

# ELECTRON CLOUD DENSITY MEASUREMENTS USING RESONANT TE WAVES AT CESRTA\*

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## Abstract

The Cornell Electron Storage Ring has been reconfigured as a test accelerator (CESRTA) with beam energies ranging from 2 GeV to 5 GeV of either positrons or electrons. Research at CESRTA includes the study of the growth, decay and mitigation of electron clouds in the storage ring. Electron Cloud (EC) densities can be measured by resonantly exciting the beam-pipe with microwaves where standing waves are established between discontinuities. The EC density that is within the standing waves will change the beam-pipe's resonant frequency. When the EC density is not uniform, it is especially important to know the standing wave pattern in order to know exactly where the EC density is being sampled by the microwaves. We present our current understanding of this technique in the context of new test sections of beam-pipe installed in August 2012. This includes bench measurements of standing waves in the beam-pipe, simulations of this geometry and recent EC density measurements with beam.

## INTRODUCTION

In August 2012, four sections of test beam-pipe were assembled and installed in the CESRTA storage ring. Each chamber is instrumented with a Time Resolved Retarding Field Analyzer (TR-RFA) to evaluate the mitigation properties of the different geometries and surface coatings. The TR-RFA detects the flux of cloud electrons into the beam-pipe wall [1].

There are two different cross sections of round beam-pipe, one smooth and the other with triangular grooves on the top and bottom inside surfaces as shown in Fig. 1. With these two cross sections, one pair has been made with a surface of bare aluminum. The other pair have a coating of Titanium Nitride (TiN) on the inner surface. The chambers are assembled together and when installed, each chamber will be centered in one of four chicane dipole magnets.

Having established the basic technique for the resonant TE wave measurement of EC density [2, 3, 4, 5], we investigated the possibility of using this technique to make independent EC density measurements on each of the four test chambers. Each resonance has its own characteristic standing wave pattern and the TE Wave measurements are localized to the region of the standing wave. So the choice

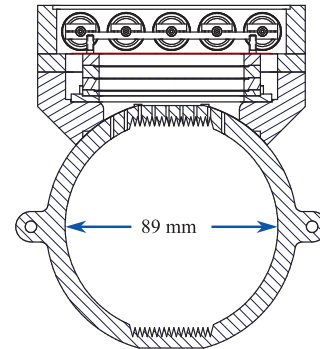


Figure 1: A cross section of grooved beam-pipe is shown above with a Time Resolved RFA assembly on the upper surface.

of the resonances used in a measurement determines where the cloud is sampled along the length of the beam-pipe.

## BENCH MEASUREMENTS

A bead pull is a common technique for measuring the fields in resonant cavities [6]. If a small dielectric bead is positioned in a cavity, there will be a shift in its resonant frequency that is proportional to  $E^2$  of the standing wave at the location of the bead.

Previous bench measurements had been made using various combinations of grooved and smooth sections of beam-pipe. These measurements showed that the first two resonances were mostly confined to a grooved section if it is between smooth sections of beam-pipe [4]. This is due to the fact that the cutoff frequency of the grooved pipe is lower than that of the smooth pipe. This result influenced the decision to alternate grooved and smooth beam-pipe when assembling the actual vacuum chambers.

### Bead Pull of the Assembly

Before it was installed in the storage ring, a bead pull measurement was made on the four chamber assembly (Fig. 2). For the measurement, short sections of smooth beam-pipe were added to the ends of the assembly and the flanges at the far ends had aluminum plates covering the openings in order to produce reflections. A  $0.3 \text{ cm}^3$  nylon bead was positioned inside the beam-pipe using a thin mono-filament fishing line. At each position along the length of the beam-pipe, the frequency shift was measured by recording the peak response on a spectrum analyzer.

