Electron gun design for a hollow-beam klystron

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Table 1: Target hollow-beam electron gun parameters

Quantity	**Value**
Voltage	108 kV
Current	177.5 A
Focusing magnetic field	0.06 tesla
Cathode inner radius	5.28”
Cathode outer radius	5.46”
Cathode area	39.18 cm^2
Average current density	4.53 A/cm^2
Drift tube radius	6.00”
Vacuum chamber radius	8.00”

Trak was employed to design an electron gun to drive a hollow-beam klystron[1]. The target requirements are listed in Table 1. The gun operates in a strong solenoid magnetic field. Figure 1 shows a detail of the cathode-anode gap in the baseline geometry. Focusing electrodes at the top and bottom of the cathode structure intersect the emission surface at the Pierce angle of 22.5°. The flat surfaces smoothly transition to a filleted edge with $R = 0.5$ in. The anode tip has the same radius. The goal of the calculation was to find the following quantities:

The cathode-anode gap spacing to achieve the target current.

The transverse momentum content of the extracted beam.

The maximum electric field magnitude $|\mathbf{E}|$ on the electrode surfaces.

I made a series of runs, adjusting the anode position to achieve the target current. The calculations included self-consistent space-charge forces and the effects of beam-generated magnetic fields. With the cathode surface at $z = 0.0$” and the anode tip at $z = 1.72$”, the total current was 177.4 A. The space-charge-limited cathode current density varied from 4.439 A/cm^2 at the inner edge to 4.725 A/cm^2 on the outside. Figure 2 shows the profile of the extracted beam. A radial oscillation was superimposed on the motion with axial wavelength equal to the single-particle betatron wavelength in the uniform magnetic field, λ_b. The radial beam motion was an inevitable consequence of the strong negative-lens behavior of electric fields at the entrance to the drift tube.

[1]The focusing magnet for the klystron case study is described in the tutorial **PerMag Design of a Focusing Magnet for a Hollow-beam Klystron**. The biased-collector design is reviewed in the tutorial **Trak Design of a Single-stage Collector for a Hollow-beam Klystron**.

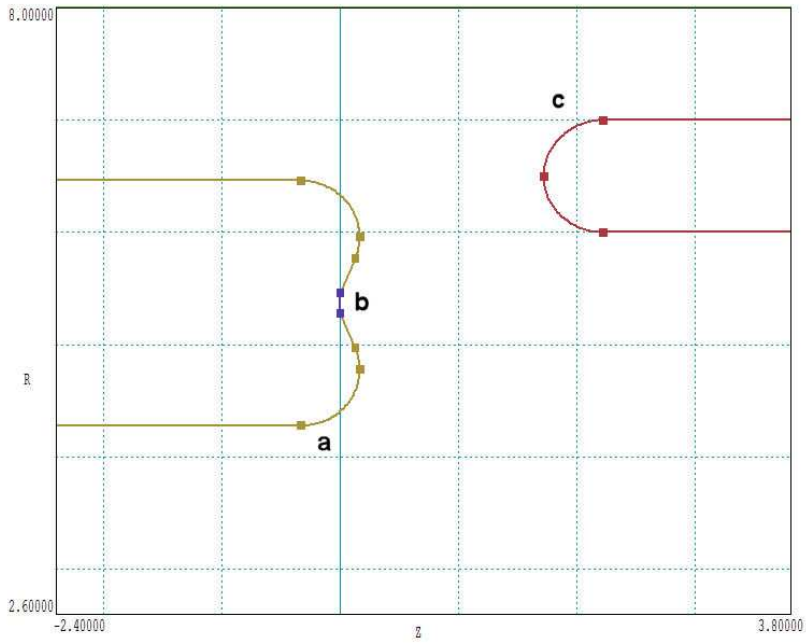

Figure 1: Detail of vectors to define electrode surfaces. *a*) Focusing electrodes. *b*) Emission surface. *c*) Anode.

