Design, Construction and Initial Evaluation of a Folded Insertable Head Gradient Coil

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Target Audience: Physicists and engineers interested in the design and construction of high performance gradient coils.

Introduction: Gradient performance is one of the primary limitations of high speed, high resolution imaging. This has become especially important for imaging the brain. In conventional Magnetic Resonance Imaging (MRI) scanners, the gradients are designed to image the body and cover a large field of view, and this entails hardware and safety limitations. The speed of these coils is limited by both peripheral nerve stimulation and the large inductance of the coil. In this project, the goal was to overcome these limitations by building an insertable head gradient coil that could operate an order of magnitude faster than the whole-body gradients[1,2].

Methods: *Design.* The concept was a symmetric, ultra-short, folded, shielded gradient[3,4] suitable for human head imaging. The ultra-short design allows for brain imaging without shoulder cutouts (Fig. 1), and allows for convenient insertion and removal. The ultra-short symmetric, folded design operated in a whole-body magnet also means both force and torque balancing, leading to a quieter coil with minimized vibration and better eddy current performance than expected with asymmetric or longer designs. *Construction.* X and Y gradients were wound using litz wire, while Z primary and shield windings were hollow copper to allow for cooling (Fig. 2), aided by thin-wall Teflon cooling tubes located between wire layers. *Performance characterization.* The design parameters of the coil are summarized in Table 1 and compared to a conventional clinical gradient (GE MR750).

Table 1	Clinical Gradient	Head Gradient
Linear region	48 cm	22cm (X,Y), 17cm (Z)
Gradient strength	50 mT/m	80 mT/m
Slew rate	200 T/m/s	2935 T/m/s
Inner diameter	68 cm	34 cm

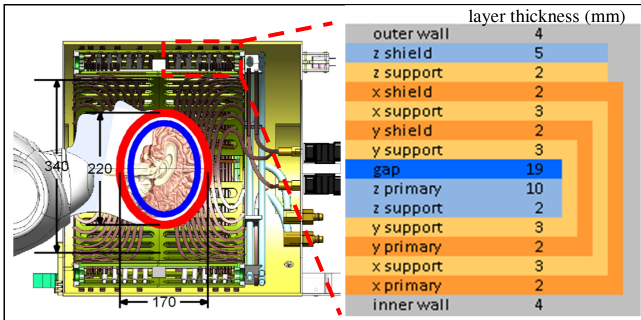

Figure 1. Design concept showing imaging region and radial stack-up of folded gradient concept. Wires fold over each end of gradient to form shield turns at larger radius.

Figure 2. Completed windings of gradient coil.

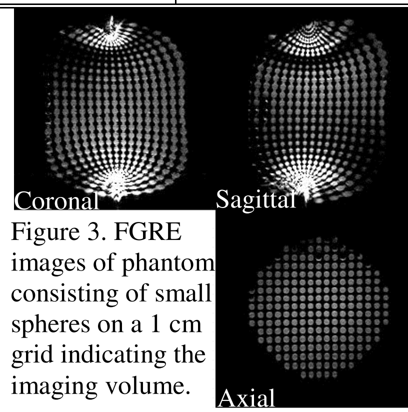

Figure 3. FGRE images of phantom consisting of small spheres on a 1 cm grid indicating the imaging volume.

Gradient linearity and efficiency were evaluated using a 3 axis magnetic field probe to map the magnetic field inside the gradient when driven with 40 amps DC on each of the axes, and also by imaging a grid phantom. Thermal dissipation capability was evaluated by driving a constant DC current and monitoring temperature increases with embedded thermocouples and with a thermal camera.

Results & Discussion: The gradient was successfully built, potted in thermal epoxy and interfaced to a clinical 3T scanner (GE MR750). The electrical impedance values of the gradient coil are summarised in Table 2, as is the gradient efficiency as measured using the 3-axis magnetic field probe. The efficiency with the implemented wire pattern differed slightly from the design target, but agreed with measured efficiency, reaching a gradient strength of at least 70mT/m at 600A. The coil was tested at a slew rate of up to 470 mT/m/s, but technical difficulties prevented a complete characterization of eddy currents, preventing higher slew rates. The imaging region can be visualized by observing distortions in the 1.0 cm grid phantom shown in Figure 3, indicating that the gradient is able to visualize the designed FOV. The X-coil, which is located nearest the inner surface, and furthest from cooling, was found to be the limiting axis for heat dissipation. Based on an inner bore limit of 40°C with 10°C water cooling, the gradient was capable of dissipating 600W (90A DC) from the x-coil.

Table 2	X	Y	Z
Inductance (µH)			
H2 Coil (designed)	48	58	42
H2 Coil (measured)	65	76	52
Clinical	519	518	486
Resistance (mΩ)			
H2 Coil (designed)	76	91	47
H2 Coil (measured)	74	88	22
Clinical	101	100	109
Efficiency (mT/m/A)			
H2 Coil (simulated)	0.124	0.118	0.141
H2 Coil (measured)	0.129	0.118	0.110

Conclusion: Preliminary evaluation of the insertable head gradient coil indicates that is performing as expected with respect to gradient efficiency and linearity, reaching a gradient strength of 70mT/m when interfaced with a clinical scanner.

References: [1]EC Wong, *NeuroImage*, 62:660-664 (2012) [2]A vom Endt, et. al., *Proc. Intl. Soc. Mag. Reson. Med.* #1370 (2006) [3]BC Amm et. al. US patent 7,932,722 (2011) [4]D Green, et. al., *Proc. Intl. Soc. Mag. Reson. Med.* #352 (2008)

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