DESIGN, SIMULATION AND COMPARE OF FLAT CATHODE ELECTRON GUNS WITH SPHERICAL CATHODE ELECTRON GUNS FOR INDUSTRIAL ACCELERATORS

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Abstract

In this article, electron guns with flat and spherical cathodes have been designed and simulated for industrial accelerators. After checking the different features of each cathode geometry, has been discussed about optimum values of this features. The most important features for selecting the best cathode geometry for industrial accelerators are beam waist radius, beam waist position, current density and price. Finally after comparing different features of both geometries, suitable geometry was selected.

INTRODUCTION

The electron guns of different industrial electrostatic accelerators are alike. All of these guns are thermionic type. The fundamental of these guns based on the heating of the cathode by a filament to reduce work function and get a large amount of electron beam. The in-formation of several types of thermionic electron gun with different plans are introduced in reference [2]. The thermionic electron guns run in two modes of space charge and thermal. In the thermal mode the emitting current is defined by Richardson-Dushman formula. According to this theory the beam current density is a function of the work function and the cathode temperature [3]. In this mode the emitted cur-rent rises by increasing the cathode temperature. The more and more increasing of the cathode temperature to a special level, the different potential of anode-cathode cannot extract the created electron bunch from the front of the cathode. This electron bunch causes a negative space charge in front of the cathode and then causes that some electrons return back to the cathode surface. After it, the more increasing of the cathode temperature does not effect on the emitted current and then the electron gun mode changes to the space charge mode. In this mode the amount of the emitted current is just depend on anode-cathode different potential. The temperature of changing mode is named critical temperature. In the space charge mode the emitting current is defined by Child–Langmuir law [4]. The thermionic electron guns are being made in both flat and spherical geometries. In this article two electron guns in space charge mode have been de-signed, simulated and compared. First gun has a spherical cathode and the second gun has a flat cathode.

SPHERICAL CATHODE GUN

In the spherical thermionic electron guns the anode aperture is smaller than that of flat cathodes. Therefore in the spherical cathodes, the electric field lines of accelerating tube section, has smaller penetration in the anode-cathode gap and has smaller effect on the space charge mode of gun. Also the beam waist radius in the spherical geometries is smaller than that of flat cathodes [1]. Figure 1 shows the structure of a spherical geometry electron gun [1].

$$I = 14.67 \times 10^{-6} \frac{(1-\cos\theta)}{(-\alpha)^2} V^{\frac{3}{2}} \quad (1)$$

In this equation V is the anode-cathode difference potential, θ half of angel of cone and α is a numerical coefficient that can be calculated by equation (2):

$$(-\alpha) = \gamma + 0.3\gamma^2 + 0.075\gamma^3 + 0.01432\gamma^4 + 0.00216\gamma^5 + 0.00035\gamma^6 \quad (2)$$

Also γ can be calculated by equation (3):

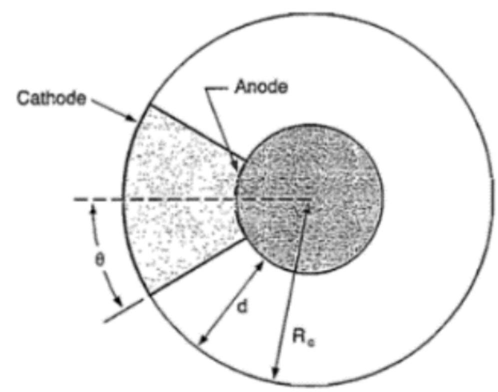

Figure 1 : Structure of a spherical cathode electron gun.

$$\gamma = Ln\left(\frac{1}{1-\frac{d}{R_c}}\right) \quad (3)$$

In this equation d is the anode-cathode gap distance and Rc is The radius of curvature of the cathode.
Also the Perveance has been given by equation (4):

$$P = \frac{I}{V^{\frac{3}{2}}} \quad (4)$$

FLAT CATHODE GUN

In this geometry the beam waist radius is more than that of the spherical geometries. Figure 2 shows the schematic of the flat cathode pierce electron gun [2].

