Magnetic Field of a Helmholtz Coil

Introduction

A Helmholtz coil is a parallel pair of identical circular coils spaced one radius apart and wound so that the current flows through both coils in the same direction. This winding results in a uniform magnetic field between the coils with the primary component parallel to the axis of the two coils. The uniform field is the result of the sum of the two field components parallel to the axis of the coils and the difference between the components perpendicular to the same axis.

The purpose of the device is to allow scientists and engineers to perform experiments and tests that require a known ambient magnetic field. Helmholtz field generation can be static, time-varying DC, or AC, depending on application.

Applications include cancelling the earth's magnetic field for certain experiments; generating magnetic fields for determining magnetic shielding effectiveness or susceptibility of electronic equipment to magnetic fields; calibration of magnetometers and navigational equipment; and biomagnetic studies.

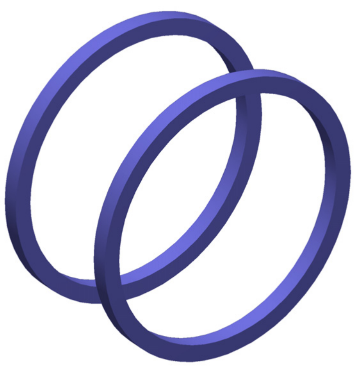


Figure 1: The Helmholtz coil consists of two coaxial circular coils, one radius apart along the axial direction. The coils carry parallel currents of equal magnitude.

Model Definition

The model is built using the 3D Magnetic Fields interface. The model geometry is shown in Figure 2.

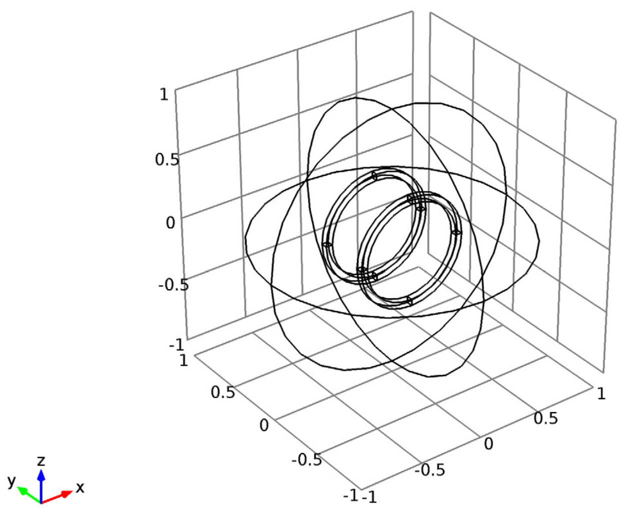


Figure 2: The model geometry.

DOMAIN EQUATIONS

Assuming static currents and fields, the magnetic vector potential **A** must satisfy the following equation:

$$\nabla\times(\mu^{-1}\nabla\times\mathbf{A}) = \mathbf{J}^{\mathrm{e}}$$

where μ is the permeability, and $\mathbf{J}^{\mathrm{e}}$ denotes the externally applied current density.

The relations between the magnetic field **H**, the magnetic flux density **B** and the potential are given by

$$\mathbf{B} = \nabla\times\mathbf{A}$$

$$\mathbf{H} = \mu^{-1}\mathbf{B}$$

This model uses the permeability of vacuum, that is, $\mu = 4\pi\cdot10^{-7}$ H/m. The external current density is computed using a homogenized model for the coils, each one made by 10 wire turns and excited by a current of 0.25 mA. The currents are specified to be parallel for the two coils.

Results and Discussion

Figure 3 shows the magnetic flux density between the coils. You can see that the flux is relatively uniform between the coils, except for the region close to the edges of the coil.

