**Figure 2.1**. Working environment of the **OmniView** postprocessor for **OmniTrak**

# Chapter 2. Walkthrough example

## 2.1. Geometry and mesh definition

This chapter reviews an application example to give a quick overview of **OmniTrak** procedures and advanced features. Figure 2.1 shows the geometry – electrons from a ribbon cathode are extracted through a circular aperture. The example is a good exercise of the three-dimensional capabilities of the code. We want to find space-charge limits on current and the distribution of the extracted beam. We shall assume uniform
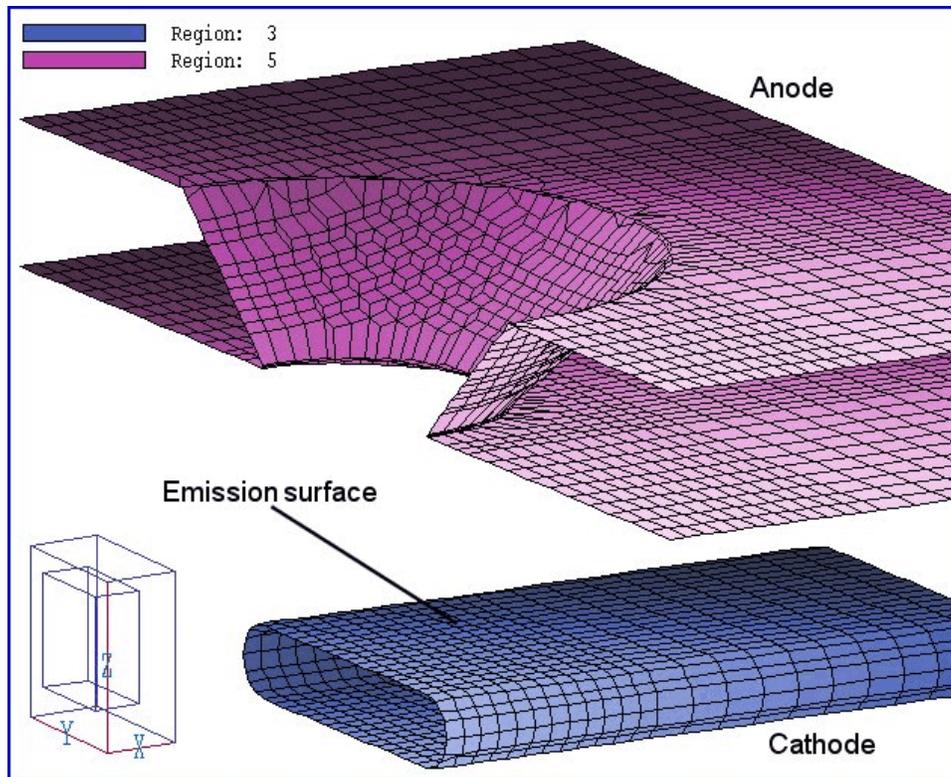
**Figure 2.2**. Anode and cathode shapes – ribbon example.

emission along the length of the ribbon in the solution volume. The flat
face of the ribbon has width 2.0 mm and the aperture has a radius 1.0 mm.
The distance between the emission face of the ribbon and the adjacent
anode surface is 1.75 mm. We shall use a symmetry boundary at $x = 0.0$
but treat the full width of the system in $y$. This choice gives flexibility to
model effects of cathode misalignments. Neumann boundaries at $y = \pm 4.0$
mm and $x = +4.0$ mm approximate the effect of extended electrodes.

Move the input files for the example (`ribbon.min`,
`ribbon.hin`, `ribbon.oin` and `ribbon.gcn`) to a working
directory (*i.e.*, `\amaze\buffer`). The files control the programs
**MetaMesh**, **HiPhi**, **OmniTrak** and **GCon**. Run **MetaMesh** and load
`ribbon.min`. The file contents are listed in Table 2.1. This example
illustrates several useful MetaMesh techniques and the special features
required for an **OmniTrak** simulation.

