A COMPARISON OF ELECTRON CLOUD DENSITY MEASUREMENTS AT CESRTA*

J.P. Sikora†, J.A. Crittenden, D.O. Duggins, Y. Li, X. Liu, CLASSE, Ithaca, New York, USA
S. De Santis, LBNL, Berkeley, California, USA

Abstract

Several techniques have been employed to measure the electron cloud (EC) density in accelerators. These include Time-Resolved Retarding Field Analyzers and Shielded Pickups that sample the flux of cloud electrons onto the beam-pipe wall, as well as TE wave resonance techniques that measure the EC density in a region within the volume of the beam-pipe. We have made measurements to test the EC mitigation properties of different surface coatings and geometries, often with more than one technique used in the same test chamber. We present a comparison of measurements in bare aluminum chambers with those having a TiN coating, as well as the effect of beam conditioning. In addition, we will compare the results of the different measurement techniques used in the same chamber under the same conditions. These measurements were made at the Cornell Electron Storage Ring (CESR) which has been reconfigured as a test accelerator (CESRTA) having positron or electron beam energies ranging from 2 GeV to 5 GeV.

INTRODUCTION

At CESRTA [1], a number of instruments have been installed for the study of electron cloud (EC) buildup. Data has been accumulated for both positron and electron beams, at beam energies from 2 to 5 GeV. This paper will focus on a subset of these measurements, with positron beams at 5.3 GeV. It will also focus on the three types of instrument for the detection of electron cloud signals described below.

Shielded pickups (SPU) [2, 3] sample the flux of electrons that are incident on the beam-pipe wall. The vacuum space is extended by an array of small holes in the beam-pipe wall. The holes, having a depth to diameter ratio of about 3:1, isolate a collecting electrode from the direct beam signal. The 1.7 cm diameter collecting electrodes are the same design as those used for the beam position monitor system at CESRTA and have more than 1 GHz bandwidth. There are four collectors at each location: two along the beam axis and two spaced 1.4 cm to either side of the beam axis. Only the on-axis button data will be presented here. There are two sets of SPUs at CESRTA: one set in a 3 m long bare aluminum chamber, the other in a similar chamber coated with Titanium Nitride. The electron signal from the SPU is amplified with a voltage gain of 100 and digitized by an oscilloscope.

The Time-Resolved Retarding Field Analyzers (TR-RFA) [4, 5] are similar to the SPU in that they sample the cloud electrons that are incident on the beam-pipe wall. One distinguishing feature is that there are three grids in the vacuum space between the holes and the collecting electrodes. The outer two grids are grounded. If the middle grid is negatively biased, it will prevent lower energy electrons from passing through to the collectors. For all of the data shown here, the grid was held at +50V to avoid the suppression of low energy electrons. There are nine 6-mm-wide collectors arranged horizontally so that the electron flux at different horizontal positions can be distinguished. The collectors are numbered such that #1 is radially outside and #9 is radially inside. TR-RFAs have been installed in four 70-cm-long test chambers assembled together as a string. Two chambers have a round cross-section, the other two are round, but have longitudinal grooves in the top and bottom vacuum surfaces. For each type of surface geometry, one is bare aluminum and the other has a TiN coating. The electron signal from each collector is amplified with a voltage gain of 100 and digitized by an oscilloscope.

The TE wave detectors respond to the electron cloud within the volume of a section of beam-pipe rather than to the flux of electrons onto the beam-pipe wall [6, 7]. This is done by taking advantage of changes in the beam-pipe geometry to set up TE wave resonances – using beam position monitor buttons to couple microwaves in and out of the beam-pipe. The resonant frequency will be changed by the presence of the electron cloud. When the beam-pipe is excited with a fixed frequency on resonance, the cloud from a train of bunches in the storage ring will produce modulation sidebands spaced at the revolution frequency on either side of the drive frequency. The EC density can be calculated from the ratio of the drive and sideband amplitudes. Three TE wave detection locations will be discussed. One is the roughly 3 m long section of aluminum chamber at that includes an SPU. Another two TE wave regions are in the grooved chambers that include the TR-RFAs – one of bare aluminum and the other with a TiN coating. Bead pull measurements have shown that TE wave resonances can be confined to the grooved chamber length of less than one meter [8].

DETECTOR SIGNALS

The SPU signals are recorded as digitized oscilloscope traces. Simulations of particular bunch patterns and cur-

* This work is supported by the US National Science Foundation PHY-0734867, PHY-1002467 and the US Department of Energy DE-FC02-08ER41538, DE-SC0006505.
† jps13@cornell.edu

ISBN 978-3-95450-122-9

rents are used in order to estimate the EC density. For the purpose of comparison, the signal voltages (into a 50 Ω load) are integrated to give the EC charge deposited on the collector with each revolution of the stored beam. The coulombs/turn signals can be useful when making relative comparisons of EC density.

