Progress in the Development of a Quiet, High-performance, Head Gradient Coil

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Synopsis: A dimensionless approach to multi-parameter gradient optimization, that fully incorporated resistance, inductance, shielding, gradient uniformity, gradient magnitude, and null point, and approximately incorporated acoustic output, nerve stimulation, and some manufacturing issues, was found to have significant deficiencies treating thermal and manufacturing issues in the global optimization of a high-performance head gradient coil. These issues are being addressed by coupling of computational fluid dynamics (CFD) and manufacturing process optimization to the magnetic optimization problem.

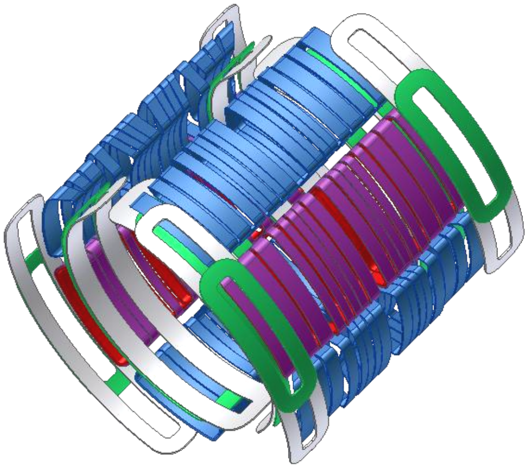

Figure 1. Winding groups for the head gradient coil y-axis. Note that individual wires are not resolved. Each band contains two or four parallel wires of 1 to 8 turns each.

Introduction: Available gradient coils have inadequate continuous gradient capability for some applications at high fields, such as diffusion weighted imaging, non-^{1}H imaging, and microscopy using small rf coils for specific regions in the head and neck. There is also strong motivation for reducing acoustic noise from high-field gradient coils. Here, we report our progress in the development of a novel head gradient coil incorporating 3D windings, ceramic formers, and direct water flooding of current elements, with thin polymeric coatings for electrical isolation, to address these issues.

Methods: A novel winding configuration, utilizing a combination of 3D crescent windings and cylindrical-surface Golay (or racetrack) windings, promises substantial reduction in acoustic noise (possibly 30 dB) along with improved continuous gradient capability for human head applications, where both the patient's shoulders and the magnet bore impose severe constraints on winding dimensions. The winding geometry for one transverse axis is shown in **Figure 1** and a photo of the primary assembly of the first prototype is shown in **Figure 2**. The highly parallel coolant flow scheme, chosen to reduce flow-space requirements in certain critical areas, requires detailed CFD analysis to avoid stagnation in some regions. Approximate analytical solutions to the acoustic radiation efficiency in three frequency regimes were used to guide the mechanical design. The heavy windings (nearly 50 kg of copper) contribute to reduced acoustic noise, increased gradient capability, and robustness. Manufacturing of early prototypes was found to be extremely labor intensive and complex, but innovative manufacturing methods are being developed and will be described that promise to permit competitive production of the unit.

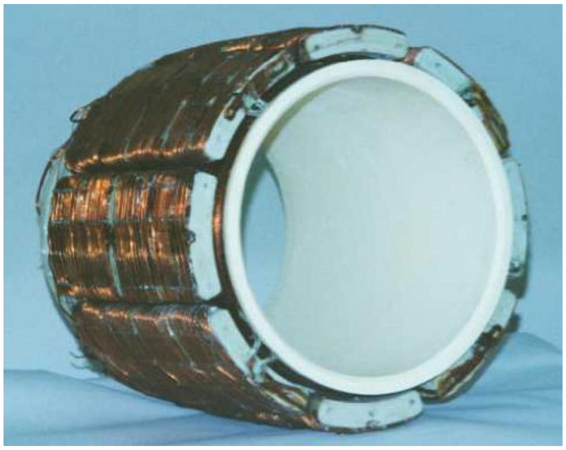

Figure 2. Photo showing 8 crescent coils surrounding the alumina ceramic former.

Results: The CFD/thermal analysis of the next-generation design suggests 75 mT/m continuous gradients will be practical in a fully shielded coil with 36 cm bore, 53 cm outside diameter, and uniform gradient extending within 9 cm of the shoulder edge. With gradient gain of 0.14 mT/m/A and inductance of 250 µH, slew rates over 380 T/m/s are expected on the transverse axes using 700 V drivers. Test results in a 3 T Siemens Trio and a 1.5 T GE Advantage will be reported.

References:

F. D. Doty, "Optimization of MRI Gradient Coils" in Spatially Resolved Magn. Reson., Ed. by P. Blumler, B. Blumich, R. E. Botto, and E. Fukushima, Wiley-VCH, Weinheim, 1998.

Yuhua Wu, B. A. Chronik, C. Bowen, C. Mechefske, and B. K. Rutt, "Gradient-Induced Acoustic and Magnetic Field Fluctuations in a 4T Whole-Body Imager," *MRM*, 44:532-536, 2000.

Acknowledgements: This work supported by NIH R44 NS41127-02.