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SIMULATION STUDY OF ELECTRON GUN FOR SIX MEV LINAC FOR X-RAY CARGO INSPECTION

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Abstract

Electron guns are designed in different models. Output beam quality and efficiency of the linear accelerator for each application depends on choosing the suitable model of electron gun. The most common types are Diode and Triode electron guns. Simulation Study of diode electron gun of 6MeV Linac for X-Ray cargo inspection represented in this article. The Vaughan analytical method was used to obtain the initial dimensions. In final stage, the CST Particle Studio software is used to obtain the dimensional details.

INTRODUCTION

Electron gun is one of essential parts of electron accelerators. The role of electron gun is producing and shaping of current of electrons in a proper form for injection into accelerating fields. Electron guns can work in a continuous or pulsed mode. They used in various type of devices such as vacuum tubes and particle accelerators. There are different methods for production of burst of electrons in electron guns. Major methods are thermionic, photoelectricand electric field emissions [1]. Two important characteristics of cathode of electron guns are their emission continuity and uniformity [2,3]. The DC thermionic electron guns basically configured by cathode, Anode, focusing and control electrodes. They have constructed in different configuration that major of them are Triode and Diode [4]. In first steps for construction of cargo inspection systems in Iran, only task is production of gray images from inside of containers. Therefore, this systems work only in a single energy, and there is no necessity for application of triode type electron guns with grid and complicated method of brazing procedure. In this article, Design study and simulation of electron gun by 3D CST software was performed. Initial dimensions of electron gun were selected based onVTC6364 model of Varian Inc. Electron gun was designed for production of 350 mA peak current across 10 keV by 1 μperv output electron beam.

ELECTRON GUN PARAMETERS FOR CARGO INSPECTION SYSTEMS

Perveance is one of important characteristics of electron guns that was selected between 0.5 to 1 μperv in X-ray cargo inspection systems. For production of approximately 500 cGray dose rate in distance of one meter from X-Ray target with repetition rate of 100 pulses by 5 μs RF pulse duration from MG5193 Magnetron that is requirement of cargo inspection systems, we need to have electron guns by ability to production of 125 μA with 0.75 kW beam power in 6 MeV electron beam energy on X-ray target [5]. Dose rate for container cargo inspection is usually between 400 to 600 cGy per minutes. Also, electron gun should be able to produce of 300 mA. For improving quality of images and reduction of detectors cost based on their types, we decide to design electron gun for current equal to 375 mA. The spot size of electron beam on X-ray target should be lower than 2 mm. Based on beam dynamic considerations, the electron beam transverse dimension should be 0.7 of beam holes radius of accelerator cavity. Commonly, the child-Langmuir model is used for DC electron guns. Tungsten dispenser cathode that includes matrix porous tungsten impregnated by BaO, CaO, and Al_2O_3 was used for design and simulation in this study. The work function of this type of cathode in temperature of 1248 ºk is 2 eV. The beam current in simulations calculated in the waist of beam in Z_w position that is located in first accelerating cell.

ANALYTICAL CALCULATIONS FOR PRELIMINARY DIMENSIONING OF ELECTRON GUN

By application of Rodney-Vaughan method, the rough estimates of dimensions can be established for electrodes, and their shapes in electron gun. This method has commonly used for design of pierce type Diode thermionic guns [6]. In this method the anodic lenses formulas by Danielson, Rosenfeld, and Saloon have combined by transverse form of Langmuir-Blodgett equations. This can be used for medium perveance electron guns. Based on this method, we produced a MATLAB code by iterative method to converge to the final best results. In this calculation method, there are four input parameters, 6 direct output parameters and 3 dependent output parameters. Four input parameters that completely characterized the pierce type electron gun are its Voltage, V, output beam current, I, radius of beam waist, rW and cathode emission density, JC. The best geometry for thermionic pierce electron guns has represented in the Fig. 1.

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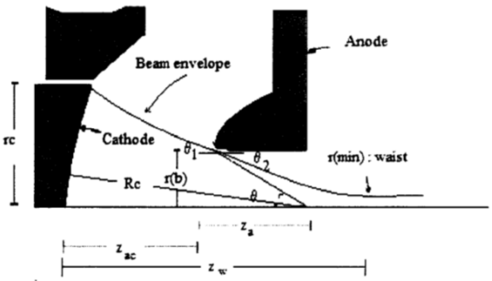

Figure 1: Geometry and essential parameters for average perveance pierce type electron guns.

The first estimate for cathode angle has obtained by θ=30 (μP) $^{1/2}$. In Rodney-Vaughan method, the essential assumption is that the slope of beam envelope before and after anode electrode should be equal, and follow the continuity criteria. Based on above assumption about continuity of beam envelope, after selection of first value for θ, the next values for this parameter should be selected based on $\theta=\theta\,(\tan\varphi_2/\tan\varphi_1)^{1/2}$ in each step for convergence of iterative method.

SIMULATION OF THERMIONIC ELECTRON GUN BY PARTICLE TRACKING SOFTWARE

In this study, the CST particle tracking was used for simulation and precise dimensioning of the electron gun. The rough schematic of electron gun is shown in Fig. 2. Also, in the Figs. 3a and 3b the isobar profile of electric field was represented in absence and presence of focusing electrode, respectively. The electron tracking results of electron gun in the absence and presence of focusing electrode was represented in Figs. 4a and 4b, and its importance was emphasized. The focusing electrode is Equipotential with cathode. For the best investigation of electron beam characteristics during DC acceleration, the phase space of electron beam was studied in two different positions. The phase space results from the CST were represented in Figs. 5a and 5b. In final step, the beam transverse profile was studied to ensure the quality of beam in the entrance position to RF filed acceleration and is represented in Fig. 6.

