DESIGN AND SIMULATION OF A THERMIONIC ELECTRON GUN FOR A 1MEV PARALLEL FEED COCKCROFT-WALTON INDUSTRIAL ACCELERATOR

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Abstract

In this article a diode electron gun is designed and simulated for a 1MeV parallel feed Cockcroft-Walton accelerator for industrial applications. The pierce configuration is selected for focusing electrode. Simulations are carried out using CST Particle Studio. The gun is thermionic with indirect heating of spherical dispenser cathode and is made from porous tungsten which is impregnated with barium compounds. The required current in our accelerator is about 100 mA and this gun can easily provide it.

INTRODUCTION

With respect to extensive applications of industrial accelerators in industry, we want to improve our abilities in this field in Iran. Electron accelerators are made of different parts. One of the main parts of every electron accelerator is its electron gun. Electron gun works in both space charge limited and thermal limited mode [1]. Electron guns with space charge limited mode have a more stable performance [2]. Their output electron beam is being controlled by the difference potential between anode and cathode instead of cathode temperature [3]. In the industrial accelerators space charge limited electron guns are very more intended than thermal limited because of their good stabilities. In industrial accelerators the electron gun cathode should have a large life time, otherwise we are forced to replace cathode frequently. For changing the cathode we should turn off the accelerator and it is not good for accelerator performance. Therefore we should use cathodes with large life time. Dispenser cathodes are one of the best choices for this application. Dispenser cathodes life time is about 10 thousand hours and their current density is about 20 $\frac{A}{cm^2}$ in 1100 ℃ [4]. Output electron beam in the industrial accelerator should be spread on a wide length [5]. If the electron beam be so focused our target wouldn't be uniformly irradiated therefore we need to a wide beam in industrial applications otherwise the target may hurt. Thus we don't need to generate a focused beam by the gun. Therefore our cathode should be planar or almost planar. In our design, cathode is spherical but its radius is so big and it is almost such as a planar cathode. A good feature of spherical cathode guns against planar cathode guns is better performance of spherical type in space charge limited mode because of the least field effect of accelerating tube on anode cathode gap of the spherical cathode guns. Schematic diagram of a spherical diode electron gun has been given in Fig. 1 [1].

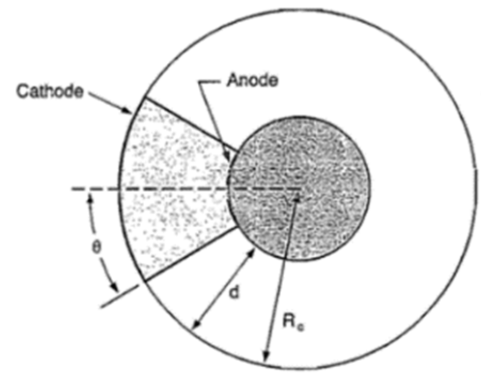

Figure 1: Schematic diagram of a spherical diode e- gun.

Achievable current of a spherical diode electron gun in space charge limited mode is calculated by Langmuir & Blodgett [1].

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

In this equation V is potential difference between anode and cathode and α is achievable from equation (2)

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

And γ has been given by equation (3)

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

SIMULATIONS WITH CST PARTICLE STUDIO

In our intended electron gun cathode is a dispenser type from porous tungsten which is impregnated with barium compounds. Its work function is 2eV, its spherical radius (R_c) is 30mm and its radius (r_c) is 5mm. Anode radius (R_a) is 20mm and anode aperture radius (r_a) is 4.4 mm. Distance between anode and cathode (d) is also 15mm. Know with respect to our parameters and equations of (1), (2) and (3) we have $\gamma = 0.693$ and $(-\alpha) = 0.865$ therefore our current can now be calculated by equation below

$$I = 0.297 \times 10^{-6} \times V^{\frac{3}{2}} \quad (4)$$

Now according to equation (4) the emitted current of our gun is just a function of $V^{\frac{3}{2}}$ and we can change the emitted current just with changing anode-cathode difference potential. A scheme of our designed electron gun with CST is shown in Fig. 2 and trajectory of particles has been shown on it.

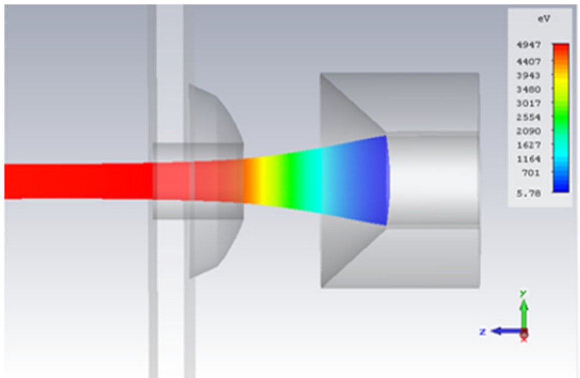

Figure 2: designed electron gun and particles trajectory.

