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Development of Electron Guns for Linacs and DC Accelerator

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Abstract. Electrons guns for RF linacs and DC Accelerators are designed and developed at Electron Beam Centre (EBC)/APPD/BARC. Planar geometry grid and Pierce geometry grid configuration diode and triode guns with LaB6 cathode are developed. The cathode assembly consists of cups and heat shields made out of Tantalum and Rhenium sheets. The cathode assembly and the electron guns are tested on a test bench for beam characterization. The paper presents the development of the electron guns.

1. Introduction

The Accelerator and Pulse Power Division of BARC has developed three industrial electron accelerators for radiation applications - a) a 500 keV Cockcroft-Walton accelerator (at BRIT, Vashi), b) a 10 MeV RF linac at EBC, c) a 3 MeV DC Accelerator at EBC; and one 9 MeV RF Electron Accelerator at ECIL, Hyderabad, for cargo scanning. A 6 MeV RF electron accelerator is under development at EBC and will also be used for cargo scanning applications.

These accelerators 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. A 5 kV thermionic DC electron gun is used as injector for the two accelerators. The RF linac structure is similar for the 10 MeV, 9 MeV and 6 MeV linacs and so a 50 keV thermionic pulsed electron gun is used as injector for them with the beam current between 500 mA to 1 A.

For irradiation of the products, the accelerated beam (using accelerating tubes or linac structures), passes through the magnetic sweep scanner, scan horn and is brought into air through a titanium foil of 25 μ - 50 μ m thickness, for irradiating the products. The beam size is typically 20 mm diameter just outside the titanium foil. For cargo scanning application, the accelerated beam (using linac structures) passes through a focusing solenoid coil and is focused to a size of < 2 mm diameter on a Tungsten target to generate the x-rays.

2. Gun Design

2.1. Gun for DC Accelerator

A triode gun, having a flat cathode and parallel discs with apertures for the grid and anode has been designed. The electron trajectories have been obtained using the SLAC gun design code EGUN [1] and also with CST Particle Studio 'figure 1'. A Pierce geometry gives a beam current of 26 mA at 5 kV and with a beam size of about 3.5 mm diameter 'figure 2'.

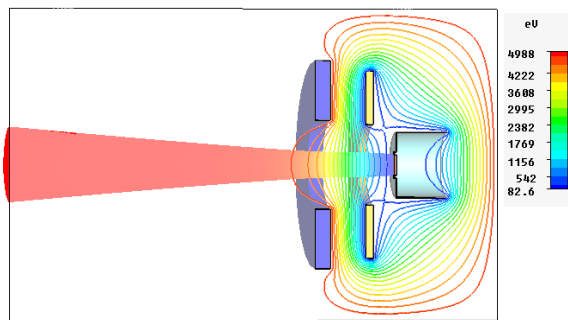


Fig. 1. A CST Particle Studio simulation of Planar Diode Gun at 5 kV and 48 mA with perveance $1.4 \times 10^{-7} \text{ A/V}^{3/2}$. A beam size of 12.7 mm diameter is obtained at 19 mm from anode.

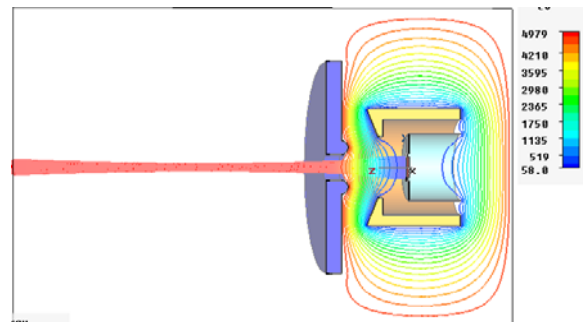


Fig. 2. A CST Particle Studio simulation of Pierce Diode Gun at 5 kV and 26 mA with perveance $7.54 \times 10^{-8} \text{ A/V}^{3/2}$. A beam size of 3.3 mm diameter is obtained at 19 mm from anode.

2.2. Guns for RF Accelerators

A triode electron gun operating in diode mode (cathode-grid shorted) was designed. Two different configurations were tried; (a) planar configuration with the cathode as flat disc and parallel discs with apertures for the grid and anode 'figure 3', (b) Pierce grid configuration with cathode as flat disc, and grid as a shaped electrode and a shaped anode 'figure 4'.

