# OPERATIONAL EXPERIENCE AND MODIFICATIONS IN ELECTRON GUN FOR THE 10 MeV RF LINACS

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*Abstract*

The 10 MeV Industrial RF Electron accelerator at EBC, Kharghar, is commissioned and is delivering a beam power of 3 kW. Another similar 9 MeV RF Electron accelerator is operational at ECIL, Hyderabad and will be used for cargo scanning. A 50 keV thermionic pulsed electron gun is used as injector for both these RF linacs. The gun is capable of delivering a maximum current of 1 A. This paper presents the gun testing, the mechanical modifications done in the gun and the grid biasing experiments, to achieve maximum output current from the linac.

## DESIGN ASPECTS

The RF linac structure is same for both the linacs and so is the injector. For the EBC and ECIL linacs, the required gun currents are ~ 1 A and ~ 500 mA.

A triode electron gun operating in diode mode (cathode-grid shorted) was designed. Two different configurations were tried; (a) planar configuration with the cathode, grid and anode as flat discs and (b) Pierce grid configuration with planar cathode and shaped anode. The cathode is a LaB6 pellet of dimensions 10 mm dia. x 1 mm thk. The beam emission area is taken as a diameter of 8 mm and 6 mm of the cathode, respectively for the two guns at EBC and ECIL. The cathode, grid and anode are separated by insulators and can take independent potentials.

LaB6 cathode is chosen because it has low thermionic work function 2.6 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. The gun was simulated with EGUN [1] and recently with CST Particle Studio [2].

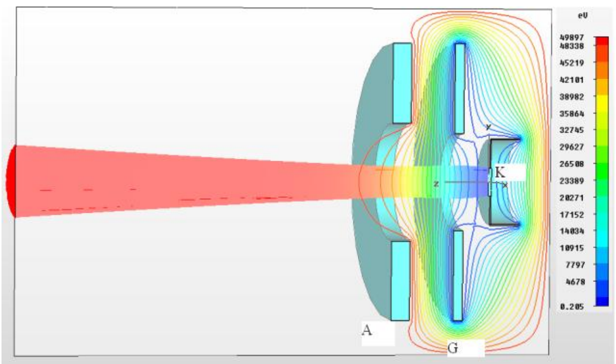


Fig 1: A CST Simulation of 50 kV, 842 mA Planar Diode Gun. A is the anode, K the cathode, and G the grid.

## GUN FABRICATION AND TESTING

The cathode pellet is housed in a rhenium cup which is then housed in an outer cylindrical tantalum heat shield of 25 mm diameter. The opening of the rhenium cup decides the beam emission area of the cathode to be of diameter 8 mm or 6 mm. The heater coil made up of a tungsten wire of 0.5 mm diameter is housed in one inner cylindrical tantalum heat shield (of diameter 20 mm) and placed close to the $LaB_6$ pellet. The inner cylindrical Ta heat shield also has two Tantalum discs as heat shields on the upper part. The outer cylindrical heat shield is connected to the ceramic base by 4 Ta strips and a SS 304 base. The filament is spot welded to two tantalum rods 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 base. This forms the cathode assembly (fig. 2).

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 dics. The sealing for vacuum is obtained using Indium wire gaskets, which are placed between the ceramic tube and the corresponding metallic flanges. All SS 304 components of the electron gun were electropolished before assembly. Cathode and grid are shorted externally.

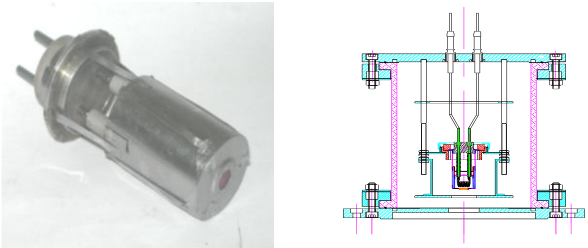

Fig 2: The cathode assembly and schematic of the gun.

The high voltage testing of the guns were carried out on a test bench [2], using a 50 kV, 10 µs pulsed solid state gun modulator, a 70 kV HV Isolation Transformer for filament heating and a diffusion pumping system. The vacuum levels were of the order of 2 x $10^{-5}$ mbar. The results of tests on various gun configurations are summarised in table 1 below. The planar gun (8 mm) characteristic is given in fig 3.