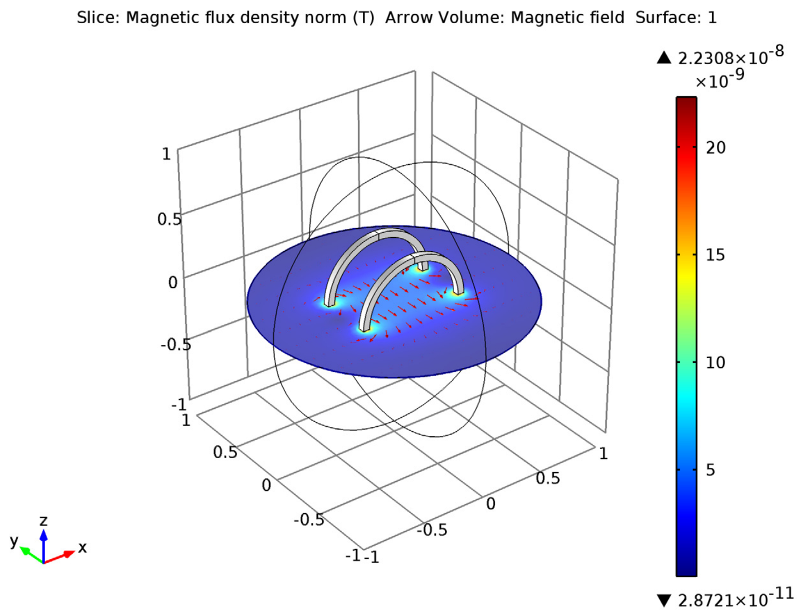


Figure 3: The slice plot shows the magnetic flux density. The arrows indicate the magnetic field (H) strength and direction.

This uniformity is the main property and often the sought feature of a Helmholtz coil.

Model Library path: `ACDC_Module/Inductive_Devices_and_Coils/helmholtz_coil`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

1 In the **New** window, click the **Model Wizard** button.

MODEL WIZARD

1 In the **Model Wizard** window, click the **3D** button.

2 In the **Select physics** tree, select **AC/DC>Magnetic Fields (mf)**.

3 Click the **Add** button.

4 Click the **Study** button.

5 In the tree, select **Preset Studies>Stationary**.

6 Click the **Done** button.

GLOBAL DEFINITIONS

Parameters

1 On the **Home** toolbar, click **Parameters**.

2 In the **Parameters** settings window, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Description
`I0`	`0.25[mA]`	`Coil current`

GEOMETRY 1

On the **Geometry** toolbar, click **Work Plane**.

Square 1

1 In the **Model Builder** window, under **Component 1>Geometry 1>Work Plane 1** right-click **Plane Geometry** and choose **Square**.

2 In the **Square** settings window, locate the **Size** section.

3 In the **Side length** edit field, type `0.05`.

4 Locate the **Position** section. From the **Base** list, choose **Center**.

5 In the **xw** edit field, type `-0.4`.

6 In the **yw** edit field, type `0.2`.

Square 2

1 Right-click **Plane Geometry** and choose **Square**.

2 In the **Square** settings window, locate the **Size** section.

3 In the **Side length** edit field, type `0.05`.

4 Locate the **Position** section. From the **Base** list, choose **Center**.

5 In the **xw** edit field, type `-0.4`.

6 In the **yw** edit field, type `-0.2`.

Work Plane 1

1 On the **Work Plane** toolbar, click **Close**.

2 On the **Geometry** toolbar, click **Revolve**.

Sphere 1

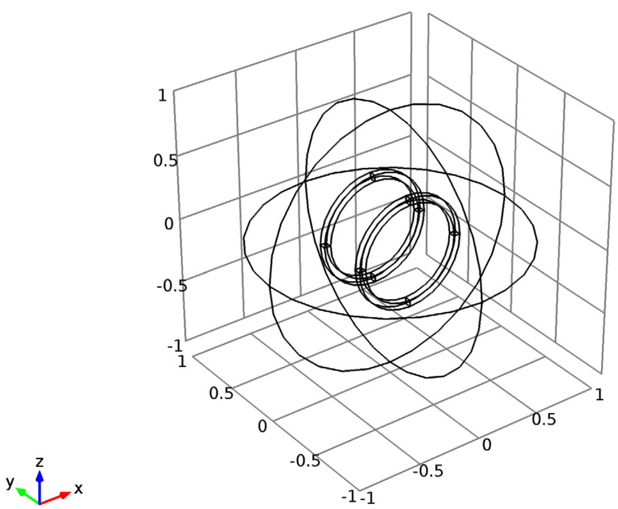
1 On the **Geometry** toolbar, click **Sphere**.

2 In the **Model Builder** window, under **Component 1>Geometry 1** right-click **Sphere 1** and choose **Build Selected**.

3 Click the **Zoom Extents** button on the Graphics toolbar.

Your geometry is now complete. To see its interior, choose wireframe rendering:

4 Click the **Wireframe Rendering** button on the Graphics toolbar.



MATERIALS

On the **Home** toolbar, click **Add Material**.

ADD MATERIAL

1 Go to the **Add Material** window.

2 In the tree, select **Built-In>Air**.

3 In the **Add material** window, click **Add to Component**.

By default, the first material you add applies on all domains so you need not alter any settings.

