Torque Measurements in MRI Safety Testing

N. M. Szeverenyi[1], and M. Thakur[2]

[1]Radiology, SUNY Upstate Medical University, Syracuse, NY, United States, [2]Bioengineering, Syracuse University, Syracuse, NY, United States

Introduction

Although the MRI community is very much aware of the rotational forces imposed on non-symmetric ferrometallic objects in a uniform magnetic field, why this happens is not quite as clear. ASTM standard F2213-04[1] provides a brief description of these torsional forces and also how to construct a balance for measuring the effects. We describe our experience in the construction of such a torsion balance and the surprising results obtained on stainless steel needles.

Methods

Several versions of a torque balance were designed and fabricated in house. In general our devices resemble the one described in ASTM F2213-04, but were significantly easier to fabricate and to use. Our initial designs were based on torsional springs, but we replaced the mechanical gear assembly with a laser diode light source which was reflected from a first surface mirror attached to the sample holder. The entire assembly could therefore be rotated in the magnetic field while the reflection was observed on a calibrated scale. A more recent design replaced the torsional springs and used the strain gauges and electronics from a digital pocket scale. This version has proven to be the simplest and most accurate device (Fig 1). Data was collected at three field strengths (0.2, 1.5 and 3 tesla) on a variety of ferromagnetic objects. Torque was measured at 10 degree increments as the sample was rotated relative to the static field. In the case of non-symmetrical samples, three orthogonal axes were investigated (Fig 2). The torque meters were calibrated by hanging weights of known mass attached to a moment arm (2.0×10^{-4} Nm/deg). The strain gauge device produced the most linear behavior over a large range of torque.

Results

Torque was plotted as a function of orientation to the static field for an ordinary paper staple and a medical needle (Fig 2 and 3), producing graphs identical to the ASTM standards. Our initial interest was in characterizing the maximum torque of a vascular access port needle fabricated from 304 stainless steel, but upon observing the field dependence our interest increased concerning the theoretical basis for these effects. As seen in Fig. 3 the forces on the needle are largely independent of magnetic field above 1.5 tesla. Measurements at 0.2T were more difficult as the direction of the field was parallel to gravity so that the sample and holder had to be balanced to avoid contributions from this source. Remnant magnetization was also found to be a factor in the lower field measurements, causing memory effects that can be seen in the less symmetric plots at 0.2T (Fig 3).

Discussion

The fact that the maximum torque on a device is insensitive to the value of the static magnetic field above a certain value is stated in the fine print (note X2.1) of the ASTM document, but is largely unappreciated by the MRI community. In analogy to the translational forces, it seems reasonable to expect at least a linear dependence of the torque with field strength. This is not the case. The explanation involves the magnetic shape anisotropy and the associated demagnetization factors[2,3] resulting in surface poles. Computing demagnetization factors as a function of geometry is still is a ongoing area of research[3], finding applications in material science and nano technology.

References

[1] Standard Test Method for Measurement of Magnetically Induced Torque on Medical Devices in the Magnetic Resonance Environment, ASTM International, West Conshohocken, PA, current edition approved January 2004.

[2] Schenck JF, Safety of Strong Static Magnetic Fields, JMRI, 2000;12:2-19.

[3] Paterson JH, Cooke SJ, Phelps ADR, Finite-difference calculation of demagnetizing factors for shapes with cylindrical symmetry, JMagMagneticMaterials, 1998;177:1472-1473

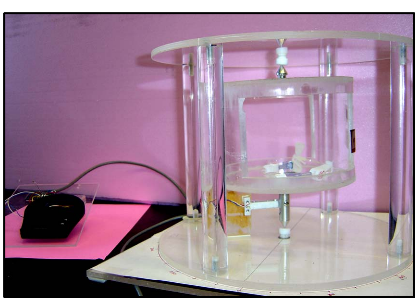

Figure 1. Torque meter design based on strain gauges.

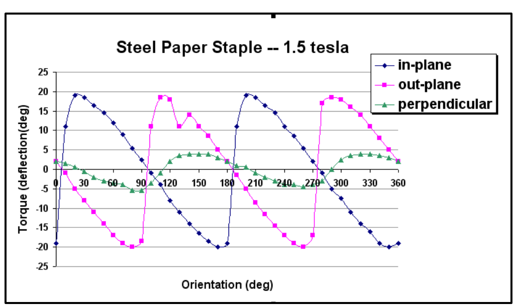

Figure 2. Torque on a paper staple as a function of symmetry axes.

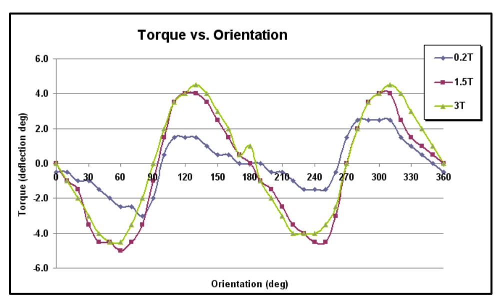

Figure 3. Torque on a stainless steel needle as a function of field strength.