CLEARING ELECTRODES FOR VACUUM MONITORING AT THE FERMILAB RECYCLER

D. Broemmelsiek* and S. Nagaitsev, Fermilab, Batavia, IL 60510, USA

Abstract

The Fermilab Recycler is a 3.3-km 8-GeV/c fixed kinetic energy storage ring located in the Fermilab Main Injector tunnel [1]. Each split-plate beam position monitor (BPM) in the Recycler is also used to generate an ion clearing field for ions trapped by the antiproton beam. Approximately 100 locations have been instrumented with pico-amp meters to measure the electron current, generated by the beam-ionized residual gas in the vacuum chamber. This electron current is found to be proportional to the beam current and to the residual gas pressure in the Recycler and can therefore be used as a vacuum diagnostics tool.

RECYCLER VACUUM SYSTEM

The Recycler vacuum chamber, including BPMs, is an elliptical 100mm x 48mm (width and height), non-electropolished stainless steel tube (316L). The majority of pumping in the Recycler is performed by Titanium Sublimation Pumps (TSP). The TSPs are spaced approximately 5m apart and have a nominal pumping speed of 180L/s (N_2/CO) at the beam pipe opening. The original design called for 30L/s diode ion pumps to be installed every 30m. About 120, 20L/s ion pumps, capable of pumping argon, were added to the Recycler during Autumn 2003 bringing the total number of installed ion pumps to ~240. Originally, ion gauges (IG) were only installed on TSP cans making the pressure reading interpretation difficult. During Autumn 2003, six vacuum crosses were installed directly on the beam-pipe and instrumented with IGs and Residual Gas Analyzers (RGAs).

Even after the Autumn 2003 upgrades, very little information about the vacuum far away from the IGs was available. To increase the density of vacuum monitoring equipment without extensive rebuilding of the vacuum system, approximately 100 vertical BPM locations were instrumented with current amplifiers to detect the local clearing current.

PICO-AMP AMPLIFIER/RECYCLER BPM

Initial ionization current estimates were based on the measured residual gas composition in the Recycler vacuum and ionization cross sections [3,4]. For the range of beam currents and pressures found in the Recycler, currents of 1-10pA were predicted. A prototype amplifier was installed to verify the feasibility of this measurement. Surprisingly, 2 – 3 times more clearing current than predicted was measured.

A two stage differential current amplifier is connected to one of the plates of the elliptical split plate BPMs used in the Recycler. The amplifier provides 1V/1pA total gain with a 1 Hz bandwidth and <10fA/Hz$^{1/2}$ rms noise.

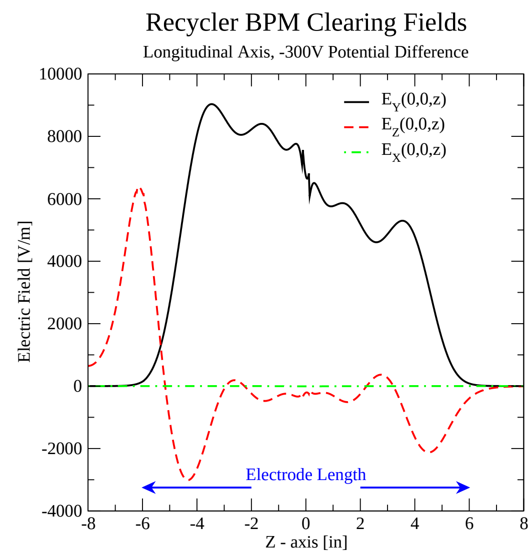

Figure 1: The fields are calculated [2] for the elliptical geometry using a 3-D finite element program. The mesh geometry causes the non-physical fluctuations. For most of the BPMs, the antiproton beam travels from -Z to +Z and the Z-field rejects the forward scattering events upstream of the detector.

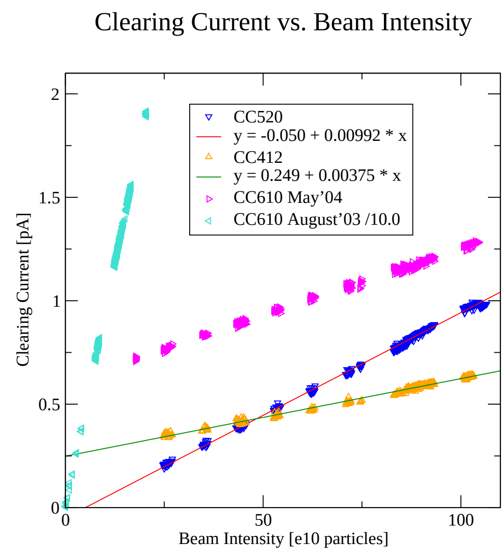

Figure 2: Two example locations and the linear fits to those data are shown. Data from location CC610 before and after vacuum work show the ionization current decreasing by a factor of 25. Slopes and intercepts are dependent on amplifier and location in the vacuum system.

*broemmel@fnal.gov

This plate is then kept at virtual ground by the op-amp. The opposing plate can is attached to a bipolar 500V high voltage supply which is normally kept at -300V. Based on the fields shown in Figure 1, the collection efficiency is expected to be high for electrons/ions from ionization events within the BPM.

