Investigation of liquid Nitrogen cooled coils for low field MR Imaging

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Introduction

Low field clinical MRI has the advantage of reduced manufacturing and operating costs at the expense of image SNR. Recent studies show that image quality in low field MRI can be enhanced by minimizing the thermal noise in the receiver system [1],[2]. In these preliminary experiments, we have investigated the improvement in SNR of human hand images when a small copper receive-only coil was cooled to 77K from room temperature using liquid nitrogen. These results will be used as guidelines in a later stage of the research project to develop relevant high temperature superconducting (HTS) coils for clinical applications in low field MRI.

Background

The thermal noise in a receiver system is due to the coil resistance and conductive loss coupled from the image sample. The coupled loss is inherently lower at lower frequency and is proportional to the size and filling factor of the receive coil. By using a small surface coil, the coupled loss becomes relatively small compared to the coil resistance at room temperature. In this circumstance, the coil resistance becomes the dominant thermal noise source. Hence cooling the coil to cryogenic temperatures will yield significant improvement in image SNR.

Experiment Method

A Helmholtz-like transmit coil (Figure 1a) was built to provide uniform B_1 RF excitation field. The receive coil used was a spiral copper surface coil with a diameter of 50mm (Figure 1b) on an alumina substrate. The coils were loaded using a cylindrical phantom with 5g/L NaCl solution. To cool down the receive coil, liquid nitrogen was poured into the alumina tubing, and the inner part of the Dewar was maintained at vacuum to prevent rapid boil-off of liquid nitrogen. Bench measurements were made to determine the improvement in loaded quality factor (Q) when the coil was cooled from 300K and 77K. Two type of imaging tests were performed using a standard spin echo (SE) sequence in a Niche 0.17T MRI scanner (Figure 1d). The first test was performed with both coils loaded with the image phantom to investigate the sensitivity of the receive coil along the coil axis at both room temperature and 77K. The second test was to study the SNR improvement for human hand imaging when the receive coil was cooled down.

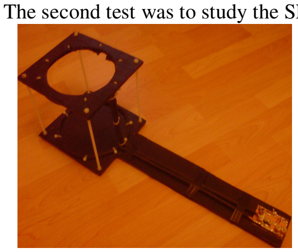

Figure 1a. Transmit coil, in Helmholtz-like configuration

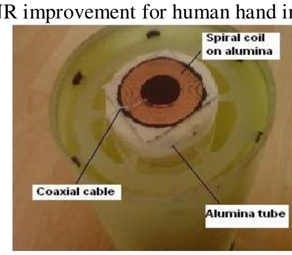

Figure 1b. Receive coil in spiral configuration, 13 turns, 50mm in diameter

Figure 1c. Cryogenic Dewar, made from G10 materials

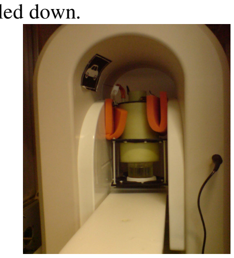

Figure 1d. Phantom imaging setup in Niche MRI scanner

Results and Discussions

The loaded quality factor of the receive coil improved by a factor of 2 when the coil was cooled from room temperature to77K. The results from the phantom imaging test (Figure 2a) show the sensitivity of the receive coil along the coil axis deteriorates significantly with distance away from the coil. This means the image sample must be placed in close proximity (<5mm) to the coil for optimum SNR performance. The images from human hand imaging test (Figure 2b and Figure 2c) show that the SNR improved with 40% when the coil was cooled from room temperature to 77K. In the current Dewar design, the human hand cannot be placed in the desired proximity to the coil as a foam pad of 10mm in thickness must be placed in between to provide sufficient thermal insulation. This explains the relatively poor quality of the human hand images at both room temperature and 77K.

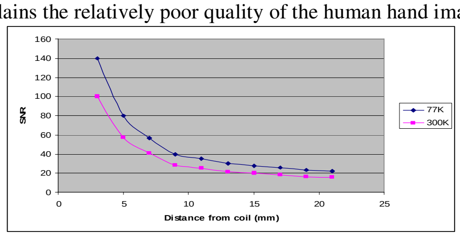

Figure 2a. The sensitivity of receive coil along coil axis

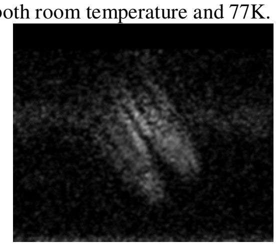

Figure 2b Hand image at 300K

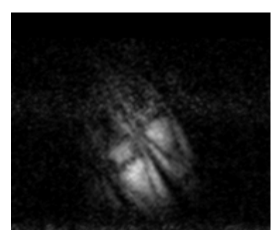

Figure 2c Hand image at 77K

Conclusions

The results from human hand imaging tests show that significant improvement in SNR can be achieved when the receive coil is cooled to cryogenic temperature. However, the thermal design of the Dewar must be improved to minimize the distance between the coil and image sample in order to achieve better SNR performance. The next phase of the experiment is to develop a mechanism to cool the preamp components and replace the copper coil with a HTS coil made of YBCO (T_c at 95K) in the same configuration. Such a setup should give SNR improvement of at least 2.0 in human hand imaging at 77K compared to room temperature copper coils.

References

1. Cheng, M.C., et al., *A High Temperature Superconductor RF Tape Receiver Coil For A Low Field Magnetic Resonance Imaging System.* Superconductor Science and Technology, 2005. **18**: p. 1100-1105.
2. Ma, Q.Y., et al., *Superconducting RF coils for clinical MR imaging at low field.* Acad Radiol, 2003. **10**(9): p. 978-87.

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