STATUS OF THE EXPERIMENTAL STUDIES OF THE ELECTRON CLOUD AT THE LOS ALAMOS PROTON STORAGE RING*

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Abstract

The electron cloud (EC) at the Los Alamos Proton Storage Ring (PSR) has been studied extensively for the past several years with an overall aim to identify and measure its important characteristics, the factors that influence these characteristics, and to relate these to the two-stream (e-p) transverse instability long observed at PSR. Some new results since PAC2001 are presented.

INTRODUCTION

Experimental studies of the electron cloud at PSR during the past two years were undertaken to consolidate the understanding gained from earlier exploratory studies [1],[2] and to determine the important characteristics that are needed to adequately explain the e-p instability at PSR. In addition, we sought to understand how well the instability might be cured by suppression of the electron cloud. To accomplish this, our studies aimed to resolve several important issues which include:

1. Will sufficient electrons from the "prompt" pulse emerging at the end of the bunch passage survive the gap (between successive passages of the bunch) to be captured by the bunch and cause the instability?
2. Will electron suppression by TiN coating of the vacuum chamber surfaces or the use of weak solenoids provide a cure?
3. A beam "conditioning effect" on the e-p instability threshold intensity curves had been observed in prior years. Is this effect caused by a reduction in the electron cloud from "beam scrubbing" i.e., does this effect correlate with a reduction in the EC density?
4. What are the important source terms for the initial or "seed" electrons that get amplified by the beam-induced, trailing-edge multipactor process?
5. What causes the electron "burst" phenomenon in PSR?

ELECTRONS SURVIVING THE GAP

Electrons left in the pipe just after passage of the beam pulse will degrade by secondary emission processes to a few eV after the next collision with the wall. The retarding field analyzing detector (RFA) is not suited to the task of measuring these electrons as it only measures those striking the walls not those left in the pipe. To solve this problem, the electron sweeping diagnostic (ESD) was developed to measure low energy electrons lingering in the pipe. Basically it is an RFA with an electrode opposite the RFA. The electrode is pulsed with a short fast pulse (up to 1kV) to sweep low energy electrons from the pipe into the detector. It is described in more detail in reference [3] and the references therein.

The observed swept electron signal which was pulsed at the end of the ~ 90 ns gap (shown in Figure 1) implies an average neutralization of ~1-2% at the location of this detector (section 4 of PSR). This is approximately the value needed to explain the observed e-p instability threshold curves, assuming this represents the average neutralization of the beam [4].

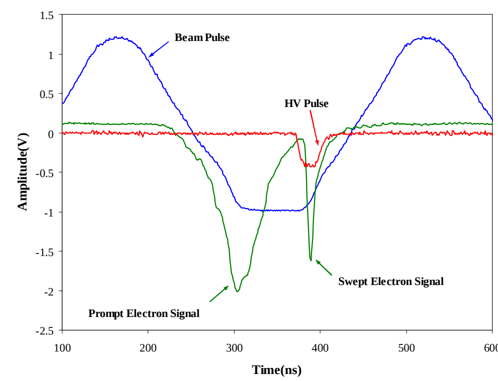

Figure 1. Swept electron signal from ESD plotted in time relationship to the HV and beam pulses.

Another important feature of the swept electron signal at the end of the ~90 ns beam-free gap is that it saturates above a certain level (possibly from space charge effects) as illustrated in Figure 2 while the prompt electron signal continues its rapid increase with intensity.

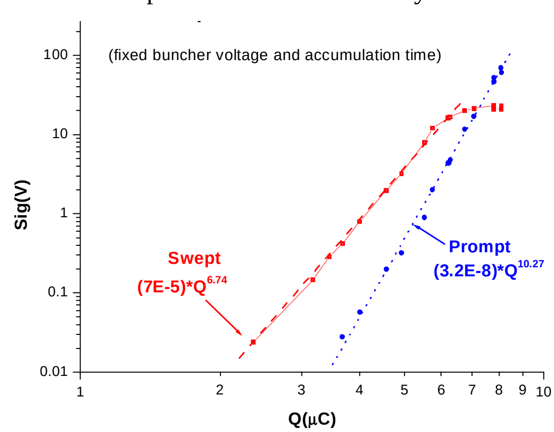

Figure 2. Prompt electron and "swept" electron signal amplitudes plotted as a function of stored beam intensity.

With the electron sweeper it was possible to measure the electrons in the beam pipe as a function of time after single turn extraction from PSR. Some early results for a 5 μC/pulse beam are plotted in Figure 3 and show the

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unexpected feature that significant numbers of electrons are still observed 1 µs after the end of the beam pulse. The long exponential tail (~180 ns time constant) implies a relatively high reflectivity (de ~0.5) for low energy electrons (2-5 eV) at the peak of the secondary emission spectrum.

