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EFFECTIVE USE OF NEODYMIUM IRON BORON MAGNETS, CASE STUDIES

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Abstract: Magnets based on neodymium iron boron (NdFeB) alloys have been available for about 15 years, yet many design engineers are frustrated in their attempts to incorporate this material into new devices. These are problems that cannot be solved by research focused on higher energy product materials, nor are they the result of the three well-known objections to NdFeB magnets: higher cost per kilogram than ferrite, limited maximum operating temperature and poor corrosion resistance when uncoated. We address situations encountered by design engineers trying to use magnets correctly, reviewing several common design situations and offering ways to improve device performance through more effective use of NdFeB.

Key words: Permanent Magnets, Neodymium Iron Boron, NdFeB, Rare Earth Magnets, Magnetic Circuit Design.

I. INTRODUCTION

The advent of neodymium iron boron magnets in the early 1980s was met with great enthusiasm. [1,2,3] Compared to samarium cobalt magnets of the day, the simultaneous increase in energy product and reduction in raw material cost of NdFeB was seen as breakthrough technology. Fifteen years later we see just a fraction of the potential fulfilled. Even as the magnetic properties gradually improve and the cost gradually decreases, as was originally predicted, the use of neodymium magnets has not risen accordingly.

Performance issues appear to have slowed their growth. After closer review, many underperforming magnetic designs arise directly from limited, outdated and inaccurate information concerning NdFeB magnets. In these applications, the magnetic material is not the root cause. We present three common, yet subtle, design problems, in hopes of offering solutions based on practical experience. The basic magnetic properties of NdFeB magnets are summarized in Table I, given as a point of reference.

II. EXAMPLE 1

The first example is the conversion of a 2-pole motor design of ferrite with a 4 MGOe energy product to a bonded NdFeB with a 10 MGOe energy product. The motor drives a fuel pump. The ferrite magnets in the original designs were unable to meet a performance specification at low temperatures. Unlike all other permanent magnet materials, the H_{ci} of ferrite magnets decreases as the temperature falls, an awkward characteristic.

The original approach was a direct replacement of the ferrite magnet with an identically sized bonded NdFeB magnet, keeping the original 2-pole design. There was a slight increase in flux and the performance specification was met, although marginally. The magnetic circuit was analyzed using the finite element method, specifically Maxwell 2-D Field Simulator from the Ansoft Corporation [5]. A two dimensional solution is satisfactory for highly symmetric situations. As can be seen from Figure 1, the return path is saturated, a clear sign that there is too much magnet in the circuit.

TABLE I
NdFeB MAGNETIC CHARACTERISTICS [4]

Property	MQ1	MQ2	MQ3/sintered	Units (CGS)
Energy Product $(BH)_{max}$	8.5 to 11	14 to 15	32 to 42	MGOe
Residual Induction (B_r)	6.1 to 7.1	8 to 8.25	11.6 to 13.1	kG
Coercive Force (H_c)	5.2 to 5.6	7 to 7.2	11 to 12.3	kOe
Intrinsic Coercive Force (H_{ci})	9 to 17	17.5 to >18	16 to >20	kOe
Magnetizing Field (H_s)	25 to 35	45	35 to 45	kOe
Recoil Permeability (μ_r)	1.15 to 2.31	1.14	1.06 to 1.09	G/Oe
Maximum Operating Temp.	70 to 180°	180 to 200°	150 to 200°	°C
Curie Temperature (T_c)	305 to 470	335 to 370	335 to 370	°C

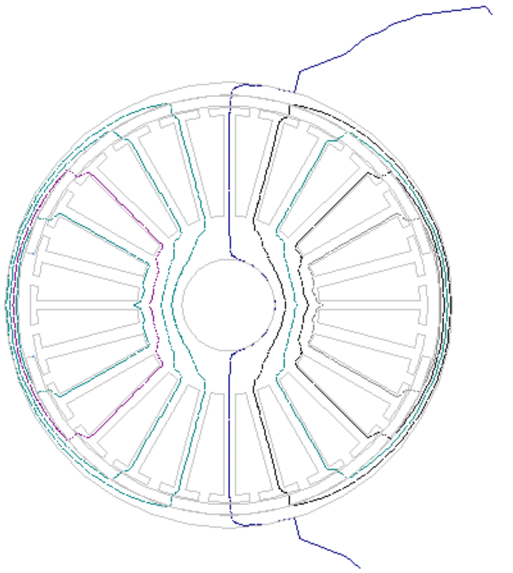

Figure 1. Motor cross-section, with large included angle magnet and saturated return path.

