Spatial inhomogeneity of a magnet magnetization

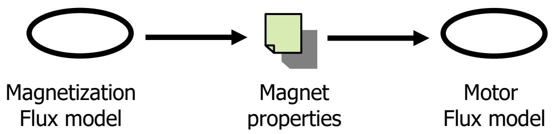
Overview

Introduction

This document deals with the following issue: "How to take into account the spatial inhomogeneity of the remanent induction in magnets?" To answer this question, a simple example is achieved with Flux.

This example helps to show:

- the modeling of a **magnetization device** (magnetizer)
  (radial magnetization of tiles of hard ferromagnetic material)
- the modeling of a **motor using the above magnets**
  (rear view mirror motor with magnets to the stator)



The first model allows the calculation of the residual magnetization in the tile. This residual magnetization (or remanent magnetization) is transferred (via file) in the second model. The magnets are modeled using a spatial model.

Contents

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Procedure: open the Flux example from the supervisor
Procedure: details of operations
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Results: which model to choose for ferrite?

Remanent magnetic flux density: theoretical aspect

Magnetization process

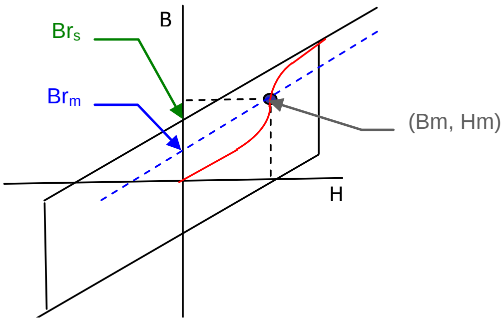
Magnetization process:
The future magnet is placed in the magnetizer. The magnetization bench generates the magnetic excitation required for the magnetization of the future magnet.

The operating point (on the B(H) characteristics) is then located on the **first magnetization curve** (upper right quadrant).

Residual magnetic flux density

The **residual** (or **remanent**) **magnetic flux density** corresponds to the value of the magnetic flux density B remaining in the substance when the applied magnetic field strength H is brought to zero.

- If the saturation is reached, the magnet is magnetized "to saturation", its residual (or remanent) magnetic flux density is the Br "of the catalog".
- If the saturation is not reached, the magnet has a lower residual flux density.



The point (Hm, Bm) is the point reached in some areas of the magnet

- for “saturated” magnetized area
  ⇒ remanent magnetic flux density equal to Br_s
- for the area excited with Hm
  ⇒ remanent magnetic flux density equal to Br_m

Computation of the residual magnetic flux density

For all the points of the future magnet, where the excitement H reaches the value Hm, the residual magnetic flux density Br_m can be calculated using the following formula:

$$Bm = \mu_0\ \mu_r\ Hm + Br_m \qquad \text{ie} \qquad Br_m = Bm - \mu_0\ \mu_r\ Hm$$

with:

- $\mu_0 = 4*\pi*10^{-7}$
- μ_r: magnetic permeability
- Bm: magnetic flux density at the point of maximum excitation
- Hm: magnetic field at the point of maximum excitation
- Br_m: remanent magnetic flux density at the point of maximum excitation

In the device …

The magnet, placed in the destination device, is now the source of magnetic excitement.

The operating point (on the B(H) characteristics) is now located on the **demagnetization curve** (upper left quadrant).

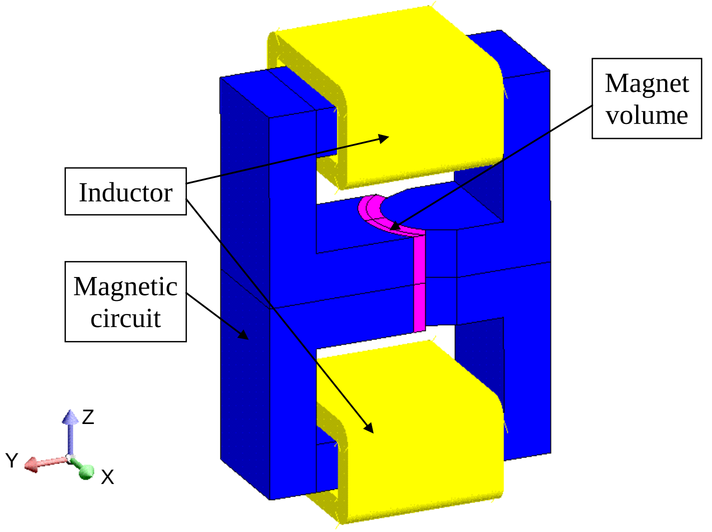
Modeling the magnetizer (magnetization of the magnet)

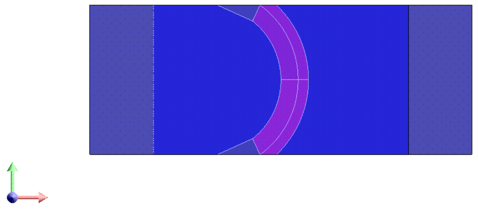
Modeled device

The magnetizer comprises a magnetic circuit with an inductor.

