Modeling and Simulation of a Two- Frequency Electron Gun

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This paper summarizes work conducted at Colorado State University on the development of a two-frequency electron gun for implementation in a thermionic cathode system. Initial simulations were done using PARMELA and show up to 80% beam power loss. The cause of these losses is expected to be a result of the simulation technique. Compared to previous work these numbers are quite high. Continuing efforts will run similar simulations using SPIFFE and future work entails building and testing a prototype system.

Introduction

This paper outlines simulation work of a two-frequency electron gun operating at frequencies of 1.3 GHz and 2.6 GHz for use in a thermionic emission system.

Production of high-brightness, low-emittance beams is necessary for high average power free electron lasers. In the current process the use of photocathodes dominate. While photocathodes produce high brightness beams, they are fairly inefficient and require high-energy drive lasers. The use of thermionic emission simplifies the process and eliminates the need for a drive laser system. However this presents two major complications; how to operate the accelerator in pulsed mode when characterizing the system and how to prevent the electron back bombardment in the off phase mode of the RF power. This paper does not address pulsed power operation.

If a thermionic emitter will emit electrons any time the field at the cathode is negative; however, there is a certain range of phases where, although electrons are emitted, the field oscillations permit a field polarity change before the electrons have sufficient energy to exit the RF cavity. These electrons are then accelerated back onto the cathode. To partially alleviate this problem a two-frequency gun is proposed.

Previous work on this project simulated the same geometry concept but at a lower frequency. The frequencies for that work were 350 MHz and 700 MHz. Beam simulations showed that back bombardment power was minimized to about 0.3% [1] This earlier work also looked at a parameter scan of the harmonic field ratio.

In this current work we wish to scale the previous geometries and simulations to our CSU Accelerator Laboratory preferred frequencies of 1.3 GHz and 2.6 GHz. Exciting the cavity with two frequencies and scaling them appropriately effectively takes a second order approximation to a ramp function Fourier series and creates a field temporal profile which is less susceptible to back-bombardment effects. The next few sections discuss the cavity design and the particle simulations performed

.

Accelerator Cavity Design

The cavity design is based on a double-pillbox design that will have two dominate TM modes. The double pillbox has two effective radii, which are proportional to the desired frequency modes. These modes are tuned to be harmonics of each other. Figures 1 and two show the field maps for the two modes created by SUPERFISH [3].

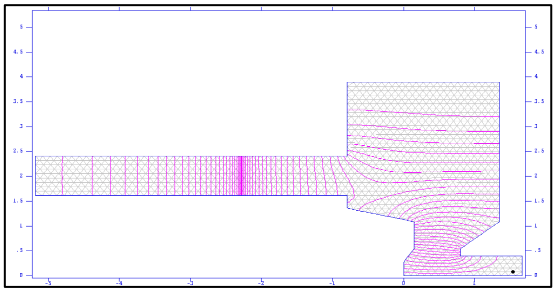

Figure 1: RF Cavity Design Showing Mode at 2.6GHz [3]

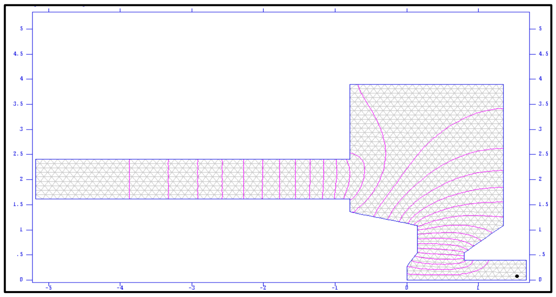

Figure 2: RF Cavity Design showing Mode at 1.3GHz [3]

In the tuning process a frequency scan was conducted to find additionally the TE modes. TE modes can be problematic for an accelerating structure if they are excited accidently.

To avoid accidental excitation the modes must be properly positioned in frequency. To locate these modes a frequency scan of the TE modes was also performed over the range of frequencies. The frequency scan showed a TE mode between the TM modes as expected and this mode is separated enough from the TM modes that it is not a concern for the geometry. Figures 3 and 4 show the results of these frequency scans [3].

