Title

Simulations of Electron-Cloud Current Density Measurements in Dipoles, Drifts And Wigglers at CesrTA

Author

Calvey, J.

Publication Date

2009-05-11

SIMULATIONS OF ELECTRON-CLOUD CURRENT DENSITY MEASUREMENTS IN DIPOLES, DRIFTS AND WIGGLERS AT CESRTA

J. Calvey, J. A. Crittenden, G. Dugan, S. Greenwald, D. Kreinick, J. A. Livezey, M.A. Palmer, D. Rubin, CLASSE, Cornell University, Ithaca NY 14850 USA*
K. C. Harkay, ANL, Argonne, Il, USA **
P. Jain, K. Kanazawa, Y. Suetsugu, KEK, Ibaraki, Japan
C. M. Celata, M. Furman, G. Penn, M. Venturini, LBNL, Berkeley, CA, USA†,
M. T. F. Pivi, L.Wang, SLAC, Menlo Park, CA, USA

Abstract

A core component of the CesrTA research program at Cornell is to fully understand the electron cloud effect through the use of simulation programs that have been developed to predict the growth of the cloud and its interaction with the beam. As a local probe of the electron cloud, several segmented retarding field analyzers (RFAs) have been installed in CesrTA in dipole, drift and wiggler regions. Using these RFAs, the energy spectrum of the time-average electron cloud current density striking the walls has been measured for a variety of bunch train patterns, with different bunch currents, beam energies, emittances, and bunch lengths, and for both positron and electron beams. This paper will compare these measurements with the predictions of simulation programs.

INTRODUCTION

Complete understanding of data taken with an RFA requires a simulation program that models the behaviour of the electron cloud, in the vacuum chamber and in the RFA itself. This allows one to extrapolate backwards from RFA data to the actual dynamics of the cloud; with the eventual goal of determining its effect on the beam and evaluating the effectiveness of mitigation techniques. In order to have confidence in this method, one needs simulation programs that can reliably predict the response of RFAs in a variety of beam conditions and locations around the ring. This paper will discuss the effort to bring RFA simulation and data into agreement.

RFA DATA

There are four different types of RFAs employed at CESR, summarized in Table 1. Here "area" refers to the effective collector area that is exposed to the vacuum chamber, taking into account beam pipe and grid transparencies. For a more detailed discussion of the RFA hardware, see [1].

RFA data was taken under a variety of beam conditions. The two main modes of data taking were "voltage scans," in which the retarding voltage on the RFA was varied (typically between +100 and -250 V), and "current scans," in which the bunch current was varied.

For the sake of brevity, this paper will focus on voltage scan data taken with segmented, dipole, and wiggler RFAs, in a particular set of conditions (Table 2).

Table 1: Summary of RFA Types at CesrTA

Type/Location	Ground/ Retarding Grids	Collector number/ area (mm^2)	Magnetic Field (T)
APS-style[2]/drift	1/1	1 / 18	0
Segmented/drift	1/1	5 / 6.4	0
Dipole/dipole	0/3	9 / 8.7	.2011 @ 5.3 GeV
Wiggler/wiggler	0/1	12 / 3.5	1.9

Table 2: Beam Parameters

Parameter	Value
Beam Energy	2.1/5.3 GeV
Bunch Structure	1 Train of 45 Bunches
Bunch Spacing	14 ns
Species	Positron
Bunch Charge	1 - 1.25 mA

The segmented and dipole data shown here were taken with a bunch current of 1mA and a beam energy of 5.3 GeV; the wiggler data was taken with 1.25 mA bunches at 2.1 GeV. Note that the wiggler RFA discussed here is at the center of a wiggler pole, in a 1.9 T transverse field. Figures 1, 2, and 3 show data taken under these conditions with each of the RFA types mentioned. In these plots, collector current is given in nA/mm^2, using the effective areas given in Figure 1.

The segmented RFA data is fairly uniform across its five collectors, while the dipole data shows strong multipacting at the location of the beam. The wiggler data is more difficult to understand. Since the field at the pole center is transverse, one would expect it to behave essentially like a dipole, yet the distribution across the twelve collectors is much flatter at low retarding voltage, and the center collector retains most of its current up to 250V.

SIMPLE RFA MODEL

The primary cloud simulation program used for RFA comparisons was POSINST [3]. In certain cases, ECLOUD [4] and WARP/POSINST [5] were also used.

