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UPDATE ON ELECTRON CLOUD MITIGATION STUDIES AT CESR-TA[*]

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Abstract

Over the course of the past three years, the Cornell Electron Storage Ring (CESR) has been reconfigured to serve as a test accelerator (CESRTA) for next generation machines, in particular for the ILC damping ring. A significant part of this program has been the installation of diagnostic devices to measure and quantify the electron cloud effect, a potential limiting factor in these machines. In particular, several Retarding Field Analyzers (RFAs) have been installed in CESR. These devices provide information on the local electron cloud density and energy distribution, and have been used to evaluate the efficacy of different cloud mitigation techniques. This paper will provide an overview of RFA results obtained at CESRTA over the past year, including measurements taken as function of bunch spacing and wiggler magnetic field. Understanding these results provides a great deal of insight into the behavior of the electron cloud.

INTRODUCTION

A Retarding Field Analyzer (RFA) measures the flux of the electron cloud on the vacuum chamber wall, from which we can infer the local cloud density. It can also measure the energy distribution of the cloud by applying a retarding potential between two grids, thus rejecting any electrons below a certain energy[1]. In addition, most RFAs used in CESRTA are segmented to allow characterization of the geometry of the cloud build-up.

A great deal of RFA data has been taken during the CESRTA program, under a wide variety of beam conditions, in different magnetic field elements, and in the presence of different electron cloud mitigation schemes [2, 3]. Measurements over the past year have focused on continuing evaluation of mitigation techniques in a set of standard characterization conditions, as well as conducting dedicated experiments to gain leverage over less well understood aspects of the cloud. Two such experiments involve monitoring the RFA signal as a function of bunch spacing and wiggler magnetic field; the resulting measurements will be discussed in later sections.

MITIGATION COMPARISONS

We have installed RFAs in arc drift sections adjacent to the 15E and 15W quadrupoles in CESR. The photon flux for a positron beam at 15W is about twice that of 15E. Measurements have been taken at both locations with TiN [4] and amorphous carbon [5] coatings, as well as with an uncoated aluminum chamber. In addition, a chamber with diamond-like carbon (DLC) coating has recently been installed at 15E. By comparing measurements taken at the same location in CESR, we ensure the comparisons can be made under identical beam conditions, including photon flux. Fig. 1 compares the RFA signal with each of these coatings for a typical set of CESRTA beam conditions.

All coated chambers show a sizeable reduction in signal when compared to uncoated aluminum. After extensive processing, both TiN and amorphous carbon coated chambers show similar mitigation performance. The details of the small difference between 15E and 15W (where in one case TiN appears slightly better and in the other amorphous carbon does) require further analysis to understand fully.

Diamond-like carbon may perform better than other coatings at very high beam current. It should be noted that bench measurements of the Secondary Electron Yield (SEY) of DLC have found that the material can retain charge if bombarded with a sufficiently high electron flux, thus modifying the apparent SEY performance. This effect may also be influencing the in situ measurements presented here.

BUNCH SPACING STUDIES

Because the properties of the electron cloud can change over the course of nanoseconds, it is interesting to investigate its behavior as a function of bunch spacing. At CESRTA we have taken RFA data with bunch spacings varying from 4ns to 112ns.

Fig. 2 shows the signal in the central collector of a dipole RFA as a function of bunch spacing. This RFA is part of a chicane of dipole magnets manufactured at SLAC [6]; the vacuum chamber is made of aluminum and has a half-height of 4.4cm. The magnetic field is set to 810G.

We observe two distinct peaks in the positron data, at approximately 14ns and 60ns. The electron beam data shows almost no signal before 36ns, and is peaked around the same place as second the positron peak.

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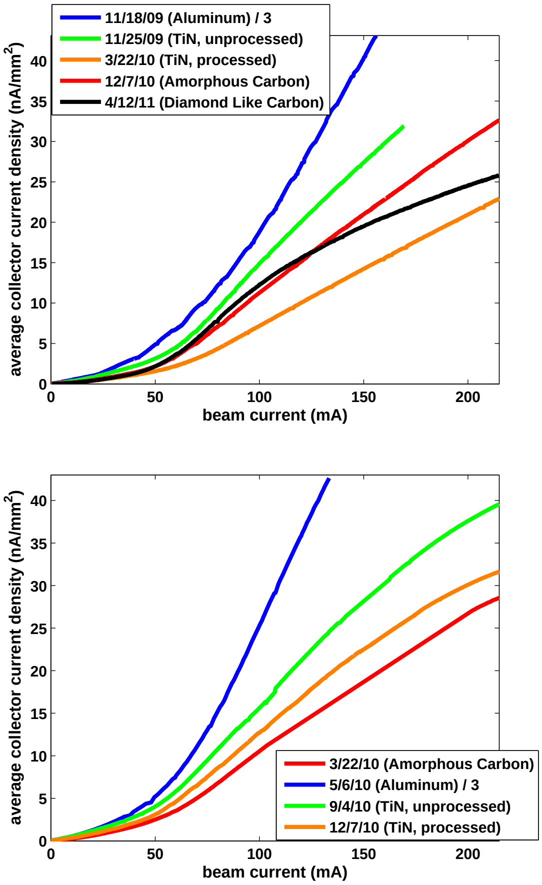

