Generator

Introduction

This example shows how the circular motion of a rotor with permanent magnets generates an induced EMF in a stator winding. The generated voltage is calculated as a function of time during the rotation. The model also shows the influence on the voltage from material parameters, rotation velocity, and number of turns in the winding.

The center of the rotor consists of annealed medium carbon steel, which is a material with a high relative permeability. The center is surrounded with several blocks of a permanent magnet made of Samarium Cobalt, creating a strong magnetic field. The stator is made of the same permeable material as the center of the rotor, confining the field in closed loops through the winding. The winding is wound around the stator poles. In Figure 3-1 shows the generator with part of the stator sliced, in order to show the winding and the rotor.

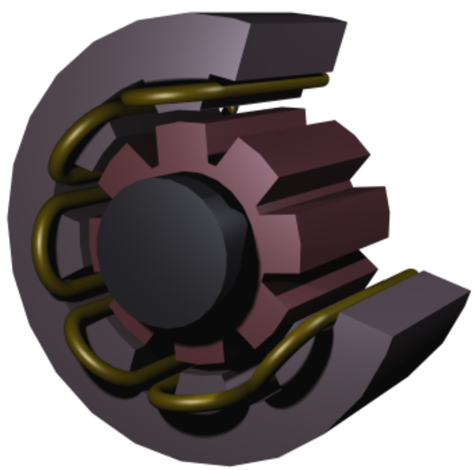


Figure 3-1: A drawing of a generator showing how the rotor, stator, and stator winding are constructed. The winding is also connected between the loops, interacting to give the highest possible voltage.

Modeling in COMSOL Multiphysics

The COMSOL Multiphysics model of the generator is a time-dependent 2D problem on a cross section through the generator. This is a true time-dependent model where

Generator in 3D

Introduction

This model is a 3D version of the 2D generator model on page 42, so most of the details about the model are explained there. The main difference is that this is a static example, calculating the magnetic fields around and inside the generator.

Modeling in COMSOL Multiphysics

The model has some differences compared to the 2D generator model. The PDE is simplified to solve for the magnetic scalar potential, V_m, instead of the vector potential, **A**. It is based on the assumption that currents can be neglected, which holds true when the generator terminals are open. The equation for V_m becomes

$$-\nabla \cdot (\mu \nabla V_m - \mathbf{B}_\mathrm{r}) = 0$$

The stator and center of the rotor are made of annealed medium-carbon steel (soft iron), which is a nonlinear magnetic material. This is implemented in COMSOL Multiphysics as an interpolation function of the B-H curve of the material. The difference compared to the 2D version is that the norm of the magnet flux, $|\mathbf{B}|$, has to be calculated from the norm of the magnetic field, $|\mathbf{H}|$, in this model.

Results and Discussion

Figure 3-10 shows the norm of the magnetic flux for a slice through a centered cross section of the generator. The plot also shows the streamlines of the magnetic flux. The starting points of the streamlines have been carefully selected to show the closed loops between neighboring stator and rotor poles. A few streamlines are also plotted at the edge of the generator to illustrate the field there.

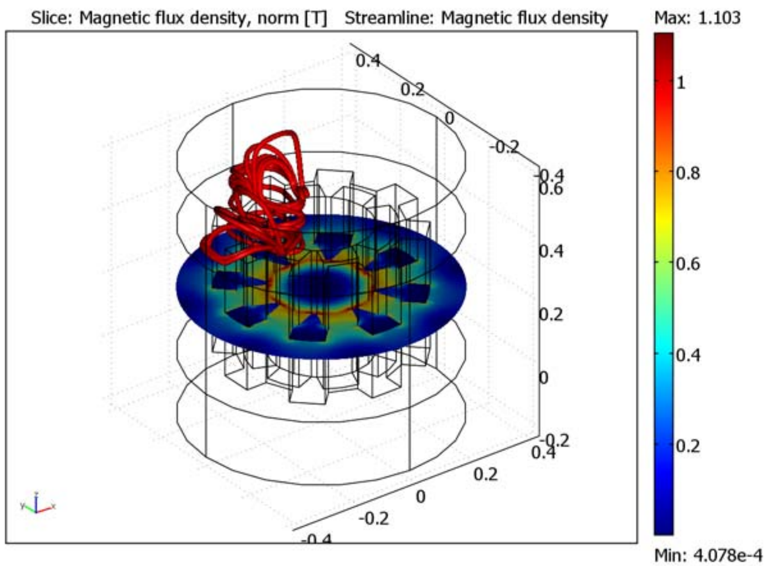


Figure 3-10: A combined slice and streamline plot of the magnetic flux density.

