DIAGNOSTIC FOR ELECTRON CLOUDS TRAPPED IN QUADRUPOLES*

R. J. Macek#, and A. A. Browman, TechSource, Inc., Santa Fe, NM 87504, USA

Abstract

Simulations have indicated that electron clouds generated by beam-induced multipactor can be trapped in the mirror-like fields of magnetic quadrupoles and thereby contribute significantly to the electron cloud buildup in high intensity accelerators and storage rings. This could be a very important source of electrons driving the two-stream (e-p) instability at the Los Alamos Proton Storage Ring (PSR) and may also play a significant role in electron cloud effects at some of the new high intensity accelerator projects. We describe the physics design and optimization of an electron-sweeping detector designed to measure the trapped electrons at various times after the beam pulse has passed. The instrument can also serve as an electro-magnetically shielded detector which provides a signal obtained from electrons striking the wall during the passage of beam bunches.

INTRODUCTION

Electron cloud generation and trapping in quadrupoles can be an important source of electrons driving the two-stream e-p instability for long bunch proton rings such as the Los Alamos PSR or the SNS ring now under construction. The importance of electron clouds in PSR quadrupoles is attributed to several factors:

- Seed electrons born at the wall from grazing angle beam halo losses are expected to be most numerous in quadrupoles where the beta functions have their maxima. These are the electrons that undergo the largest amplification from trailing edge multipactor.
- Simulations using POSINST 12.1 (described in the next section) show significant multipacting and trapping from seed electrons born at the vacuum chamber wall in quadrupoles.
- Trapped electrons oscillate against the proton beam during the entire passage of the beam pulse and are thus expected to be most effective in driving the e-p instability.
- Simulations and analytical analysis shows that **E**x**B** drifts of electrons (especially trapped electrons) in quadrupoles during passage of the beam pulse result in rapid ejection of numerous electrons into nearby drift spaces and contribute to the electrons available for further amplification by trailing edge multipactor in the drift spaces. [1]

Little is known experimentally about the electron cloud generated and trapped in PSR quadrupoles and because the angular distribution of grazing losses is also not known with sufficient precision, simulations are unlikely to predict the strength of the e-cloud to better than a factor of 10 to 100. For these reasons development of a diagnostic that can measure the electron cloud in quadrupoles (especially those trapped in the quadrupole after passage of the beam pulse) is proposed.

SIMULATIONS

Extensive simulations of electron cloud generation and trapping in PSR quadrupoles were carried out using POSINST 12.1 [2], [3], [4] to characterize the e-cloud and estimate the signals that would be produced in the proposed diagnostic (described in the next section). An 8 μC/pulse beam with an experimentally determined bunch profile (red curve in Figure 1, top left graph) was used along with a proton loss rate of 4.4×10^{-8} /m/stored proton (an observed loss rate averaged over the ring circumference) and the assumption of 100 seed electrons per lost proton. Examples of the simulation results for the central 30 cm of a PSR quadrupole are shown in Figure 1. The top left graph shows bunch intensity (red) and electron line density (green). The lower dot plot is a snapshot of the trapped electron positions 1.5 μs after the end of the last bunch passage (3.2 μs on the upper plot). The ellipse is the rms spot size of the proton beam.

