Modeling of Resonant TE Waves for Electron Cloud Density Measurements in CesrTA

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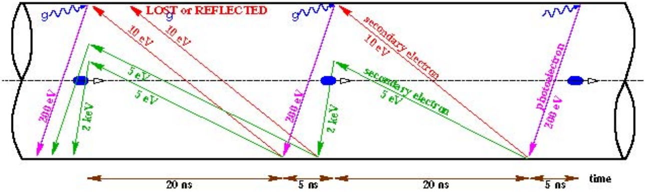
Introduction

Electron Cloud in Particle Accelerators

- At CesrTA, primary Low Energy Electrons are produced from synchrotron radiation (photoelectrons), which may lead to production of secondary electrons.
- Electron clouds cause instabilities in the positron beams which limit the maximum beam current in the accelerator.



Measuring Electron Cloud Density

Methods for Measurement of Electron Cloud Density in CesrTA

- Measuring Beam Response to E-Cloud (e.g. Tune Shift)
- Collection of electrons and current measurement (RFA & Shielded Pickup)
- TE Wave Method

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Reasons for Using TE Waves:

- Non-Invasive
- Cheap
- Localized over Finite Length/Volume
- Cross-Check with Simulation and other Measurement Techniques

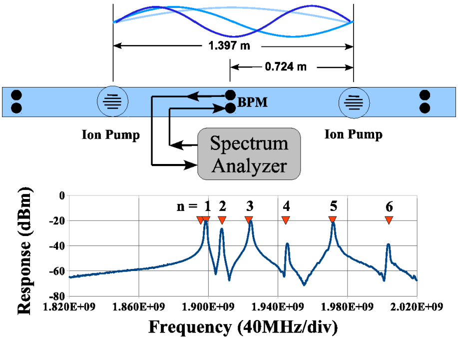
TE Wave Technique

How it Works

Uses existing Beam Position Monitor buttons to couple microwaves into the beam-pipe

What it does

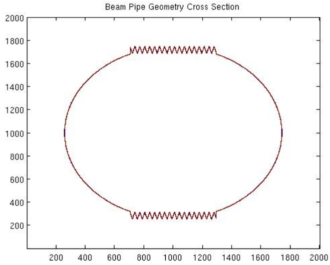
Measures resonant frequency shift – proportional to e-cloud density in the volume



Grooved Chamber

Purpose

Attenuation of Electron Cloud Density



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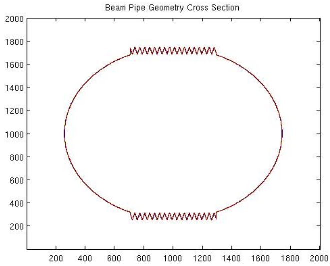
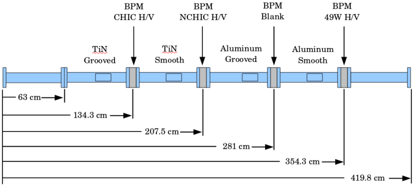


Installation of new beam-pipe assembly in L3



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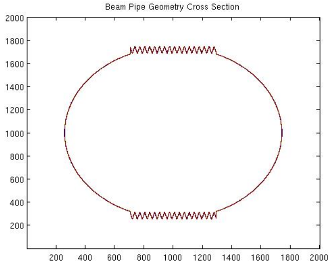

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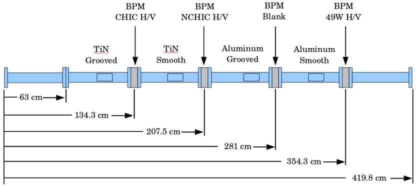
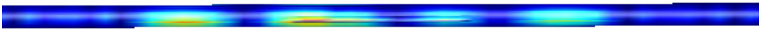


Experimentally:
it was observed that it was possible to trap waves within grooved pipe section at the right frequencies

VORPAL

Vorpal solves Maxwell's equations numerically & handles both particles and fields.



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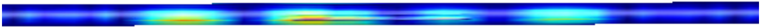

Bérenger's PML

unphysical; serves purpose of absorption of wave; as if it were an infinitely long pipe

Smooth-Grooved-Smooth Pipe with PMLs at each end in Vorpal

Simulation Data

Frequency Scans

Cutoff Frequencies

Cutoff frequencies were found using simulation for smooth and grooved geometries. As expected, grooved geometry had lower cutoff.
Smooth: $f_c = 1.974 GHz$ Grooved: $f_c = 1.875 GHz$

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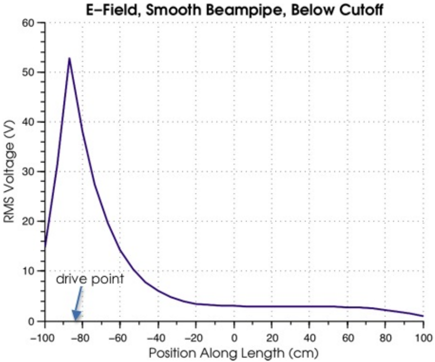


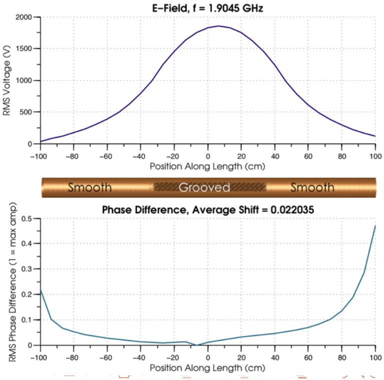
MATLAB was then used to plot voltage data from VORPAL along length of beam-pipe.

