
# BStat

## Finite-element Magnetostatics

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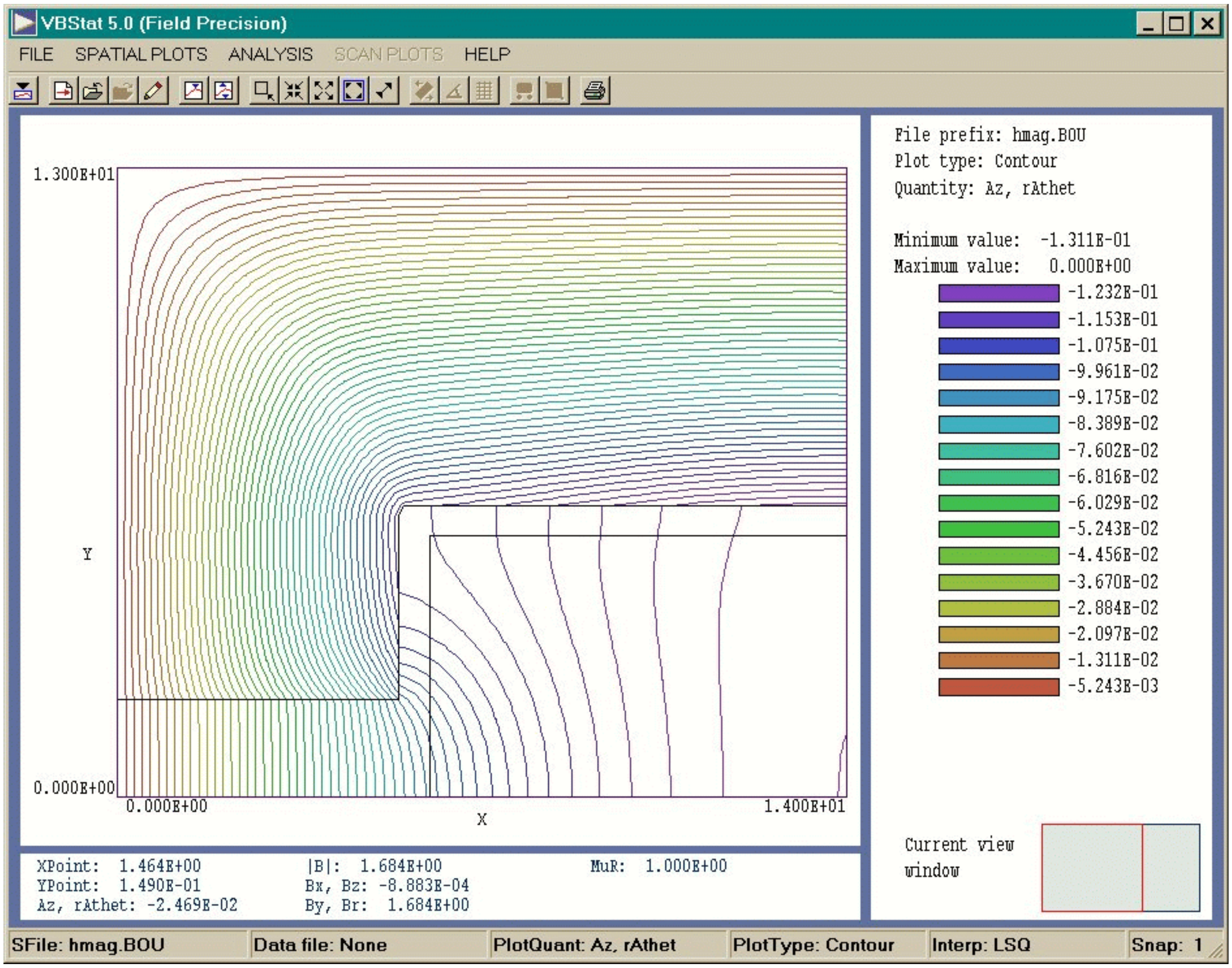


**Figure 1**. **VBStat** screen display

## 2. Walkthough example

We shall consider the *HMag* example included in the library of examples to illustrate a complete magnetostatic solution. The simulation illustrates many useful features of **BStat** such as assignment of symmetry boundaries and the ability to generate detailed solutions within a macroscopic solution volume. The *H magnet* configuration is often used in particle accelerators to create dipole fields. The length of the magnet is usually much larger than the transverse dimensions so the two-dimensional planar approximation is valid in regions removed from the ends. Figure 2 shows the simulation geometry, which represents one-quarter of the magnet cross section. By symmetry lines of magnetic flux density are vertical at the magnet midplane. Therefore, we can eliminate the left-hand portion of the magnet and apply a Dirichlet boundary condition (Section 9) along the vertical midplane (left-hand boundary in Fig. 2). Similarly, lines of

