Example: A Permanent Magnet

As an example of a magnetostatics problem, consider how to model a horseshoe-shaped permanent magnet. It consists of a ferromagnetic material, but the two end sections, often painted red and white, are premagnetized in opposite directions. The magnetic field pattern around such a permanent magnet is well known.

The domain consists of four regions:

- Three parts of the permanent magnet—the two premagnetized ends and the curved midsection
- The air surrounding the magnet

The permeability μ in air equals $\mu_0 = 4\pi \cdot 10^{-7}$. Because the magnet is made of a ferromagnetic material, its relative permeability normally depends on the strength of the magnetic field, but in this model it is a constant with a value of 5000. The premagnetization adds a magnetization vector, pointing in the positive x-direction at the upper end and in the negative x-direction in the lower end. The magnitude of the magnetization is 750 kA/m.

It is reasonable to neglect the field at the boundaries of the computational domain, thus leading to the Dirichlet boundary condition **A** = 0 on the exterior boundary.

Model Library Path: `COMSOL_Multiphysics/Electromagnetics/permanent_magnet`

Modeling Using the Graphical User Interface

MODEL NAVIGATOR

1 Go to the Model Navigator and select **2D** in the **Space dimension** list.

2 Open the **COMSOL Multiphysics>Electromagnetics** folder and then select **Magnetostatics** in the list of application modes.

3 Use the default quadratic Lagrange elements.

4 Click **OK**.

OPTIONS AND SETTINGS

1 Enter the following values in the **Axes/Grid Settings** dialog box. To set the grid spacing, click the **Grid** tab and clear the **Auto** check box.

AXIS		GRID	
x min	`-3`	x spacing	`0.2`
x max	`3`	Extra x	
y min	`-2`	y spacing	`0.2`
y max	`2`	Extra y	

2 Enter these names and expressions in the **Constants** dialog box:

NAME	EXPRESSION
`murFe`	`5000`
`Mpre`	`750000`

GEOMETRY MODELING

Start by modeling the upper and the lower premagnetized parts of the magnet.

1 Click the **Rectangle/Square** button and draw a rectangle from (0, 0.2) to (0.4, 0.4).

2 Click the **Rectangle/Square** button and draw a rectangle from (0, −0.4) to (0.4, −0.2).

Next draw the rest of the magnet using boundary modeling:

3 Click the **Line** button, and click the points (0.4, 0.2), (0.4, 0.4), and (0.6, 0.4).

4 Click the **2nd Degree Bezier Curve** button, then click at the points (1, 0.4), (1, 0), (1, −0.4), and (0.6, −0.4).

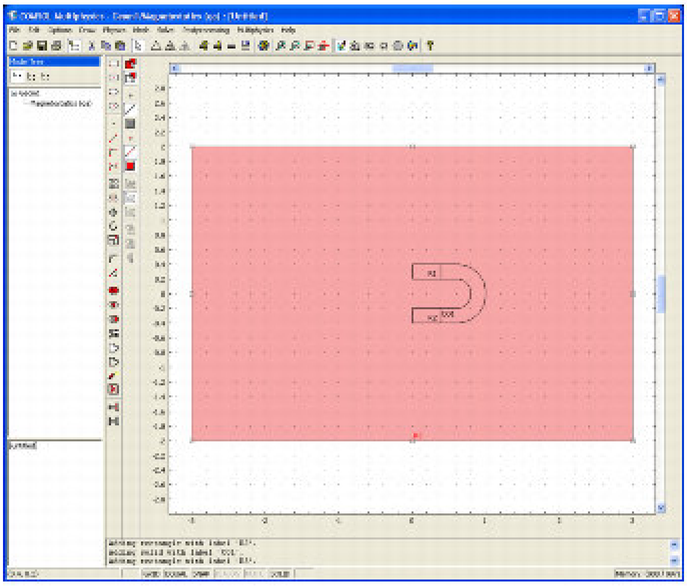
5 Click **Line** and then click at the points (0.4, -0.4), (0.4, −0.2), and (0.6, -0.2).

6 Click **2nd Degree Bezier Curve** and then click at the points (0.8, −0.2), (0.8, 0), (0.8, 0.2), and (0.6, 0.2).

7 Close the region with the right mouse button.

The last step in creating the geometry is to model the surrounding air.

8 Draw a rectangle from (−3, −2) to (3, 2).



PHYSICS SETTINGS

Boundary Conditions

Use the default magnetic insulation boundary condition everywhere.

Subdomain Settings

The relative permeability for the magnet is 5000, and the magnetization vector is (M_{pre}, 0) in the upper premagnetized part and ($-M_{pre}$, 0) in the lower part.

