Effects of magnetic circuits on magnetic field gradients produced by planar gradient coils

S. Handa[1], F. Okada[1], K. Kose[1]

[1]Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaragi, Japan

Abstract

Effects of magnetic circuits on magnetic field gradients produced by planar gradient coils were measured for two MRI permanent magnets. As a result, it was found that the enhancement rates of the magnetic field gradients were different among x, y, and z directions. The difference gave us useful information on the mechanism of the gradient field enhancement phenomena.

Introduction

Magnetic field gradients produced by gradient coils in MRI permanent magnets are enhanced due to the presence of magnetic materials. The enhancement mechanism has been theoretically analyzed using a mirror-current approach and the finite element method [1]. However, as far as we know, there is no experimental report on this subject. In the present study, we measured magnetic field gradients produced by a planar gradient coil set in a free space and in gap spaces of two MRI permanent magnets and found that the yoke must be considered to calculate the enhancement rate.

Materials and methods

A planar gradient coil set was designed according to the target field method [2, 3]. The design parameters were as follows: magnet gap: 16 cm, target region: 12 cm dsv, diameter of the current flowing region: 34 cm, number of turns of wires: 25 for Gx and Gy, 28 for Gz. Each gradient coil element was wound on a 0.5 mm thick FRP plate using a 1.0 mm diameter polyethylene coated Cu wire. The 3-axis gradient coil assembly was made by piling up the G_y, and G_z coils on the G_x coils (Fig.1). Two permanent magnets were used for the measurements: a C shaped magnetic circuit (Fig.2), field strength; 0.21 T, gap; 25 cm, pole-piece diameter; 52cm, and a magnetic circuit with two columns (Fig.3), field strength; 0.21 T, gap; 16 cm, pole-piece diameter; 40cm. The gradient coil set was placed in a free space and the magnetic field distribution was measured using a Hall magnetometer. The gradient coil set was then fixed in the magnet gap spaces and the gradient fields were measured using water phantoms and 3D imaging sequences.

Results and discussion

Table 1 shows the efficiency of the gradient coils obtained from a numerical calculation and the measurements. Agreement between the calculation and the measurement in a free space is good. The enhancement rates can be roughly explained by the mirror-current theory for the pole-pieces [1]. However, those of the Gz coil are definitely smaller than those of the Gx and Gy coils. This result suggests that the effect of the yoke must be considered for the enhancement-rate calculation for the Gz coil, because the magnetic flux generated by one piece of the Gz coil set tries to decrease the magnetic flux generated by the other piece of the Gz coil set through the yoke. For Gx and Gy coils, however, there is no such interaction. Figure 4 shows images of a phantom acquired in the xz plane in the two magnets. Because the image distortion observed for the 16cm-gap magnet is slightly larger than that for the 25cm-gap magnet, the pole-piece degrades the homogeneity of the gradient fields. In conclusion, for the enhancement-rate calculation of planar gradient coils for permanent magnets, the presence of yoke must be considered for Gz coils.

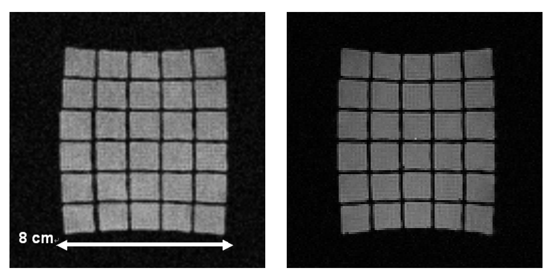

Fig.1 Planar gradient coil set Fig.2 C shaped magnet Fig.3 Two column magnet Fig.4 Phantom images (L: with C shaped, R: with two column)

	Calculation	Free space	C shaped magnet	Two column magnet
Gx	0.0963 (1.01)	0.095	0.110 (1.16)	0.168 (1.77)
Gy	0.0931 (1.02)	0.091	0.107 (1.18)	0.168 (1.85)
Gz	0.191 (0.97)	0.196	0.216 (1.10)	0.319 (1.63)

Table 1. Efficiency of the gradient coils (G cm^{-1} A^{-1}). Numbers in the parentheses are values normalized by those measured in a free space.

References

[1] Mood CH, Park HW, Lee SY. Meas. Sci. Technol. 1999;10:N136-141. [2] Turner R. J Phys D: Appl Phys 1986;19:147-151.
[3] Jianming Jin: Electromagnetic analysis and design in magnetic resonance imaging, (CRC Press, 1998).