The analysis of TE wave signals is still under development. The following procedure was used for all of the data presented here. With a train of bunches: the duration of the EC density is taken to be a rectangular pulse whose length is equal to the length of the bunch train plus 100 ns (this being the approximate lifetime of the electron cloud); the EC density pulse produces a shift in the resonant frequency of the beam-pipe ; this frequency shift results in a phase shift across the resonance; the phase shift is convoluted with the 400 ns response time of the resonance and the Fourier transform of this phase modulation gives the magnitude of the sidebands with respect to the drive frequency. For the TE wave measurements, the plots show the calculated amplitude of the rectangular EC density pulse.

SIGNAL COMPARISONS

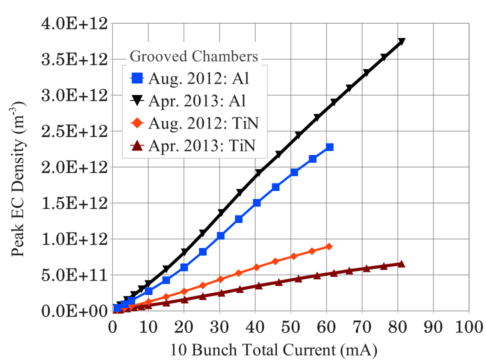

Figure 1: TE wave data with ten bunches of positrons with 14 ns spacing shows that the EC density decreases with beam processing in the TiN coated chamber, but increases in the bare aluminum chamber.

Data was taken with either two or ten positron bunches spaced by 14 ns in the CESRTA storage ring. The revolution period is 2562 ns. The effect of beam processing can be seen, since data from August 2012 was taken shortly after the chambers were installed – when there had only been about 0.55 amp-hours of beam. Data from December 2012 had over 600 amp-hours and April 2013 data was taken after a total of 1144 amp-hours of beam processing. The flux and energy spectrum of the synchrotron light varies considerably at the various detector locations, but this variation has not been taken into account in these plots.

Figure 1 shows a TE wave measurement of EC density in the bare Al and the TiN grooved chambers as a function of the 10-bunch total current. While the TiN chamber showed a reduction in EC density with processing, the bare Al chamber showed an increase in EC density.

The TR-RFA signals in the same chambers show a similar effect: that the EC density signal in the Al chamber increases (Fig. 2), while it decreases in the TiN coated chamber (Fig. 3). All data shown were taken at 54 mA total current (8.6×10^{10}/bunch). The ringing on the TR-RFA signal is due to direct beam signal that couples into the volume of the detector.

Figure 4 shows SPU signals taken with two bunches spaced by 14 ns. These signals have the same general character as the signals from the grooved chambers in that the TiN chamber signal decreases with beam processing, while the Al chamber signal increases. The SPUs are in oval pipe roughly 300 meters away from the TR-RFAs, so the increased EC density with processing seems to be due to the aluminum surface rather than some detail of the chamber geometry or location. Measurements by Cimino *et al.* have shown that the quantum efficiency of aluminum increases with processing by VUV light [9].

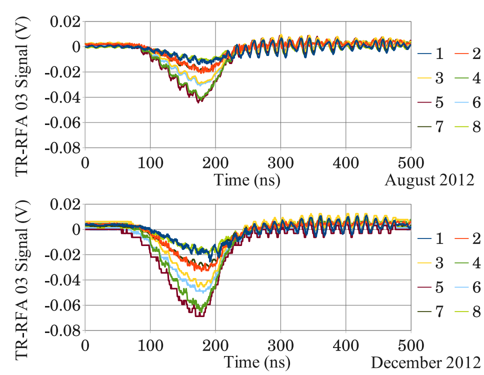

Figure 2: The 10-bunch TR-RFA signal from the grooved Al chamber increases with beam processing. The signals from eight of the collectors are overlayed.

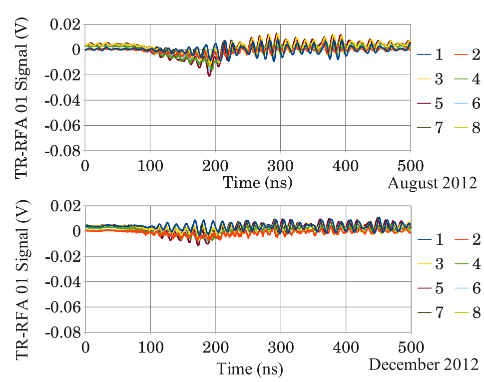

Figure 3: The 10-bunch TR-RFA signal from the grooved TiN chamber decreases with beam processing.

COMPARISON WITH SIMULATIONS

ECLOUD simulations of EC density include the synchrotron light flux, energy and spatial distribution as well as beam-pipe geometry, quantum efficiency, and secondary electron yields [10]. Simulated EC densities are combined with a model for the detector response to simulate the detector signal. ECLOUD simulations have given reasonable agreement with the measured TR-RFA signal in the grooved aluminum chamber [5].The upper simulation of Fig. 5 for ten bunches of positrons at 8 mA/bunch shows a peak EC density of 1.4×10^{12} m^{-3}. This corresponds to the plot of TE wave data in Fig. 1 at 80 mA total current. The TE wave measurement is higher by about a factor of two. A similar comparison of 2-bunch data and simulation in the aluminum grooved chamber (not shown) gives a similar comparison.