The amplitude of the radial displacement was $\Delta r \cong \pm 0.095$", comparable to the radial beam thickness of 0.174". The corresponding maximum radial angle of the beam is given by:

$$|r'| = \frac{2\pi \Delta R}{\lambda_b}. \tag{1}$$

Inserting values, Eq. 1 implies that $|r'| = 0.124$. Therefore, the transverse momentum of electrons in the beam is about 12.4% of the axial momentum. The only feasible method to reduce the oscillation is to include an inner grounded electrode at the drift tube entrance. It would be necessary to support the electrode from upstream, complicating the design of the gun.

Figure 3 shows a plot of $|\mathbf{E}|$ on the cathode and anode surfaces. The peak value of 5.355 MV/m occurs on the outside of the focusing electrode. The high value was mainly a result of the small gap (1.00") between the outer surface of the focusing electrode and the vacuum chamber. Electric field levels on other surfaces of the cathode assembly were generally less than 3.0 MV.m.

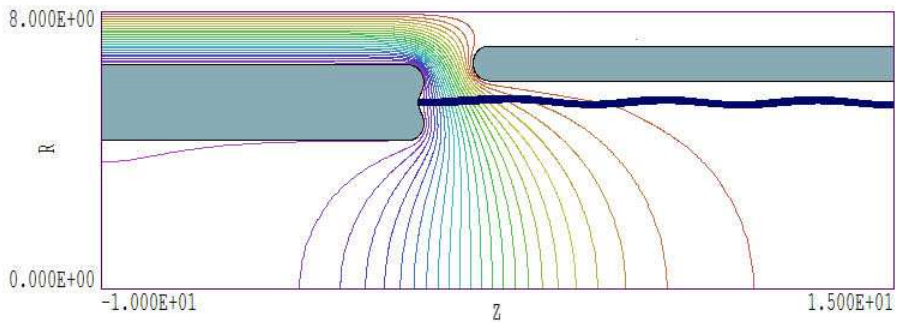

Figure 2: Model electron orbits and equipotential lines of the calculated electric field (dimensions in inches).

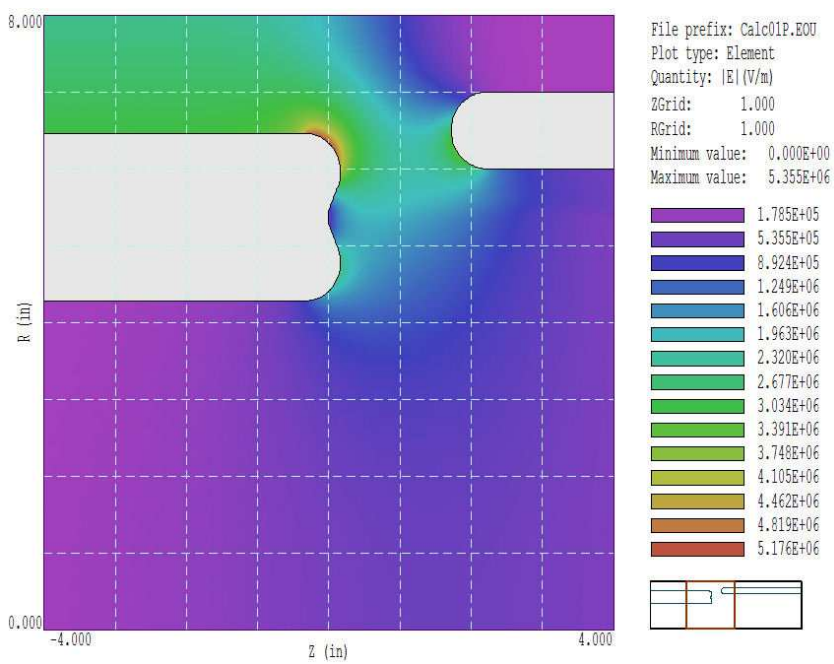

Figure 3: Plot of $|\mathbf{E}|$, detail near the gun acceleration gap.

