

Position Sensor-Simulation with ANSYS[®] Maxwell 3D

(Hands-On Notes)

Topics: Introduction into Maxwell for static magnetic field simulation

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1 Position Sensor Simulation

1.1 Introduction

The correct measurement of an angular position (or speed) is required in many different applications. One of the typical realization principle is based on the evaluation of the magnetic field quantities which are effected by moveable (rotating) permeable region nearby. Many of such applications are using a difference signal of 2 field sensors(e.g. Hall or MR elements) to measure the H-Field showing reluctance effects (for static methods) or eddy effects (for dynamic effects).

A well known application of such a principle using MR-elements is shown in figure 1. Here cylindrical permanent magnet works as a field source for the 2 sensor elements and the structured rotating wheel.



Figure 1

While the field source remains constant, the magnetic resistance depends on the angular position of the structured wheel.

Figure 2 gives a more detailed picture of the region of interest (sensor region). As the size of the sensors is significantly small compared to the wheel, the simulation needs to evaluate the field distribution with care.



Figure 2

The goal of the simulation is to determine the field quantities with respect to the angular position of the wheel. In some further optimization runs – the difference signal should be optimized, while the magnet size should be minimized.

1.2 First Steps (initial Settings of Workbench)

- Open ANSYS Workbench
- Set the Language to English: Tools > Options... > Regional and Language Options > Language > English
- Close ANSYS Workbench, that the language changes become active
- Open ANSYS Workbench again.



1.3 Setting up Sensor Simulation

- Insert a new Maxwell3D Simulation (from analysis systems inside the project page)
- Open Maxwell3D (double-click onto the analysis system)

The figure shows the GUI of ANSYS Maxwell:



Figure 3

Modeling Setup

• Import the Geometrie (Parasolid): Modeler > Import... > SENSOR_GEOM.x_t

🚳 Import File							—X —
Suchen in:	📔 Test		•	+ 🗈 💣 📰 ◄			
Ca.	Name	^		Änderungsdatum	Тур	Größe	
Z data basuala	🌗 sens_prac	e_files		24.09.2013 15:59	Dateiordner		
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 Strict 	Auto	C Manual					



- Save the Workbench Project: File > Save As... > SENSOR_GEOM.x_t.wbpj
- Open the Maxwell3D component system

Assign Material Properties to all Solid Parts:

- Point onto the Magnet (inside Solid Tree or within graphics window)
- Use RMB to choose Assign Material



Figure 5

• Insert "NdFE" into the material name box to search for existing data sets

D Search	by Name Relative Permittivity	○ by Property	[personal] core [sys] Materials		
/ Name	Location	Origin	Relative Permeability	Bulk Conductivity	•
NdFe30	SysLibrary	Materials	1.0445730167132	625000siemens/m	-8
NdFe35	SysLibrary	Materials	1.0997785406	625000siemens/m	-{
Nelco N4000-13 (tm)	SysLibrary	Materials	1	0	0
Nelco N4000-13 SI (tm)	SysLibrary	Materials	1	0	0
Neltec NH9294 (tm)	SysLibrary	Materials	1	0	0
Neltec NH9300 (tm)	SysLibrary	Materials	1	0	0
Neltec NH9320 (tm)	SysLibrary	Materials	1	0	0
Neltec NH9338 (tm)	SysLibrary	Materials	1	0	0
Neltec NH9348 (tm)	SysLibrary	Materials	1	0	0
Neltec NH9350 (tm)	SysLibrary	Materials	1	0	0
Neltec NX9240 (tm)	SysLibrary	Materials	1	0	0_
		1	i	i	•

• Accept the material with OK

You may check the content of the material data (from Library) – as well as adjust settings with the View/Edit function. Here you can see that the magnetization direction is oriented as global X direction. This setting is correct for our analysis here.

Proceed similar for the other solids, to point vacuum to the sensors (the are non magnetic regions), as well as the region. Choose "Iron" from the library to point onto the wheel. For the first analysis the linear description of iron is suitable here.

The graphics properties can also be adjusted for each solid. You may use the Properties Window (left side under the tree) to adjust colors and transparency. Moreover also the use of the solid within the simulation can by specified (Model or Non-Model).



As the next step, the boundary condition should be set. Thus its helpful to rotate the model. This can be done with the middle mouse button, while the scroll-wheel helps for zooming in and out.