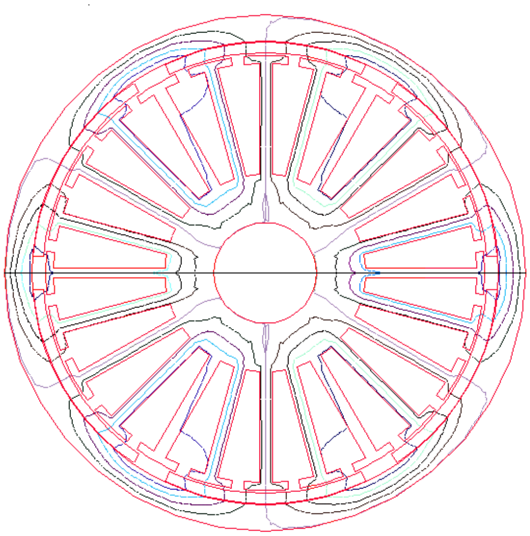

Figure 2. Similar motor cross-section as Figure 1. Design changed to increase number of poles to 6 and increase thickness of return structure.

The situation can be improved by either making the return path thicker or reconfiguring the magnet. Thickening the magnet allows it to carry all the available flux and is a straightforward approach, although not the most effective.

Making the magnet either smaller by reducing the included angle or changing to a 4, 6 or 8 pole design would make better use of the magnet. From a manufacturing perspective, a single ring is preferable to arc segments. The ring geometry is well suited for multi-pole configurations, provided the assembly is properly magnetized, which typically means the use of a special magnetizing fixture.

The preferred solution is a multi-pole ring, with a thicker return path, as shown in Figure 2.

III. EXAMPLE 2

The second example involves a case where less than expected motor performance is observed, specifically more cogging than anticipated. The challenge is to determine the cause and cure the problem. The motor uses isotropic MQ2 magnets. Finite element analysis of the circuit reveals magnetizing as the problem, a common event with isotropic materials because magnetizing, not the material, determines the flux pattern. In this case, the field created by the magnetizer is not perpendicular to the surface of the magnet, as was imagined in the design stage. The flux is off slightly from the intended angle, as shown in Figure 3.

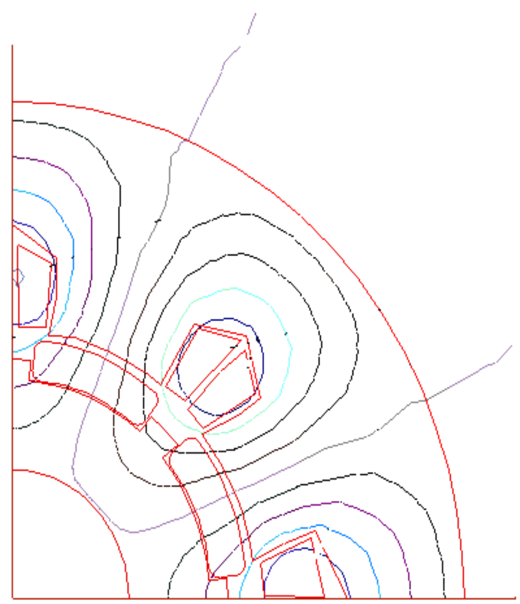

Figure 3. Flux pattern induced by magnetizing fixture.

Once the model is altered to reflect the true pattern of the flux, the excess cogging is clearly obvious. Since altering the direction of the field delivered by the magnetizing fixture is not possible, the only option available is to magnetize the magnets before assembly.