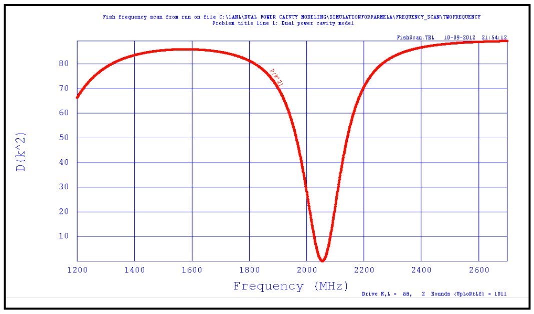

Figure 3: TE Mode Scan for Cavity Design [3]

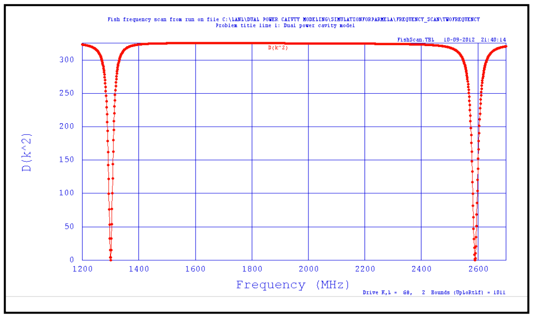

Figure 4: TM Mode Scan for Cavity Design [3]

The frequency scan of the cavity shows two TM modes at harmonics of 1.3GHz and 2.6GHz with a TE mode at about 1.8GHz. We can see a wide peak for the TE mode, which is not desirable. However since this mode is well centered on the two TM modes it is not a large concern for accidental excitation. Having complete field maps for the cavity, beam simulations were then conducted.

Beam Simulation Technique

In order to understand the context of the results we will begin by reviewing the simulation technique. The simulation code used for these results was PARMELA, a LANL-developed linac design code. The simplest form of simulation in this case would be a single pass electron beam. Since we are trying to simulate a thermionic emitter the emission is continuous, therefore to replicate a single pass, a beam that occupies a compete RF phase is injected into the simulation.

PARMELA [4] begins the dynamics by inserting all the particles at the beginning of the linac geometry. The code then passes them forward through the lattice computing the various fields, space charge effects etc. In order to make the simulation work properly the particles need to be located longitudinally, before the cathode. To simulate a single pass of the thermionic cathode the inserted bunch has the temporal length of one RF period. Results of this simulation would show characteristics in units per RF period.

Simulation Results

The simulation results are presented in units of percentage of particles lost. Due to the nature of PARMELA it is difficult to differentiate between particles lost due to simulation issues vs. particles lost due to back bombardment. We will assume initially that all particles lost are due to back-bombardment and then based on that assumption analyze the results.

The results of the simulations using PARMELA were varied. We did a simple parameter scan varying the harmonic field ratio with different initial bunch energies as well. We expect to see about 50% of the particles lost for a continuous emitter excited at only one frequency. This is however not what we see.

Figure 5 shows the percentage of particles lost for simulations while varying the simulation parameters. One of the parameters varied in previous efforts was the harmonic field ratio. With the intention of comparing our current results to the previous work we varied this parameter as the first step.

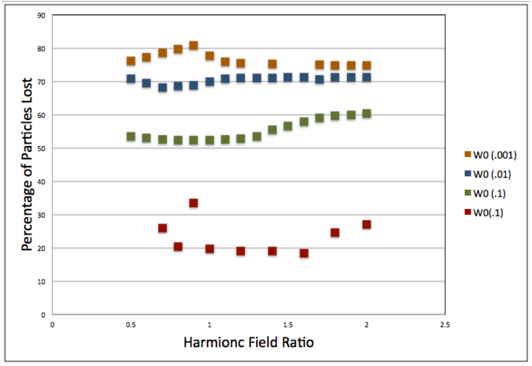

Figure 5: Beam Simulation Results from PARMELA [4]

The x-axis we have the harmonic field ratio and along the y-axis we have the total percentage of particles lost. Each series is a variation in the beam initial energy. The initial beam energy is varied in order to give information into the nature of the particle losses.

We can see that as we increase the beam energy there are fewer particles lost however the loss percentages are still quite high. A simple analytical calculation shows that for an initial electron energy of 1eV there is about a 50% loss. Our PARMELA simulations are showing losses much larger than 50% for initial beam energies larger than 1eV. This is an indicator that there is an issue with the method of simulating a thermionic cathode in PARMELA.

Conclusions

Observing a beam percentage lost of greater than 50% suggests an issue with the simulation. To confirm this result we will perform the same simulations using SPIFFE as it has the capability to simulate a full thermionic emitter.

Simulations using SPIFFE have already been completed and analysis of those results is currently underway.

Acknowledgements

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References

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[3] J. Billen “Poisson Superfish Codes”, Los Alamos National Laboratory, Copyright 1985-2005

[4] L. Young “PARMELA Codes” Los Alamos National Laboratory, Copyright 1985-2005