Optimizing Magnetic Effects through Shaped Field Magnets

G. MARTINEK[1], U. WYSS[2], D. MAYBURY[2], S. CONSTANTINIDES[3]
1) Arnold Magnetic Technologies, Donaustrasse 7, 63452 Hanau, Germany
2) Arnold Magnetic Technologies, Lupfig, Switzerland
3) Arnold Magnetic Technologies, Rochester, NY, USA

Abstract: *Shaped field magnets exhibit a continuously varying magnetization direction over the volume of the magnet, resulting in significantly better performance in numerous applications. The optimized magnetization patterns in this new class of sintered magnets are achieved by implementing corresponding patterns for the magnetic anisotropy during particle alignment in the near-net-shape production process. These factors can be accurately modeled prior to manufacturing. Empirical examples from products in current serial production show more than 20% higher torque in permanent magnet couplings, or 30% weight reduction for sensor magnets.*

Key Words: *SmCo, sintered magnets, field shaping, flux concentration, torque coupling*

Address: Steve Constantinides, Arnold Magnetic Technologies, Rochester, NY, 14625, U.S.A., Tel: (1-585) 385-9010, E-mail: sconstantinides@arnoldmagnetics.com

1. Introduction

The overwhelming majority of modern sintered magnets are used with quasi-uniform magnetization. This is ideal for situations where the magnetic flux from the magnet can be conducted by soft-magnetic "iron" parts which direct the flux into the region of interest (e. g. the gap of a loudspeaker system). In cases where the magnet is used in an "open circuit" large portions of the flux will be in regions where it is not needed. This undesirable flux can be minimized by introducing a spatially varying magnetization direction. The most striking example for this principle is found in "Halbach" configurations [1,2], which maximize magnetic flux on one side of a planar magnet array (or inside a ring), nearly eliminating flux on the other side. Even before the theoretical treatments were published, similar principles had been applied in some applications, for instance, in Alnico braking magnets in Ferraris-type electricity meters.

In sintered magnets, examples of non-uniform anisotropy have been rare, limited essentially to segments or rings with radial magnetization. More often, they have been noted as undesirable side effects of the pressing process. However, developing the control of parameters to eliminate these side effects has opened other doors, as well. We now have successfully developed anisotropic "shaped field" sintered magnets with complex, optimized magnetization patterns.

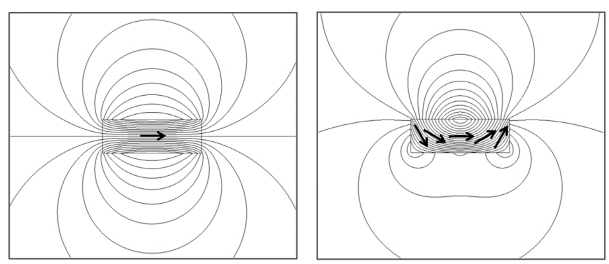

Fig. 1: Uniform magnetization vs "shaped-field" configuration.

2. Manufacturing

The anisotropy in the common sintered magnet materials (hard ferrite, SmCo or NdFeB) is introduced by aligning the powder particles before and during compaction. The deliberate, controlled formation of strongly non-uniform anisotropy patterns therefore requires the application of a corresponding non-uniform field. This is achieved by a careful layout of magnetizing coils and permeable components in and around the tool. As the punches and powder move during compaction, the field will change. Special care must be taken to create the desired field configurations at the right stages.

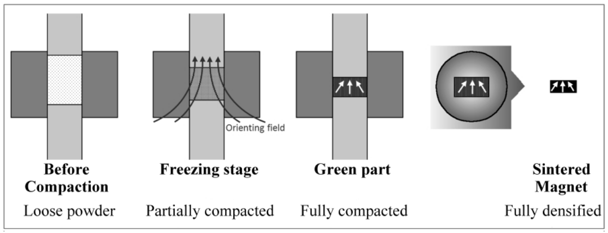

Fig. 2: Manufacturing process

3. Shaped field magnets for angular position sensing

Manufacturers of angle sensors typically suggest cylindrical magnets with diametric orientation. A more effective magnet, however, could show a curve pattern as indicated in Fig. 3 (upper right).

