Magnetic filed shimming of a high T_c superconducting bulk magnet using a cylindrical single-channel shim coil

Daiki Tamada[1], Keisuke Maruyama[1], Katsumi Kose[1], and Takashi Nakamura[2]

[1]Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki, Japan, [2]RIKEN, Wako, Saitama, Japan

INTRODUCTION

The high critical temperature (Tc) superconducting bulk magnet reported by our group [1] is a novel magnet for MRI. The superconducting bulk magnet has several advantages over conventional superconducting magnets; compactness and no cryogen refill. At present, however, because it is difficult to obtain large crystals for the bulk magnet, the room temperature bore diameter is limited (23 mm at most) and therefore it is difficult to use a conventional multichannel shim coil assembly to obtain a homogeneous magnetic field. In this study, we have developed a cylindrical single-channel (SC) shim coil [2,3] to correct the inhomogeneous magnetic field of the bulk superconducting magnet.

MATERIALS AND METHODS

The bulk magnet comprised six annular bulk superconductors (60 mm OD, 28 mm ID, 20 mm high) made of c-axis oriented single-domain $EuBa_2Cu_3O_y$ crystals (Tc = 93 K). The bulk magnet was cooled using a pulse tube refrigerator. The magnet was energized by a field cooling method using a vertical wide bore (89 mm) superconducting high-resolution NMR magnet operated at 4.7 T. The diameter of the room temperature bore of the bulk magnet was 23 mm and the "captured" magnetic field at the center of the bulk magnet was 4.7 T. We made a saddle shaped RF coil (10 mm diameter and 12 mm long) using a 0.1 mm thick Cu foil and a three-axis gradient coil assembly wound over an acrylic pipe (18 mm ID, 19 mm OD) using a 0.3 mm diameter polyurethane coated Cu wire.

The magnetic field distribution was measured using a 3D lattice phantom and 3D SE sequences with positive and negative readout gradients. The 3D lattice phantom comprised a plastic lattice made by the rapid prototyping method installed in an NMR sampled tube (7.0 mm ID) filled with $CuSO_4$ water solution. The cylindrical SC shim coil was designed to correct the measured inhomogeneous magnetic field. The coil elements (base functions) used for the SC shim coil were circular current loops periodically placed on the cylindrical surface. The currents for the loops were optimized using a nonlinear least square method after a spatial smoothing operation. The obtained current density distribution was carefully converted to a wire pattern for the SC shim coil. After the shim coil was made on a flexible flat film as shown in Fig.1 using a 0.3 mm diameter polyurethane coated Cu wire, the shim coil was fixed around the gradient coil. The magnetic field distribution was measured for various shim coil current values.

RESULTS AND DISCUSSION

Figure 2 shows projections, MIP images, and cross sections of 3D image datasets acquired with and without the shim coil current (1.2 A). These images show that image distortion along the readout direction (horizontal direction in the images) was reduced. Figure 3 shows theoretical and experimental peak to peak values of the magnetic field calculated in a rectangular region (5 mm × 5 mm × 7 mm) plotted against the shim coil current. Although the quantitative agreement between theory and experiment is not good, the tendency of the variation is similar.

CONCLUSION

In this study, the SC shim coil was successfully installed in a narrow bore space and about 30% improvement in the magnetic field homogeneity was achieved. Although further improvements will be required, our study demonstrated usefulness of our approach.

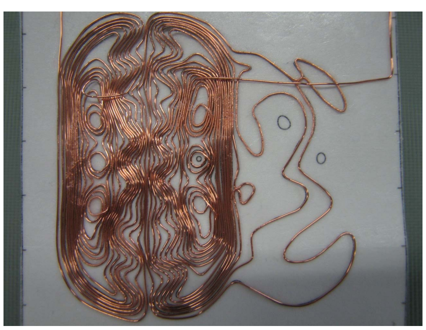

Fig.1 Single channel shim coil

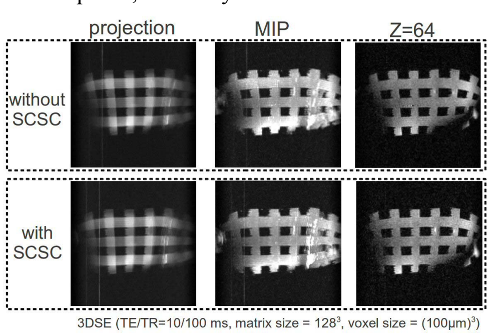

Fig.2 Phantom images with and without shim coil current

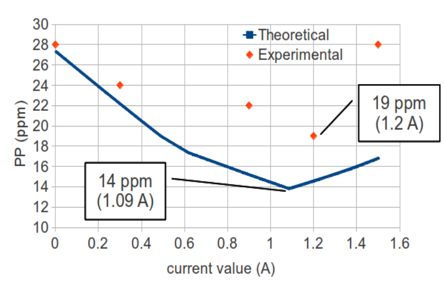

Fig.3 Current vs homogeneity

References:

[1] K. Ogawa et al. "Development of a magnetic resonance microscope using a high Tc bulk superconducting magnet," Applied Physics Letters, vol. 98, no. 23, p.234101, 2011. [2] D. Tamada, et al, "Bi-planar shim coil designed by Stream Function method improves B_0 homogeneity along Z-axis," in ISMRM, 2011, p. 3793. [3] D. Tamada et al, "Design and Evaluation of a Planar Single-Channel Shim Coil for a Permanent Magnetic Resonance Imaging Magnet," Applied Physics Express, vol. 4, no. 6, p. 066702, 2011.