A new magnet design for field cycling OMRI

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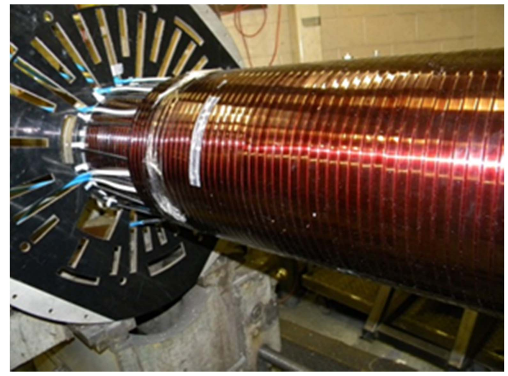
Background: Overhauser-enhanced MRI (OMRI) is a double resonance experiment establishing a polarization transfer from the free electron of a stable free radical to the surrounding water protons. This promising method has been used to measure pO_2[1-3] or redox state[4-6] in biological tissues. However OMRI is not widely used in part due to the unavailability of commercial OMRI scanners and the difficulties of building and designing a custom OMRI system. In this report we present a new approach to design a low cost field-cycling magnet that can be used in combination with a standard commercial MRI console to conduct OMRI experiments.

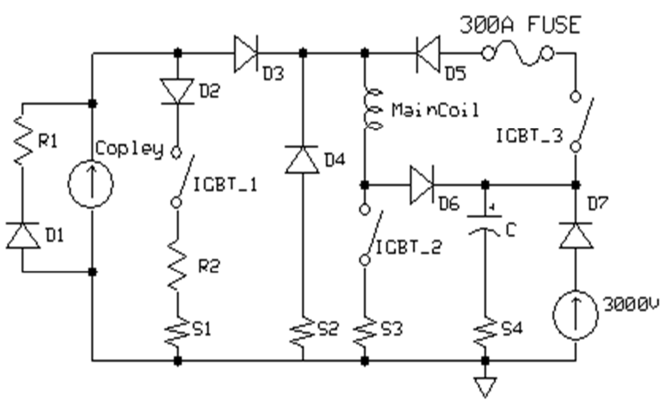


Magnet design:

Magnet fabrication: The newly fabricated solenoid magnet shown in the right figure is embedded entirely in one block of epoxy to provide high stability and is cooled by refrigerated water flowing through tubes inserted during the fabrication process. The resistance and inductance of the air-core coil were optimized to be as low as possible in order to minimize the switching rate between the two magnetic field strengths for dynamic polarization (< 200 Gauss) and the MRI data acquisition (4700 Gauss) while still ensuring a good homogeneity (sweet-spot) over the field of view. The magnet bore size is large enough to accommodate the Bruker-Biospin BG12 gradient coil and MRI probes. All these design criteria resulted in a 13 layer magnet coil with a length of 0.8 meters and with a bore size of 0.2 meters. The last two coil layers have reduced current density to homogenize the center of the coil. Axial plots, 0ff-axis plots and radial plots were calculated to ensure homogeneity by configuring the dimensions of the outside notch. In order to approximate on axis, off axis and radial magnetic field plots for individual layers in the central region of the solenoids, a polynomial involving Legendre polynomials (Montgomery and Terrell, 1961) was used. The characteristics of the magnet are: Inductance = 0.118 Henry; resistance = 0.502 Ohm; length = 800 mm; rectangular wire = 4 x 10 mm (Nomax insulated); total turns = 1200; layers = 13 (excluding 2 notches).

The proposed design also aims to improve two critical aspects of field-cycling OMRI instrumentation: field stability and field gradient rise time.

Field cycling: To achieve high magnetic field stability and minimize electrical noise, the magnet is stabilized with a novel electrical system powered by batteries. The use of batteries has two significant advantages. 1) It eliminates short term instabilities generated by the power grid and 2), the noise floor is approximately 40 dB lower than that from a regular power supply that gets its power from the power grid. The superior field stability enables one to detect the changes of the electrical current finely and consequently correct the magnetic field strength.



Field gradient rise time: The fast ramp time is achieved by using state of the art Isolated Gated Bipolar Transistors (IGBT) made recently available. These components enable a switching voltage of 3000 V utilizing a unique electronics design. The schematics on the left illustrate the switching electronics of the OMRI system. It consists of the solenoid coil, 3 IGBT's, 7 diodes; Copley Amplifier 400A / 160V; a Storage Capacitor consisting of 4mF capacitance with a maximum rated voltage of 5 kVDC four 300 A Shunt Resistors; 2 half ohm resistors, 300 A fuse and a 3000 V /100 mA power supply to recharge the Storage Capacitor.

Conclusion: A custom-built low-inductance solenoid magnet enables the cycling of the magnetic field strength in the range from 0 to 4700 Gauss in less than 10 msec. This fast field cycling time and wide Gauss range is unique for a single solenoid magnet with a bore size that can image small animals (192 mm).

References: **1**, Krishna, M.C.,et al., PNAS, 2002. 99 (4): 2216, **2**, Subramanian, S., et al., Nmr Biomed., 2004. 17:263, **3**, Benial, A.M.F., et al. JMR. 2010, 204:131, **4**, Ahn, K., et al. Inter. J. Rad. Oncol. Biology Physics. 2010, 78:S162. **5**, Ichikawa, K et al., Free Rad. Biol. Med. 2010, 49: S62.

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