*Work supported by the US National Science Foundation and Department of Energy
† Work supported by the US DOE under contract DE-AC02-05CH11231
**Work supported by the Office of Science, U.S. Department of Energy under contract DE-AC02-06CH11357

Prediction of RFA currents was done using a simple RFA model implemented in a post-processing script written in MATLAB. This script uses the output of a simulation program (e.g. the "death certificates" file in POSINST). For each macroparticle that has collided with the beam pipe wall, the script determines the effective transparency of the beam pipe wall and any grids (based on the particle's energy, position, and incident angle), and deposits the appropriate amount of the macroparticle's

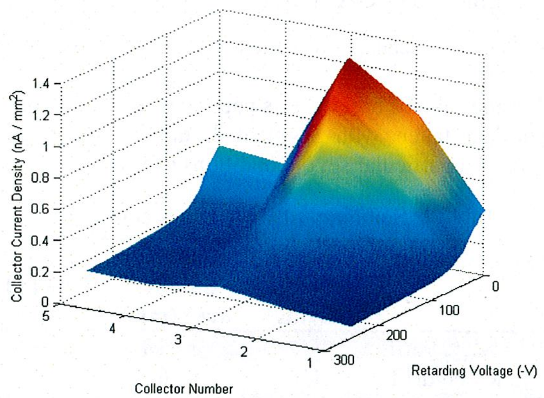

Figure 1: Segmented RFA Data (Drift), taken with a 45 bunch train of positrons with 1 mA/bunch, at 5.3 GeV.

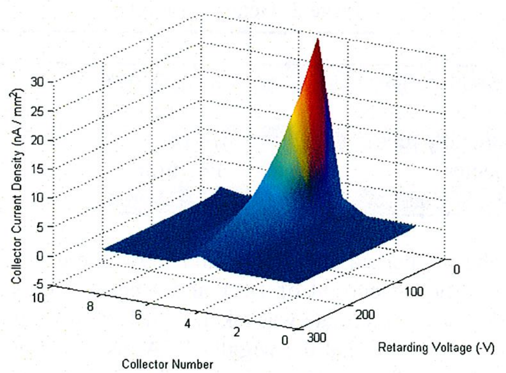

Figure 2: Dipole RFA Data, taken with a 45 bunch train of positrons with 1 mA/bunch, at 5.3 GeV.

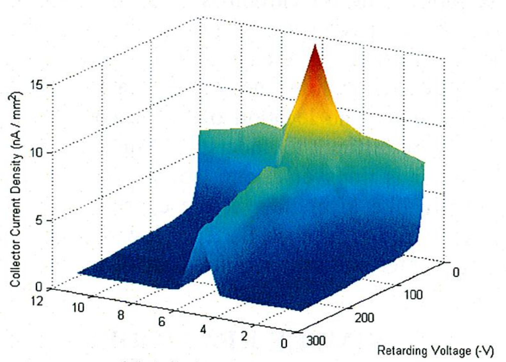

Figure 3: Wiggler RFA Data, taken with a 45 bunch train of positrons with 1.25 mA/bunch, at 2.1 GeV.

charge on the grids and collector.

This method allows for a relatively simple but complete prediction of the RFA currents. Its principal disadvantage is that it cannot predict any effect of the RFA on the cloud dynamics. This will be discussed in the next section.

Runs were done with a reflectivity of 20%, quantum efficiency of 10%, and SEY parameters given below each figure. These parameters were based on values for unprocessed copper (for the drift and wiggler) and aluminium (for the dipole), and were only tuned to give agreement within a factor of two with the data. An important part of our future simulation work will be finely adjusting them. Figures 4, 5, and 6 show simulations for conditions corresponding to Figures 1, 2, and 3 respectively. For the drift and dipole case, the match is good to within about a factor of two, although simulations tend to overemphasize the center collector. This effect gets worse with increasing magnetic field strength, and in the 1.9 T field of the wiggler this central spike completely dominates over the other features.

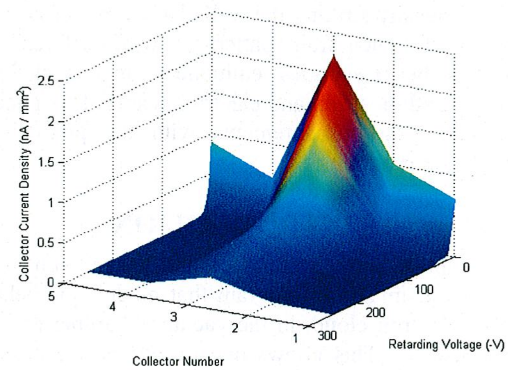

Figure 4: Drift Simulation, Corresponding to Fig. 1, Peak SEY is 2.0 at 276eV.

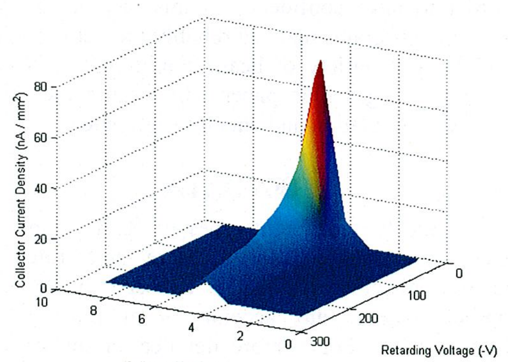

Figure 5: Dipole Simulation, Corresponding to Fig. 2, Peak SEY is 1.6 at 310 eV.

