STUDY ON CHARACTERISTICS OF ASYMMETRIC CENTRE IRIS OF PHOTOCATHODE MICROWAVE ELECTRON GUN

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Abstract

The characteristics of the asymmetric centre iris between the first cell and the second cell of the 1.6 cell photocathode microwave gun are studied in this paper. For π-mode, the RF transverse field of two sides of the iris is non anti-symmetric. Thus, the RF transverse force at the centre iris is not negligible. In this paper, we present the status of the optimization simulations, using the SUPERFISH and ASTRA particle-in-cell code. Numerical results of beam dynamics show that it can improve the beam quality at the exit of the gun, especially the beam emittance.

INTRODUCTION

The rapidly advancing technology of high-brightness, relativistic electron beam source has made possible a wide range of new and exciting tools for research and industry. Some of the new applications include linear particle colliders, Compton scattering sources, electron cooling of protons and heavy ions stored in a ring, energy recovery linac (ERL) light sources, FELs, inverse FELs, ultrafast electron diffraction and so on. In many cases these new devices would not be possible without the invention of the photocathode gun. Laser photocathode microwave guns have proved to be promising candidates for the generation of such beams. In 1985, the first photocathode gun as the electron source for an FEL experiment was constructed at Los Alamos National Laboratory [1], following which many such structures have been studied, developed, and are currently operating in many laboratories around the world [2–4].

The typical gun is the BNL/SLAC/UCLA 1.6 cell structure [5] and is designed to resonate at 2856 MHz in the π mode in Fig. 1. The gun consists of a cathode, a 0.6 length cell and one full length cell. These cavities operate typically in a TM_{010} transverse magnetic mode including E_z, E_r and B_θ [6]. The transverse force of electron beam through the gun is [7]

$$f_r = e\left(E_r - \beta c B_\theta\right) \tag{1}$$

There is little transverse force near the cathode since the low electron velocity makes the first term small and the second term as well since it is proportional to $\sin(k_z z)$ and $z \approx 0$ near the cathode. The largest transverse force is at the two locations: the centre iris and the gun exit iris. In the entrance and exit of the centre iris, the beam can be defocused $f_{1,\text{ defocus}}$ and focused $f_{2,\text{ focus}}$, respectively. And then, it is defocused at the gun exit iris, $f_{3,\text{ defocus}}$. The total transverse force of the gun is

$$f_{\text{total}} = f_{1,\text{ defocus}} + f_{2,\text{ focus}} + f_{3,\text{ defocus}} \tag{2}$$

For symmetric centre iris, the field of the π-mode is anti-symmetric about the iris, the transverse force at the centre iris is also negligible. However, the transverse force at the exit iris is significant since doesn't change sign across the exit iris. Thus, the total transverse force is an impulse given at the exit iris, as the following:

$$f_{\text{total}} = f_{3,\text{ defocus}} \tag{3}$$

As we know, the emittance is increased and the beam quality is degraded by the gun's RF defocusing.Therefore, we propose a scheme that an asymmetric centre iris is used in the 1.6 cell gun. It generate the non-anti symmetric field at the centre iris. The well designed field can increase the focus force and decrease the defocus. As a result, the total transverse force of beam is non-defocus through the gun, as follows:

$$f_{\text{total, center iris}} = f_{1,\text{ defocus}} + f_{2,\text{ focus}} > 0 \tag{4}$$

In the next Section, the theory analysis of the radial momentum is performed and the electromagnetic field is simulated to find the proper parameter to satisfy the beam quality requirement using the 2D solver code SUPERFISH [8]. The RF fields of the different centre iris of 1.6 cell gun are calculated to generate the field distribution along the centre axis for beam dynamic. And then, the beam dynamic is performed to study the characteristics of the gun. We simulate the beam dynamics of the photocathode RF gun using ASTRA [9] to study the emittance. Finally, we describe the conclusion.

ELECTROMAGNETIC FIELD SIMULATION

The structure of the gun which is discussed in this paper is based on the BNL/SLAC/UCLA 1.6 cell RF gun in Fig. 1.

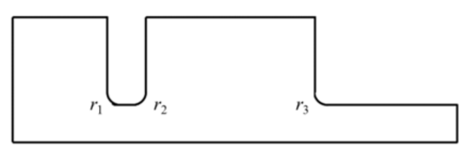

Figure 1: The structure of the 1.6 cell RF gun.