A 2-bunch simulation of 3 mA bunches at the SPU in the 3 m aluminum chamber gives a peak EC density of 1.5×10^{12} m^{-3} (Fig. 5). This simulation is also in good agreement with data from the SPU located in this chamber. The 2-bunch TE wave data with a 2-bunch total current of 6 mA shown in Fig. 6 is in reasonable agreement with the peak EC density of the simulation.

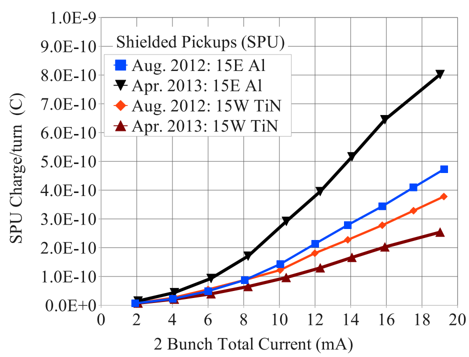

Figure 4: The SPU signals in the Al and TiN chambers also show a decrease in the TiN signal and an increase in the Al signal with beam processing.

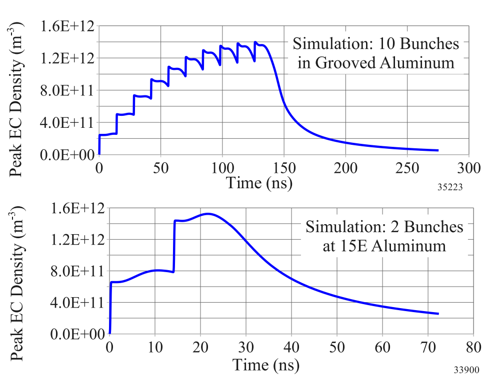

Figure 5: The upper simulation matches Dec. 2012 TR-RFA data in the grooved aluminum chamber with ten bunches of positrons at 80 mA total (1.28×10^{11} /bunch). The lower simulation matches Aug. 2012 SPU data in the 3 m aluminum chamber with two bunches at 6 mA total (4.8×10^{10} /bunch)

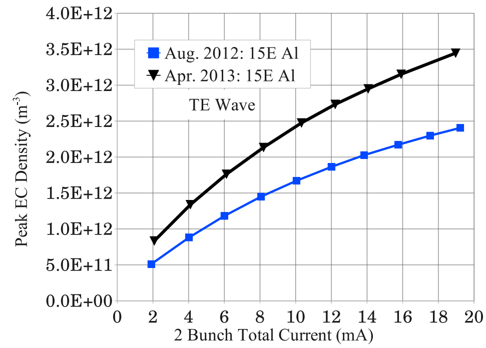

Figure 6: 2-bunch TE wave data taken in the 3 m Al beam-pipe also shows increased EC density with processing.

CONCLUSIONS

A significant change in EC density can be seen in data from these detectors between initial installation and extensive beam processing. Data from the SPU and TR-RFA have helped to establish simulation parameters. Further analysis of the TE wave technique is needed in order to establish its absolute calibration of EC density.

REFERENCES

[1] G.F. Dugan, *et al.*, ICFA Beam Dynamics Newsletter No. 50, J. Urakawa and W. Chou, Eds. (2009).

[2] J. P. Sikora, *et al.*, "Time Resolved Measurement of Electron Clouds at CESRTA Using Shielded Pickups ," in Proc. of PAC'11, New York, NY, USA, August 2011, WEP195, p.1855, (2011).

[3] J.A. Crittenden, *et al.*, "Electron Cloud Modeling Results for Time-resolved Shielded Pickup Measurements at CESRTA," in Proc. of PAC'11, New York, NY, USA, August 2011, WEP142, p.1752, (2011).

[4] J. P. Sikora *et al.*, "Electron Cloud Measurements Using a Time Resolved Retarding Field Analyzer at CESRTA", in Proc. of IBIC'12, Tsukuba, Japan, October 1-4 2012, MOPB56 (2012).

[5] J.A. Crittenden *et al.*, "Model Development for Time-Resolved Retarding Field Analyzer Measurements at CESRTA", IPAC13, MOPWA072 these proceedings.

[6] J. P. Sikora *et al.*, "Resonant TE Wave Measurements of Electron Cloud Densities at CESRTA", in Proc. of IPAC'11, San Sebastián, Spain, August 2011, TUPC170, p.1434, (2011).

[7] J. P. Sikora *et al.*, "TE Wave Measurement and Modeling", in Proc. of ECLOUD'12, La Biodola, Isola d'Elba, Italy, June 5-8 2012.

[8] J. P. Sikora *et al.*, "Electron Cloud Measurements Using Resonant TE Waves at CESRTA", in Proc. of IBIC'12, Tsukuba, Japan, October 1-4 2012, TUPB49 (2012).

[9] R. Cimino, V. Baglin and I.R. Collins, *Phys. Rev. ST Accel. Beams* **2**, 063201 (Jun. 1999).

[10] F. Zimmermann, *et al.*, ICFA Beam Dynamics Newsletter No. 33, K. Ohmi & M. Furman, Eds. (2004).

ISBN 978-3-95450-122-9