ELECTRON CLOUD DIAGNOSTICS IN USE AT THE LOS ALAMOS PSR *

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Abstract

A variety of electron cloud diagnostics have been deployed at the Los Alamos Proton Storage Ring (PSR) to detect, measure, and characterize the electron cloud generated in this high intensity, long bunch accumulator ring. These include a version of the ANL-developed retarding field analyzers (RFA) augmented with LANL-developed electronics, a variant of the RFA denoted as the electron sweeping diagnostic (ESD), biased collection plates, and gas pulse measuring devices. The designs and experience with the performance and applicability to PSR are discussed.

INTRODUCTION

To thoroughly understand the electron cloud (EC) at PSR we seek as much information as possible on the sources of electrons, their relative strengths, the electron phase space density distribution as a function of time, and the interactions of the cloud with the proton beam and the accelerator hardware. In practice much less information is attainable. Historically, the first information on the electron cloud at PSR came in the early 1990's from various biased electrodes in the ring. The results were rather confusing and not understood but they did provide evidence of a large number of electrons at high beam intensities and even more electrons associated with unstable beam. A big step forward was the introduction in 1999 of the RFA augmented with fast electronics which showed clear evidence of many electrons striking the wall at the end of each beam bunch passage. The data including the energy spectra were consistent with trailing edge multipactor as a main contributor to the signal. In 2001 we implemented the electron sweeping diagnostic, a variant of the RFA, to measure the cold electrons remaining in the pipe during the beam-free gap between bunch passages.

RETARDING FIELD ANALYZER

The planar RFA, developed at ANL for application to the APS, is described in more detail in the literature [1]. This simple device, which measures the electrons striking the beam chamber wall, consists of two grids and a graphite-coated collector in a housing which is mounted on the beam pipe wall. Electrons enter the device through small slots (total area ~ 1cm^2) in the beam pipe and pass through a grounded grid, through a repeller grid that can be biased for electron energy selection, and finally reach the collector which is biased positive (+45 V) to insure electron collection and to suppress secondary emission.

Fast electronics [2] connected to the collector are used to obtain information on the time structure of the electrons. A block diagram of the present version of the electronics is shown in Figure 1. The chassis is placed about 1 meter below the beam line to reduce radiation damage to solid state components. The collector signal is connected to the electronics input by 1.2 m of 93 Ω cable. It has provision for gain changing attenuators (1, 0.1, and 0.01) and over-voltage clamps to protect sensitive components. The output amplifier drives a 50 Ω cable to a digital oscilloscope for data collection.

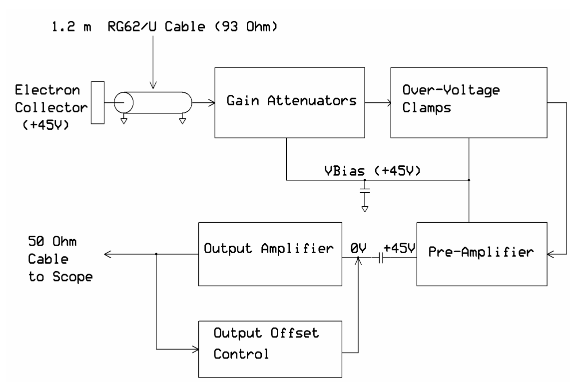

Figure 1. RFA Electronics Block Diagram.

Representative samples of the signals for various values of the repeller voltage are plotted in Figure 2 in time reference to the beam signal (wall current monitor). The data shown are for an earlier version with a transimpedance of 3.5 kΩ. Multiply the signal amplitude by 250 to convert to current density (μA/cm^2) striking the wall.

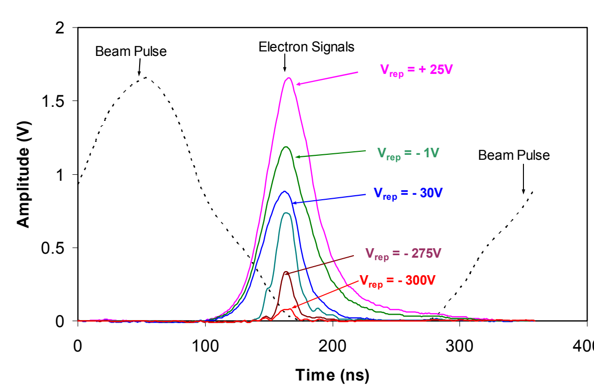

Figure 2. RFA signals in time reference to the circulating beam pulse. Data collected in section 4 of the ring for ~8 μC/pulse beam 7/2000.

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ELECTRON SWEEPING DIAGNOSTIC

The low energy electrons remaining at the end of the beam-free gap between bunch passages are of special interest since these will be captured by the next bunch passage and contribute most heavily to the average neutralization of the beam. They oscillate against the beam for the duration of the bunch passage and are therefore the ones most likely to drive the two-stream instability. To measure the low energy electrons lingering in the pipe we developed the electron sweeping diagnostic (ESD) [3]. It consists of a curved electrode ~40 cm long subtending a half-angle, α, of 75° placed opposite a large-aperture RFA (~10 cm^2) as shown in Figure 3.