■ The foundation mesh is created with variable resolution to
concentrate elements in *x-y* in the region of beam extraction and in *z*
near the acceleration gap.

## Table 2.1. MetaMesh input file ribbon.min

```
* File RIBBON.MIN                 * Ribbon cathode
Global                              Part 3
  XMesh                               Type Extrusion
    0.00  1.50  0.125                   L  -1.00 -0.25  1.00 -0.25 S
    1.50  4.00  0.250                   A   1.00 -0.25  1.25  0.00  1.0  0.0 S
  End                                   A   1.25  0.00  1.00  0.25  1.0  0.0 S
  YMesh                                 L   1.00  0.25 -1.00  0.25 S
   -4.00 -1.50  0.250                   A  -1.00  0.25 -1.25  0.00 -1.0  0.0 S
   -1.50  1.50  0.125                   A  -1.25  0.00 -1.00 -0.25 -1.0  0.0 S
    1.50  4.00  0.250                 End
  End                               Region 3
  ZMesh                               Fab 10.00
   -3.00 -1.00  0.250                 Rotate 90.0 90.0 0.0 YXZ
   -1.00  3.00  0.125                 Surface Region 1 0.98
    3.00  6.00  0.250                 Surface Region 2 0.98
  End                                 Coat 2 4
  RegName 1 Vacuum upper            End
  RegName 2 Vacuum lower            * Extractor anode
  RegName 3 Ribbon cathode          Part 4
  RegName 4 Emission surface          Region 5
  RegName 5 Extractor anode           Type Turning
  RegName 6 Lower boundary             L  2.00  6.00  2.00  1.00  SE
  RegName 7 Upper boundary             L  2.00  1.00  3.00  2.00  SE
End                                     L  3.00  2.00  3.00  6.00  S
* Solution volume                       L  3.00  6.00  2.00  6.00  S
* Lower solution volume               End
Part 1                                Fab 0.0 360.0
  Type Box                            Surface Region 2 Edge
  Region 1                          End
  Fab 8.00 8.00 6.00                * Lower boundary
  Shift 0.00 0.00 -3.00             Part 5
End                                   Type BoundZDn
* Lower solution volume               Region 6
Part 2                              End
  Type Box                          * Upper boundary
  Region 2                          Part 6
  Fab 8.00 8.00 6.00                  Type BoundZUp
  Shift 0.00 0.00  3.00               Region 7
End                                 End
                                    EndFile
```

■ Unfilled regions of the types *BoundZUp* and *BoundZDn* are used to set nodes on the top and bottom surfaces of the solution volume. The nodes assume fixed-potential values in the **HiPhi** solution.