The operating frequency of the gun is 2856 MHz in the π mode. According to the electromagnetic theory, the amplitude of the transverse field is proportional to the amplitude E_z along the centre axis, thus the transverse force f_r is proportional to the amplitude E_z. The radial momentum, p_r, is expressed by the equation of motion,

$$\frac{\mathrm{d}p_r}{\mathrm{d}t} = \frac{f_r}{mc} \tag{5}$$

Where we're using Kim's definition of the dimensionless radial momentum [10]

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$$p_{\mathrm{r}} = \frac{r}{c}\frac{\mathrm{d}r}{\mathrm{d}t} \tag{6}$$

The change in radial momentum is computed by integrating the force impulse for each iris

$$\Delta p_{\mathrm{r}} = \frac{1}{mc^2}\int_{z1} f_{\mathrm{r},1}\mathrm{d}z + \int_{z2} f_{\mathrm{r},2}\mathrm{d}z + \int_{z3} f_{\mathrm{r},3}\mathrm{d}z \tag{7}$$

It is straightforward that the radial momentum is decided by the amplitude field E_z and the motion length around the iris from the formula (7). The greater amplitude field E_z is the greater radial momentum. But to suppress the emittance growth, the beam energy must be accelerated to relativistic energy to overcome the space charge effect through the comparatively short distance. It is required that the amplitude E_z must be too enough. Thus, to decrease the radial momentum, it is necessary to study the structure in detail, especially the iris.

In the structure, the transverse fields of iris including two centre iris and one exit iris are closely related to the geometry parameter r_1, r_2 and r_3.The non-anti-symmetric field of the centre iris is decided by the geometry parameter r_1 and r_2. In this section, the geometry parameter of iris are changed to get the different structure to generate the different field distribution.

Symmetric Centre Iris

The preliminary design and numerical calculation of the RF parameters of the RF gun is performed using the 2D electromagnetic field solver code SUPERFISH. The full cell of the gun is half-wavelength, having an electric field directed opposite to that in the 0.6 cell as shown in Fig. 2.

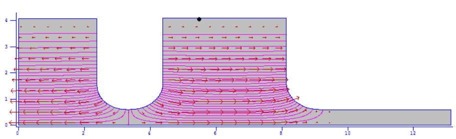

Figure 2: The electric field distribution of the RF gun.

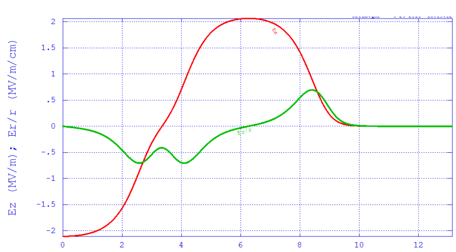

Figure 3: The electric field along the beam direction.

The electromagnetic field in the two cells of the RF gun is coupled through an aperture at the centre of the disk separating the two cells. The size of the aperture is decisive in determining the coupling of electromagnetic power between the two cells. The electric field along the beam direction is shown in Fig. 3. Because of the anti-symmetric field of centre iris, it's only the defocus for the gun. According to the formula (7), the change in radial momentum is computed by integrating the force impulse over the position of the exit iris. It's not necessary to discuss the details of the symmetric centre iris. Table 1 shows the electrical parameters of the symmetric centre iris of RF gun structure.

Table 1: Electrical Parameters of the RF Gun

Parameter	Value	Unit
Frequency f	2856	MHz
Quality factor Q	16407	
Shunt Impedance Z_s	67.38	MΩ/m
r/Q	206.5	Ω
E_{max}/E_0	2.17	

Asymmetric Centre Iris

In order to study the characteristic of the asymmetric centre iris, the method of univariate analysis is used to calculate the electromagnetic field of the different parameter r_1 and r_2 of the gun.

Firstly, r_1 is changed from 10 to 5 mm and r_2 is the constant, the normalized electric field is shown in the Fig. 4. The amplitude E_z of the electric field along the centre axis in the 0.6 cell decrease while the parameter r_1 in decrease. Due to point effect, the transverse field around the r_1 iris increase, especially the inner surface. For larger beam size, the transverse force will be large, but the distance become short. Thus, the total radial momentum around the r_1 iris need to discuss by combining with the beam dynamic in following.

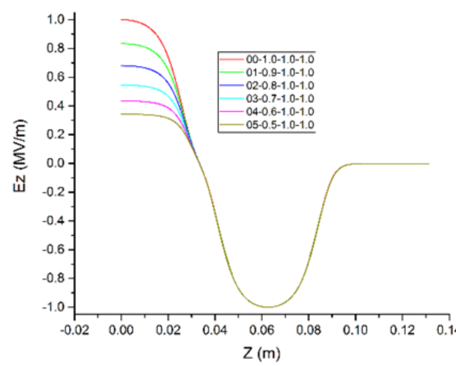

Figure 4: Electric field along centre axis for different r_1.