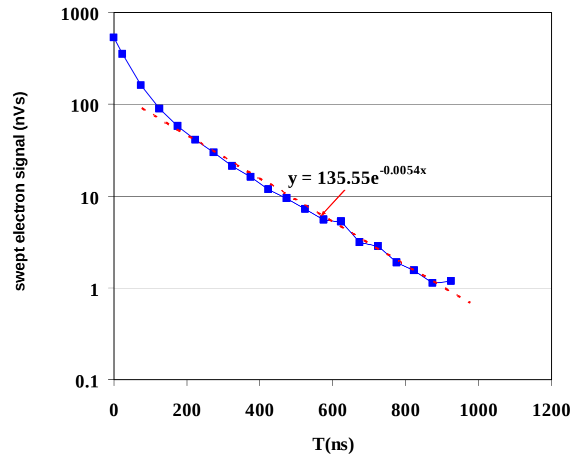

Figure 3. Swept electron signal (integral of pulse) plotted as a function of time after the end of the beam pulse.

TESTS OF ELECTRON SUPPRESSION

We have tested the effect of TiN coatings on the electron cloud signal in three regions of PSR and obtained mixed results, which are summarized in Table I. The most encouraging test was the first one in 1999 where a comparison test of a 2.5 m vacuum chamber coated with TiN and one that was not coated showed a good factor of 100 reduction of the prompt electron signal for the TiN coated chamber. This was carried out in straight section 5 of PSR, which is the region of lowest beam loss in PSR. The comparisons were made for the same beam intensity (within ~ 5%) to limit the effect of the strong dependence of the electron signal on beam intensity.

Table I. Results of TiN coating tests.

Test Location	Date	Beam Intensity	Prompt e reduction factor	Swept e reduction factor
Sect. 5	1999	8.5 µC	>100	N. A.
Sect. 4	2002	8 µC	no initial reduction	none
Sect. 9	2002	7 µC	~40	N. A.
Sect. 4 **	2002	8 µC	~ 5	None

**Plus 2 months of operational beam scrubbing.

In the past year we tested TiN coatings in two more sections; section 4 and section 9, a high loss region near the extraction septa. Section 9 showed a factor of ~ 40 reduction in prompt electrons with the TiN coating. The test in section 4 included an electron-sweeping detector and showed no change in either the prompt or swept electrons signal with and without TiN coating. It should be noted that the prompt electron signal for the TiN coated chamber in section 4 did show a conditioning effect in which the prompt signal (at a fixed intensity) was reduced by a factor ~ 5 after a few weeks of continuous beam operation at 100 µA.

Weak solenoids with an embedded RFA were tested in two locations in PSR, section 9 (2001) and section 2 (2002). Results are shown in Figure 4 where a factor of ~50 reduction is seen with a magnetic field of 20 G.

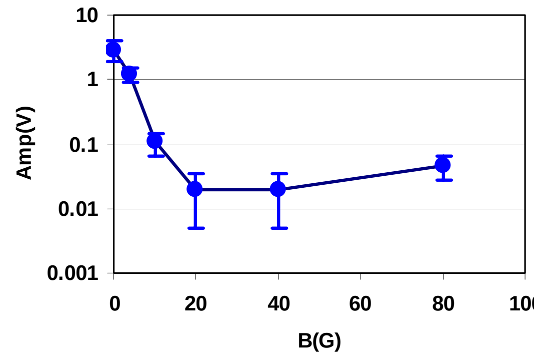

Figure 4. Effect of a weak solenoid field on the prompt electron peak amplitude.

Studies in the 2002 run cycle showed a significant reduction (factor of ~ 5) in the prompt electron signal with time. It is presumably due to beam scrubbing [5]. A related phenomenon is the aptly named 1st pulse instability. For a time after beam operations are resumed following a several month shutdown, a high intensity pulse accumulated in ring after a several minute wait is unstable while the same intensity pulses that follow a short time later are stable. Instability threshold curves for the "first pulse" instability (after a wait time of 3 minutes) are plotted in Figure 5 and compared with the threshold curves for subsequent pulses that follow in a regular pattern (~1Hz). The reduction in threshold for the first pulse is evident. The other characteristics of the instability are identical with the standard e-p instability. The disappearance of the first pulse instability after a few weeks of operation is additional evidence that beam scrubbing is beneficial.

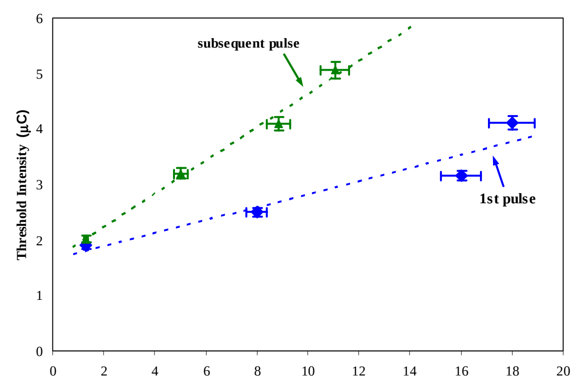

Figure 5. Plots of the instability threshold curves for the 1st pulse after a several minute wait and for the subsequent pulses for a small emittance beam in PSR.