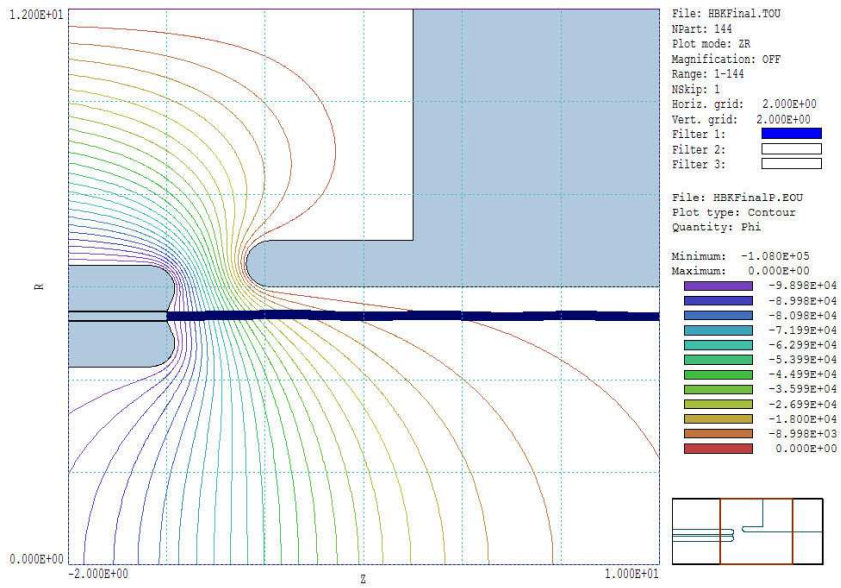

Figure 4: Geometry of the final gun design for the hollow-beam klystron. Applied magnetic field: 1000 G.

To complete the design, I made two refinements:

> Inclusion of a radial gap of width 0.025" between the annular cathode and the inner and outer focusing electrodes.
>
> Addition of a connection between the anode tube and the grounded vacuum chamber at a distance of about 3.000" from the cathode.

The accelerating voltage was 108 kV and there was a uniform applied magnetic field of 1000 G. To resolve the interelectrode gap, I used a fine radial mesh spacing (0.005") in the cathode region. The number of computational electrons was doubled to 144 for better accuracy and improved plots.

Figure 4 shows the electrode geometry, equipotential lines of the self-consistent electric field and particle orbits. With radial oscillations, the beam in the transport region covered the range 5.271" $\leq r \leq$ 5.497". The radial width of the beam was 0.176". Therefore, the amplitude of the oscillations was about 0.025". For a betatron wavelength of 2.7", the fraction of transverse momentum was about 5.8% and the fraction of transverse energy was about 0.34%.

The modifications of geometry made it necessary to change the spacing between the cathode and anode to maintain the beam current at 177.5 A. The current was equal to the target value when the distance between the cathode surface and the anode tip was 1.616". Figure 5 shows a plot constructed from

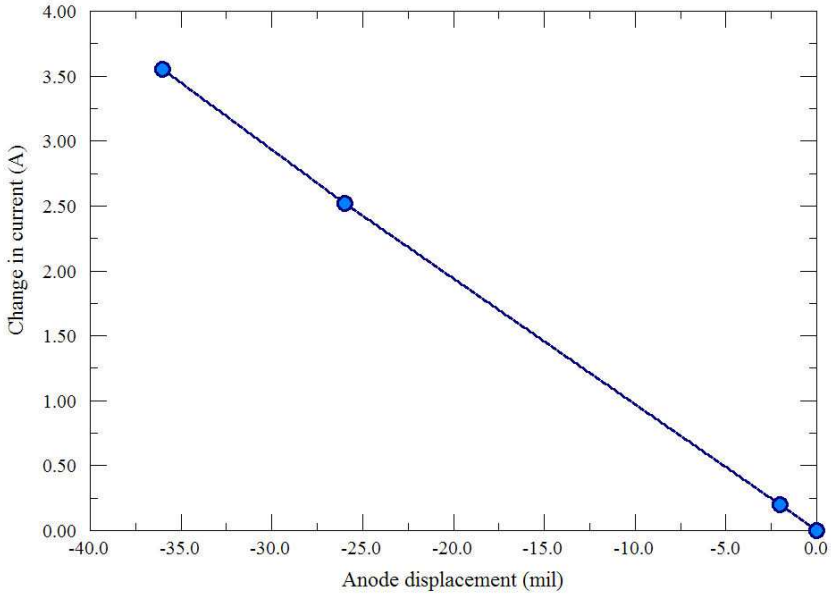

Figure 5: Variation of current with decreasing cathode-anode spacing.

data generated during the search. The figure illustrates how total current changes with the anode position. The horizontal axis equals the spacing minus 1.616" and the vertical axis is the total current minus 177.5 A.

