Towards simultaneous PET and field-cycled MRI: active shielding for PMT detectors

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Introduction: Combined PET and MR scanners are currently under development as a means to obtain specific functional data from PET, registered both temporally and spatially with high-resolution anatomical images from MRI. One approach is to use field-cycled MRI (FCMRI), which uses two separate and dynamically controlled magnets for the polarization and readout phases of MRI [1,2]. A FCMRI scanner with an open geometry design, as shown in Figure 1, leaves room for a ring of PET detectors to surround the imaging volume. A primary difficulty is the operation of the photo-multiplier tubes (PMTs) inside the magnetic fields produced by the FCMRI [2]. It has already been shown that the two systems can operate successfully in an interleaved manner [2]; however, it would be greatly beneficial to increase the total counts for PET by operating PET detectors during the polarizing phase of the FCMRI experiment. One possible solution is to actively shield the FCMRI system polarizing magnets to reduce the magnetic field over the region in which the PMTs would be placed. This is feasible because FCMRI does not require a highly uniform polarizing magnetic field over the sample [1]. The goal of this abstract is to determine the extent to which a significant reduction in the magnetic field over the region containing the PMT can be achieved without detrimentally affecting the field homogeneity and strength of the FCMRI polarizing magnets.

Methods: A simple model of an open-geometry FCMRI polarizing magnet was used with an inner radius of 10.5 cm, an outer radius of 22.5 cm, a total length of 21.6 cm and a gap of 10 cm between the magnets. The efficiency of the initial Helmholtz pair was calculated to be 1.41 mT/A, requiring 354.6 A to produce a field strength of 0.500 T at isocenter. All magnetic field calculations were static and used numerical integration of the Biot-Savart law based on a discretization of the current carrying conductors. The active shielding coils were modeled as discrete loops carrying current opposite to the direction of the main polarizing magnets, and they were placed inside the gap between the main magnet coils as shown in Fig 2. The number, positions (radial and axial), and current of these loops were optimized using a conjugate gradient descent algorithm [3]. A functional containing the field strength in the vicinity of the PMT and the uniformity over the imaging volume of the FCMRI, was minimized using this algorithm. Specifically, the region over which the average field was minimized was an annulus 4 cm wide (z direction) and 8 cm long (radially), with a mean radius of 21 cm. The algorithm consistently converged to an optimal geometry and current value for the shielding coils regardless of initial parameters.

Results and Discussion: The magnetic field (normalized to the value at isocentre) for the optimally shielded coil is shown in Fig 2. With 64 windings in the shielding coils it was possible to reduce the average magnetic field over the region containing the PMT from 80 mT to 19 mT. A field reduction of this size is critical, as mesh PMT's have been shown to operate successfully in transverse fields of over 30 mT. This shielding would therefore allow mesh PMT operation during the polarizing phase of FCMRI, resulting in an increase of approximately 50% in the feasible duty-cycle of PET data acquisition in a field-cycled/PET system. This shielding improvement was accompanied by a reduction in the uniformity and field efficiency of the system. Without shielding the field strength was 0.50 T at the center of the polarizing magnet, and with the addition of the shielding coils this value was reduced to 0.35 T. If the current in the polarizing magnet was increased by a factor of 1.4 to compensate for this primary field reduction, the average magnetic field over the PMT region would increase to 27 mT, still within the typical operating tolerances of mesh PMTs. The polarizing field uniformity over a 10 cm DSV was degraded from 1.9% to 7.0% with the addition of shielding. This reduction in field uniformity is perfectly acceptable, as it only affects the magnetic field during the polarizing phase of the experiment, resulting in magnitude shading of the final images. Only simple shielding configurations were used in this study, and optimization of more complex shielding coils is expected to give further improved results.

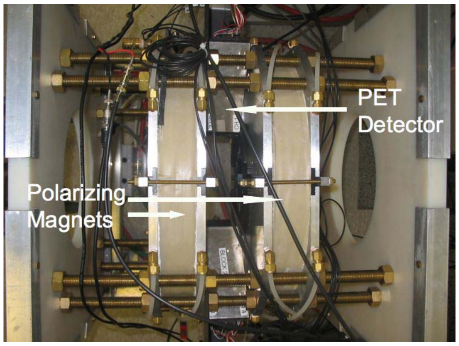

Figure 1. Polarizing magnet model with integrated PMT detectors.

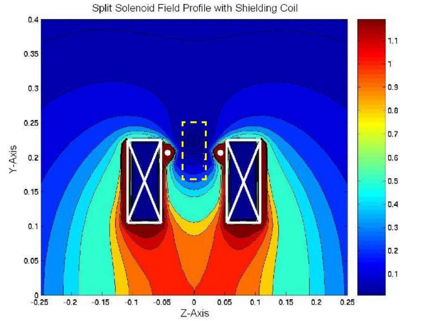

Figure 2. Normalized magnetic field profile for the shielded polarizing magnet (large rectangles). The white dots indicate shielding coil locations and the yellow rectangle indicates PMT location.

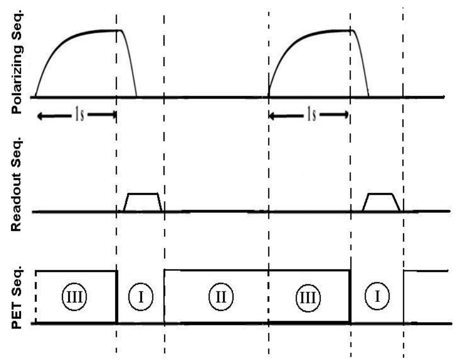

Figure 3. Pulse sequence for interleaved PET/FCMRI. Region I and II correspond to the time when MR and PET operate independently. Region III indicates where PET can operate simultaneously with FCMRI as a result of shielding the polarizing magnet. This increases the duty cycle of PET by a considerable amount.

References:
[1] Gilbert K M et al. 2006 Phys. Med. Biol. **51** 2825-2841
[2] Peng H et al. 2007 Proc. 15th ISMRM p3284.
[3] Wong E C et al. 1991 Magn. Reson. Med. **21** 39-48