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The Interaction between Two Permanent Magnets with Significantly Different Permeance Coefficients

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Abstract

Even though Gauss' law for magnetic flux density (B-field) indicates there is no free magnetic charge, we can still define the effective bound magnetic charges from the magnetization of magnetic material [1]. The positive magnetic charge is called the "north pole", and correspondingly, the negative magnetic charge is called the "south pole". The interaction between the magnetic charges is governed by Coulomb's law so that like poles repel and unlike poles attract [2]. However, experiment shows that when two permanent magnets with significantly different permeance coefficients (P_c) were put together, with their directions of magnetization (DOM) pointing against each other, instead of repelling, they can attract to each other, especially when the coercivity of the big magnet is relatively low. This phenomenon may lead people to think that Coulomb's law for magnetic charges is not always right, and in some cases, like poles attract.

In this work, we show that the above bizarre phenomenon is caused by the partial demagnetization in the low P_c magnet, rather than violation of Coulomb's law. When the experiment is carried out using sintered NdFeB magnet of N50 grade, the working point for the stand-alone low Pc magnet is very near to the knee of its demagnetizing curve, so it's very vulnerable to the external and its self-demagnetizing field. Finite Element Analysis (FEA) shows that demagnetization happens obviously in the central region of the magnet with low P_c, but the magnetization remains in the same direction all over the magnet. FEA also gives an attractive force when the above low P_c and high P_c magnets are close to each other with opposite DOMs. Based on the magnetic charge model and Coulomb's law, the numerical integration of Coulomb's force is carried out, which gives almost the same attractive force as FEA.

Background

Knowledge from the secondary physics tells us that a magnet have a north pole and a south pole, and like poles repel whereas unlike poles attract. However, experiment shows that when two NdFeB magnets with significantly different permeance coefficients (Pc) were put together, with their directions of magnetization (DOM) pointing against each other as shown in the figure below, instead of repelling, they will attract to each other, especially when the coercivity of the large magnet is relatively low. It seems that in some cases, like poles attract, is that true?

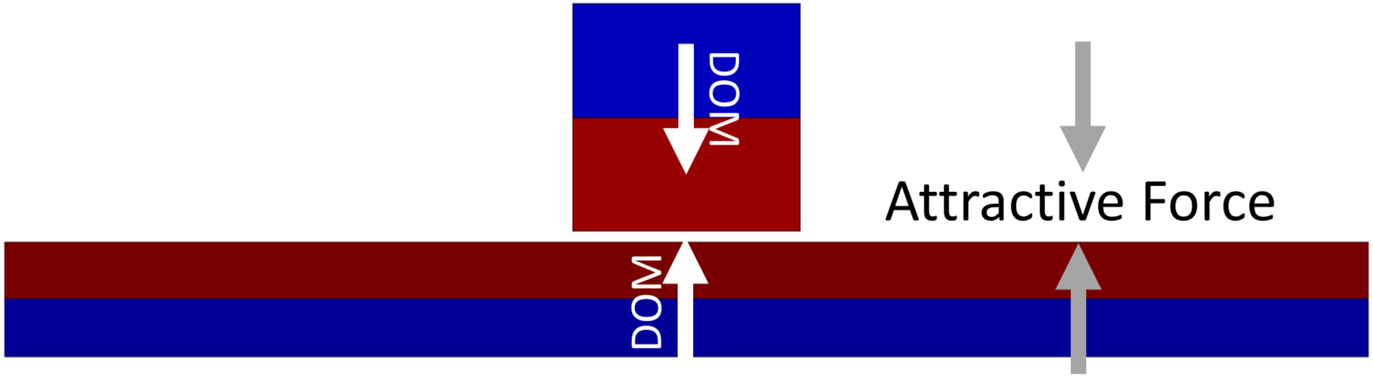

Fig.1 Schematic of the model

Research Method

Even though Gauss' law for magnetic flux density (B-field) indicates there is no **free** magnetic charge, we can still define the effective **bound** magnetic charges from the magnetization of magnetic material [1]. The **positive magnetic charge is** called the "**north pole**", and correspondingly, the **negative magnetic charge** is called the "**south pole**". The interaction between the magnetic charges is governed by Coulomb's law so that like poles repel and unlike poles attract [2],

$$\overrightarrow{F_{12}} = \frac{1}{4\pi\mu_0}\frac{m_1 m_2}{|\overrightarrow{r_1}-\overrightarrow{r_2}|^2}\overrightarrow{r_{12}}$$

