# Magnet Design and Construction for a Field-Cycled MRI/PET System

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**Introduction**: Conventional MRI employs a single field-strength superconducting magnet to polarize a sample and acquire data. Field-cycled MRI differentiates these tasks by using two separate, actively controlled resistive magnets [1, 2]. A high-strength (~0.5 T) magnet is used to polarize the sample, followed by a low-field (5 MHz) homogeneous field under which data is acquired. Data is acquired in the same manner as conventional MRI. The ability to vary the polarizing field strength and duration allows for a large range of T1 dispersion contrast. The polarizing field need only be strong, but not necessarily uniform, as inhomogeneities in this field only shade the image. Imaging at low field reduces susceptibility artifacts, SAR, and acoustic noise. A typical field-cycled MRI pulse sequence is shown in Figure 1.

The versatility gained by the use of resistive magnets allows for an openness, and thus an inherent accessibility, in the design of the magnet system. This versatility can be exploited by placing a gap in the polarizing and readout magnets for the integration of a Positron Emission Tomography (PET) ring or a Single Photon Emission Computed Tomography (SPECT) camera [3]. Imaging at low field reduces susceptibility artifacts produced by the PET ring or SPECT camera. The following describes the design and construction of the main magnets for a field-cycled MRI/PET dual modality system, including the 5-MHz readout magnet and the 0.3 T polarizing magnet. The system was designed to image over a 10 cm FOV.

**Methods**: The radial ordering and physical sizes of the magnets were determined based on electromagnetic, SNR, and thermal considerations [4]. Two thermal models were developed to predict the thermal evolution of the magnets [5].

A manual search of the solution space was used to determine the size and locations of the coils comprising the 5-MHz readout magnet. The gap between the innermost coils was required to be > 8 cm to allow sufficient space for a PET ring. The readout magnet consisted of six coils to increase uniformity and magnet cooling, while maintaining simplicity in mechanical shimming. The polarizing magnet consisted of eight coils, separated by aluminum plates with forced-water cooling, to limit its equilibrium temperature to < 150°C. The polarizing magnet was designed to have an identical gap size in its center as the readout magnet. Coils were wet-wound, in-house, on a collapsible bobbin.

All coils are sandwiched by cooling plates, which are suspended by threaded rods. Forced water-cooling is sent through each cooling plate. Cooling plates were sectioned to limit the presence of eddy currents. Plastic formers, adjustable in height and position, were placed underneath multiple coils to relieve strain on the threaded rod.

**Results**: Figure 2 shows the dimensions of the readout magnet. A uniformity of 80 ppm was calculated for the readout magnet over a 10 cm DSV. The readout magnet can be mechanically shimmed by adjusting the longitudinal positions of the coils along the threaded rods; all coils are radially fixated. The coils are located within a 1 mm tolerance.

The calculated specifications of the polarizing and readout magnets are given in Table 1. A 6 l/min flow rate limits the temperature rise of the magnets to < 40°C over a typical field-cycled pulse sequence. A photograph of the main magnets is shown in Figure 3.

**Discussion:** This magnet design provides sufficient cooling for the required imaging times, as well as a sufficient homogeneity for imaging at low-field (5-MHz). The central gap in the field-cycled scanner, for the inclusion of PET or SPECT, allows for concurrent of anatomical (field-cycled MRI) and functional (PET/SPECT) imaging.

**Table 1:** Calculated specifications of the field-cycled MRI system.

| *Magnet:* | Polarizing | Readout |
|---|---|---|
| Field at 100 A | 0.28 T | 5 MHz |
| Inner diameter [cm] | 21 | 56 |
| Outer diameter [cm] | 42 | 69 |
| Uniformity | 10% | 80 ppm |
| Inductance [mH] | 370 | 330 |
| Resistance [Ω] | 1.80 | 1.57 |
| Cooling plates | 8 | 2/coil |
| Length [cm] | 66 | 99 |
| Weight [kg] | 350 | 500 |
| Gradient/Shim coil width [cm] | 3.5 | |
| r.f. coil diameter [cm] | 10 | |
| Gap length for PET [cm] | 9 | |

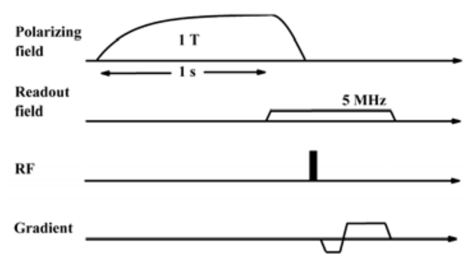


**Figure 1:** A typical gradient-recalled field-cycled MRI pulse sequence. The polarizing field can vary in both strength and duration.

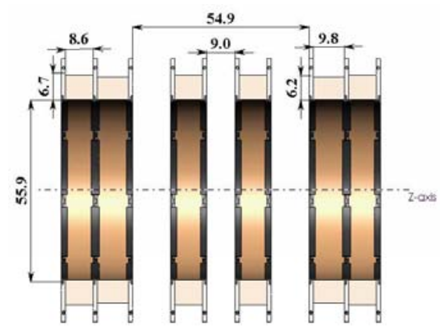


**Figure 2:** A cross-sectional schematic of the readout magnet. A 9 cm gap in the center of the magnet allows for the integration of a nuclear medicine system. All dimensions are given in centimeters.

**Figure 3:** A photograph of the main magnets of the field-cycled MRI scanner. The polarizing magnet is concentric and interior to the readout magnet.

**References**:

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