REFINEMENTS TO THE MODEL

Evidently understanding the RFA data, at least in the wiggler, requires more than the simple RFA model described above. The most obvious suspect here is the 2D nature of POSINST, which one might expect to be insufficient at modelling a 3D wiggler field,

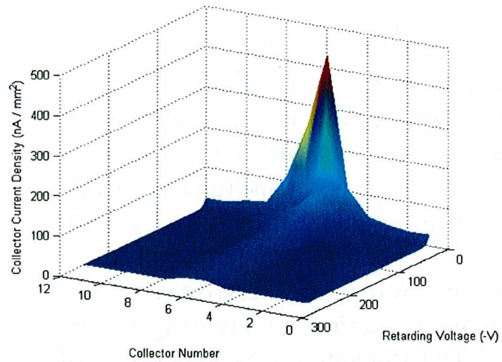

Figure 6: Wiggler Simulation, Corresponding to Fig. 3, Peak SEY is 2.0 at 276eV.

even in an approximately transverse region. However, simulations done with the 3D code WARP/POSINST show good agreement (within 50% in the central collectors, and 10% in the outer collectors) with the 2D prediction in the RFA region.

A major defect of the simple RFA model is that it does not account for the effect of the RFA on the cloud. This is particularly critical in modelling the wiggler. In a 1.9 T field, the cyclotron radius for a typical cloud electron is only a few microns (~4 μm for a 5 eV electron). This means that particle motion is essentially one-dimensional, up and down along a magnetic field line.

Consider an electron in a strong magnetic field entering an RFA. If the electron's energy is less than the retarding voltage, it will be turned around by the retarding field, so in this case the RFA behaves as a perfect reflector with an SEY of 1. If its energy is higher than the retarding voltage, it may make it through to the collector, but it might also hit the retarding grid itself. If this happens, secondaries can be produced, which are then accelerated through the retarding potential back into the vacuum chamber. Since a typical electron is strongly pinned to the field lines, it is very likely that these secondaries will escape through the same hole the primary came in.

Once an electron escapes back into the vacuum chamber, it is of course free to interact with the beam. If the electron has just the right amount of energy, it will make it to the center of the beam pipe at the same time the next bunch comes through, and will get a large kick; either back into the RFA, where it will have another chance to make it to the collector, or to the other side of the vacuum chamber, where due to its high energy it is likely to produce secondaries. The result is a resonance enhancement that depends on both the beam parameters and the RFA's retarding voltage. This effect can be seen as an enhancement in the central collector at some small but nonzero retarding voltage (about 10V, in Fig. 3).

Another shortcoming of the simple model is that it does not remove a macroparticle from the simulation (or even reduce its charge) once it has deposited current in a grid or collector. This is not likely to be a large effect in a field free region, but in the one dimensional regime of a large field, a single macroparticle (and the secondaries it generates) may very well collide multiple times with the same collector. This means that, in the cloud simulation, a macroparticle can be responsible for an apparent current many times its actual charge. To address this problem, the simple RFA model was modified to "disable" a macroparticle, together with all its descendant secondaries, once it has been collected. The effect of this refinement is a great reduction in the central spike that was seen in the naive simulation (Fig. 6). The result, though far from perfect, now agrees much better with the data (Fig. 7). In reality, this method will actually underestimate collector currents, because it ignores secondary emission on the grid.

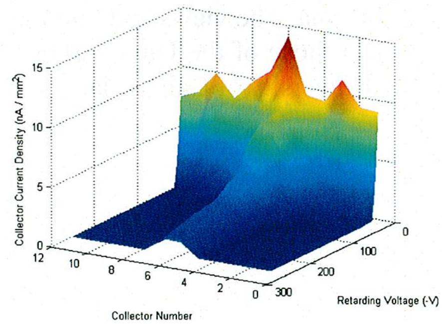

Figure 7: Wiggler Simulation, with "multiples" removed.

CONCLUSIONS

RFA simulations in drifts and dipoles agree well with data, although simulations tend to overestimate the current in the central collector. Matching the wiggler data is more difficult because the RFA affects the dynamics of the cloud, at least in the region the RFA is sampling.

To this end, we are working on incorporating an RFA model into ECLOUD which will include the loss of charge into the RFAs, as well as secondary emission on the grid. A similar effort of incorporating an RFA in POSINST is underway at LBNL. Future work will also include a systematic comparison of data and simulation, adjusting SEY parameters and fully incorporating the corrections mentioned here.

REFERENCES

[1] Y. Li et al, contributions to this conference: MO6RFP005 and TH5RFP029

[2] R.A. Rosenberg, K. Harkay, NIM A 453, 507 (2000)

[3] M. A. Furman and G. R. Lambertson, Proc. MBI-97, KEK Proceedings 97-17, p. 170.
M. A. Furman and M. T. F. Pivi, PRST-AB 5, 124404 (2002).

[4] F. Zimmermann and G. Rumolo, Electron Cloud Effects in Accelerators, ICFA Beam Dynamics Newsletter No. 33, eds. K. Ohmi and M.A. Furman (2004)

[5] J.-L. Vay, M. A. Furman, P. A. Seidl, R. H. Cohen, A. Friedman, D. P. Grote, M. Kireeff Covo, A. W. Molvik, P. H. Stoltz, S. Veitzer and J. P. Verboncoeur, NIMPR A 577, 65 (2007).