Model created in COMSOL Multiphysics 6.4

Tubular Permanent Magnet Generator

Introduction

This tutorial demonstrates how to model a tubular permanent magnet generator in a 2D axisymmetric system. This is accomplished by coupling the **Magnetic Fields** interface with a **Moving Mesh**. *Note: for rotational electrical machines, the Rotating Machinery, Magnetic interface is the recommended method.* As the tubular generator is a type of linear motor, this can be modeled using a 2D axisymmetric geometry and applying periodic conditions on the appropriate boundaries.

This tubular generator model considers an array of magnetics moving with a constant velocity through a tube of open circuit-connected three phase coils in the stator. The model results show the magnetic fields in the system with the key result being the calculated induced voltages from the generator. This can be the basis for then applying a proper current.

Model Definition

The geometry consists of two parts, the stationary stator and the moving slider. The stator consists of three coils running three different phases. The slider contains an array of cylindrical magnets with alternating polarities separated by nonlinear magnetic material, see Figure 1. The slider is modeled using a **Moving Mesh** and is connected to the stator using a **Periodic Magnetic Continuity** boundary pair.

As the tubular generator consists of a periodic array of magnets and coils, symmetry can be utilized to reduce computational cost. Here, only one unit cell of the structure is modeled and a periodic condition is applied to the top and bottom boundaries of the geometry to represent the rest of the array. This is done by applying continuous **Periodic Conditions** to the edges of the slider and stator.

The study step of this model is divided into two parts. An initial stationary study to get the initial condition followed by a time dependent study to analyze the induced voltages as the slider moves through the stator.

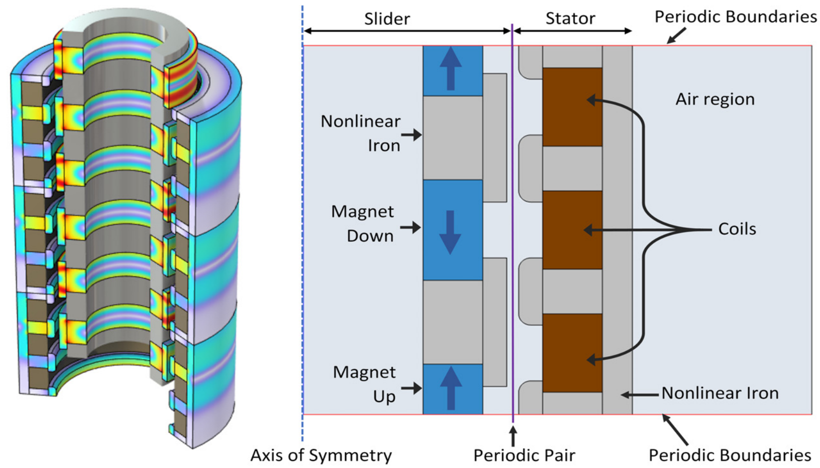


Figure 1: Left: 3D view of the tubular generator showing the magnetic flux density in the nonlinear magnetic material. Right: 2D cross-sectional axisymmetric view of the tubular generator. This shows the arrangements of the coils, the permanent magnets, and the nonlinear magnetic material. The left "Slider" section of the geometry is mapped using a moving mesh while the right "Stator" section uses a fixed mesh. These two meshes communicate through the applied periodic magnetic continuity boundary pair. The red periodic boundaries apply a repeating functionality allowing for the representation of a larger geometry.

Results and Discussion

This model produces results in both 2D cross-sectional and revolved views. Figure 2 shows the cross-sectional magnetic flux in the generator where the field lines show the continuity across the periodic conditions. In Figure 3, the geometry is partially revolved to show the 3D nature of the tubular generator with a section left out to show the internal magnetic vector potential in the nonlinear iron. Finally, Figure 4 shows the voltage induced by the generator in each of the three coil phases.

Several of the key variables for the performance of the motor are set in the **Parameters** sections of the model. This allows for convenient changing of variables such as the slider speed and the number of turns in the coils to experiment with and produce different voltage curves from the generator.