The 10 MeV accelerator at EBC, and the 9 MeV accelerator at ECIL, Hyderabad, used planar electron guns with 8 mm and 6 mm cathode diameter beam emission areas respectively. The cathode for these guns is a LaB6 pellet of dimensions 10 mm dia. x 1 mm thk.

It is known that a converging or collimating beam of smaller beam diameter at the linac input will improve the capture efficiency and hence the transmission of the beam. For the 9 MeV ECIL Linac, the output beam should be of diameter $\leq 2 \text{ mm}$ at the Tantalum target. To achieve this, a Pierce gun design approach was attempted.

A design goal of beam current of 500 mA at 40 kV with a beam size less than 3.5 mm and using an 8 mm cathode diameter for beam emission was decided. To design the electron gun, simulations were conducted using the CST Particle Studio. It is a Diode Type thermionic Gun. It incorporates a Pierce geometry Grid, also known as Focusing electrode. Studies were conducted to obtain good beam quality, beam size and beam current by varying (a) Planar anode inner diameter, (b) Pierce angle of the Grid, (c) cathode-anode gap, (d) cathode-grid gap, (e) anode shapes.

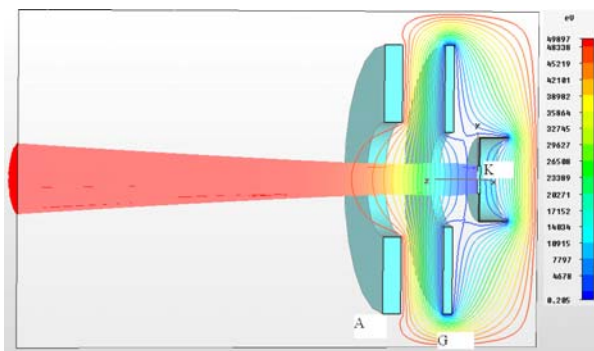


Fig. 3. A CST Particle Studio simulation of Planar Diode Gun at 50 kV and 1.154 A with perveance $1.03 \times 10^{-7} \text{ A/V}^{3/2}$. A beam size of 13.7 mm diameter is obtained at 49 mm from anode.

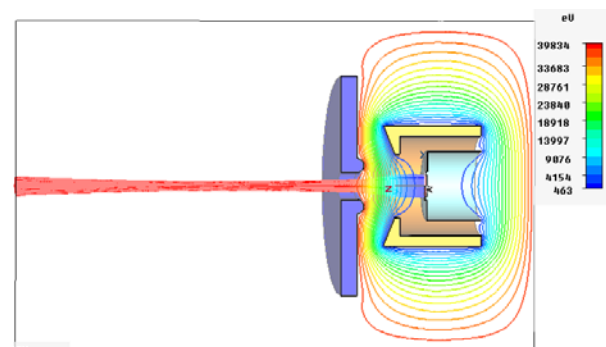


Fig. 4. A CST Particle Studio simulation of Pierce Diode Gun at 40 kV and 598 mA with perveance $7.53 \times 10^{-8} \text{ A/V}^{3/2}$. A beam size of 3.0 mm diameter is obtained at 49 mm from anode.

The simulations resulted in the required 40 kV Diode electron gun with Pierce Focusing electrode (grid) of ID 23 mm and angle $\sim 67.5^\circ$, to give ~ 600 mA of beam current and having a diameter of less than 4 mm at a distance of 100 mm from the cathode. The anode is also shaped with aperture of 10 mm. The cathode-grid distance is 9 mm and the anode-cathode distance is 25 mm. The gun is operated in the space charge region.

3. Choice of cathode

The cathode is a LaB6 Pellet of dia. 10 mm and thickness 1 mm. The Lab6 pellet is indirectly heated by a coil filament made out of Tungsten wire. A filament power of 270 W raises the temperature of the LaB6 pellet enough to emit the required current of 500 mA at 40 kV.

