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

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1. Requirements

• FEMM 4.2 (download: www.femm.info)
• Matlab R2020b
• FEMM model from part 1 of this tutorial, called `tutorial_SRM_QUEVAL_20210201.fem`

2. Introduction

In this document, we show 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.

Let's create two copies of the FEMM model:

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

2) Make a copy of `tutorial_SRM_QUEVAL_20210201.fem`, and rename it `tutorial_SRM_fromMATLAB.fem`. It will be used from Matlab.

3. Open, run and close FEMM with Matlab

To open and run 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') %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 modify the rotor angle θ_m.

4.1 Rotation with FEMM interface

Open the model `tutorial_SRM_QUEVAL_20210201.fem` with FEMM.

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

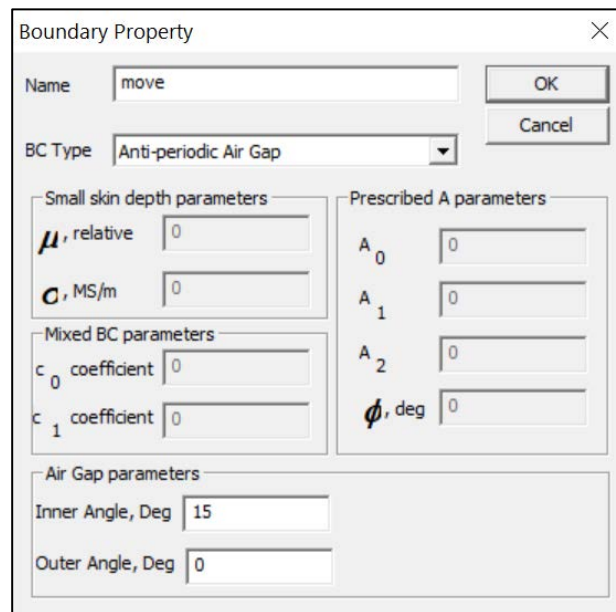You can repeat the procedure for different rotor angles. You should obtain the results summarized in Figure 2.

Figure 1 – Boundary property dialog.

4.2 Rotation with Matlab

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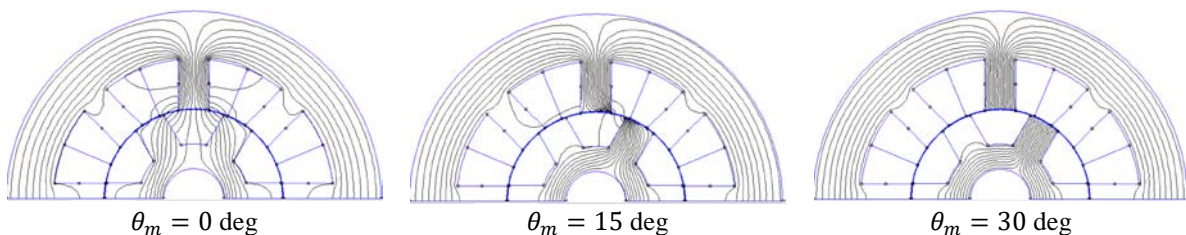

$\theta_m = 0$ deg $\theta_m = 15$ deg $\theta_m = 30$ deg

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

5. Current

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

5.1 Current with FEMM interface

Open the model `tutorial_SRM_QUEVAL_20210201.fem` with FEMM. Set the rotor angle to 0 deg.

In the `Properties` menu, select `Circuits`. In the `Property Definition` dialog, select the circuit `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 ![run icon]. Then click on the glasses icon ![glasses icon] to view the analysis results. Plot the flux density distribution ![flux icon] (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.
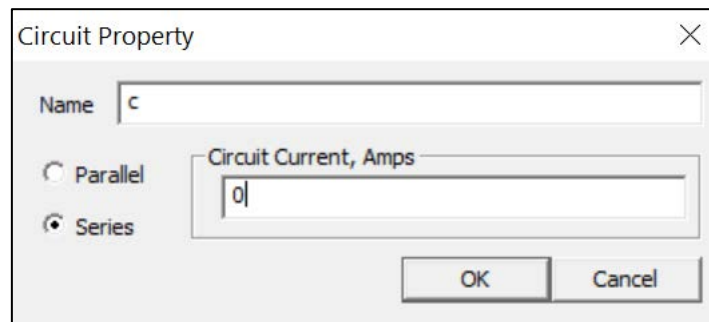

Figure 3 – Circuit property dialog.

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`).

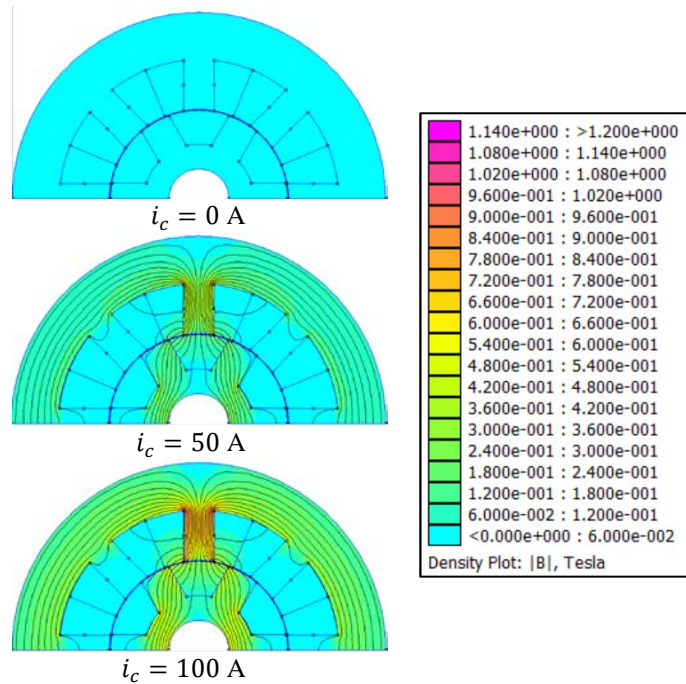You can change the current. You should obtain the results summarized in Figure 4.

