A Cryogenic Solenoid Transmit/Receive Coil Cooled with Liquid Nitrogen for Sodium Imaging at 11.7 T

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Target Audience: MRI researchers interested in coil design; vendors designing MRI equipment;
Purpose: To design and test a useful cryogenic solenoid transmit/receive coil cooled with liquid nitrogen (LN2) and to demonstrate the higher signal-to-noise ratio images that can be obtained with it when imaging sodium.
Methods: A homogeneous solenoid transmit/receive resonator coil resonating at 132 MHz for sodium MRI at 11.7T was constructed to operate at cryogenic temperature (Fig. 1). It has a coil diameter of 21 mm and is built with multiple capacitors distributed on each turn. The electronic circuitry is separated into two parts. The coil and balancing circuitry are kept at cryogenic temperature inside the cryostat, while the frequency tuning and matching circuit is kept outside the cryostat at room temperature for easy access. The coil and the external tuning circuits are connected by a section of phase cable. One variable capacitor is used to tune the resonant frequency and another to match the coil. The resonant frequency can be tuned over a range of 250 kHz which is sufficient to compensate the frequency shift due to various sample loadings. The cryostat consists of the room temperature housing and a LN2 container, with the intervening space evacuated to minimize heat transferred from the scanner environment. The coil is contained in the vacuum space and is attached to the LN2 container through a 10mm diameter sapphire rod. The high thermal conductivity of sapphire results in a minimal temperature increase from the LN2 container (77K) to the coil (79K). The coil can be maintained at this operating temperature for over three hours with a single LN2 filling. Additional refills of LN2 can be done to keep the coil at the low operational temperature. A well packed non-metallic multi-layer radiation screen was inserted in the vacuum space between the coil and the room temperature vacuum housing to achieve a very low LN2 boil-off rate. Images of a 3 mm thick anatomical human patella specimen (Fig. 2) were obtained using a Bruker 11.7T (BioSpec 117/16) animal MRI scanner both with the cryo-coil and with a room temperature coil of identical structure for comparison. There is interest in quantifying sodium distribution within articular cartilage since it reflects GAG concentration, a useful biomarker of degeneration[1]. Small reference sodium chloride solution (300 mM) capsules were added near the cartilage allowing sodium concentration quantification.

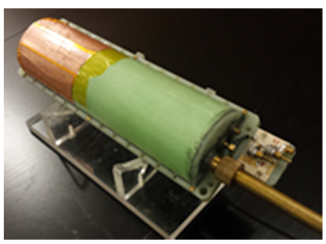

Figure 1. Cold copper solenoid coil apparatus.

Figure 2. Photo of the human patellar specimen (3 mm thick slab).

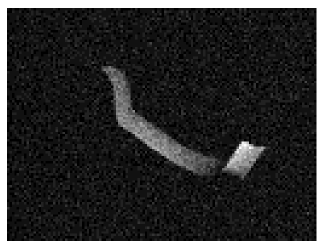

Figure 3. Image of the human patellar specimen using the cryogenic coil.

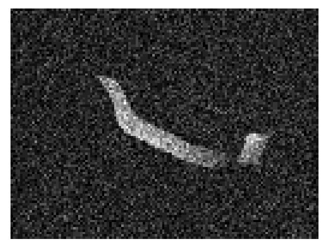

Figure 4. Image of the human patellar specimen using a room temperature coil

Results: The vacuum in the cryostat following 2 hours of evacuation reached 10^{-5} mbar before filling with LN2, and $2x10^{-6}$ mbar after filling with LN2. The temperature of the coil reached 79K after about half an hour. The unloaded Q of the cooled coil was 860. Images were obtained with a multislice GRE sequence having an in-plane resolution of 0.31×0.42 mm^2 and slice thickness of 1 mm. Signal averaging was done for 20 minutes. These sodium images showed intensity only in the cartilage tissue and the saline reference capsule (Figs. 3 and 4). The underlying bone was not visualized. Signal to noise ratios on high intensity regions were calculated as 13.5 and 8.0 corresponding to Figs. 3 and 4.
Discussion: Cryogenic coils[2] and HTS RF receiver coils[3] have been studied since the early 90's as a technology to achieve higher SNR, provide improved image quality and increase the speed of MRI. For sodium imaging, improvement of SNR is particular important given its low concentration and MRI signal strength compared to hydrogen. For the cold copper coil presented in this work, a 70% higher SNR comparing to a similar coil operated at room temperature was obtained. The tuning and matching circuitry was kept at room temperature, making coil adjustment convenient during operation, but degrades the circuit Q.
Conclusion: A solenoid MRI coil probe operating at 79K has been designed and fabricated. The tuning part of the coil probe is kept outside of the cryostat by using a phase line. The system incorporates a high efficiency cryostat which is able to maintain the coil at LN2 temperature for an extended time. The package is small and convenient enough for commercial use. Further SNR gain could be obtained if the coil temperature were made even lower and if the frequency tuning and matching circuitry were at cryogenic temperature.
References:
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