The peak value of electric field on the outer radius of the outer focusing electrode was 4.283 MV/m. Figure 6 is a magnified view of model electron orbits showing how the radial oscillations are induced by the strong radial electric fields near the anode tip. Finally, Fig. 7 plots current density as a function of radius near the cathode.

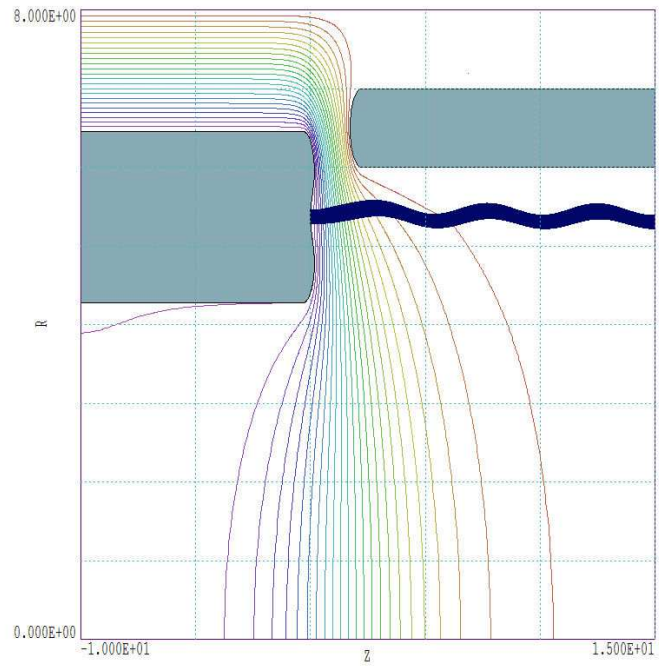

Figure 6: View of the model electron orbits with strong magnification in the radial direction. (Dimensions in inches.)

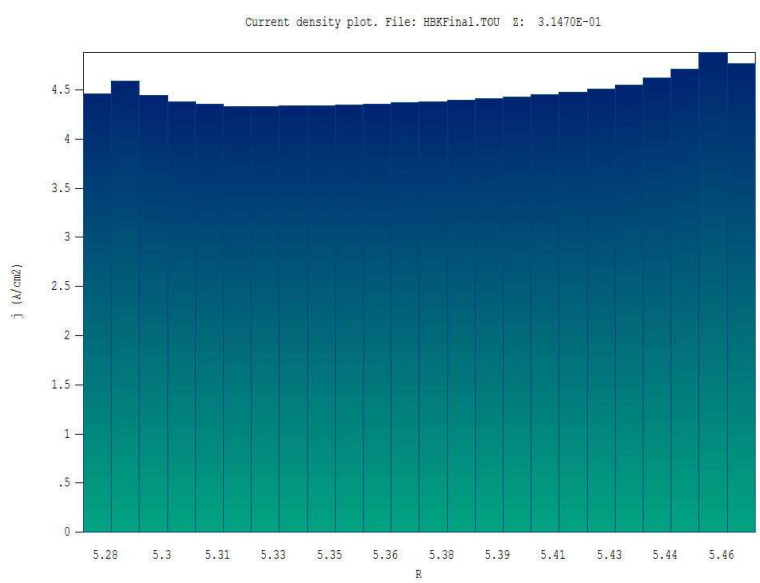

Figure 7: Radial variation of current density of the beam near the cathode. Horizontal axis in inches, vertical axis in A/cm^2, The rounding at the inner and outer edges in a characteristic of the cloud-in-cell method used.