The output is a single ended voltage signal that is transported upstairs on existing cables previously used for the BPM pre-amplifiers. A remotely settable 12V DAC is used to provide a regulated 1.2V across a GΩ resister to provide a 1.2pA diagnostic signal in parallel with the ionization current.

RESPONSE LINEARITY

A linear response to beam current indicates that there are no additional ionization mechanisms contributing to the measured current. The clearing current is found to have a linear response with respect to beam current, Figure 2.

Another indication that primary ionization electrons are being collected is the response with respect to the clearing voltage. Figure 3 indicates that the collection efficiency for either ions or electrons is similar. Not completely shown is the relatively longer tail to the electron current. One possible explanation is the different momentum distributions for ions and electrons.

CLEARING CURRENT VS. PRESSURE

With all the ion pumps being on, the residual gas composition, as measured by an RGA, is primarily H_2, with small fractions of CO, water and CO_2. The residual gas composition may be changed by two methods. Turning the ion pumps OFF increases the content of Methane dramatically and the content of Ethane and Argon modestly, while leaving the fraction of other gases unchanged. Similarly, turning the IG filament OFF and then ON produces a burst of gas, mostly hydrogen. We have used these features to determine the effective detector length or electron collection efficiency of the clearing electrodes.

Two of the clearing current amplifiers were installed nearby ion gauges with pumps located sufficiently distant that identical pressures are expected. Turning OFF two nearest (to the IG) ion pumps insures the identical partial pressure of methane at the clearing electrode and the ion gauge locations. The clearing voltages were set to -300 V at both locations, thus the clearing current amplifier was registering locally produced electrons. Curves 1 and 2 in Figure 4 demonstrate the clearing current increase in one of the detectors when the nearby IPs were turned OFF and later ON. Similarly, curves 3 and 4 demonstrate the clearing current (in the second detector) response to the ion pumps OFF-ON cycle and to an IG filament OFF-ON cycle, respectively. Assuming that the pressure increase, Δp_{IG}, is due to a single type of gas, one can write the following expression for the current increase,

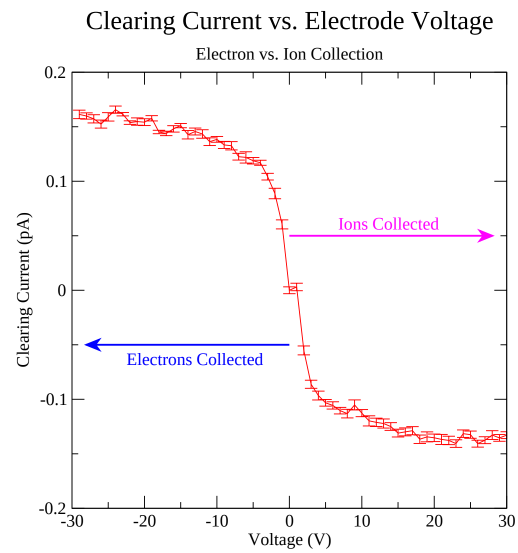

Figure 3: The clearing voltage is changed in 1V steps starting at -30V. There is a discontinuity noticeable at zero volts due to the BPM capacitance.

$$\Delta I_{CC} = I_B \cdot \frac{\Delta p_{IG}}{kTS_{IG}} \cdot \sigma_i \cdot L_{eff}, \quad (1)$$

where I_B is the beam current, k is the Boltzmann's constant, T is the temperature, S_{IG} is the ion gauge correction factor, σ_i is the ionization cross-section and L_{eff} is the effective length of the detector.

Table 1 presents the calculated value of L_{eff}, as determined from slopes in Figure 1, assuming a single type of gas. It appears from Table 1 that the calculated effective length of the detector is very close to its physical length (30 cm), which we will use for our pressure calculations.

Assuming that the residual gas composition at these two detector locations (with IPs ON) is hydrogen and CO, one can calculate the partial pressures of these two gases. This results in the hydrogen pressure of 2.9×10^{-10} Torr for

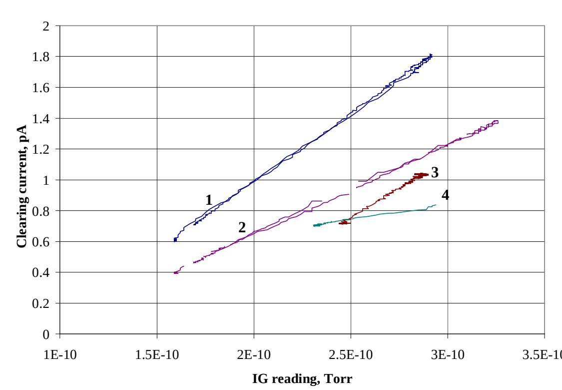

Figure 4: Clearing currents as a function of ion gauge pressures.