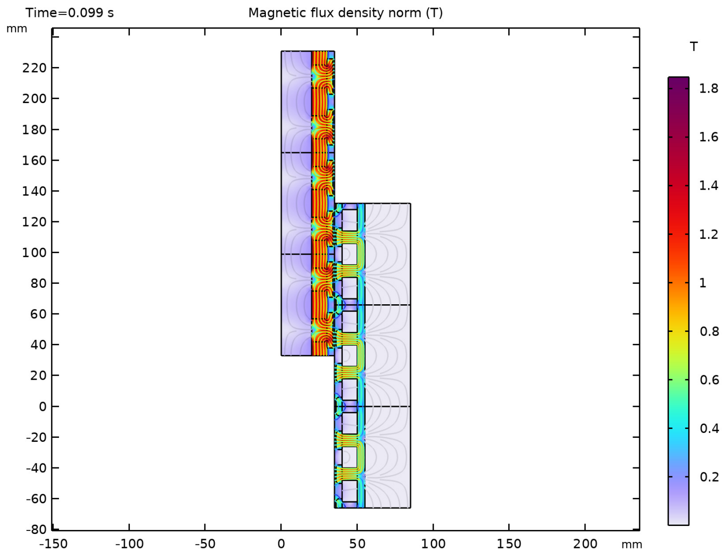


Figure 2: Cross-sectional view of the magnetic flux in the tubular generator. Three of the modeled unit cells are stacked together to illustrate the periodic nature of the system.

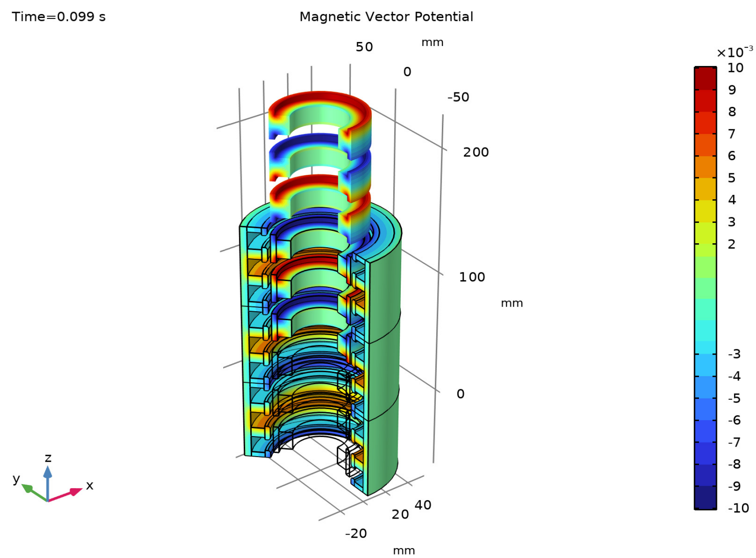


Figure 3: Revolved representation of the 2D simulation showing the magnetic vector potential in the nonlinear magnetic material in both the slider and the stator. This plot shows three stacked copies of the modeled geometry to represent a larger section of the linear generator. This illustrates how the periodic conditions knit the vector potentials together at the boundaries of the geometry.

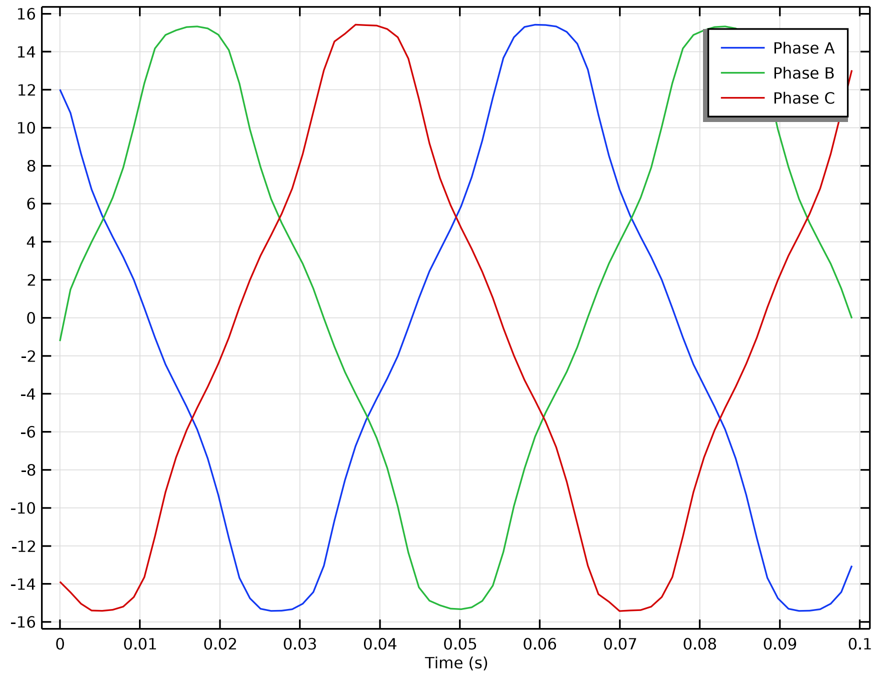


Figure 4: Open circuit voltages produced in each of the three phases of coils.

