Magnetic induction B created by a solenoid

2D Textbook Case Summary

Program	Dimension	Physics	Application	Work area
Flux	2D - axi	Magnetic	Static	Magnetic

Study of the magnetic induction field radiated by a solenoid. This example shows how to estimate the impact of the field radiated by a solenoid on its environment (EMC type application).

Objective

Use of the magnetic induction N at a point M (0,y) located on the Y-axis. The parameters the user can change are:

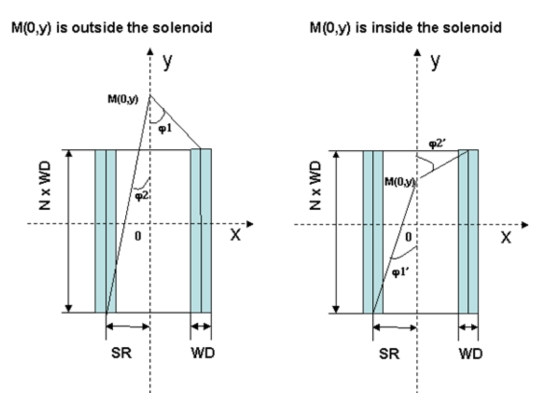
- Solenoid number of spires (N)
- Current (I) injected in the solenoid

Theoretical reminders

Analytical computation of the B variation on the solenoid considering different parameters:

If M (0, y) is inside the solenoid: $|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 1') + \cos(\varphi 2')]$

If M (0, y) is outside the solenoid: $|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 2) - \cos(\varphi 1)]$

<table>
<tr><th>Illustration</th><th>Main characteristics</th></tr>
<tr><td>


</td><td>

- Copper conductor rated diameter: WD = 1 mm
- Solenoid rated radius SR = 10 mm
- Rated number of spires N = 80
- Rated injected current I = 10 A

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</table>

Results

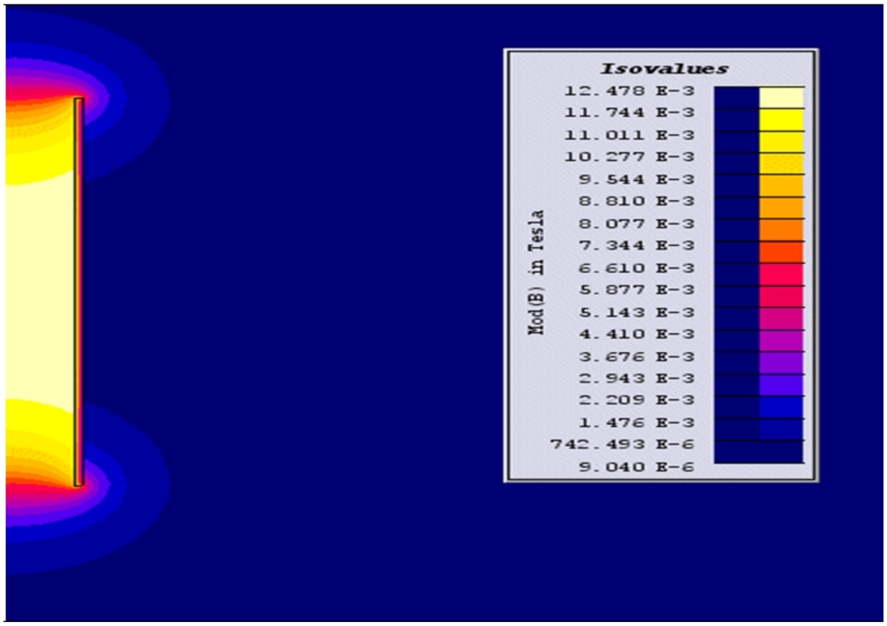


Figure 1: Distribution of the magnetic flux surface density (B in Tesla)

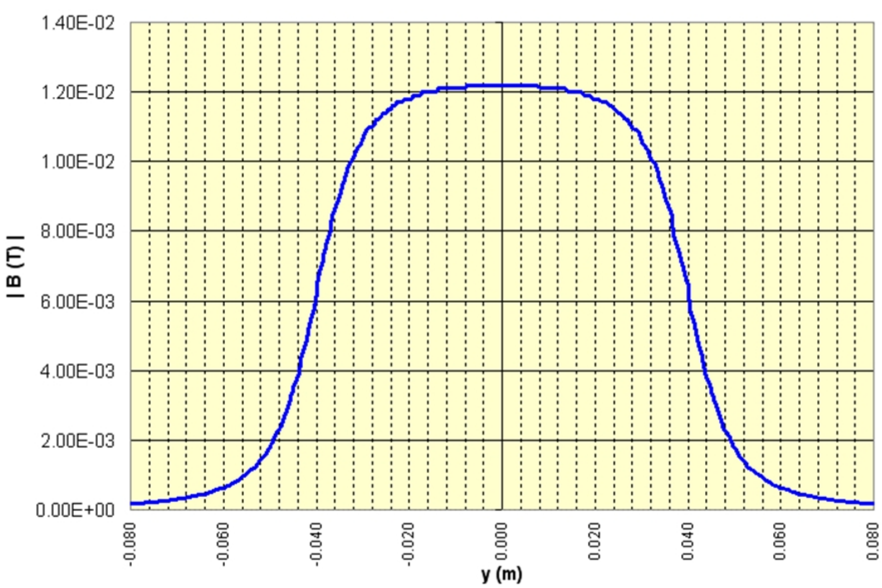


Figure 2: Magnetic induction B along the Y-axis

To go further:

- Study of the magnetic field created by a coil solenoid around a magnetic core
- Similar analysis in steady AC magnetic or transient magnetic

Model in Flux

Domain

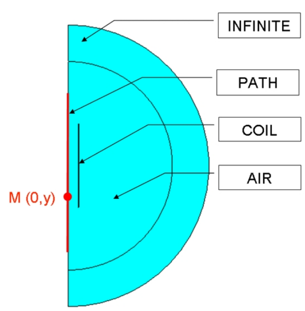
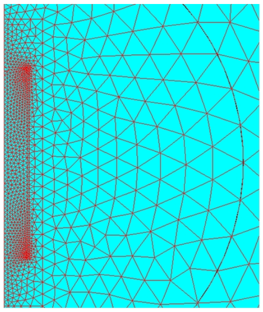
Dimension	2D	Depth	axi
Length unit.	mm	Angle unit.	degrees

Infinite Box		Disk
Size	In. radius : 100	Out. Radius :135

Symmetry	1 symmetry	SymmetryYaxis_1 : Symmetry on the Y-axis – H tangent

Application	Magnetostatic

Geometry / Mesh

Full model in the FLUX environment	Mesh
	

Mesh	2nd order type	Number of nodes	4718

Input Parameters

Name	Type	Description	Rated value
N	Geometrical	Number of spires	80
SR	Geometrical	Solenoid radius	10 mm
WD	Geometrical	Conductor wire radius	1 mm
I	Physical	Current intensity	10 A

Regions

NAME	AIR	WIRE	INFINITE
Nature	Surface density	Surface density	Surface density
Type	Air region or vacuum	Coil conductor type region	Air region or vacuum
Material	-	-	-
Mechanical Set	-	-	-
Corresponding circuit component	-	COILCONDUCTOR	-
Electrical characteristics	-	N spires	-
Current source	-	-	-
Thermal characteristics	-	-	-
Possible thermal source	-	-	-

Electrical circuit

Component	Type	Characteristics	Associated Region
COILCONDUCTOR	Coil conductor	Stiff current (A) : I	WIRE

Solving process options

Type of linear system solver	Automatically chosen	Parameters	Automatically defined

<table>
<tr><td rowspan="2">Type of non-linear system solver</td><td rowspan="2">Newton Raphson</td><td>Precision</td><td>0.0001</td><td>Nb iterations</td><td>100</td></tr>
<tr><td colspan="2">Method for computing the relaxation factor</td><td colspan="2">Automatically determined method</td></tr>
</table>

Solving

Scenario	Name of parameter	Controllable parameter	Variation method	Interval definition	Step selection
REFERENCEVALUES	-	-	-	-	-

Annex

Theoretical reminders

Computation of the magnetic induction B

Maxwell equation: $\vec{\nabla} \times \vec{H} = \vec{J}$

Biot & Savart Law: $d\vec{B} = \frac{\mu_0 I d\vec{l}}{4\pi r^2}$

Final equations:

If M (0, y) is inside the solenoid: $|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 1') + \cos(\varphi 2')]$

If M (0, y) is outside the solenoid: $|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 2) - \cos(\varphi 1)]$

Notations and symbols

Symbol	Description	Unit
B	Magnetic induction field	T
H	Magnetic field	A/m
μ_0	Absolute permeability of vacuum $\mu_0 = 4 \times \pi \times 10^{-7}$	H/m
J	Current surface density	A/m²
I	Current injected in the conductor	A
N	Number of spires	
WD	Copper wire diameter	m

Numerical applications

Case study

Let's consider a solenoid made of N = 80 spires in which we inject a current I = 10A. The solenoid radius is SR = 10 mm and the spire diameter is WD = 1mm.

Solenoid length = N x WD = 80 mm

- Computation of the magnetic induction variation at a point located on the axis, at one of the solenoid ends (y = 40 mm compared to the solenoid centre):

$$|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 1')]$$

$$|B| = \frac{4 \times \pi \times 10^{-7} \times 10}{2 \times 10^{-3}} \times \frac{80 \times 10^{-3}}{\sqrt{(80 \times 10^{-3})^2 + (10 \times 10^{-3})^2}} \approx 6.23mT$$

- Computation of the magnetic induction variation on the solenoid axis at a 80 mm distance of its centre (outside the solenoid):

$$|B| = \frac{\mu_0 \times I}{2 \times WD} \times [\cos(\varphi 2) - \cos(\varphi 1)]$$

$$|B| = 6.28 \times 10^{-3} \times \left(\frac{4 \times 10^{-3}}{(40 \times 10^{-3})^2 + (10 \times 10^{-3})^2} \times \frac{(80 + 40) \times 10^{-3}}{\sqrt{(120 \times 10^{-3})^2 + (10 \times 10^{-3})^2}} \right) \approx 166 \mu T$$