Magnum
Three-dimensional Magnetostatics

Field Precision
Copyright 2003
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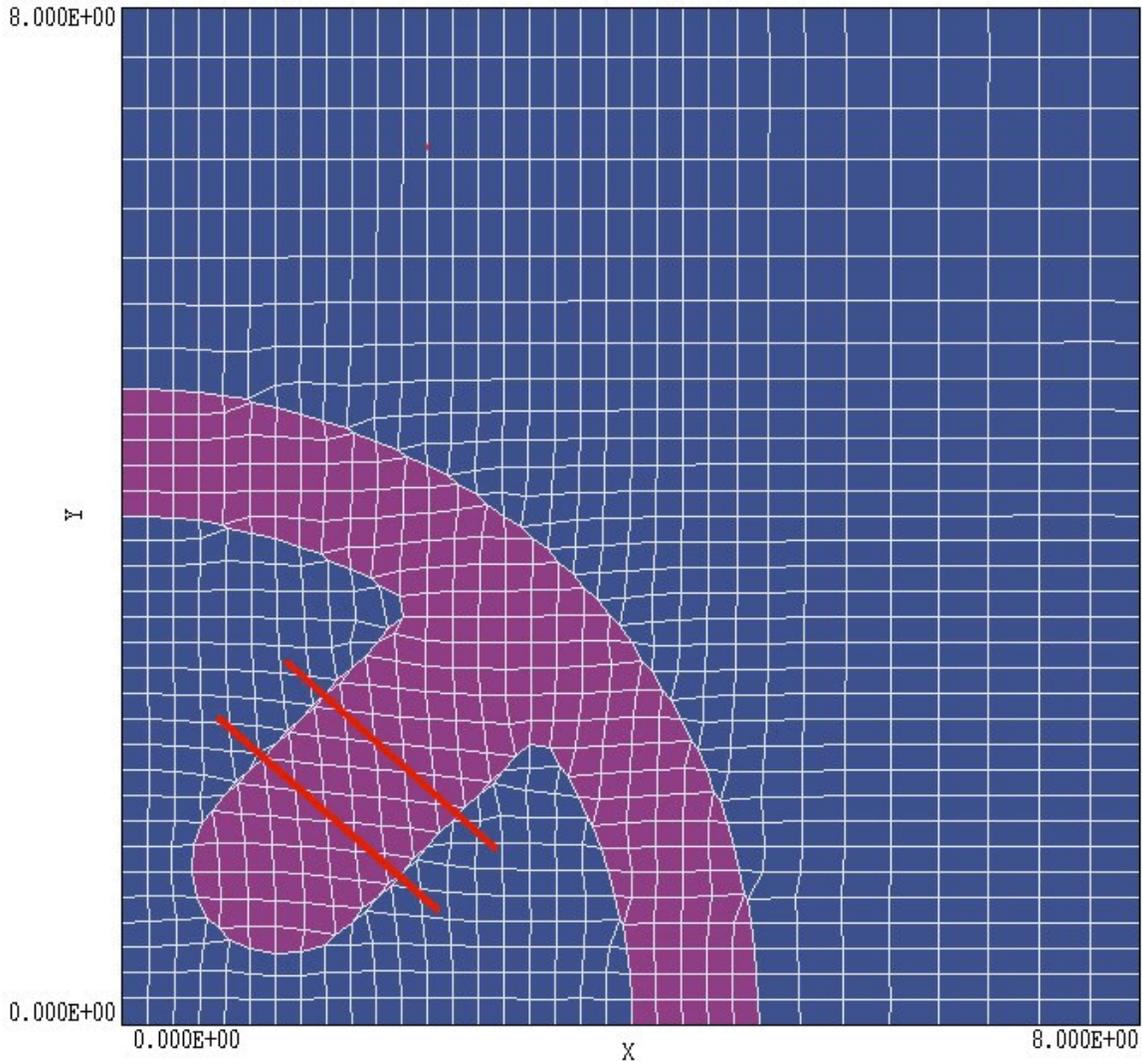**Telephone: 505-220-3975, FAX: 505-294-0222**

Figure 1.1. Mesh plot of the cross-section of the quadrupole magnet in a plane normal to *z* at *z* = 4.0 cm. A projection of the drive coils is shown in red.

