Electron guns – modeling the gap between the cathode and a focus electrode

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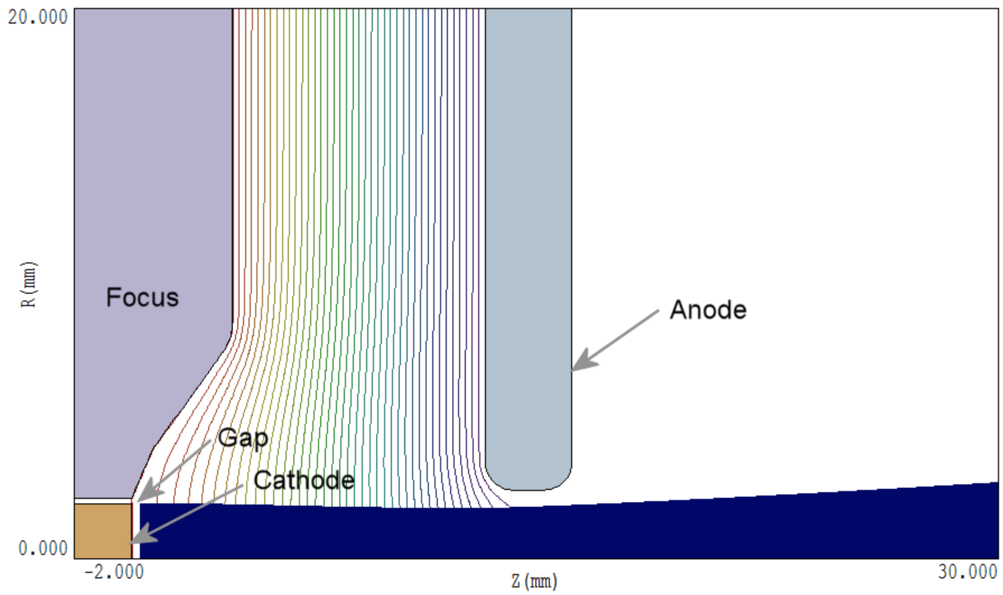

Figure 1: Two-dimensional **Trak** model of a high-current electron-beam gun. Dimensions in mm.

High-current electron-beam guns typically have the geometry of Fig. 1. The flat or concave cathode operates in the space-charge limited mode. A shaped focusing electrode compensates for the effect of beam-generated electric fields to generate a parallel or converging beam. The heated cathode is composed of a high-temperature material like tungsten. The focusing electrode is composed of a more easily-machined material like molybdenum. The narrow gap between the components prevents conductive heat loss and melting of the focusing electrode.

It is relatively easy to set a narrow gap in a two-dimensional **Trak** mesh. The task is more challenging for three-dimensional **OmniTrak** meshes, where large numbers of elements lead to long run times. One purpose of this tutorial is to demonstrate how to a create a cathode surface with good facets by optimizing the fitting logic for parts of the cathode assembly. A second activity is to confirm that **Trak** and **OmniTrak** generate almost identical results for a test geometry.

The benchmark electron gun of Fig. 1 has a flat cathode with 2.0 mm radius. The applied voltage on the cathode and focusing electrode is -54 kV. The focusing electrode shape gives some beam convergence in the acceleration gap and a modest divergence after passing through the extraction aperture. The combined effects of the focusing electrode profile and the 0.2 mm gap give a beam with good current-density uniformity and low emittance. A **Trak** calculation gives current density $j_e = 16.4 \pm 0.8$ A/cm^2 at the cathode