Figure 1: Comparison of different beam pipe coatings, 15E (top), and 15W (bottom) drift RFAs. Plots show average collector signal vs beam current for 20 bunches of positrons with 14ns spacing, at beam energy 5.3GeV. Note that the aluminum chamber signals are divided by 3.

The enhancement of the signal at 60ns could be due to a resonance between the bunch spacing and the cloud development (often called a “multipacting resonance” [7]). This effect will be enhanced by the dipole field, which renders the motion of the electrons essentially one dimensional.

A very simple model for a multipacting resonance is that if the time for a typical secondary electron to travel to the center of the beam pipe is equal to the bunch spacing, this electron will be kicked strongly by the beam, and is likely to produce more secondary electrons. In reality, peak secondary production will occur when this electron is given an amount of energy corresponding to the peak of the SEY curve. However, for aluminum the SEY is greater than 1 well into the keV range, so an electron anywhere near the beam is a candidate to produce more secondaries. Thus we expect the “resonance” to be somewhat broad.

If we ignore the time for the kicked electron to travel to the beam pipe wall (which will be small if the kick is strong), the resonance condition is simply $t_b = a/v_{sec}$, where t_b is the bunch spacing, a is the chamber half-height (i.e. the distance from the wall to the beam), and v_{sec} is a characteristic secondary electron velocity. For a 1.5eV electron, this peak will occur at 61ns. The fact that there is a finite width to the secondary energy distribution will further smear out the peak.

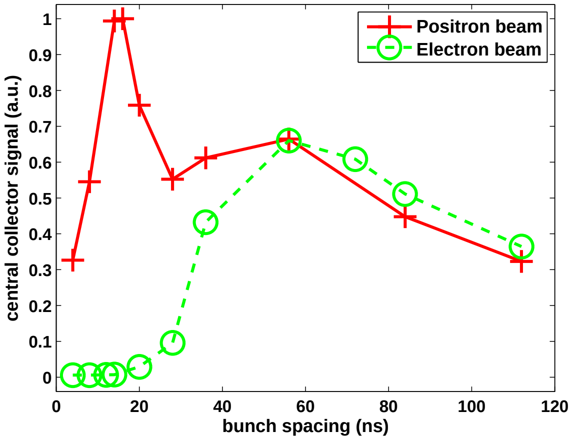

Figure 2: Central collector signal in a dipole RFA as a function of bunch spacing, for a 20 bunch train with 3.5mA (5.6×10^{10} particles) per bunch, at 5.3 GeV.

The lower energy peak in the positron data could be a higher order multipacting resonance, where it takes two bunches to set up the resonance condition. Here we consider the case where the first bunch gives some additional energy to the electron, so that it makes it to the center of the chamber in time for the second bunch. If we again neglect the time for the kicked electron to reach the beam pipe wall, the resonance condition becomes:

$$\begin{aligned} t_{b,2} &= \frac{a - r_1}{v_{sec}} = \frac{r_1}{v_2} \\ v_2 &= v_{sec} + \frac{2cN_b r_e}{r_1} \end{aligned} \tag{1}$$

Here r_1 is the distance from the electron to the beam during the first bunch passage, v_2 is the velocity of the electron after it is kicked by the first bunch, N_b is the bunch population and r_e is the classical electron radius. Solving for $t_{b,2}$ gives us Eq. 2, where we have defined $k \equiv 2cN_b r_e$.

$$t_{b,2} = \frac{k + 3av_{sec} - \sqrt{k^2 + 6kav_{sec} + a^2 v_{sec}^2}}{4v_{sec}^2} \tag{2}$$

For a 1.5eV secondary electron, $t_{b,2}$ is 11ns, somewhat less than the 14ns that is observed. A more sophisticated model (which would include, among other things, the time for the kicked electron to reach the wall) may yield a more accurate result. Note that this resonance condition applies only to positron beams, so only one peak is predicted for the electron data (which is what we find). Overall, a multipacting scenario with a 1.5eV peak secondary energy is approximately consistent with both the positron and electron beam data.