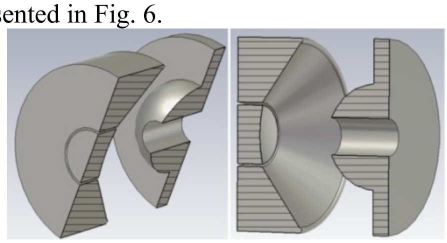

Figure 2: Schematic of thermionic electron gun.

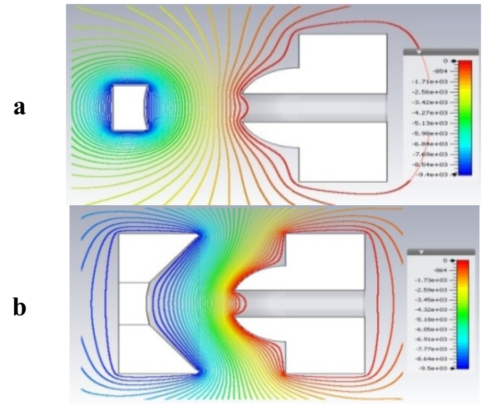

Figure 3: Electric field profile in a) absence of focusing pierce electrode, b) presence of optimized pierce focusing electrode.

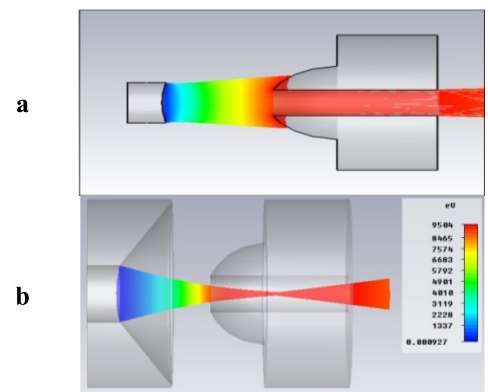

Figure 4: Particle tracking in a) electron gun without focusing, b) best optimized electron gun by proper focusing.

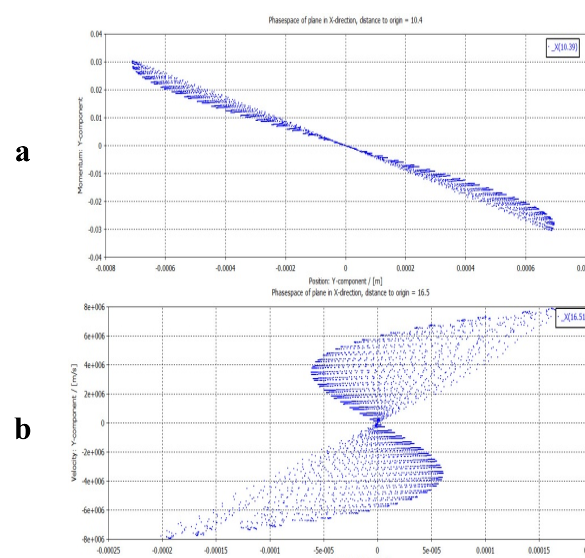

Figure 5: The phase space plot for electron gun in the position of a) 10.4 mm from cathode center, b) 16.511 mm from cathode center in the position of beam waist.

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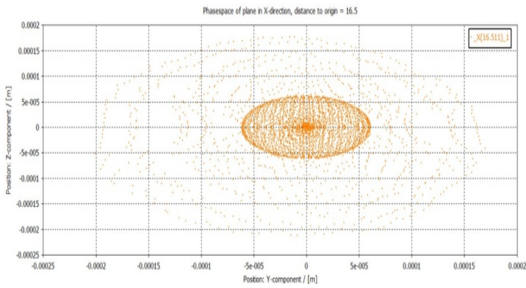

Figure 6: Electron beam transverse profile (SPOT SIZE) in beam waist at position.

RESULTS

According to the comparison between the experimental results presented in Reference 6 and the results of written code on some sample of electron gun, the Vaughan method has high error in the electron gun with very high and low perveance. But this method is very reliable and useful to have access to the initial dimension of the diode gun with medium perveance. Also, the simulation results by the CST code have very good agreement with the results of the Vaughan method. Electronic beam is much less than 2 mm at the beam waist; therefore, the generation of X-ray is essential on the target according to the survey on the phase space of the output electron beam from the electron gun at beam waist and the place that there is no anode field. Furthermore, the transverse profile obtained in the beam waist indicates the high efficiency of the electron gun at an accelerating particle in the first acceleration cavity cell. This leads to better output beam parameters of the acceleration cavity and increases the quality of the resulting image inside the container, Table 1.

Table 1: The Comparison between the Mentioned Simulated Parameter by the CST and Analytical Relations

Parameter (mm)	r_a	R_c	R_a	r_p	Z_p	Z_w
CST code	1.727	12.221	4.734	9	4.427	16.511
MATLAB (Vaughan)	1.5209	11.9565	5.55	9	4.427	17.716

CONCLUSION

The done simulations by the CST indicate the accuracy of the dimensions.These results confirm the CST code is applicable for the diode electronic gun design with medium perveance. On the other hand, the bottlenecks of the gun can be identified using the results obtained from the simulation and the parametric investigation of the dimensional effect on the quality of the output beam. Also, investigation on the analytical methods shows the accuracy and precision of the initial investigation of the electron gun dimension with the medium perveance.

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