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NEW TECHNIQUE FOR PRODUCING A STRONG MULTI-POLE MAGNET

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ABSTRACT

A new technique for producing a strong multi-pole magnet is developed. A cylindrical magnet oriented with its easy axis of magnetization perpendicular to the cylinder axis is magnetized by a multi-pole magnetizer. This procedure results in a multi-pole magnet with a flux density almost sixty percent greater than the flux density produced by a multi-pole magnet which is not oriented. The technique is especially effective for producing small cylindrical magnets with many poles and agreement of a theoretical analysis with experimental results is very good, with deviations of no more than a few percent.

1. INTRODUCTION

Stepping motors and other electrical machines employ cylindrical magnets with many poles and with high flux densities. In such magnets it is desirable that the particular easy axes be oriented in the directions of their respective fluxes. Radial or polar orientations have been customarily used in multi-poled structures. Radial orientation is difficult to obtain when the axial length of the magnet is much greater than its diameter and when the number of poles is large for the size of the magnet. This is because it then becomes difficult to apply a magnetizing coil of sufficient cross sectional area and current capacity for the necessary flux. Moreover, these conditions necessitate more complex injection tools and result in lower yields and higher costs.

Accordingly, a simpler method for the production of strong multi-poled magnets was developed in which all magnetization vectors are aligned or anti-aligned to a single axis of orientation[1]. Because this technique employs a simple injection tool that affords multi-cavity molding yields are increased and costs lowered. It is the purpose of this paper to describe the rationale of the new technique, to discuss the results of a numerical analysis thereof and to compare the results of the theoretical analysis with experimental data.

2. MULTI-POLE MAGNETIZATION

In the course of fabrication the cylindrical magnet is oriented with its easy axis transverse to the cylinder axis as shown in Figure 1. It is then magnetized by an electric coil whose elements are alternately parallel and antiparallel to the cylindrical axis as shown in Figure 2. The yoke is made of carbon steel and the magnet to be magnetized is polymer bonded. Figure 3 shows the resulting flux density on the surface of the magnet, as a function of the azimuthal angle. The amplitude of the flux density is seen to be approximately 0.08(T) as compared to the 0.05(T) obtained with the same magnetizing coil in isotropic magnets of the same dimensions. The sixty percent increase clearly illustrates the advantage of orientation.

3. METHOD OF ANALYSIS

The field distribution in the magnet obeys the equation

$$\frac{\partial}{\partial x}(\frac{\partial \phi}{\partial x}) + \frac{\partial}{\partial y}(\frac{\partial \phi}{\partial y}) \approx J - \nu (\frac{\partial M_x}{\partial x} + \frac{\partial M_y}{\partial y}) \tag{1}$$

where $\nu$ and $\nu_0$ are the reluctivities of iron and air, $\phi$ is the magnetic vector potential, $J$ is the exciting current density and $M_x$ and $M_y$ are the components of magnetization. Figure 4 illustrates the dependence of flux density on magnetizing field[1]. $M_x$ and $M_y$ in equation (1) are obtained from the magnetization and demagnetization curves.

When the oriented magnet is magnetized in the manner described above, most regions are exposed to...
applied magnetizing fields with directions different from the easy axis orientation. It is assumed that any resulting magnetization will be along the orientation axis only and the effective magnetizing field would then be $B' \cos \phi$ as shown in Figure 5, where $B'$ is the field applied by the coil and $\phi$ is its orientation with respect to the axis of alignment of the magnet. Although the effective magnetizing field becomes smaller with increasing $\phi$ it is apparently sufficient to magnetize the material even for values of $\phi$ very close to $\pi/2$. These considerations are illustrated in Figures 6 to 10. Because the fields from the individual coil loops become smaller and increasingly interfere with each other as one approaches the center of the magnet, magnetization for small radii is negligible as shown in Figure 9 and, effectively, one is left with the magnetization pattern of Figure 10.

Figure 11 shows the flux pattern arising from the magnetization distribution of Figure 10. Here we have a visual confirmation of the remarkable constancy of flux amplitude with $\phi$. This is a consequence of how the magnetic poles are distributed on the surface and on the magnetization reversal boundaries. As $\phi$ increases the pole density on the boundaries decreases

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**Fig. 4** Magnetizing process of a magnet.

**Fig. 5** Magnetization in the direction different from orientation.

**Fig. 6** Magnet model.

**Fig. 7** Calculated and measured flux densities.

**Fig. 8** Distribution of flux density.

**Fig. 9** Distribution of magnetization.
4. CONCLUSIONS

A new technique has been developed for producing small, high flux density, multi-pole magnets with more than 100 poles. At present, there is no other way to accomplish this. Work is now in progress to produce even stronger magnets of similar configuration.

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