Determination of Resonances

Phase Difference

Resonances will have an average phase shift close to zero or π rad, indicating that the part of the wave is in or exactly out of phase.

- Standing waves were determined using amplitude, shape, and phase of E-field along the pipe
- Phase shift calculated relative to drive point at $x = -6.67cm$
- Average Shift in Grooved Section only $= 0.022035\pi$ rad.



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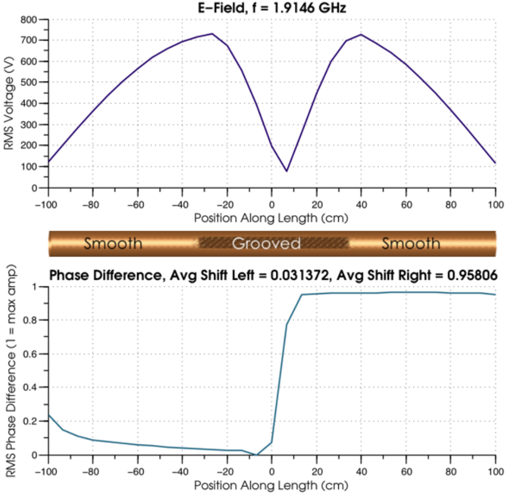


Phase Difference Plot:

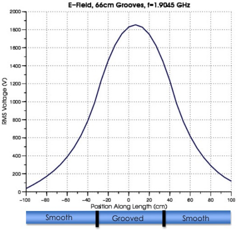
- Close to zero indicates in-phase portions of wave
- Close to π rad indicates exactly out-of-phase portions

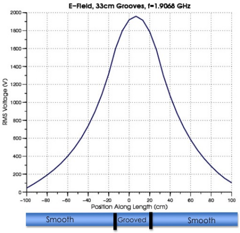
Frequency Scans

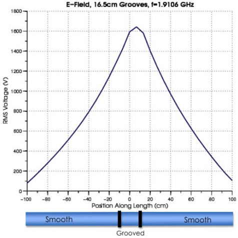
Frequency Shift from Shortened Grooved-Pipe

$n = 1$ Mode

Shortening length of grooved section shifts frequency up, as expected from behavior of standing waves







Resonant Frequencies

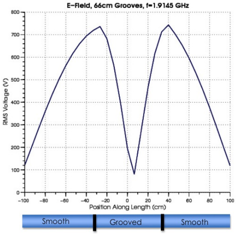
$66cm$: $f = 1.9045 GHz$

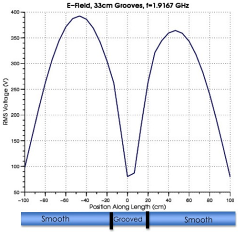
$33cm$: $f = 1.9068 GHz$

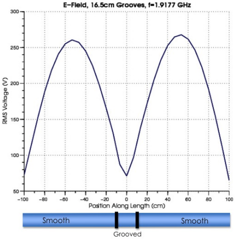
$16.5cm$: $f = 1.9106 GHz$

Frequency Shift from Shortened Grooved-Pipe

$n = 2$ Mode







Resonant Frequencies:

66cm: $f = 1.9145 GHz$

33cm: $f = 1.9167 GHz$

16.5cm: $f = 1.9177 GHz$

Resonant Frequency Shift Due to Electron Cloud

Resonant Frequency Shift

$$\frac{\Delta\omega_n}{\omega} = \frac{e^2}{2\epsilon_0 m_e \omega^2} \frac{\int_V n_e E_0^2 dV}{\int_V E_0^2 dV}$$

Resonant Frequency Shift Due to Electron Cloud

Frequencies of 1^{st} Resonance (GHz)			
Grooves	E-Cloud Density		
	No e^-	$1e14$	$2e14$
Whole	1.9045	1.907	1.910
Half	1.9068	1.910	1.912
Quarter	1.9107	1.913	1.916

this agrees well with the equation

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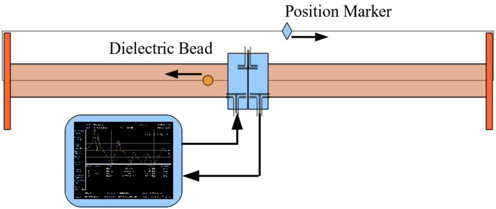
Frequencies of 2^{nd} Resonance (GHz)			
Grooves	E-Cloud Density		
	No e^-	$1e14$	$2e14$
Whole	1.9146	1.9155	1.917
Half	1.9167	1.9175	1.918
Quarter	1.9177	1.9185	1.919

this doesn't agree quite as well :(

Experimental Results

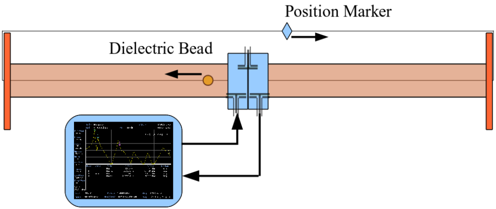
Bead Pull Method



Shift Due to Dielectric in Resonant Cavity

$$\frac{\Delta\omega}{\omega} = \frac{\int_V (1-\varepsilon_r) E_0^2 \, dV}{2\int_V E_0^2 \, dV}$$