The future magnet is placed in the center.

Due to the symmetry (XY plane), only one half of the device is modeled. This simplification is possible because there is the same symmetry in the motor.





Physical description

Physical application: 3D Magneto Static
Physical description in Flux: see table below.

Region	Material	Model (properties)
MAGNET	FERRITE	Isotropic analytic saturation (arctg, 2 coef.) $\mu r = 2$ Js = 0.25T
MAGNETIC CIRCUIT	IRON	Isotropic analytic saturation (arctg, 2 coef.) $\mu r = 1000$ Js = 0.3T

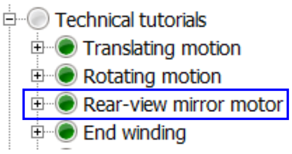
Non mesh coil	Associated electrical component
COIL_1	COIL_CONDUCTOR
Turn numbers = 2000	Imposed current = 10 A

Modeling the motor (use of the magnet)

Note

The device in which is inserted in the magnet (previously magnetized) is a rear-view mirror motor.

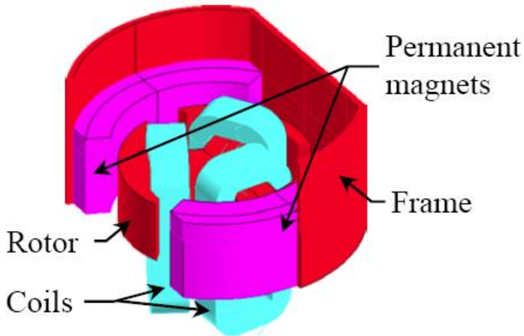
This motor is described in detail in the technical tutorial "**Rear-view mirror motor analysis**". This example is available from the Supervisor in the context Examples (technical tutorials).



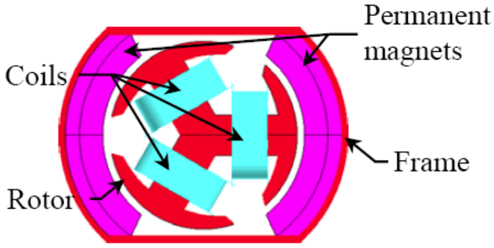
Modeled device

In the normal function, the two magnets polarize the magnetic circuit and, according the current emitted in coils, a torque is exerted on the rotor.

The coils are not simulated in the models of test case.



Due to the symmetry (XY plane), only one half of the device is modeled.



The comparison between an ideal magnet magnetization and the export computed magnetization is done by simulation of the torque exerted on the rotor in rotation.

Physical description

Physical application: 3D Magneto Static
Physical description in Flux: see table below.

Region	Material	Model (properties)
MAGNET_MINUS	MAGNET_MINUS	Spatial model (imported quantities)
MAGNET_PLUS	MAGNET_PLUS	Spatial model (imported quantities)
FRAME_REGION	STAINLESS_LIN	Linear isotropic / μr = 1550
ROTOR	STAINLESS_LIN	Linear isotropic / μr = 1550

Mechanical set	Movement	Kinematic
ROTOR	Rotation around the OZ axis	Multi static
STATOR	Fixe	-

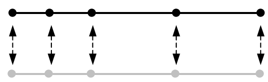
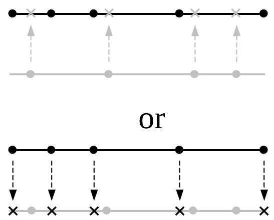
Exchanges - data transfer in Flux: software aspect

Introduction

This topic deals with reminders on the exchange of data in Flux. This information is extracted from the Flux documentation « Multiphysics co-simulation: principles ».

On the supports of exchange

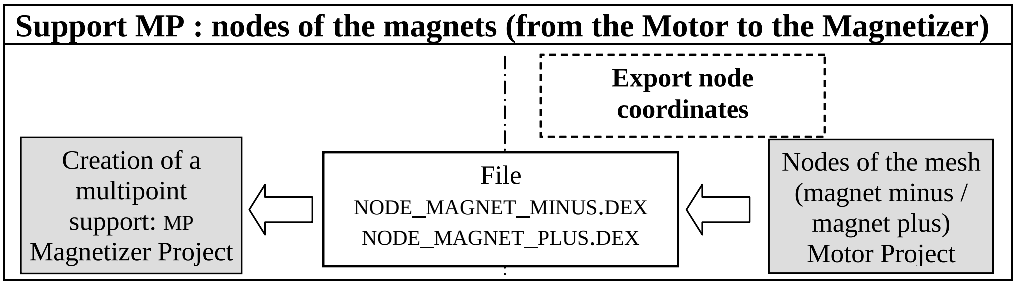
The data exchanges can be carried out on various supports: points of domain, nodes of mesh…