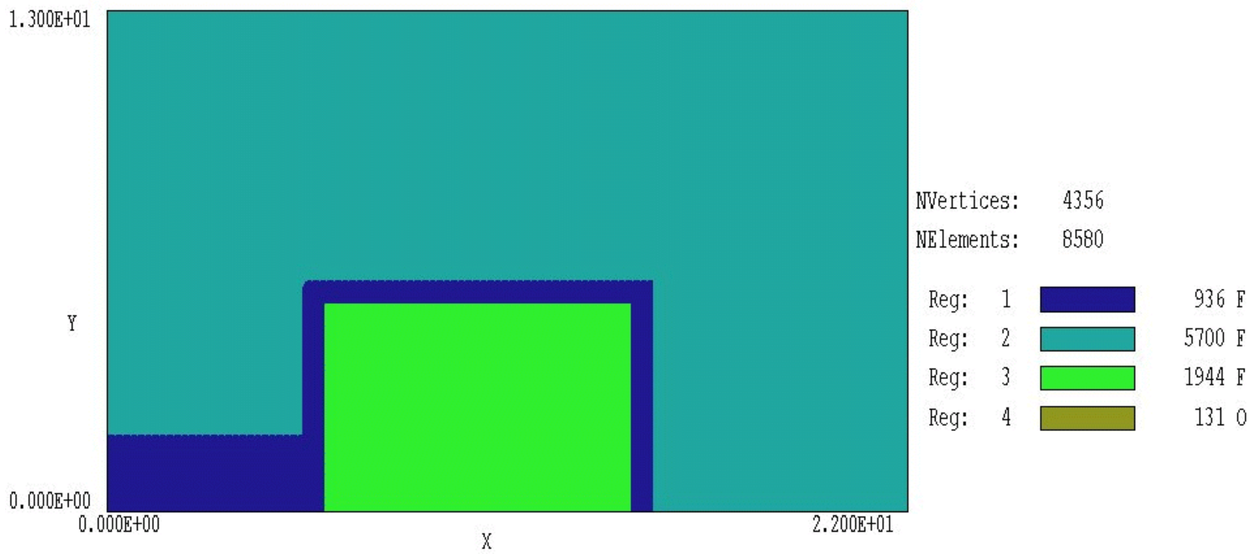


**Figure 2**. Solution volume and region assignments for the `hmag` example

magnetic flux density **B** are normal at the horizontal midplane; therefore, we can eliminate the bottom half of the magnet and apply a Neumann condition along the bottom boundary. A Dirichlet condition is also applied along the top and right-hand boundaries. The condition is equivalent to the assumption that all magnetic flux is contained within the iron core. In the case of a highly-saturated core it may be necessary to include an air volume around the outside of the solution volume for the correct representation of leakage flux.

In Fig. 2 the dark-blue area (Region 1) is the air gap, the dark-green area is one-quarter of the iron core cross-section, and the light-green area is one-half of the right-hand side of the magnet winding. The current in the coil segment is directed in to the page. The Dirichlet symmetry condition means that there is a symmetric virtual coil on the left-hand side that carries current out of the page. The fourth region is a set of nodes around the left-hand, top and right-hand boundaries that are assigned the Dirichlet condition (**B** lines parallel). The bottom boundary automatically assumes the Neumann condition (**B** lines normal) so a specification is not needed.

To begin, copy the files `HMAG.MIN`, `HMAG.BIN`, `HMAG2.MIN`, `HMAG2.BIN` and `HMAG2.SCR` to a convenient working directory (*i.e.*, `\TRICOMP\BUFFER`). The first step is to generate a file of geometric information, a required input for **BStat**. Make sure the data directory in the **TC** program launcher is set to your working directory, and then run