Application Library path: `ACDC_Module/Devices,_Motors_and_Generators/tubular_permanent_magnet_generator`

Modeling Instructions

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

NEW

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

MODEL WIZARD

1 In the **Model Wizard** window, click **2D Axisymmetric**.

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

3 Click **Add**.

4 In the **Select Physics** tree, select **Mathematics** > **Deformed Mesh** > **Moving Mesh** > **Prescribed Deformation**.

5 Click **Add**.

6 Click **Study**.

7 In the **Select Study** tree, select **General Studies** > **Stationary**.

8 Click **Done**.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 Click the **Load** button. From the menu, choose **Load from File**.

4 Browse to the model's Application Libraries folder and double-click the file `tubular_permanent_magnet_generator_parameters.txt`.

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **mm**.

4 Locate the **Advanced** section. From the **Default repair tolerance** list, choose **Relative**.

Rectangle 1 (r1)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `M_w`.

4 In the **Height** text field, type `P_P`.

5 Locate the **Position** section. In the **r** text field, type `S_r`.

6 Click to expand the **Layers** section. In the table, enter the following settings:

Layer name	**Thickness (mm)**
`Layer 1`	`Mg_h/2`
`Layer 2`	`Sl_ch`

7 Select the **Layers on top** checkbox.

Rectangle 2 (r2)

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `Sl_tw`.
4 In the **Height** text field, type `Sl_h`.
5 Locate the **Position** section. In the **r** text field, type `S_r+M_w`.
6 In the **z** text field, type `Mg_h/2-(Sl_h-Sl_ch)/2`.

Move 1 (mov1)

1 In the **Geometry** toolbar, click **Transforms** and choose **Move**.
2 Select the object **r2** only.
3 In the **Settings** window for **Move**, locate the **Input** section.
4 Select the **Keep input objects** checkbox.
5 Locate the **Displacement** section. In the **z** text field, type `Mg_h+Sl_ch`.

Rectangle 3 (r3)

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `M_w`.
4 In the **Height** text field, type `P_P`.
5 Locate the **Position** section. In the **r** text field, type `S_r+M_w+Sl_tw+A_g+St_w`.
6 Locate the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (mm)
Layer 1	St_h/2
Layer 2	C_h
Layer 3	St_h

7 Select the **Layers on top** checkbox.

Rectangle 4 (r4)

1 In the **Geometry** toolbar, click **Rectangle**.
2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.
3 In the **Width** text field, type `St_w`.
4 In the **Height** text field, type `St_h*1.5`.
5 Locate the **Position** section. In the **r** text field, type `S_r+M_w+Sl_tw+A_g`.

6 In the **z** text field, type St_h+C_h-St_h*1.5/2.

Move 2 (mov2)

1 In the **Geometry** toolbar, click **Transforms** and choose **Move**.

2 Select the object **r4** only.

3 In the **Settings** window for **Move**, locate the **Input** section.

4 Select the **Keep input objects** checkbox.

5 Locate the **Displacement** section. In the **z** text field, type C_h+St_h.

Rectangle 5 (r5)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type St_w.

4 In the **Height** text field, type St_h*1.5/2.

5 Locate the **Position** section. In the **r** text field, type S_r+M_w+Sl_tw+A_g.

Rectangle 6 (r6)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type St_w.

4 In the **Height** text field, type St_h*1.5/2.

5 Locate the **Position** section. In the **r** text field, type S_r+M_w+Sl_tw+A_g.

6 In the **z** text field, type P_P-1.5*St_h/2.

Fillet 1 (fil1)

1 In the **Geometry** toolbar, click **Fillet**.

2 On the object **mov2**, select Points 1 and 4 only.

3 On the object **r4**, select Points 1 and 4 only.

4 On the object **r5**, select Point 4 only.

5 On the object **r6**, select Point 1 only.

6 In the **Settings** window for **Fillet**, locate the **Radius** section.

7 In the **Radius** text field, type A_g.

Rectangle 7 (r7)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `S_r+M_w+Sl_tw+A_g/2`.