SOURCES OF INITIAL ELECTRONS

The numbers of initial or primary electrons from the various sources e.g., beam losses, residual gas ionization, the stripper foil etc, are important parameters needed as inputs to the EC simulation codes [6]. We found evidence that both residual gas ionization and beam losses make significant contributions to the initial electrons, with somewhat more from beam losses under typical operating conditions. Experiments showed that the prompt electron signal varies linearly with either residual gas pressure or beam losses while the swept electron signal is constant. The results for the variation with gas pressure are shown in Figure 6. Normal operating vacuum range is 10-100 nTorr for section 4 of PSR.

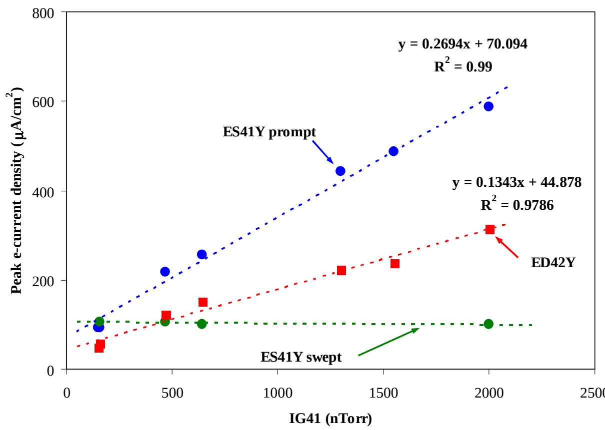

Figure 6. Prompt and swept electron signals amplitudes at the end of accumulation are converted to peak current density at the wall for two detectors in section 4 and plotted as a function of vacuum pressure as measured at ion gauge, IG41. Beam intensity was a fixed 8.2 µC/pulse.

ELECTRON BURSTS

Electron bursts are the name given to the rapid turn-to-turn variations in the prompt electron signal amplitude. This puzzling phenomenon is illustrated in Figure 7 where signals for a train of pulses (120 turns) are shown.

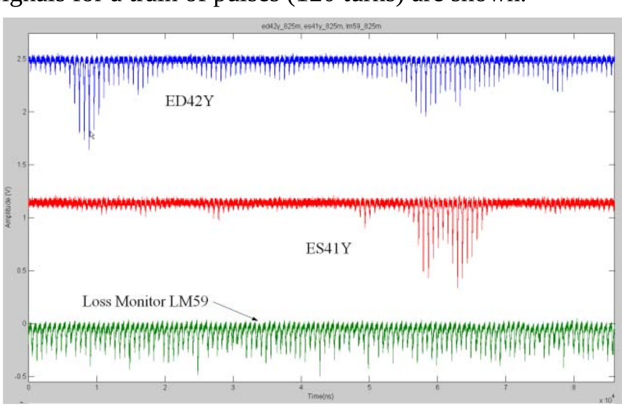

Figure 7. Simultaneous signal traces for two electron detectors (ES41Y, ED42Y) and a local loss monitor (LM59) for 120 turns.

The lack of significant correlation of the bursts with the local loss monitor signal (LM59) in Figure 7 suggests that fluctuations in the local losses are not the cause of the bursts. However, some correlation has been observed between detectors in other locations and suggests some aspect of the beam structure drives the bursts.

The electron burst phenomena, which has become more pronounced with time, is the least understood aspect of the electron cloud in PSR. Perhaps this should not be a surprise, given that beam-induced multipacting is a cascade or avalanche-like process. The fluctuations from the bursts complicate data collection on the electron cloud and necessitate considerable averaging to get reproducible results. It is unclear what impact the bursts have on the instability or other beam dynamics.

SUMMARY AND CONCLUSIONS

Data obtained using the electron sweeping diagnostic (ESD) show that a surprisingly large number of electrons survive passage of the beam-free gap and implies ~1% average neutralization during the beam pulse passage for nominal operating beam intensities. This is approximately the fractional neutralization needed to account for the observed e-p thresholds. The long exponential survival curve for electrons in a beam free region is another important result obtained with the electron sweeping diagnostic and is evidence for a relatively high (~0.5) reflectivity or secondary emission yield, $\delta_e(E)$, from very low energy electrons (2-5 eV peak of the secondary emission distribution).

Our tests of TiN coatings gave mixed results which are not well understood but which suggest caution in assuming that this coating is a universal cure for ECE. The prompt electron peak was reduced by a factor ~40-50 by ~20 G field in tests in two sections of the ring. However, there was no measurable effect on the instability threshold when weak solenoids covering ~ 10% of the ring circumference were excited.

Operating experience at PSR since 1999 provides evidence that beam scrubbing has been effective in significantly raising the threshold for the e-p instability. Studies in the 2002 run cycle showed a significant reduction (factor of ~ 5) in the prompt electron signal with time and are presumably due to beam scrubbing. The disappearance of the first pulse instability after a few weeks of operation is additional evidence that beam scrubbing is beneficial.

Our studies also provide evidence that both the residual gas and beam losses make significant contributions to the initial electrons that are then amplified by the beam-induced multipacting processes.

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