

Permanent Magnet Simulation Benchmark

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Permanent Magnet Simulation Benchmark

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Introduction

For a large fraction of permanent magnet applications, the magnet properties are characterized by a second quadrant magnetization curve with two points:

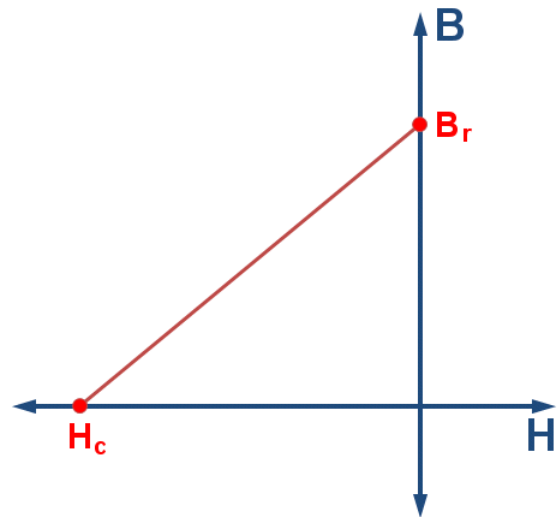
- B_r – the B value for $H=0$
- H_c – the H value for $B=0$

This is especially appropriate for highly linear materials such as Neodymium ceramics, but even nonlinear materials such as Alnico normally need to be stabilized for predictable behavior, then are used in a regime which is reasonably linear. Hence, for a given application effective B_r & H_c values can be selected.

The slope of this graph, in Gauss-Oersted units, gives the effective permeability of the magnet.

An ideal – uniform magnetization – magnet would have an effective permeability of 1. Real magnets have higher permeability, though not as high as typical ferromagnetic. For example, Neodymium magnets typically have effective permeabilities of 1.05. Hence, analytic calculations based on uniform magnetization can often be performed for an approximation to the magnet properties. These will typically be correct within a few percent – the difference being due to the non-uniform magnetization that arises from self-effects (demagnetization) of the magnets. Simulation software is required to more accurately predict the fields from real magnets.

Since many real magnets are close to ideal, it is possible to benchmark software for permanent magnet calculations by creating an ideal B-H characteristics and comparing model results when it is applied to geometry with known analytic results for ideal cases. One can be confident that the ability to compute this case will be strongly correlated with the ability to compute similar cases with real materials.



Model Description

Any commercial simulation software *should* be able to give acceptable answers along the magnetization axis for disk (cylindrical) and rectangular bar magnets. However, if you require accuracies much smaller than 1% and/or far away from the magnet, you may have a lot of difficulty obtaining this result with software based on Finite Element or Finite Difference methods. You should perform such simple tests for basic verification of your software, however, the benchmark proposed here is much more challenging and realistic.

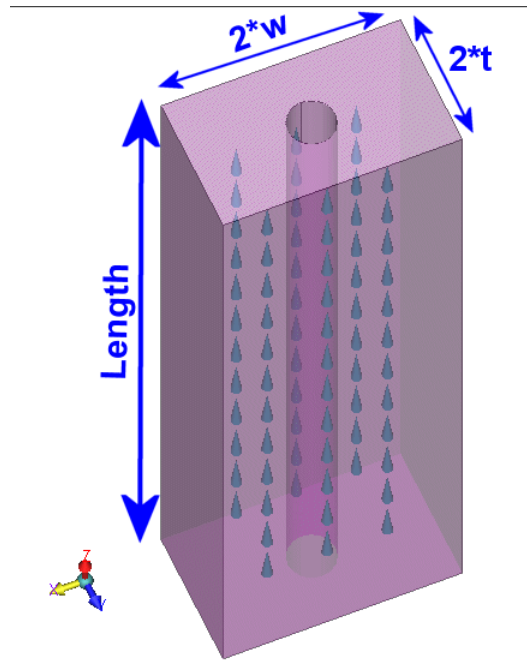
The model consists of a rectangular bar magnet, magnetized along the length ("l" in the formula below):

$$B = \frac{B_r}{\pi} \left[\tan^{-1} \left(\frac{d+l}{tw} \sqrt{t^2 + w^2 (d+l)^2} \right) - \tan^{-1} \left(\frac{d}{tw} \sqrt{t^2 + w^2 + d^2} \right) \right]$$

Where "w" and "t" are shown in the image to the right. "d" is the distance above the top center of the magnet.