1.2. Test run

A quick way to understand the solution procedure is to step through an example. The calculation describes a finite-length quadrupole magnet. A coarse mesh and symmetry boundaries are used for a fast solution – the process takes less than 1 minute. Figure 1.1 shows a cross-section of the magnet in the *x-y* plane. The orientation was chosen so that the planes *x* = 0.0 and *y* = 0.0 are symmetry planes that satisfy the condition $B_\parallel = 0.0$. Therefore, it is sufficient to model only one quadrant of the magnet. Similarly, the symmetry condition $B_\perp = 0.0$ holds at the axial midplane (*z* = 0.0), so it is sufficient to model only the portion of the magnet in the
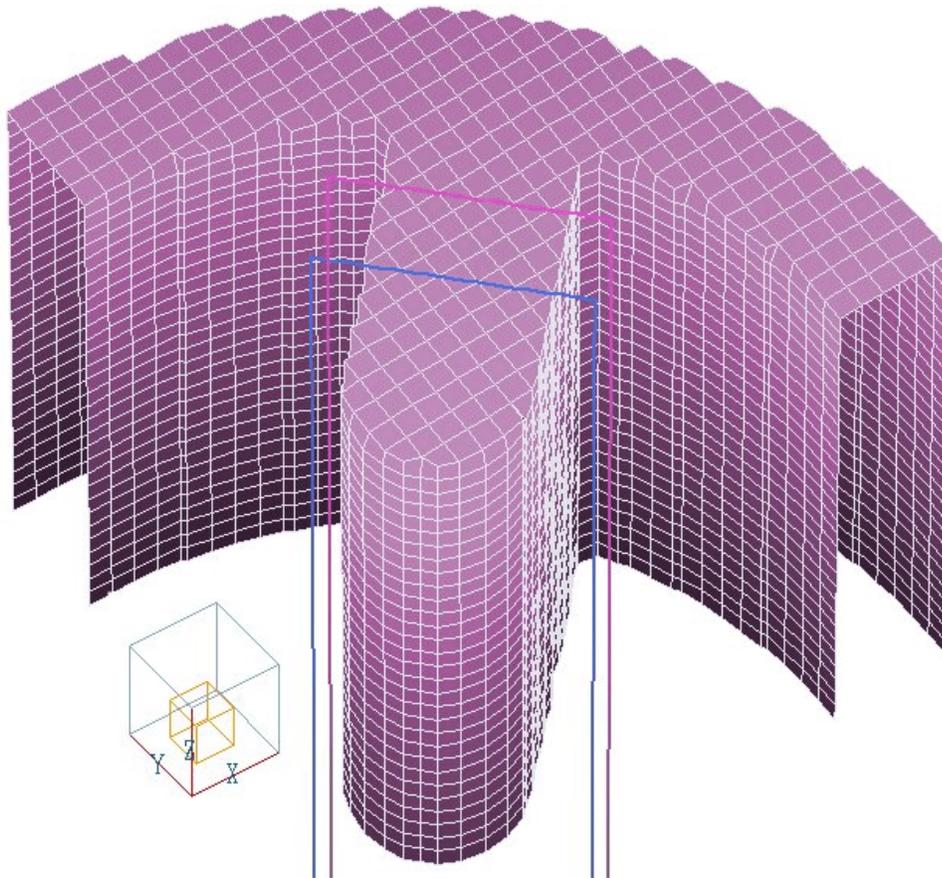
Figure 1.2. Three-dimensional view of the pole piece in the solution volume and a portion of the drive coils.

region $z > 0.0$. The iron pole has an axial length of 12.00 cm. It extends from $z = 0.0$ cm to $z = 6.0$ cm in the half-plane simulation. The outer radius is 5.0 cm. A peripheral region of coarse mesh extending to $x = 8.0$ cm, $y = 8.0$ cm and $z = 16.0$ cm has been included for an accurate representation of the fringing fields. Figure 1.2 shows a three-dimensional view of the pole piece and drive coils.

