Learn Magnet Basics

In this first of two installments, readers learn the basics of magnetic theory and construction. A look at the main components of electromagnets and permanent magnets leads into a discussion of how magnetic strength is rated using the Force Index.

Magnets have been used for centuries as a way of lifting and classifying objects. Today nearly every industry imaginable uses magnets, from mining to advanced semiconductor research to the aerospace industry, where possible "Star Wars" applications have been mentioned.

There are two kinds of magnets: electromagnets and permanent magnets. The latter retain their magnetism for a long time without external energy input. Because electromagnet theory is elemental to the understanding of magnetic principles, we will explore this area first, then discuss applications and problem solutions to magnets in general - both electro and permanent.

Magnetic Theory and Design

Any wire that carries an electrical current also has a magnetic field around it. These magnetic field lines are invisible lines of force that can be measured and put to use in separating, lifting, and classifying in a modern magnetic separator.

To visualize these field lines, imagine a wire with an electrical current traveling through it. The field lines will encircle the wire (Figure 1) with the number of magnetic lines present in direct proportion to the amount of current flowing through the wire.

If you mentally lengthen this wire and wrap it over onto itself (Figure 2), the magnetic from each loop of wire will line up and point down through the inside diameter of the circle. The other return path is outside the loop.

These loops of wire, called coils, form the heart of all electromagnets. But before these magnetic field lines can go to work lifting, the magnetic attraction must be strengthened and focused.

If we use only the coil of wire inside a magnet for lifting, it will be relatively weak and require large inputs of energy. To increase the magnetic field in the use area, a highly permeable material such as mild steel is installed inside the coil to "attract" the filed lines, thus concentrating them inside the core material.

Figure 3 shows the magnet as now designed - many loops of wire carrying an electrical current and a rod of highly permeable material inside the coil to concentrate the field so they can be directed where we want them.

Using these design principles, we can identify three ways of changing the force a magnet exerts on an object: * Changing the amount of current the coil carries, because the field lines generated by the coil are proportional to the amount of current flowing through the coil.

* Adding more loops of wire for more field lines.

* Increasing the permeability of the core material, thus concentrating more of the field lines inside the core. Practically speaking, only the first two options, varying the current and adding wire loops, are cost-effective in magnet construction. Increasing core permeability is not practical because once most field lines are concentrated, little benefit is gained from additional changes to this material.

Typical Magnet Construction

Next, a steel case encloses the wire coils and core material they surround. Besides protecting the coils, the magnet enclosure serves as the return path for the field lines. Remember that field lines return to the end of the coil by circling to the outside of the coil. These lines now exit the bottom of the magnet, go out into the material to be attracted and lifted, and then return through the four sidewalls and the top of the magnet enclosure (Figure 4). The enclosure concentrates the field lines returning outside the coil of wire.

Despite the theoretical controlling effect of the enclosure, real magnets exhibit several non-ideal effects such as the leakage of magnetic field lines and saturation. The "saturation" effect takes place when the electric current applied to the coils is increased.

In an ideal magnet, the number of field lines is directly proportional to the current in the coil. In actual practice, once the current is raised to certain level, the core cannot accept additional magnetization, and becomes" saturated". Additional increases in current result in smaller increases in actual magnetic field.

As we've seen, the magnet enclosure becomes part of the magnetic loop. That makes the choice of material for the bottom plate of the magnet, where the field lines exit to the target material before returning through the magnet sidewalls, an important one. If the bottom plate were made of common steel (which is a permeable material), we would have a closed magnetic circuit. That is, the field lines would be generated, travel through the bottom plate to the sidewalls, and back up to the top plate without ever exiting the magnet. Clearly, we need a nonmagnetic material for the bottom plate that will allow the field lines to escape the magnet enclosure and attract and pick up material. Typically, this bottom plate is stainless steel (type 304 or equivalent). The rest of the magnet box usually is welded from ordinary steel.

Coil windings and insulation have probably undergone the most evolution over the years. Coils used to be exclusively copper with either varnish, cotton, silk, or some other organic compound serving as insulation. Magnet life was relatively short, because the insulation degraded and the windings shorted out. This increased the temperature of the magnet, accelerating the insulation breakdown, and so on.

One particularly successful solution to this problem was anodizing thin aluminum strips several inches wide into an aluminum oxide insulation. The aluminum with stands temperatures greater than almost any organic compound, it is abrasion resistant, and it will not absorb or hold water - all problems associated with most organic insulation materials.

In addition to the insulation, many magnet manufacturers cool their magnets with a type of cooling oil. The oil dissipates generated heat to the enclosure, where convection keeps the magnet temperature under control.

There are several different types of cooling oil, all of which are distinctly different and offer certain advantages. The most costly type of oil is silicone oil, which is not only fireproof but chemically inert. For these reasons, silicone oil typically is specified in food processing operations, where a fire could cause harmful by products to be dispersed and accidentally ingested.

Silicone oil typically costs about 50 percent more than regular flameproof oil. Flameproof oil is just that - flameproof - but not necessarily nontoxic under accidental ingestion conditions. However, it is the most common type of oil specified today for industrial conditions.

In the past, transformer-type oils containing PCBs were used in magnets, but these have been abandoned due to PCB toxicity problems. For this reason, used magnets should have the oil checked for PCB content before purchase.

Permanent Magnet Design

Permanent magnets represent, without a doubt, the majority of magnet installations for industries such as food processing or agricultural handling (grain storage), and sites where material is conveyed in chutes or pneumatically rather than on large conveyor belts.

