Design and Simulation of High Power RF Modulated Triode Electron Gun

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Abstract: In this paper the high power RF modulated triode electron gun as an electron generator of electron accelerators are studied. We designed a triode electron gun with low emittance and high perveance where a grid and a cathode are electrically coupled to a grid DC voltage and also RF signal in order to produce bunch of electrons. The calculation and simulation result showed that in this scheme the feeding of RF power to the cathode-grid assembly is critical for the proper operation of the triode electron gun. The optimum output beam energy and beam current suitable for high power electron accelerator are obtained in this electron gun.
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1. Introduction

The RF electron accelerators require intensive electron beams with small losses during acceleration. The beam quality at a RF electron accelerator exit is mainly determined by electron gun because the electrons are injected into an accelerator structure from an electron gun so electron gun configuration is very important. In thermionic electron gun the electrons emitted from the cathode are accelerated and focused through the beam hole in the anode. The cathode is usually at ground potential and anode connected to positive high voltage the current in the beam for a given anode to cathode voltage is largely determined by the ratio of the cathode-anode spacing and the cathode diameter [1]. In order to vary the beam current over a wide range without varying the anode to cathode voltage use control grid between the cathode and the anode. Figure1 shows in a triode electron gun structure.

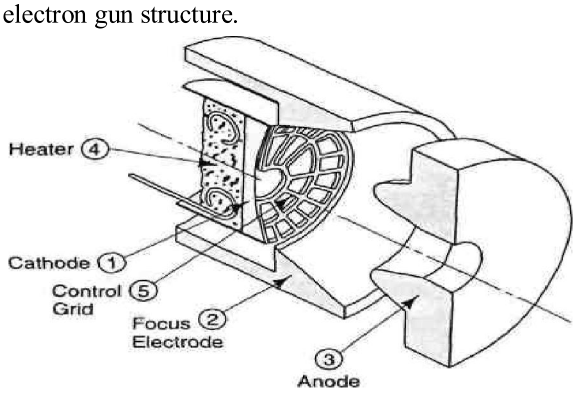

Figure 1: The schematic of triode electron gun

There are many types of cathodes in use for various gun applications that are basically divided into two different types namely, oxide cathodes and dispenser cathodes. The oxide cathode can be operated at relatively low temperature but the maximum current density is about 1 A/cm^3, so the oxide cathodes are used in low current applications. The dispenser cathodes are generally, higher current density at the cathode and less susceptibility to gas poisoning. But the operating temperature for dispenser cathodes is much higher than for oxide cathodes. Tungsten dispenser cathodes are used almost exclusively in microwave devices, since they are capable of high current densities with long lifetimes [2-3].The distance between the cathode and grid should be small enough to provide a reasonable required [4]. The grid is formed to control the electron beam current from cathode the use of grid permits the beam current to be controlled with a smaller voltage depended to cathode-anode voltage by high voltage. The current from such a gun will be given by equation (1).

$$I_{(A)} = P \times V^{3/2} \qquad (1)$$

Where V is voltage between cathode and anode and P is a geometrical function called perveance [4]. In the design of electron gun must be care about average current, Peak current, Pulse length, emittance (beam quality), perveance, Reliability (lifetime), Beam energy, Physical size and cost. The thermionic guns produce an electron beam with high energy, small emittance moreover economic and compact configuration in comparison with other electron guns [5-8].

2. Materials and methods

The Y824 cathode provided by Eimac as the dispenser cathode which can provide higher current density with good homogeneity electron emission (see figure 2) chosen for this investigation[9] .In the pulsed-grid configuration electrons emitted from the cathode are held on the cathode by applying a negative bias of sufficient voltage on the grid [6]. The grid and cathode are coupled to a DC grid voltage source and also to a RF signal. The DC voltage source places the grid at a first potential and the RF signal places the grid at a second potential selected to produce bunch of electrons. The RF signal is received a signal from a RF source or feedback from acceleration cavity of accelerator. The RF signal is attenuated or phase shifted before it is provided to the grid of the electron gun.

