A 180mT Pulsed Homogeneous Magnet for Prepolarized Knee MRI

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Introduction: Low field MRI following remote polarization (e.g., hyperpolarized gas, hyperpolarized 13C, prepolarized MRI) offers the same SNR as high field MRI, provided the reception frequency is high enough that body noise dominates coil noise [1]. Body noise dominance was experimentally demonstrated at 5 MHz in a human head using room temperature copper coils [2]. Here we present an inexpensive homogeneous magnet design that can operate above 7 MHz MRI frequency, which should provide body noise dominance for prepolarized knee MRI.

Methods: The key magnet design challenges include coil layout, power supply matching, avoidance of eddy currents, and efficient water cooling. We previously built an edge-cooled copper foil magnet, and found that eddy currents across the broad foils were prohibitive. Hence, here we chose *hollow wire construction* to avoid self-eddy currents. This is an extremely efficient cooling structure with no insulation between conductor and water. We designed for 250 ppm inhomogeneity over a 14 cm diameter spherical volume (DSV). This homogeneity matches practical manufacturing tolerances. Greater homogeneity can be achieved with inexpensive shims. We modified the magnet design software package described in [3] to layout the knee coils, and designed a water cooling structure composed of 38 "pancake coil pairs" [4], shown in Fig. 1. Here, water and current enter at the outside, spiral inward, cross over at the former, and then spiral outward. The hottest coil is at the bottom right (exit). Note that winding pitch is largely removed.

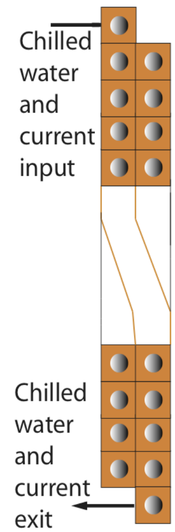

Figure 1. Pancake coil.

Results: Table 1 and Fig. 2 give the specifications for the 4-coil, 250-ppm knee magnet. The total magnet length is 50 cm; the total conductor mass is 147 kg. "Double-nine" gauge square hollow wire (4.6 mm edge with 2.4 mm hole) was used to match the 2 ohm (220 V, 108 A) power supply. At 98 A, the magnet dissipates 19 kW at 180 mT (about 7.7 MHz). The magnet inductance is estimated to be 200 mH, which translates to 135 ms ramping time to 90A with our power supply. The coils are wound onto a 12-inch (31cm) G10 former. When the 38 pancakes are driven in parallel with 10°C water cooling at 1 atm differential pressure, the hottest wire operates below 30°C (40% duty cycle) despite the 800 A/cm^2 current density. Total flow at 19 kW is about 1/2 liter per second.

Coil #	Position (cm)	Radius (cm)	Turns	Pancakes
2, 3	3.50	19.49	122	5
1, 4	18.00	19.85	406	14

Table 1: 180 mT (98A) magnet specifications.

Discussion: We designed an inexpensive hollow wire homogeneous magnet for a knee-sized volume that can operate up to 180 mT (7.7 MHz). The only drawback is the coarse wire placement. The ramping rate is less than 10% of the 20 T/s FDA limit on dB/dt. The magnet ($4000 in materials) is now being constructed by Stangenes Industries. This could improve the SNR of human wrist and knee images by a factor of up to 4 relative to our current 1.1 MHz scanner, assuming f$^{3/4}$ SNR variation [1]. Hollow wire pulsed magnets may offer similar advantages for low-field hyperpolarized gas or PHIP.

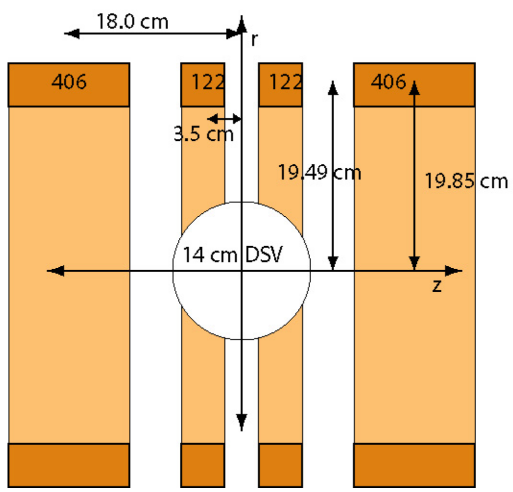

Figure 2: Homogeneous magnet layout. The end coils are comprised of 14 pancakes. Bore is 31 cm; length is 50 cm.

References:

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