The Harmonic Gradient Coil: Enabling Mobile FOV Gradients

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Introduction

The Harmonic Gradient Coil concept was first introduced as a means of exploiting the well known inverse co-dependence of gradient strength and linearity volume to optimize application specific gradient performance [1]. By providing continuous variation in the size of the gradient linearity region, the Harmonic gradient allows the size of linearity region to be matched to the size of the anatomical region of interest, resulting in maximum gradient performance. Furthermore, since gradient induced peripheral nerve stimulation (PNS) thresholds are known to increase with decreasing gradient linearity volume [2], the ability to vary the gradient linearity volume size permits a greater range of PNS-constrained performance. We now present an extension to the functionality of the Harmonic gradient concept by demonstrating the capacity to continuously vary the position, in addition to the size, of the region of gradient linearity within the coil volume. This mobile FOV functionality makes available the entire length of the gradient coil cylinder for imaging, thus enabling true whole-body imaging without the need to reposition the patient. It may also present a more favourable alternative to moving table acquisition techniques, such as moving table peripheral MRA, by alleviating problems associated with motion induced artifacts, while at the same time maximizing patient comfort. Finally, by adjusting the size of the mobile FOV, optimal off-center imaging performance can also be achieved.

Methods

The design concept is demonstrated here in a single transverse gradient axis. We begin by specifying a desired one-dimensional magnetic field profile inside the cylinder across the entire coil length near the center line; for a transverse design this can be approximated by a square wave with a central lobe of length corresponding to the desired gradient linearity region length. To move the desired linearity region off-center, we simply shift the position of the central lobe by a user-selectable amount toward either end of the coil. The essence of the Harmonic approach is then to approximate this resulting desired field profile by a sum of its first three or four Fourier harmonics. Using a minimum inductance target field method we then design separate winding layers to yield each of the desired cosine and sine harmonic profiles. We then assume that each layer can be driven in proportion to the corresponding coefficient of the Fourier expansion. The proposed method is not limited to Fourier harmonic expansions, and future implementations could exploit other and possibly more compact basis function expansions.

Results

A 6 layer, 3 Fourier harmonic, unshielded transverse gradient coil with an inner bore diameter of 65cm and 130cm length was designed. Gradient performance was then simulated with the region of linearity shifted from coil center to the coil end in 25% increments (at 100% shift the edge of the linearity region coincides with the physical edge of the coil) for two different linearity sizes equal to 30cm and 48cm (defined using extent of 50% deviation from linearity at center). The asymmetric current densities of the individual sinusoidal harmonic layers lead to non-zero net torques on these layers ranging from 10-30 Nm/A/T.

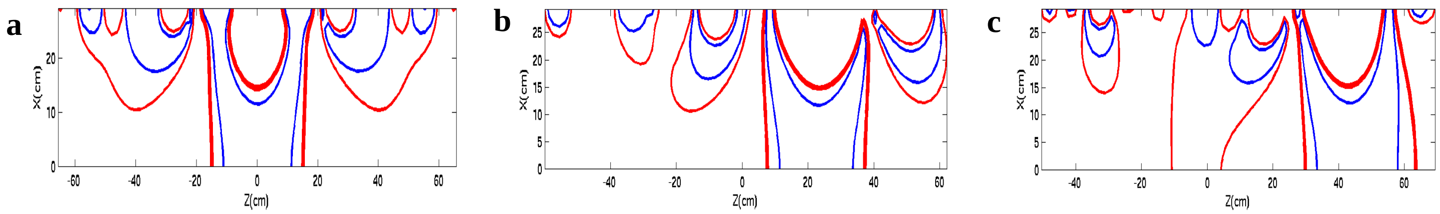

Figure 1. Contour plots of 30% and 50% (thickened lines) deviations from gradient linearity at region of interest for DSV 30cm at shifts of (a) 0% (b) 50%, and (c) 100%.

Table 1. Combined gradient strengths and operating currents for 2 sample DSV operating modes, each positioned incrementally from coil center to coil end (matched individual layer inductances of 300 µH).

		DSV 30 cm	**DSV 48 cm**
0% shift	G [mT/m]	43.4	18.8
	I [Amps] (cos1, sin1, cos2, sin2,…)	300, 0, 262, 0, 176, 0	210, 0, 39, 0, -300, -6
25% shift	G [mT/m]	48.3	19.1
	I [Amps] (cos1, sin1, cos2, sin2,…)	283, 222, 130, 300, -17, 202	191, 111, 26, 34, -84, -300
50% shift	G [mT/m]	38.3	22.6
	I [Amps] (cos1, sin1, cos2, sin2,…)	119, 300, -137, 214, -152, -28	165, 241, -6, 54, 300, -206
75% shift	G [mT/m]	32.6	21.6
	I [Amps] (cos1, sin1, cos2, sin2,…)	-19, 300, -203, -38, 33, -140	71, 300, -38, 30, 272, 232
100% shift	G [mT/m]	35.8	17.0
	I [Amps] (cos1, sin1, cos2, sin2,…)	-172, 300, -77, -281, 162, 57	-28, 275, -39, -12, -117, 300

Conclusion

We have introduced an added dimension to the variable FOV Harmonic gradient coil concept; specifically, the ability to vary the position of the gradient linearity region in addition to its size. Together, these two capabilities offer an unprecedented range and flexibility in the gradient linearity region, which in turn permits gradient performance to be customized and optimized for almost any imaging application. While simulation results suggest that this sort of gradient performance is theoretically possible, several practical challenges remain. In addition to the fabrication and implementation challenges of such a highly multi-layered design, this latest work also highlights the need for some form of torque compensation on the sinusoidal harmonic layers. Several strategies have previously been described and successfully employed to balance torque in asymmetric gradients [3, 4]. Hence it is expected that torque compensation can also be achieved in this design without compromising its functionality.

References and Acknowledgements

1. C Gazdzinski, J Odegaard, BK Rutt, ISMRM, 2004.
2. B Zhang, YF Yen, BA Chronik, BK Rutt, PISMRM, 54 (2002).
3. AM Abduljalil et al. MRM 31:450-453 (1994).
4. DC Alsop and TJ Connick. MRM 35:875-876 (1996).

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