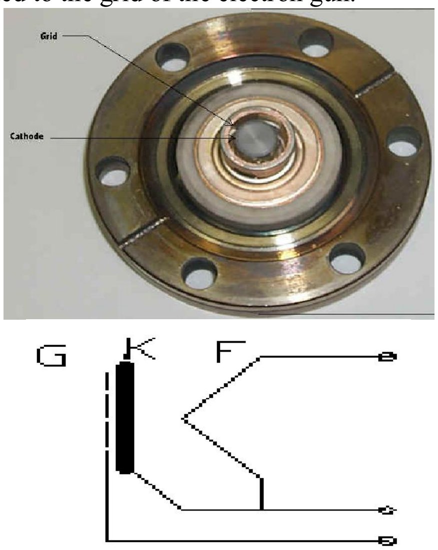

Figure 2: The photo of Y824 electrodes

The grid bias is selected by grid in depended with the magnitude of the RF signal provided by RF source. The RF signal provided to the grid within electron gun from RF device is attenuated and shifted in phase to ensure that bunches of electrons produced within electron gun appropriately generated an in phase with the RF provided to accelerator. The RF signals to cathode and grid connection using an appropriately sized coaxial transmission line coupled between RF source and variable attenuator and variable phase shifter. The connection from RF source to grid and cathode is preferably selected to be impedance matched at the RF frequency. The magnitude of electron bunches or current of beam can be adjusted by modifying the magnitude of grid bias or the magnitude of the attenuated and phase shifted RF signal. Furthermore, the phase of these electron bunches can be modified by adjusting delay line to ensure that electronic current produced by electron gun is in phase with the RF accelerating signal. Figure 3 shows the layout of designed triode RF modulated electron gun for high power electron accelerators. .In this scheme RF power collected by pickup loop extending into the lower part of the RF acceleration cavity is used to modulate the electron beam from the electron gun so that the electrons are mainly released by the electron gun when the RF phase in the RF cavity is right for their acceleration. This RF power from the pickup is feed to the grid-cathode through an adjustable phase shifter that allows for the phase of the electron bunches leaving the electron gun to be adjusted with respect to the accelerating field inside the RF cavity. Where, the phase shifter is a mechanical adjustable coaxial delay line called trombone. The inductive L_1, L_2, L_3 and also variable C_5 ,C_6 are for impedance matching. The $R_{1(50\ \mathrm{OHM})}$ is a damping dissipated RF power resistor.C_3,C_4 (100PF, 50KV) are RF capacitors cooling loop that isolate RF signal out of DC high voltage.

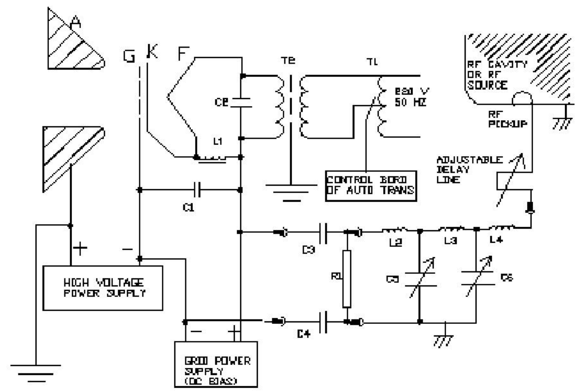

Figure 3: The scheme of designed RF modulated triode electron gun

The L_1, and C_1 considering cathode to grid capacitor and RF frequency range (from 20MHz to 5GHz) are resonating circuit of course the cathode to grid capacitor is not real component also L_1 is a strip line PCB inductive. For three electrode of gun need three power supplies. The filament power supply heats the cathode to the temperature required for electron thermo emission where the maximum temperature is 1800º K , so the maximum possible filament reference voltage that can be set is 12V and the minimum voltage is 6 V and maximum filament current is 3A.The voltage of filament can chosen AC or DC signal. In this design used the AC signal provided by T_2 and T_1.The T_2 is a 220VAC to12VAC isolation transformer and T_1 is a autotransformer that placed at input the isolation transformer that can be change the filament voltage by control board of step motor connected to autotransformer. The grid power supply required grid voltage to control the beam current is typically 2-5% of the anode-to-cathode voltage. The mean grid voltage around the instantaneous voltage will oscillate because of the coupling to the RF signal. The high voltage power supply is a DC variable voltage and current that the maximum voltage is 50kV. The high voltage power supply structure is very important because the voltage of power supply determined the energy of electron beam output of gun and also the maximum electron beam current limited by current of high voltage Power Supply and also stability of electron beam depended on the high voltage power supply.

Calculation of RF power

The electric field in the RF gun is calculated with the equivalent circuit model shown in figure 4. In this circuit the RF gun is expressed as LCR resonate circuit .where C is given by the vacuum capacitance value of the distance between cathode and grid will be given by equation (2).

$$C=\varepsilon_0 A/D \qquad (2)$$

Where, A is cathode area, D is distance between cathode and grid, and ε_0 is vacuum permittivity .The grid cathode is consisted of the diode region which acts as a capacitive load combined with a resistance. The area of cathode and grid, and the distance between them In Y-824, are 2 cm^2 and 190 μm [9].

