DESIGN AND SIMULATION OF A C-BAND PHOTOCATHODE RF GUN FOR UEM *

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Abstract

For discovering smaller structure, ultrafast electron microscope (UEM) becomes much more important and has been widely used in many fields. As a part of the UEM, a photocathode RF gun working at C-band frequency of 5712MHz is being developed, which provides electron beams with high energy and good quality for UEM. This paper presents the physics and structure design, including optimization of cavity shape parameter for improving shunt impedance and mode separation. We adopt coaxial coupling to feed power into the cavity, which could decrease the multipole field and build better accelerating field in the RF gun. In this paper, we discussed the simulation process and results of the RF gun and introduce the design of the coaxial input coupler.

INTRODUCTION

Electron microscope is a useful tool for observing and studying materials and cells in very small length scale and is widely used in many laboratories. Ultrafast electron microscope uses electron beams with higher energy as the probe to discover minute structure, and could also be used to observe dynamic process. An electron microscope consists of many parts. Electron gun, which provides electron beams with high energy to contact materials, is the most important part in electron microscope and also determines the quality of observed images. [1,2] Electron microscope usually uses photocathode gun, field-emission gun and thermal emission gun as the electron source. Among them, photocathode gun, which could provide electron beams with much higher energy and better dynamic properties, is most chosen in electron microscope.

Traditional ultrafast electron microscope with photocathode gun uses direct current gun (DC gun) to get electron beams. [3-6] However, the breakthrough of DC photocathode gun in vacuum limits the maximum voltage on the cathode and also limits the energy of electron bunch, which causes the expansion of bunch dimensions due to space charge effect. Thus, radio frequency gun (RF gun) is chosen to be used in this experiment to get better electron beams. With RF gun, the electron emitted from the cathode will be accelerated rapidly to near realistic speed, which will decrease space charge effect.

Side coupling is one of the way to feed the cavity. However, this will increase the size of the cavity and also decrease the magnetic field built by solenoid magnet. Hence, we choose coaxial coupler, which feed power from the coaxial line and do not increase the diameter of the electron gun.

In this research, we use CST Microwave Studio to simulate the electron field in 1.6-cell C-band gun cavity and design the structure of coaxial coupler. This photocathode RF gun on C-band will have smaller size and higher accelerating gradient, which will produce electron beam with higher energy and better dynamic property. With coaxial coupling, the solenoid could produce stronger magnetic field and will compensate the emittance much better.

RF STRUCTURE DESIGN

The gun cavity consists of two cells. The first cell is called half-cell because of its length and the second cell is called full-cell. Considering the effect of space charge effect, we choose that the first cell length is 60 percent of the full cell length. The RF structure design and simulation are done by superfish and CST Microwave Studio. During simulation, main microwave parameters are calculated. We mainly optimize the iris shape parameters and length of cells to get higher shunt impedance and adjust radius of half-cell and full-cell to make the gun working on 5712MHz. Considering the tiny change of cavity sizes which could cause the frequency shift, we calculate the cavity frequency change when the sizes varies around 1mm, which will have help on tuning.

The 2D pi-mode field result is calculated in superfish and showed in Fig.1, in which the arrows are represented the field direction and line density represents the field strength. The Ez field is used to accelerate particles and result is showed in Fig.2.

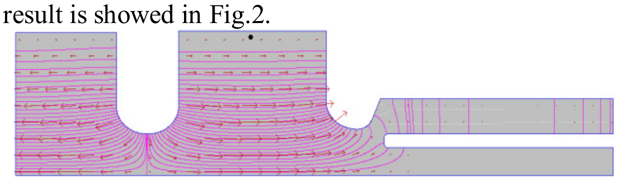

Figure 1: 2D model of the full model with pi-mode electric field in superfish.

