CesrTA Retarding Field Analyzer Modeling Results*

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Abstract

Retarding field analyzers (RFAs) provide an effective measure of the local electron cloud density and energy distribution. Proper interpretation of RFA data can yield information about the behavior of the cloud, as well as the surface properties of the instrumented vacuum chamber. However, due to the complex interaction of the cloud with the RFA itself, understanding these measurements can be nontrivial. This paper will examine different methods for interpreting RFA data via cloud simulation programs. Techniques include postprocessing the output of a simulation code to predict the RFA response; and incorporating an RFA model into the cloud modeling program itself.

INTRODUCTION

The electron cloud is a well known effect in particle accelerators which can seriously affect the quality of the beam. A valuable tool for investigating the behavior of the cloud, as well as evaluating the effectiveness of mitigation techniques, is the Retarding Field Analyzer (RFA) [1]. An RFA can measure both the energy distribution (by scanning the voltage on a retarding grid) and transverse structure (through the use of segmented collectors) of the cloud. The CesrTA program at Cornell has allowed for RFA measurements to be taken in a wide variety of beam conditions [4] (see Table 1).

In principle, a single RFA measurement gives a great deal of information about the local behavior of the cloud. In practice, however, gleaning quantitative information from RFA data is highly nontrivial. Typically, this gap is bridged through the use of cloud simulation programs, which track the motion of cloud particles during and after the passage of a bunch train. At CesrTA we have primarily used two such programs, POSINST [2] and ECLOUD [3]. Generally speaking, there are two ways to obtain a predicted RFA signal from a cloud simulation program: by postprocessing the output of a simulation program, or by integrating an RFA model into the actual code. The relative advantages and disadvantages of each method will be discussed.

POSTPROCESSING MODEL

Both ECLOUD and POSINST are capable of producing an output file which lists every macroparticle-beam pipe collision, along with the incident energy and angle. This information can then be post-processed to produce a prediction for RFA current. The simplest postprocessing script does the following:

Table 1: CesrTA Beam Parameters

Parameter	Values
Species	electron, positron
Number of Bunches	9 - 45
Bunch Population	8e9 - 1.6e11
Bunch Spacing	4 - 280 ns
Beam Energy	2.1 - 5.3 GeV

- Determine if the macroparticle has hit in the azimuthal region where one of the RFA collectors exists.
- Calculate an efficiency (probability of passing through the beam pipe hole) based on the incident angle.
- Determine if the macroparticle has enough transverse energy to make it past the retarding field.
- Deposit an appropriate ammount of charge on the grid and collector.

This method is (relatively) quick and easy, but assumes that the RFA does not affect cloud development, an assumption that we have found to be unjustified in certain circumstances (see next section). Nonetheless, under a variety of beam conditions and in a drift region, with a reasonable choice of simulation parameters one can generally reproduce the RFA signal fairly well. Fig. 1 shows a typical example, a 45 bunch train of positrons with .9 mA (1.44×10^{10} particles) per bunch, at a beam energy of 2.1 GeV, and 14ns spacing. Both ECLOUD and POSINST simulations are shown. The agreement between data and simulation is quite good at high retarding voltage; but in the low energy regime, one finds that this simple model significantly underestimates the RFA current. We believe that this extra signal in the data is at least partially due to secondary electrons being produced inside the beam pipe holes of the RFA.

Beam Pipe Hole Secondaries

During bench tests of an RFA prototype, we found an unexpected enhancement at low energy [4]. It was eventually determined that this increase in signal was due to low energy secondary electrons being produce inside the holes of the pipe before the RFA, effectively increasing the effi-

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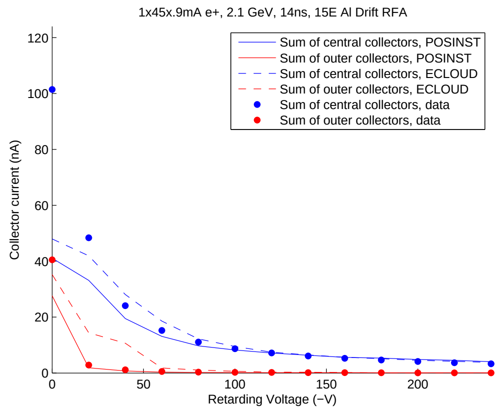

Figure 1: Simulation comparison: 1x45x.9mA e+, 14ns, 2.1GeV

ciency. This effect is also present in the data taken with an actual beam.