Figure 4 – Flux density distribution as a function of the current (θ_m = 50 A).

6. Flux linkage

In this section, we want to compute the flux linkage of the phase c λ_c.

6.1 Flux linkage with FEMM interface

Open the model `tutorial_SRM_QUEVAL_20210201.fem` with FEMM. Set the rotor angle to 0 deg, and the current to 50 A.

Run the analysis with [icon]. Then click on the glasses icon [icon] to view the analysis results. Press the [icon] 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 can be unambiguously interpreted as the coil c self inductance (i.e. 0.3 mH).
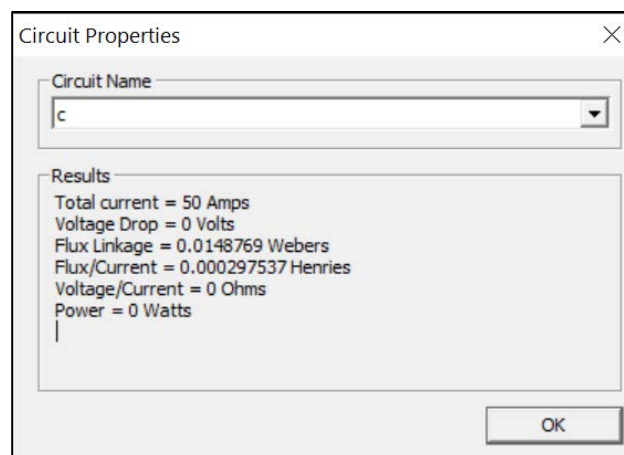

Figure 5 – Circuit Properties dialog (θ_m = 0 deg, i_c = 50 A).

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 `tutorial_SRM_QUEVAL_20210201.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 the `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).
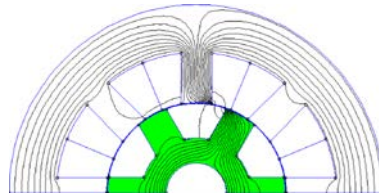

Figure 6 - Selection of the rotor domain (θ_m = 15 deg, i_c = 50 A).
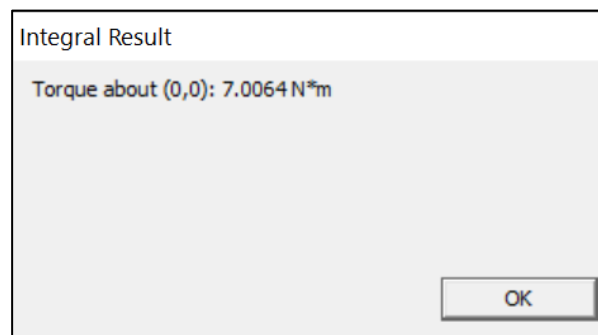

Figure 7 - Integral Result dialog (θ_m = 15 deg, i_c = 50 A).

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 θ_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 λ_c and the torque T_e for a given given rotor angle θ_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, and store them in a .mat file. Create another script to plot the lookup tables. You should obtain the results summarized in Figure 8.

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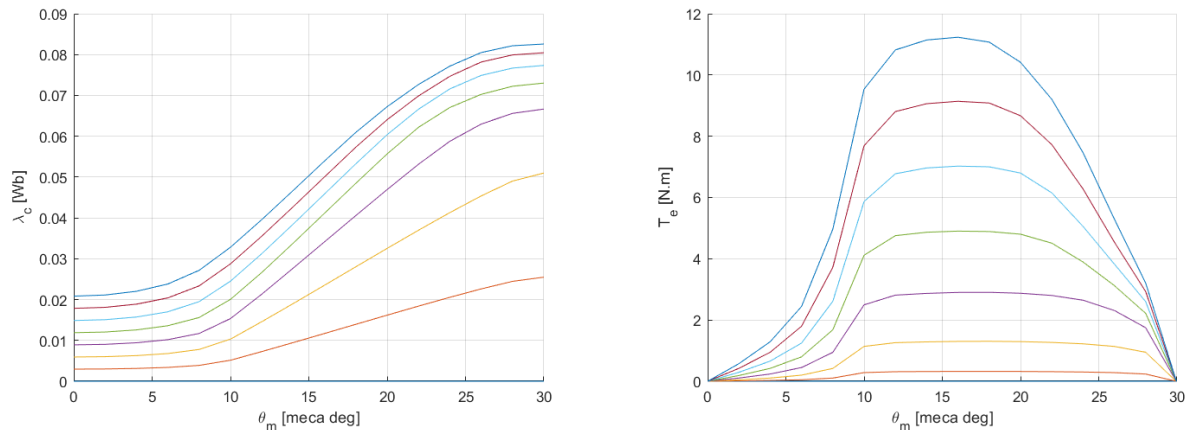

Figure 8 - Flux linkage and torque lookup tables.

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;
• Modify the current from FEMM interface and from Matlab;
• Modify the rotor angle from FEMM interface and from Matlab;
• Compute the flux linkage from FEMM interface and from Matlab;
• Compute the torque from FEMM interface and from Matlab;
• Compute the flux linkage and the torque lookup tables of a SRM.