If identical mesh	If different mesh
Data exchange on the nodes of the mesh	Data exchange on a group of points
	
Support of exchange = group of nodes	Support of exchange = group of nodes

To each **node** (of one mesh) a **position** (of the other mesh) is associated

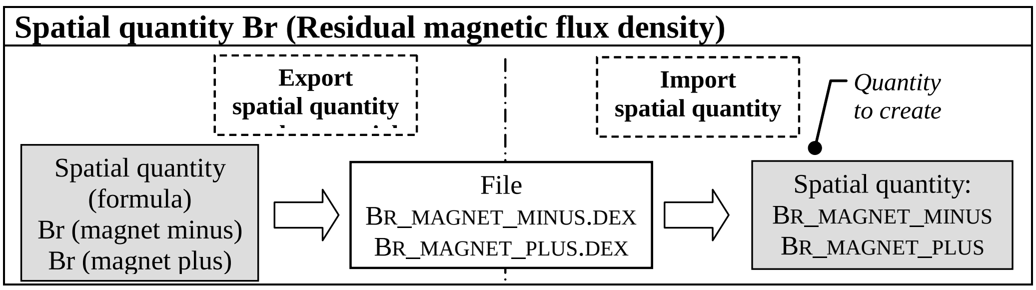
Multipoint support

The 1st exchange type concerns the transfer of the coordinates of the nodes (stored through multipoint support).



Spatial quantity

The 2nd type of exchange concerns the transfer of the physical quantities (stored through Spatial quantity).



Note: This is the same command that allows the import and the creation of the new spatial quantities (in the Motor project)

Procedure: open the Flux example from the supervisor

How to proceed ?

To start this double simulation Flux-Flux, you have to open the 2 examples:

- **Magnetizer** (1rst)
- **RVM motor** (2nd)

Step	Action
1	Select the working directory in which the examples will opened

2	Select the example
	Double simulation Flux-Flux: magnet magnetization
	  Magnetization then use of a magnet
	    Magnetizer
	    RVM motor

3	Click on "open the selected project" (or double-click on the name)

How it works?

Both examples are launched in parallel in the working directory.
Synchronization of exchanges is carried out in the script files.

… at the end of the process

At the end of the process, you have the following items in your working directory …

	MAGNETIZER	MOTOR_RVM
Pythons files / Scripts of the process	TESTCASE_INI.FLU buildGeomesh.py buildPhys.py mainEx.py postprocessing.py solving.py	buildGeomesh.py buildPhys.py buildPhys_exchange.py mainEx.py postprocessing.py solving.py
Flux projects	physbuilt.FLU postprocessed.FLU solved.FLU	Case1_GeoMesh.FLU Case1_Phys.FLU Case1_Postprocessed.FLU Case1_Solved.FLU
Exchange files	BR_MAGNET_MINUS.DEX BR_MAGNET_PLUS.DEX	NODE_MAGNET_MINUS.DEX NODE_MAGNET_PLUS.DEX
Synchronization file	Synchro_MAG.txt	Synchro_RVM.txt

Procedure: details of operations

Introduction

To understand the data exchange process, you can achieve it "by hand" using the following operating mode. The first block gives an overview of the procedure. Detail of operations is then presented in the following blocks.

Procedure

To start you must first retrieve the intermediate Flux projects created previously (see § Procedure: open the Flux example from the supervisor). It is recommended to work in another directory.

	MAGNETIZER	MOTOR_RVM
0	Open the solved project MAGNETIZER / solved.FLU	Open the project MOTOR_RVM / Case1_GeoMesh.FLU and run the command file MOTOR_RVM / buildPhys.py
0+		Create 2 global cylindrical coordinate systems • MAGNET_MINUS: RotationAngles (0, 0, 180), • MAGNET_PLUS: RotationAngles (0, 0, 0),
1		Export the **node coordinates** of the magnet region into a data exchange file: NODE_MAGNET_PLUS.DEX *Be careful with the* ***coordinate system*** *of exportation (MAGNET_PLUS)*
2	Create 1 **multipoint supports** MP_MAGNET by importation of the node coordinates i.e. NODE_MAGNET.DEX file *Importation* ***Coordinate system*** *= STATOR*	
3	Export the residual flux density (Br values) of the magnet region from the multipoint supports into a data exchange file • BR_MAGNET_MINUS.DEX → Br = B-μ_0H • BR_MAGNET_PLUS.DEX → Br = - (B-μ_0H) *Exportation* ***Coordinate system*** *= STATOR*	
4		Create 2 **tabulated spatial quantities** by importation of the residual flux density (Br values) from the data exchange file • BR_MAGNET_MINUS • BR_MAGNET_PLUS *Be careful with the* ***coordinate system*** *of importation (MAGNET_MINUS & MAGNET_PLUS)*

	The actions presented above are in python files ...	
	MAGNETIZER / postprocessing.py	MOTOR_RVM / buildPhys_exchange.py

