Superelliptical Insert Gradient Coil with Field Modifying Layers for Breast MRI

S. M. Moon[1], K. C. Goodrich[1], J. R. Hadley[1], G. L. Zeng[1], G. Morrell[1], M. A. McAlpine[2], B. A. Chronik[2], and D. L. Parker[1]

[1]UCAIR (Utah Center for Advanced Imaging Research), Radiology, University of Utah, Salt Lake City, UT, United States, [2]Physics and Astronomy, University of Western Ontario, London, Ontario, Canada

INTRODUCTION

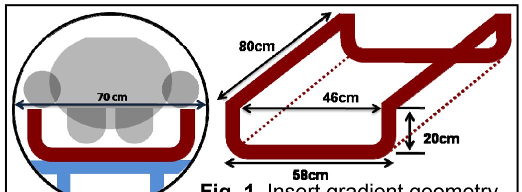

Fig. 1. Insert gradient geometry.

With higher gradient strength and slew rate, local gradient coils such as planar insert gradients can attain higher spatial and temporal resolution than the body gradients. Many imaging tasks, such as dynamic contrast enhanced (DCE) MRI for breast lesion characterization, can benefit from high spatial and temporal resolution. However, the homogeneous gradient volume (HGV) of the planar gradient is relatively small due to its inherent geometry and for applications such as breast imaging, the HGV may be too small to cover both breasts. Cylindrical gradient coils with a vertical bore have been designed to image one breast [1]. The magnetic field and gradient strength of uni-planar gradient systems falls off nearly exponentially with distance from the coil surface. As a result, the usable linear gradient region is narrow in the direction of each gradient.

In this work, to create a wider HGV, the planar insert gradient geometry was stretched laterally and the edges were bent vertically using a superelliptical curvature on the left and right sides, resulting in a superellipse former (see Fig 1). Distribution of the wire patterns on the vertical edges increases the gradient uniformity in the left/right and anterior/posterior directions. Furthermore, to increase the gradient strength and to further improve the gradient homogeneity in all directions, an extra outer layer or Field Modifying (FM) layer of current windings was added. We present the design and optimization methods, performance analysis, and force/torque calculations for a multi-layered superelliptical local insert gradient designed for breast imaging with an HGV that is extended in all directions. This design overcomes flat planar gradient limitations [2] and can accommodate both breasts.

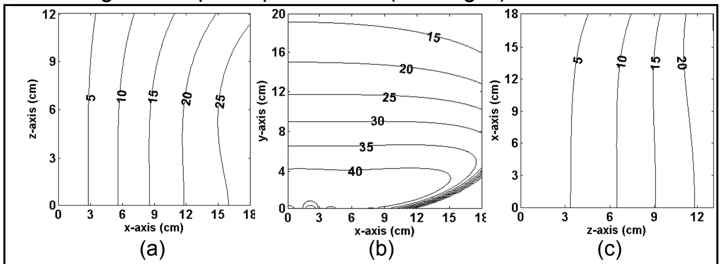

Fig. 2. Magnetic fieldmaps of each gradient (in mT at 300A). (a) x/z-view of x-gradient, (b) x/y-view of y-gradient,(c) x/z-view of z-gradient.

METHODS

First, wire patterns were created on a cylinder by using stream functions (SF), $S(\varphi, z) = h(z)\sum_{m=-\infty}^{\infty} v_m e^{im\varphi}$. For the y-gradient, m=1 is used as in the conventional design, and m=2 is used for the x-gradient to create four fingerprint patterns on the cylinder. Secondly, these cylindrical wire patterns were transformed onto a superellipse geometry to widen the HGV using the transformation, $|x/a|^m + |y/b|^n = 1$. The transformation technique has been used previously [3] and works well for this application. The relatively small linear gradient region of the uni-planar gradient systems is caused by a field drop-off along the y-axis. To increase the linear homogeneous region, an extra outer FM layer of current windings has been added to the primary superellipse gradient coil layer. The magnetic field of the FM winding is superimposed with the magnetic field of the primary gradient coil to increase the linearity and size of the HGV region over the Superellipse layer alone. Each gradient axis is formed using these two layers (primary and FM layer), for a total of six winding layers for the complete 3-axis gradient set. Three cooling layers were also included in the design. The proposed insert gradient design was 46 cm inner diameter, 58 cm outer diameter, and 80 cm in length, with 20 cm vertical sides on each end of the x-axis (Fig 1). The minimum wire spacing was limited to 7 mm.

RESULTS & DISCUSSION

Fig. 2 shows magnetic fieldmaps of the Bz component of each axis, and Fig. 3 shows resultant gradient fieldmaps (contour lines at 10% deviation from the desired field) including the primary and FM windings. The results show that the superellipse gradient design can produce an HGV large enough to accommodate both breasts, overcoming the limits of planar gradients shown in previous work [2]. Table 1 shows the detailed performance measures.

	X-gradient	Y-gradient	Z-gradient
Efficiency (η, mT/m/A)	1.0	0.723	0.577
Inductance (μH)	1979	1350	1010
HGV (5%, x/y/z-axis in cm)	20.3/11.0/34.2	26.3/13.8/12.6	9.0/8.0/27.0
HGV (20%,x/y/z-axis in cm)	29.6/23.8/54.0	43.0/22.0/26.2	37.0/19.0/32.0

Table 1. Field-modified superelliptical insert coil performance measures.

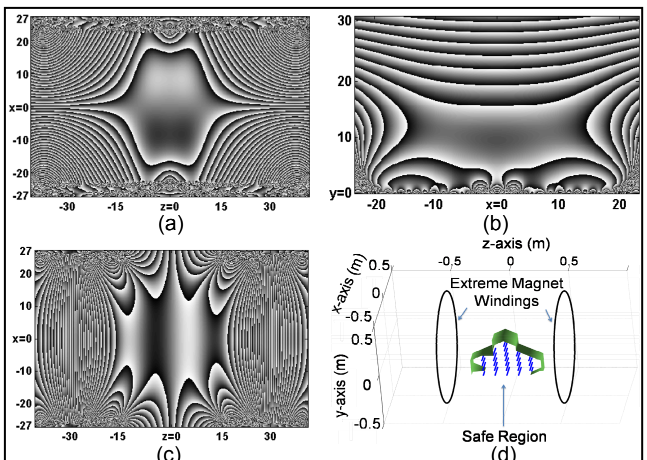

Fig. 3. The resulting gradient fieldmaps after field modification. (a) x/z-view for the x-gradient, (b) x/y-view for the y-gradient, (c) x/z –view for the z-gradient, (d) force and torque safe region

REFERENCE

[1] Maier CF et al., Practical design of a high-strength breast gradient coil, MRM;39:392-401, 1998.

[2] Aksel B et al., Local planar gradients with order-of-magnitude strength and speed advantage. MRM;58:134-143, 2007.

[3] Moon SM et al., Local uni-planar gradient array design using conformal mapping and simulated annealing, Concepts in MR, Part B;35B(1), 2009.

Acknowledgments This work is supported by Siemens Medical Solutions, the Ben B. and Iris M. Margolis Foundation, and NIH 5R33 EB004803.