Curved planar gradient coil design using the Boundary Element Method

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Introduction

Over the past several years, a powerful and general method for designing gradient coils has been developed that holds the promise of allowing gradient design of virtually arbitrary geometry [1,2]. We have implemented a boundary element (BE) method following the specific approach of Poole and Bowtell [1]. In the present study, we have used this method to design and analyze the performance of a single-axis (y-axis) curved surface gradient coil design, as a function of the degree of curvature. A curved surface gradient would be of use in the context of providing a specific fourth gradient channel exclusively for very high performance diffusion weighted imaging in a specified volume of tissue such as the breast, prostate, or posterior regions of the brain. It has also been shown experimentally that planar gradient designs offer significantly improved peripheral nerve stimulation properties as compared to traditional whole-body gradient designs [3].

Methods

The BE method requires that the surface of the coil first be discretized into triangular elements. The vertices of these triangles are the nodes, and for each node the current circulating within it is described by a set of basis functions. These basis functions summed together with weight coefficients describe the entire current density over the surface. These basis functions can be used to describe the magnetic field, power dissipation, and torque. A functional is created and minimized in order to obtain gradient coils for low field inhomogeneity, power dissipation, and torque. In this study, a series of 12 curved coils were designed, ranging from a completely flat coil (Fig. 1a) up to a half-circle cross-section (Fig 1c). For all coils, the total extent in the x-direction was 52cm (±26cm) and the length in the z-direction was 60cm. The coils were designed to match a set of target field points over a rectangular region centered at (x, y, z) = (0cm, 7.5cm, 0cm) and extending ±2.5cm in the y direction and ±5cm in the x and z directions. The BE method resulted in continuous current densities defined over the curved geometry and these were converted into discretized wire patterns using stream-function methods in Matlab®.

Results

The wire paths for three of the y-gradient coils are shown in Figure 1. Fig. 1a shows a planar coil, Fig. 1b shows a coil with an arc angle of 60°, and lastly, Fig. 1c displays a half cylinder (180°) gradient coil. All of the coils resulted in an imaging region (defined as region of 30% gradient nonuniformity) of 4-5cm in the y direction and 20 cm in the x direction. The wire pattern density for each coil was scaled such that each coil inductance was 800μH. The gradient efficiency was then obtained and plotted against the arc angle as shown in Figure 2. The efficiency of the coils were all very high, ranging from 1.39 to 1.67 $mTm^{-1}A^{-1}$. The coil performance was found to increase monotonically with increasing arc angle, as might be expected. It is interesting to note that the improvement of the half-circle design over the fully planar design is only approximately 20%.

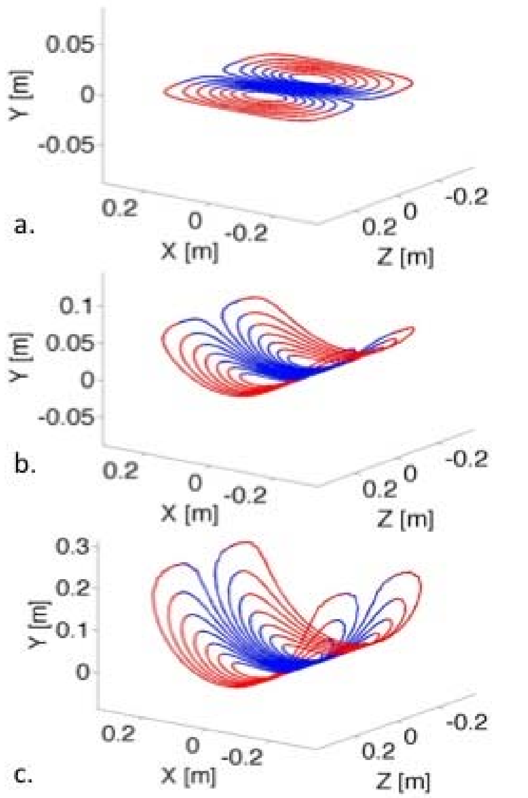

Figure 1. Three Y-gradient coils with varying radius of curvature, r. a) planar coil (r=∞, θ=0°) b) slightly curved coil (r=52cm, θ=60°) c) half cylinder coil (r=26cm, θ=180°)

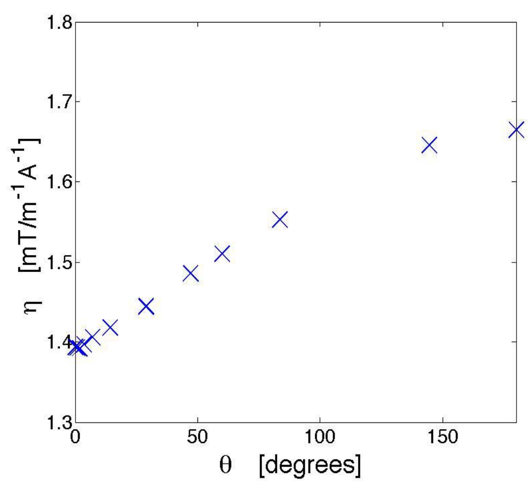

Figure 2. Gradient efficiency vs. arc angle θ, for y-gradient coils scaled to an inductance of 800μH.

Discussion and Conclusion

The BE method as reported by Poole and Bowtell allows for the relatively straightforward design of gradient coils with virtually arbitrary geometry. It is important to recognize that as seemingly simple as this design study may appear to be, it would have been exceedingly difficult to accomplish with analytic methods. The results of this specific study are important to efforts currently underway in our lab to develop optimized planar gradient coils for a variety of customized applications. This work is currently being extended to both Gx and Gz axis designs for the planar-like geometry.

References

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