

# Finite Element Model of the Switched Reluctance Machine with FEMM and Matlab – Part 2

Lo c QUEVAL (loic.queval@centralesupelec.fr) & Guillaume KREBS  
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## 1. Requirements

- FEMM 4.2 (download: [www.femm.info](http://www.femm.info))
- Matlab R2020a
- FEMM model from part 1 of this tutorial, called `tutorial_SRM_QUEVAL_20210201.FEM`

## 2. Introduction

In this document, we detail how to run FEMM from Matlab. This allows us to easily compute the flux linkage and the torque of a switched reluctance machine (SRM) as a function of its rotor angle and phase current.

Make a copy of `tutorial_SRM_QUEVAL_20210201.FEM`, and rename it `tutorial_SRM_fromFEMM.FEM`. It will be used from the FEMM interface.

Make a copy of `tutorial_SRM_QUEVAL_20210201.FEM`, and rename it `tutorial_SRM_fromMATLAB.FEM`. It will be used from the Matlab.

## 3. Open, run and close FEMM with Matlab

To load and compute the FEMM model from Matlab, use the following script:

```
% main_SRM_FEMM

clear all, close all, clc

%% load femm model
addpath('C:\femm42\mfiles') % import femm fonctions
openfemm %open femm
opendocument('tutorial_SRM_fromMATLAB.FEM.fem') %open the femm model
mi_saveas('temp.fem') %save a temporary copy of the femm model

%% run analysis
mi_analyze(0); % run analysis
mi_loadsolution; % open "view results" window
```

To close the FEMM model from Matlab, use the following script:



```
%% close femm model
mo_close; % close "view results" window
mi_close; %close the temporary copy of the femm model
```

## 4. Rotation

In this section, we want to set the rotor angle  $\theta_m$ .

### 4.1 Rotation with FEMM interface

Open the model `TD1_SRM_FEMM.fem` with FEMM.

In the Properties menu, select Boundary. In the Property Definition dialog, select move and click on Modify Property. The Boundary Property dialog opens. To rotate the rotor by an angle of 15 degrees in the counter clockwise direction, enter 15 in the Air Gap parameters: Inner Angle (Figure 1). Click OK to close both dialogs. Run the analysis with . Then click on the glasses icon  to view the analysis results.

You can repeat the procedure for different rotor angles. You should obtain the results summarized in Figure 2.

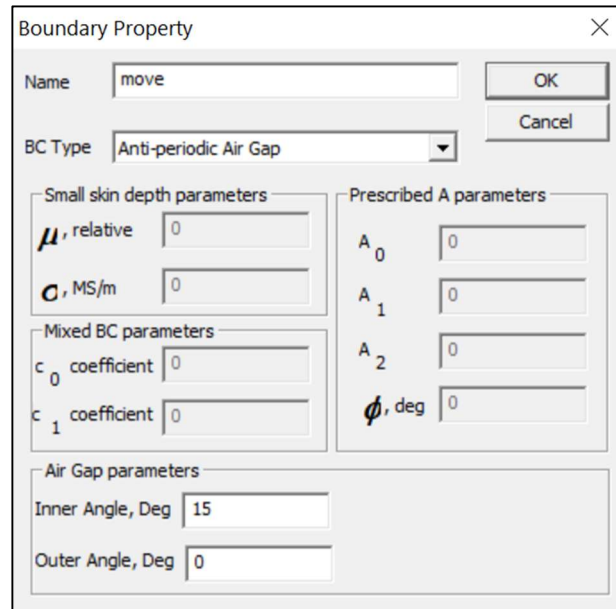


Figure 1 – Boundary property dialog.

### 4.2 Rotation with Matlab

To set the rotor angle from Matlab, use the following script:

```
%% Set rotor angle
theta_m = 15; % [deg] rotor angle
mi_modifyboundprop('move',10,theta_m); % modify boundary property 'move'
```

You change the rotor angle. You should obtain the results summarized in Figure 2.

