Active magnetic shielded cancelling coils for direct detection of MR signals with an atomic magnetometer in ultra-low field MRI

Takenori Oida[1], Masahiro Tsuchida[1], and Tetsuo Kobayashi[1]

[1]Department of Electrical Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Kyoto, Japan

Introduction

In recent years, optically pumped atomic magnetometers (OPAMs) operating under spin-exchange relaxation-free conditions have reached sensitivities comparable to and even surpassing those of magnetometers based on super-conducting quantum interference devices (SQUIDs)[1]. We have been developing a high-sensitivity OPAM as a magnetic sensor to measure biomagnetic fields and magnetic resonance (MR) signals. Since OPAM does not require cryogenic cooling, it allows easily to measure extremely small magnetic fields.

Recently, an ultra-low field (ULF) MRI system with an OPAM has demonstrated. The resonant frequencies of alkali atoms such as potassium used in OPAMs are different from that of proton placed in the same magnetic field, so that Savkov et al. proposed[2] remote MR signal detection with a flux transformer (FT). However, the sensitivity of MR signal detection was found to be limited by the sensitivity of FT[3]. In this study, we propose an active magnetic shielded cancelling coils for direct MR signal detection with OPAM.

Methods

We have fabricated a compact module type OPAM as shown in Fig. 1. In this study, we consider the ULF-MRI with this OPAM module. Static magnetic field applied to an OPAM head cell placed in an ULF–MRI was cancelled by a Helmholtz coil with 90 mm in diameter (Fig. 2). The magnetic field for ULF–MRI was assumed to be 23.48 μT, corresponding to the resonant frequency of 1 kHz. Active magnetic shielding coils were arranged at the outer surface of a cylinder, whose diameter was larger than that of the cancelling Helmholtz coil, for reducing the magnetic distortion in the sample position caused by the cancelling Helmholtz coil. In this study, the diameter of active shielding coils was set to 110 mm. The active shielding coils were designed by a method proposed by Mansfield et al.[4]. To validate the performance of the coils, numerical magnetic field distribution analyses were carried out in the vicinity of the sample shown in Fig. 2.

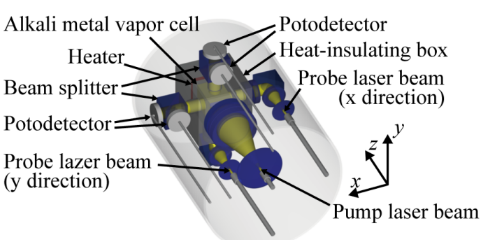

Fig. 1. Schematic of OPAM module for direct MR signal detection.

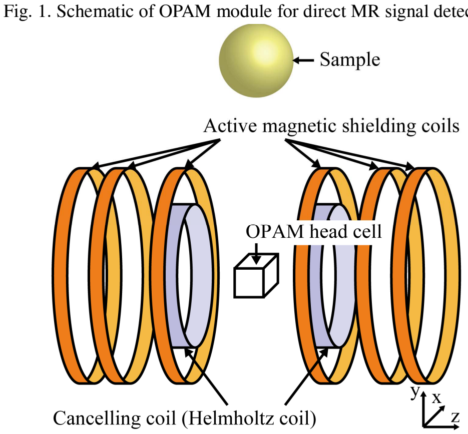

Fig.2. Schematic of an active magnetic shielded cancelling coils.

Results and Discussion

The designed active shielding coil positions along z direction were ±12.1, ±14.6, ±16.3, ±17.6, ±18.7, and ±19.7 mm. The magnetic field distributions generated by the cancelling coil without and with these coils in the vicinity of the sample were shown in Fig. 3(a) and 3(b), respectively. In addition, the magnetic fields averaged along z direction were plotted in Fig. 3(c). These results indicated that the magnetic field distortion due to cancelling Helmholtz coil was successfully reduced by the active magnetic shielding coils. In addition, using the active magnetic shielding coils, the magnetic fields could be close to the target field of 23.48 μT.

Conclusion

We proposed the active magnetic shielded cancelling coils for direct detection of MR signals with an OPAM. Results of magnetic field distribution analyses demonstrated that the active shielded coils were feasible to measure MR signals. .

Reference

1. Kominis IK, et al., Nature 2003; 422, 596–599.
2. Savukov IM, et al., J. Magn. Reson. 2009; 199(2), 188–191.
3. Oida T, et al., IEEE Trans. on Magnetics 2011; 47(10), 3074–3077.
4. Mansfield P, et al., J. Magn. Reson. 1986; 66(3), 573–576.

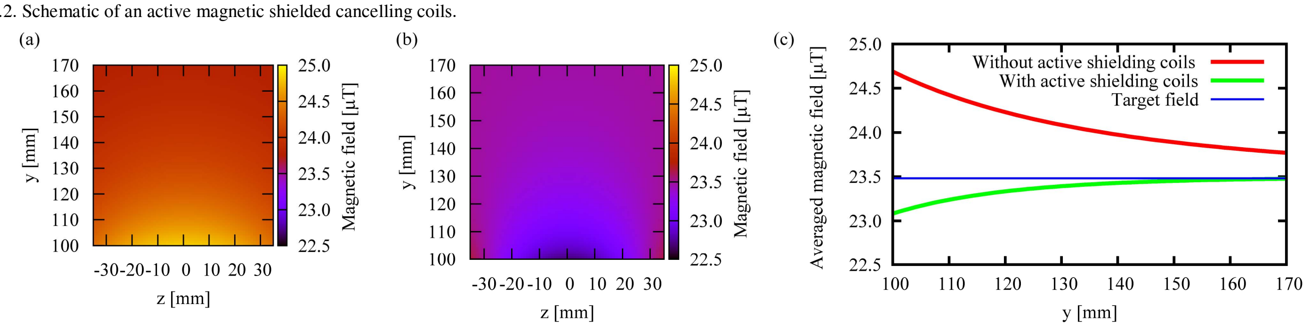

Fig. 3. The resulting magnetic field distributions in the vicinity of the sample without and with active magnetic shielded cancelling coils. (a) The magnetic field distribution with cancelling coil only. (b) The magnetic distribution with an active magnetic shielded cancelling coil. (c) The magnetic fields averaged along z direction in (a) and (b).