3 shows an example of spill signals during acceleration and targeting. The system shows good amplitude linearity for both fast and slow spills.

Sensitivity for injected beam losses compared to high energy beam losses is greatly reduced because the 50 MeV protons do not penetrate the steel walls of the straight section. The ion chamber then responds to the slower decaying secondary radiation, such as gamma rays. Good information is still obtained as can be seen in Fig. 4. This is a photograph of the injected beam spill at the section where the inflector is located. The loss signal comes from uncaptured beam which hits the inflector. The long tail of the pulse in Fig. 4 appears to result from two different half-lived decays. This long decay time prevents us from distinguishing capture losses from injection losses. Injected beam loss in any other section is usually indicative of an obstruction or incorrect injection orbit.

Conclusions

The monitor system has been in operation two years and has been used mostly when looking for beam obstructions. It has been proved helpful in optimizing injected beam orbits and beam extraction. Occasionally, it is used as a targeted beam structure monitor. In all cases, the design requirements have been satisfied.

Acknowledgments

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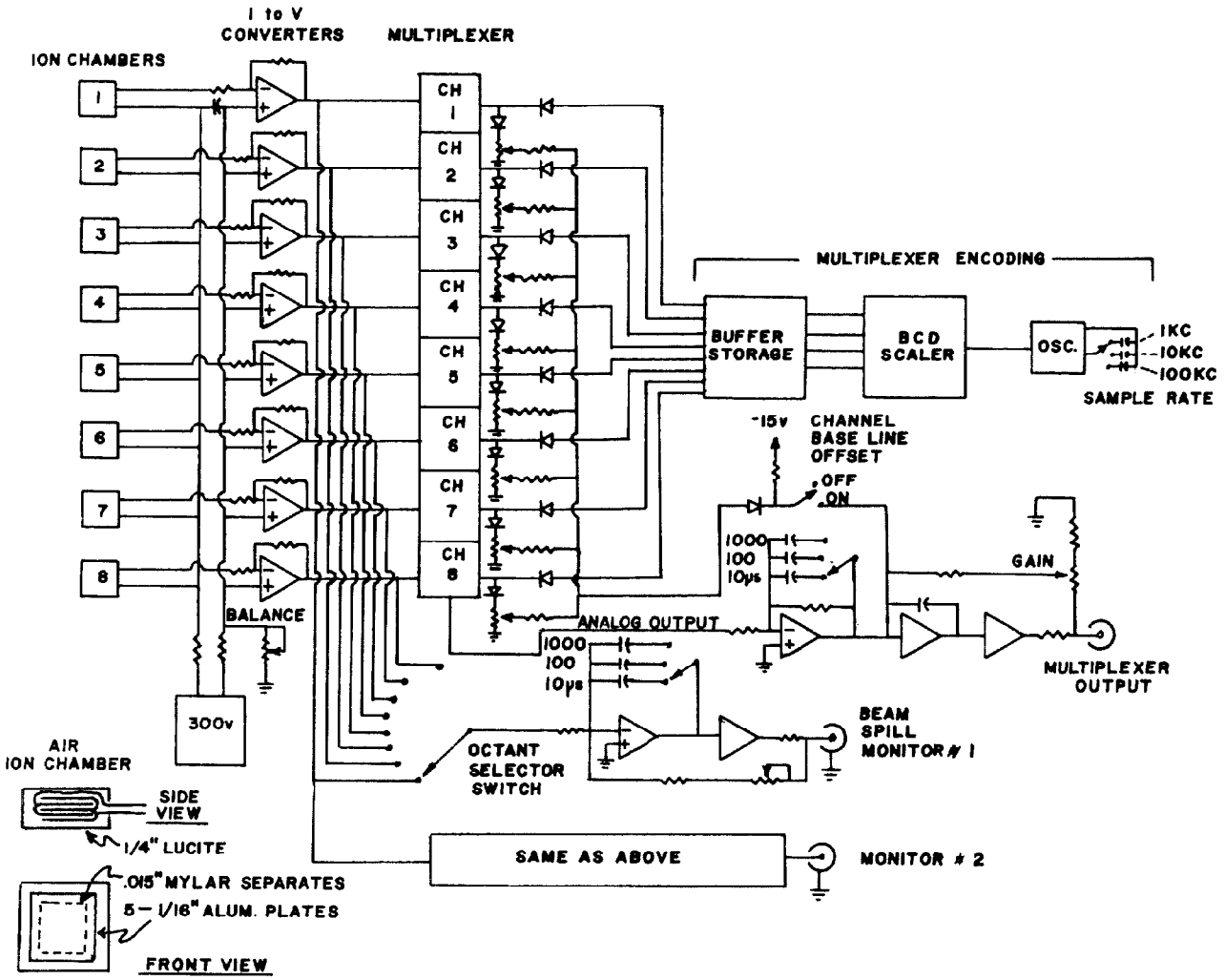


Fig. 1 Diagram of the Monitor System. Cables Connecting Ion Chambers to the Electronics are About 500 ft Long.

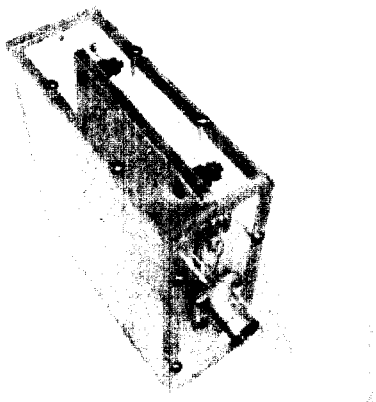


Fig. 2 Ion Chamber Assembled in Lucite Box. Bolts Through Back Side Fasten Chamber to Mounting Bracket.

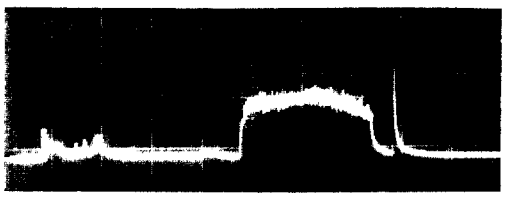


Fig. 3 Example of a Slow and a Fast Spill During Normal Operation. The Early Losses Occur When Vertical Beam Instabilities Arise. Vertical = 0.2 V/cm; Horizontal = 0.2 s/cm

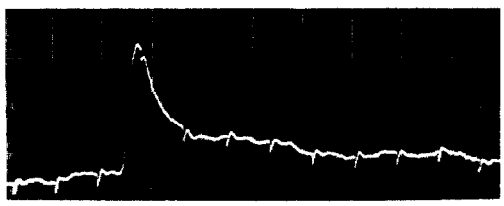


Fig. 4 Injected Beam Spill. Noise Spikes are Due to Multiplexer Crosstalk. Vertical = 20 mV/cm; Horizontal = 1 ms/cm