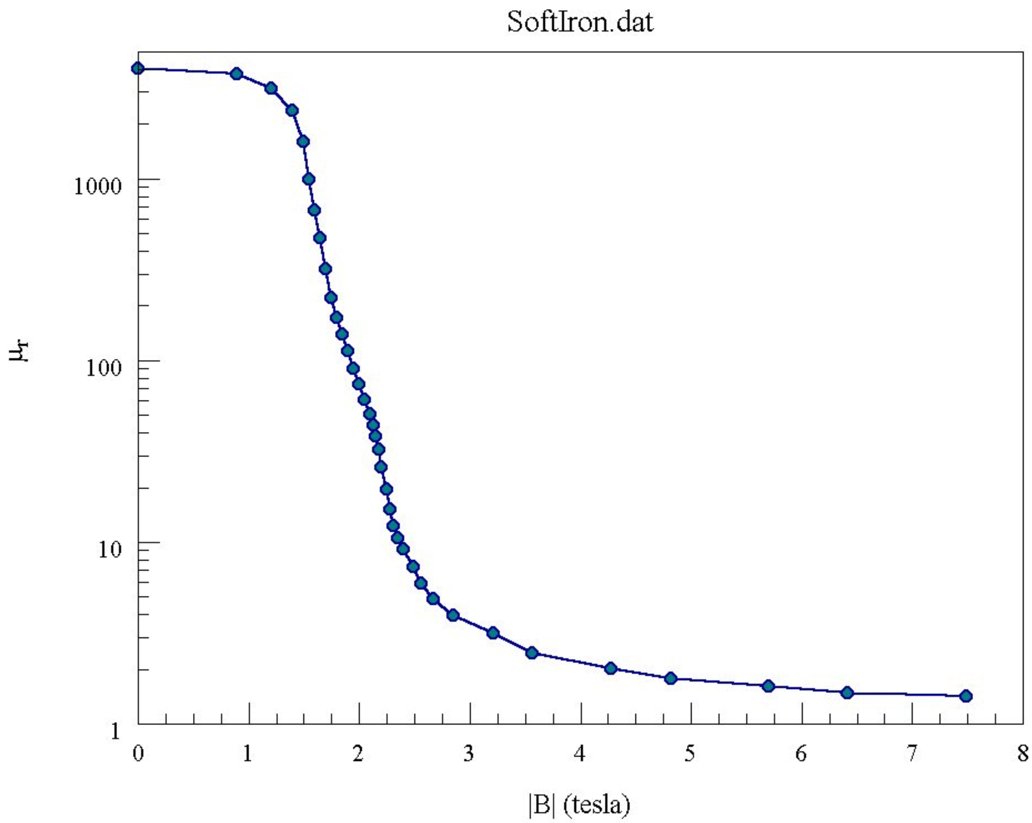


**Figure 3**. Field-dependent relative magnetic permeability

the **Mesh** program from **TC.** Click on *Load script (MIN)*, pick HMAG.MIN in the dialog. and click *OK*. The file has the format described in the **Mesh** manual. It contains a set of vectors that define the shapes in Figure 2. Click on the *Process* command. When mesh generation is complete, click on *Save mesh (MOU)* to create the file HMAG.MOU. At this point, you can use commands in the plot menu to inspect the geometry.

The next step is to run **BStat** from **TC**. The second required input is the control script HMAG.BIN. Click on *Edit input files* in the *File* menu and choose HMAG.BIN to show the following content:

```
* FILE HMAG.BIN
SET ResTarget 5.0E-8
SET Geometry Rect
SET DUnit 100.0
SET Omega 1.90 1.95
SET MaxCycle 3000
* Main solution volume
```

```
REGION 1 Mu 1.0
* Return yoke
REGION 2 Mu Table SoftIron.dat
* Coil
REGION 3 Current -30000.0
REGION 3 Mu 1.0
* Dirichlet boundary
REGION 4 VecPot 0.0
ENDFILE
```

The first group of commands beginning with the keyword *SET* controls the solution process. For example, `SET DUNIT 100.0` specifies that dimensions in the **Mesh** file are given in centimeters. Section 5 describes the *SET* commands in detail. The second group of commands beginning with the word *REGION* defines material properties associated with solution regions. The air and coil regions are assigned a fixed value of relative permeability, $\mu_r = 1.0$. The coil region is also assigned a current of 30,000 A-turns. The total drive current (top and bottom) is therefore 60,000 A-turns. To simulate saturation effects, the iron (Region 3) is associated with a lookup table that defines a field-dependent value of magnetic permeability (Section 7). The file `SOFTIRON.DAT` is in ASCII format and can be inspected with an editor. Figure 3 shows the defined variation of $\mu_r = \mathbf{B}/\mu_o\mathbf{H}$ as a function of $|\mathbf{B}|$. Several tables are supplied with **BStat**, and you can also create your own tables to represent specialized materials. The final command sets the fixed vector potential condition $A_z = 0.0$ along boundaries.