Assume the field at the end regions of the sector of the wheel are not effected by the magnet -a flux parallel boundary condition (natural) is sufficient for the basic setup.

The definition of initial mesh parameters help to improve the performance and accuracy. For this step a sizing for the sensor region is required.

- Select the Sensor Solids
- Use RMB to choose Apply Mesh Operation > Inside Selection > Length based



Figure 7

• Specify 0.02 mm

Proceed similar to define 1mm for the magnet and 3 mm for the wheel.



As the basic setup is nearly finished – the analysis setup can be implemented:

• RMB in Analysis > Add Solution Setup



Figure 8

The original setup shows 10 adaptive iterations to fulfil the energy criteria (global)

Solve Setup	— ×
General Convergence Expression Cache Sol	lver Defaults
Name: Setup1	
Adaptive Setup	
Maximum Number of Passes:	10
Percent Error:	1
Parameters	
Solve Fields Only	
Solve Matrix: After last pass 	
C Only after converging	1

The validation checking can be used to validate of all requirements for the analysis are fulfilled. Use the appropriate function from the main menu.

Validation Check: MaxwellProject - Maxwell3DDesign1	—
Maxwell3DDesign1	 Design Settings 3D Model Boundaries and Excitations
Validation Check completed.	Parameters Mesh Operations
	 Analysis Setup
	 Optimetrics
Abort Close	

Figure 10

Next the analysis can be started.

ð	A	NSY:	S Ma	bowe	ell - I	Max	wel	Proj	ect - N	/laxwe	IIBDD	esign1	l (Ma	xwell	3D De	sigr	n) - 3D	M	odele	r -
1		ile	Ed	it	Viev	v	Proj	ect	Draw	Mo	deler	Ma	xwell	3D	Tools	۷	Vindo	w	Help)
l	D	(iii)			у, Б	b	ß	8	$ \times$	Ω	<u>C</u>	3	₽	ę				•	Ψ	
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			-	9	Boun	darie	es									^P M	AGNE			
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			⊨ -,	S I	Analy	sis									•-6	/ SE	:NS_FI	ND		
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					Resul	t						_	52	1	LISIS					
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		€-(Defir	nition	s /	S	elete	2			Dele	te							
							P	rope	rties											
							0)i <u>s</u> ab	le Setu	q										
1						Γ	A	naly	ze											
						-	_													

The simulation progress can be seen on the main screen – showing also the adaptive iterations.



Figure 12

The convergence can be check with:

• RMB Analysis Setup1> Convergence

Solutions: MaxwellProject - Maxwell3D)Desig	n1			
Simulation: Setup1		-			
Design Variation:					
Profile Convergence Force Torque	Matrix	Mesh Statistic	s		
Number of Passes	Pass	# Tetrahedra	Total Energy (J)	Energy Error (%)	Delta Energy (%)
Completed 3	1	26874	0.0084917	2.8066	N/A
Maximum 10	2	34940	0.0085952	0.6942	1.2196
Minimum 2	3	45430	0.0086139	0.3285	0.21757
Energy Error/Delta Energy (%) Target (1, 1) Current (0.3285, 0.21757) View: • Table O Plot Export			4		
		C	ose		

To proceed with some further steps, it may be helpful to hide the field region. This can be done with the "eye" filters in the main menu.





Insert a field-plot to display the magnetic field of the wheel.

- Select the solid body of the wheel
- Use RMB to choose Fields > H> Mag_H



Figure 16

• Check the Box "on surface only" to create a contour plot

Create Field Plot	
Specify Name Mag_H1	Fields Calculator
Specify Folder H	Category: Standard 🗨
Design: Maxwell3DDesign1	Quantity In Volume
Solution: Setup1 : LastAdaptive	Mag_H H_Vector Mag_B N_A_A N_A_A Mag_B SENS_FWD
Field Type: Fields	Mag_J REGION J Vector AllObiects
Intrinsic Variables	energy coEnergy appEnergy Ohmic_Loss Temperature Volume_Force_Density Mag_Displacement Displacement_Vector ✓ Plot on surface only
Done	Cancel Streamline



The resulting field plot should look like figure 18. The field is concentrated to the region near to the magnet and will be symmetric, as the initial position with respect to the structure of the wheel is also symmetric.



1.4 Sensor Parameter Setup (Calculator)

As the sensor signal is derived from the magnetic field in the region of the sensor domain, the field calculator of Maxwell will be used to determine this data.