4 In the **Height** text field, type `P_P`.

Rectangle 8 (r8)

1 In the **Geometry** toolbar, click **Rectangle**.

2 In the **Settings** window for **Rectangle**, locate the **Size and Shape** section.

3 In the **Width** text field, type `50`.

4 In the **Height** text field, type `P_P`.

5 Locate the **Position** section. In the **r** text field, type `S_r+M_w+Sl_tw+A_g/2`.

6 Locate the **Layers** section. In the table, enter the following settings:

Layer name	Thickness (mm)
Layer 1	A_g/2+St_w+C_w+St_ith

7 Clear the **Layers on bottom** checkbox.

8 Select the **Layers to the left** checkbox.

Moving Part

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, type `Moving Part` in the **Label** text field.

3 Select the objects **mov1**, **r1**, **r2**, and **r7** only.

4 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

Statoric Part

1 In the **Geometry** toolbar, click **Booleans and Partitions** and choose **Union**.

2 In the **Settings** window for **Union**, type `Statoric Part` in the **Label** text field.

3 Select the objects **fill(1)**, **fill(2)**, **fill(3)**, **fill(4)**, **r3**, and **r8** only.

4 Locate the **Selections of Resulting Entities** section. Select the **Resulting objects selection** checkbox.

Magnets

1 In the **Geometry** toolbar, click **Selections** and choose **Explicit Selection**.

2 In the **Settings** window for **Explicit Selection**, type `Magnets` in the **Label** text field.

3 On the object **uni1**, select Domains 2, 4, and 6 only.

Laminated Core

1 In the **Geometry** toolbar, click **Selections** and choose **Explicit Selection**.

2 In the **Settings** window for **Explicit Selection**, type `Laminated Core` in the **Label** text field.

3 On the object **uni1**, select Domains 3, 5, 8, and 9 only.

4 On the object **uni2**, select Domains 2–6, 8, 10, 12, and 13 only.

Coils

1 In the **Geometry** toolbar, click **Selections** and choose **Explicit Selection**.

2 In the **Settings** window for **Explicit Selection**, type `Coils` in the **Label** text field.

3 On the object **uni2**, select Domains 7, 9, and 11 only.

Form Union (fin)

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** click **Form Union (fin)**.

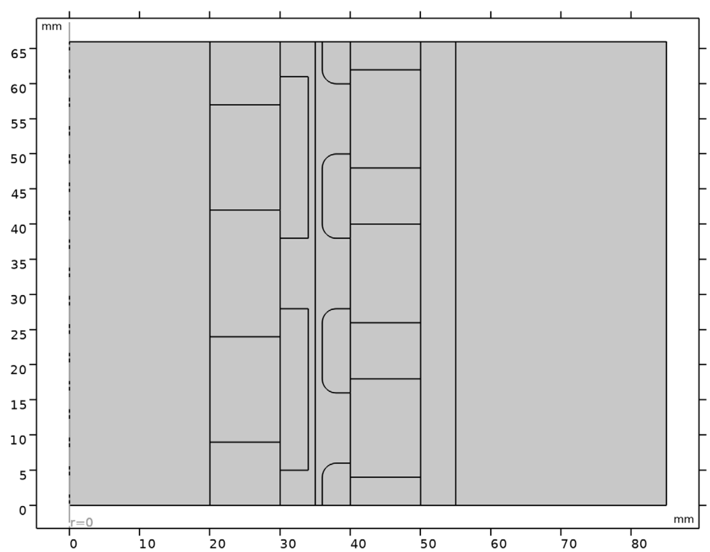
2 In the **Settings** window for **Form Union/Assembly**, locate the **Form Union/Assembly** section.

3 From the **Action** list, choose **Form an assembly**.

4 From the **Repair tolerance** list, choose **Relative**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.

6 In the **Geometry** toolbar, click **Build All**.



The geometry should look like the figure above.

ADD MATERIAL

1 In the **Materials** toolbar, click **Add Material** to open the **Add Material** window.

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

3 In the tree, select **AC/DC** > **Soft Iron (Without Losses)**.

4 Click the **Add to Component** button in the window toolbar.

MATERIALS

Soft Iron (Without Losses) (mat1)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Selection** list, choose **Laminated Core**.

ADD MATERIAL

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

2 In the tree, select **AC/DC** > **Hard Magnetic Materials** > **Sintered NdFeB Grades (Chinese Standard)** > **N50 (Sintered NdFeB)**.

3 Click the **Add to Component** button in the window toolbar.

MATERIALS

N50 (Sintered NdFeB) (mat2)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Selection** list, choose **Magnets**.