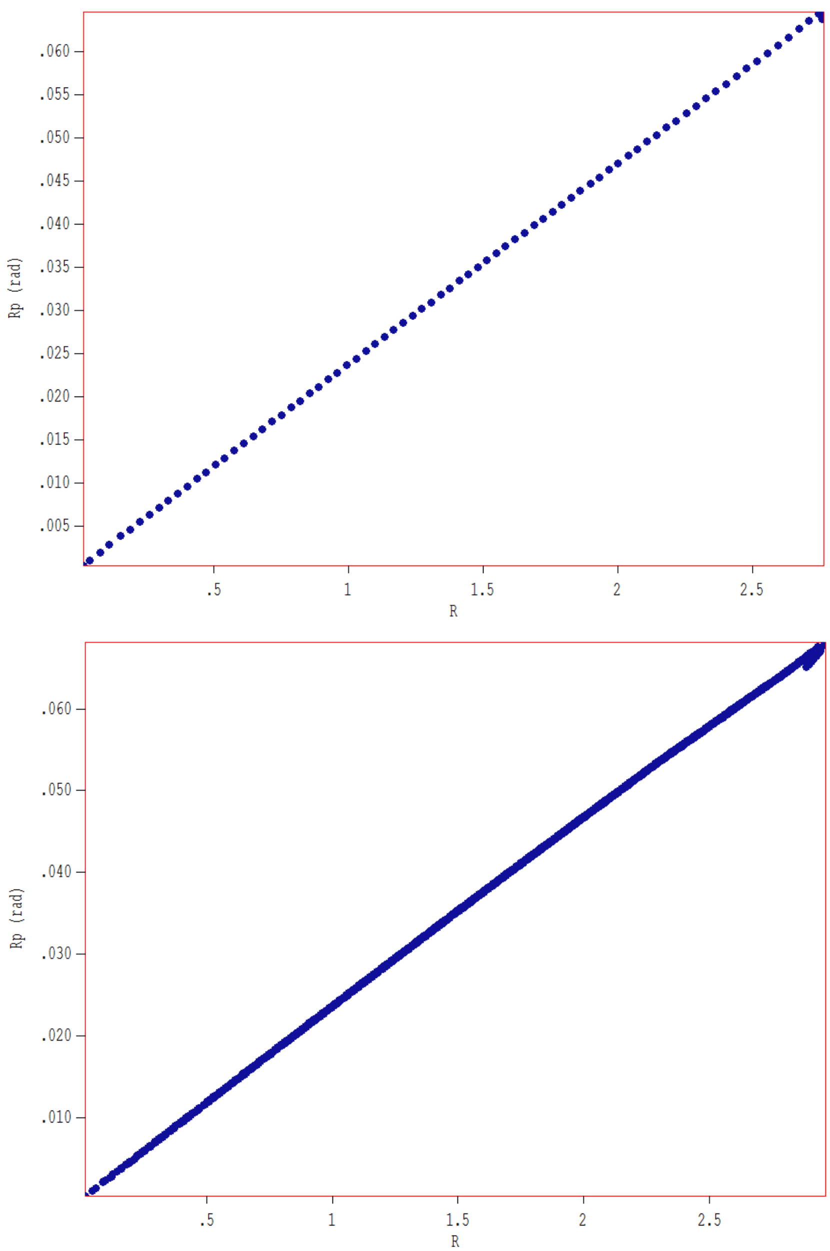

Figure 2: Phase-space distributions (r, r') for the extracted beam at $z = 30.0$ mm. Top: **Trak** calculation. Bottom: **OmniTrak** calculation.

and total current 2.062 A. The top plot in Fig. 2 shows the phase-space distribution (r, r') at $z = 30.0$ mm. Over-focusing at the edge is relatively small. The accompanying input files for the **Trak** calculation have the prefix `GAPDEMO2D`.

The input files for the **OmniTrak** calculation have the prefix `GAPDEMO3D`. To minimize run time, the calculation is performed in the first quadrant of the x-y plane ($x \geq 0.0$ mm, $y \geq 0.0$ mm) with symmetry boundaries at $x = 0.0$ mm and $y = 0.0$ mm for both the fields and electron trajectories. The element sizes near the emission surface have the same dimensions as those in the **Trak** calculation ($\Delta x = \Delta y = 0.050$ mm, $\Delta z = 0.125$ mm). The mesh had 1.63 million elements. Figure 3 shows a slice view of the mesh geometry near the cathode surface. The cathode assembly is formed from three parts:

> A turning to represent the cathode, with outline specifications taken from the **Trak** input file. The part is associated with the `CATHODE` region (fixed potential equal to -54 kV) in the **HiPhi** and **OmniTrak** calculations.
>
> A turning to represent the focusing electrode, again with outline vectors from the **Trak** input file (`FOCUS` region with -54 kV fixed potential).
>
> A turning to represent the gap, with inner radius 2.0 mm and outer radius 2.2 mm. As shown, the shape extends a few elements past the cathode surface. The part is assigned to the `GAP` region, which has the same physical properties in the electrostatic calculation as the `VACUUM` region ($\epsilon_r = 1.0$).