For industrial applications, electron beam waist radius should not be so focused. As has been shown in Fig. 2 our beam waist radius electron gun is about 2.3mm and is suitable for our application. According to equation 4 we can achieve our required current beam by varying anode-cathode difference potential. Current variations via anode-cathode difference potential achieved from both theory and simulations has been given in table 1.

Table 1: Current Variations With Potential Variations

V (kV)	Simulation Current(mA)	Theoretical Current(mA)
3	48.92	48.80
4	75.3	75.1
5	105.2	105.0
6	138.3	138.03
7	174.3	173.9
8	212.9	212.5

Difference between theoretical and simulation results has been plotted in Fig. 3.

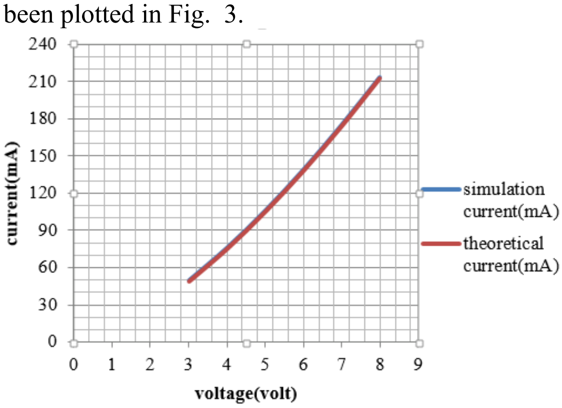

Figure 3: comparison of I-V diagrams of theory and simulation.

As has been shown, in both diagrams, the differences of the results is negligible and they are almost fitted on each other.

GUN PERVEANCE

Perveance is a numerical constant for the electron guns with performance of space charge limited mode. This quantity is just a function of gun geometry [2]. It has been defined with equation (5)

$$P = \frac{I}{V^{\frac{3}{2}}} \tag{5}$$

Therefore In spherical cathode electron guns with respect to equation (1) and (5) Perveance is given by equation (6)

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

Perveance dimension is $Amp/Volt^{\frac{3}{2}}$ $=\mu perv.$ and Perveance of our electron gun is 0.297×10^{-6} $Amp/Volt^{\frac{3}{2}}$ or 0.297 $\mu perv$ [6].

BEAM WAIST POSITION

Beam waist is a place that beam has the least radius. Beam waist position is the distance between cathode surface and beam waist [6]. This point should be out of electron gun and behind of anode aperture otherwise electrons hit to anode before arriving to next section (accelerating tube) of accelerator. Beam waist position vary with current variations and table 2 shows this variations in our designed electron gun [4].

Table 2: Variations Of Beam Waist Position And Radius With Current Variations

V (kV)	Simulation Current(mA)	Beam waist position(mm)
3	48.92	41.13
4	75.3	41.13
5	105.2	38
6	138.3	38
7	174.3	38
8	212.9	38

According to table 2 beam waist position for currents of below 100mA is almost stabled to 41mm and for currents of up to 100mA be 38mm. therefore our beam waist positions are invariable and it's a good feature for our application. Also beam waist position is out of the anode for all currents and it is a good factor for us to change beam current without any problem.

BEAM WAIST RADIUS

Beam waist radius is a very important parameter of every electron gun [6]. Especially in industrial electrostatic accelerators beam waist radius shouldn't be very little.

ISBN 978-3-95450-147-2

Generally beam waist radius raises when beam current raises and vice versa. Table 3 shows the variations of beam waist radius with beam current in our designed electron gun.

Table 3: Variations Of Beam Waist Radius With Current Variations In Designed Electron Gun

V (kV)	Simulation Current(mA)	beam waist radius(mm)
3	48.92	2.2
4	75.3	2.2
5	105.2	2.3
6	138.3	2.3
7	174.3	2.4
8	212.9	2.5

With respect to table 3 beam waist radius increases with raising beam current but the variations of beam waist radius is negligible for example when the current vary from 50 mA to 200 mA beam waist radius vary from 2.2mm to 2.5 mm.

CONCLUSIONS

Electron gun is one of the most impotent parts of industrial electron accelerators. In this application some of characteristics of electron gun such as cathode life time, cathode current density, beam waist radius, beam waist position and stable performance in different currents are very important for us. In our designed electron gun beam waist radius vary from 2.2mm to 2.5mm and beam waist position vary from 38mm to 41mm and this stability is so good for our application.

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