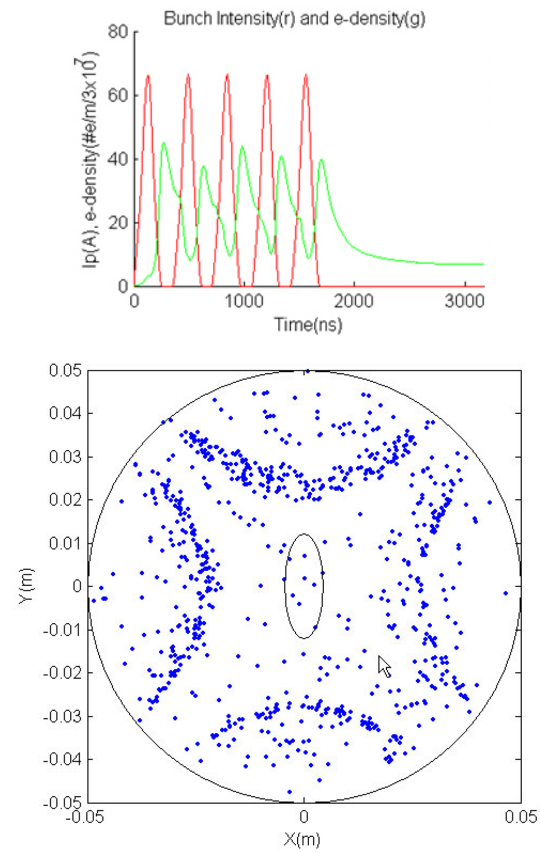

Figure 1. Simulation results for five bunch passages plus 1.5 μs with no beam.

Simulations show generation of numerous electrons on the trailing edge of the beam pulse and that a significant fraction of the electrons are trapped after the beam pulse is gone. Furthermore, the trapped electrons survive for many microseconds after the beam pulse has passed.

*Work supported by SBIR phase I grant DE-FG02-04ER84105. # rjmacek@comcast.net

DIAGNOSTIC CONCEPT

The diagnostic concept that we proposed is shown schematically in a PSR quadrupole in Figure 2. It is an adaptation of the electron sweeping detector which we developed earlier for use in drift spaces at PSR [5]. A cross-section with the quadrupole magnetic field and the electric fields lines (when the HV electrode is pulsed) superimposed is shown in Figure 3.

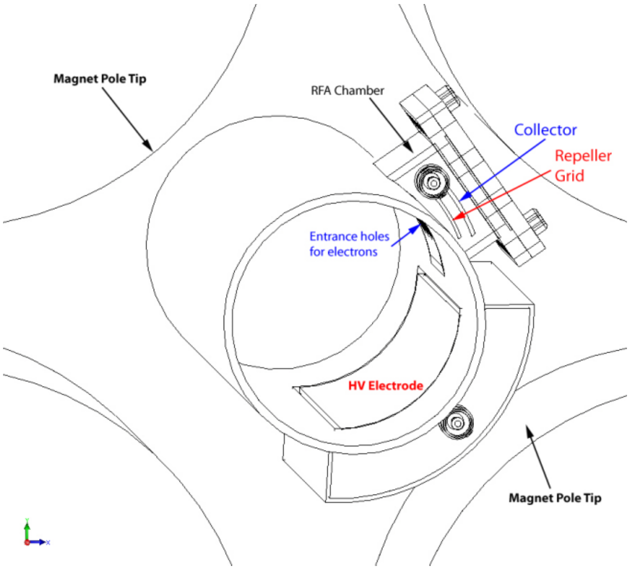

Figure 2: 3D sketch of electron sweeping diagnostic in a PSR quadrupoles.

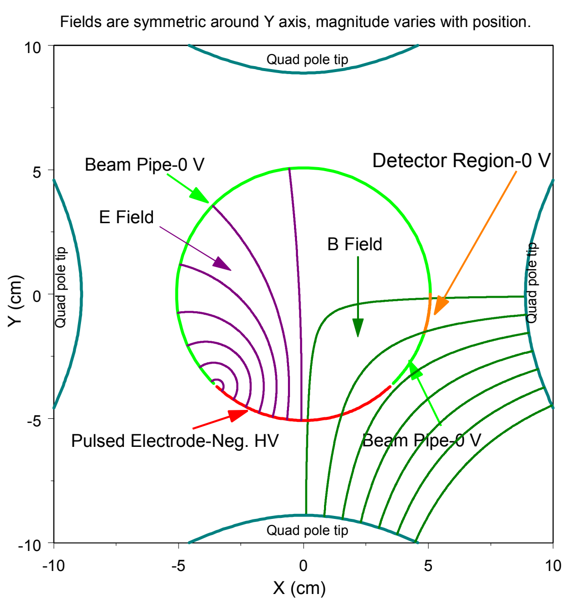

Figure 3: Electric (E) and Magnetic (B) field lines. Note that the picture is rotated 45°to make more efficient use of the display space.