The electrodes of three Beam Position Monitor (BPM) flanges in the assembly were used to couple microwaves in

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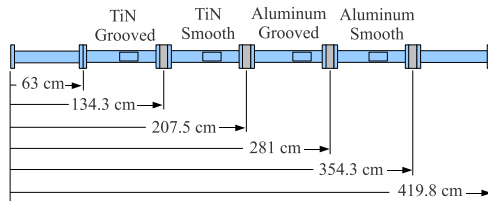


Figure 2: A sketch of the L3 chamber assembly is shown above. For the bead pull measurement, 63 cm extensions were added at either end with shorting plates on the end flanges.

and out of the chamber. For simplicity, only single buttons were used. For example, a vertical measurement would use a button on the top of the beam-pipe for excitation and a button on the bottom for receiving. For each BPM and plane, six to eight resonances were chosen from the spectrum for a measurement series.

Some of the bead pull measurement results are shown in Figs. 3, 4 and 5. Figures 3 and 4 used horizontal excitation and receiving at the BPMs indicated. As expected from previous bench measurements with grooved beam-pipe, the standing waves were localized in the grooved sections near 1.95 GHz. The two frequencies correspond to a one-half and a two-halves wavelength resonance along the length of these sections.

A response in the smooth chambers is shown in Fig. 5, where vertical buttons were used for excitation and receiving. The standing waves of the two frequencies are not as well confined, in that there is significant field in both smooth chambers and to a lesser extent in the TiN grooved chamber. So extracting separate EC densities for the two smooth chambers will not be as straightforward as with the grooved chambers. Measurements would need to be made at both frequencies shown in Fig. 5, as well as one frequency from each of the plots of Fig. 3 and 4. These measurements, when combined with a bit of linear algebra, should give the separate EC densities for the four chambers.

In order to understand why the smooth sections had standing waves within them, we made careful measurements of the inner diameters. Both the flanges and the extrusions have a nominal inner diameter of 89 mm. It turned out that the smooth beam-pipe aluminum extrusions had an inner diameter about 0.5 mm larger than the machined flanges. So the smooth beam-pipe, with a cutoff frequency roughly 10 MHz lower than the flanges surrounding it, could also contain a local resonance.

## DATA WITH BEAM

In an accelerator, the presence of an electron cloud will shift the frequency of the resonance according to Eq. 1 [7, 8, 9]. This, along with some simplifying assumptions: a train of bunches will produce a periodic EC density; the duration of the cloud is long compared to the

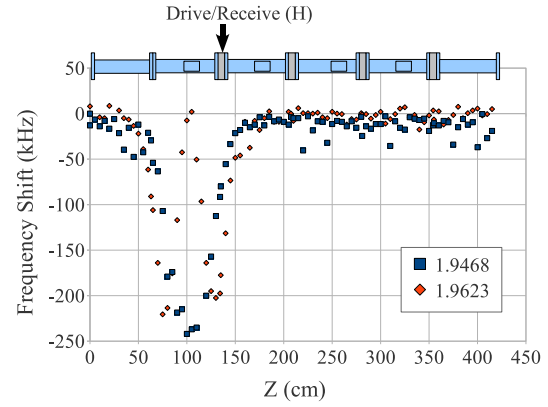


Figure 3: A bead pull measurement shows that the standing waves of two resonances near 1.9 GHz are primarily in the TiN grooved chamber.

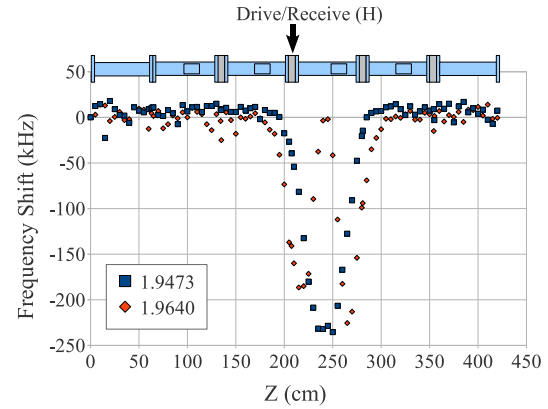


Figure 4: The bare aluminum grooved chamber also shows two resonances.