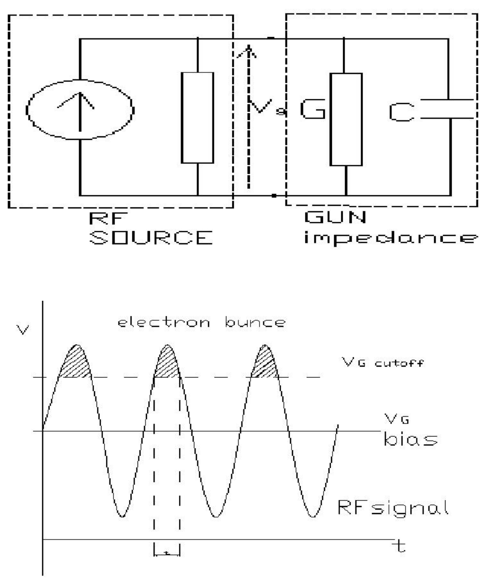

Figure 4: Equivalent electron gun circuit and graph of RF signal and grid voltage

The diode region can be represented by a parallel combination of a capacitance, C and an unknown conductance G. The capacitance of Y-824 is about 10 PF. For the Y-824 maximum beam current is 50mA and maximum amplitude of RF signal on grid-cathode is 400 V peak to peak [9].Of course the actual value in the presence of the electron beam will be different from this, but not much if we operate the diode with the current level well below the space charge limited value. The G is determined by the resistive beam loading effect and represents the power dissipation due to the electron beam. For Y-824 in f=2.998 GHz, the input impedance of grid cathode is 53Ω. And the grid cut off voltage is -130V that the grid no accelerated electron and fully grid turn on voltage is 90 V. While the gun is fully turned on the RF signal received from RF source to place the gun in a fully turned on state from cut off state, the required RF power which must be provided to grid from variable attenuator is:

$$P=V^2 / X =90^2 /53=152.83 \text{ W}$$

The graph in figure4 depicting the relationship between the RF signal applied to grid and the grid source voltage generated by grid bias. For RF modulated electron gun the electron emission from the cathode takes place during the accelerating positive half cycles of RF field. The grid cut off voltage is less than the average voltage of the RF signal. In order to generate individual bunches of electrons in phase with the RF signal input into accelerator. The RF power provided to grid from variable attenuator must be greater than the voltage swing of the grid from -Vg the point at which the grid is turned off to +Vg the point at which the grid is fully turned on. Generally an electron bunch width of approximately 10% of the wave period is suitable for use with pulse linear accelerators. And 25% of the wave period for CW electron accelerators.

Electron Gun Simulations

In this investigation the CST particle code used for simulations of RF modulated triode electron gun. The view of electron gun simulated on CST work spacing software shown in figure5.The electron gun runs for the different electrical parameter and different geometry by changing the anode cathode gap distance and other dimensions where the length and angle of the nose and focus electrode. This modification was considered due to concern about electrical breakdown between the tip of the nose and cathode. For the reduced gap distance the outputs show some increase in the divergence of the extracted beam, an effect which turned out to be much greater for the measured case. For this dimensions and following high voltage tests for anode cathode voltage up to 50 kV so the output electron beam energy of this electron gun will be 50keV.

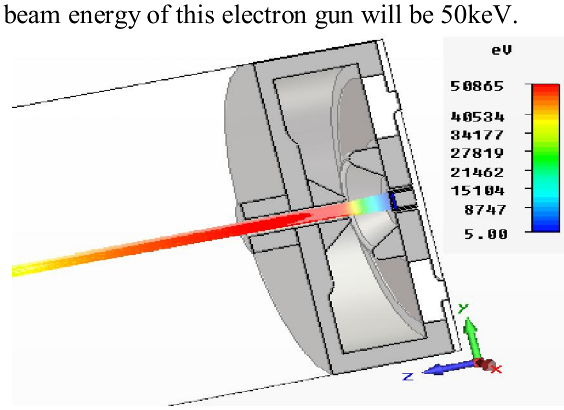

Figure 5: The 3D electron gun simulation view on CST

3. Results and Discussion

After calculation and measured by simulation the characteristics of the designed electron gun achieved that are shown in this part. In figure 6 as can be seen the perveance grows with the decrease of the cathode to anode distance.