The model is made more challenging by putting a hole of radius "r" through the center. Since ideal (uniform magnetization) material is being used, this is equivalent to superimposing a rod magnet with opposite magnetization. The formula for such a magnet is:

$$B = \frac{B_r}{2} \left[\sqrt{\frac{d+l}{(d+l)^2 + r^2}} - \sqrt{\frac{d}{d^2 + r^2}} \right]$$



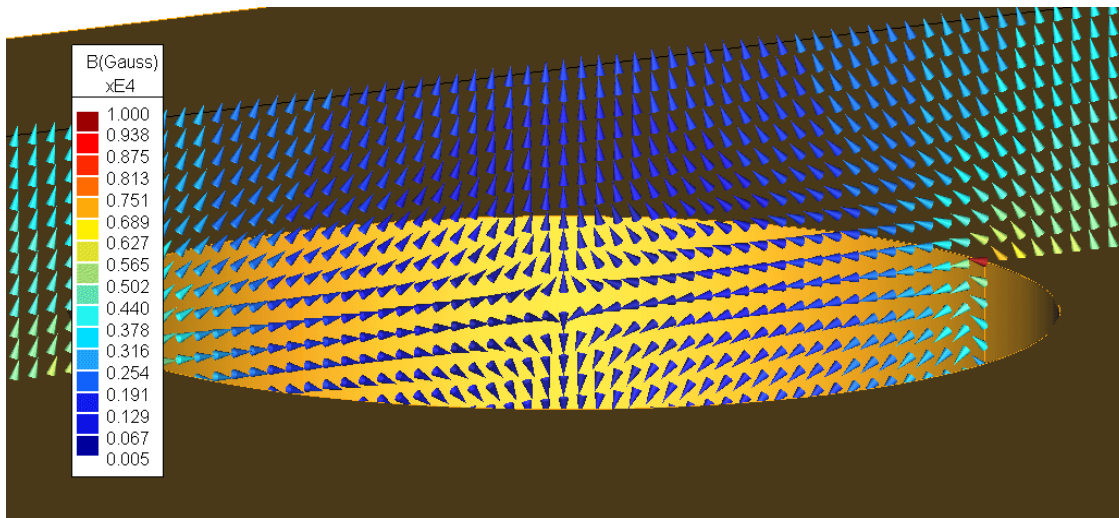
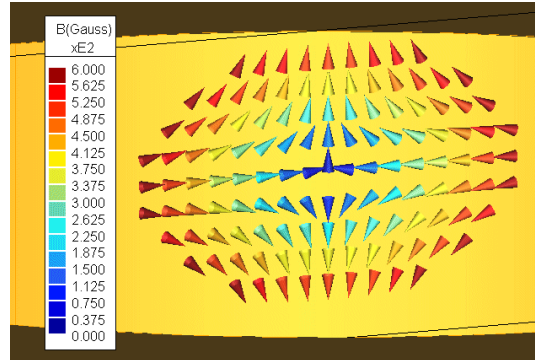
The magnetic field at any position above the center of the hole is thus given by difference in value predicted. [Download this Excel spreadsheet](#) for a template to calculate the field for rectangular and rod (disk) bar magnets, as well as their superposition to simulate holes.

D8		fx =B8 + C8		
	A	B	C	D
1	Br	10000	Gauss	
2	length	30	mm	
3	half thickness	3	mm	
4	half width	5	mm	
5	radius	1	mm	
6				
7	Distance from End (mm)	Bar Magnet	Cylinder Magnet	Total Field
8	0	4947.9276	-4997.2245	-49.2970
9	0.01	4935.5880	-4947.2289	-11.6409
10	0.02	4923.2487	-4897.2482	26.0004
11	1	3755.3681	-1461.8667	2293.5015
12	1000	2.7408E-03	-1.4351E-04	2.5972E-03

Five positions from the end have been selected to demonstrate three different regimes of potential interest.

Region #1 – Near the Null Field Point

The first three points in the spreadsheet show the field changing from -49 Gauss at the hole opening to +26 Gauss only 0.02 mm (1/50th of the hole radius) above. This effect may not be immediately obvious to all readers. The vertical **B** field arrow plot to the right shows what is happening to the flux. The flux generated near the hole returns through the hole. The flux generated further away takes a much longer return path around the outside of the magnet. A larger area plot is shown below.