LaB6 cathode is chosen because it has low thermionic work function 2.66 eV, high melting point 2715°C , high current density, it can work in vacuum of the order of $10^{-6} - 10^{-5}$ mbar. LaB6 offers the capability of long life and orders of magnitude less sensitivity to air exposure than conventional dispenser cathodes. In the case of mild cathode poisoning resulting in lower beam emission, it is observed that after conditioning the cathode to higher filament power a few times, there is an improvement in the output beam current.

4. Cathode assembly

The cathode pellet is housed in a 0.05 mm thk. rhenium cup which is then housed in an outer cylindrical tantalum cup of 25 mm diameter and 0.15 mm thickness. The pellet is held in place by two thin strips of rhenium which are spot welded to the tantalum cup. The opening of the rhenium and tantalum cups decides the beam emission area of the cathode to be of diameter 8 mm or 6 mm.

The Lab6 pellet is indirectly heated by a coil filament made out of tungsten wire of diameter 0.5 mm and consisting of 9 turns with coil diameter of 5 mm 'figure 5'. The gap between the tungsten wire and the pellet is about 1.5 mm. The radial heat shields consist of two cylindrical heat shields of tantalum (0.15 mm thk.) and having diameters 20 mm and 25 mm. The inner cylindrical Ta heat shield also has two Tantalum discs as heat shields in the axial direction. The inner and outer cylindrical heat shields are connected by Ta strips (2-3 mm wide, 0.15 mm thk.). The outer cylindrical heat shield is connected to the ceramic base by 4 Ta strips (2-3 mm wide, 0.25 mm thk.) and a SS 304 cup. The filament is spot welded to two tantalum rods (diameter 2.5 mm) which are rigidly supported on a ceramic base. These Ta rods have ceramic sleeves on them to electrically isolate them from the heat shields. The ceramic base sits on the SS 304 cup. One of the Ta rods is shorted to the outer cylindrical heat shield to maintain same potential of the filament and the cathode.

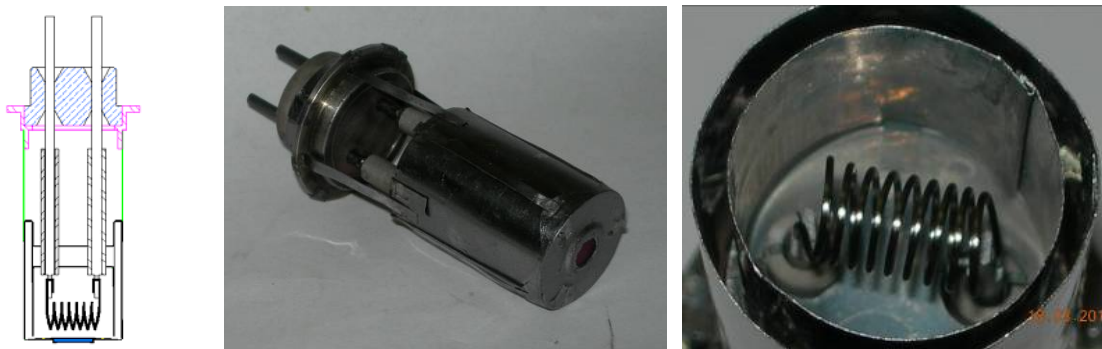


Fig. 5. Schematic of cathode assembly, fabricated cathode assembly and filament with heat shields.

5. Gun fabrication and testing

The grid and anode electrodes are made of SS 304. The grid is supported on 4 rods connected to the top metallic flange. This flange also has 4 no. of 14 kV, 56 A capacity HV ceramic feedthroughs. Two feedthroughs are connected to the filament and remaining two is spare. The anode is isolated from the

HV top flange by a ceramic tube of OD 160 mm and length 200 mm. The grid is isolated from the cathode assembly by using MACOR discs. The sealing for vacuum is obtained using Indium wire gaskets or rectangular Viton gaskets, which are placed between the ceramic tube and the corresponding metallic flanges. Initially the anode flange was placed below the ceramic insulator tube. Later a gun chamber of height ~ 180 mm consists of two DN 100 ports and one DN 63 port was added. The anode flange is connected below the gun chamber and the sealing is with an aluminium wire gasket (0.5 mm diameter). Recently, the size of the gun is redesigned to a smaller one with the ceramic insulator of size OD 120 mm and length 150 mm and the gun vacuum chamber of height 140 mm. Also, the anode is connected to a pipe connected to an intermediate flange and not at the end of the gun vacuum chamber. The grid is supported on a pipe 'figure 6'. All SS 304 components of the electron gun were electropolished before assembly. Cathode and grid are shorted externally. The cathode, grid and anode are separated by insulators and can take independent potentials. The cathode, grid and anode are aligned using Aluminium and SS jigs.