Model Library path: `ACDC_Module/Motors_and_Drives/generator_3d`

Modeling Using the Graphical User Interface

MODEL NAVIGATOR

1 Select **3D** in the **Space dimension** list.

2 In the **AC/DC Module** folder, select **Statics, Magnetic>Magnetostatics, No Currents**.

3 Click **OK** to close the **Model Navigator**.

GEOMETRY MODELING

1 Choose **Draw>Work-Plane Settings**.

2 In the dialog box that appears, click **OK**.

3 Choose **Draw>Specify Objects>Circle** twice to create circles with the following properties:

NAME	RADIUS	BASE	X	Y	ROTATION ANGLE
C1	0.3	Center	0	0	22.5
C1	0.235	Center	0	0	0

4 Choose **Draw>Specify Objects>Rectangle** four times to create rectangles with the following properties:

NAME	WIDTH	HEIGHT	BASE	X	Y	ROTATION ANGLE
R1	0.1	1	Center	0	0	0
R2	0.1	1	Center	0	0	45
R3	0.1	1	Center	0	0	90
R4	0.1	1	Center	0	0	135

5 In the **Create Composite Object** dialog box, clear the **Keep interior boundaries** check box.

6 Enter the formula `C2+C1*(R1+R2+R3+R4)`.

7 Click **OK**.

8 Create a circle with the following properties:

NAME	RADIUS	BASE	X	Y	ROTATION ANGLE
C1	0.215	Center	0	0	0

9 Draw four rectangles with the following properties:

NAME	WIDTH	HEIGHT	BASE	X	Y	ROTATION ANGLE
R1	0.1	1	Center	0	0	22.5
R2	0.1	1	Center	0	0	-22.5
R3	0.1	1	Center	0	0	67.5
R4	0.1	1	Center	0	0	-67.5

10 In the **Create Composite Object** dialog box, enter the formula `C1*(R1+R2+R3+R4)`.

11 Click **OK**.

12 Create a circle with the following properties:

NAME	RADIUS	BASE	X	Y	ROTATION ANGLE
C1	0.15	Center	0	0	22.5

13 In the **Create Composite Object** dialog box, make sure that the **Keep interior boundaries** check box is not selected.

14 Enter the formula `C1+CO2`.

15 Click **OK**.

16 Draw a circle with parameters according to the table below.

NAME	RADIUS	BASE	X	Y	ROTATION ANGLE
C1	0.15	Center	0	0	22.5

17 Click the **Zoom Extents** button to get a better view of the geometry.

18 Choose **Draw>Extrude**.

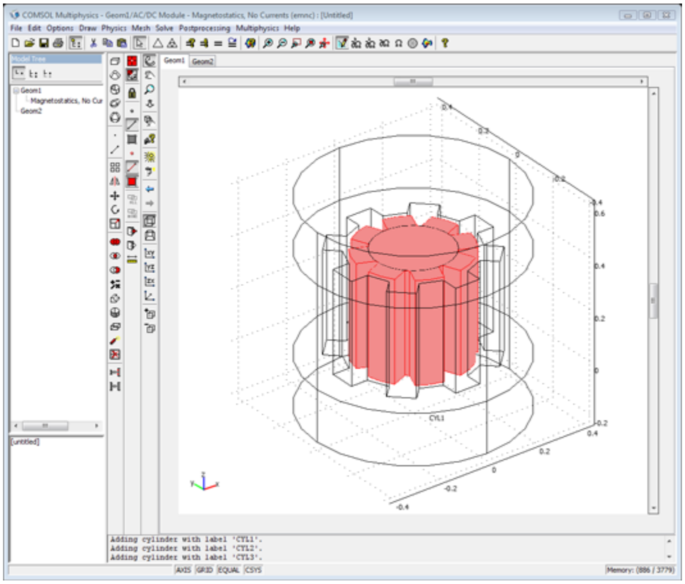
19 In the dialog box that appears, select all objects and type `0.4` in the **Distance** edit field.