For practical magnet, the magnetic charge is distributed around the magnet, therefore we should use volume charge density ρ(r) ($\nabla \cdot M$), or surface charge density σ(r) ($n \cdot M$) to replace the point charge m. For most anisotropic rare earth magnet, the magnetization is uniform, therefore, σ(r) plays the key role.

Below we consider the magnetic force between two coaxial hollow circles with uniformly distributed magnetic charge as shown in Fig. 2. After a series of simplification, the magnetic force between these two circles can be written as,

$$F_{12} = \frac{2}{\mu_0}\iint_{ir1,ir2}^{or1,or2} \frac{\sigma_1\sigma_2 l r_1 r_2 \mathrm{EllipticE}[\frac{-4r_1r_2}{l^2+(r_1-r_2)^2}]}{(l^2+(r_1+r_2)^2)\sqrt{l^2+(r_1-r_2)^2}}\,dr_1\,dr_2$$

where EllipticE is the complete elliptic integral. When ir1=ir2=0, it gives the special case of magnetic charge distributed in solid circles.

In the next section we use the equation above to calculate the magnetic forces between a small (D4mm*4mm) an a large (D24mm*2mm) cylindrical magnet with Br of 1.4T.

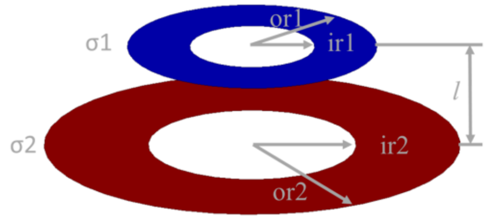

Fig.2 Schematic of the magnetic charge model of two coaxial circles

Results and Discussions

1. working point analysis

The magnet with higher P_c will generate stronger magnetic field near its surface than the magnet with lower P_c, as a result, the tendency of demagnetization for the large magnet will increase when it is pushed against the small magnet as shown in Fig.3a.

For comparison, Fig.3b and 3c show the magnets with the same P_c.