In a flat cathode electron gun the current density is being defined by equation (5):

$$J = 2.33 \times 10^{-6} \frac{V^{\frac{3}{2}}}{X^2} \qquad (5)$$

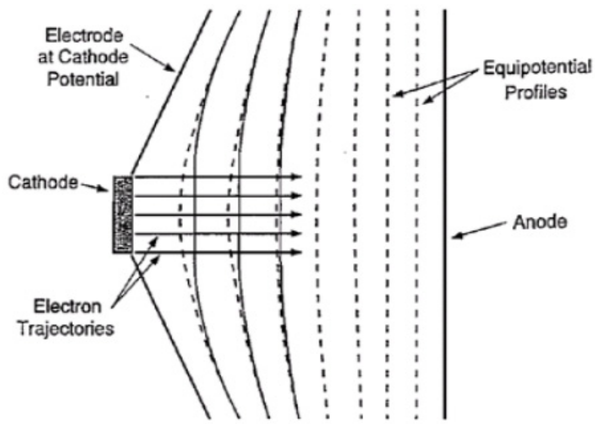

Figure 2: Schematic of the flat cathode pierce electron gun.

In this equation V is the anode-cathode difference potential and X is the anode-cathode gap distance. The Perveance formula given by equation (4) is also valid for flat cathodes electron guns.

DESIGN AND SIMULATION OF SPHERICAL CATHODE GUN

The specifications of the simulated spherical cathode electron gun are presented in Table 1.

Table 1: Specifications of the Simulated Spherical Cathode Electron Gun

Parameter	Value
I	105 mA
V	5 kV
R_c	30 mm
r_c	5 mm
R_a	15 mm
r_a	4.4 mm
d	15 mm
θ	10°
ɣ	0.693
α	0.865

In our simulations parameters of beam current, anode-cathode difference potential and cathode radius are equal for two geometries and the other parameters are different. Know the parameters of Table 1 should be replaced in equation (1)

$$\mathrm{I} = 14.67 \times 10^{-6} \left(\frac{1 - \cos\theta}{(-\alpha)^2}\right) \mathrm{V}^{\frac{3}{2}}$$
$$= 0.297 \times 10^{-6} \mathrm{V}^{\frac{3}{2}} \qquad (5)$$

After doing simulations by CST STUDIO software, the earned emitted beam current was about 106 mA. Therefore theoretical and simulation results have a good agreement with each other. Figure 3 shows the designed spherical cathode electron gun (left side) and electron beam trajectory (right side). More information about this electron gun design has been given in reference [5].

After doing simulations, the beam waist radius was 2.3 mm and the beam waist position was in 38 mm of cathode surface. This electron gun has been designed for an industrial parallel fed Cockcroft-Walton accelerator. Therefore the beam waist radius should not be so focused.

DESIGN AND SIMULATION OF FLAT CATHODE GUN

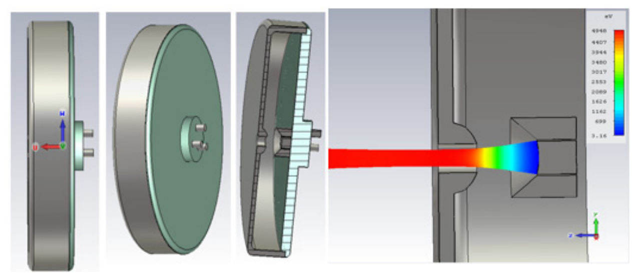

Figure 3: Designed spherical cathode electron gun and particle trajectory.

The second designed electron gun (flat cathode) specifications in the space charge mode are shown in Table 2.

Table 2: Specifications of the Simulated Flat Cathode Electron Gun

Parameter	Value
I	105 mA
V	5 kV
r_c	5 mm
D	9 mm

The density of emitted current from cathode surface is considered $1 \mathrm{A/cm^2}$.