Fig. 6. Comparison of electron gun sizes. The right one is the gun for the 6 MeV linac.

The high voltage testing of the guns were carried out on a test bench, using a 50 kV, 10 μ s pulsed solid state gun modulator, a 70 kV HV Isolation Transformer for filament heating and a diffusion pumping system 'figure 7'. The vacuum levels were of the order of 2×10^{-5} mbar. With cathode conditioning, the beam current improved in the 2nd and 3rd runs. The effective capacitance between cathode and anode with cathode grid shorted was ~ 37 pF. For the planar configuration, the beam sizes were measured on graphite plate and also with segmented graphite faraday cup placed at various distances from the anode. For the Pierce configuration (8 mm cathode), the beam spot sizes were measured on graphite plate and as puncture impressions on four 12 μ m aluminium foils followed by an aluminium collector; kept at various distances (48 mm, 55 mm, 62 mm, 69 mm and 74 mm) from the anode. At the filament power of 264 W and extraction voltage of 40 kV, a beam current of 500 mA was extracted and a beam size of ≤ 3.5 mm diameter was obtained 'figure 8', 'figure 9' and 'figure 10'. With the 6 mm cathode, a beam current of 350 mA was achieved at 50 kV extraction voltage, 270 W filament power, 2×10^{-5} mbar vacuum and beam spot size ≤ 3.5 mm. The test bench based on diffusion pumping system is replaced by a TMP based system 'figure 7'.

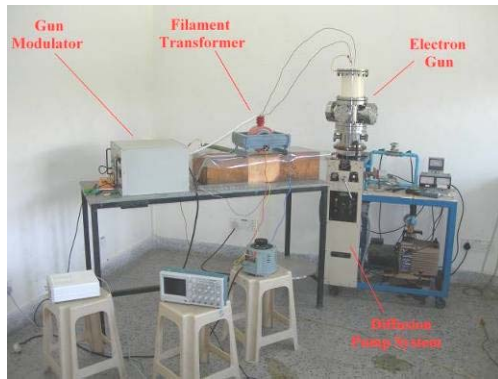


Fig. 7. Electron gun on DP based test bench (left) and on the TMP based test bench (right).

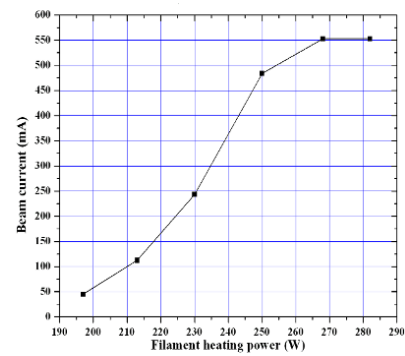
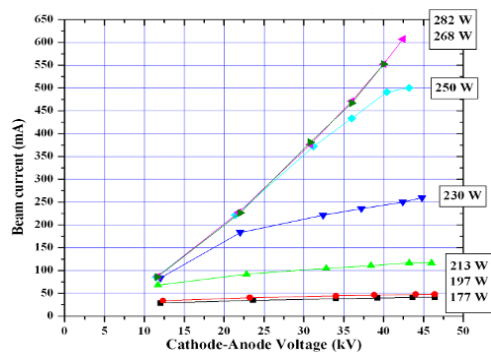


Fig. 8. Beam characteristics (left) and variation of beam current at 40 kV (right) of Pierce Gun with, 8 mm diameter cathode.

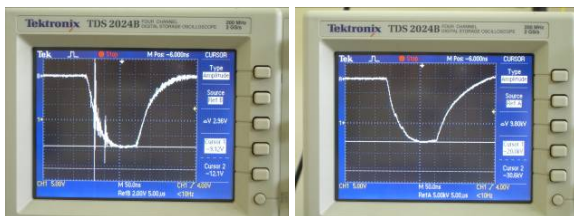


Fig. 9. Beam current waveform 542 mA (left) and Extraction voltage 41.6 kV (right).