ADD MATERIAL

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

2 In the tree, select **AC/DC** > **Copper**.

3 Click the **Add to Component** button in the window toolbar.

4 In the **Materials** toolbar, click **Add Material** to close the **Add Material** window.

MATERIALS

Copper (mat3)

1 In the **Settings** window for **Material**, locate the **Geometric Entity Selection** section.

2 From the **Selection** list, choose **Coils**.

MOVING MESH

Prescribed Deformation 1

The **Moving Mesh** models the linear motion of the slider.

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Moving Mesh** click **Prescribed Deformation 1**.
2 In the **Settings** window for **Prescribed Deformation**, locate the **Geometric Entity Selection** section.
3 From the **Selection** list, choose **Moving Part**.
4 Locate the **Prescribed Deformation** section. Specify the *dx* vector as

speed*if(isdefined(t),t,0[s])	Z

MAGNETIC FIELDS (MF)

Free Space 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Magnetic Fields (mf)** click **Free Space 1**.
2 In the **Settings** window for **Free Space**, locate the **Stabilization** section.
3 From the σ_{stab} list, choose **Automatic**.

Domain Coil 1

1 In the **Physics** toolbar, click **Domains** and choose **Domain Coil**.
2 Select Domains 16, 18, and 20 only.
3 In the **Settings** window for **Domain Coil**, locate the **Coil** section.
4 From the **Conductor model** list, choose **Homogenized multiturn**.
5 In the I_{coil} text field, type `0[A]`.
6 Locate the **Homogenized Conductor** section. In the *N* text field, type `Nturns`.
7 From the **Coil wire cross-section area** list, choose **Filling factor**.
8 In the *f* text field, type `0.8`.

Domain Coil 3

Right-click **Domain Coil 1** and choose **Split by Connectivity**.

Magnet 1

1 In the **Physics** toolbar, click **Domains** and choose **Magnet**.
2 Select Domains 2, 4, and 6 only.

3 In the **Settings** window for **Magnet**, locate the **Constitutive Relation Jc-E** section.

4 From the **Constrain for induced currents** list, choose **No induced currents constrain**.

North 1

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

2 Select Boundaries 7, 9, and 14 only.

South 1

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

2 Select Boundaries 5, 11, and 13 only.

Laminated Core

1 In the **Physics** toolbar, click **Domains** and choose **Ampère's Law in Solids**.

2 In the **Settings** window for **Ampère's Law in Solids**, type `Laminated Core` in the **Label** text field.

3 Locate the **Domain Selection** section. From the **Selection** list, choose **Laminated Core**.

4 Locate the **Constitutive Relation B-H** section. From the **Magnetization model** list, choose **B-H curve**.

Periodic Condition 1

1 In the **Physics** toolbar, click **Boundaries** and choose **Periodic Condition**.

2 Select Boundaries 2, 3, 5, 14, 16, and 29 only.

Periodic Condition 2

1 In the **Physics** toolbar, click **Boundaries** and choose **Periodic Condition**.

2 Select Boundaries 34, 35, 37, 41, 49, 68, 70, 77, 79, and 80 only.

Periodic Magnetic Continuity 1

1 In the **Physics** toolbar, click **Pairs** and choose **Periodic Magnetic Continuity**.

2 In the **Settings** window for **Periodic Magnetic Continuity**, locate the **Pair Selection** section.

3 Click **Add**.

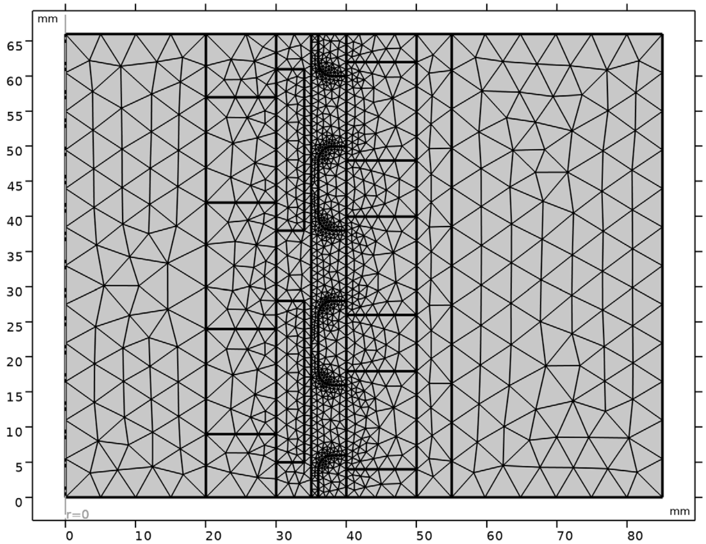
4 In the **Add** dialog, select **Identity Boundary Pair 1 (ap1)** in the **Pairs** list.

