AUTOMATED DESIGN FOR STANDING WAVE ELECTRON PHOTOGUNS: TOPGUN RF DESIGN*

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Abstract

Systematic design of RF photoguns involves multiple RF simulations in conjunction with beam dynamic simulations. RF simulations include tuning gun frequency, matching the gun to the feeding RF circuit, balancing the on axis electric fields between gun cells, minimizing surface electric and magnetic fields and power consumption, and optimizing separation of resonant mode frequencies. We created a tool that allows this multiple parameter optimization to be done automatically. We used SUPERFISH to accomplish the RF simulations. We present an example of the rf photogun TOPGUN design using these tools.

INTRODUCTION

The TOPGUN collaboration is planning to create a cryogenic normal conducting photoinjector that will attain surface electric fields significantly larger than previously seen for an S-band photogun [1]. Due to the high gradients we expect to see large rf average heating in the photogun. Designing a cryosystem that can handle high average power at low temperatures will be challenging. To make this rf average heating manageable for the cryo system the traditional rf design for the gun needs to be updated, particularly to reduce surface magnetic fields. We have created a code that will automatically solve a given geometry in the 2D electromagnetic simulation software SUPERFISH [2]. First, we will show the capabilities of the automated design, and then the updated TOPGUN rf design.

GEOMETRY

The toolkit presented here was designed to simulate general photoguns that can be constructed from one half cell and an arbitrary number of full cells fed by a cylindrical waveguide. We will couple power to the gun using the cylindrical waveguide and a mode launcher [3, 4]. To make the toolkit the most useful we made the geometry general as practical. The generalized half cell is constructed from 8 independent geometric variables, that are depicted in Fig. 1.

Full cells will be constructed from two of the half cells back to back, giving 14 independent parameters (the cell height and cell half length will be equal for each half). The cylindrical waveguide will be coupled to the last full cell. Figure 2 shows an example full cell and the cylindrical waveguide.

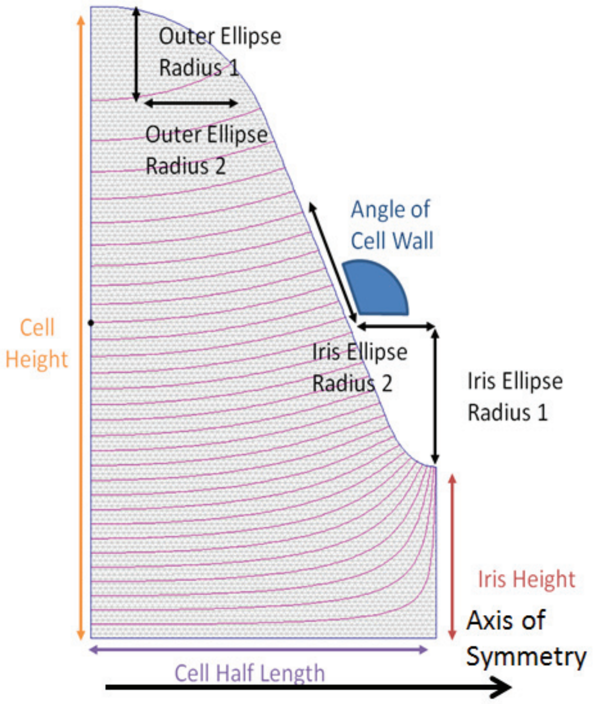

Figure 1: Figure showing the 8 independent variables for half of a cell of photogun geometry.

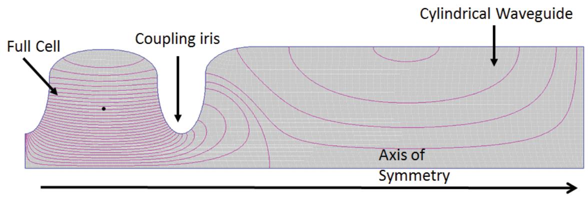

Figure 2: Figure showing one full cell and the cylindrical waveguide.

This geometry does not include nosecones. This toolkit is flexible and has already been adapted to creating standing wave linacs.

FREQUENCY TUNING

We would like to quickly tune an input geometry to a chosen frequency. This is why we have chosen to use SUPERFISH to model our azimuthally symmetric structures, since 2D codes can be significantly faster than full 3D codes. The method to tune a photogun is to set each cell to the correct freqeuncy, by modelling them separately with perfect H boundaries at the ports. We use an iterative method, where

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the structure is first solved to find f_{calc}, and then the cell height (CH) is changed as shown here:

$$CH_{i+1} = CH_i \frac{f_{target}}{f_{calc}}.$$

Within a few iterations, the cell being tuned will reach the target freqeuncy. This process is applied to each cell in turn so that the photogun will be operating in the π mode.

After frequency tuning this toolkit can also balance on axis fields in a 1.5 cell gun, making the max on axis electric field equal in both cells. This is accomplished by changing the full cell height in one direction, and changing the half cell in the other direction. This will not change the frequency of the rf photogun significantly, while changing the ratio of max on axis electric field in the full cell to the half cell. After tuning and balancing the input geometry will quickly output a structure that is at the chosen frequency in the π mode and has E field balanced between the first half cell and the full cell.