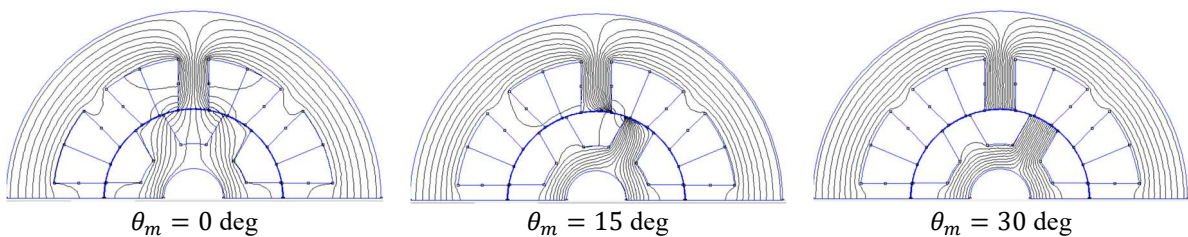




Figure 2 – Flux lines as a function of the rotor angle ( $i_c = 50 \text{ A}$ ).

## 5. Current

In this section, we want to set the current of the phase c  $i_c$ .

### 5.1 Current with FEMM interface

Open the model `TD1_SRM_FEMM.fem` with FEMM. Set the rotor angle to 0 deg.

In the **Properties** menu, select **Circuits**. In the **Property Definition** dialog, select **c** and click on **Modify Property**. The **Circuit Property** dialog appears. To set the current of the phase c to 0 A, enter 0 in the **Circuit Current (Figure 3)**. Click **OK** to close both dialogs. Run the analysis with . Then click on the glasses icon  to view the analysis results. Plot the flux density distribution (set the **Lower Bound** to 0 and the **Upper Bound** to 1.2).

You can repeat the procedure for different currents. You should obtain the results summarized in Figure 4.

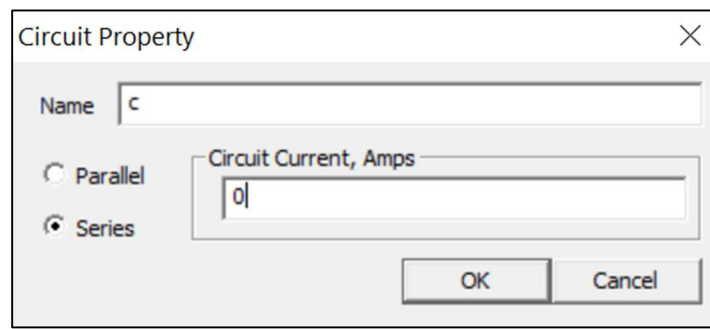


Figure 3 – Circuit property dialog.

### 5.2 Current with Matlab

To set the current  $i_c$  from Matlab, use the following script:

```
%% Set current in phase c
i_c = 0; % [A] current of circuit 'c'
mi_modifycircprop('c',1,i_c) % modify circuit property 'c'
```

Plot manually the flux density distribution (set the **Lower Bound** to 0 and the **Upper Bound** to 1.2).

You change the current. You should obtain the results summarized in Figure 4.

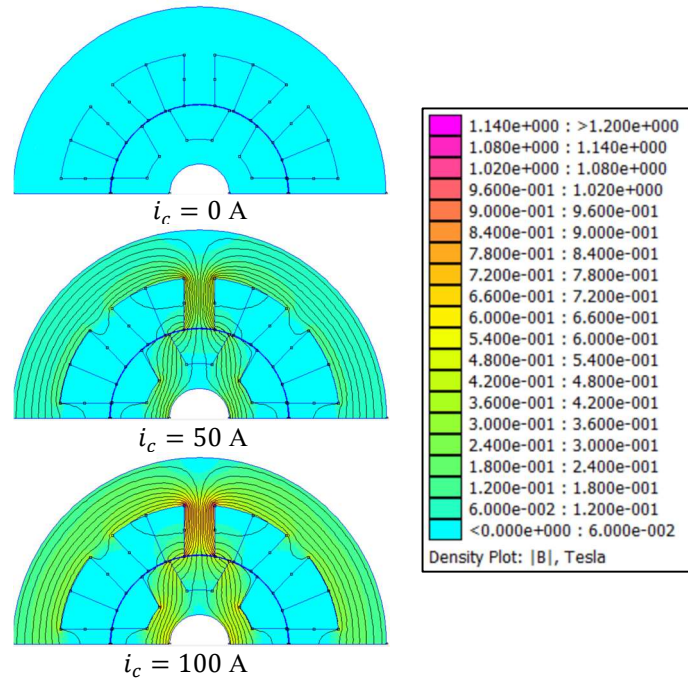





Figure 4 – Flux density distribution as a function of the current ( $\theta_m = 50^\circ$ ).