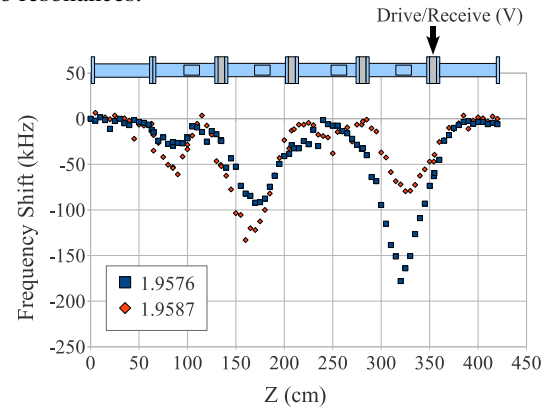


Figure 5: Resonances in the smooth chambers are mutually coupled and very close in frequency.

damping time of the resonance and that external magnetic fields can be ignored – allows a calculation of the EC density from the phase modulation sidebands that are produced [2].

$$\frac{\Delta\omega}{\omega} = \frac{e^2}{2\epsilon_0 m_e \omega^2} \frac{\int_V n_e E_0^2 dV}{\int_V E_0^2 dV}. \quad (1)$$

The TE wave data taking system in L3 was reconfigured to make use of the information from the bead pull that sug-

gested 13 resonances of interest. The modulation sidebands from four of these resonances were used to calculate the EC densities given in Fig. 6. The frequencies correspond to the  $n=1$  and  $n=2$  resonances of the bare aluminum and TiN grooved chambers. As expected, the aluminum grooved chamber shows a higher EC density than TiN. Also, the EC densities for both resonances ( $n = 1, 2$ ) are in good agreement in the TiN chamber. The agreement between the resonances is not as good for the bare aluminum grooved chamber, but they are nevertheless within 10%. Further analysis is needed to compare the two chambers since the amount of synchrotron light in the aluminum chamber is less than in the TiN chamber. This needs to be quantified.

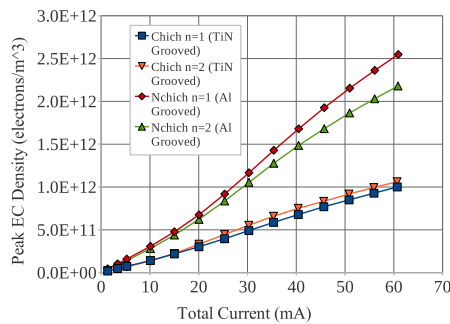


Figure 6: Data taken with a 10 bunch train of 5.3 GeV positrons with currents up to 6 mA ( $9.6 \times 10^{10}$  particles) per bunch.

## SIMULATION OF A GROOVED BEAM-PIPE

In addition to bead pull measurements, there has been a parallel effort to use simulations of the TE wave resonance. This will become increasingly important with more complex beam-pipe geometries, including the round grooved pipe. Figure 7 shows the result of a VORPAL [10] simulation of grooved beam-pipe with smooth beam-pipe adjacent to it.

To find resonances, the driving frequency is changed and the magnitude and phase outputs of the simulation are examined. The resonant frequency will be that in which the magnitude is at a maximum and phase difference from the drive phase is close to zero or  $\pm\pi$ .

## CONCLUSIONS AND FUTURE WORK

The use of bead pull measurements on beam-pipe has greatly improved our understanding of localized resonances. The independent measurement of EC densities in chambers less than a meter long seems to be straightforward when lower cutoff frequencies allow standing waves to be set up. This method is unique in that it measures the EC density in the volume of the beam-pipe, rather than the flux of electrons into the beam-pipe wall. Work on analysis

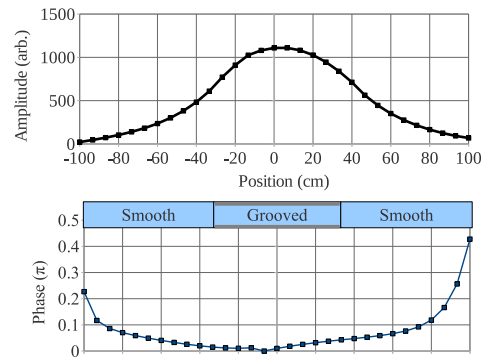


Figure 7: The simulation of a resonance in grooved chamber between two smooth chambers is shown near the  $n=1$  resonance.

and simulation will continue in parallel in order to improve our understanding of this technique.

## ACKNOWLEDGEMENTS

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