Data taken in a quadrupole also demonstrates an interesting dependence on bunch spacing. As seen in Fig. 3, for a positron beam we do not observe a strong dependence on bunch spacing, though there does seem to be a modest enhancement around 14ns. The fact that there little decrease in the signal out to 112ns is evidence that the cloud is persisting in the quadrupole much longer than that timescale. The data for an electron beam is even more surprising, actually showing a monotonic increase with bunch spacing. Again this points to a very long timescale for cloud development in the quad.

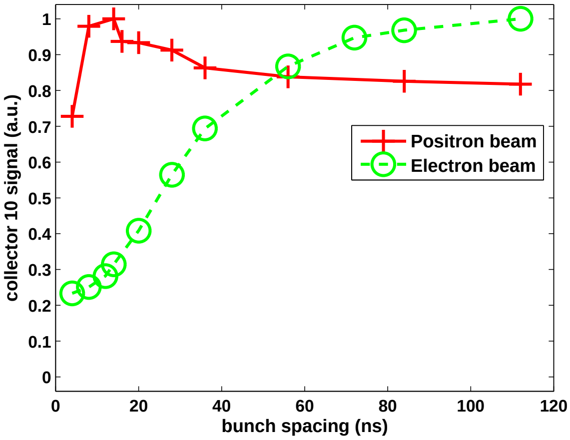

Figure 3: Signal in a quadrupole RFA as a function of bunch spacing, for the same beam conditions as in Fig. 2. The collector which is in line with the quad pole tip (and sees the most signal [2]) is plotted.

WIGGLER RAMP STUDIES

As part of the conversion of CESR for the CESRTA program, six superconducting wigglers were installed in the L0 straight section of the ring. Very little dipole radiation is expected to reach the downstream vacuum chambers in the straight, but they will be illuminated by radiation from the wigglers. Therefore, by varying the field in the wiggler magnets, we can vary the number of photons striking the wall at a given point along the straight. This will also vary the number of photoelectrons produced there, so electron cloud diagnostic devices located in L0 can provide an indirect measurement of the properties of the wiggler photons.

Fig. 4 shows the signal in three L0 RFAs (plotted as solid lines) as a function of wiggler field strength. Each of these RFAs is located in the center of a magnet pole inside a wiggler [8]. We observe a “turn on” of the signal in each detector at a specific wiggler field value. Note that the detectors that are further downstream (i.e. those with a higher *s* value) turn on first. This is because as the wiggler field is increased, the radiation fan becomes wider. The farther downstream a detector is, the less wide the fan must be for photons to hit at that location. This measurement can help us understand the scattering of photons in L0, since only photoelectrons produced on the top or bottom of the beam pipe can initiate the build-up of the part of the cloud detected by the RFA.

The L0 wiggler straight is also instrumented with microwave transmission (TE-Wave [9]) hardware, which provides a alternate measurement of the electron cloud development. Fig. 4 also includes two types of TE-Wave data- “resonant mode,” where the same detector is transmitting and receiving the TE-Wave, and “transmission mode,” where the wave is propagated from one detector to another. The former is plotted in with dotted lines, and the latter with dashed lines. The TE-Wave data also shows the turn-on behavior described above, and the location of the turn on points matches those of nearby RFAs.

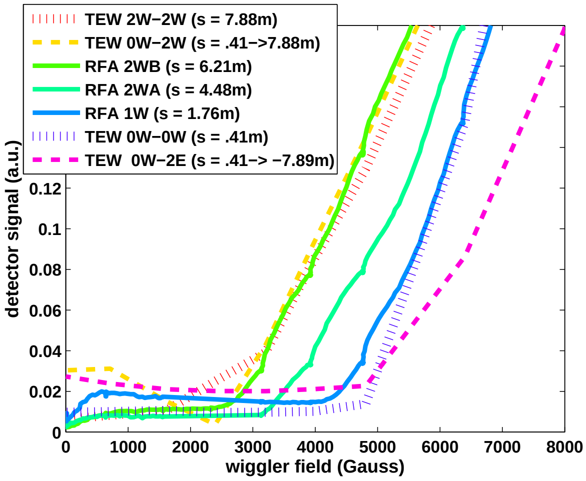

Figure 4: RFA/TE-Wave comparison during a wiggler ramp measurement. Beam conditions are 45 bunches of positrons at .75mA/bunch, 2.1GeV, 14ns spacing. Each of the signals is normalized to 1 at peak wiggler field (1.9T), because at the moment we do not have a way of quantitatively comparing the RFA and TE-Wave data (though progress has recently been made on this front [9]).

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