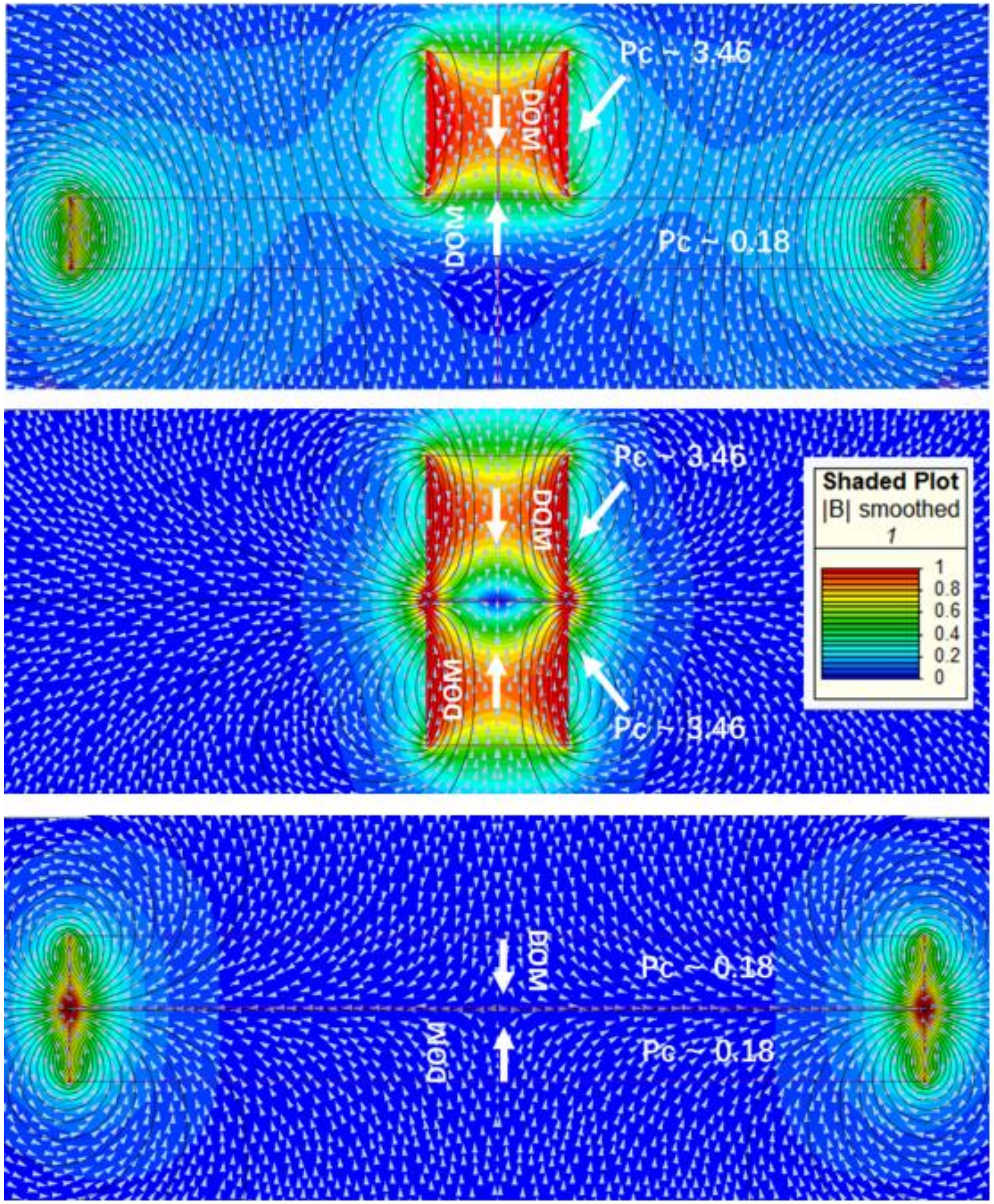

Fig. 3 →

The magnetic field distribution when two magnets are pushed together with their DOMs against each other (a) with different P_c, (b) & (c) with the same P_c

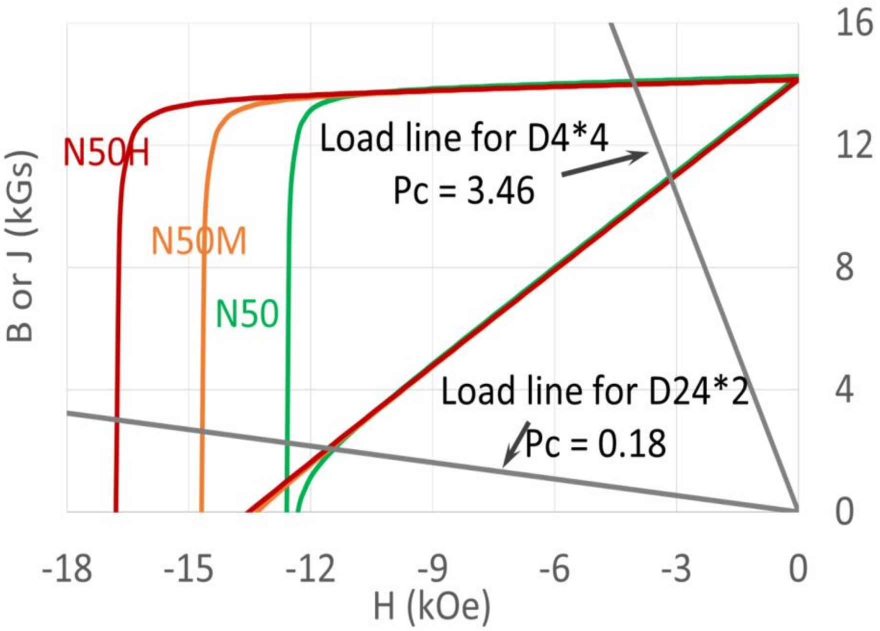

Fig.4 Demagnetization curves for N50, N50M, and N50H, and load lines for magnets with the shape of D4*4 and D24*2.