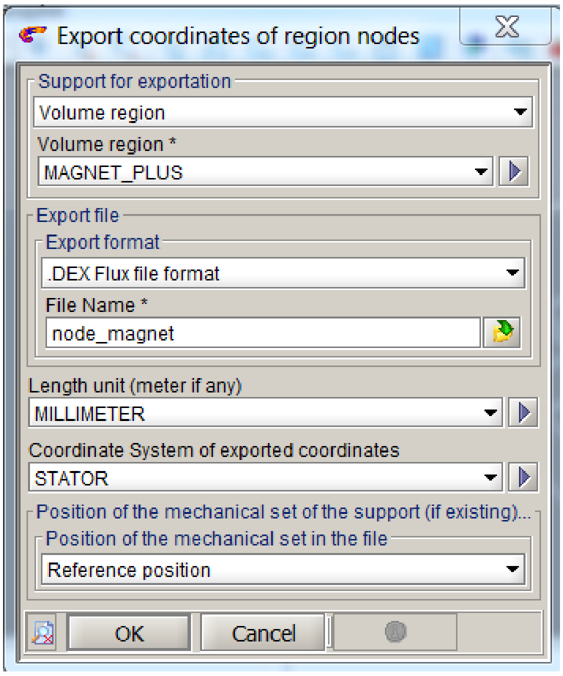
(continued)

	MAGNETIZER **(solved.FLU)**	MOTOR_RVM **Case1_Phys.FLU**
5		Make use of the tabulated spatial quantity in the material definition. • MAGNET_MINUS → Br = BR_MAGNET_MINUS • MAGNET_PLUS → Br = BR_MAGNET_PLUS
6		It's possible to solve the model with one step in live. Use the scenario SCENARIO_ONE_STEP (solve time ≈ 1min)
7	Close the model	Close the model

Step 1

Export the **node coordinates** of the magnet region into a data exchange file:
NODE_MAGNET_PLUS.DEX

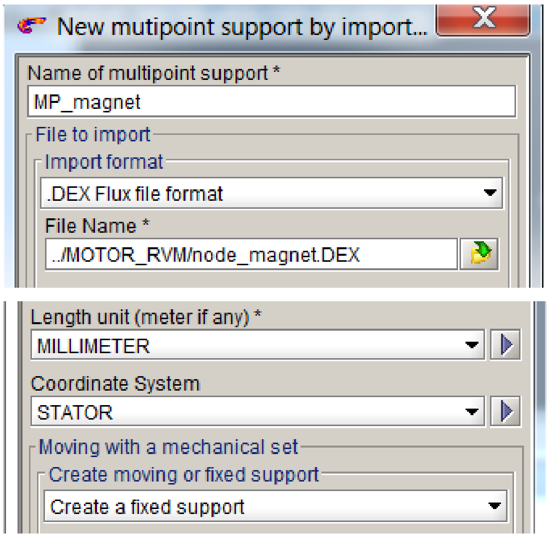
Command :
[Parameter/Quantity]
[Export node of regions]
[Export coordinates of region nodes]



Step 2

Create 1 **multipoint supports**
MP_MAGNET
by importation of the node coordinates i.e.
NODE_MAGNET.DEX file

Command :
[Support]
[Multipoint support]
[New multipoint support by importation of a list of points]

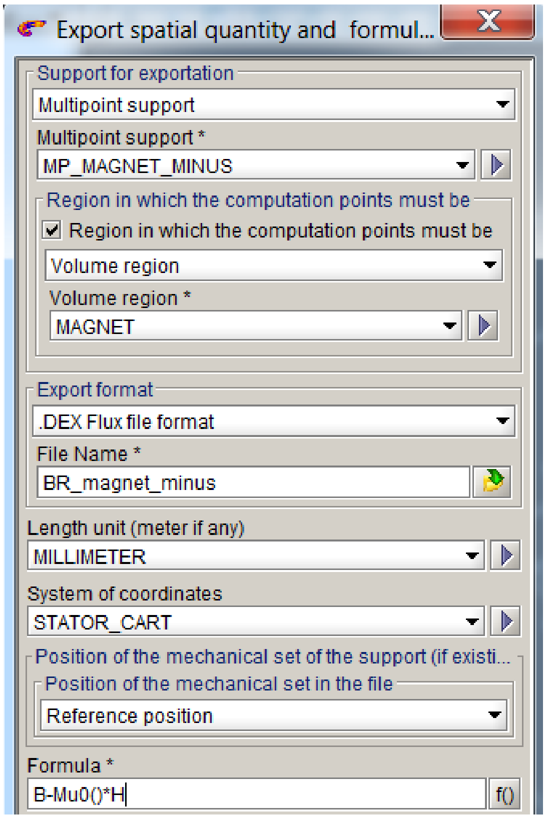


Step 3

Export the residual flux density (Br values) of the magnet region from the multipoint supports into a data exchange file