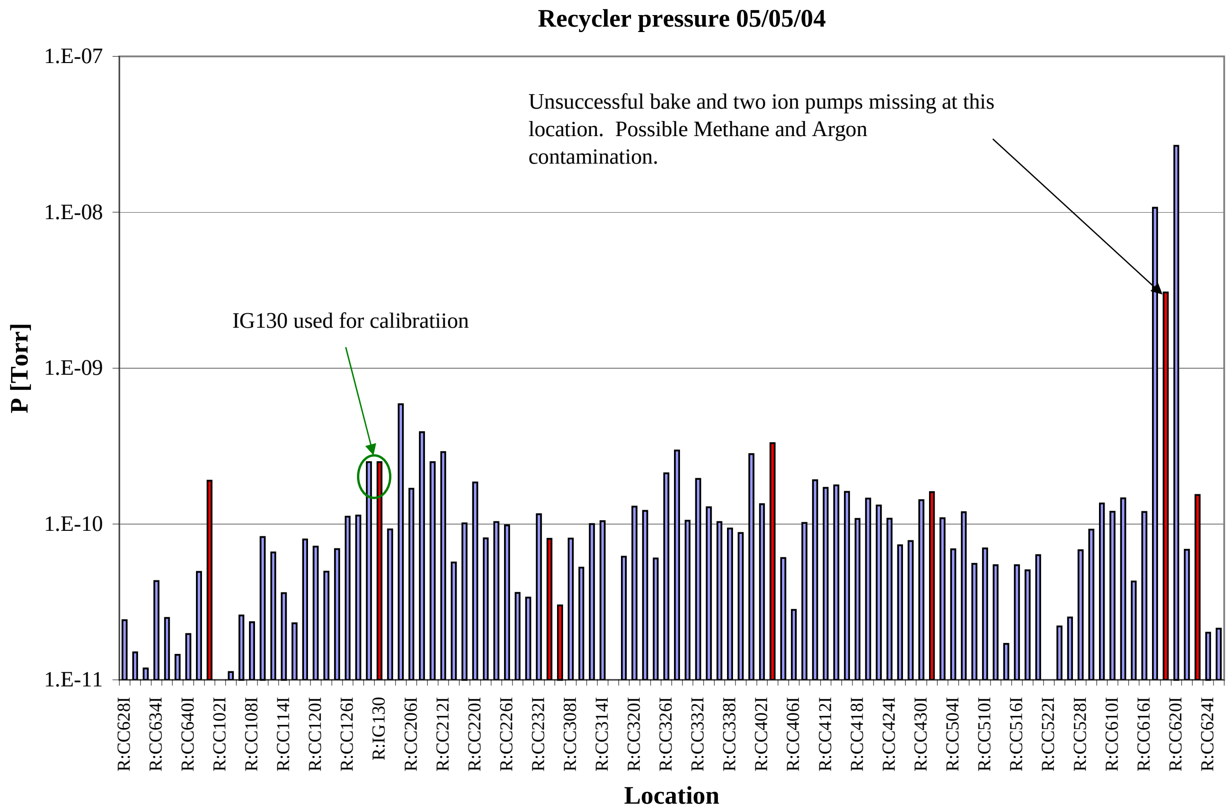

Figure 5: Recycler pressure profile after each clearing current measurement (BLUE) is corrected for zero offset and scaled to the pressure measured at the ion gauge (RED) located at position 130.

the first clearing detector and 4.9×10^{-10} Torr for the second with the partial pressure of CO being about 9×10^{-12} Torr at both locations.

Since in all other clearing detector locations we do not have an ion gauge, we normalize the pressure reading at the clearing detectors to an ion gauge at one of the two locations. This does not take into account the gas composition difference in ionization cross-sections but it gives a good quantitative comparison between various locations around the ring, Figure 5.

Table 1: Effective detector length determined from Figure 1.

Curve #	I_B [mA]	Gas	S_{IG}	σ_i [10^{-18} cm^2]	L_{eff} [cm]
1	11.0, p	CH_4	1.4	1.2	31
2	7.0, pbar	CH_4	1.4	1.2	32
3	6.6, pbar	CH_4	1.4	1.2	44
4	6.6, pbar	H_2	0.45	0.21	26

CONCLUSIONS

Only 6 months elapsed from the original idea to having 100 working amplifiers installed with data readout in the Recycler vacuum system. These local clearing current monitors provide an accurate measure of the gas pressures in the Recycler beam pipe as seen by the beam. The high granularity of the information greatly assists in assessing the vacuum system performance and planning of future improvements. In addition, the linear response is easily modeled and can be used with data from the IGs and RGAs to obtain gas species information.

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REFERENCES

[1] Jackson, G., “The Fermilab Recycler Ring Technical Design Repport,” Fermilab-TM-1991, Nov. 1996.

[2] TOSCA, Vector Fields Limited, England, 2002.

[3] M.E. Rudd, Y.-K. Kim, D.H. Madison and J.W. Gallagher, *Rev. Mod. Phys.* **57**, p. 965 (1985).

[4] Reiser, M., “Theory and Design of Charged Particle Beams,” (John Wiley & Sons, Inc., New York, 1994) pp. 273-278.