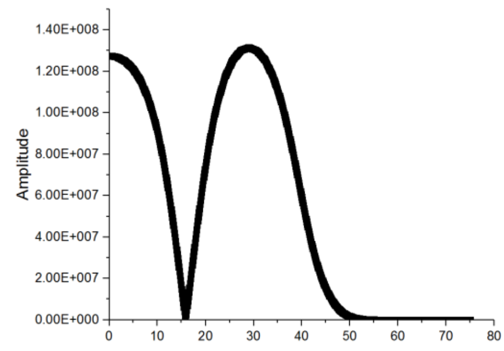

Figure 2: Ez of pi-mode along axis.

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Table 1: Main Microwave Parameters

Pi-mode frequency	5712.04MHz
0-mode frequency	5699.82MHz
Mode separation	12.22MHz
Shunt impedance per meter	141.55 $M\Omega / m$
Q factor	12084.3

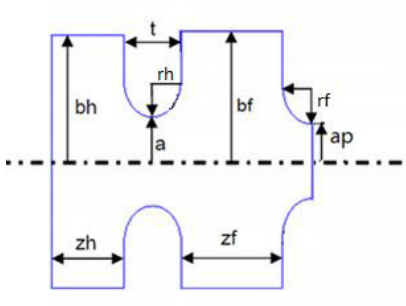

Figure 3: parameter position of gun cavity.

Main microwave parameters are listed in Table 1 and parameter positions are showed in Fig.3.The shape design use LCLS gun as reference. [7] We scan different value of half-cell length, full-cell length and iris radius to calculate shunt impedance and mode separation. We find that we need to balance the high shunt impedance and high mode separation. We finally improving shunt impedance to 141.55 $M\Omega / m$ and ensure the mode separation to avoid mode shift.

Table 2: Frequency Dependence of Parameter

Parameter	$\frac{\Delta f}{\Delta z} / MHz \cdot \mu m^{-1}$
bf	0.191
bh	0.112
a	-0.051
rh	0.042
ap	-0.02
zf	0.013
zh	-0.009
rf	0.006

Considering dimension error during model making and tiny dimension change due to temperature change and misalignment, frequency shift per 1 μm is calculated and results are listed in Table 2. From the data, the frequency change due to dimension change of half-cell radius bh and full-cell radius bf is much bigger than other parameter dimension change. Hence, tuning is necessary in afterwards experiment to make sure the cavity is working on the working frequency.

COAXIAL COUPLER DESIGN

We adopt the coaxial coupler in this C-band gun to make the field in cavity to keep symmetry and also to decrease the radius of gun cavity and to make the solenoid compensating emittance better. The model is divided into two part in coupler design: the first part is the coaxial coupler connecting to rectangular waveguides, the second part is the coupling aperture connecting the coaxial line and gun cavity. After finishing two parts, the full model is built and calculated.

Design of coaxial coupler connecting to rectangular waveguides

Previous research shows that asymmetric structure leads to producing dipole field, which has no benefit on building accelerating field and might have bad influence on beam dynamics. Hence, we adopt coaxial coupler to avoid such effect and we can also put solenoid magnetic closer to the gun. The coaxial coupler connects two rectangular waveguides and a coaxial transmission line. One of the waveguides, connected with power source, feeds microwave power for the RF gun. The other waveguide is set for keeping symmetry and the port of it is set as short.

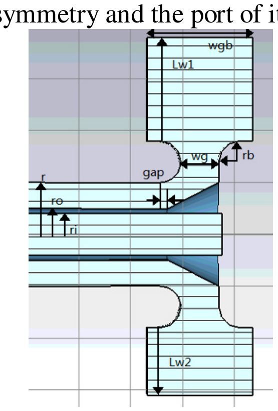

Figure 4: Cross section of coupler transformer structure.

The cross section of this part is showed in Fig.4. We use CST to simulate electromagnetic field in the coupler and calculate S11 parameter as our goal parameter. In the coaxial coupler structure, the doorknob structure is most important to make the field match. The S11 parameter is sensitive to the width of coupling aperture and the blending radius. Hence, we optimize these two parameters to get good S11 curve which is showed in Fig.5.