In order to take this into account, a standalone simulation code which includes secondary emission was written to track the motion of individual electrons through a model of the RFA beam pipe. Fig. 2 shows the simulated RFA efficiency as a function of incident energy and angle, with and without secondaries. Of course, without secondaries there is no dependence of the efficiency on particle energy, but such a dependence does arise when secondaries are included. We find that low energy electrons maintain some probability of a successful passage even at high incident angle (due to elastic scattering), while high energy electrons have a higher efficiency at intermediate angles (due to the production of ”true secondaries” [2]).

Once this is taken into account, the simulation and data agree much better at low energy (Fig. 3).

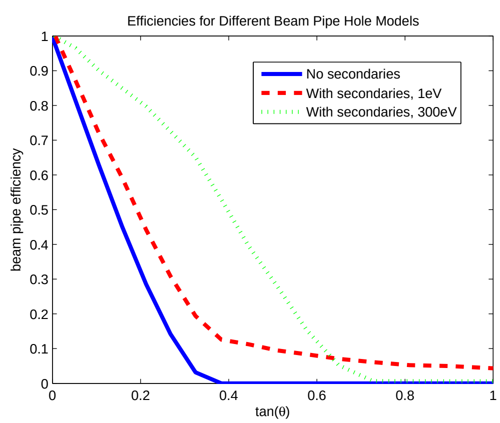

Figure 2: Beam pipe efficiency

Of course, if we have chosen the correct photoelectron and secondary electron parameters in the simulation, we should be able to match the data reasonably well in a wide variety of beam conditions. To that end, we have begun a systematic comparison of data and simulation in the rather

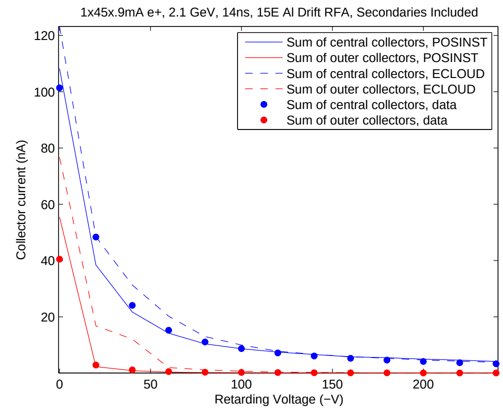

Figure 3: Simulation comparison including secondaries: 1x45x.9mA e+, 14ns, 2.1GeV

large parameter space in which we have made measurements. This analysis is still in its preliminary stages, but has already produced some interesting results. For example, we have found that the simulation drastically underestimates the RFA signal for most data sets taken with an electron beam. This can be partially remedied by increasing the primary photoelectron energy from a few eV to a few hundred eV, so that a sufficient sample of electrons overcome the beam potential. Photoelectron emission is a relatively poorly understood aspect of the cloud, and it is likely we will need to develop a more sophisticated model to obtain agreement with the electron data.

INTEGRATED MODEL

One major disadvantage of using a postprocessing RFA model is that one cannot accurately model any interaction between the RFA and the cloud. For an example of such an interaction, see Fig. 4. It shows a measurement made in the center pole of a wigger (approximated by a 1.9 T dipole field). Here one can see a clear enhancement in the signal at low (but nonzero) retarding voltage. Since the RFA should simply be collecting all electrons with an energy more than the magnitude of the retarding voltage, the signal should be a monotonically decreasing function of the voltage. So the RFA is not behaving simply as a passive monitor.

We believe this spurious signal comes from a resonance between the bunch spacing and retarding voltage. To understand this, consider an electron which collides with the retarding grid and generates a secondary. Because electrons are so strongly pinned to the magnetic field lines in a 1.9T field, this electron is likely to escape through the same beam pipe hole that the primary entered. In other words, the motion of the electrons is approximately one-dimensional. An electron ejected from the grid will gain energy from the retarding field before it re-enters the vacuum chamber. If it is given the right amount of energy, it will be near the center of the vacuum chamber during the next bunch passage, and get a large beam kick, putting it in