Generally, published magnetic properties, like those in Table I, are based on two assumptions. First that the magnets are magnetized to saturation before the properties are measured, and second, that the magnets are measured parallel to the direction that they were magnetized. If one or both of these conditions are not met, the published properties become irrelevant, and underperformance follows.

IV. EXAMPLE 3

The third example is a diametrically magnetized isotropic bonded NdFeB ring, i.e. MQ1. A relatively uniform magnetic field inside the ring is needed for sensing purposes. A flux plot of the ring is shown in Figure 4. Unfortunately most of the flux travels within the wall of the ring and is not available inside the ring where it is needed. As a result, the flux density at the center of the ring is feeble, roughly 50 Gauss.

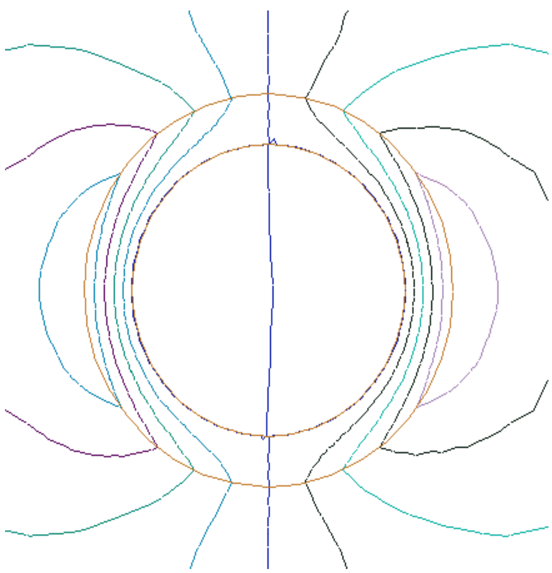

Figure 4. A diametrically magnetized MQ1 ring.

Our approach is to create the field using a Halbach ring [6,7], in the dipole configuration. The field at the center of such a ring can be predicted by the following equation

$$B = B_r \ln (d_o/d_i) \qquad (1)$$

where d_o is the outside diameter and d_i is the inside diameter.

However, unlike most Halbach rings, which are typically assembled from many segments, each with a specific direction of magnetization, a single ring of any isotropic permanent magnetic material: MQ1, MQ2, isotropic ferrite, either Ceramic 1 or bonded, or bonded SmCo can be used, eliminating the need for assembly. Proper magnetizing becomes the primary concern because the flux pattern is determined by the magnetizing coil and not the magnet. Special fixturing is required to apply the flux correctly throughout the ring. Figure 5 shows the flux pattern in the magnet; note that very little flux is wasted outside the ring. Using MQ1, an anticipated induction is 650 Gauss, with an outside diameter of 15.8 mm and an inside diameter of 14.2 mm, based on equation (1).

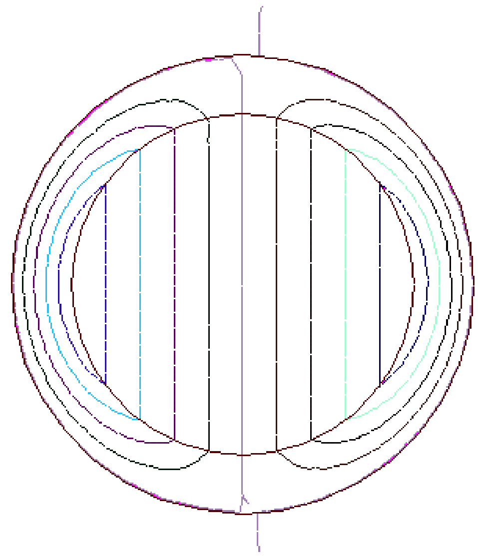

Figure 5. An MQ1 ring magnetized as a Halbach dipole.

V. CONCLUSIONS

As we have shown, neodymium iron boron magnets are frequently poorly incorporated into designs with correspondingly poor device performance. A more thorough understanding of the material and how to apply it would often prevent disappointment. Consultation with a magnet application engineer is always prudent.

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