- BR_MAGNET_MINUS.DEX
  → $Br = B-\mu_0 H$
- BR_MAGNET_PLUS.DEX
  → $Br = -(B-\mu_0 H)$

Command :
[Data exchange]
[Export quantity]
[Export spatial quantity and formula starting from different types of supports]

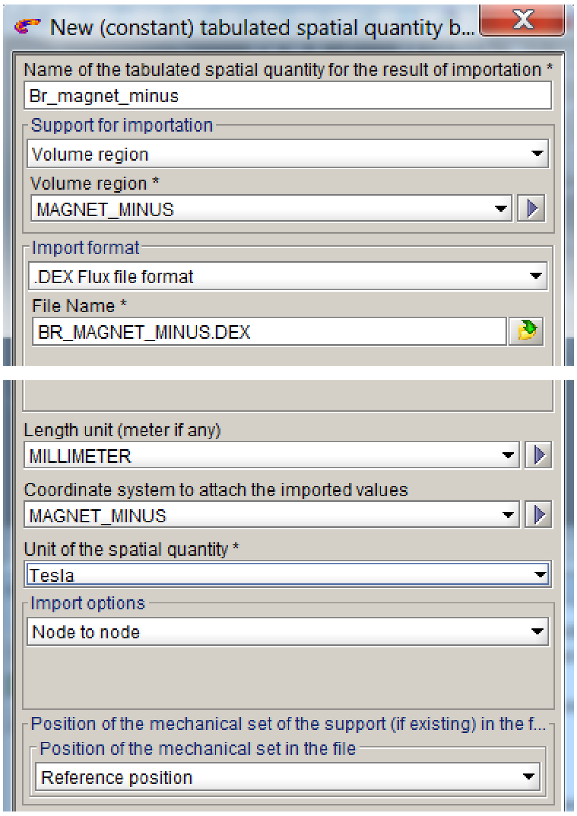


Step 4

Create 2 **tabulated spatial quantities** by importation of the residual flux density (Br values) of the magnet region from the data exchange file

- BR_MAGNET_MINUS
- BR_MAGNET_PLUS

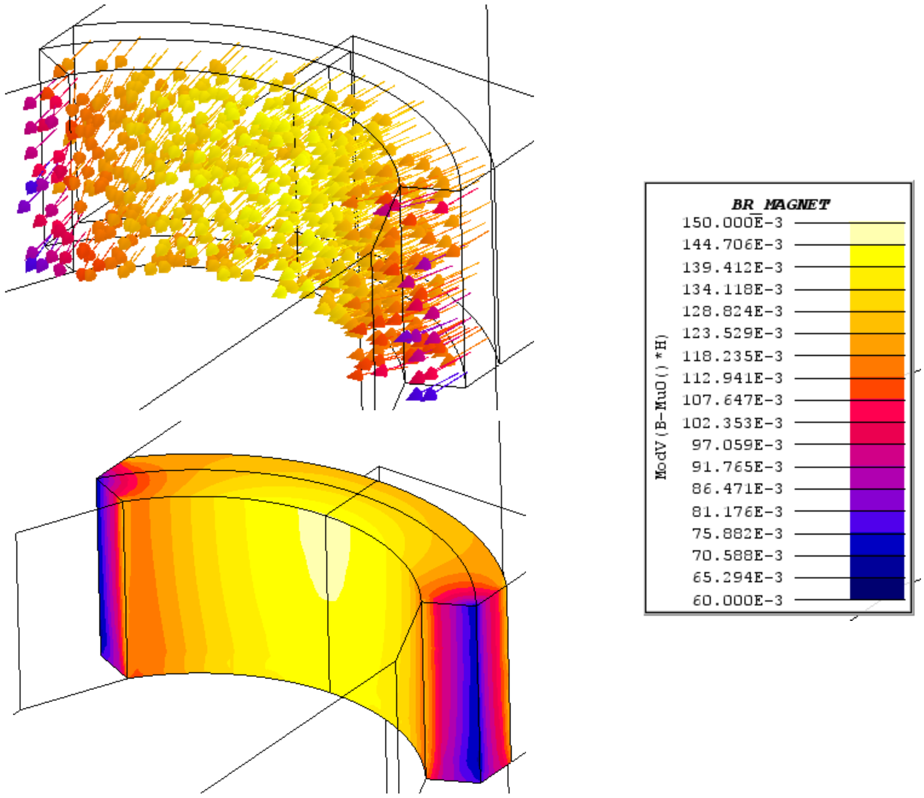
Command :
[Parameter/Quantity]
[Import parameter and quantity]
[New (constant) tabulated spatial quantity by importation]