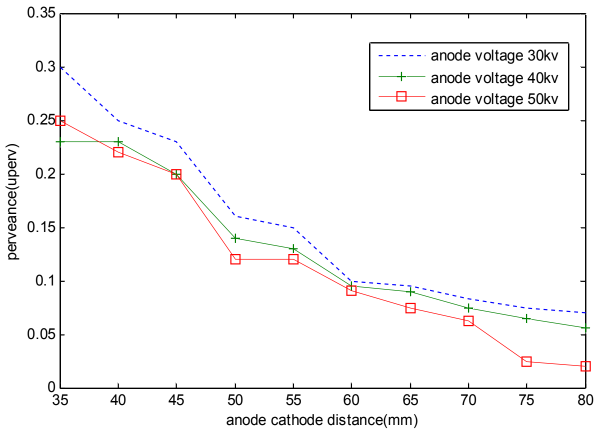

Figure 6: Perveance on several anode- cathode distance and voltage

The perveance grows with the increasing of the electrode focus angle and for the same electrode focus angle and the beam current follows the same behavior the perveance grows with the decreasing of the cathode-to-anode voltage. The beam current grows with the increasing of the control grid bias voltage it can be observed in figure 7.

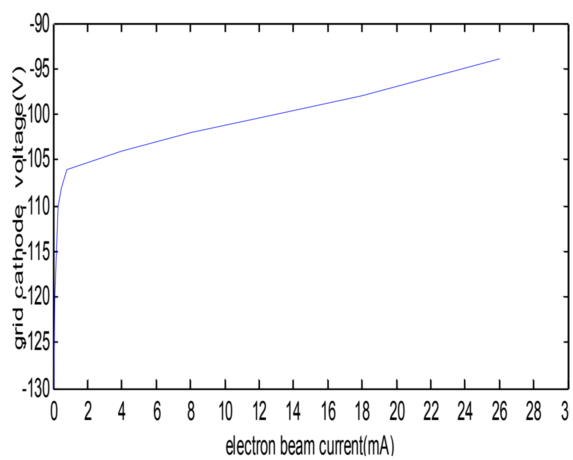

Figure 7: Beam current and control grid voltage

For the same control grid bias voltage, the beam current grows with the decreasing of the anode-cathode distance. Figure 8 shows the relation between RF phase and grid voltage and current of beam.

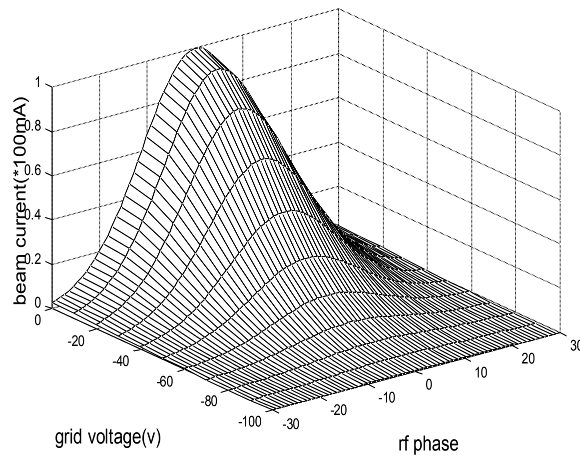

Figure 8: The depended of RF phase and grid voltage and beam current

The beam emittance measured, as a function of beam Current and anode voltage. The emittance of beam in several anode cathode voltages is shown in figure 9.

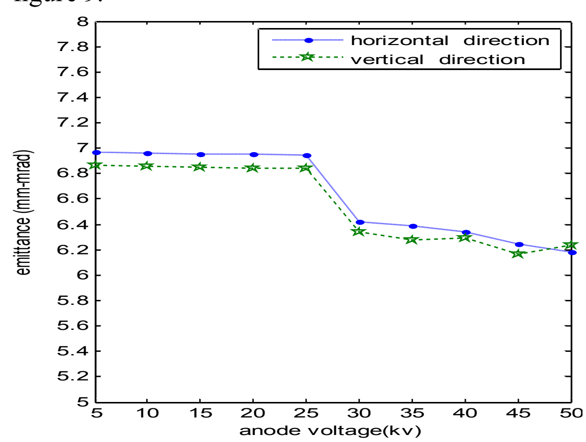

Figure 9: Beam Emittance and several cathode-anode voltages

According this measuring can be see that for a same beam current the Emittance decrease with increasing anode cathode voltage and that, for a given voltage, the Emittance appears to increases with increasing current.

4. Conclusion

The result shows, the designed triode electron gun can generate electron bunches as an electron injection system for a variety of RF electron accelerator. This scheme can be use in wide band of frequency by changing of lump elements(C,L) value in resonate circuit .The optimum output electron beam energy of this gun is 50keV with 25mA beam current. The low Emittance, high perveance, high current and energy are advantages of this electron gun which is suitable for high power industrial electron accelerators.

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