For NdFeB grade with lower Hcj such as N50, the working point for the low P_c magnet is near its knee as shown in Fig. 4, so it is more vulnerable to demagnetization.

2. Perfect magnets

Perfect magnet means that the magnetization inside both magnets is absolutely uniform and equal the remanence.

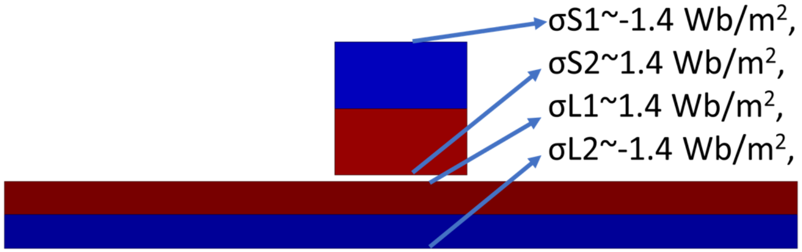

Fig.5 Case for perfect magnets

Table 1 Interactive force between different magnetic charge slices and the net force for the case of Fig.5

	σL1	σL2	Total
σS1	-6.605N	5.330N	**0.348N**
σS2	9.717N	-8.094N	

3. Magnets with its intrinsic coercivity relatively weak

As is discussed in 1, for the N50 grade, the working point for the large magnet is very close to the knee, therefore, the magnetic field generated by the small magnet will demagnetize the large magnet locally and partially. We assume only the magnetization in the portion of the large magnet which is located directly under the small magnet is weakened to 1.0T.

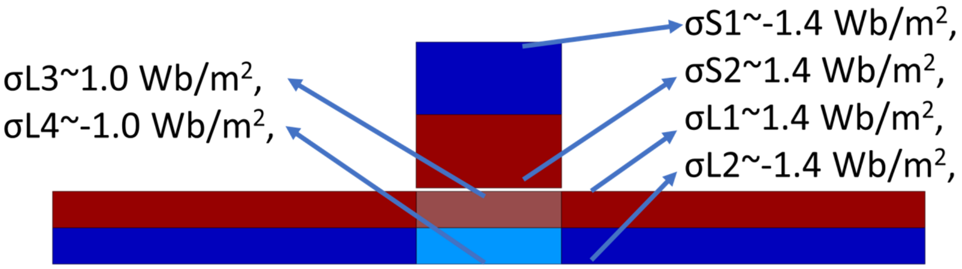

Fig.6 Case for the magnetization in the large magnet being weakened in the central region

The net force in this case becomes attractive (negative) even though the polarities of the magnets remain the same. Note that the interactive force between each pair of magnetic charge slices still obeys the Coulomb’s law.

	σL1	**σL2**	**σL3**	**σL4**	**Total**
σS1	-5.723N	4.873N	-0.630N	0.326N	**-1.351N**
σS2	1.189N	-5.937N	6.092N	-1.541N	

Table 2 Interactive force between different magnetic charge slices and the net force for the case of Fig.6

Conclusion

A numerical analysis base on Coulomb’s law is carried out to interpret a bizarre magnetic phenomenon. The statement that “like poles repel, unlike poles attract” still holds. The phenomenon is caused by the partial demagnetization (magnetic charge redistribution) in one of the magnet with lower permeance coefficient.

References:
[1] J. M. D. Coey, Magnetism and Magnetic Materials, 2010, Cambridge University Press, p.45.
[2] Soshin Chikazumi, Physics of Ferromagnetism, second edition, 1997, Oxford University Press, p.3.