■ The anode with a shaped extraction aperture is a *Turning*. The complex three-dimensional structure requires only a few data lines for its definition. The ribbon cathode is an extrusion. Here, rotation operations are applied so that the long axis extends along *x*. We could
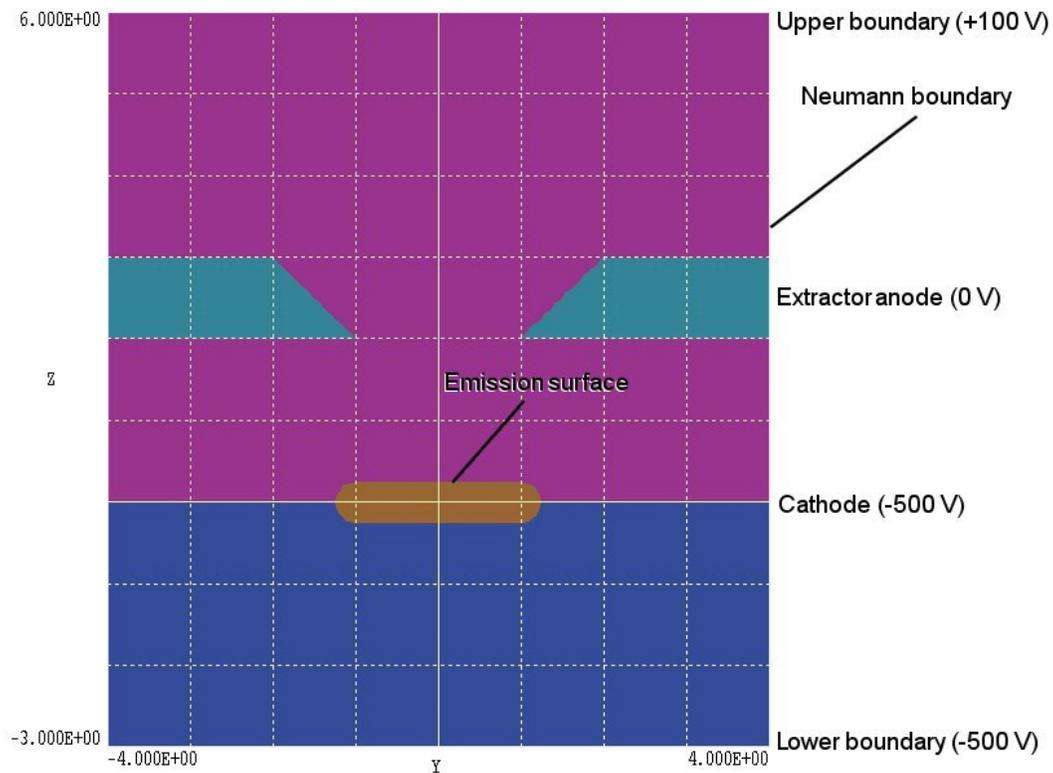
**Figure 2.3**. Cross-section of the geometry of example `ribbon.min` in a plane normal to *x* at *x* = 0.0. Lower vacuum volume: region 1 (blue). Upper vacuum volume: region 2 (violet). Cathode: region 3 (orange). Anode: region 5 (green).

add a non-zero *y* displacement in the *Shift* command to investigate cathode misalignment.

■ To implement automatic generation of electrons in **OmniTrak** we must define an *emission surface*, a region of nodes on the surface on an electrode with a unique region number. In the **OmniTrak** run, all element facets whose four nodes have the designated region number are treated as sites for electron initiation. Chapter 7 describes the process in detail. In the present example, we shall define the upper surface of the ribbon cathode as an emission region. Figure 2.3 shows a cross-section of the system in a plane normal to *x* at position *x* = 0.0. Note that the vacuum volume has been divided into upper and lower regions in *z* with a boundary at the cathode midplane. In response to the statement `Coat 2 4` in the definition of the cathode (Part 3), the program checks all facets that border on Region 2 (upper vacuum volume) and changes the associated nodes to Region 4. The result is that all facets on the top of the cathode will be treated as emission facets.

Process and save the mesh following instructions in the **MetaMesh** manual. You can use the plot capabilities of **MetaMesh** to confirm features discussed in this section.

## 2.2. Field and orbit solutions

The next step is to run **HiPhi** to generate a baseline electrostatic solution. The short input file `ribbon.hin` sets Regions 1 and 2 to the vacuum condition and defines the potential values shown in Fig. 2.3. The file also specifies that mesh input coordinates are given in millimeters. The solution takes about 21 seconds on a 1.5 GHz computer and generates the output file `ribbon.hou`. We can now proceed to the **OmniTrak** simulation. You can start the program from the **AMaze** program launcher (`amaze.exe`). Click on *Edit input files* in the *Files* menu and pick `ribbon.oin` to show the content listed in Table 2.2. Commands enclosed in the *Fields* section define properties of electric and/or magnetic fields. The *DUnit* command specifies that spatial quantities in succeeding statements should be converted from millimeters. The command *EField3D* loads the file `ribbon.hou` as the three-dimensional electrostatic solution. This solution will be modified in **OmniTrak** to reflect the presence of beam space charge. We use default values for most of the field relaxation parameters. The line

```
NCheck E 5
```

specifies frequent checks of convergence to avoid wasted time during latter relaxation cycles when the solution has only small changes..

