Composite Shim Coil Design for System-Specific Field Corrections

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Introduction: In many magnetic field shimming applications, the required correction fields can be divided into two types: relatively large corrections that are constant or nearly constant, and corrections that need to be made on a sample specific basis. Particular examples of the first type would be the correction needed for the initial inhomogeneities of an imperfect magnet, and the field inhomogeneity created by the presence of magnetic materials within the magnet bore, such as the scintillation crystals required for Positron Emission Tomography (PET) systems integrated within MRI scanners. In situations such as these, we propose that the problem of shimming could be approached in two stages. A single, composite shim axis would be designed to compensate specifically for the large, consistent inhomogeneity. Then a set of less powerful, individual shim coils would be used to fine-tune the shim on a sample specific basis. This approach would minimize the number of high-power shim axes required, minimize the total required power in the shim set, and reduce the radial space required for the shim system. In this abstract, we investigate these ideas with the design of a very efficient, single-axis composite zonal shim coil to correct for main magnet inhomogeneities within a resistive field-cycled MRI system we have constructed in our labs [1].

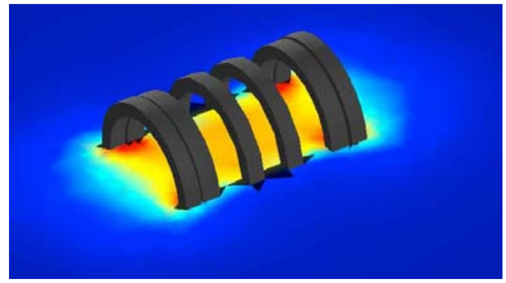

Fig. 1 FEM simulation of magnetic field within the 6-coil field-cycled MRI system

Methods: The field-cycled MRI system was modelled using the Finite Element Method (FEM) with a commercial software package (Comsol Multiphysics 3.3, Comsol, Burlington, MA). This method allowed the actual current density distributions through the thick solenoidal windings to be included in the simulation. The field strength of this magnet was 0.1 T. The Bz field inhomogeneity was calculated over a 10 cm diameter spherical volume (DSV), the z-axis variation of which is shown in Figures 1 and 3. The field inhomogeneity along the z-axis was fit with a 4th order polynomial. Analytic target field design methods [2] were implemented to obtain a single composite shim current density that would compensate for the inhomogeneity. The current density was sampled and a discrete wire pattern was obtained (Fig. 2). This discrete wire pattern was then used to model the field corrections achievable as a function of the power dissipated in the coil structure.

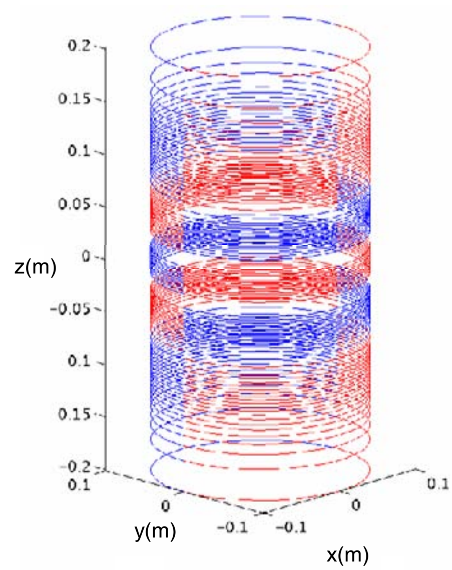

Fig. 2 Wire pattern for composite shim coil. This coil has R = 0.304 Ohms and L = 218 uH.

Results, Discussion: The magnetic field inhomogeneity of the field cycled readout magnet is shown in Figure 3. The magnet design yields an inhomogeneity of 100 ppm over a 10 cm DSV. The correction field profile obtained numerically from the actual composite zonal shim coil design is shown in Figure 3, with the final corrected field also shown. The electrical parameters of the composite shim are as follows: 86 windings, L = 218 uH, R = 0.304 Ohms. The single axis composite shim coil is able to bring the magnet down to a peak inhomogeneity of less than 8 ppm, and it is capable of doing so with only 18.5 W dissipated power (7.8 A). This approach to shimming the resistive field cycled system saves radial room within the scanner bore, in addition to achieving the corrected field at greatly reduced power as compared to conducting the same corrections using four difference single-axis zonal shim coils.

This concept of producing single-axis composite shim coils for applications in which field inhomogeneity is dominated by a single contribution, is being extended to several other applications. Firstly, this approach is being used to design and construct shim axes for correcting field distortions introduced by scintillation material in combined PET/MRI systems we are developing. The PET ring introduces large, though consistent, field inhomogeneities depending on the composition of the scintillation material.

Although in this abstract we have demonstrated this concept using composite zonal shim coils, we are also extending it to include tesseral shims. Although it is possible to design and construct a completely general single axis composite shim, we believe it is more practical to construct a separate composite coil for each order of tesseral field harmonic.

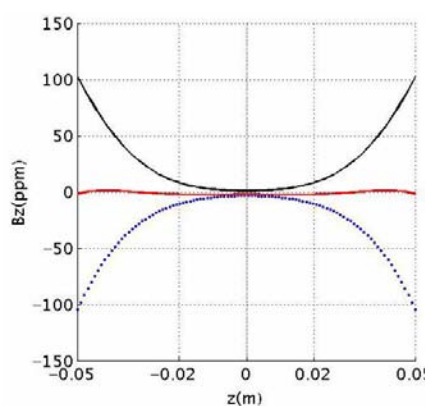

Fig. 3 The dotted line is the field inhomogeneity produced by the MRI system. The solid line on the top is the field produced by the composite shim and the middle line is the final field inhomogeneity in the system

References, Acknowledgements:

[1] Gilbert. et al. PMB v51, p2825-2841 (2006)
[2] Turner, MRI v11, p903-920 (1993).