Results: comparison with classic model

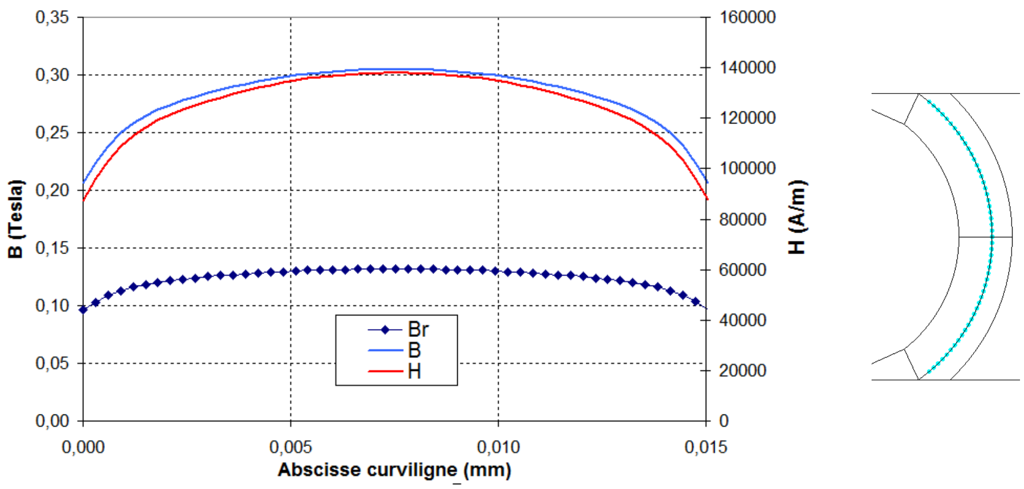
In the magnetizer

Display of Br in the magnet:
- isovalues: ModV(B-Mu0*H)
- arrows: B-Mu0*H



In the magnetizer

Display of B, H and Br on a path in the center of the magnet.

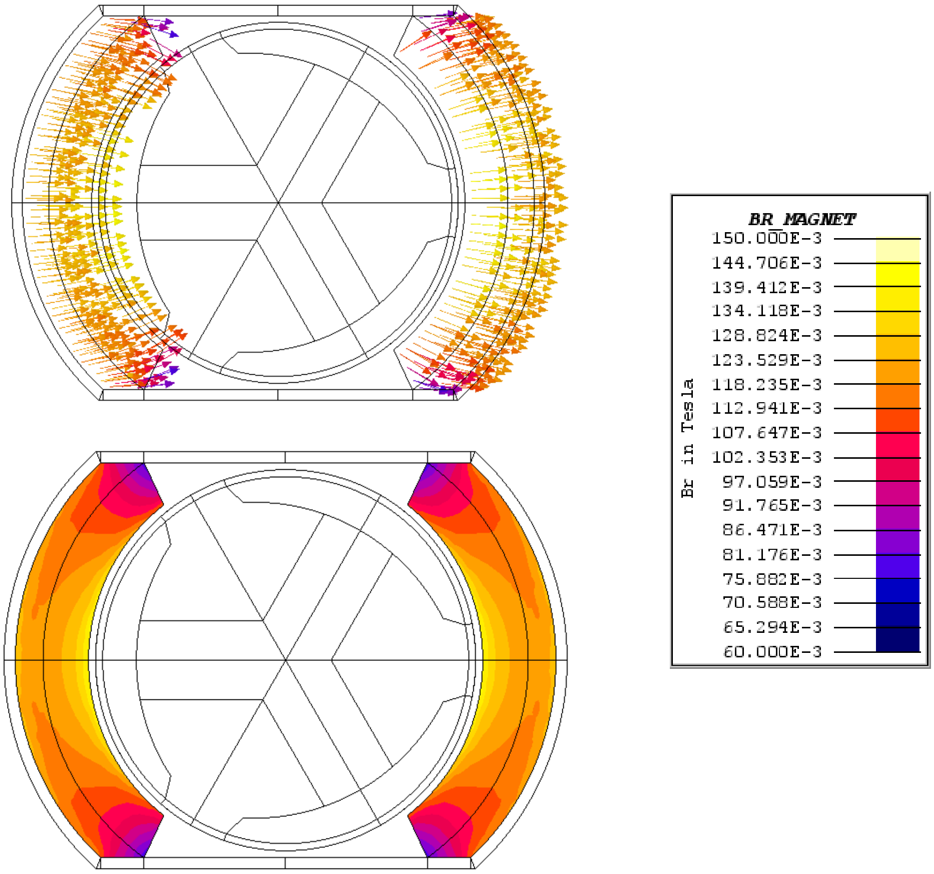


Comment

There is a rather low Br value (Br_m = 0.13T) compared to the ideal theoretical value (Br_s = 0.25T).