Named Expressions-			Context: Maxwell3DDes	sign1 —
Name		*	Solution: Setup	1 : LastAdaptive 📃 💌
Mag_H	Mag(Smooth(<ł	E Delete	Field Type: Fields	
Mag_B	Mag(Smooth(<e< td=""><td></td><td></td><td></td></e<>			
Mag_J	Mag(Smooth(<.	Clear All		
H_Vector	Smooth(<hx,h)< td=""><td></td><td></td><td></td></hx,h)<>			
•	4			
Add	Сору	to stack		1
Library: Load F	rom Sav	ve To	Change Var	iable Values
Push F	Pop RIUp General	RIDn Scalar	Exch Clear Vector	Undo Output
Push F Input Quantity ±	Pop RIUp General	BIDn Scalar Vec? ★	Exch Clear Vector Scal? 🛨	Undo Output Value
Push F Input Quantity ± Geometry	Pop RIUp General +	RIDn Scalar Vec? ★ 1/x	Exch Clear Vector Scal? ± Matl	Undo Output Value Eval
Push F Input Quantity ± Geometry Constant ±	Pop RIUp General + ·	RIDn Scalar Vec? ★ 1/x Pow	Exch Clear Vector Scal? ± Matl Mag	Undo Output Value Eval Write
Push F Input Quantity ± Geometry Constant ± Number	Pop RIUp General +	BIDn Scalar Vec? ★ 1/x Pow	Exch Clear Vector Scal? ± Matl Mag Dot	Undo Output Value Eval Write
Push F Input Quantity ± Geometry Constant ± Number Function	Pop RIUp General +	RIDn Scalar Vec? ★ 1/x Pow Trig ★	Exch Clear Vector Scal? ± MatL Mag Dot Cross	Undo Output Value Eval Write Export
Push F Input Quantity ± Geometry Constant ± Number Function Geom Settings	Pop RIUp General +	BIDn Scalar Vec? ★ 1/x Pow Trig ★ d/d? ★	Exch Clear Vector Scal? ± Matl Mag Dot Cross Divg	Undo Output Value Eval Write Export
Push F Input Quantity ± Geometry Constant ± Number Function Geom Settings Read	Pop RIUp General +	BIDn Scalar Vec? ± 1/x Pow √ Trig ± d/d? ±	Exch Clear Vector Scal? ± Matl Mag Dot Cross Divg Curl	Undo Output Value Eval Write Export
Push F Input Quantity ± Geometry Constant ± Number Function Geom Settings	Pop RIUp General + · · · · · · · · · · · · · · · · · ·	RIDn Scalar Vec? ★ 1/x Pow √ Trig ★ d/d? ★ Min ★	Exch Clear Vector Scal? \bigstar Matl Mag Dot Cross Divg Curl Tangent	Undo Output Value Eval Write Export
Push F Input Quantity \bigstar Geometry Constant \bigstar Number Function Geom Settings Read	Pop RIUp General +	RIDn Scalar Vec? ± 1/x Pow √ Trig ± d/d? ± Min ± Max ±	Exch Clear Vector Scal? Matl Mag Dot Cross Divg Curl Tangent Normal	Undo Output Value E val Write Export
Push F Input Quantity ± Geometry Constant ± Number Function Geom Settings Read	Pop RIUp General + · · · · · · · · · · · · · · · · · ·	BIDn Scalar Vec? ⊈ 1/x Pow √ Trig ⊈ d/d? ⊈ Min ⊈ Max ⊈	Exch Clear Vector Scal? ± MatL Mag Dot Cross Divg Curl Tangent Normal Unit Vec ±	Undo Output Value Eval Write Export
Push F Input Quantity ± Geometry Constant ± Number Function Geom Settings	Pop RIUp General + · · · · · · · · · · · · · · · · · ·	RIDn Scalar Vec? ★ 1/x Pow √ Trig ★ d/d? ★ Min ★ Max ★ Ln	Exch Clear Vector Scal? \bigstar Matl Mag Dot Cross Divg Curl Tangent Normal Unit Vec \bigstar	Undo Output Value Eval Write Export

• Select Field Overlays (in tree) > RMB Calculator

The equation in figure 20 shows the relation that should be evaluated with the field calculator for both sensors:





For the Forward Sensor (FWD)

- Qty H Scalar Y
- Geom Sens_Fwd Integ
- Qty H Scalar X
- Geom Sens_Fwd Integ
- /
- Trig Atan
- Constant PI /
- Number 180.0 *
- $[Add] \rightarrow Ang_Fwd$

And also for the Backward Sensor (Back)

- Qty H Scalar Y
- Geom Sens_Back Integ
- Qty H Scalar X
- Geom Sens_Back Integ
- /
- Trig Atan
- Constant PI /
- Number 180.0 *
- [Add] \rightarrow Ang_Back

Finish with DONE.



