From static to dynamic: Construction of a B0 insert for field-cycled contrast in a clinical MR scanner

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Introduction: We discuss the design, construction and testing of a high-power, actively shielded B0 insert for field-cycled style T1-dispersion-slope imaging in static-field superconducting MR imagers. By temporally modulating the magnetic field of clinical MR imagers, this insert will permit researchers access to unique field-cycled contrasts [1][2] that are rarely investigated due to the scarcity of field-cycled systems. This particular insert has an efficiency of 0.7mT/A and permits continuous field shifts of up to 70mT. Higher field shifts are achieved by a reduction of the insert's duty cycle. Total material cost were less than $5k CAD.

Methods

Design: Main-field homogeneity is less of a concern for this particular implementation of field-cycled-generated contrast where magnetic field shifts are required only during the evolution of tissue magnetization and are absent during the signal acquisition. The rapid ramping of insert coils however, can produce eddy-currents capable of producing main field instability during image acquisition. Complete elimination of eddy-currents requires that the insert produce no magnetic field outside its radial extent. From a computational standpoint this is equivalent to requiring zero net flux outside the insert.

The actively shielded B0 insert (see Figure 1) is composed of two separate magnets: The primary coil, a smaller powerful solenoid responsible for producing the magnetic field shift and the shield, a counter-wound coil used to remove the insert's net flux. The position of each shield winding was computed to minimize the net flux outside the insert. Figure 2 illustrates the calculated net magnetic flux in the XY plane produced by the insert as a function of radial distance (r) from the coil's center. Flux calculations for the shielded and unshielded primary coil are plotted. The addition of the shield reduced the net flux at 50 cm by a factor of 1400. Figure 3 shows the insert's calculated magnetic field profile efficiencies in the XZ plane as well as the relative positions and sizes of the primary coil and shield.

Construction: The primary magnet is an epoxy-reinforced solenoid wound with #4 AWG, square x-section, magnet wire. Its ID, OD and length are 19, 25 and 27 cm respectably. The shield employs 108 turns of #7 AWG-equivalent Litz wire wound around a 36 cm diameter Ultem birdcage-like form. The insert is cooled with approximately 100 m of 6.35 cm OD thin-wall Teflon tubing wound in close proximity to the inner and outer surfaces of the magnets. The entire insert was potted in 15 gallons of thermally conductive epoxy resin resulting in a total system weight of about 150kg.

Results: System inductance and resistance were measured to be 7.0 mH and 400 mΩ (at 20°C) in excellent agreement with calculations. Total flux through a 50cm radius in the transverse plane was measured at various points along the insert's length (see Figure 4). Measurements show that the addition of the shield reduced the total flux by approximately 220 times. This falls short of the 1400 times predicted by simulation.

MR compatible thermocouples were used to evaluate the maximum sustained insert-coil current. With 6L/min flow of 20°C coolant water, it as seen that a 100 A of sustained current raised the internal temperature to 90°C, a conservative temperature limit for some of the insert materials.

Conclusions and Discussions: We have demonstrated the feasibility of building actively shielded B0 inserts to produce field-cycled MR contrast in clinical MR scanners. Comparing the total flux produced by our actively shielded B0 insert to other MR compatible insert coils [3], has shown that actively shielded B0 inserts will not damage MR units or produce significant artefact. Thermal testing has indicated that continuous operation is limited to 100 A. With system benchmarking completed, integration into a 1.5T clinical MR is underway and imaging studies will begin shortly.

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Figure 1. The dreMR insert. Dimensions: 40 cm OD by 79 cm long.

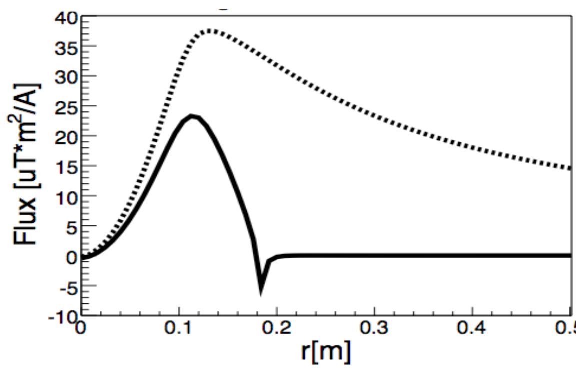

Figure 2. Flux within a circle of radius r with shield (solid line) and without shield (dashed line).

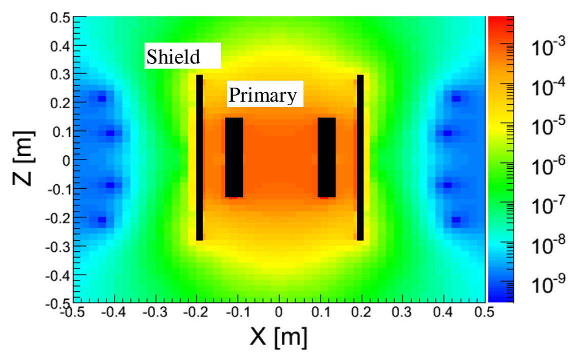

Figure 3. Computed magnetic field magnitude in XZ plane.

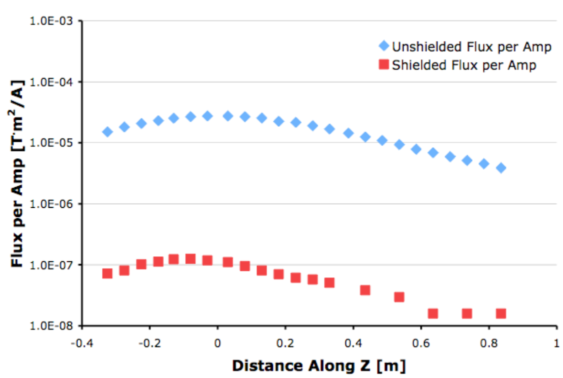

Figure 4. The shield lowers the net flux by ~220 times. Log scale.