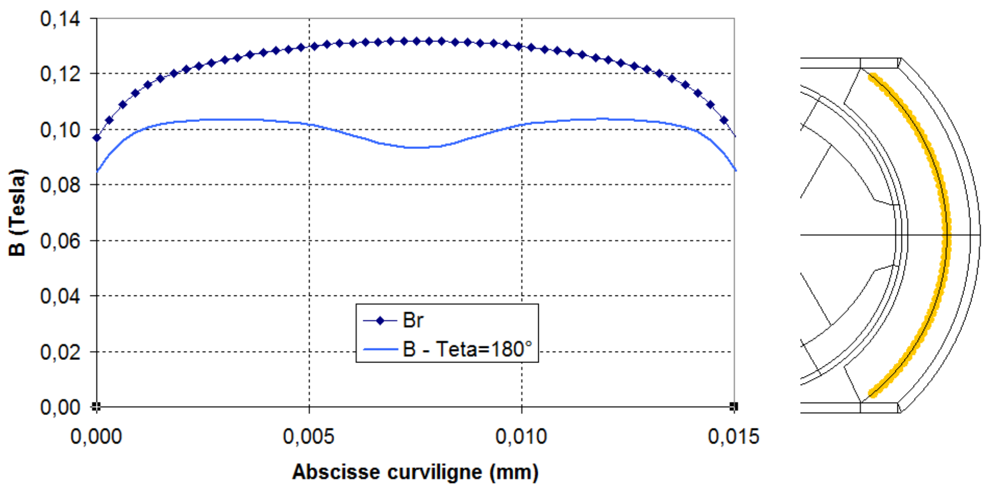
In the motor

Display of Br in the magnet
- isovalues: Br
- arrows: Br



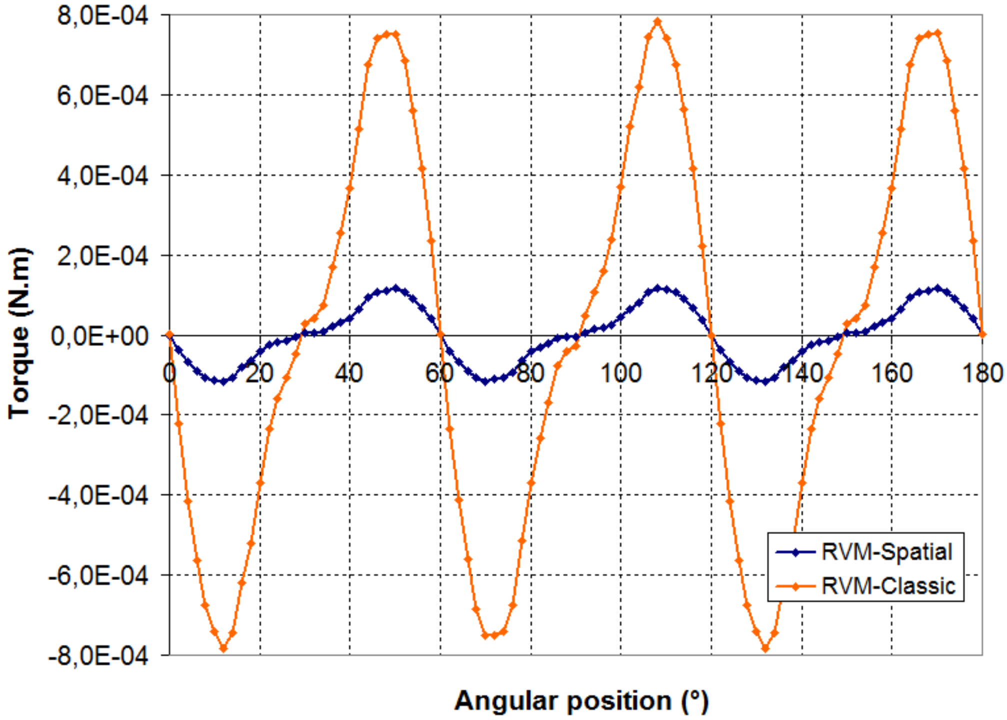
In the motor

Display of B and Br on a path in the center of the magnet.



Torque computation

Display of electromagnetic torque versus angular position of the rotor and comparison with the classic motor (ideal magnetization).

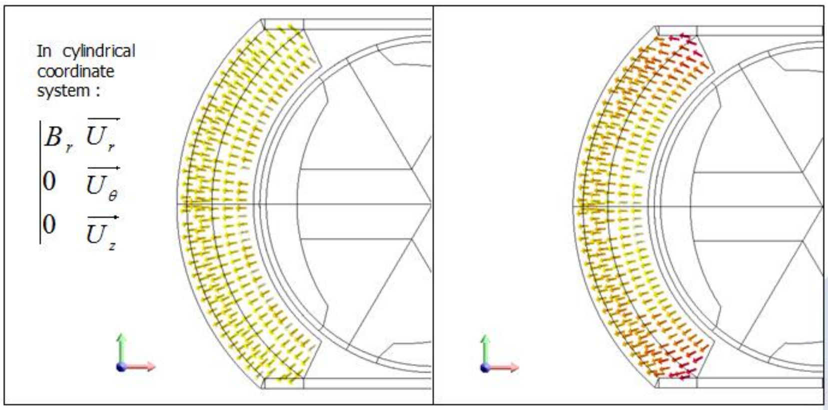


Comment

We note a significant difference on the torque between the two models.