20 Click **OK**.

21 Use the **Cylinder** tool to create cylinders with parameters according to the table below.

NAME	AXIS BASE POINT Z	RADIUS	HEIGHT
CYL1	-0.2	0.4	0.2
CYL2	0	0.4	0.4
CYL3	0.4	0.4	0.2

22 Click the **Zoom Extents** button to get a better view of the geometry.



PHYSICS SETTINGS

Constants

1 From the **Options** menu, select **Constants**.

2 In the **Constants** dialog box, define the following constants with names, expressions, and (optionally) descriptions; when done, click **OK**.

NAME	EXPRESSION	DESCRIPTION
`BrSmCo`	`0.84[T]`	`Remanent flux in permanent magnets`
`murSmCo`	`1`	`Relative permeability in permanent magnets`

Scalar Expressions

1 From the **Options** menu, select **Expressions>Scalar Expressions**.

2 In the **Scalar Expressions** dialog box, define the following expression; when done, click **OK**.

NAME	EXPRESSION	DESCRIPTION
`R`	`sqrt(x^2+y^2)`	`Radial coordinate`

Subdomain Settings

1 Enter subdomain settings for the active subdomains according to the table below.

SETTINGS	SUBDOMAINS 1, 3, 4	SUBDOMAINS 5, 9, 10, 13	SUBDOMAINS 6, 8, 11, 12	SUBDOMAINS 2, 7
Library material				Soft Iron (without losses)
$\mathbf{B} \leftrightarrow \mathbf{H}$	$\mathbf{B} = \mu_0\mu_r\mathbf{H}$	$\mathbf{B} = \mu_0\mu_r\mathbf{H} + \mathbf{B}_r$	$\mathbf{B} = \mu_0\mu_r\mathbf{H} + \mathbf{B}_r$	$\mathbf{B} = f(\lvert\mathbf{H}\rvert)\mathbf{e}_H$
μ_r	1	`murSmCo`	`murSmCo`	
B_{rx}		`-BrSmCo*x/R`	`BrSmCo*x/R`	
B_{ry}		`-BrSmCo*y/R`	`BrSmCo*y/R`	

For Subdomains 2 and 7, choose the material from the **Electric (AC/DC) Material Properties** library in the **Materials/Coefficients Library** dialog box, which you open by clicking **Load**.

2 Click **OK**.

Boundary Conditions

In the **Boundary Settings** dialog box, apply the **Magnetic insulation** condition to all boundaries, then click **OK**.

MESH GENERATION

1 In the **Free Mesh Parameters** dialog box, select **Finer** from the **Predefined mesh sizes** list.

2 Click **Remesh**, then click **OK**.

COMPUTING THE SOLUTION

Click the **Solve** button on the Main toolbar to compute the solution.

POSTPROCESSING AND VISUALIZATION

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

2 On the **General** page, select the check boxes for **Slice** plot and **Streamline** plot.

3 Click the **Slice** tab. From the **Predefined quantities** list, select **Magnetic flux density, norm**.

4 Type `0` in the edit field for **x levels**, and type `1` in the edit field for **z levels**.

5 Click the **Streamline** tab and select **Magnetic flux density** in the **Predefined quantities** list.

6 Click the **Specify start point coordinates** button and enter the values according to the table below.

FIELD	EXPRESSION
x	`0 0 0 0 0 0 0`
y	`0.35 0.35 0.35 0.35 0.35 0.3 0.2`
z	`range(0.1,0.49/6,0.59)`

7 Select **Tube** in the **Line type** list, then click **OK**.