I employed two techniques to ensure that the facets on the cathode surface were flat and well-formed. The first is simple: pick a foundation mesh that minimizes the work that **MetaMesh** must perform. In this case, I made sure that a foundation element boundary occurred at $z = 0.0$ mm, the position of the cathode surface. Here is the complete mesh specification in z:

```
ZMesh
    -2.00  -0.25   0.250
    -0.25   0.50   0.125
     0.50  30.00   0.250
End
```

If the element boundary were at an arbitrary position ($z \neq 0.0$ mm), then it would be necessary for **MetaMesh** to perform thousands of needless operations to shift facets.

The second technique is to plan fitting operations carefully. Fitting of a part is controlled by the commands:

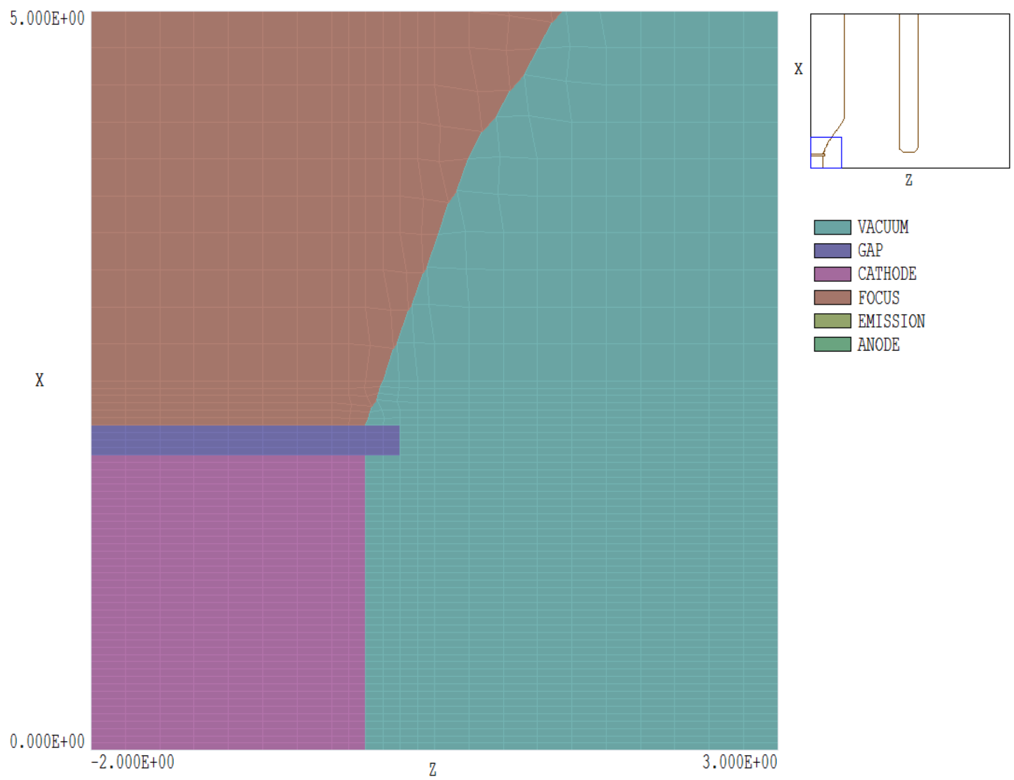

Figure 3: Detailed cross-section of the mesh for the OmniTrak calculation in the plane $y = 0.0$ mm.

```
SURFACE REGION RegNo
SURFACE PART PartNo
```

In response to the first command, **MetaMesh** collects all facets of the part that are shared with elements that have region number *RegNo*. The program them shifts the facet nodes toward the theoretical outer surface of the part. These steps are critical to successful fitting and are worth repeating:

> **MetaMesh** collects all facets of the currently-analyzed part that are shared with elements that have region number *RegNo*.
>
> The program shifts nodes of the facet collection toward the theoretical boundary of the currently-analyzed part.

The second command form has similar function, except that **MetaMesh** picks facets adjacent to elements with part number *PartNo*.

Let's consider how fitting works for the cathode assembly. Here is a ummary of fitting commands for the contiguous parts of the cathode assembly:

```
PART
  Region: Gap
  Name: Gap
  Surface Region Cathode
  Surface Region Focus
END
PART
  Region: Cathode
  Name: Cathode
  Coat Vacuum Emission
END
PART
  Region: Focus
  Name: Focus
  Surface Region Vacuum
END
```

To begin, note the order of parts. The dielectric part appears before parts with fixed potential. With this order, any shared nodes are assigned the region number of the `CATHODE` or `FOCUS` parts, giving the correct fixed-potential condition on the electrode surfaces.