1 Go to the **Physics** menu and choose **Subdomain Settings**.

2 Enter the PDE coefficients as shown in the following table. For subdomains 1 and 4 use the default constitutive relationship $\mathbf{B} = \mu_0\mu_r\mathbf{H}$, and for subdomains 2 and 3 use the constitutive relationship $B = \mu_0\mathbf{H} + \mu_0\mathbf{M}$.

SUBDOMAIN	**1**	**2**	**3**	**4**
μ_r	1			murFe
M_x		-Mpre	Mpre	
M_y		0	0	

MESH GENERATION

To resolve the field at the ends of the magnets, use a smaller mesh size at those boundaries:

1 From the **Mesh** menu, choose **Free Mesh Parameters**.

2 Click the **Boundary** tab.

3 Select boundaries 4 and 7 (the ends of the magnet).

4 Type `0.01` in the **Maximum element size** edit field.

5 Click **OK**.

6 Click the **Initialize Mesh** button in the Main toolbar to create the mesh.

COMPUTING THE SOLUTION

Use the adaptive solver to improve the solution accuracy.

1 Go to the **Solve** menu and choose **Solver Parameters**.

2 In the **Solver Parameters** dialog box, select the **Adaptive mesh refinement** check box underneath the **Solver** list.

3 Click **OK**.

4 Click the **Solve** button.

POSTPROCESSING AND VISUALIZATION

Use the streamline plot to visualize the magnetic field using field lines where the distance between the lines is inversely proportional to the magnetic field strength.

1 Open the **Plot Parameters** dialog box.

2 Select the **Streamline** check box.

3 Click the **Streamline** tab.

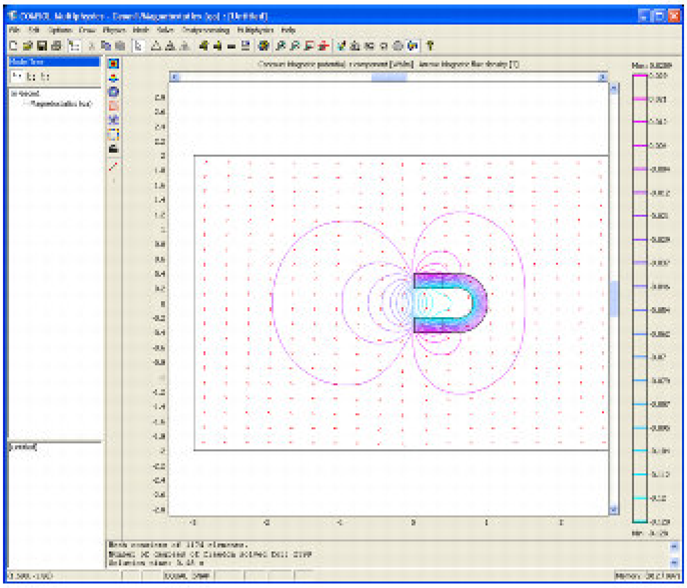
4 Select **Magnitude controlled** from the **Streamline plot type** list.

5 Type `50` in the **Density** edit field.

6 Click the **Line Color** tab.

7 Click the **Color** button, and then select a white color from the palette in the **Streamline Color** dialog box. Click **OK**.

8 Click **OK**.



The resulting plot shows the well-known field pattern.

Alternative Modeling Approach

An alternate way to model a permanent magnet is to set surface currents on the premagnetized parts. To do so, change the model from the previous discussion in the following fashion:

PHYSICS SETTINGS

Boundary Conditions

1 Select the **Interior boundaries** check box in the **Boundary Settings** dialog box.

2 Enter these boundary coefficients:

BOUNDARY	**5, 9**	**6, 8**
Type	Surface current	Surface current
J_{sz}	`Mpre`	`-Mpre`

Subdomain Settings

Modify the subdomain settings to remove the magnetization:

SUBDOMAIN	**2, 3**
M_x	0

COMPUTING THE SOLUTION

Go to the **Solver Parameters** dialog box and clear the **Adaptive mesh refinement** check box to turn off the adaptive solver. Simply use the mesh obtained by solving the previous problem. Solve the problem again.

POSTPROCESSING AND VISUALIZATION

The solution plot reveals a result identical to the one where you modeled the premagnetization using a magnetization vector.

References

1. Cheng, D. K. *Field and Wave Electromagnetics.* Addison-Wesley. Reading, MA, 1989.

2. Jin, Jianming. *The Finite Element Method in Electromagnetics*, John Wiley & Sons, New York, 1993.

3. Popovic, Branko D., *Introductory Engineering Electromagnetics*, Addison-Wesley, Reading, MA, 1971.