To prepare for the run, move the example input files SHORTQUAD.MIN, SHORTQUAD.CDF, SHORTQUAD.GIN and SHORTQUAD.SCR to the working directory (*i.e.*, \AMAZE\BUFFER). Run AMAZE.EXE (the **AMaze** program launcher) and click on *Set data directory*. Move to \AMAZE\BUFFER and click *OK*. Then launch **MetaMesh**. The first step in the solution process is to create a volume mesh. Table 1.1 shows the **MetaMesh** script SHORTQUAD.MIN. The mesh serves two purposes. First, the region assignments and shapes of the conformal elements define

the material division of the solution volume (*i.e.*, the boundaries of the pole piece in Fig. 1.2). Second, the mesh serves as an armature for projecting the applied fields. The calculated field values at nodes are used to determine source terms for the magnetic field solutions in **Magnum**. Furthermore the **MagView** postprocessor uses the values for interpolations of applied fields at points in the solution volume. Load and process the file SHORTQUAD.MIN, and save the mesh to create the file SHORTQUAD.MDF.

Table 1.1. MetaMesh script file SHORTQUAD.MIN

```
* File ShortQuad.MIN
Global
  XMesh
     0.00  5.20  0.20
     5.20  8.00  0.40
  End
  YMesh
     0.00  5.20  0.20
     5.20  8.00  0.40
  End
  ZMesh
     0.00  6.20  0.20
     6.20 16.00  0.40
  End

  RegName 1 Air volume
  RegName 2 Quad pole
  RegName 3 Symmetry boundary
End
* Air volume
Part 1
  Type Box
  Region 1
  Fab 16.00  16.00  32.00
End
* Quad pole
Part 2
  Type Extrusion
     L    4.00E+00  0.00E+00  5.00E+00  0.00E+00
     A    5.00E+00  0.00E+00  6.08398E-08  5.00E+00  0.00E+00  0.00E+00 S
     L    0.00E+00  5.00E+00  0.00000E+00  4.00E+00
     A    4.86719E-08  4.0E+00  2.28388E+00  3.28388E+00  0.0E+00  0.0E+00 S
     L    2.28388E+00  3.28388E+00  7.50000E-01  1.75000E+00 S
     A    7.50E-01  1.75E+00  7.50E-01  7.50E-01  1.25E+00  1.25E+00 S
     A    7.50E-01  7.50E-01  1.75E+00  7.50E-01  1.25E+00  1.25E+00 S
     L    1.75E+00  7.50E-01  3.28388E+00  2.28388E+00 S
     A    3.28388E+00  2.28388E+00  4.0E+00  0.0E+00  0.0E+00  0.0E+00 S
  End
  Region 2
  Fab  12.00
  Surface Region 1
End
* Symmetry boundary in X
Part 3
  Type BoundXDn
  Region 3
End
* Symmetry boundary in Y
Part 4
  Type BoundYDn
  Region 3
End
EndFile
```
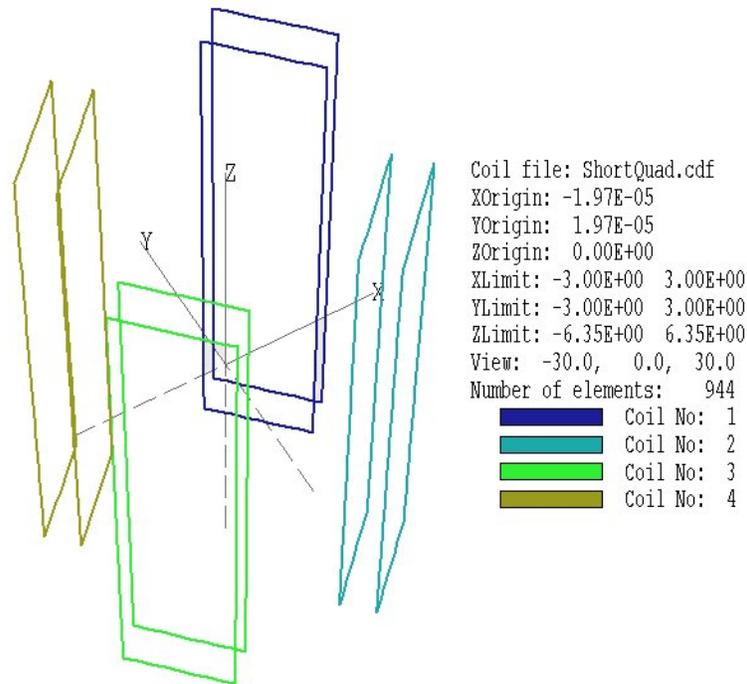
Coil file: ShortQuad.cdf
XOrigin: -1.97E-05
YOrigin: 1.97E-05
ZOrigin: 0.00E+00
XLimit: -3.00E+00 3.00E+00
YLimit: -3.00E+00 3.00E+00
ZLimit: -6.35E+00 6.35E+00
View: -30.0,   0.0, 30.0
Number of elements: 944
Coil No: 1
Coil No: 2
Coil No: 3
Coil No: 4

Figure 1.3. Current element set created by **CPrep** for the
SHORTQUAD example.