## 6. Flux linkage

In this section, we want to compute the flux linkage of the phase c  $\lambda_c$ .

### 6.1 Flux linkage with FEMM interface

Open the model `TD1_SRM_FEMM.fem` with FEMM. Set the rotor angle to  $0^\circ$ , and the current to 50 A.

Run the analysis with . Then click on the glasses icon  to view the analysis results. Press the  button to display the resulting attributes of each Circuit Property that has been defined. For the circuit c, the resulting dialog is shown in Figure 5.

*Note: Since there is only one current, the Flux/Current result can be unambiguously interpreted as the coil c self inductance (i.e. 0.3 mH).*

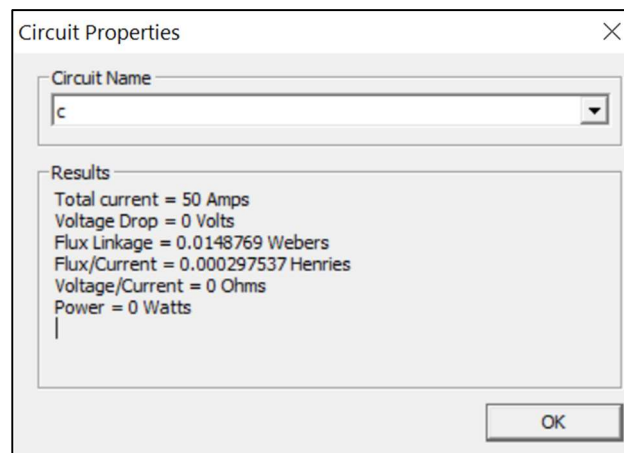


Figure 5 -Circuit Properties dialog ( $\theta_m = 0^\circ$ ,  $i_c = 50$  A).

You can change the rotor angle and the current, and repeat the procedure to obtain the flux linkage as a function of the rotor angle and of the current. You should obtain the results summarized in Table 1.

## 6.2 Flux linkage with Matlab

To get the flux linkage from Matlab, use the following script:

```
% get flux linkage
cir_c = mo_getcircuitproperties('c'); % get properties of circuit 'c'
lambda_c = cir_c(3) % get flux linkage of circuit 'c'
```





Make sure that you obtain the results summarized in Table 1.

## 7. Torque

In this section, we want to compute the electromagnetic torque  $T_e$ .

### 7.1 Torque with FEMM interface

Open the model `TD1_SRM_FEMM.fem` with FEMM. Set the rotor angle to 15 deg, and the current to 50 A.

Run the analysis with . Then click on the glasses icon  to view the analysis results. Switch to Area mode by pressing Area icon . Select the rotor iron domain. The area will turn green, denoting that it is selected (Figure 6). Click on the Integral icon . The Block Integral dialog opens. Select Torque via Weighted Stress Tensor and click OK. A dialog will pop up containing the Integral Results (Figure 7).

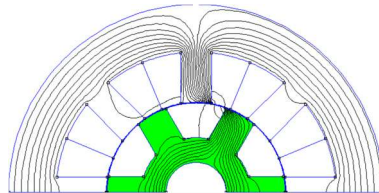


Figure 6 - Selection of the rotor domain ( $\theta_m = 15$  deg,  $i_c = 50$  A).

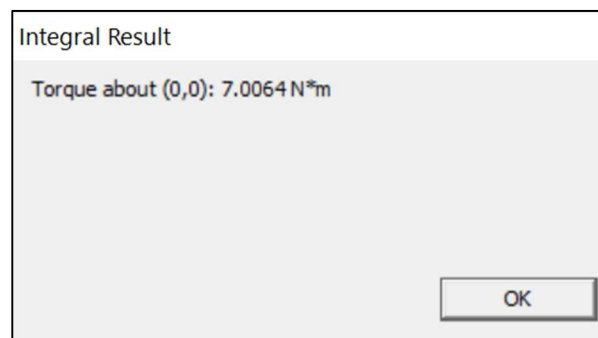


Figure 7 - Integral Result dialog ( $\theta_m = 15$  deg,  $i_c = 50$  A).