I will point out some features of the fitting list and then explain how they work. The `GAP` part has its own region assignment and contains commands for fitting to both the `CATHODE` and `FOCUS`. The `CATHODE` part has no `SURFACE` command, while the `FOCUS` part has a single command for surfaces in contact with elements of the `VACUUM` region. The order is chosen to ensure that facets on the front and side faces of the cathode are shifted only in the x-y plane, not in z. Here is the logic:

> Fitting parts with sharp edges (like a cylinder or the annular shape of the `GAP`) involves ambiguity. Should the facet be moved toward one edge or the other? This is the reason why I extended the `GAP` past the `CATHODE` and `FOCUS`. The end is far enough away to ensure that **MetaMesh** moves facets to the inner and outer cylindrical surfaces when fitting the `GAP`. In other words, node displacements are purely in the x-y plane.
>
> There are two reasons why there is no `SURFACE` command for the `CATHODE`: 1) nodes on the front surface already lie at $z = 0.0$ and 2) the side surfaces have already been positioned through fitting of the `GAP`.
>
> The inner surface of the `FOCUS` has already been set by fitting of the `GAP`. The single `SURFACE` command specifies that front-surface facets (adjacent to `VACUUM` elements) should be adjusted. The `GAP` was defined as a separate region to ensure that only nodes on front surface facets are moved.
>
> The `COAT` command for the `CATHODE` resets the region number of the nodes of facets adjacent to `VACUUM` elements. The new region number has the emission property in **OmniTrak**. Because the `GAP` has its own region number, only facets on the front face of the `CATHODE` are set as emitters.

Figure 4 is a three-dimensional view of the completed cathode assembly. Facets on the front cathode face are flat and well-formed. The **OmniTrak** calculation gives a quadrant current of 0.512 A, corresponding to a total current 2.046 A. The bottom plot of Fig. 2 shows the phase-space distribution at $z = 30.0$ mm for 5024 model electrons. A comparison at this distance provides a sensitive test of correspondence. The distributions are almost identical. Beam is slightly larger in the **OmniTrak** calculation.

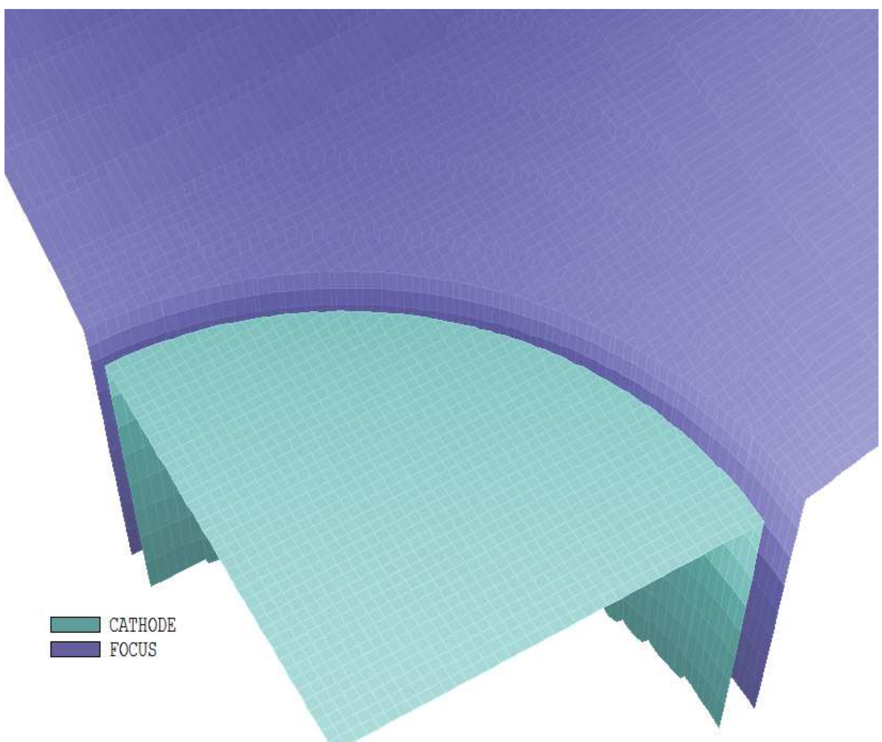

Figure 4: Three-dimensional view of the completed cathode and focus electrode.