Bead Pull Method



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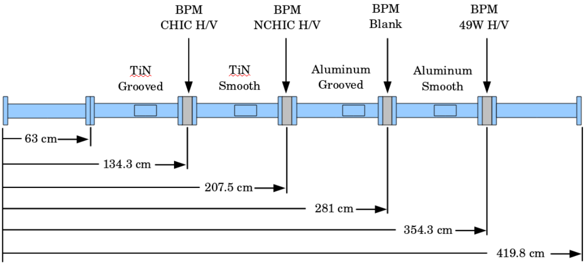
Bead Pull on L3 Beam-Pipe

New beam-pipe assembly for installation in L3 was measured using bead pull method.



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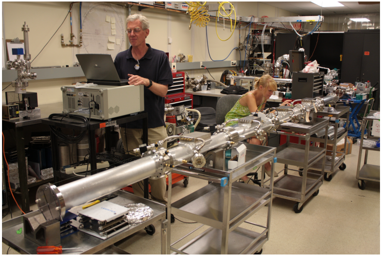
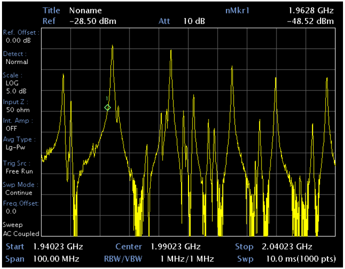


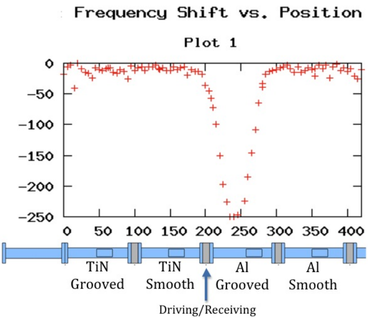
Spectrum Analyzer

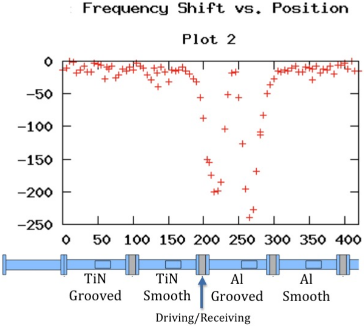


- Microwaves were coupled into BPM buttons
- Bead Pull Method was performed for several resonances at each BPM detector
- "Trapped Modes" were observed in grooved sections of the beam-pipe assembly
- 6 or 8 measurements were taken at each BPM detector

Bead Pull Results I

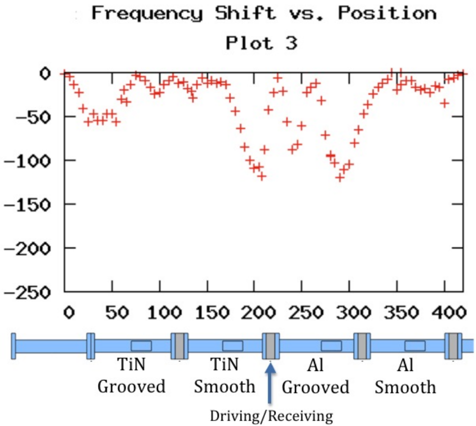
$n = 1$ and $n = 2$ Modes Inside Aluminum Grooved Section





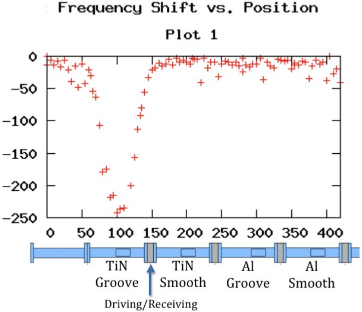
Bead Pull Results II

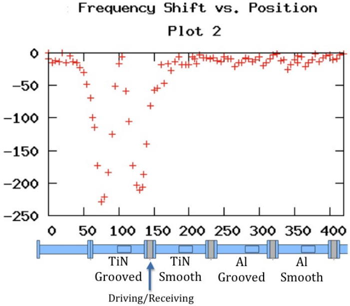
$n = 3$ Mode Inside Aluminum Grooved Section



Bead Pull Results III

$n = 1$ and $n = 2$ Modes Inside TiN Grooved Section





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- Both simulation and experiment show $n = 3$ mode to propagate out into smooth chambers
- Simulation data with electron cloud for $n = 1$ mode agreed well with theory while $n = 2$ mode did not agree well
- It seems that measurements of electron cloud density within the newly installed grooved chambers should work well using the TE Wave Method

Thank you!

Thank you! Questions?