MODELING AND SIMULATION OF RETARDING FIELD ANALYZERS AT CESRTA*

J.R. Calvey, J.A. Crittenden, G.F. Dugan, J. Makita,
M.A. Palmer, W. Hartung, CLASSE, Cornell University, Ithaca, NY, USA
M. Furman, M. Venturini, LBNL, Berkeley, CA, USA

Abstract

Over the course of the CESRTA program at Cornell, Retarding Field Analyzers (RFAs) have been installed in drift, dipole, quadrupole, and wiggler field regions of the CESR storage ring. RFAs are used to measure the local electron cloud flux on the vacuum chamber wall. Through the use of a retarding grid and segmented collectors, they also provide information on the energy and transverse distribution of the cloud. Understanding these measurements on a quantitative level requires the use of cloud buildup simulation codes, adapted to include a detailed model of the structure of the RFA and its interaction with the cloud. The nature of this interaction depends strongly on the type and strength of the local magnetic field. We have developed models for RFAs in drift and dipole regions. The drift model has been cross-checked with bench measurements, and we have compared the RFA-adapted cloud buildup simulations with data. These comparisons have then been used to obtain best fit values for the photo-emission and secondary electron emission characteristics of some of the vacuum chamber materials and cloud mitigating coatings employed at CESRTA.

INTRODUCTION

A retarding field analyzer consists of three main components: holes drilled in the beam pipe to allow electrons to enter the device; a "retarding grid," to which a voltage can be applied, rejecting electrons with less than a certain energy; and a positively biased collector, to capture any electrons which make it past the grid. A model of this basic structure, created in Opera 3D (and described in detail in the next section), is shown in Fig. 1. Each of these three components must be well understood to enable the translation of an RFA measurement into physical quantities relating to the development of the electron cloud. To bridge this gap, accurate models of both the cloud development and the RFA itself are required. The former task is handled by a well validated cloud simulation code such as POSINST [1], which tracks the motion of cloud particles during and after the passage of a bunch train. The latter is the subject of this paper.

Previous efforts to analyze RFA data [2] have relied on post-processing the POSINST "death certificates" file, which contains a record of all the macroparticle-wall collisions that took place during the simulation. Recently, models for a few different RFA types have been integrated into the code, and a file containing the simulated RFA signals is automatically produced by the simulation. In addition to being much faster and using less disk space than the post-processing method, the integrated model is more self-consistent, since it allows for charge that enters into the RFA to be taken out of the cloud in the vacuum chamber.

* Work supported by National Science Foundation and by the US Department of Energy under contract numbers PHY-0734867, PHY-1002467 and DE-FC02-08ER41538,DE-SC0006505

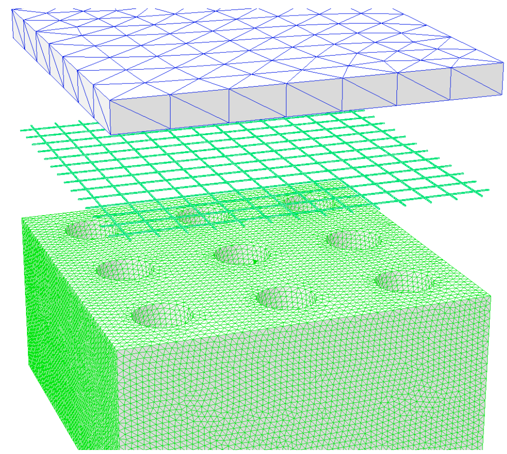

Figure 1: Opera 3D model of a typical drift RFA, showing (from top to bottom) the collector, thin retarding grid, and faceplate/vacuum chamber.

The integrated RFA model is implemented as a special function that is called before the normal secondary emission code. It checks to see if the macroparticle is in the region covered by the RFA. If so, a certain fraction of the macroparticle charge, which depends on the incident angle and energy (as well as the overall beam pipe transparency), is added to the collector signal. The charge is binned by energy and transverse position, simulating the energy and position resolution of the RFA. The macroparticle then has its charge reduced by the amount that went into the RFA.

DRIFT RFA MODELING

A large quantity of drift RFA data, taken under a wide variety of beam conditions and with different beam pipe coatings, has been obtained from RFAs installed in the 15E and 15W arc sections of CESR [3]. To better interpret these measurements, we constructed a bench experiment to test the response of the RFA under controlled conditions. The system consists of an electron gun, which can produce a monoenergetic and roughly uniform beam of electrons, aimed at a test RFA. The RFA includes a faceplate with holes drilled in it to mimic the vacuum chamber, a high