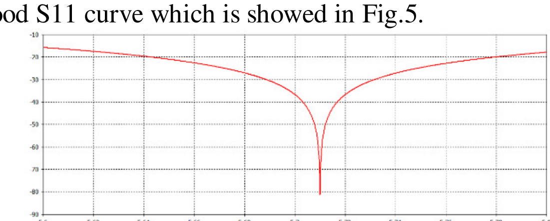

Figure 5: S11 curve.

Design of Coupling Aperture Connecting to the Gun Cavity

The coupling aperture connects the coaxial transmission line and the gun cavity. In this part, we use eigenmode solver in CST to simulate the electromagnetic field in the model. By calculating the quality factor of the cavity Q_0, and the external quality factor Q_{ex}, we could get the coupling coefficient β_c, according to the equation,

$$\beta_c = \frac{Q_{ex}}{Q_0}$$

$$P_c = \frac{4\beta_c}{(1+\beta_c)^2} P_0$$

Where P_c is the power in cavity and the P_0 is the input power. When the coupling coefficient equals one, the input power is fully used to build electromagnetic field in the cavity and has no reflection in the aperture. In this case, the coupling coefficient is the best coupling condition for this model. Hence, structure parameters need to be optimized to fit the demand. A circular truncated cone is used to connect the transmission line and the gun cavity. The most sensitive parameter is the length of the cone, zc, and the length of inner cylinder in the transmission line, Lt. The goal is getting best coupling coefficient by adjusting these two parameters.

In CST, electromagnetic fields and quality factors are calculated. By scanning different value of zc and Lt, the variation trends is found for optimization and the results is showed in Fig.6 and Fig.7. The external quality factor is increasing as zc is decreasing and Lt is decreasing. After optimization, the best coupling coefficient is calculated and we also get other RF parameters in the structure.

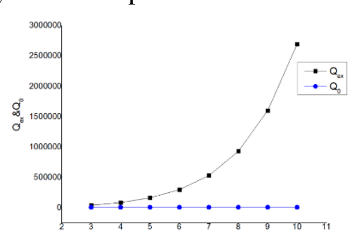

Figure 6: Q_{ex} and Q_0 varies with zc.

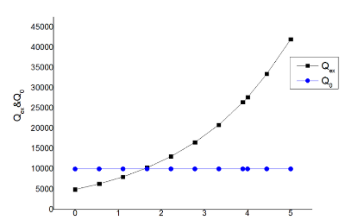

Figure 7: Q_{ex} and Q_0 varies with Lt.

Full Model Results and Discussion

After the design of two parts of coupler is finished, the full model is built and simulated using time domain solver in CST. The pi-mode electric field is showed in Fig.8 and S11 curve is showed in Fig.9. The curve has two resonance peaks at 5700MHz and 5712MHz, which is same with the result of cavity design microwave calculation.

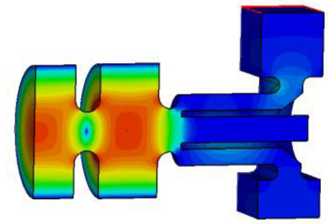

Figure 8: pi-mode electric field in full model.

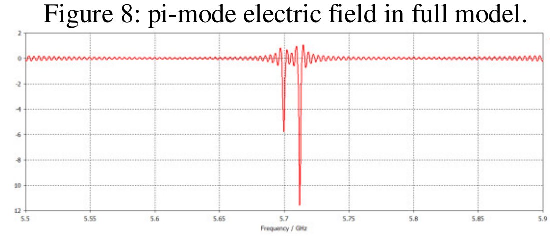

Figure 9: S11 curve of full model.

CONCLUSION

In this paper, we design a 1.6-cell C-band photocathode electron gun using for UEM with coaxial input coupler. We first design the cavity shape and structure and calculate the main microwave parameters. The detail of coaxial coupler design is presented and the model is calculated using time-domain solver. The full model is designed and dynamic simulation will be done and solenoid will be added in future simulation to perfect the design and structure of the full model.

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