5 Click **OK**.

MESH 1

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Mesh 1** and choose **Build All**.

2 Click the **Zoom Extents** button in the **Graphics** toolbar.



The mesh should look like the figure above.

STUDY 1

Step 2: Time Dependent

1 In the **Study** toolbar, click **Time Dependent**.

2 In the **Settings** window for **Time Dependent**, locate the **Study Settings** section.

3 In the **Output times** text field, type `range(0,0.02,1.5)*P_P/speed`.

Solution 1 (sol1)

1 In the **Study** toolbar, click **Show Default Solver**.

2 In the **Model Builder** window, expand the **Solution 1 (sol1)** node.

3 In the **Model Builder** window, expand the **Study 1** > **Solver Configurations** > **Solution 1 (sol1)** > **Time-Dependent Solver 1** node, then click **Fully Coupled 1**.

4 In the **Settings** window for **Fully Coupled**, click to expand the **Method and Termination** section.

5 From the **Jacobian update** list, choose **On every iteration**.

6 In the **Study** toolbar, click **Compute**.

RESULTS

Revolution 2D 1

In the **Model Builder** window, expand the **Results** > **Datasets** node, then click **Revolution 2D 1**.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.
2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
3 From the **Geometric entity level** list, choose **Domain**.
4 Click **Paste Selection**.
5 In the **Paste Selection** dialog, type `3, 5, 8, 9, 11-15, 17, 19, 21, 22` in the **Selection** text field.
6 Click **OK**.

Revolution 2D 2

1 In the **Results** toolbar, click **More Datasets** and choose **Revolution 2D**.
2 In the **Settings** window for **Revolution 2D**, click to expand the **Revolution Layers** section.
3 In the **Start angle** text field, type `-90`.
4 In the **Revolution angle** text field, type `225`.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.
2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
3 From the **Geometric entity level** list, choose **Domain**.
4 From the **Selection** list, choose **Magnets**.

Revolution 2D 3

1 In the **Results** toolbar, click **More Datasets** and choose **Revolution 2D**.
2 In the **Settings** window for **Revolution 2D**, locate the **Revolution Layers** section.
3 In the **Start angle** text field, type `-90`.
4 In the **Revolution angle** text field, type `225`.

Selection

1 In the **Results** toolbar, click **Attributes** and choose **Selection**.
2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
3 From the **Geometric entity level** list, choose **Domain**.

4 From the **Selection** list, choose **Coils**.

Magnetic Flux Density (mf)

1 In the **Model Builder** window, expand the **Results** > **Magnetic Flux Density (mf)** node, then click **Magnetic Flux Density (mf)**.

2 In the **Settings** window for **2D Plot Group**, locate the **Color Legend** section.

3 Clear the **Show maximum and minimum values** checkbox.

4 Select the **Show units** checkbox.

Contour 1

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

2 In the **Settings** window for **Contour**, locate the **Expression** section.

3 In the **Expression** text field, type `r*mf.Aphi`.

Color Expression 1

1 Right-click **Contour 1** and choose **Color Expression**.

2 In the **Settings** window for **Color Expression**, locate the **Coloring and Style** section.

3 Clear the **Color legend** checkbox.

Surface 2

1 In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Surface 1** and choose **Duplicate**.

2 In the **Settings** window for **Surface**, click to expand the **Title** section.

3 From the **Title type** list, choose **None**.

4 Locate the **Coloring and Style** section. Clear the **Color legend** checkbox.

Transformation 1

1 Right-click **Surface 2** and choose **Transformation**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type `P_P`.

Surface 3

In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Surface 2** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, expand the **Surface 3** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type -P_P.

Streamline 2

In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Streamline 1** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, expand the **Streamline 2** node.

2 Right-click **Streamline 2** and choose **Transformation**.

3 In the **Settings** window for **Transformation**, locate the **Transformation** section.

4 In the **z** text field, type P_P.

Streamline 3

In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Streamline 2** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, expand the **Streamline 3** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type -P_P.

Contour 2

In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Contour 1** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, expand the **Contour 2** node.

2 Right-click **Contour 2** and choose **Transformation**.

3 In the **Settings** window for **Transformation**, locate the **Transformation** section.

4 In the **z** text field, type P_P.

Contour 3

In the **Model Builder** window, under **Results** > **Magnetic Flux Density (mf)** right-click **Contour 2** and choose **Duplicate**.