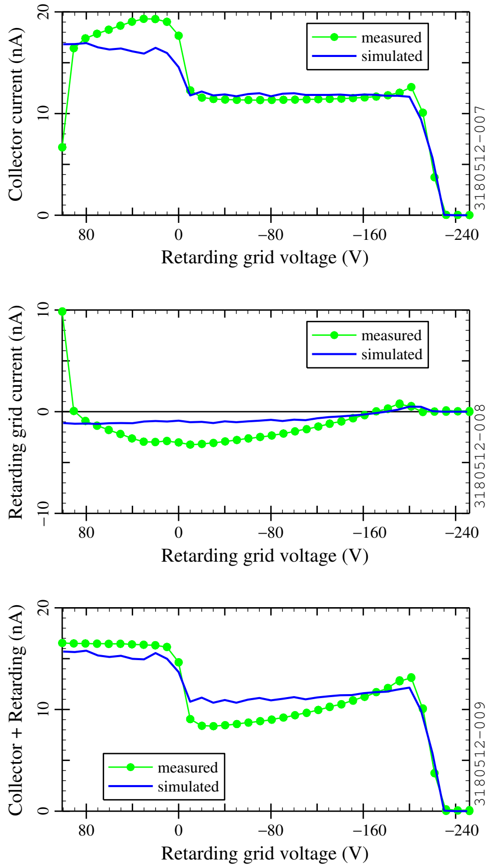

Figure 2: Simulated (blue lines) and measured (green dots) test RFA signals. The plots show the current in the collector (top), retarding grid (middle), and their sum (bottom).

efficiency (nominally 92%) retarding grid, and a collector. We are able to independently control the voltage and read the current on the collector, grid, and faceplate, as well as a top ring surrounding the faceplate. To do a measurement with this system, we set the electron gun to a specific energy, and adjust the focusing of the gun until the beam just covers the faceplate (i.e. until no current is observed on the top ring). We can then study the response of the RFA as a function of incident energy (by changing the gun energy) and angle (by changing the distance from the gun to the RFA). An example retarding voltage scan, done with 100 nA of a 200 eV beam, is shown in Fig. 2 (green dots). The collector was set to 100 V, and the faceplate to 0 V. A few things are worth noting about the measurement:

- The collector signal is mostly flat for a retarding voltage between 0 and -200 V, as expected for a monoenergetic beam.
- When the grid voltage is positive, there is a strong enhancement of the signal, caused by the production of low energy secondary electrons in the faceplate holes.
- The signal does not immediately disappear with -200 V on the retarding grid, but drops off steadily, reaching zero current at -230 V. This effect is caused by focusing of the beam by the non-ideal field of the grid, which allows electrons with energy slightly lower than the retarding voltage to slip by.
- The current on the retarding grid is strongly negative for most of the scan, meaning its average secondary electron yield is much higher than unity.

We have also developed a specialized particle tracking code, which tracks the motion of electrons through a model of the RFA. This model includes a detailed replica of the faceplate, grid, and collector, shown in Fig. 1. It allows for the production of secondary electrons on both the faceplate and grid. The secondary emission code is a simplified version of the one used in POSINST, and includes both elastic and “true” secondaries. The RFA model also features a realistic map of the electric fields produced by the grid and collector, generated by the electrostatic calculation tool Opera 3D.

Fig. 2 compares the results of a bench measurement with the model. It shows excellent agreement for the collector signal for negative grid voltage, including the focusing effect described above. The model underestimates both the collector signal at positive voltage and the magnitude of the signal on the grid. However, it matches the sum of the two fairly well, implying that the discrepancy arises from an underestimation of the number of secondaries produced by the grid. These secondaries are repelled to the faceplate when the voltage is negative, but attracted to the grid when the voltage is positive. To account for this effect, the fits described below use the sum of the grid and collectors when comparing the signal at positive voltage.

Overall, the style of RFA modeled in our test setup is fairly well understood. We are currently doing measurements at additional energies and angles to further validate this model.

DRIFT DATA FITTING

A χ^2 minimization procedure has been employed to obtain best fit parameters to a wide variety of drift RFA data. The basic methodology has been described in a previous paper [2]. Several improvements have been made to the procedure since then, including:

- The RFA model has been incorporated into POSINST, enabling much faster analysis of the simulation. This model includes most of the effects described in the previous section, including the enhancement of the collector signal at positive voltage due to secondaries from the beam pipe holes and retarding grid.
- The initial photon flux at each RFA is based on a fully 3D simulation of photon production and scattering, which includes diffuse scattering and a realistic model of the CESR vacuum chambers [4].
- The starting points for the main secondary emission parameters are based on in-situ measurements of the SEY curves done at CESRTA [5].
- The fit includes a wider variety of data, including different beam energies, bunch currents, train lengths, bunch spacings, and species.