The evaluated quantities can be displayed with:

- Results RMB> create field report > Data table
- Choose from the calculator expression ANG_BACK and ANG_FWD



Figure 21

Insert these variables as convergence criteria:

- RMB Analysis Setup 1 > Properties > Expression Cache > Add
- ADD the ANG_BACK and ANG_FWD
- Done
- Adjust the convergence to 0.05 for each parameter

General	Convergence	e Expression C	ache Solver	Defaults	
		-			
	Title	Expression	Context	Intrinsics	Convergence
AN	G_FWD1	ANG_FWD	None	None	0.05
AN	G_BACK1	ANG_BACK	None	None	None

Figure 22

The next analysis run will also consider this definition.

1.5 Insert Parametric Rotation of the Wheel

As the sensor detects the field quantities as a function of the angular position of the wheel, a rotation of the geometry is inserted:



- Select the Wheel and Region !
- RMB > Edit > Arrange > Rotate > type angle into the data field to rotate about z

Figure 23

The program will ask for the value of the new defined parameter "angle":

Add Variab	le	×
Name	angle	
Unit Type	Angle	•
Unit	deg	•
Value	80	
	Define variable value with units: "1 mm"	
Туре	Local Variable	-
	OK Cancel	

Figure 24

Type an initial value of 0 into the field and finish with ok. The parameter could be found and adjusted in details window (properties) of the Maxwell3DDesign.

This can also be used to check the operation with different values.

1.6 Workbench Parametric Run

To evaluate the function of the field values (for the sensor) relating to the position the Workbench Parameter Run can be used (in combination with other physics or the optimization tool OptiSlang)

- Choose Optimetrics > DefaultDesignXplorerSetup
- RMB properties > check include to the variable angle
- Choose Calculation Tab > Add Expression Cache for Ang_FWD and Ang_BWD
- Done and OK

Save the Simulation Setup within Maxwell (Crtl+S). This will link the Maxwell parameters into WB.

	▼		А		
	1	🙀 Ma	xwell 3D		
	2	🖉 Ge	ometry	~	
	3	😨 Se	tup	~	
	4	🔊 Sol	lution	7	
\rightarrow	5	ក្រៃ Pa	rameters		
		Maxwe	ll 3D Des	ign	
1					_
ίp₊I I	ara	meter S	et		

Figure 25

Now the parameter sets can be defined and the parametrized analysis could be started:

- Double-Klick onto the Parameter Set
- Type a new value into the empty field under the existing angle (line2 = current design)
- Proceed to define values from -7.5 to 7.5
- Use Update Project or Update All Design Points to start a local run of the simulation

ng Extensions Help								
👔 Import 🖗 Reconnect 😹 Refresh Project 🍠 Update Project 🚿 Resume 👭 Update All Design Points 🛛 🔅 👋								
Outline: No data 🔹 🗣 🗶 Table of Design Points 🔹 👻 🕂 🗶								
	A		Read modified inputs and generate outputs				D	Ε ^
1	ID	Para	1	Name 💌	P1 - angle	P2 -	P3 -	Exported
2	 Input Parameters 				[ueg]	Express	Expres	
3	Maxwell 3D Design (A1)		2	Current	0	1	1	
4	(p P1	angle [de	3	DP 1	1	4	1	
*	New input parameter	New nam	4	DP 2	2	1	1	
6	 Output Parameters 		5	DP 3	3	9	7	
7	Maxwell 3D Design (A1)		6	DP 4	4	4	4	
8	P2 ₽2	ExprCad	7	DP 5	5	9	9	
9	P3	ExprCad	8	DP 6	6	4	1	
	New output parameter		9	DP 7	7	1	1	
11	Charts		10	DP 8	8	9	9	

Figure 26



The evaluated curves can be shown also inside the parameter manager with inserted charts:

- Insert Charts
- Choose Angle for the x axis definition
- Choose Ang_Back for y axis 1 and Ang_Fwd for y axis 2



Abbildung 27