Exit the editor and click the *Start run* command in the *Run* menu. Pick the file `hmag.bin` and click *OK* to start the solution. **BStat** applies an iterative relaxation technique to solve the finite-element equations while adjusting material properties in the iron core following the table `SOFTIRON.DAT`. The solution takes a few seconds on a high-performance personal computer. When the solution is complete, the program creates the file `HMAG.BOU` which contains information on the locations of nodes and the associated value of vector potential.

Run **VBStat** from **TC** to analyze the solution. Click the *Load solution* command in the *File* menu and pick `HMAG.BOU`. The program creates the default plot of Fig. 1 showing contours of $A_z$. In a two-dimensional solution the contours lie along lines of magnetic flux density. In the *Spatial plot* menu click on *Plot type* and choose *Element*. Next, click on plot quantity and choose *Mu (relative)* to display the plot of Fig. 4. At the given drive current, the major part of the core volume is near saturation except for the top-left and top-right areas.

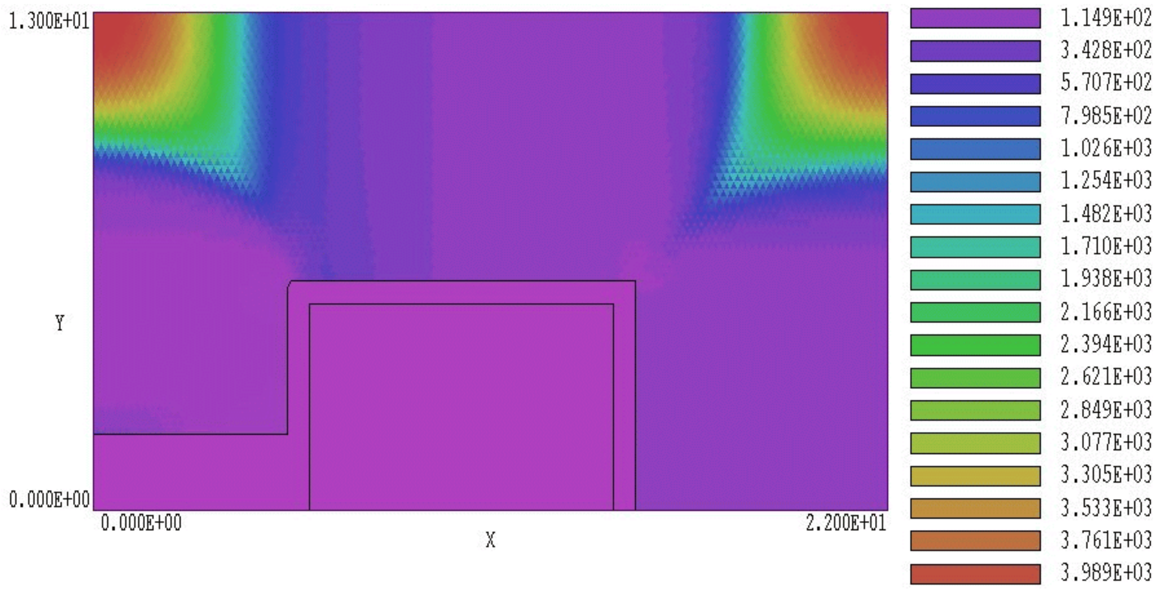


**Figure 4**. Variation of $\mu_r$ in the solution `hmag`

Version 5.0 of **VBStat** incorporates a feature that we can use to generate a more detailed picture of saturation near the pole tip. Run **Mesh** and process the file `HMAG2.MIN`. The solution covers a subset of the volume of `HMAG.MIN` near the air gap. Save the mesh file and return to **BStat**. Use the internal editor to inspect the file `HMAG2.BIN`. The file has the following content:

```
* FILE HMAG2.BIN
SET ResTarget 1.0E-9
SET Geometry Rect
SET DUnit 100.0
SET Omega 1.90 1.95
SET MaxCycle 5000
SET Boundary HMag
SET MatAvg 0.10 25 150
* Main solution volume
REGION 1 Mu 1.0
* Return yoke
REGION 2 Mu Table SoftIron.dat
ENDFILE
```