ISBN 978-3-95450-115-1

To get a good fit to the data, we choose parameters which have a strong effect on the simulations, and are relatively independent of each other. We have found that a reasonable fit can be obtained with as little as three parameters- typically the peak true secondary yield (dtspk in POSINST [1]), zero energy elastic yield (P1epk), and quantum efficiency (queffp). The true secondary yield has the strongest effect on simulations with short bunch spacings and high bunch currents. The elastic yield, meanwhile, is best determined by large bunch spacing, while the quantum efficiency is most sensitive to low beam current runs.

Other important parameters, which were not varied in these fits, include the rediffused yield (P1rinf, which was left at its default value of .2), peak yield energy (E0epk), and the "shape parameter" (powts).

Current best fit values for aluminum, TiN, and amorphous carbon (aC) coated chambers are given in Table 1. In these fits, the quantum efficiency was varied separately for different beam energies, and for electron and positron beams. The fits show a consistently lower value for 2.1 GeV than for 5.3 GeV, suggesting that the fit may be improved by adjusting other photoelectron parameters. The quoted errors come from the covariance matrix, and represent the width of the local minimum in parameter space. Thus they should be taken as lower bounds on the uncertainties in the parameters.

Table 1: Best fit parameters for different vacuum chambers. Quantum efficiencies are given for a 5.3 GeV and 2.1 GeV positron beam. Uncertainties are given for parameters which were varied, others were set based on in-situ measurements [5].

Parameter	Al	TiN	aC
dtspk	$2.01 \pm .06$	$.51 \pm .05$	$.41 \pm .07$
P1epk	$.36 \pm .03$	$.19 \pm .10$	$.22 \pm .16$
queffp, 5.3	$.103 \pm .011$	$.069 \pm .009$	$.056 \pm .017$
queffp, 2.1	$.054 \pm .008$	$.039 \pm .007$	$.026 \pm .008$
E0epk	280 eV	370 eV	300 eV
powts	1.54	1.32	1.77

DIPOLE RFA MODELING

Modeling an RFA in a dipole magnetic field presents an entirely different set of challenges. Most of the dipole data taken at CESRTA was done with a chicane of four dipole magnets built at SLAC [6]. The dipole field is adjustable, but was set to .081 T for most of our measurements. Fig. 3 shows the efficiency (probability of making it through the beam pipe hole) as a function of incident angle in this RFA, calculated using the same particle tracking code described above. Note that low energy particles have a very high efficiency, due to their small cyclotron radius.

Unlike the drift case, the exact locations of vacuum chamber holes in the dipole RFA have to be modeled. This is because in a strong dipole field, electrons are mostly

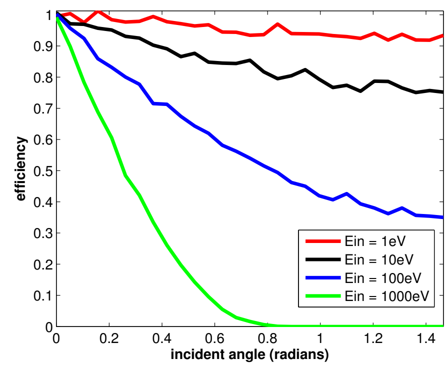

Figure 3: Simulated RFA efficiency vs incident angle for a SLAC chicane dipole RFA, with a .081 T magnetic field.

pinned to the field lines, and do not move very far transversely. So in a real measurement, the RFA will deplete the cloud in precisely the region it is sampling, i.e. under the beam pipe holes. Not taking this into account will result in an overestimate of the RFA signal.

Accurately modeling the locations of the holes means that only a fraction of the macroparticles colliding with the top of the vacuum chamber will produce an RFA signal. This increases the statistical error in the simulation results, and slows down the analysis. Nonetheless, a dipole data fitting effort is currently underway.

CONCLUSIONS

A detailed model of a Cornell drift RFA has been developed, and its behavior has been checked against bench measurements. This model has been incorporated into POSINST, and used to obtain best fit parameters through comparison with data. A dipole RFA model has also been developed, and dipole simulations are currently underway. Future work includes obtaining best fit parameters from the dipole data, and using the test setup to directly study the effect of a strong magnetic field on the RFA performance.

REFERENCES

[1] 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).

[2] J. Calvey et al., "Methods for Quantitative Interpretation of Retarding Field Analyzer Data", PAC11, MOP214.

[3] J. Calvey et al., "Update on Electron Cloud Mitigation Studies at CESRTA", IPAC11, San Sebastian, MOPS083.

[4] G. Dugan, D. Sagan, "Synrad3D Photon propagation and scattering simulation", proc. of ECLOUD10.

[5] J. Kim et al., "In Situ SEY Measurements at CESRTA", ECLOUD10, Ithaca, October 2010.

[6] M. T.F. Pivi, J. S.T. Ng et al. Nucl. Instr. Methods A, doi:10.1016/j.nima.2010.04.052.