The second required input component is the spatial distribution of applied
currents to drive the magnetic fields. The values are contained in a file
with a name of the form DataName.FSC, where FSC stands for *free-
space coil*. The file contains a set of current element specifications. Each
data line gives the start point, end point and current of an element for the
applied magnetic intensity $\mathbf{H}_s$ at nodes of the solution volume. The input
file SHORTQUAD.FSC contains information on 944 current elements. In
most cases, you need not create this file directly. The **Magnum** package
contains the utility program **CPrep** which reads coil specifications and
automatically divides the coils into small current elements.

Run CPrep.EXE and choose *Open coil file* in the *File* menu. Pick the
file SHORTQUAD.CDF (where *CDF* stands for Coil Definition File).
CPrep immediately processes the file and shows a plot similar to Fig. 1.3.
Table 1.2 shows the content of the script. It defines eight box coils that
surround the four pole extensions of the quadrupole magnet. You could
define a larger number of coils to give a better approximation of the
winding density – we used a small number in this example to ensure a fast
solution time. Note that we need to define the full complement of four coil
sets over the complete axial range even though the solution in **Magnum** is

Table 1.2. CPrep script file SHORTQUAD.CDF

```
* File ShortQuad.CDF
GLOBAL
  DUnit = 100.0
  Ds = 0.250
END
COIL  1  Quadrant 1
  Current = 1000.0
  Rotation 90.0 0.0 -45.0  XYZ
  Shift  1.750 1.750 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
  Rotation 90.0 0.0 -45.0  XYZ
  Shift  2.250 2.250 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
END
COIL  2
  Current = -1000.0
  Rotation 90.0 0.0 -135.0  XYZ
  Shift  1.750 -1.750 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
  Rotation 90.0 0.0 -135.0  XYZ
  Shift  2.250 -2.250 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
END
COIL  3  Quadrant 3
  Current = 1000.0
  Rotation 90.0 0.0 -225.0  XYZ
  Shift  -1.750 -1.750 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
  Rotation 90.0 0.0 -225.0  XYZ
  Shift  -2.250 -2.250 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
END
COIL  4  Quadrant 4
  Current = -1000.0
  Rotation 90.0 0.0 -315.0  XYZ
  Shift  -1.750 1.750 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
  Rotation 90.0 0.0 -315.0  XYZ
  Shift  -2.250 2.250 0.000
  Rectangle  (-1.061, -6.354) (1.061, 6.354)
END
ENDFILE
```

carried out only in the first quadrant. This is a consequence of the solution technique applied in the program – **Magnum** first calculates applied fields from a Biot-Savart integral and then uses finite-element techniques to compute the field contributions from materials. The **MagView** post-processor displays a superposition of the applied and material field

components. Although symmetry boundaries influence the material fields, we must ensure the symmetry of the applied fields directly by including the full area of all coils. Chapter 2 gives a more detailed description of the solution process.

Next run **Magnum** from **AMaze**. After the program starts, pick *Run* from the main menu or use the run tool. In the dialog, pick the file SHORTQUAD.GIN. Table 1.3 shows the contents of the file. **Magnum** reads the mesh and current elements files, calculates applied fields, determines element matrices and coupling coefficient necessary for the finite-element solution and then proceeds with a dual relaxation solution. The entire process takes less than a minute on a 1.6 GHz computer. The program creates the binary output file SHORTQUAD.GOU and the ASCII listing file SHORTQUAD.GLS. You can use the *Edit listing file* command to inspect SHORTQUAD.GLS.