Commands of the *Particles* section control tracking of particle orbits and space-charge updates of the field solution. Chapter 10 gives a detailed discussion of the methods used to simulate self-consistent Child law emission. The *Dt* command explicitly sets the orbit integration time step. The value is chosen so that maximum-velocity electrons travel less than the width of one element in a time step. The *NCycle* command specifies twelve cycles of orbit tracking and field updates while the command *AvgE* controls space-charge averaging between cycles. The parameters were chosen to achieve good solution convergence for the specific problem. The *Material* commands set properties of elements in Regions 3 (cathode) and 5 (anode). Electron orbits are terminated when they enter a material element. The command

**Table 2.2. OmniTrak input file ribbon.oin**

```
* File RIBBON.OIN
FIELDS
  DUnit = 1000.0
  EField3D = RIBBON.HOU
  NCheck E 5
END
PARTICLES SCharge
  NCycle 12
  Emit 4 0.0 -1.0 0.10  2
  Material E 3
  Material E 5
  AvgE 0.40
  Dt 2.5E-12
END
DIAGNOSTICS
  EDump RIBBONP.HOU
  PTable RIBBON
END
ENDFILE
```

```
    Emit 4 0.0 -1.0 0.10  2
```

states that element facets bounded by nodes with region number 4 are emission facets. The other parameters in the command line have the following functions: 1) set the mass and charge of emitted particles to correspond to electrons, 2) set the distance between the emission boundary and the physical cathode surface to 0.10 mm, and 3) set the number of electrons per facet to $2^2$. The *Diagnostics* section controls the creation of output files.

Exit the editor and choose *Start run* from *Run* menu. Processing starts automatically and takes about 230 seconds on a 1.5 GHz computer. During the simulation **OmniTrak** performs several activities: 1) read the electrostatic input file and create coupling coefficients for the field update, 2) identify emission facets and generate 2112 particle starting points at the emission surface, and 3) track orbits and recalculate the field solution over multiple cycles. During the run the program creates four output files:

**ribbon.ols**

> The file contains an extensive listing of useful and not-so-useful quantitative information. You can inspect the file with a text editor or abstract information using the **GCon** utility.

**ribbon.oou**

> This file is an ASCII listing of orbit vectors calculated on the final cycle. You can load the file into **OmniView** to create plots or to transfer the data to your own analysis programs.

**ribbonp.hou**

> This binary file in standard **HiPhi** output format is generated in response to the *EDump* command. It contains information on modified electrostatic fields including contributions from beam space charge. You can create field plots from the file with **PhiView** or **OmniView**. You can also reload the file into an **OmniTrak** simulation to trace single particle orbits in the self-consistent fields.

**ribbon.prt**

> This ASCII file contains particle parameters at the orbit termination points calculated on the final cycle. The file can be used as input for subsequent **OmniTrak** runs, it can be loaded in **OmniView** for distribution analyses or it can be ported to your own analysis programs.

In the remainder of this section, we will review features of the solution and analysis tools in the **OmniTrak** package. First, we shall extract data from the listing file to determine the convergence history of the run and the final value of total current emitted from the ribbon. Launch **GGon** from the **AMaze** program launcher. Choose *Run GCon script* and pick the file `ribbon.gcn`. The file content is shown in Table 2.3.