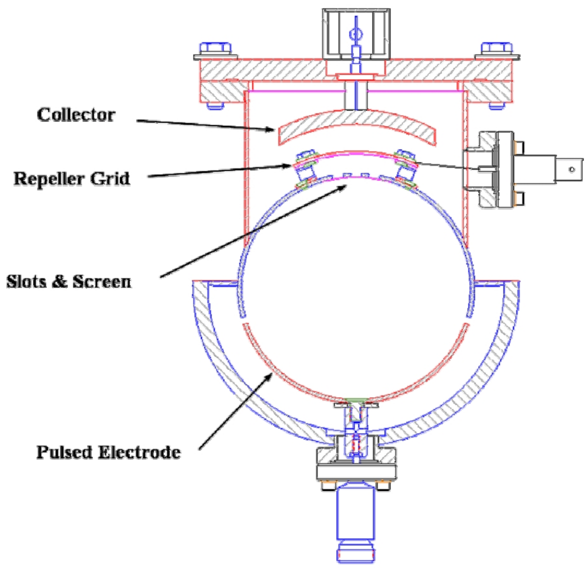

Figure 3. Cross-section of the electron sweeping diagnostic.

A short, fast (~15-20 ns rise time) pulse of ~-500V amplitude (can be up to ~ 1kV) applied to the electrode sweeps electrons into the RFA and thus selects the sampling time in the gap. The curved electrode is terminated with a suitable network of diodes (Phillips BYC8-600) and resistors to prevent charging the electrode by the beam yet allow application of the fast negative pulse. Calculations [4] of the various electron trajectories have been made to map out the detector acceptance assuming zero initial electron energy. The resulting acceptance region is shown in Figure 4 and corresponds to ~30% of the cross-sectional area of the beam chamber.

A sample of the data collected by the ESD is shown in Figure 5 for a 7.7 μC beam pulse. A typical prompt electron signal is seen at the end of the beam bunch since the ESD functions as large area RFA until the HV pulse is applied to the sweeping electrode. The "swept" electron signal at the end of the gap has a very fast rise time (~5ns) and a narrow width (~10 ns) as expected from design calculations but with a longer tail that is not completely understood. The ESD has also been used to measure the electron survival after the last bunch passage in the ring (after single turn extraction) with the interesting result that these electrons can linger for ~1 μs with an exponential decay time of ~ 170 ns [5].

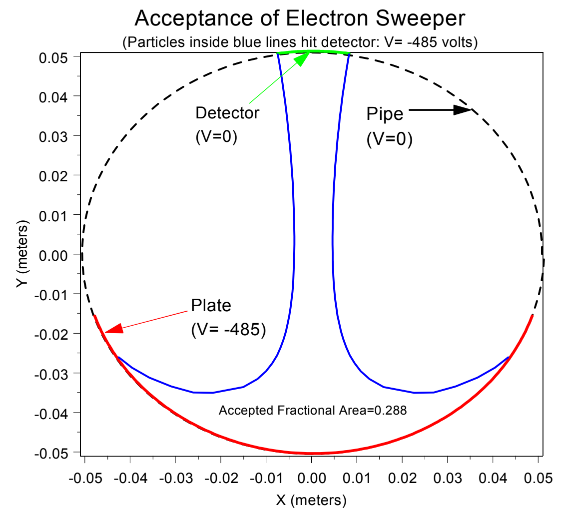

Figure 4. Acceptance region for the ESD. Low energy electrons inside the "trumpet" shaped region will strike the slotted area of the RFA.

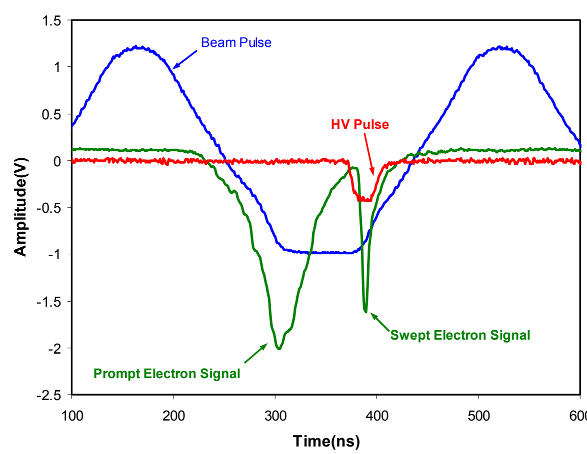

Figure 5. Representative signal from the ESD in time relation to the beam pulse and the -500V pulse applied to the sweeping electrode.

BIASED COLLECTION ELECTRODES

In our first efforts to measure electrons, we tried a variety of biased collection electrodes including parallel and curved plates, BPM striplines, split cylinders and the like in drift regions and in quadrupoles and finally using thin striplines in a ring dipole. Because of the large induced AC signals (100-200 V) from coupling to the beam it was necessary to heavily filter the signal with the result that the time resolution within a turn was lost.

