Development of an MRI Gradient Coil for Use in a Compact Head-only MRI Platform Capable of Imaging C7 and Below

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Introduction

Magnetic resonance imaging (MRI) plays an ever growing role in diagnostic imaging. A significant push is towards the development of head-only MRI systems which can be driven harder and faster than whole-body MRIs. Unfortunately, in these systems imaging is limited to the brain only. This is due to their small imaging-region size and compact nature making patient entrance past the shoulders impractical.

Previously, we have proposed the development of a head and neck gradient coil with cut-outs to accommodate the shoulders for use in these head-only systems.[1] Unfortunately, this led to an imbalance in performance across the X- and Y-gradient axes.

We hypothesize that by rotating these axes by π/4 we will be able to design balanced gradient axes with the presence of the shoulder cut-outs.

In addition to this we performed heating and flow simulations to explore the possibility of an all hollow-wire design for improved cooling.

Methods

The boundary element method (BEM) was implemented using in-house custom-built MATLAB software.[2] Briefly, in the BEM a target-field profile is chosen, and the current density on an input surface is solved for using a stream function value at each node. Once the stream function is solved for it is contoured giving wire-patterns which best approximate our current density.

To employ the BEM, a set of discrete field targets were chosen as a 0.20 m diameter sphere situated at the isocentre. The field targets were a linear field gradient rotated by π/4. We denote the rotated reference frame directions as d_1 and d_2.

Figure 1 shows an example 3D rendering of the a patient inside the gradient configuration and an illustration of gradient directions.

Heating simulations were performed using an in-house Darcy-Weisbach equation solver which uses pressure drop across a hollow conductor of inner diameter (ID) and solves for water flow parameters. Using this combined with thermal simulations of copper heating relying on the wire outer diameter (OD), ID, the copper resistivity, and length the amplifier current required to raise the supply water 30 degrees Celsius was calculated.

Methods

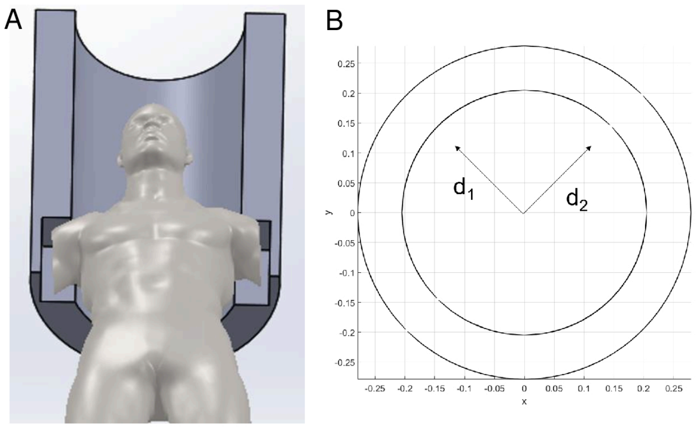

Figure 1.
A) Example 3D rendering of gradient coil with patient
B) Gradient coil rotated reference frame

Electromagnetic Parameters

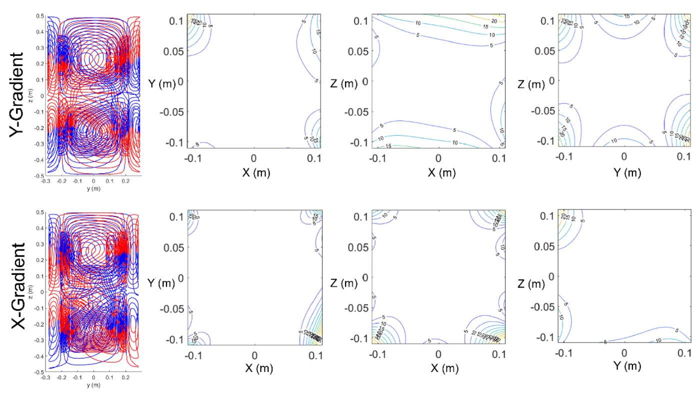

Figure 2. Selected gradient coil wire patterns (sagittal view) and homogeneity plots for the x-, y-, and z-gradients. Colour indicates current direction with respect to azimuthal direction

	Gradient Coil	
	d_1	d_2
Max Gradient [mT m^{-1}]^a	84	84
Resistance [mΩ]	96	102
Slew Rate [T m^{-1} s^{-1}]^a	480	475
Min Wire Spacing [mm]	3.6	4.8
DSV_{30} [m]^b	0.28	0.28

Table 1
a) Calculated assuming amplifier of 1400 V and 675 A
b) Diameter of spherical volume with <30% deviation in the gradient field

Results

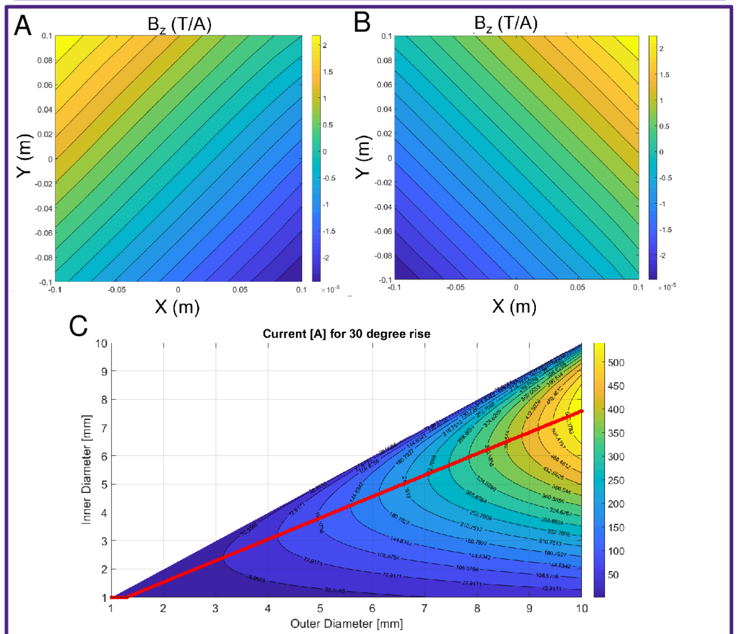

Figure 3.
(A,B) Simulated field profiles for both gradient axis.
(C) Calculated amplifier current required to raise cooling supply water by 30 K. Supply water pressure = 3 Atm, hollow conductor length = 55 m. Red line indicates optimal inner diameter for each outer diameter.

Discussion and Conclusion

As shown in **Table 1** the rotation of the gradient axes allows the X- and Y-gradients to obtain similar performance to each-other while achieving electromagnetic properties acceptable for imaging and a large imaging region defined by a DSV_{30} of approximately 0.28 m for each axis.

One important future direction is to shift the linear field region (imaging region) further towards the patient end allowing direct comparison of previous work and to improve cervical spine imaging.

This proof-of-concept study demonstrates the feasibility of designing a gradient coil with shoulder cut-outs that well balances the performance of the transverse axes.

This provides the possibility of manufacturing a compact head-only MRI system with the ability to not only image the brain but also the lower cervical spine in a single compact scanner.

References

1. Lessard EJ et al. Proc. Intl. Soc. Mag. Reason. Med. 27 (2019) Abstract #1481
2. Harris et al. Concepts Magn. Reason., 41B(4): 120-129 (2012)

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