---

### Table 2.3. GCon input file ribbon.gcn

```
ABSTRACT
  INDATA \SIMULATIONS\AMAZE\BUFFER\RIBBON.OLS
  OUTDATA \SIMULATIONS\AMAZE\BUFFER\RIBBONCURRENT.DAT
  ITEM Total emitted current
ENDABSTRACT
```

**GCon** opens the file `ribbon.ols` (1.7 MB in length) and extracts each line that contains the string *Total emitted current*. You can use the *Edit files* command in the *Files* menu of **GCon** to check the resulting data file `ribboncurrent.dat`. It has the following content:

```
Total  emitted  current:     1.3594E-01
Total  emitted  current:     1.2515E-01
Total  emitted  current:     1.7510E-01
Total  emitted  current:     1.9928E-01
Total  emitted  current:     1.9264E-01
Total  emitted  current:     1.4928E-01
Total  emitted  current:     1.5194E-01
Total  emitted  current:     1.5142E-01
Total  emitted  current:     1.5148E-01
Total  emitted  current:     1.5152E-01
Total  emitted  current:     1.5156E-01
```

The results show that there is good convergence of the emitted current between cycles 7 and 11.

## 2.3. Analysis and plotting

Our final task is to use the **OmniView** postprocessor to make plots and to perform quantitative analyses of the solution. Run the program from the **AMaze** program launcher and choose *Load OmniTrak dist file* from the *Files* menu. Pick the file `ribbon.prt` and click *OK*. The *Distributions* menu becomes active and the status bar at the bottom of the window is updated. Go to the *Distributions* menu. By default, the program shows a plot of final particle positions in the *x-y* plane (at all values of z). The display is confusing because the positions of extracted particles (that travel through the aperture and travel to the boundary at $z = 6.0$ mm) are superimposed on those of electrons that strike the anode plate near $z = 2.0$ cm. To improve the display, click on the *Set particle filter* command in the *Analysis* menu. The default setting is that all orbits are included, regardless of charge, mass, final position or final energy. Set the filter entry *ZMin* to 5.0, thereby eliminating electrons that strike the anode. You will see the display in the background of Fig. 2.4 showing a slightly elliptical beam. To get quantitative information about the filtered particles, click on the *Beam analysis command* in the *Analysis* menu. **OmniTrak** displays the data window shown in Fig. 2.4 that reports calculated beam quantities relative to a reference axis. In this case, the program uses the default *z* axis as the reference. Note that the total extracted current is 0.011 A, less than 10 per cent of the current emitted from the ribbon. The extracted current for a full circular aperture is 0.022 A.
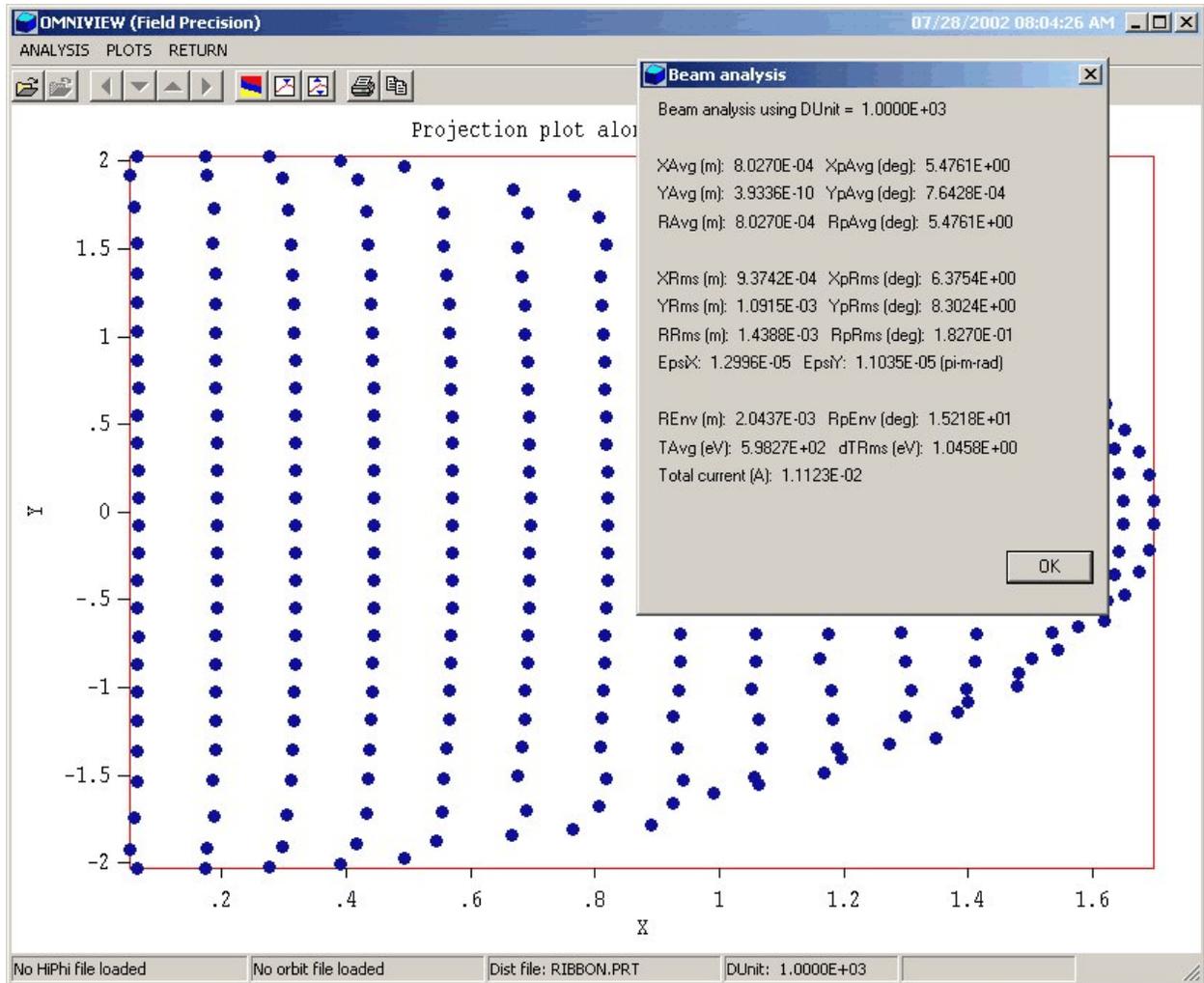
**Figure 2.4**. Distribution of extracted particles in the *x-y* plane for the *ribbon* example with beam analysis information window.