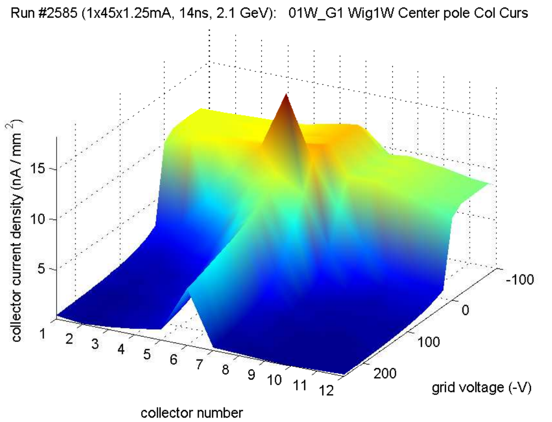

Figure 4: RFA data showing a resonant spike at low energy, 1x45x1.25mA e+, 2.1 GeV, 14ns

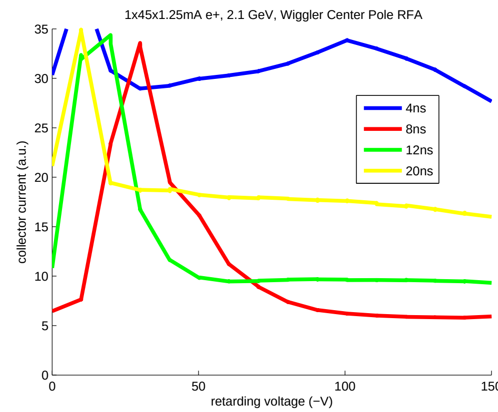

Figure 5: Resonant spike location at different bunch spacings, 1x45x1.25 mA e+, 5GeV

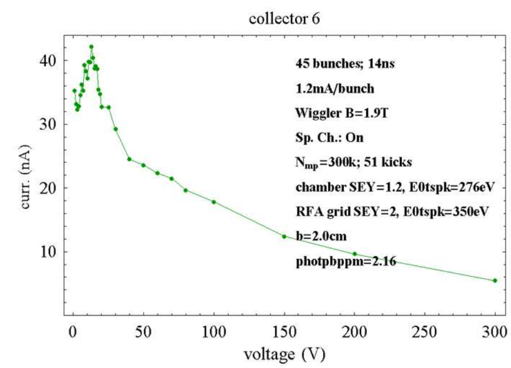

Figure 6: POSINST simulation showing a resonant spike

a position to generate even more secondaries. The net result is a resonance condition that depends on bunch spacing and retarding voltage, since the shorter the bunch spacing, the more kinetic energy an electron needs to arrive at the beam in time for the next bunch passage.

If one assumes that beam kicks are very large and that the time spent in the RFA is negligible, resonance occurs when the time to get from the wall to the center of the beam pipe equals the bunch spacing. From this condition one can derive the resonance voltage:

$$V = \frac{m_e(h^2 - t_b^2 v_e^2 - 2hy_b + y_b^2)}{2qt_b^2} \qquad (1)$$

Here m_e is the electron mass, h is the height of the vacuum chamber (including the RFA), t_b is the bunch spacing, v_e is the initial velocity of emitted secondaries, y_b is the height of the bunch in the chamber, and q is the electron charge. The most important implication of this equation is the approximate inverse dependence on the square of the bunch spacing; Fig. 5 shows that this dependence is (roughly) present in the data, though the low energy spike in the 4ns data is not predicted by the equation.

To model the interaction of the RFA with the cloud, integrated models have been added to ECLOUD and POSINST. The model used in ECLOUD is relatively simple; it performs the same calculation as in the postprocessing model each time a macroparticle encounters the RFA, but does allow for secondary generation on the grid. The model developed for POSINST is more sophisticated, and actually tracks the motion of the particle through an RFA structure with accurate geometry. Both integrated models are able to account for the resonant enhancement. Fig. 6 shows an example from the POSINST model.

The resonant enhancement is present in much of the wiggler data, so an integrated RFA model will be needed to obtain a more complete understanding of the cloud behavior in a wiggler magnet. This effect is also present to a lesser extent in our dipole data, indicating that a postprocessing model may not be sufficient there either. However, agreement has been confirmed between the postprocessing and integrated models in a drift region.

CONCLUSIONS

It is difficult, but possible, to bridge the gap between RFA data and physical vacuum chamber parameters using simulations. For a drift region, a postprocessing model is sufficient, but for a wiggler field it is not, and one must have an RFA integrated into the simulation.

Some progress has been made in matching RFA simulation and data, and a systematic study is underway to use this analysis to obtain values for the SEY and PEY parameters of various vacuum chambers.

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