The device takes advantage of the fact that PSR quadrupoles have a 7.125 inch clear aperture of which only a 4 inch diameter is used by the beam pipe. This allows us to add a retarding field analyzer (RFA) chamber with a repeller grid and collector outside of an array of small 0.125 inch holes in the beam pipe. In the orientation that our studies show gives the strongest signals, the RFA aperture is aligned with one quadrupole pole tip and a high voltage electrode is placed opposite another pole tip 90 degrees from the RFA. To measure electrons trapped in the quadrupole field (after the beam pulse has passed), a voltage of ~-500V is applied to the electrode at various times after the beam pulse has passed. The electrons, which are approximately constrained to follow the magnetic field lines, will be swept into the RFA and show up as a fast pulse on the collector.

The electrode shown in Figure 2 is grounded to the pipe by resistors and diodes when the HV pulse is absent. This detector can also measure the "prompt" electrons striking the wall during the passage of the beam. Electrons approaching the wall will enter the RFA chamber and, if they have sufficient energy to penetrate the negative repeller bias, will be detected as a signal on the collector. Utilizing this signal the detector can be used to measure both the flux and cumulative energy distribution of prompt electrons hitting the wall.

DESIGN OPTIMIZATION

A ray tracing program was written to determine the location and size of the detectors and pulsing electrode. This program solved the non-relativistic equations of motion in E and B fields using the adaptive Runge-Kutta routine Rkadapt in Mathcad [6]. An analytical expression for E field [7] and the quadrupole component of the B field were used. This program followed a particle with initial positions (x,y,z) and initial velocities (vx,vy,vz) in the given fields until it hit the beam pipe wall. The fields were assumed to extend indefinitely in the z direction since the detector and pulsing electrode will be installed in the center of a quadrupole with field length significantly longer than the collector plate of detector. Some swept electron trajectories (-485 V applied to HV electrode) are plotted in Figure 4.

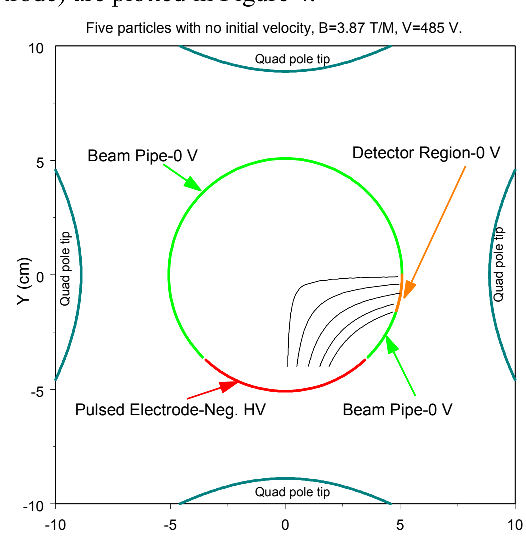

Figure 4: Some swept electron trajectories for electrons of zero initial velocity starting at y = -4 and various x values.

Simulations described earlier show that the average kinetic energy for trapped electrons is ~ 2.5 eV and thus will have swept trajectories very similar to those with zero initial energy. The gyro-motion of the electrons about the B field lines has a typical radius of <0.1 mm and does not show up in Figure 4. Trajectories for energies of 25 eV and various angles with respect to the B field lines also show similar behavior i.e., swept electrons follow the field lines fairly closely and thus have the acceptance limits shown in Figure 5. Most of the trapped electrons initially present in the acceptance region will be swept into the detector region (orange segment in Figure 5).

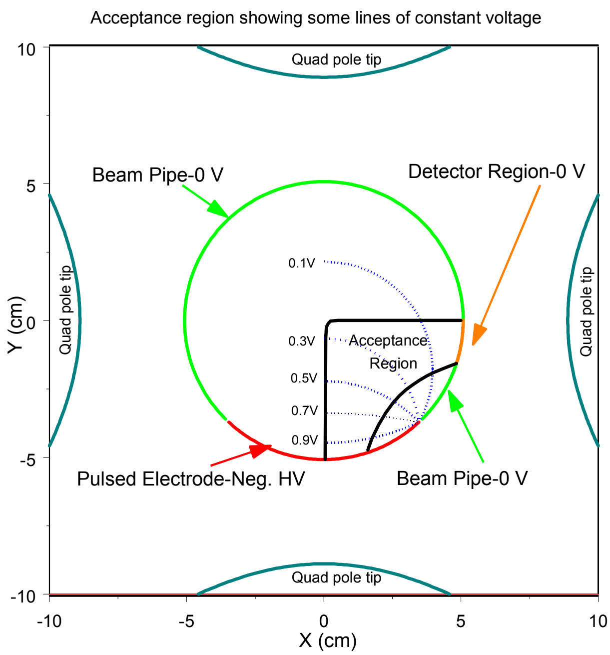

Figure 5: Acceptance limits of the nominal configuration.

