A Shielded NMR System Suitable for Parahydrogen-Induced Polarization

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Introduction: Current diagnosis of disease is simplified by access to measures of abnormal blood flow and tissue perfusion. In the future, visualization of metabolic processes may provide additional, crucial information. Parahydrogen-induced polarization (PHIP) can be used to create high signal-to-noise MRI agents which are suitable for either application[1]. The PHIP equipment (hereafter referred to as the "reactor") must be installed near the MRI, because the agent has short relaxation time (~40s [2]). However, the polarization process requires a homogeneous and well-controlled magnetic field (B0) as well as accurate decoupling and polarization transfer pulses that are uniform over the entire sample (B1). Building on the design of GE Healthcare[1], we present the design and testing of a new, shielded reactor and magnetic field coils.

Methods: The reactor, in which catalyzed hydrogenation takes place, is placed inside a B1 coil. This assembly is in turn inside a B0 coil. We have reconfigured both coils to accommodate mu-metal cylinders (CO-NETIC, Magnetic shield corporation, IL, USA) now installed outside the B0 coil. During hydrogenation, the bulk of the liquid material is contained inside a 4 cm diameter. Only inside this region is field homogeneity critical. In order to minimize total equipment size while achieving adequate shielding, we chose a three-layer mu-metal cylinder with innermost diameter 155mm and length 400mm. Based on considerations of decoupling efficiency, as well as convenient pulse width and RF power, we calculated the target conditions of B0 and B1 homogeneity. These targets are summarized in table 1. Optimization of the coil configurations were performed using numerical codes (POISSON/SUPERFISH code[3] for the B0 coil and FEMM code[4] for the B1 coil) considering magnetic non-linearities imposed by the mu-metal as well as induced eddy currents in the B1 coil design. We chose an end-compensated solenoid for the B0 coil (two layers of windings, with two extra layers at the ends) because it provides adequate homogeneity and is easily constructed from a single piece of wire. We note that the optimum number of end-compensating turns is reduced by the presence of the shielding. The B1 coil design is based on a saddle-coil (a pair of square loops wrapped on a cylinder), but because of the relatively large volume in which homogeneity is required, we found significant improvement by using a pair of saddle coils wound from a single wire. The coil opening angles and positions were optimized for the frequency range 15-100 kHz and are summarized in figure 4. Both coils were constructed and characterized using a fluxgate magnetometer (B0) and a lockin amplifier / pickup coil (B1).

Results: A relation between B0 coil winding pattern and homogeneity of magnetic field (Bz) over the reaction region was calculated (see figure 2). As shown in figure 3, we found that the optimum configuration (with L=151.4mm) yields a highly homogeneous (0.116%) within ±20mm on the axis (see figure 3). A relation between straight line position ($\theta 1$, $\theta 2$) of saddle coil and homogeneity of magnetic field (Bx) was calculated as well. As shown in figure 5, we found the configuration whose ($\theta 1$, $\theta 2$) = (42.75deg, 78.75deg) yields the optimum homogeneity. Measurements with a pickup coil confirm this high homogeneity region (1.0%) within ±20mm. Because of measurement equipment limitations, these preliminary measurement were done at somewhat lower magnetic field than target conditions, but we expect the homogeneity measurements to remain applicable up to B0>30G because the mu-metal does not become saturated.

Conclusion: A new magnetic field coils for PHIP reactor with magnetic shield was designed and constructed. Achievement of target design conditions was confirmed by magnetic field measurement.

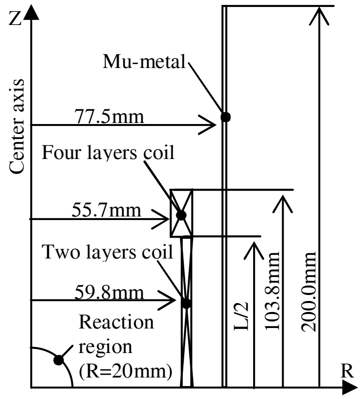

Figure 1 B0 coil configuration

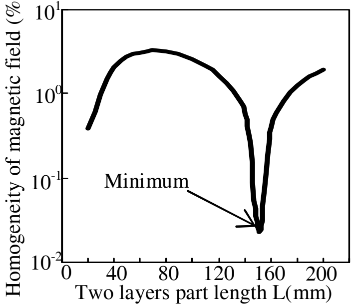

Figure 2 Calculated results of B0 coil

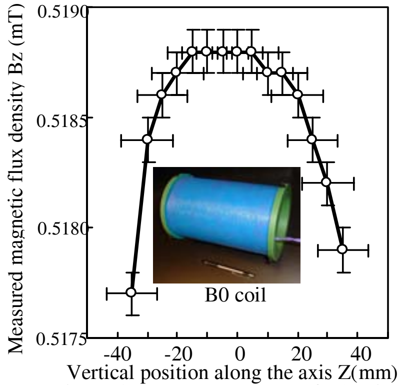

Figure 3 Measured results of B0 coil

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References:

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Table 1 Design target conditions

	B0 coil	B1 coil
Inner radius(mm)	55.0	47.0
Outer radius(mm)	65.0	50.0
Length (mm)	< 200.0	< 200.0
Magnetic field (mT)	2.0	0.05(15 ~100kHz)
Homogeneity	< 0.1%	< 1%

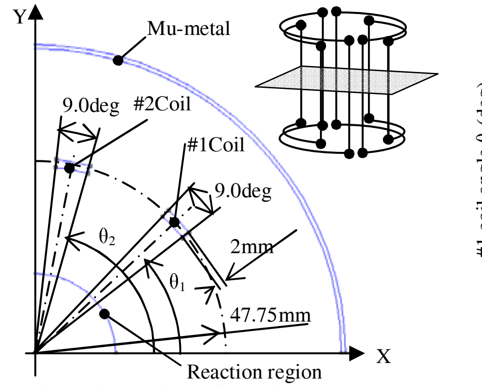

Figure 4 B1 coil configuration

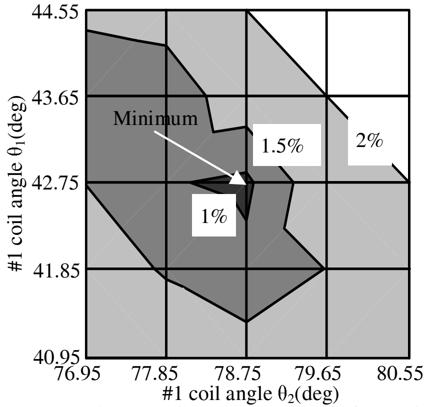

Figure 5 Calculated results of B1 coil

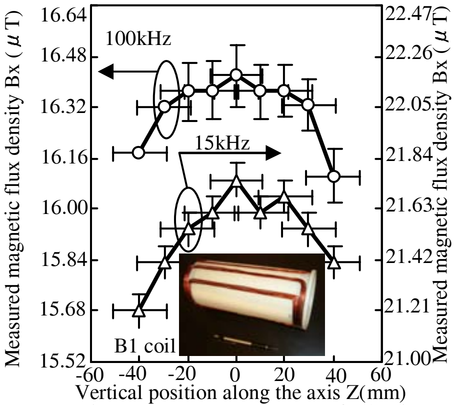

Figure 6 Measured results of B1 coil