There are a number of permanent magnet materials, but only one currently enjoys large commercial success. This is a ceramic formulation, typically composed of barium carbonate and iron oxide. The powdered chemicals are pressed into near net shape during manufacture of the magnetic block, then fired in a kiln to amalgamate the elements into a suitably hard "building block" for manufacturing permanent magnet units. Before assembly, these ceramic blocks are magnetized in a chamber in which a magnetic field orients the grains to create a south pole and north pole on opposite ends of the block.

Another type of permanent magnet material is alnico, an aluminum, nickel, and cobalt combination. Alnico's magnetic strength is about 40 percent greater than ceramic, but it has a definite price disadvantage, because the nickel and cobalt content make it much more expensive than ceramic. Alnico also has a relatively low resistance to demagnetization - an important consideration for some applications.

A third class of magnetic materials gaining popularity is rare earth formulations containing elements from the rare earth metals section on the periodic chart of the elements. A typical formulation is neodymium, iron, and boron. Although these formulations cost many times more than even alnico products, rare earths exert 20 to 30 times more powerful attractive forces. Many industries that have experienced problems with weak magnetic materials find that getting a previously unattainable amount of magnetism in a small package is well worth the relatively high price of these magnets.

Measuring Magnetic Performance

How do we measure magnetic performance? It is measured by the number of field lines per unit area in the material we want to lift, separate ferrous objects from, etc. and is usually specified by the distance from the bottom plate of the magnet. The number of field lines per square centimeter typically is called the "Gauss" of the magnet. In general then, it seems obvious that the more Gauss, the stronger the magnet, right? Well, not necessarily; here's why.

Let's assume that we are going to specify a magnet that will pull miscellaneous pieces of tramp iron from a conveyor belt carrying coal to a power plant bunker. Let's further assume that the magnet will be suspended a distance of 16 inches above the belt.

If we take Gauss readings at the 16-inch suspension height for apparently equivalent magnets, we may obtain various readings such as:

Magnet A: 700 Gauss
Magnet B: 620 Gauss
Magnet C: 725 Gauss

Now let us take look at how the field lines are actually generated by the magnet (Figure 5).

The actual work performed at 16 inches is not a product of the number of Gauss lines, but rather how these lines change in number as the distance from the magnet changes. For instance, if Magnet A above has 700 Gauss lines at 16 inches, but exactly the number at 14 inches, there would be not net force exerted on a piece of steel in the bed of coal.

Rating with the Force Index

The Force Index has great practical application for the buyer or specifier of a magnet, and offers a truly unbiased way of determining which magnet among several is the strongest. To illustrate with an example: Magnet A above has 700 Gauss lines at 16 inches. At 14 inches, the magnet has 1,000, and at 18 inches has 510. Therefore, the force index is:

FI = Gauss X Change in Gauss With Distance =
700 X (1,000-510)/(18"-14") = 85,750.

Now let's say Magnet B has 620 Gauss at 16 inches, 300 at 18 inches and 900 at 14 inches, the Force Index is:

FI = Gauss X Change in Gauss With Distance =
620 X (900-300)/(18"-14") = 93,000.

If Magnet C has 725 Gauss at 16 inches, 940 at 14 inches and 520 at 18 inches, the Force Index is:

FI = Gauss X Change in Gauss With Distance =
725 X (940-520)/(18"-14") = 76,125.

In this example, the Force Index reveals magnet B as the strongest, even thought it had the fewest Gauss Lines at 16 inches. Table 1 lists common Force Index numbers required to lift common objects:

Force Index rating required for overhead magnet to lift.
(X 1,000)

1/2" nut under 8" coal - 757
1" nut under 10" coal - 442
1" cube under 10" coal - 651
< 1/2" x 8" rebar under 6" coal - 59

Purchasing Considerations

There are other misconceptions about how to purchase magnets besides buying the largest number of Gauss. Typical are buying the model which draws the largest wattage, or the heaviest model.

As shown above, either increasing the number of turns in the magnet coil or increasing the current to the coil will change a magnet's pulling power. Actually, the magnetic force is increased as the product of the number of loops of wire times the current. So a decrease in the current can be compensated for by an increase in the number of windings.

Buying a magnet by wattage only means you've ignored the number of turns in the coil. Purchasing a magnet with more windings and a lower wattage requirement can give you a stronger, more efficient magnet that will be cheaper to operate.

In the same way, some purchasers consider a magnet to be like plate steel or other bulk materials and make their purchase decision based on the price per pound of magnet. Magnet manufacturers trying to sell to someone interested in the "heft" of a magnet will simply weld an additional plate to the top of the magnet to increase its weight. This plate has no practical value at all.

Science and Art

A good deal of scientific consideration goes into developing magnets; however, magnet design is much more of an art than a science. The effectiveness of magnetic separation depends not only on magnet design, but such factors as product preparation, installation, flow rates, etc. Evaluating aforementioned variables such as weight, physical size, watts, or Gauss may not provide the purchaser with the proper decision making tools.

Overall, the best tack is to know your application and be able to describe it properly, including conveyor velocities; volume, in cubic feet per minute or tons per hour; suspension height requirements; and a description of the conveyed material and the ferrous fraction to be removed. *William F. Graveman*

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The second installment of this series on magnets will discuss applications, including four magnets and their typical installations, and a special system developed for use in the solid waste industry.