Table 1.3. Magnum script SHORTQUAD.GIN

```
* File ShortQuad.GIN

SOLTYPE Standard
DUNIT 100.0
SOURCE ShortQuad.FSC
NCHECK = 10
MAXCYCLE = 2000
RESTARGET 5.0E-8

MU(1) = 1.0
MU(2) = 500.0
POTENTIAL(3) = 0.0

ENDFILE
```

Following completion of the solution, start the program **MagView.** Pick *Load solution file* from the *File* menu or click on the tool. Pick the file SHORTQUAD.GOU in the dialog. **MagView** can generate a wide variety of 2D and 3D plots. Figure 1.4 shows an example, a 3D representation of the pole piece with |**B**| plotted in a plane normal to the z axis. Chapters 10, 11and 12 give detailed information on plotting capabilities. Here, we shall create a simple example to test the program. Click on *Plane plots* to bring up the plane plot menu.
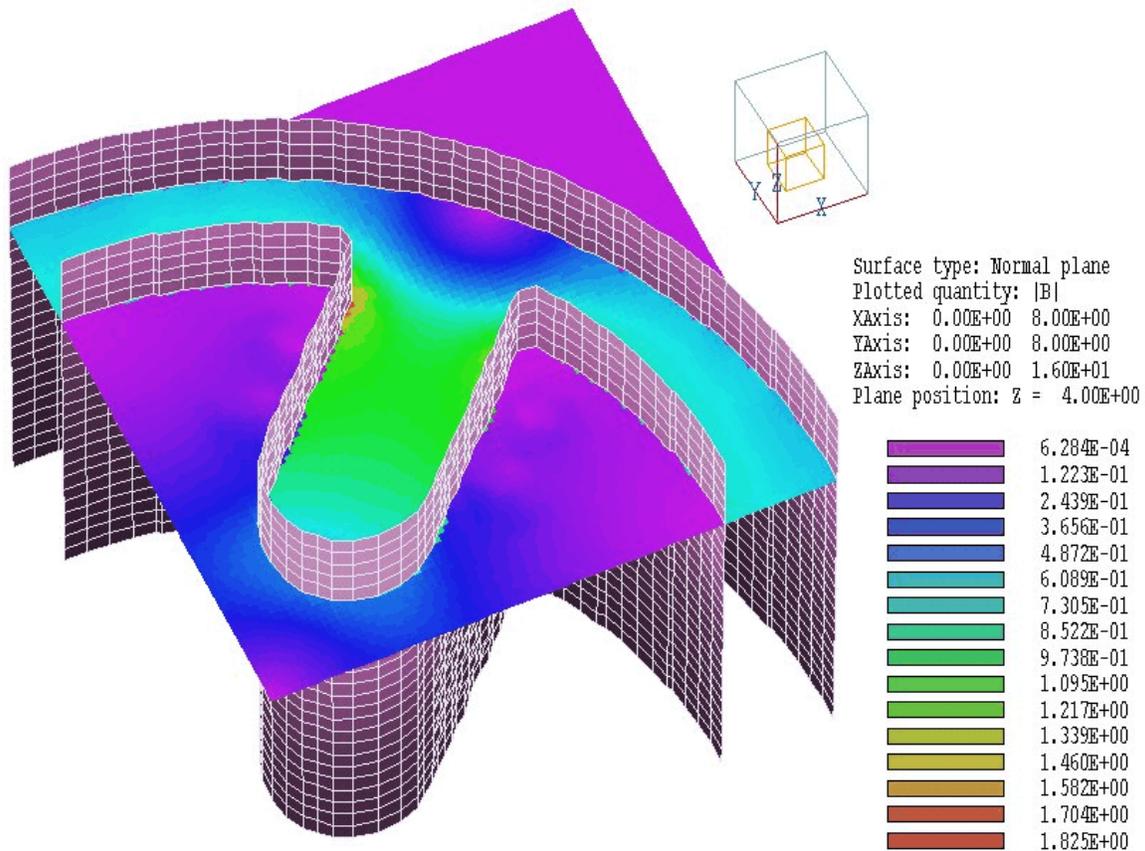
```
Surface type: Normal plane
Plotted quantity: |B|
XAxis:  0.00E+00  8.00E+00
YAxis:  0.00E+00  8.00E+00
ZAxis:  0.00E+00  1.60E+01
Plane position: Z =  4.00E+00
```

```
6.284E-04
1.223E-01
2.439E-01
3.656E-01
4.872E-01
6.089E-01
7.305E-01
8.522E-01
9.738E-01
1.095E+00
1.217E+00
1.339E+00
1.460E+00
1.582E+00
1.704E+00
1.825E+00
```

Figure 1.4. Three-dimensional view of physical surfaces with a plot of |**B**| in a plane normal to *z*.

