DESIGN AND OPERATING EXPERIENCE OF TRIODE ELECTRON GUNS FOR INDUSTRIAL ELECTRON ACCELERATORS

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Abstract

The Accelerator and Pulse Power Division of BARC is presently constructing three industrial electron accelerators for radiation applications. a) a 500keV, 10 KW Cockcroft-Walton accelerator b) a 10MeV , 10kW electron linac and c) a 3MeV, 30kW DC machine. While the DC machines require an almost parallel beam with less than 1.0 degree divergence, the RF linac gun requires a 50keV, 2 ampere pulsed beam of low emittance. Using relativistic electron optics, including space charge effects, very simple triode gun designs with flat cathode, grid and anode apertures which fulfil these requirements and are easy to fabricate experimentally are described. Our operating experience with these guns are also described.

INTRODUCTION

The Accelerator and Pulse Power Division of BARC is presently constructing three industrial electron accelerators for radiation applications. a) a 500 keV, 10kW Cockcroft-Walton accelerator b) a 10 MeV , 10 KW electron linac and c) a 3 MeV, 30 KW DC machine. These accelerators, for irradiation purposes, require electron guns with special requirements. The two DC machines require an almost parallel beam with less than 1.0 degree divergence from the gun to enable the beam to drift through the accelerating modules. The linac requires a 50 to 80 keV , 1 to 3 ampere pulsed beam with a duty cycle of 0.1% . In this case a normalized emittance of the electron beam less than 100π mm mR MeV/c is required. Using relativistic electron optics, including space charge effects, very simple gun designs are presented which fulfill these requirements. A triode gun, having a flat cathode and parallel discs with apertures for the grid and anode have been used in the designs. The electron trajectories have been obtained using the SLAC gun design code EGUN [1].

GUN DESIGN

The triode gun is shown schematically in Fig.1. In the figure, C is the flat cathode, G the grid and A the anode. The diameter of the grid aperture is D_g and that of the anode is A_g. 'g' is the distance between the cathode and grid and 'a' the distance between the grid and the anode. The thickness of the grid and anode are t_g and t_a respectively. These parameters completely define the gun. All three, viz. the cathode, grid and the anode are separated by insulators and can take independent potentials.

Different values were tried in the program EGUN for the grid aperture D_g and the anode aperture A_g , the cathode-grid spacing 'g' and the grid-anode spacing 'a' in the program [2]. The electron beam profile obtained if the correct parameters are not used in the design is shown in Fig.1(a). By trial and error, the correct geometry has been obtained which results in a parallel beam as shown in Fig.1(b).

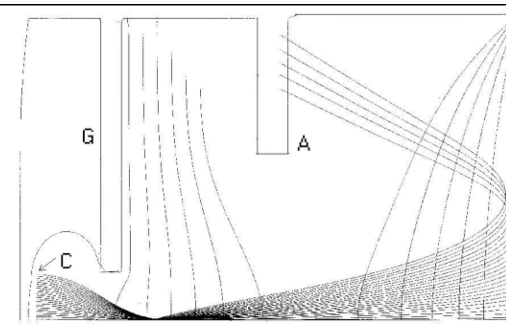

Figure 1(a): The effect on the electron trajectories if the proper apertures are not used.

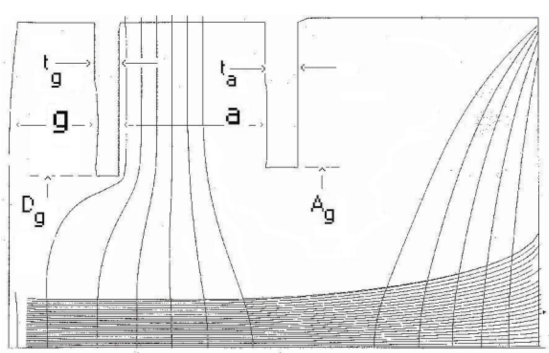

Figure 1(b): With the proper parameters, a parallel beam is obtained.

In our DC machines, the electron gun is followed by the NEC (National Electrostatic Corporation) accelerating tube section. The first three accelerating electrodes of the NEC accelerating tube were included in the EGUN program to see their effect on the electron trajectories. The first three electrodes were given potentials of +13kV, +33kV, and +53kV respectively . The results are shown in Fig.2(a).