MATCHING

Part of the rf gun design is matching the cavity to the input waveguide with designed coupling coefficient. We would like to calculate the coupling, β, directly, however SUPERFISH only calculates standing wave cavities. To calculate Q external (Q_E), in the toolkit we are simulating a resonantor composed of the accelerating cavity and a shorted waveguide. We vary the length of the shorted waveguide and find the dependence of the resonant frequency of the resonator on the waveguide length. From this information we can extraxt the Q_E of the cavity using an equivalent circuit model.

In the equivalent circuit model, the impedance (Z_C) and reflection (S_C) of the accelerating cavity are:

$$\begin{aligned} Z_C(f) &= \frac{f_0}{2i(f-f_0)Q_E}, \\ S_C(f) &= \frac{Z_C(f)-1}{Z_C(f)+1}. \end{aligned}$$

Where f_0 is the resonant frequency of the cavity. The reflection (S_W) from a shorted waveguide of a given length l, cutoff frequency f_c, and ϕ the phase at the beginning of the waveguide:

$$\begin{aligned} S_W(f) &= -e^{2ilk(f)}e^{i\phi} \\ k(f) &= \frac{2\pi}{c}\sqrt{f^2-f_c^2}, \end{aligned}$$

where c is the speed of light. When $S_W = S_C$ then the resonator is at resonance.We vary the length of the waveguide and extract Q_E from the variation in frequency. Fig. 3 shows a scan of waveguide length and the resulting resonant frequency.

Using this process the coupling can be tuned to a desired value by changing the size of the coupling iris between the last cell and the waveguide.

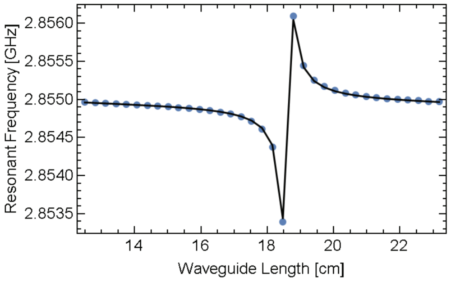

Figure 3: Graph shows resonant frequency versus waveguide length, with data from simulations as the blue points. The line is a fit to the data, used to find the Q_E of the system. The parameters for this example are $Q_E = 19,400$, $f_0 = 2.855$ GHz, and $\phi = 4.38$ rad.

DIMENSION SCANS

The toolkit makes possible quick tuning, field balancing, and matching of rf guns. Therefore, it could be used to quickly scan geometric variables for optimization or specific rf parameters.

Example

In this example we vary the radius of curvature on the outer diameter of the half cell and full cell. As we vary the cell rounding the cavity is frequency tuned and the fields are balanced at each point. At each value of the cell rounding, we can record chosen rf parameters. In this example we have shown the change in the shunt impedance versus the change in the cell rounding, presented in Fig. 4. To maximize the chunt impedance the maximum cell rounding was chosen.

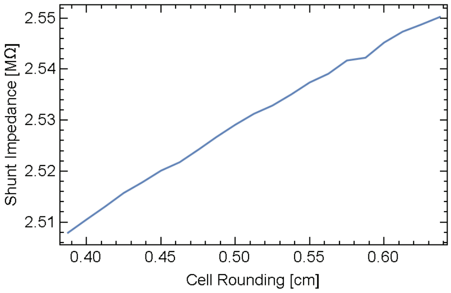

Figure 4: Dependence of shunt impedance on cell rounding. We used the maximum allowable of cell rounding.

TOPGUN RF DESIGN

The rf gun for the TOPGUN project will be a 2.856 GHz 1.45 cell normal conducting copper structure operated at cryogenic temperatures [1]. All of the cell walls and irises were rounded as much as allowed by the geometry, to minimize surface electric and magnetic fields. So that we get the desired coupling of $\beta = 9$ at cryogenic temperatures, the coupling was tuned to be $\beta = 1.875$ at room temperature. The geometry is presented in Fig. 5 and rf properties are in Table 1.

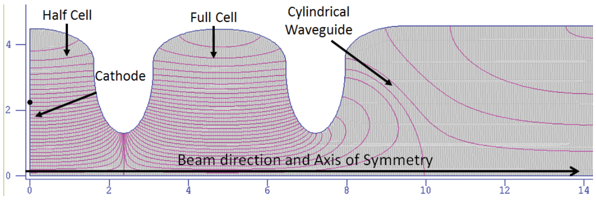

Figure 5: RF geometry of the TOPGUN photoinjector. Units are in centimeters.

Table 1: RF Parameters for the TOPGUN Photogun

f_0	2.856 GHz
Q_0	13,800
Q_E	25,875
Shunt Impedance	2.58 MΩ
Max Cathode Electric Field	250 MV/m
Max Iris Electric Field	236 MV/m
Max Magnetic Field	484000 A/m
Stored Energy	30.6 J

CONCLUSION

We created a toolkit for optimization of rf guns. We used the toolkit to optimize the design of the TOPGUN rf photoinjector, including solving the frequency quickly, balancing fields, setting coupling beta, and optimizing rf parameters with changing geometries. In the future we plan to incorporate particle tracking software into the toolkit, so that we can do complete simulations of rf guns, including coupled rf and beam dynamics simulations.

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