Table 1: Results of various electron guns.

| Gun | $K_{DIA}$ (mm) | $V_{KA}$ (kV) | $I_{GUN}$ (mA) | $P_{FIL}$ (W) | Beam dia. (mm) |
|---|---|---|---|---|---|
| Planar | 8 | 50 | 850 | 295 | $\leq 13$ |
| Planar | 6 | 37 | 316 | 261 | $\leq 5$ |
| Pierce | 8 | 40 | 500 | 264 | $\leq 3.5$ |
| Pierce | 8 | 50 | 520 | 285 | $\leq 3.5$ |
| Pierce | 6 | 50 | 350 | 270 | $\leq 3.5$ |

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, by keeping an aperture flange, 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, the beam spot sizes were measured on graphite plate and as puncture impressions on four 12 µm aluminium foils followed by an aluminium collector; kept at various distances from the anode [2].

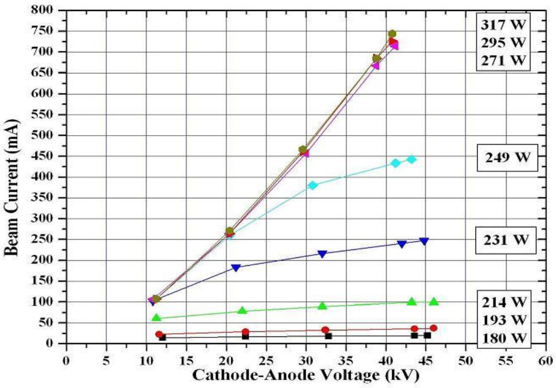


Fig. 3: Variation of beam current with extraction voltage, at different filament powers (planar configuration, 8 mm).

The gun with planar configuration of 8 mm was connected to EBC linac. The gun with planar configuration of 6 mm which was implemented at ECIL is now replaced with the Pierce configuration of 6 mm [2].

## PROBLEMS AND SOLUTIONS

To achieve better beam current at output of EBC linac, the distance between the gun and linac was reduced from 700 mm to 45 mm, by removing the components in between them. 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 two 70 l/s TSIPs pump the gun region to 1 x $10^{-7}$ mbar. A water cooled aperture (9 mm diameter) flange was connected between the gun and linac to avoid damage to the mouth of the linac.

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. It was also observed that the linac output beam current magnitude varied to more than 20% its max value at the rate of line frequency. DC heating of gun filament was implemented by incorporating a rectifier and filter (choke) in series, which resulted in steady beam current. The ECIL electron gun is placed horizontally, hence for mechanical stability; it has 4 Delrin supporting rods across the ceramic gun tube.

## GRID BIASING EXPERIMENTS

The grid biasing was done by using a resistive voltage divider. The gun modulator output was taken across a series combination of a low value resistor $R_1$ (0.5 kΩ to 2 kΩ) and $R_2$ (25 kΩ); $R_1$ being connected to the HV terminal and $R_2$ to the Gnd. The HV terminal was connected to the grid, GND terminal to anode. The tapped voltage was connected to the cathode. The output beam current was measured for various negative grid bias voltages from 1 kV to 3 kV. It was found experimentally that the grid bias voltage of 2 kV with an accelerating voltage of 50 kV gave a good beam performance (82 mA) as compared to other bias voltages. Further with $R_1$ as 1 kΩ and $R_2$ as 50 kΩ, a maximum beam current of 165 mA was achieved when the gun was operated at ~67 kV.

### *Further Experiments at EBC*

Various experiments were conducted to check the effect of RF power, injection voltage, gun filament power and PRF on the beam current. Beam current increase is ~25% with increase in RF power from 1.5 MW to 3 MW. Beam current increase is ~50% with increase in E-Gun injection voltage from 25 kV to 50 kV. Beam current increase is ~65% with increase in Gun Filament power from 200 W to 250 W. With PRF increase from 50 Hz to 250 Hz, beam current increases by 30%.

### *ECIL Gun*

With the 6 mm planar gun, the output beam current was 64 mA at 65 kV gun voltage. Using the Pierce gun of 6 mm, a maximum beam current of 105 mA at 65 kV gun voltage was achieved. Grid biasing experiments resulted in maximum beam current of 146 mA with a positive grid bias of 3.8 kV and $V_{KA}$ = 66.8 kV.

## 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 $LaB_6$ pellet as cathode, which can operate well in vacuum of the order of 5 x $10^{-6}$ mbar.

## REFERENCES

[1] Arvind Jain et al, “Design and operating experience of triode electron guns for industrial electron accelerators,” Proc. APAC 2007, WEPMA011.

[2] D. Bhattacharjee et al, “Design and Development of a Pierce Electron Gun”, this proc.

[3] CST Particle Studio Software.