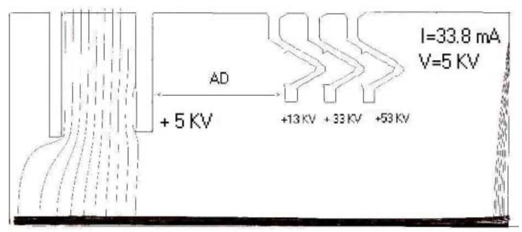

Figure 2(a): The first 3 accelerating electrodes are introduced in Fig.1(b),

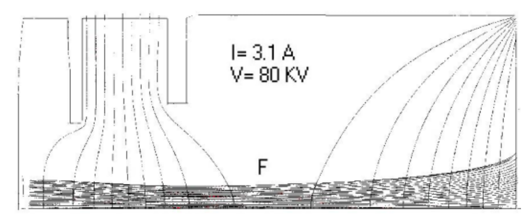

Figure 2(b): the gun geometry and electron trajectories for the linac gun.

Table 1: Parameters obtained in the triode gun design. (All dimensions in mm)

	For DC machines	For Electron Linac
Diameter of grid aperture, D_g	31.0	27.64
Diameter of anode aperture, A_g	34.0	34.14
cathode grid spacing, g	7.5	8.13
grid anode spacing ,a	13.8	13.82
grid thickness, t_g	3.0	2.44
anode thickness, t_a	5.0	3.25

The distance "AD" between the anode and the first accelerating electrode has been adjusted in the program so that the parallel nature of the electron beam obtained in the earlier design is not disturbed by the accelerating electrodes although the beam profile is not very sensitive to this parameter. The beam current from the gun can be controlled either by decreasing the heater power or by giving a negative bias on the grid G. For example, with a grid bias of -600V, the beam current can be reduced from 33.8mA to 16.61mA. The design obtained has been used for the 3 MeV machine also. In this case, the length of the accelerating columns is six times longer, and the requirement of a parallel or weakly focused beam becomes essential. The final design of the gun is given in Table 1.

For the linac gun, the beam characteristics required are different. A pulsed gun is required to deliver a 3 ampere peak current at about 80 KV with a duty cycle of 0.1%. The emittance of the gun required is less than 100 π mm mR MeV/c. A simple triode gun design was obtained as shown in Fig.2(b) and the parameters of this design are listed in Table 1.

EXPERIMENTAL RESULTS AND OUR OPERATING EXPERIENCE

The DC electron gun shown in Fig.1(b) was fabricated with the geometrical parameters in Table 1. The cathode used was a flat LaB_6 pellet of diameter 10 mm having a thickness of 1 mm [3]. With a heater power of 180 watts, the gun gave a current of 30 mA for a anode voltage of 6KV. The emittance was measured by placing concentric rings of decreasing aperture at a distance of 10 cm. from the anode. The beam was found to be almost parallel, as expected.

The RF electron gun shown in Fig.2(b) was fabricated according to Table 1.Again, the cathode was a flat LaB_6 pellet with a diameter of 10 mm and thickness 1 mm.[4] The pellet is housed in a rhenium cup and is housed in a cylindrical tantalum heat shield of 25 mm diameter. The heater coil is made up of a tungsten wire of 0.5 mm diameter also housed in a tantalum heat shield and placed close to the LaB_6 pellet. The grid and anode electrodes are made of stainless steel. With a heater power of 400 watts, (23.5V, 17A), the gun gave a peak current of 1.4A for an anode voltage of of 50 kV. The voltage was applied at a pulse rate of 400 pulses per second with a pulse width of 10 microseconds. Using the $V^{3/2}$ law, this current will scale to 2.83A at 80keV, which is close to the design value of 3.1A obtained in the computer program. The beam emittance was measured by measuring the beam diameter and divergence with the help of a segmented graphite faraday cup placed at a distance of 15cms from the anode. The emittance measured is 57mm mR MeV/c. The anode current is less than 6% of the beam current. This current is mainly due to the low energy electrons, back-scattered electrons from the faraday cup and secondary electrons. This current will reduce when the beam is injected into the linac cavity because the faraday cup will not be in the path of the beam.

CONCLUSIONS

Simple triode gun designs have been obtained for industrial electron accelerators. These guns use flat LaB_6 cathodes, parallel discs with apertures for the grid and anode, and are easy to fabricate experimentally. Our operating experience with the guns are described. The experimental results agree well with the computer calculations. The parameters of the guns are listed, and with proper scaling, the gun designs can be used for other electron machines where similar beam characteristics are required.

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