4 Close the **Add Material** window.

MAGNETIC FIELDS

Multi-Turn Coil 1

1 On the **Physics** toolbar, click **Domains** and choose **Multi-Turn Coil**.

2 Select Domain 2 only.

3 In the **Multi-Turn Coil** settings window, locate the **Coil Type** section.

4 From the list, choose **Circular**.

5 Locate the **Multi-Turn Coil** section. In the I_{coil} edit field, type `10`.

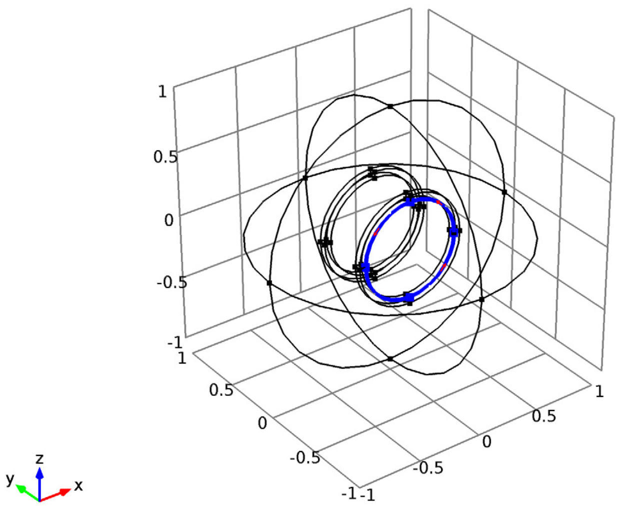
In order to specify the direction of the wires in the circular coil, you need to add a Reference Edge subfeature and select a group of edges forming a circle. The path of the wires will be automatically computed from the geometry of the selected edges. For the best results, the radius of the circular edges selected should be close to the average radius of the coil.

Reference Edge 1

1 Right-click **Component 1>Magnetic Fields>Multi-Turn Coil 1** and choose **Edges>Reference Edge**.

2 In the **Reference Edge** settings window, locate the **Edge Selection** section.

3 Click **Clear Selection**, then select Edges 20, 21, 36, and 39 only.



Now set up the second coil in the same way.

Multi-Turn Coil 2

1 On the **Physics** toolbar, click **Domains** and choose **Multi-Turn Coil**.

2 Select Domain 3 only.

3 In the **Multi-Turn Coil** settings window, locate the **Coil Type** section.

4 From the list, choose **Circular**.

5 Locate the **Multi-Turn Coil** section. In the I_{coil} edit field, type `10`.

Reference Edge 1

1 Right-click **Component 1>Magnetic Fields>Multi-Turn Coil 2** and choose **Reference Edge**.

2 In the **Reference Edge** settings window, locate the **Edge Selection** section.

3 Click **Clear Selection**.

4 Select Edges 25, 26, 56, and 59 only.

MESH 1

1 In the **Model Builder** window, under **Component 1** click **Mesh 1**.

2 In the **Mesh** settings window, locate the **Mesh Settings** section.

3 From the **Element size** list, choose **Coarse**.

Free Tetrahedral 1

Right-click **Component 1>Mesh 1** and choose **Free Tetrahedral**.

Size 1

1 In the **Model Builder** window, under **Component 1>Mesh 1** right-click **Free Tetrahedral 1** and choose **Size**.

2 In the **Size** settings window, locate the **Geometric Entity Selection** section.

3 From the **Geometric entity level** list, choose **Domain**.

4 Select Domains 2 and 3 only.

5 Locate the **Element Size** section. Click the **Custom** button.

6 Locate the **Element Size Parameters** section. Select the **Maximum element size** check box.

7 In the associated edit field, type `0.05`.

8 In the Settings window, click **Build All**.

STUDY 1

1 In the **Model Builder** window, click **Study 1**.

2 In the **Study** settings window, locate the **Study Settings** section.

3 Clear the **Generate default plots** check box.

4 On the **Home** toolbar, click **Compute**.

Add a selection to the computed data set to exclude the outer boundaries.

DEFINITIONS

Explicit 1

1 On the **Definitions** toolbar, click **Explicit**.

2 In the **Explicit** settings window, locate the **Output Entities** section.

3 From the **Output entities** list, choose **Adjacent boundaries**.

4 Select Domains 2 and 3 only.

5 Right-click **Component 1>Definitions>Explicit 1** and choose **Rename**.

6 Go to the **Rename Explicit** dialog box and type `Coils` in the **New name** edit field.

7 Click **OK**.

RESULTS

Data Sets

1 In the **Model Builder** window, under **Results>Data Sets** right-click **Solution 1** and choose **Add Selection**.
2 In the **Selection** settings window, locate the **Geometric Entity Selection** section.
3 From the **Geometric entity level** list, choose **Boundary**.
4 From the **Selection** list, choose **Coils**.

