Bi-planar shim coil designed by Stream Function method improves B0 homogeneity along Z-axis

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INTRODUCTION

In most NMR/MRI study, shimming is required to accomplish field homogeneity. The use of a large number of shim coils enables more accurate field compensation, but at the same time, it causes problems such as gap space narrowing and requires more complicated power supply. In order to overcome these problems, we have designed single-channel shim coil using the target field (TF) approach [1]. However, the TF method has a difficulty in correcting the inhomogeneity three-dimensionally. Here we propose an alternative method using stream function (SF) which enables three-dimensional inhomogeneity correction.

MATERIALS AND METHOD

The MRI system consists of a small yokeless permanent magnet (field strength B_0 = 1.04 T at +25 ℃ , gap width = 40mm, homogeneity ~ 20ppm in 20 mm dsv, weight 85 kg). The magnet was installed in variable temperature thermostatic bath (temperature range = -15 ~ +50 ℃). The magnetic field distribution B_z was measured as follows. The lattice phantom consist of 11 acrylic discs (diameter = 23.9, interval = 3.0mm) stacked in a cylindrical container (ID = 24.0 mm, OD = 26.2 mm, length =62 mm) with baby oil. The 3D images of the phantom were measured at -5 ℃ using 3D SE sequence (matrix = 256^3, voxel size = $(125\ \mu m)^3$) with positive and negative readout gradients. The spatial coordinates of the vertex points of the square lattice in the images were detected using a GUI program. The magnetic field strengths at the vertex points were calculated from positional shift of the vertices along the readout direction. Then the B_z in cubic area ($(15\ mm)^3$) was approximated using polynomial in the Cartesian coordinate.

In the SF method, the shim coil current density was calculated according to the following procedure. Magnetic field inhomogeneity distribution $\Delta B_0 \equiv B_z - B_0$ was fitted by the linear combination of the magnetic fields B_i and B_{HC} produced by Anderson coils [2] and the Helmholtz coil, respectively. The fitting function is expressed as $B_{shim} = \sum_i c_i B_i + c_{HC} B_{HC}$. We used genetic algorithm to efficiently optimize the coefficients of the terms B_i which are not orthogonal to each other. Then, the stream function was calculated from the fitting function. Finally, the wire pattern was derived from contour line of the stream function. For comparison, we used the TF method [1] to design shim coil to correct ΔB_0 in the plane at z = 0 mm.

RESULT AND DISCUSSION

The inhomogeneity ΔB_0 in 15 mm dsv (15.76 ppm (RMS), 86.44 ppm (p-p)) was improved using the SF method (8.45 ppm (RMS), 49.09 ppm (p-p)) and the TF method(6.46 ppm (RMS), 34.60 ppm (p-p)). However, the SF and TF methods give different spatial distributions. Figures 1a-c show the inhomogeneity ΔB_0, ΔB_{TF}, and ΔB_{SF} in the xz plane at y = 0 mm, where ΔB_{TF} and ΔB_{SF} denote the inhomogenous magnetic fields calculated by the TF method and the SF method, respectively. Figures 1d-f shows those in the xy plane at z = 0 mm.

As show in Fig. 1e, using the TF method, the inhomogeneity in xy plane was almost corrected. However, as shown in Fig.1b, it was hard to correct the inhomogeneity along z-axis. This is because the inhomogeneity was optimized only in xy plane at z = 0 mm and that along z-axis was not considered. In contrast in the SF method, the inhomogeneity in xy plane and that along z-axis were well corrected (Figs 1c and 1f), demonstrating the effectiveness of the SF method for three-dimensional correction.

Figures 2a and 2b are wire patterns designed by the TF method and the SF method, respectively. Both patterns were similar near the center but differed in the peripheral region. The peripheral coil patterns may be responsible for the correction along z-axis.

CONCLUSION

The SF method provided higher homogeneity along z-axis than the TF method, indicating that its effectiveness for three-dimensional correction. Furthermore, this method is extendable to more accurate correction of inhomogeneity by adding higher order terms to B_{shim}. Details including experimental validation of inhomogeneity will be discussed at the presentation.

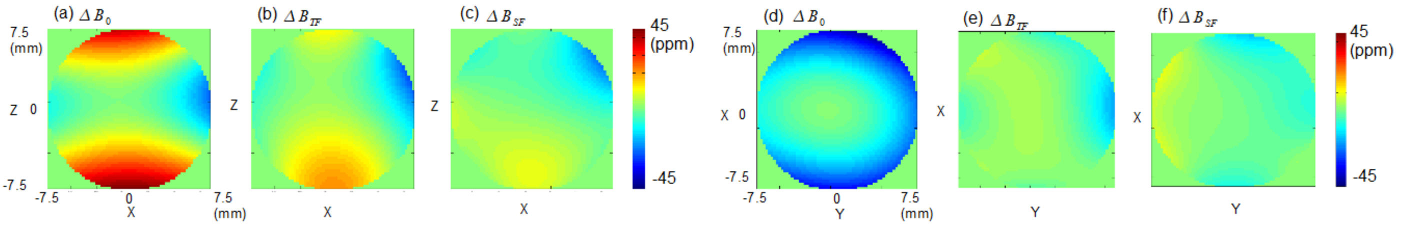

Fig.1 Spatial map of inhomogeneity. (a), (d) ΔB_0 in the xz plane at y = 0 mm and the yx plane z = 0 mm. (b), (e) ΔB_0 shimmed using target field method in the xz plane at y = 0 mm and the yx plane z = 0 mm. (c), (f) ΔB_0 shimmed using stream function method.

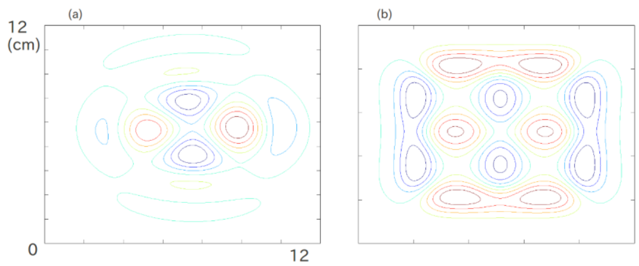

Fig. 2. Wire patters of shim coils designed (a) using target field method and (b) using stream function method.

Reference
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[2] W. A. Anderson (1961). Electrical current shims for correcting magnetic fields. Review of Scientific Instruments, 32(3), p241-250.