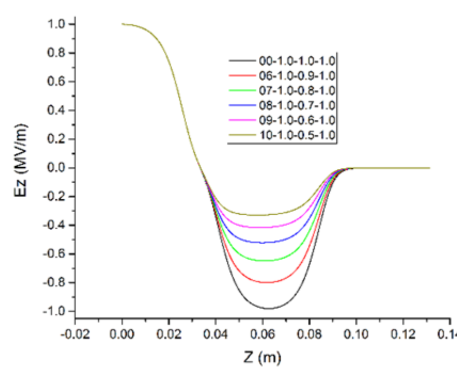

Figure 5: Electric field along centre axis for different r_2.

Secondly, r_2 is changed from 10 to 5 mm and r_1 is the constant, the normalized electric field is shown in the Fig. 5. The amplitude E_z of the electric field along the centre axis in the full cell decrease while the parameter r_2 in decrease. Due to point effect, the transverse field around the r_2 iris increase, especially the inner surface. For larger beam size, the transverse force will be large, but the distance become short. Thus, the total radial momentum around the r_2 iris need to discuss by combining with the beam dynamic in following.

BEAM DYNAMICS

The beam dynamics of an intense, relativistic electron beam with a Gaussian distribution in the transverse distribution and a flat-top distribution in the longitudinal distribution generated by a photocathode RF gun is studied using the ASTRA code. The simulation parameters of the electron beam are shown in the Table 2.

Table 2: The Initial Beam Parameter

Parameter	Value	Unit
Distribution	Gaussian	Transverse
	Flat-top	Longitudinal
Bunch charge	500	pC
Bunch length	7	ps
Peak accelerating field	100	MV/m

We perform to simulate the beam dynamic with three situations of the above electromagnetic field. The beam emittance vary with the longitudinal axis for different phase as shown in the Figs. 6, 7, 8. As a result, the beam emittance decreases firstly, and then increases with the longitudinal position after the exit of the gun in Fig. 6. It is straightforward that the result correspond to the formula (4) above.

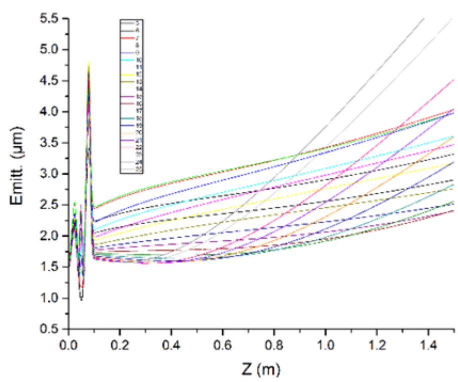

Figure 6: Emittance along Z for anti-symmetric centre iris.

CONCLUSION

The property of the transverse field around asymmetric of centre iris of photocathode microwave gun has been studied using SUPERFISH and ASTRA codes. It has potential to generate high quality electron beam. The change of beam emittance of the asymmetric centre iris is different with anti-symmetric centre iris. The prospect of the structure is used to generate the large beam size and the large charge per bunch of electron source.

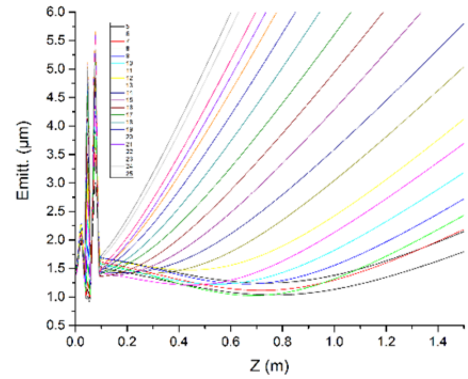

Figure 7: Emittance along Z for 03-0.7-1.0-1.0.

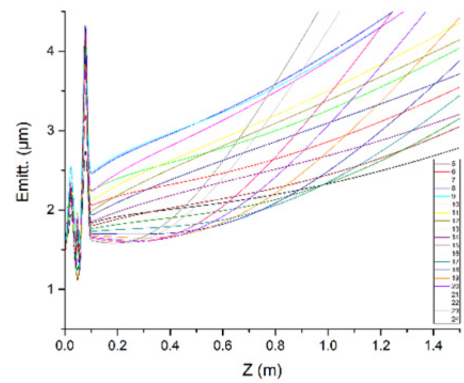

Figure 8: Emittance along Z for 08-1.0-0.7-1.0.

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