**OmniTrak** can create two- and three-dimensional plots of orbits superimposed on the three-dimensional electric field solution. Return to the main menu and click on the command *Load HiPhi solution file* in the *File operations* menu. Pick the file ribbonp.hou, the electrostatic solution with space-charge effects. Go to the *2D plots* menu. **OmniTrak** makes a default equipotential contour plot normal to the *z*-axis at the midpoint of the solution volume. In the *Change view* menu, click on the command *Set slice plane properties*. In the dialog, activate *X* in the *Normal axis* group and move the *Position along axis* slide all the way to the left. You will see the equipotential plot of Fig. 2.5. We shall now add projected particle orbits. Return to the main menu and click on the *Load OmniTrak plot file* command in the *File operations* menu. Pick the file
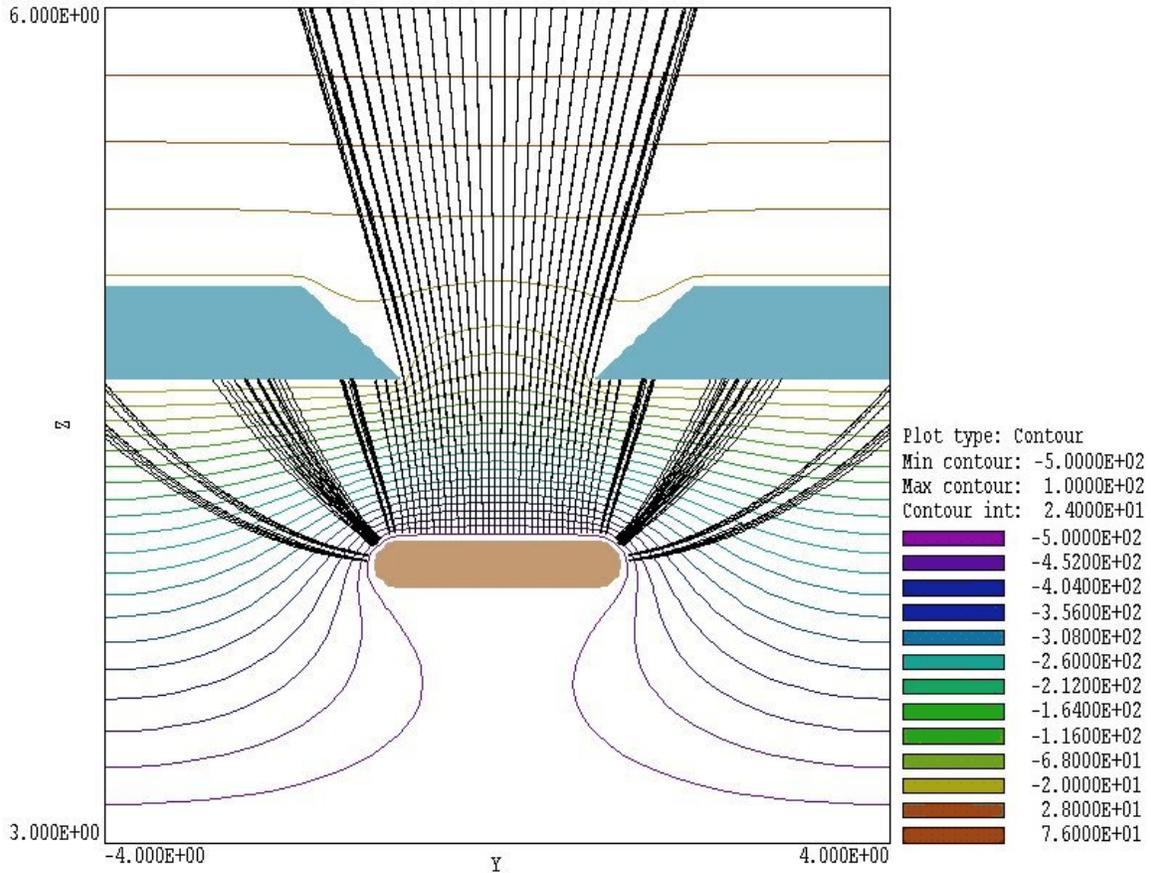
**Figure 2.5**. Two-dimensional plot of electrostatic equipotential contours and projected orbits, example *ribbon*.