A very important design consideration in these detectors is the rejection of the electromagnetic signals at the collector produced both by the beam pulse and also by the pulsing of the sweeping electrode. In order to detect the smallest number of electrons these competing signals must be attenuated as much as possible. The first level of attenuation is provided by the beam pipe but the holes in it to allow the electrons to pass through limit the amount of attenuation that can be obtained. We will provide additional attenuation by installing a grounded copper screen on the outside wall of the beam pipe and by using a screen (bypassed for AC signals) for the repeller grid.

Another design issue is the distortion of the swept electron signal from the finite size of the holes at the entrance to the RFA chamber. After the beam has passed the remaining electrons are constrained to more or less follow field lines. Some are trapped and others collide with the wall and create secondary electrons with lower energy which in turn may become trapped. Those that enter the RFA chamber with sufficient energy to penetrate the repeller barrier are lost and their secondary electrons are suppressed by the collector bias. This will reduce the number of trapped electrons following field lines that link the RFA entrance holes. When the electrode is pulsed it does change the position of electrons reaching the RFA entrance compared with the trajectory in the absence of the E field. The amount of change depends on the position of the electron when the E field is first pulsed and can be as much as 2 mm. This will bring in many electrons with trajectories that did not link the holes and have not been reduced in intensity. The overall effect is difficult to model given the small area of the entrance holes. More study of this is planned. In addition, we suggest studying it experimentally with holes of different sizes.

SUMMARY AND CONCLUSIONS

Experimental information on electron cloud generation and trapping in quadrupoles is needed to help resolve the origin of electrons driving the e-p instability at PSR. We have proposed a diagnostic that is optimized to measure the electrons trapped in the quadrupole after the beam pulse has passed and can also measure the flux and cumulative energy spectrum of electrons striking the wall during trailing edge multipactor.

ACKNOWLDEGMENTS

Robert Macek would like to thank Miguel Furman and Mauro Pivi for all of their help, guidance and training given him in the use of POSINST. We would also like to thank Don Clark for his help in preparing illustration drawings of the diagnostic concept.

REFERENCES

[1] R. Macek and M. Pivi, "ExB Drift of the e-cloud in a PSR Quadrupole and Dipole", Technical note of 3/28/05 posted to the ILC website, http://www-project.slac.stanford.edu/ilc/testfac/ecloud/elec_cloud.html.

[2] M. A. Furman and G. R. Lambertson, "The Electron cloud Instability in the Arcs of the PEP-II Positron Ring," LBNL-41123/CBP Note-246, PEP-II AP Note AP 97.27, 1997. also Proc. Intl. Workshop on Multibunch Instabilities in Future Electron and Positron Accelerators (MBI-97), KEK, Tsukuba, Japan, 15-18 July 1997, KEK Proceedings 97-17, Dec. 1997 (Y. H. Chin, ed.), p.170.

[3] M. A. Furman, "The Electron-Cloud Effect in the Arcs of the LHC", LBNL-41482/CBP Note 247/LHC Project Report 180, May 20, 1998.

[4] M. A. Furman and M. T. F. Pivi, "Probabilistic Model for the Simulation of Secondary Electron Emission", LBNL-49771/CBP Note-415, November 6, 2002; PRST-AB paper v5/i12/e124404 (2003).

[5] R. Macek et al, "Electron Cloud Diagnostics in Use at the Los Alamos PSR", Proceedings of the 2003 Particle Accelerator Conference, p. 508(2003).

[6] Commercial software Mathcad 11 by Mathsoft.

[7] T. S. Wang, D. Barlow, A. Browman and R. Macek, "The Static Electric Field of a Curved electrode in a Beam Pipe", PSR Technical Note 01-003, 5/22/ 2001.

 0-7803-8859-3/05/$20.00