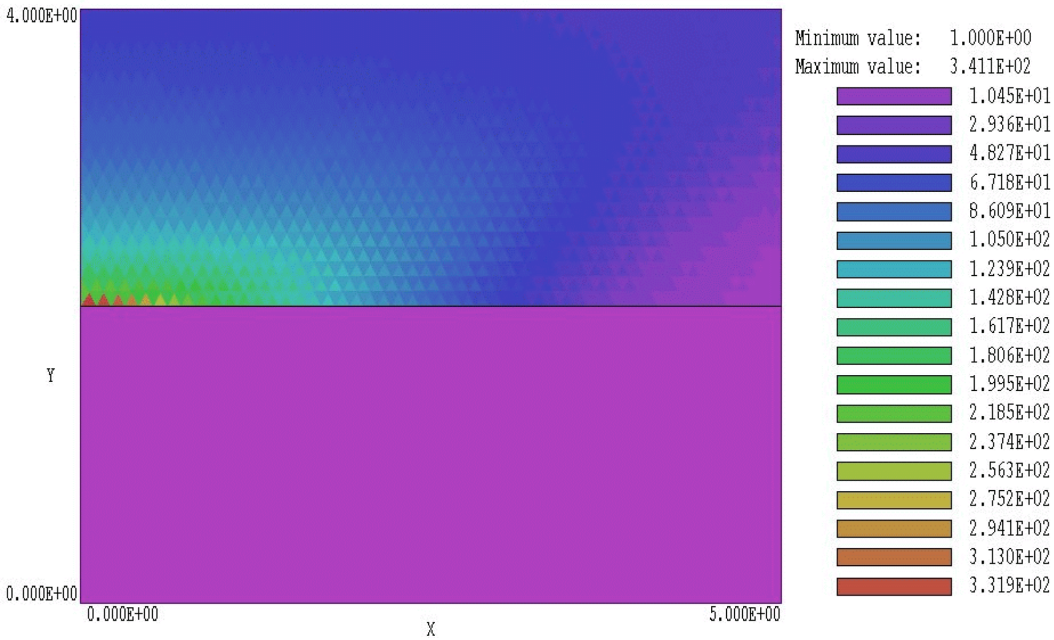


**Figure 5**. Detail of the variation of μr in solution `hmag2`

Material properties for regions inside the solution volume are the same as those in `HMAG.BIN`. The main difference is the command `SET Boundary HMag`. This command specifies that the outer boundary of the solution volume should be set to fixed values of $A_z$ (Dirichlet condition) determined by interpolating in the solution space of `HMAG.BOU`. Run the **BStat** solution and then load the file `hmag2.bou` into **VBStat**. The program displays the microscopic view of core saturation of Fig. 5. To complete the session, we shall run a script that performs automatic calculations. To inspect the file content, click on *Edit script* in the *File* menu and pick the file `HMAG2.SRC`. The file has the following content:

```
INPUT HMAG2.BOU
OUTPUT HMAG2
NSCAN 20
SCAN 0.0 0.0  5.0 0.0

ENDFILE
```

The first command ensures that the file `HMAG2.BOU` is loaded while the second command opens the data listing file `HMAG2.DAT`. The *Scan* command writes a set 21 data lines listing the vertical component of magnetic flux density along the horizontal midplane of the air gap. The following is an excerpt from the listing:

```
Scan between points
    XStart:  0.000E+00   YStart:  0.000E+00
      XEnd:  5.000E+00     YEnd:  0.000E+00

   X           By, Br
========================
   0.000E+00   1.687E+00
   2.500E-01   1.687E+00
   5.000E-01   1.687E+00
   7.500E-01   1.687E+00
   1.000E+00   1.686E+00
   1.250E+00   1.685E+00
   1.500E+00   1.684E+00
   1.750E+00   1.682E+00
   2.000E+00   1.679E+00
   2.250E+00   1.676E+00
   2.500E+00   1.672E+00
   2.750E+00   1.666E+00
   3.000E+00   1.659E+00
   3.250E+00   1.650E+00
   3.500E+00   1.638E+00
   3.750E+00   1.620E+00
   4.000E+00   1.599E+00
   4.250E+00   1.573E+00
   4.500E+00   1.540E+00
   4.750E+00   1.497E+00
   5.000E+00   1.456E+00
```

Using the two solutions we have generated, you can experiment with the extensive plotting and analysis functions of the **VBStat** postprocessor. We also recommend that you run some of the prepared examples supplied with **BStat** to understand the program capabilities and the nature of two-dimensional magnetostatic solutions. The following chapters give detailed information that will help you prepare input files for your own applications.