Permanent Magnets; Materials, Applications and Economics

While it’s true that most permanent magnet (PM) material ever commercialized (except Lodex for obvious environmental and safety reasons) are still in some limited use today there are only 5 classes of PM materials/types that are commercially important. These are shown in Figure 1.

![Figure 1: Commercially Important Permanent Magnet Types](image)

This simple chart also illustrates the gap in available material properties ((BH)\text{max}) between isotropic bonded NdFeB at 12 MGOe and sintered SmCo at 18 MGOe and hence here is an opportunity for a new magnet material. However, this chart is missing a very important factor; namely the relative market share (and commercial importance) of each of these magnet options.

So how do we get decent estimates of the relative market sizes for the different magnet options? It turns out despite all the market studies available it is difficult to achieve accurate estimates of the global PM market. Here are some of the challenges:

- It is a very fragmented Industry with 100’s of suppliers (over 800 in Asia Pacific region).
  - For NdFeB there are 20 Top tier, 50 mid-level and 100’s third tier suppliers.
- Often Installed capacity is quoted rather than sales.
- It is difficult to estimate captive or In house production of magnets.
- Estimating magnet content of value added assemblies is a challenge.
- Exchange rate fluctuations.
- Rare earth raw material price volatility.

So despite these difficulties here is an estimate of the global PM market for 2016 as shown in Figure 2 below.
Figure 2: 2016 Global Permanent Magnet Market

Figure 3 shows these estimates as market share segmentation for each of the material classes. This dramatically illustrates that the market is dominated by NdFeB and ferrite magnets (over 90%).

It is intriguing to note how these two material types which are at the opposite ends of both the price and performance spectrum dominate the applications for permanent magnets. This poses the question is there a magic or optimum price/performance metric that helps to explain this market dominance?

Using the data from the market estimates showed earlier (Figure 2) it’s possible to calculate an average $/kg and an average (BH)max for each magnet option. One can then calculate the ratio of average price/kg to the average (BH)max as shown in Figure 4. It turns out the 2 mass market materials have the similar ratios while the other materials are higher i.e. less efficient in converting purchase price in to magnetic performance.

<table>
<thead>
<tr>
<th>Material</th>
<th>Average (BH)_{max} (MGOe)</th>
<th>Average price ($/kg)</th>
<th>Price/Performance ($/kg per MGOe)</th>
<th>Market %</th>
</tr>
</thead>
<tbody>
<tr>
<td>NdFeB</td>
<td>40</td>
<td>75</td>
<td>1.9</td>
<td>60</td>
</tr>
<tr>
<td>Ferrite</td>
<td>3.8</td>
<td>7.1</td>
<td>1.9</td>
<td>31</td>
</tr>
<tr>
<td>Bonded NdFeB</td>
<td>8</td>
<td>90</td>
<td>11.3</td>
<td>5</td>
</tr>
<tr>
<td>SmCo</td>
<td>25</td>
<td>100</td>
<td>4.0</td>
<td>2</td>
</tr>
<tr>
<td>Alnico</td>
<td>7</td>
<td>58</td>
<td>8.3</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 4: Is There An Optimum Price-Performance Metric?
So taking this idea further it is possible to plot $(BH)_{\text{max}}$ versus average price per kg together with a line of constant optimum price/performance of 1.9. So what can be seen in Figure 5 is that there are two regions; one for mass market materials and one for niche materials which fall on one or the other side of the optimum price/performance line. This also means that the gap for a new mass market magnet material is much greater than the 12 to 18 MGOe previously discussed.

Let’s now take this price/performance concept and challenge the basic foundations used to develop the idea and offer some alternatives approaches. First is $$/kg……or who buys magnets by weight?

Consider a toroidal ring magnet into which we have machined a gap of know volume, $V_g$ as shown in Figure 7. Incidentally this is the type of circuit that was used in a traditional moving coil meter before we moved to digital devices. The only function of a permanent magnet is to establish a magnetic field that then interacts with another field, electrical charge or magnetic material. In this example it creates a field $H_g$ in the airgap.

Assuming no leakage or fringing fields, using Ampere’s law and some basic magnet circuit equations it’s relative easy to arrive at the equation shown below. What we find is for a given air gap, field in the air gap, $H_g$, is proportional to the volume of magnet in the circuit.

\[ H_g^2 = (B_mH_m)V_m/V_g \]
(see Culity and Graham, 2nd Ed)

The reason why comparing magnet materials on a unit weight basis is an issue is because each material type has a different density with a wide range of values as shown in Figure 8.
Let’s now show the effect of density on the price/performance metric on a volume basis. In this case we have normalized the price/performance ratio to ferrite and defined ferrite as 1.0 on both weight and volume basis.

Remember from the previous analysis on a weight basis ferrite and NdFeB have the same ratio.....so the obvious question is why does anyone use hard ferrite? Well on a volume basis NdFeB is at a 50% price disadvantage over ferrite. All other materials are significantly less efficient in converting $ to magnetic performance on a volume basis than ferrite.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NdFeB</td>
<td>7.5</td>
</tr>
<tr>
<td>Ferrite</td>
<td>5.0</td>
</tr>
<tr>
<td>Bonded NdFeB</td>
<td>5.1</td>
</tr>
<tr>
<td>SmCo</td>
<td>8.4</td>
</tr>
<tr>
<td>Alnico</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Finally let’s challenge the validity of using (BH)max as the best metric for magnetic performance in an application. The only role of a permanent magnet is to provide a magnet field in a substance or vacuum. How the field interacts with a conductor, field, charged particle or another magnetic material is the how a magnet provides a useful function.

Below is a table of the 4 major applications and the physical laws and the magnet parameters that determines the functionality (Figure 10). As can be seen most are dependent on B which assuming a straight line high coercivity magnet (rare earths and ferrite) is proportional to $B_r$ rather than (BH)max. For holding type applications the function of the system is proportional to $B^2$ and in these applications (BH)max is important.
So in conclusion while there are many types and grades of magnets available today it is very important to consider the specific needs of your application and carefully analyze all magnetic, thermal, mechanical and economic parameters to choose the optimum solution.

**About Magnet Applications, Inc. (MAI)**

Magnet Applications, Inc. is located in DuBois, PA and is one of the largest North American manufacturers of injection molded (both ferrite and NdFeB) and compression bonded NdFeB magnets. In addition MAI supplies a full range of permanent magnet products and technical assemblies supported by application and sales engineering throughout North America.

They are part of the Bunting Magnetics Group of companies. Bunting Magnetics is a family-owned group of companies manufacturing products which serve global markets and include a broad range of magnetic materials and components, magnetic separation systems, material handling equipment, metal detection equipment, magnetic cylinders for the printing industry, bonded magnets, and technical assemblies.