Active localized shielding for devices within MRI gradient coils

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Introduction

There are an increasing number of applications in which non-MRI active or passive devices are being introduced into the MRI system and required to operate normally while exposed to the static, RF, and audio-frequency (i.e. gradient) magnetic fields produced during normal scanning. In this abstract, we focus on gradient fields and consider the possibility of designing a very localized, active shield to cancel the time-varying magnetic fields for an arbitrary device located within the inside diameter of the gradient system. An example application we are interested in is minimization of gradient fields over a field-sensitive linear actuator for use in MR-guided interventions.

Methods

In this study, all coils were designed using a boundary element (BE) method, following the specific approach of Poole and Bowtell [1]. The BE method is characterized by its ability to produce optimal coil patterns over virtually any geometrical surface. The functional was composed to minimize both field variation over a set of target field points, as well as power dissipation. A standard y-gradient coil was first designed on a cylinder of 30 cm radius and 60 cm length. This gradient produced an efficiency of 0.181 $mTm^{-1}A^{-1}$ with better than 30% gradient uniformity over a region approximately 21 cm in diameter. The resistance and inductance of the coil were 181 mΩ and 800 μH respectively. All of these parameters essentially mimic a standard whole body gradient coil.

The shielding coil was designed over a 15 cm diameter spherical surface. This shield was to be placed within the cylindrical y-gradient coil, centered at the point (x, y, z) = (12.5, 12.5, 0) cm. The shield was designed to cancel the field produced by the whole-body y-gradient over a set of target points distributed throughout a 10 cm diameter spherical region of interest (also centered at (x, y, z) = (12.5, 12.5, 0) cm). To determine if this idea could be extended to multiple shielding areas, an additional design was produced which was comprised of four symmetrical insert shield coils centered at the points (12.5, 12.5, 0), (-12.5, 12.5, 0), (-12.5, -12.5, 0), and (12.5, -12.5, 0) cm. As before, each shield was designed to cancel the field produced by the y-gradient coil over a 10 cm diameter region of interest centered within each respective insert coil.

Results

The coil designs obtained in this study are shown in Figure 1. Over the designated target region of the shield, the y-gradient initially produced a maximum magnetic field of 3.41 mT at 100 A. When the single spherical shield was then run with 24 A of current, the maximum magnetic field magnitude over the target region was reduced to 0.607 mT (a decrease of a factor of 5.6). The field at the center of the target region was reduced from 2.45 mT to 0.020 mT (a factor of approximately 120). The efficiency of the y-gradient coil was virtually unaffected by the presence of the spherical shield, producing a value of 0.178 $mTm^{-1}A^{-1}$. Most surprisingly, the gradient uniformity was not significantly sacrificed outside the shielded area, as shown in figure 2. The resistance and inductance of the spherical shield were 164 mΩ and 27.6 μH respectively. Similar results were obtained for the case of the four symmetrical spherical insert coils. Each reduced the maximum field magnitude over their respective target regions by at least a factor of approximately 5 as well as reducing the field at the center of the target region by a factor of approximately 130. The efficiency of the y-gradient coil remained at 1.8 $mTm^{-1}A^{-1}$, although the size of the 30% gradient uniformity region did drop to 13.4 cm.

Discussion

These results were obtained for a single gradient axis. In practice, a separate local shield would need to be designed for each gradient axis. We have found that it is indeed possible to shield the time-varying magnetic fields in over realistically sized regions within a gradient coil using a small insert coil, without severely affecting the gradient coil's efficiency or region of homogeneity. We are now extending this design concept to investigate shielding of a variety of devices within the MRI environment.

References

[1] M. Poole, R. Bowtell, *Concepts Magn. Reson. B.* **31B**, 162-175 (2007).

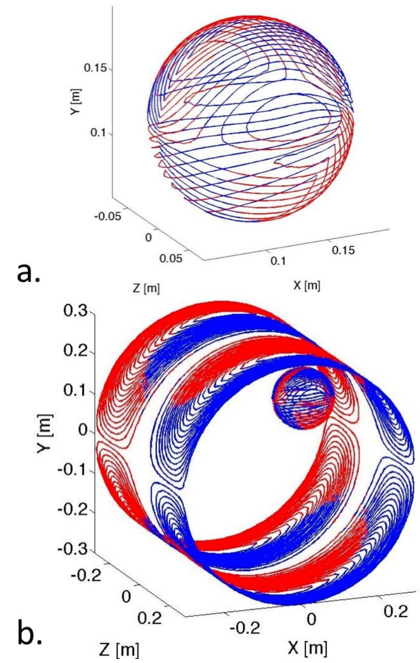

Figure 1. a) Close up of the coil pattern for a single spherical geometry insert shield. b) Insert shield placed inside a typical whole body y-gradient coil.

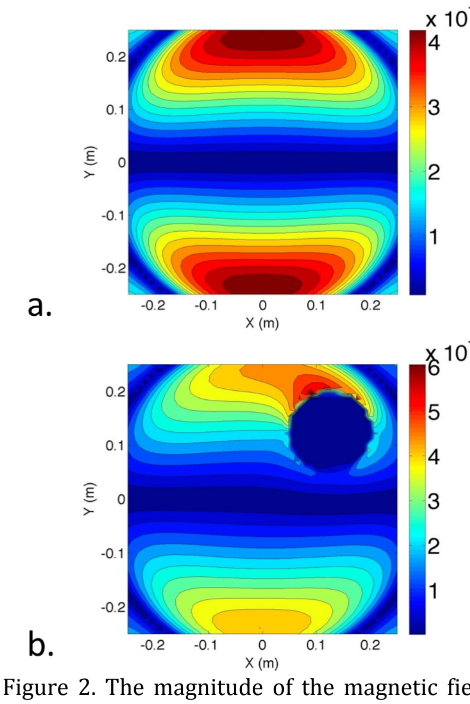

Figure 2. The magnitude of the magnetic field mapped over the region inside the y-gradient coil for a) y-gradient coil only and b) y-gradient coil with the spherical insert shield.