K&J Magnetics, Inc.

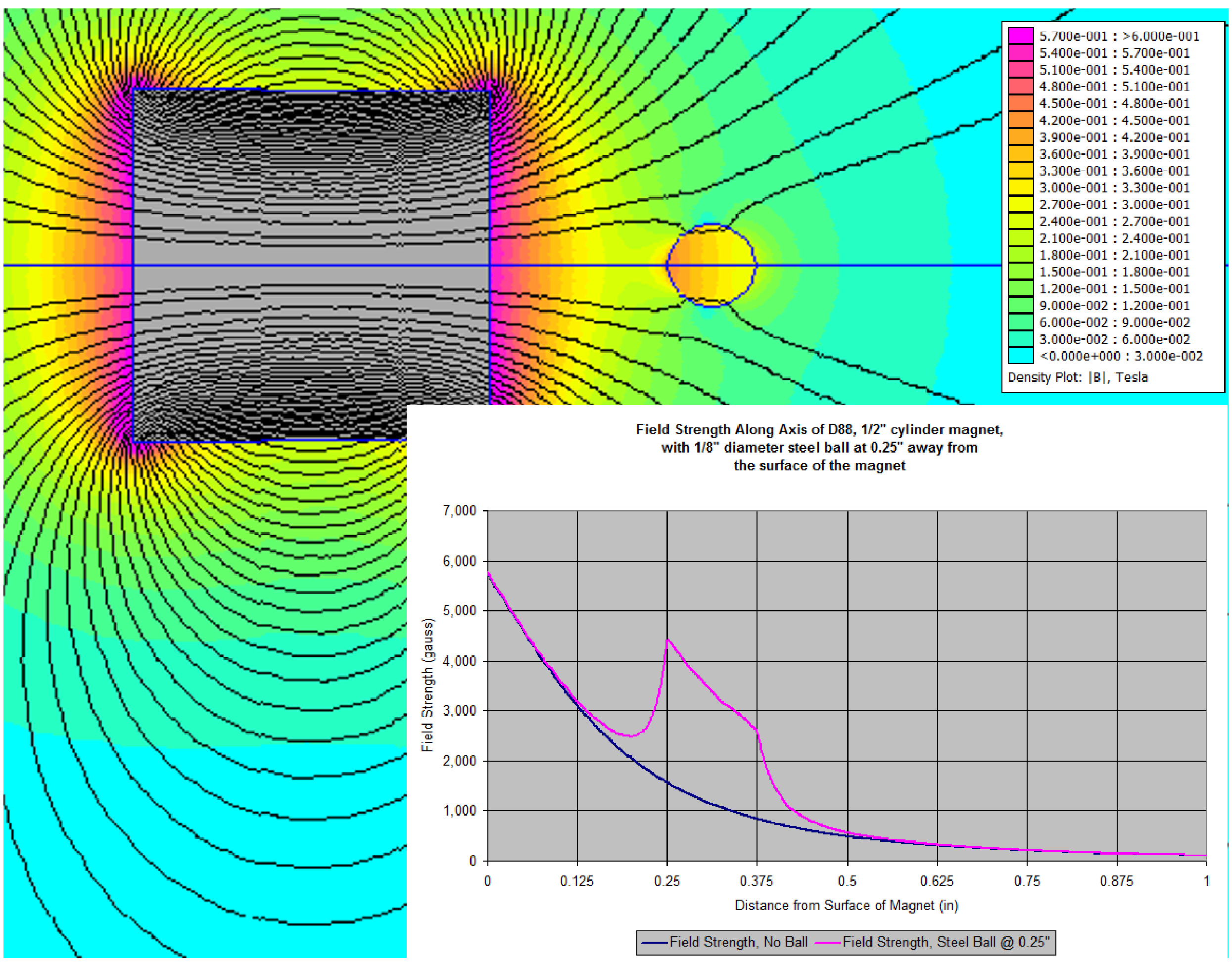
**Why is a steel ball attracted to a magnet, anyway?**

Warning: Technical content!

How does a steel object that is some distance away from a magnet get pulled towards the magnet? To understand this, we're going to look a little closer at the basics of magnetic attraction. At the end, we'll even pose a question we have that has us stumped. Maybe you can help! (Email us if you have an answer.)

You need more than a magnetic field present to move our steel ball. You also need a magnetic field gradient. In other words, the magnetic field should change as you vary the distance to the magnet.

Consider the diagram below. It shows a 1/8" diameter steel ball (NSB2) That is ¼" away from a ½" diameter D88 cylinder magnet. There's a few interesting things going on here.




http://www.kjmagnetics.com/images/blog/MagneticSeparationTechnical.pdf

First, check out the field strength inside the steel ball. It's elevated higher than the surrounding space. It is higher than that space would be if there were no steel ball present. This is because, in the presence of the strong magnetic field, the steel temporarily becomes a magnet. As long as it's in that external field, it acts like a magnet.

Second, check out the field strength on either side of the magnet. Closer to the magnet, the field strength is higher. Farther from the magnet it is weaker. It's this difference that compels the steel ball to move towards the magnet. The temporarily magnetic ball is attracted towards the region of higher field strength.

Many of the papers we've seen about attracting iron nano-particles with a magnetic field use the following formula to estimate the force on the particle. You can see how the total field strength, B and the difference in field strength, $\Delta B$, both play a role.

$$F = \frac{V \, \Delta\chi \, (\Delta B) \, B}{\mu_o}$$

- Force (N) → $F$
- Volume of the steel ball ($m^3$) → $V$
- the Difference between the magnetic susceptibility of air and steel (unitless) → $\Delta\chi$
- the Difference between the magnetic field strength on opposite sides of the steel ball (T) → $\Delta B$
- the field strength at the center of the steel ball (T) → $B$
- the magnetic permeability of free space ($4 \pi \times 10^{-7}$ N/$A^2$) → $\mu_o$

Since we know what the field strength around a single magnet looks like (see our Surface Fields article, or use our Pull Force Calculator), we figured we would plug some numbers into this formula to estimate strength. If we use some known results (from finite element analysis and testing) for a D88 magnet and 1/8" steel ball, it should verify if the formula is any good.

Here's the problem we found, which we're hoping one of our brilliant readers might help us with: the units don't match!

If we plug in numbers for all these things, the units work out to be N*m or Newton-meters.  For those not metrically inclined, you might think of that as foot-pounds.  That is not a unit we normally use to describe a force.  That sounds a lot more like a torque than a force!

While determining magnetic torque or moment is often an interesting study (like the force that turns a compass needle to align with the earth's magnetic field), it's not what we're looking for here.  In fact, since the steel ball isn't actually a magnet with a preferred magnetization direction, we wouldn't expect any torque on it at all.

Maybe we're just using the wrong formula.  That's possible.

Still there is a correlation that makes our mystery very interesting:  When we plugged numbers in the formula and just pretended the answers were in Newtons (and ignore the meters part), the numbers matched very close to our results from an FEA study.  If we multiplied the formula's answers by 10, it matched within a few percent!

What conversion factor are we missing here that makes our calculations so close, yet off by a factor of 10?  We're not sure.  Our best guess is that we're using a bad number for the magnetic susceptibility of steel.  Maybe it should be 1,000 instead of 100.

If you have an idea about where went wrong, please let us know.