<u>Modeling</u>

The actual modeling of the magnet performance is done in 2 steps:

- Simulation of the magnetic fields on the press, giving the orientation pattern of the powder.
- Implementing this orientation pattern in a magnet of the appropriate size and shape for the finished sintered part.

For a simple approximation, the potential of shaped field magnets can be roughly assessed by assuming an idealized magnetization pattern which can easily be simulated. A suitable model for the magnets in question assumes a magnetization pattern following a circular path (fig. 3, lower right). The position of the center of the circles was adapted to give the maximum field for each magnet shape and distance. The modeling indicates potential for significant improvements in the performance of the sensor magnet, as shown in Fig. 3 at left.

<u>Experimental result</u>

Cylindrical shaped field magnets of diameter 6.5 mm and thickness 2.5 mm were produced. The

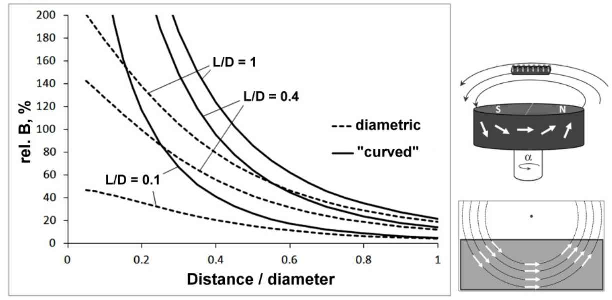

Fig. 3: Flux density on the axis of a cylindrical disc magnet of unit polarization and unit diameter. B = flux density in mT for a material with polarization 1T. L/D = ratio length/diameter.

fields were then probed and compared with what was estimated by the rigorous modeling procedure outlined in the previous section.

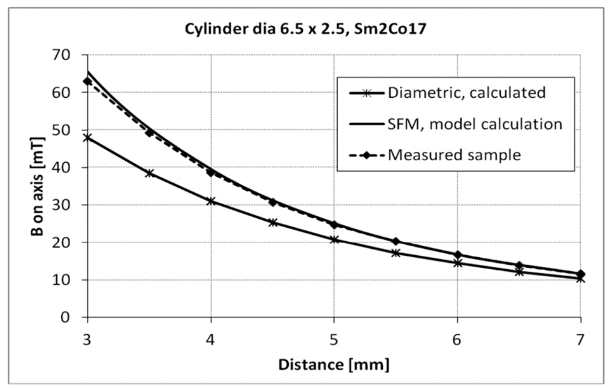

Fig. 4: Actual shaped field magnet example

The shaped field magnets are seen to give about 20% larger fields than a diametric magnet of the same dimensions and material (fig.4). In practical applications, this translates to a useful range extended by about 10%. It should be noted that rather than using the extended range, the magnet dimensions could be reduced, keeping the same distance from the sensor but reducing the cost of the magnet. This would result in a 30% smaller magnet volume for the same performance.

4. Shaped field magnets for permanent magnet couplings

This type of magnet is optimized for performance in alternating-pole periodic arrays. Fig. 5 shows the traditional setup and 2 alternative configurations. The second configuration is commonly named "Halbach", although it is really just a rough approximation to a real Halbach array with continuously rotating magnetization direction.

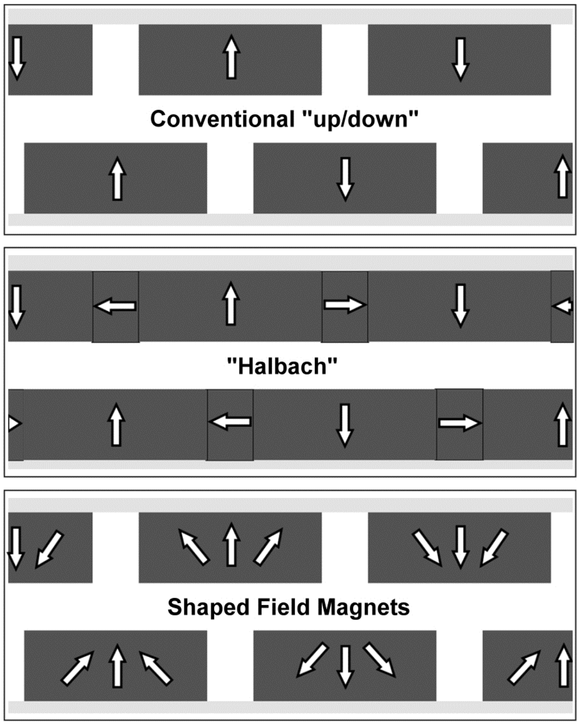

Fig. 5: Possible configurations for permanent magnet couplings.