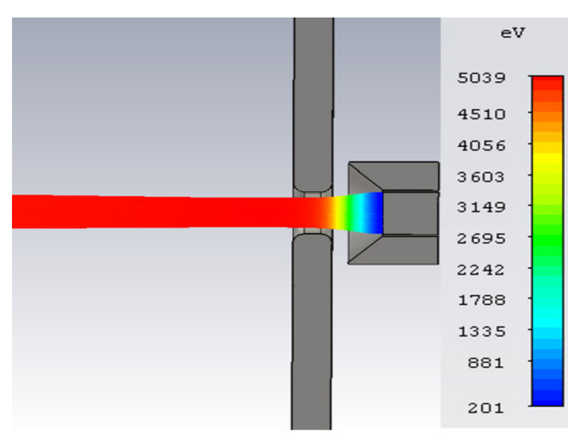

Figure 4: Trajectory of particles in the gun.

After simulating, the view of the trajectory of particles in the designed gun has been showed in Fig. 4.

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In this geometry, the radius of beam waist is 3.5 mm and its position is in 21 mm from cathode surface. Compare to the spherical cathode results, we can see that the waist radius is larger in flat geometry. Also, the beam waist is nearer to cathode in flat geometry. This results demonstrate more beam converge in spherical geometries. Also, because of complexity of making curve in cathodes, the manufacturing cost of guns with spherical geometry is more than flat geometry. According to the results and what was discussed, short radius beam waist is not as much important in industrial accelerator and spherical geometry is widely used in this type of accelerators.

Figure 5 shows the projection of beam density.

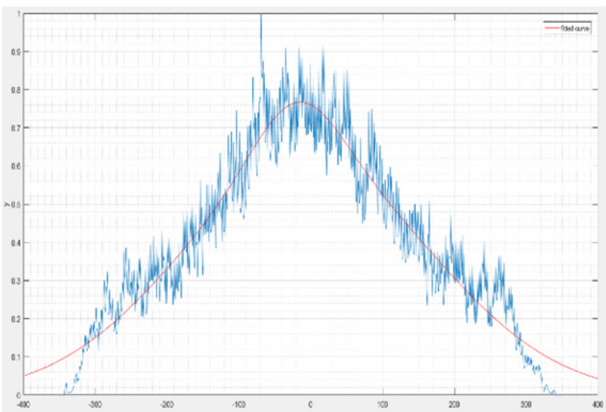

Figure 5: Projection of beam density.

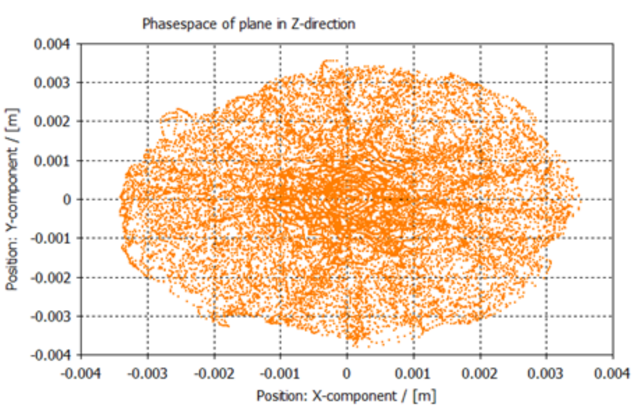

Figure 6: Beam profile at waist.

Figure 6 shows the beam profile at waist. As we can see, all particles are within 3.5 mm radius. Also, particle density is much higher in the centre compare to the marginal areas.

The Gaussian beam profile makes the gun suitable for use in industrial accelerator due to its low beam loss along the accelerating tube.

CONCLUSION

The spherical cathode electron guns have a more focused beam radius compare with the flat cathode electron guns. Therefore from this view point the flat cathode electron guns are more suitable for industrial applications. Also the flat cathode electron guns are cheaper than the spherical cathode electron guns. In all geometries profile of the electron beam should be Gaussian.

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