Many puzzling features emerged during their use at moderate to higher intensities such as rather unusual bias curves that were difficult to understand and interpret. An example is shown in Figure 6 for biased strips (2.5 cm wide and ~ 20 cm along the beam axis) in a ring dipole (1.2 T field). The strips in the vertical (top and bottom) were connected together and separately the horizontal strips (right and left) were connected together. For a given curve one pair was biased and the other grounded. The curves are labeled for the pair that was biased. The most puzzling feature is the fact that for positive bias both horizontal and vertical strips give nearly the same result. The electrons are constrained to follow the magnetic fields lines in the vertical (modified slightly by **E**x**B** drift) and it is a real mystery how the horizontal signal can be comparable to the vertical.

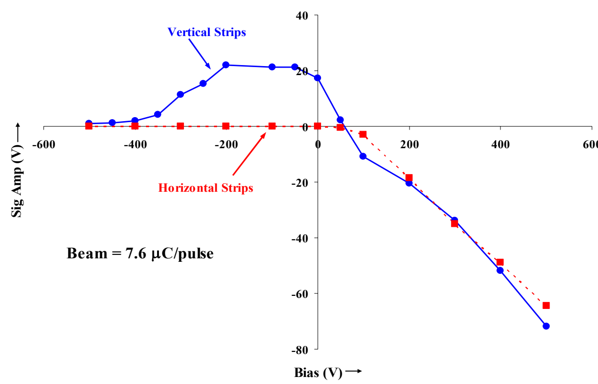

Figure 6. Signal amplitude from pairs of biased strips plotted as a function of applied bias voltage.

The biased electrode is a difficult situation to interpret. Its signal relates to the net charge or current collected i.e., electrons striking the electrode minus those leaving (e.g. secondary emission) rather than just the flux striking the wall as with the RFA. The degree of cancellation depends on a number of factors. During passage of the gap the bias field dominates electron motion and can collect electrons or sweep them to the wall depending on polarity. However, the space charge field of the beam dominates during much of the bunch passage. On the leading edge this pulls electrons into the beam away from the electrodes. On the trailing edge beam-induced multipacting can occur especially for electrons born near the wall. These effects tend to cancel one another and the average over a resolving time of tens of turns is sensitive to the degree of cancellation. In addition, the electrodes and the bias fields change the beam-wall environment and can significantly alter the multipacting process. Clearly the RFA and the ESD are more understandable devices.

ION PUMP GAS PULSE

Historically, a vacuum pressure rise was one of the first indications of the beam induced multipactor. A high flux of electrons on the wall desorbs gases which causes the pressure increase. In a machine, such as PSR, where the beam is accumulated for ~ 1ms then is off for 50 ms or more the average pressure increase is not so noticeable. However, for high peak intensity we can observe a pulse of the ion pump current that correlates well with the prompt electron signals in PSR. The diagnostic is very simple. We use a HV probe (1000:1 attenuation) to look at the voltage developed across a 100 kΩ resistor (in series with the pump) during beam accumulation. A sample signal is shown in Figure 7. The rise time of ~1 ms is consistent with the spread in velocity for light gases (H_2O, N_2) desorbed at room temperature at a location 30-40 cm from the active elements of the ion pump. The ion pump pulse tracks the RFA signal as it varies with beam intensity and as the EC diminishes over time from beam scrubbing.

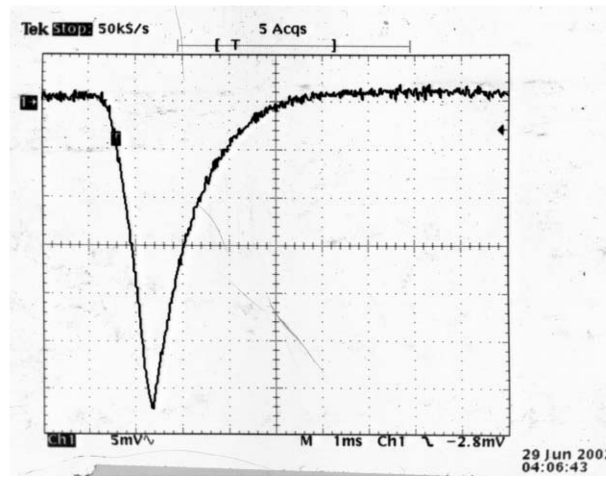

Figure 7. Ion pump pulse obtained during the accumulation and extraction of an 8 μC beam pulse.

SUMMARY AND CONCLUSIONS

Of the various EC diagnostics used at PSR, the RFA and ESD have provided the most detailed and valuable information. Furthermore, they have the advantage of not perturbing the EC or the processes of its formation. Biased electrodes do perturb the beam-wall environment, are complicated to interpret, and produce a number of puzzling features that are not understood. However, they have provided the only information we have for the EC in magnets. The ion pump pulse is a simple diagnostic to implement and, since there are many spread around the ring, they provide a more global sampling of the EC throughout the ring.

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