These differences are due to …

- a magnetization of the magnet not uniformly radially (see image below)
  → adjust the shape of the magnetizer
- there is not enough energy injected to achieve full magnetization
  → increase the current in the coils of the magnetizer
- the model chosen for the first magnetization curve of the ferrite is not good (this is discussed in the following paragraph)



Classic model
Ideal theoretical value (Br_s=0.25T).

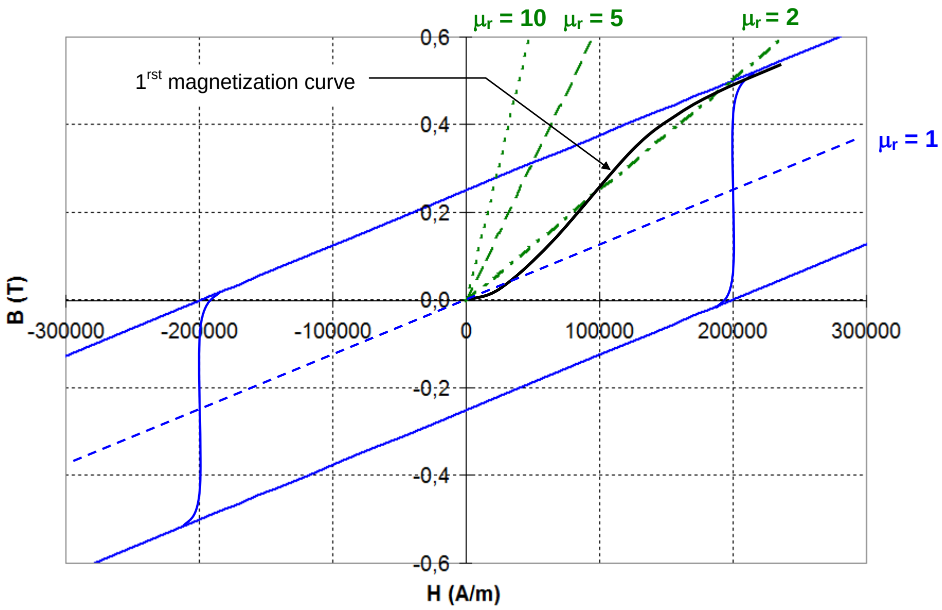
Computed model
Computed value (Br_m=0.13T)

Results: which model to choose for ferrite?

About model

To achieve a consistent result, it is important to correctly model the ferrite material and thus answer the question: which model to choose?

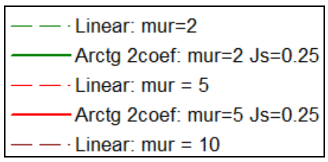
For ferrite used in this example, visualization of the B (H) is shown in the figure below.

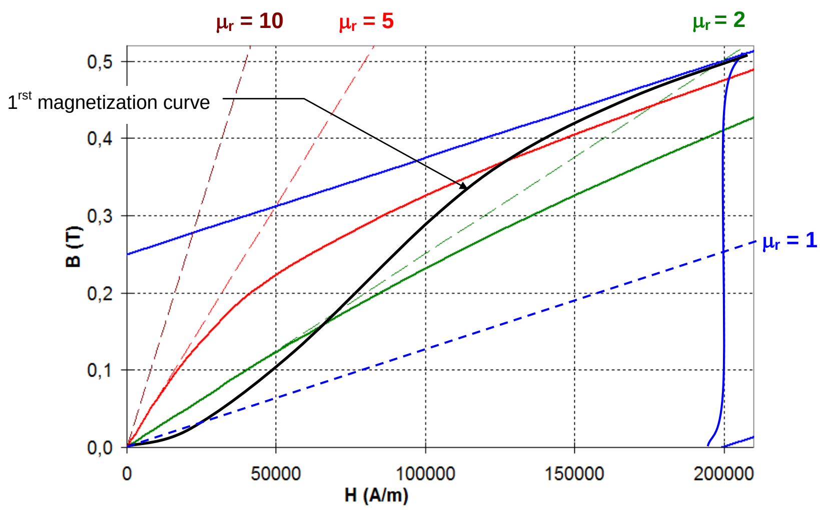


Flux models

In the example, the model used for the ferrite is a model of type Isotropic analytic saturation (arctg, 2 coef.) with $\mu_r = 2$, Js = 0.25T.

Other solutions are possible and are shown in the figure below.





The linear model ($\mu_r = 2$) is, perhaps, more appropriate for this situation.

Comment

About the energy injected ...

If we take the curve of the Magnetizer project "B, H and Br on a path to the magnet center", H varies between 90 10^3 and 140 10^3 A / m (in the center of the magnet).

When these values are projected on the previous curve "Flux Models for B (H)", we see that with the model (arctg 2 coef. $\mu_r = 2$, Js = 0.25T), it is not possible to reach a Br above 0.13T.