Fig. 10. Beam spot sizes on Al foils and Al collector disk.

The results of tests on various gun configurations are summarised in table 1 below.

Table 1. Results of various electron guns.

Type of Gun	Cathode diameter (mm)	Extraction voltage (kV)	Beam current (mA)	Filament power (W)	Beam diameter (mm)
Planar	8	50	850	295	≤ 13
Planar	6	50	250	231	≤ 5
Pierce	8	40	500	264	≤ 3.5
Pierce	8	50	520	285	≤ 3.5
Pierce	6	50	350	270	≤ 3.5
Pierce	8	66	800	300	----

6. Problems and Solutions:

With the cathode assembly within the ceramic isolator tube of the gun, it was observed that the ceramic tube was getting heated up to 80 °C, when the filament power was 280 W. Frequent leaks occurred on the locally developed gun ceramic tube. Leaks were temporarily sealed by a vacuum sealant, which opened up with time. The indium wire gasket for the ceramic-metal seal was replaced by VITON gasket. To improve vacuum in the gun and avoid heating of the ceramic, a 3-port gun vacuum chamber was incorporated. The cathode heating is within this chamber and the ceramic is less heated. There was a case of reduction in beam current due to cathode poisoning, which was then cleaned, activated and put back. Once, filament broke while replacing the contaminated cathode pellet.

While cathode conditioning at 280 W on test bench, due to accidental slippage of the viton gasket, the complete cathode assembly got heavily contaminated and had to be discarded 'figure 11'. In one case, the filament got shorted to the Rhenium strips holding the LaB6 pellet. Due to this there was a large flow of current and the Rhenium strip got removed 'figure 12'. We have incorporated Aluminium wire gasket (0.5 mm diameter) for the vacuum sealing between the collar of ceramic isolator and the SS. A leak rate of 5×10^{-10} mbar l/s is achieved.

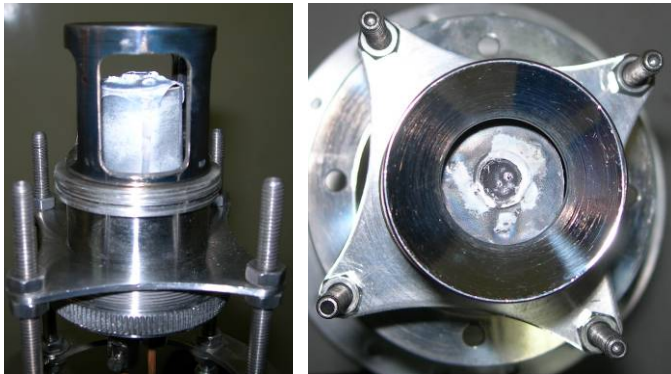


Fig. 11. Heavy contamination of cathode assembly after accidental exposure to air, during cathode conditioning.

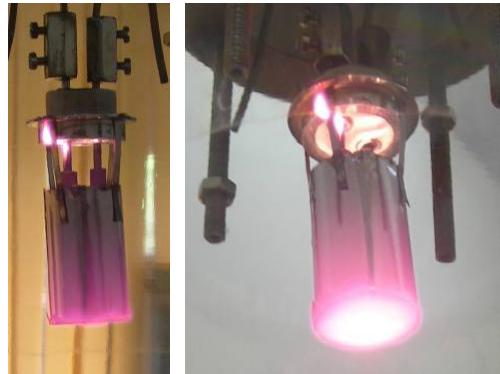


Fig. 12. Large filament current flow (30 A) through the Ta rod and Ta strip due to internal shorting of the filament with the body.

7. Conclusions:

Simple triode gun designs have been indigenously designed, developed, tested and successfully operated both for the planar and Pierce configurations. These guns use planar LaB6 pellet as cathode, which can operate well in vacuum of the order of 5×10^{-6} mbar. Efforts are being made to optimize the filament heating and studies are being done to understand the effect of magnetic field of the filament on beam optics of the gun.

References

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