Another way of thinking about this is the superposition of an upwards rectangular magnet and a downwards cylindrical magnet that generated this model. Right above the hole the B field is dominated by the downwards cylindrical magnet. Being a much smaller volume, its contribution to the total flux diminishes rapidly with distance. Hence, the spreadsheet shows that at the hole opening the two contributions cancel to 99%. This makes the field precision very important to computing the field in this area. If it is important to you to get good field results in the vicinity of holes or other irregularities in your magnets, you should check your software against the spreadsheet in this region.

Region #2 – The Easy Region

For distances comparable to magnet dimension, the result is dominated by the rectangular volume. Subtraction of the hole is not so close to cancellation, so precision is not such a big issue. Hence, any software should at least be able to give you acceptable results in this region. The spreadsheet selects a point equal to the radius of the hole above its center for a sample of this region. The subtraction of the hole only affects the result by about 30%, so the result should be relatively easy compared to Region #1.

Region #3 – The Far Region

For distances larger than the magnet, the result may become difficult to compute. This is dependent on the solver methodology.

- Differential methods (e.g. Finite Element, Finite Difference) require an artificial boundary around the model. The accuracy of the result at some significant distance from the magnet surface depends on the size and type of artificial boundary used. However, the larger the boundary is, the more difficult the overall solution will become.
- Integral methods (e.g. Boundary Element, Volume Integral) are not constrained by any artificial boundary. However, the numerical integrations will be formulated for normal problems (i.e. distances compared to the element sizes). Hence, a problem that is unusual, such as querying the field at a much larger distance than most users expect, may not be computed as well as nearby points.

To test the ability to model fields a significant distance away, the spreadsheet selected a point above the magnet at a distance of 30x its length.

AMPERES Results

INTEGRATED's software for simulating 3D magnetics without including Eddy Currents is [AMPERES](#). **AMPERES** includes both Finite Element (FEM or FEA) and Boundary Element (BEM, BEA, or MoM) solvers. However, our recommendation for permanent magnet models is Boundary Elements. The results that follow are thus for the Boundary Element solver. When evaluating **AMPERES** you would be able to compare the two solvers. We also encourage you to compare these BEM results with any 3D FEM modeling software you have available.

The model was solved on a 3 GHz single processor running WindowsXP Pro. This first set of results was obtained by setting up the model and selecting "Solve", hence using the program's default settings.

Br	10000	Gauss				
length	30	mm				
half thickness	3	mm				
half width	5	mm				
radius	1	mm				
Distance from End (mm)	Bar Magnet	Cylinder Magnet	Total Field		AMPERES*	% Difference
0	4947.9276	-4997.2245	-49.2970		-49.2957	0.0026%
0.01	4935.5880	-4947.2289	-11.6409		-11.6396	0.0110%
0.02	4923.2487	-4897.2482	26.0004		26.0017	-0.0049%
1	3755.3681	-1461.8667	2293.5015		2293.5030	-0.0001%
1000	2.7408E-03	-1.4351E-04	2.5972E-03		2.5998E-03	-0.0965%
					* 14 second solution	

For numerical analysis, this agreement with theory to levels around 0.01% or better is very good, especially for a solution that only took 14 seconds. In fact, this is accurate beyond the effect of typical

tolerances for material properties and the physical dimensions. Hence, for many users the solver conditions could be relaxed to produce faster answers.

When results are around a 0.1-1% accurate, the best way to improve them is to increase the element density in the least accurate areas. Since the result is much better than this, the limitation in accuracy is likely in the type of numeric integrations used. So, to produce a better answer the “Accuracy/Speed” factor was increased from 1 to 2. This effectively means that as higher level of integration will be used at any distance. This will slow down computations, but will make them more accurate if there are already sufficient elements. Here is the result:

Distance from End (mm)	Bar Magnet	Cylinder Magnet	Total Field	AMPERES**	% Difference
0	4947.9276	-4997.2245	-49.2970	-49.2972	-0.0005%
0.01	4935.5880	-4947.2289	-11.6409	-11.6411	-0.0021%
0.02	4923.2487	-4897.2482	26.0004	26.0002	0.0009%
1	3755.3681	-1461.8667	2293.5015	2293.5020	0.0000%
1000	2.74075E-03	-1.43510E-04	2.59724E-03	2.59725E-03	-0.0003%

** 90 second solution - Accuracy=2

All results are now accurate to 5 or 6 decimal places. The results in the near regions were each improved by a factor of about 5. The results in region 3 had been the least accurate (see relevant comments above) but are now improved by a factor of 300 and are comparable to the other results.