Development of gradient coil probes for vertical wide bore superconducting magnets with solenoid RF coils and optimized planar gradient coils

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INTRODUCTION

Commercialized gradient probes for vertical bore superconducting (SC) magnets use RF coils of which axes are parallel to the magnet bore or the static magnetic field, because sample exchange and setting is convenient. Although solenoid RF coils have an SNR advantage over such RF coils [1], as far as we know, there is no literature that reports large bore (>> 30 mm) probes with solenoid RF coils for a standard wide bore (89 mm) SC magnet. In this study, we developed two large bore gradient probes for a vertical wide bore SC magnet (4.74 T) with solenoid coils and evaluated their performance.

MATERIALS AND METHODS

Figure 1 shows gradient probes with 30 and 40 mm diameter horizontal bore developed in this study. The gradient probes, which are designed for the room temperature bore of a vertical wide bore SC magnet (Oxford Instruments, field strength = 4.74 T, bore diameter = 88.3 mm), consist of planar gradient coil sets and solenoid RF coils. The planar gradient coils were designed using the genetic algorithm to minimize power consumption under the restrictions that the linearity of the gradients was better than 10% in the imaging volume. For Gz coil design, the set of radii of circular coils was optimized. For Gx or Gy coil design, coil elements were composed of circular arcs and curved chords described by cubic Bézier curves (Fig.2) and their parameters were optimized. The designed coil units were wound on 0.5 mm thick planar FRP plates using polyurethane coated Cu wire as shown in Fig.3. The gradient coil units were fixed on aluminum frames as shown in Fig.1. The solenoid RF coils (inner diameter = 30 and 40 mm, length = 60 mm, 6 turns) were wound using 2.0 mm polyurethane coated Cu wire and divided into 6 segments by using 5 chip capacitors (6.8 and 5.1 pF) to achieve 50 Ω impedance matching at 202 MHz using three variable capacitors for each tank circuit. Design parameters and specifications for the gradient coils and RF coils are tabulated in Table 1.

SNR for the 30 mm diameter RF solenoid coil was compared with that for a saddle shaped RF coil (diameter = 35 mm, length = 70 mm) using 3D image datasets of a baby oil phantom acquired with a 3DSE sequence (TR/TE=200ms/16ms, image matrix = 256^3, FOV = $(32\ \text{mm})^3$). For the 30 mm diameter probe, gradient field linearity was measured using a 3D lattice phantom made of acrylic discs with square trenches stacked in an acrylic container (inner diameter = 26 mm) filled with baby oil. Performances of the gradient probes were evaluated using plant samples.

RESULTS AND DISCUSSION

SNR of the phantom image acquired with the solenoid coil was about 2.6 times of that with the saddle coil, as widely accepted. Figure 4 shows a cross-section selected from a 3DSE image dataset of the 3D lattice phantom acquired using the 30 mm bore probe. From the analysis of the image dataset of the 3D lattice phantom in the central 26 mm diameter spherical region, nonlinearity of the gradient fields was 11.3, 13.7, and 4.5% for Gx, Gy, and Gz. Figure 5 shows a maximum intensity projection image of a Japanese pear (diameter ~ 25 mm) acquired with a 3D gradient echo sequence (TR/TE = 200ms/3.5ms, FOV = $(32\ \text{mm})^3$, image matrix = 256^3, voxel size = $(125\ \mu\text{m})^3$, total imaging time = 3.6 h) using the 30 mm bore probe. Vascular structures are clearly visualized. Figure 6 shows a cross section selected from a 3D image dataset of *Citrus sudachi* acquired with a 3D SE sequence (TR/TE = 800ms/20ms, FOV = $(40.96\ \text{mm})^3$, image matrix=512×512×128, voxel size = 80 µm × 80 µm × 320 µm, total imaging time = 14.6 h) using the 40 mm bore probe. Fine structures are clearly visualized within a reasonable imaging time. In conclusion, these gradient probes will be useful for MR microscopy of biological samples using vertical bore SC magnets.

References

[1] Houllt DI, Richards RE. The Signal to Noise Ratio of the Nuclear Magnetic Resonance. J Magn Reson 1976; 24: 71-85.

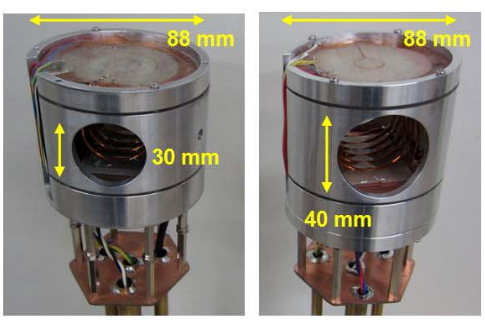

Fig.1 Gradient probes (bore = 30 and 40 mm)

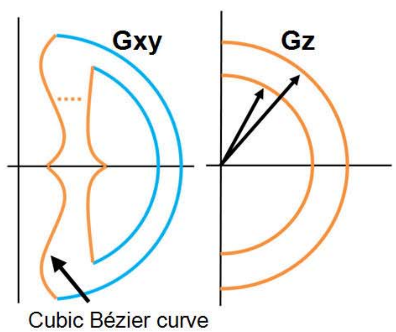

Fig.2 Coil parameters used for GA algorithm

Fig.3 Coil elements for the 40 mm bore probe

RF coil bore (mm)	30			40		
Number of turns	6			6		
Inserted capacity (pF)	6.8			5.1		
Unloaded Q (-3, -6 dB)	230, 398			118, 207		
Gradient element	Gx	Gy	Gz	Gx	Gy	Gz
Current diameter (mm)	78	78	78	79	79	79
Target diameter (mm)	30	30	30	40	40	40
Coil gap (mm)	47	50	52	55	58	60
Number of turns	30	32	23	28	24	20
Wire diameter (mm)	0.4	0.4	0.4	0.5	0.5	0.4
Resistance (Ω)	2.3	2.7	1.5	1.2	1.2	1.5
Inductance (µH)	65	101	55	59	48	48
Efficiency (G/cm/A)	1.39	1.31	1.55	0.70	0.54	0.92

Table 1 Parameters for the RF and Gradient coils.

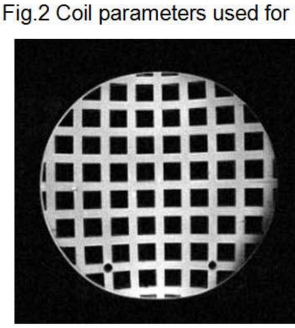

Fig.4 Cross-section of a phantom

Fig.5 MIP image of a pear

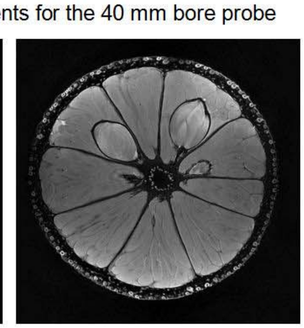

Fig.6 Crossection of *Citrus sudachi*