Now add the plots.

3D Plot Group 1

1 On the **Results** toolbar, click **3D Plot Group**.
2 On the **3D Plot Group 1** toolbar, click **Slice**.
3 In the **Slice** settings window, locate the **Plane Data** section.
4 From the **Plane** list, choose **xy-planes**.
5 In the **Planes** edit field, type 1.
6 Click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Magnetic Fields>Magnetic>Magnetic flux density norm (mf.normB)**. Confirm by double clicking or pressing Enter.
7 On the **3D Plot Group 1** toolbar, click **Plot**.
8 In the **Model Builder** window, right-click **3D Plot Group 1** and choose **Arrow Volume**.
9 In the **Arrow Volume** settings window, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Magnetic Fields>Magnetic>Magnetic field (mf.Hx,mf.Hy,mf.Hz)**. Confirm by double clicking or pressing Enter.
10 Locate the **Arrow Positioning** section.
11 Find the **x grid points** subsection. In the **Points** edit field, type 24.
12 Find the **y grid points** subsection. In the **Points** edit field, type 10.
13 Find the **z grid points** subsection. In the **Points** edit field, type 1.
14 Locate the **Coloring and Style** section. Select the **Scale factor** check box.
15 In the associated edit field, type 25.
16 On the **3D Plot Group 1** toolbar, click **Plot**.

To make the coil look like a solid object, you can add a surface plot on its boundaries.

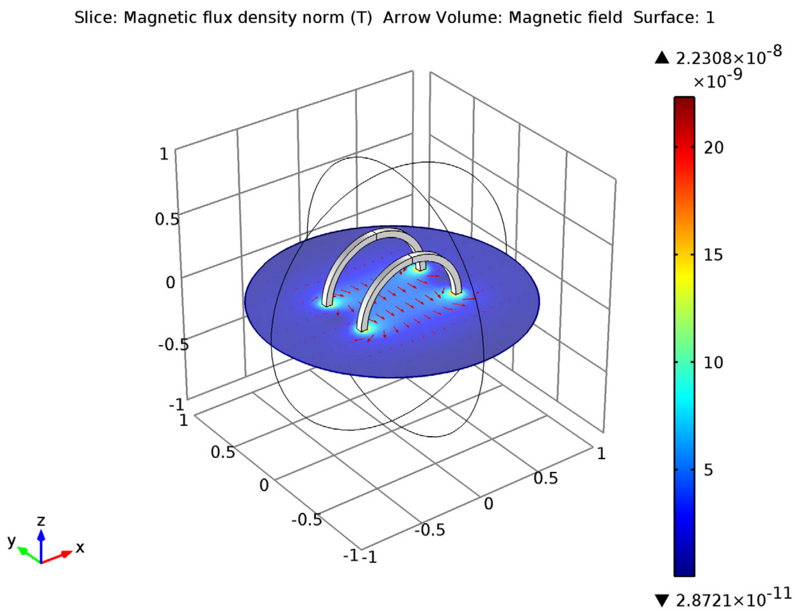
17 Right-click **3D Plot Group 1** and choose **Surface**.

18 In the **Surface** settings window, locate the **Expression** section.

19 In the **Expression** edit field, type 1.

20 Locate the **Coloring and Style** section. From the **Coloring** list, choose **Uniform**.

21 From the **Color** list, choose **White**.



To verify that the current path is computed correctly, plot the coil direction variable for each coil.

3D Plot Group 2

1 On the **Home** toolbar, click **Add Plot Group** and choose **3D Plot Group**.

2 In the **Model Builder** window, under **Results** right-click **3D Plot Group 2** and choose **Streamline**.

3 Select an internal boundary in the first coil, such as Boundary 5.

4 In the **Streamline** settings window, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Magnetic Fields>Coil parameters>Coil direction (mf.mtcd1.eCoilx,...,mf.mtcd1.eCoilz)**.

5 In the **Model Builder** window, right-click **3D Plot Group 2** and choose **Streamline**.

6 Select an internal boundary in the second coil, such as Boundary 12.

7 In the **Streamline** settings window, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Magnetic Fields>Coil parameters>Coil direction (mf.mtcd2.eCoilx,...,mf.mtcd2.eCoilz)**.

8 Locate the **Coloring and Style** section. From the **Color** list, choose **Blue**.

9 On the **3D plot group** toolbar, click **Plot**.