TORQUE IN NESTED HALBACH CYLINDERS

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Introduction

Uniform magnetic fields may be generated within the bore of infinite length cylinders with magnetisation which is constant in magnitude, but continuously varying in direction [1]. At any angular position ϕ in the cylinder, the magnetisation is at an angle 2ϕ as shown in Fig.1(a). A finite length approximation to this design is shown in Fig.1(b). The continuously varying magnetisation is approximated by a finite number of uniformly magnetised segments. By nesting two of more such cylinders [2], and rotating them relative to each other, magnetic fields, uniformly varying in both magnitude and direction may be achieved in the central bore. However, the magnetic torque exerted between the cylinders can be significant and must be considered when selecting motors used to drive the rotation of the cylinders.

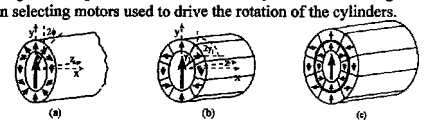

Fig.1 : (a) ideal, infinite, length cylinder; (b) finite length, segmented approximation to (a); (c) nested cylinders can give fields continuously varying in magnitude and direction.

Experimental Results

The d.c. motors which may be used to rotate the cylinders exhibit a simple relationship between torque and current. So monitoring the variation in the current drawn by the motors indicates the variation in torque. Fig.2(a) shows the current in the motor of the inner cylinder as it rotates through an angle α, while the outer cylinder is held fixed in position.

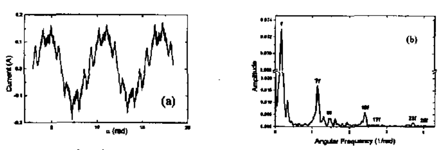

Fig.2 : (a)Current drawn by the motor rotating the inner cylinder though 2.5 cycles as the outer cylinder is held fixed; (b)Fourier transform of these data.

Fourier analysis of these data in Fig.2(b) shows that the torque varies with a fundamental angular frequency $f=1/2\pi$. Higher harmonics are apparent at angular frequencies $(kN\pm1)f$ where N is the number of segments and k is an integer.

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Calculated Results

The torque was modelled numerically using the surface charge model to calculate the field due to one cylinder at points on grids at different heights in the cylinder. The torque T on volume elements ΔV around these points are calculated from $T=\Delta V \mathbf{M} \times \mathbf{B}$ and summed to give the torque on the entire cylinder. Fourier analysis of these data again show a dominant fundamental frequency at $f=1/2\pi$. The calculated torque curve shown in Fig.3(a) is closely fit by a sine function. Fig.3(b) shows the remaining structure when this fit curve is subtracted from the original data. Fig.3(c), the Fourier transform of these data, again show higher harmonics at angular frequencies $(kN\pm1)f$.

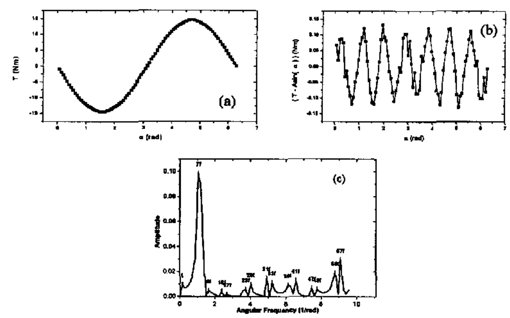

Fig.3 : (a) Calculated torque; (b) (a) minus a fit sine function; (c) Fourier Transform of (b).

Conclusion

There is zero torque exerted between ideal cylinders of the type shown in Fig.1(a) which have perfectly uniform fields. So the torque between these cylinders is due to field inhomogentities in the Fig.1(b) approximation to the ideal case. Analysis demonstrates that the fundamental component of torque, $f=1/2\pi$, is due to the field non-uniformities arising from the finite length of the cylinders. So the torque is primarily an end effect. The higher harmonics at frequencies $(kN\pm1)/2\pi$ are due to the field non-uniformities caused by segmentation.

[1] H.A. Leupold in *Rare Earth Permanent Magnets*, J.M.D. Coey (editor), Oxford University Press (1996).

[2] H.A. Leupold, E. Potenziani II, *"Applications of Yokeless flux Confinement"*, J. Appl. Phys. **64** (10) 5994 (1988).

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