You can change the rotor angle and the current, and repeat the procedure to obtain the torque as a function of the rotor angle and of the current. You should obtain the results summarized in Table 1.

## 7.2 Torque with Matlab

To get the torque from Matlab, use the following script:

```
% get torque
mo_seteditmode('area'); % switch to area mode
mo_groupselectblock(10); % select domain number 10 = rotor iron
torque = mo_blockintegral(22) % get torque via weighted stress tensor
```

Make sure that you obtain the results summarized in Table 1.

Table 1 - Flux linkage and torque as a function of rotor angle and current.

Rotor angle $\theta_m$ [deg]	Current $i_c$ [A]	Flux linkage [Wb]	Torque [N·m]
0	0	0	0
15	0	0	0
30	0	0	0
0	50	$14.9 \cdot 10^{-3}$	0
15	50	$42.2 \cdot 10^{-3}$	7.0
30	50	$77.3 \cdot 10^{-3}$	-0.1
0	100	$29.8 \cdot 10^{-3}$	0
15	100	$60.8 \cdot 10^{-3}$	17.1
30	100	$86.2 \cdot 10^{-3}$	-0.1

## 8. Lookup tables

We are now able to obtain the flux linkage  $\lambda_c$  and the torque  $T_e$  for a given rotor angle  $\theta_m$  and a given current  $i_c$ .

Now we want to obtain the lookup tables  $\lambda_c(\theta_m, i_c)$  and  $T_e(\theta_m, i_c)$  for  $\theta_m \in [0, 30]$  meca deg with a step of 2 deg, and  $i_c \in [0, 70]$  A with a step of 10 A.

Create a Matlab script that calculates the lookup tables, store them in a .mat file and plot them. You should obtain the results summarized in Figure 8.

*Note: Build your code step by step and avoid calculating all the points each time!*

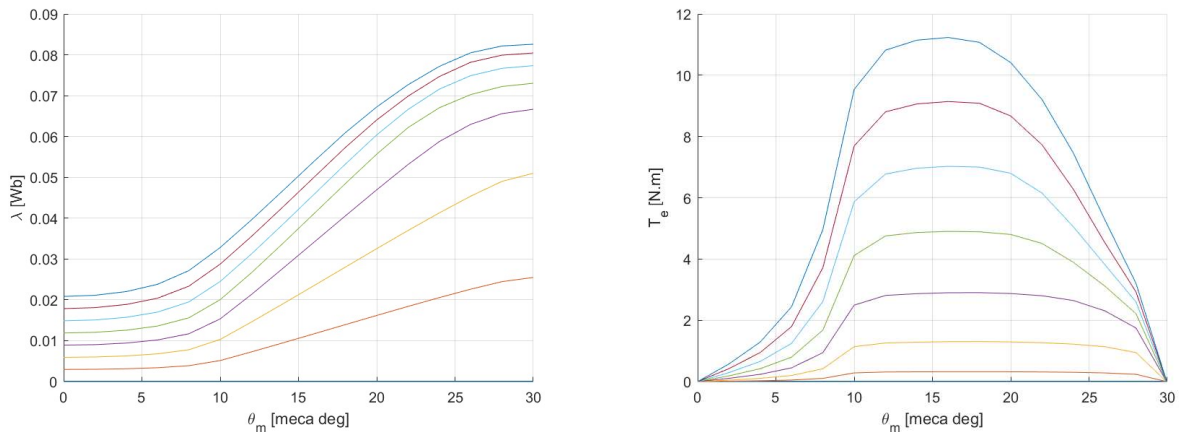


Figure 8 - Flux linkage and torque lookup tables.

## 9. Conclusions

You have now completed the finite element modeling of the SRM with FEMM and Matlab (part 2). In this tutorial, you learned how to:

- Open, run and close FEMM from Matlab
- Set currents from FEMM interface and from Matlab
- Set rotor angle from FEMM interface and from Matlab
- Compute flux linkage from FEMM interface and from Matlab
- Compute torque from FEMM interface and from Matlab
- Compute the flux linkage and the torque lookup tables of a SRM.