Transformation 1

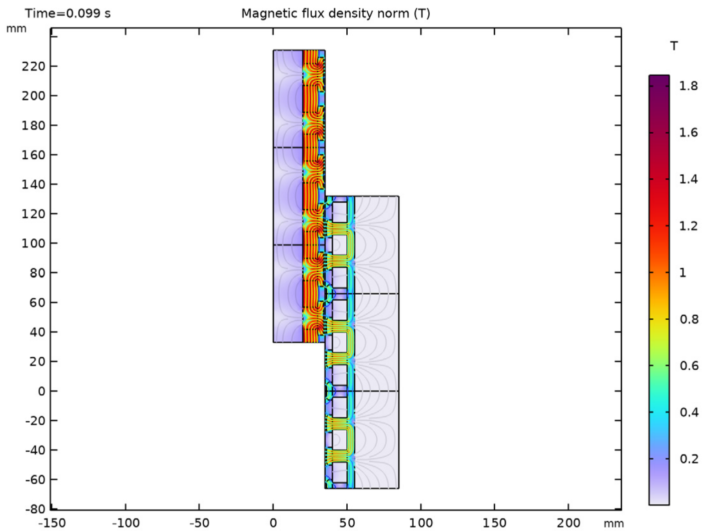
1 In the **Model Builder** window, expand the **Contour 3** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type -P_P.

4 In the **Magnetic Flux Density (mf)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.



Magnetic Flux Density Norm, Revolved Geometry (mf)

1 In the **Model Builder** window, under **Results** click **Magnetic Flux Density, Revolved Geometry (mf)**.

2 In the **Settings** window for **3D Plot Group**, type `Magnetic Flux Density Norm, Revolved Geometry (mf)` in the **Label** text field.

3 Locate the **Data** section. From the **Time (s)** list, choose **Interpolation**.

4 Click to expand the **Title** section. From the **Title type** list, choose **Custom**.

5 Find the **Type and data** subsection. Clear the **Type** checkbox.

6 Clear the **Unit** checkbox.

7 Locate the **Color Legend** section. Clear the **Show maximum and minimum values** checkbox.

8 Select the **Show units** checkbox.

Contour 1

1 In the **Model Builder** window, expand the **Magnetic Flux Density Norm, Revolved Geometry (mf)** node, then click **Contour 1**.

2 In the **Settings** window for **Contour**, locate the **Expression** section.

3 In the **Expression** text field, type `mf.normB`.

Filter 1

1 In the **Model Builder** window, expand the **Contour 1** node.

2 Right-click **Filter 1** and choose **Disable**.

Volume 2

1 In the **Model Builder** window, under **Results** > **Magnetic Flux Density Norm, Revolved Geometry (mf)** right-click **Volume 1** and choose **Duplicate**.

2 In the **Settings** window for **Volume**, locate the **Coloring and Style** section.

3 Clear the **Color legend** checkbox.

Transformation 1

1 Right-click **Volume 2** and choose **Transformation**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type P_P.

Volume 3

In the **Model Builder** window, under **Results** > **Magnetic Flux Density Norm, Revolved Geometry (mf)** right-click **Volume 2** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, expand the **Volume 3** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type -P_P.

Contour 2

In the **Model Builder** window, under **Results** > **Magnetic Flux Density Norm, Revolved Geometry (mf)** right-click **Contour 1** and choose **Duplicate**.

Transformation 1

1 In the **Model Builder** window, right-click **Contour 2** and choose **Transformation**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type P_P.

Contour 3

In the **Model Builder** window, under **Results** > **Magnetic Flux Density Norm, Revolved Geometry (mf)** right-click **Contour 2** and choose **Duplicate**.

Transformation 1

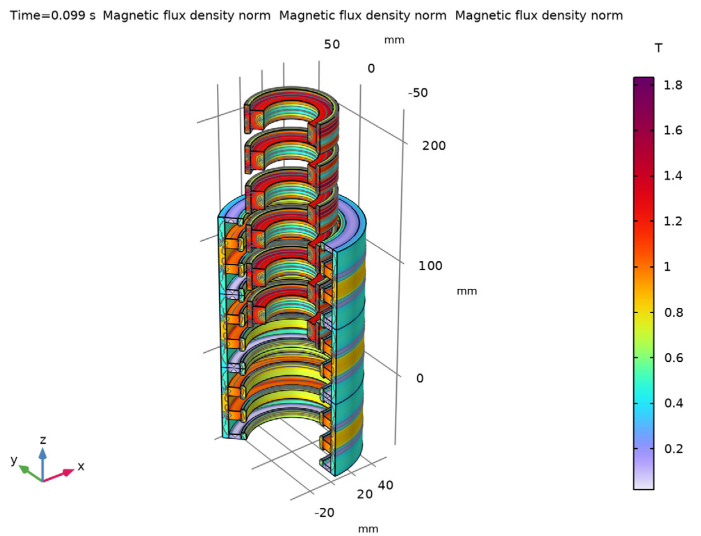
1 In the **Model Builder** window, expand the **Contour 3** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type -P_P.