The default plot shows the variation of |**B**| in a plane normal to *z* at the command. In the dialog move the slider to *z* = 4.0 cm, within the region of the pole. Change plot limits to x*max* = 4.0 cm and y*max* = 4.0 cm. Finally, in the *Plot control* menu click on *Plot style*. Increase the plot resolution to 75 in the horizontal direction. You should see a plot similar to Fig. 1.5. If you try some of the other plot styles, note that plane plots may give ragged edges on sloped or curved surfaces. This is because the plot is based on a simple division of the plane into a rectangular array with no special provisions for material boundaries. Slice plots give more accurate representations, although the available styles are more limited.

Although plots are interesting, the primary function of **Magnum** is to generate numbers. Return to the main menu and click on *Run script* in the *File* menu. In the dialog, pick the file SHORTQUAD.SCR. There is a delay while **Magnum** performs an analysis. To begin, we shall inspect the
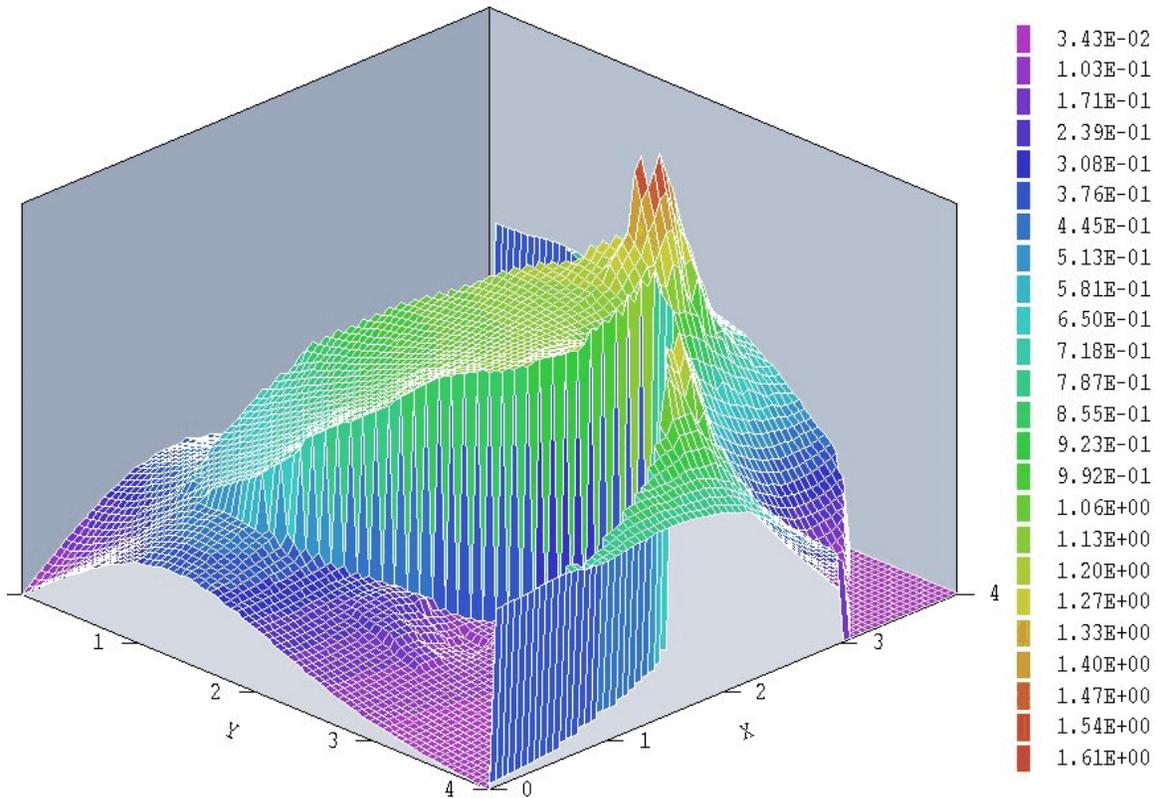
Figure 1.5. Plot of |B| in a plane normal to z at z = 4.0 cm

instructions in the data script. In the *File* menu click on *Edit script* and choose SHORTQUAD.SCR. The internal program editor loads and shows the following content:

```
* File SHORTQUAD.SCR
* Analyze linearity of field variations at
* three axial positions
INPUT ShortQuad.GOU
OUTPUT ShortQuad
NSCAN 50
LINE 0.0 0.0 1.0  0.7  0.7  1.0
LINE 0.0 0.0 5.0  0.7  0.7  5.0
LINE 0.0 0.0 6.5  0.7  0.7  6.5
ENDFILE
```

