Ultra-low-field MRI system for hybrid MEG-MRI

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Introduction

Traditionally in MRI, ever higher magnetic fields have been pursued in order to enhance SNR. In contrast, ultra-low-field MRI (ULF MRI) is a new approach, in which spins precess in fields of µT order [1,2]. To overcome the inevitable loss of SNR due to low field strength, the sample is first pre-polarized in a mT-order field. The pT-order signal is subsequently collected using extremely sensitive superconducting quantum interference devices (SQUIDs). Low magnetic fields bring several advantages compared to conventional MRI, *e.g.*, remarkably narrow line-widths, imaging of objects in the presence of metal, and enhanced T_1 contrast [1]. Furthermore, in magnetoencephalography (MEG), SQUIDs are used to measure the weak magnetic fields generated by the human brain [3]. This work is a part of an EU-funded project aiming to develop a hybrid MEG-MRI device [4].

Methods

Our experimental setup in Fig. 1 consists of coils for pre-polarization (~10 mT, orange), B_1 (~1 µT, cyan), B_0 (~50 µT, red) and three orthogonal gradients (~100 µT/m, green, yellow, and blue). The polarizing and B_1 fields are orthogonal to the B_0 field. After pre-polarizing the sample for a few T_1, a typical ULF-MRI spin-echo sequence resembles that of traditional MRI. The signal is measured with 3 SQUID magnetometers (27 mm × 27 mm pick-up loop, noise 5 fT/rHz currently limited by the dewar) and 5 planar SQUID gradiometers (13 mm × 31 mm pick-up loops with 18-mm baseline). The whole system is placed inside a magnetically shielded room for reduction of environmental magnetic noise.

Technical challenges

SQUIDs are highly sensitive devices capable of measuring fT-order fields. When placed in the polarizing field, magnetic flux is trapped in the superconducting structures preventing the proper function of the SQUID. We have modified the Elekta MEG SQUID design and packaging to improve tolerance against field pulsing. Consequently, our sensors spontaneously recover from the pre-polarization without external heating.

The walls of the magnetically shielded room (MSR) are typically made of µ-metal and aluminum. Pulsing of the different coils, particularly the polarizing coil, creates a large *dB/dt,* inducing eddy currents in the conductive parts of the MSR walls. These induced currents create transient magnetic fields inside the MSR, which, in addition to exceeding the available SQUID dynamic range, may disturb the phases of the spins. The amplitude of the transient near the center of the MSR scales linearly with the dipole moment of the coil inducing it [5]. Thus, our polarizing coil in Fig. 1 consists of two concentric and equiplanar coils: an inner (11 cm radius, 215 turns) and an outer coil (31 cm radius, 28 turns) are conncected in series for a zero total dipole moment, inducing only negligible eddy currents in the walls, while still creating ~1 mT/A polarizing field.

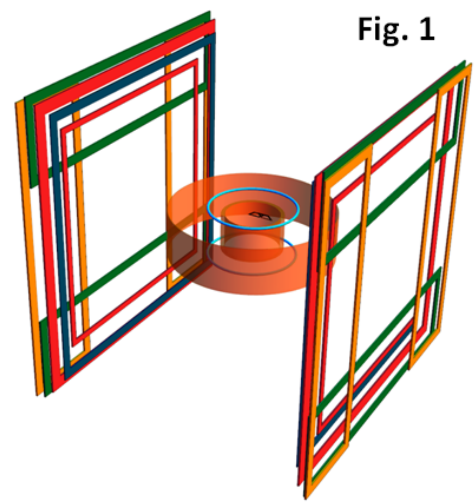

Fig. 1

Results

Fig. 2 shows ULF-MR single-sensor and composite sum-of-squares images of a water phantom placed ~25 mm below the SQUIDs. A 2D spin-echo sequence with an echo time of 600 ms was used. Prior to collecting each *k*-space line, the sample was polarized for 3 s in 8 mT-polarizing field. The imaging time was 20 minutes including 10-fold averaging. The image matrix was 27 × 27 with a voxel size of 3 mm × 3 mm × 9 mm. Maximum B_0 and gradient strengths were 30 µT and 12 µT/m, respectively.

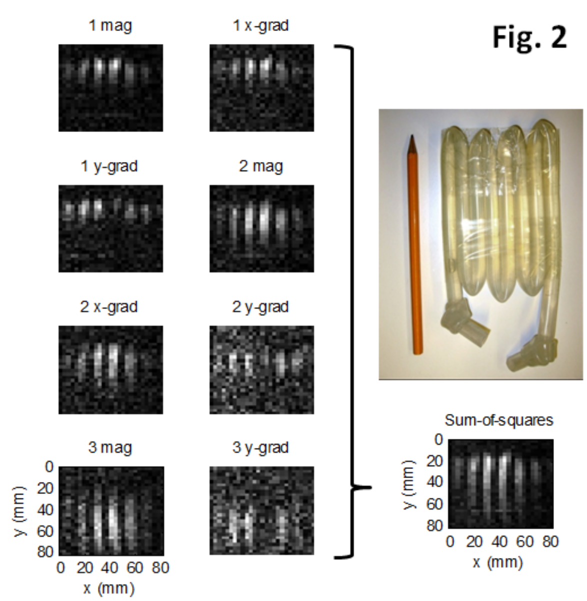

Fig. 2

Discussion

The SNR of ULF MRI is enhanced by increasing the polarizing field and reducing the noise of the SQUIDS. Furthermore, we are in the process of building an MEG-MRI system based on a commercial 306-channel MEG system by Elekta. The system includes a low-noise dewar. The combination of information from the 306 channels is expected to significantly increase the SNR.

References

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