4 In the **Magnetic Flux Density Norm, Revolved Geometry (mf)** toolbar, click **Plot**.

5 Click the **Zoom Extents** button in the **Graphics** toolbar.



Magnetic Vector Potential

1 In the **Results** toolbar, click **3D Plot Group**.

2 In the **Settings** window for **3D Plot Group**, type Magnetic Vector Potential in the **Label** text field.

3 Locate the **Title** section. From the **Title type** list, choose **Label**.

Magnetic vector potential

1 Right-click **Magnetic Vector Potential** and choose **Surface**.

2 In the **Settings** window for **Surface**, type Magnetic vector potential in the **Label** text field.

3 Locate the **Expression** section. In the **Expression** text field, type mf.Aphi.

4 Locate the **Coloring and Style** section. From the **Color table type** list, choose **Discrete**.

5 In the **Number of bands** text field, type 21.

6 Click the **Zoom Extents** button in the **Graphics** toolbar.

Magnetic vector potential Translated Up

1 Right-click **Magnetic vector potential** and choose **Duplicate**.

2 In the **Settings** window for **Surface**, type `Magnetic vector potential Translated Up` in the **Label** text field.

3 Locate the **Coloring and Style** section. Clear the **Color legend** checkbox.

Transformation 1

1 Right-click **Magnetic vector potential Translated Up** and choose **Transformation**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type `P_P`.

Magnetic vector potential Translated Down

1 In the **Model Builder** window, right-click **Magnetic vector potential Translated Up** and choose **Duplicate**.

2 In the **Settings** window for **Surface**, type `Magnetic vector potential Translated Down` in the **Label** text field.

Transformation 1

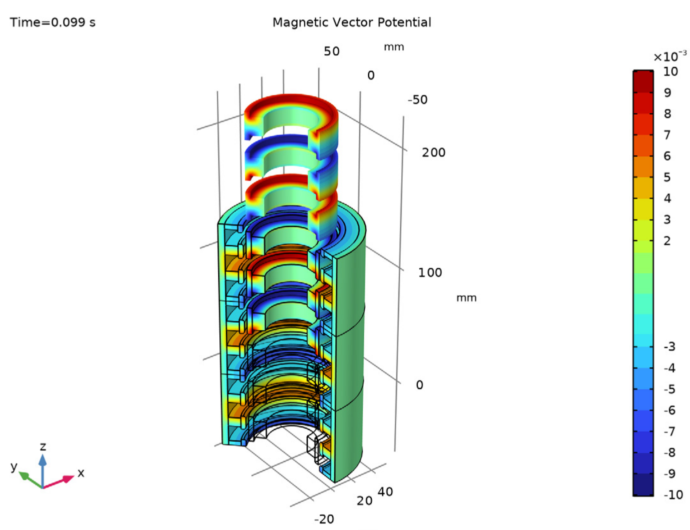
1 In the **Model Builder** window, expand the **Magnetic vector potential Translated Down** node, then click **Transformation 1**.

2 In the **Settings** window for **Transformation**, locate the **Transformation** section.

3 In the **z** text field, type `-P_P`.

4 Click the **Zoom Extents** button in the **Graphics** toolbar.

5 In the **Magnetic Vector Potential** toolbar, click **Plot**.



Phase Voltages

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Phase Voltages` in the **Label** text field.

Phase Voltages

1 Right-click **Phase Voltages** and choose **Global**.

2 In the **Settings** window for **Global**, type `Phase Voltages` in the **Label** text field.

3 Locate the **y-Axis Data** section. In the table, enter the following settings:

Expression	Unit	Description
`mf.VCoil_1`	`V`	`Phase A`
`mf.VCoil_2`	`V`	`Phase B`
`mf.VCoil_3`	`V`	`Phase C`

4 In the **Phase Voltages** toolbar, click **Plot**.