`ribbon.oou` and then return to the *2D plots* menu. Initially there are no plotted orbit vectors because the particle filter is still active. In the *Plot control* menu click on *Set particle filter*. Deactivate the present setting with the *Remove filters* button. Although the field plot shows information near $x = 0.0$, the superimposed orbit plot will show vector projections in the *y-z* plane from all *x* positions. To avoid a confusing display, define a new filter by setting $x_{max} = 0.2$. The orbit plot will therefore be limited to vectors near $x = 0.0$.

After you click *OK* to exit the dialog, the program updates the plot. Note the only a few orbits are plotted. By default, **OmniTrak** includes only a fraction of the available orbits in large sets to save time during setup. To plot all the orbits, click on the *Set NPSkip* command in the *Plot control* menu. In the dialog, change the value of *NPSkip* (number of particles to

2-10

skip between plots) to 1. After you click *OK* you should see the display of Fig. 2.5. The plot clearly shows how the combined effects of the beam-space charge and the negative lens effect at the aperture, leading to a diverging extracted beam. To create a record of the plot, you can click on the *Default printer* command of the *Export plot* menu. A hardcopy plot will be created on the default Windows printer device. **OmniTrak** also has three-dimensional plotting capabilities as shown in Fig. 2.1. Chapter 20 discusses procedures to generate such plots.