The first statement ensures that the proper solution file is loaded and the second statement opens a data file to write the results. The command *NScan 50* instructs the program to compute 51 values (50 intervals) along
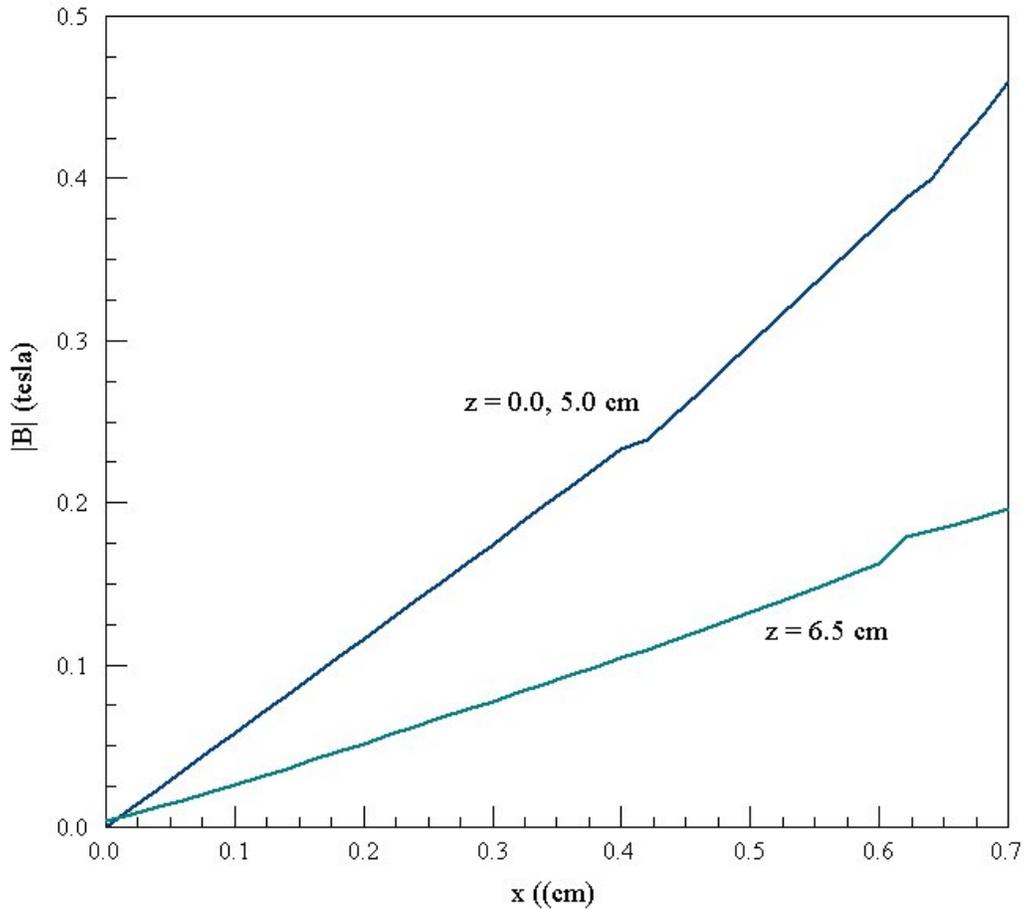
Figure 1.6. Variation of |**B**| as a function of x along a 45° line at three axial positions

a line scan. The next three lines compute scans of values from the axis to in Fig. 1.6. The lines at $z = 1.0$ and 5.0 cm are almost identical. The field variation near the axis is linear and grows faster than linear near the pole face. The nonlinearity results from the fact that the pole does not have an ideal hyperbolic shape. Note that there are small discontinuities in the plot. We have shown these as a reminder that numerical results are never exact. The interpolation routines have done the best job possible with the coarse mesh (Fig. 1.1). Improved results could be achieved with a finer mesh near the axis.