<u>Modeling</u>

Figure 6 describes an easily implementable model for simulations. This model was used to demonstrate the potential for shape-field magnets in a very basic model: A planar coupling that extends infinitely, both in the periodic direction and perpendicular to the plane of projection (Fig. 7).

The planar model contains only 4 parameters. It can be further simplified by scaling some of the dimensions against the gap, giving 3 independent parameters:

- magnet thickness / gap
- pole spacing / gap
- fill factor (= magnet width / pole/spacing)

In addition, for the shaped field magnets, the focusing parameter (α or f in fig. 6) was introduced.

Fig. 8 shows the shear force for a magnet material with polarization J=1T as a function of magnet thickness. Each point in the diagram represents a

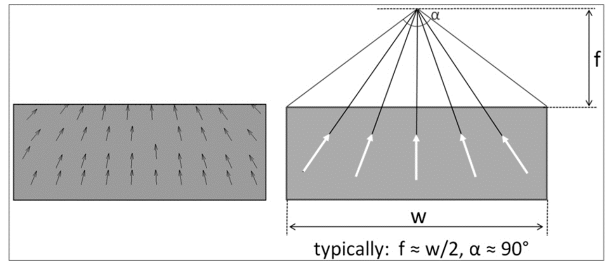

Fig. 6: Actual magnetization configuration and the approximation for modeling

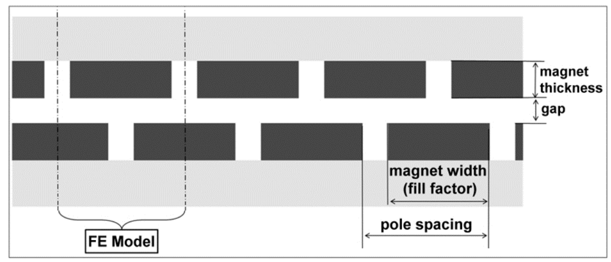

Fig. 7: Infinite planar coupling model

different configuration, where the remaining parameters (pole spacing, fill factor etc) were chosen to maximize the "efficiency" F per magnet volume.

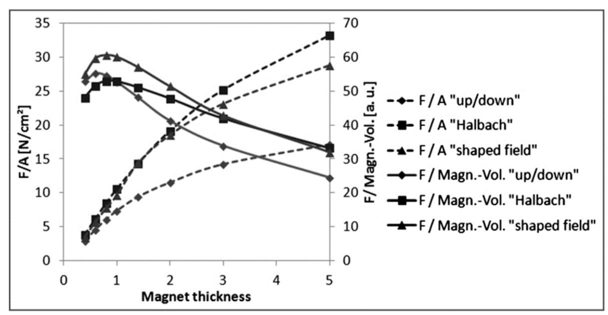

Fig. 8: Infinite planar coupling forces

<u>Case study</u>

The first implementation of this type of magnet was for a manufacturer of chemical pumps. Initially, the magnets in an existing coupling were simply exchanged for shaped field magnets of the same dimensions. This led to an increase of the transmittable torque by about 20%, both theoretically and empirically.

In a second step, the coupling was extensively redesigned for more strength: The magnet thickness was increased and the number of poles was optimized, leveraging the advantages of the focused field. These changes yielded a torque gain of 54%.

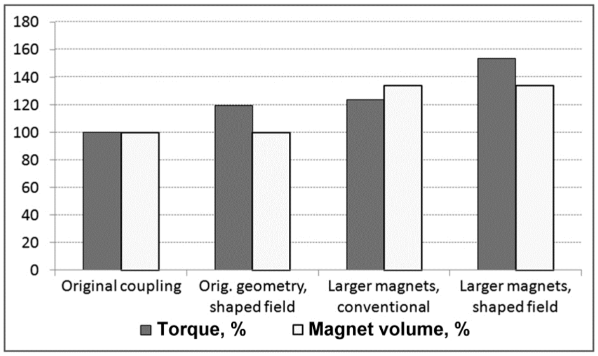

Fig. 9: Enhancements in torque in an actual coupling for chemical pumps.

References

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