The Harmonic Gradient Coil: A General Solution to the Variable Field-of-View Problem

C. Gazdzinski[1], J. Odegaard[1], B. Rutt[1]

[1]Imaging Research Labs, Robarts Research Institute, London, Ontario, Canada

Synopsis

Gradient strength and gradient linearity volume size are two of the most important gradient coil performance parameters that, due to their inverse co-dependence, often motivate the need for separate gradient systems, such as those found in "twin" gradient systems. We introduce a novel multi-layer gradient design based on decomposing the desired magnetic field profile into spatial harmonics, then representing each low order harmonic by a separate wire layer. If the multiple wire layers that form a single gradient axis are driven with arbitrary and user-selectable currents, the result is an unprecedented flexibility in the strength/linearity trade-off. Furthermore, this harmonic gradient design permits a new capability to optimize gradient performance within the limits imposed by gradient induced peripheral nerve stimulation.

Introduction

Different imaging applications emphasize different aspects of gradient performance. Cardiac and neuroimaging for instance require high gradient strength and/or slew rate, but can tolerate restricted gradient linearity region length, whereas the reverse is true for whole-body/spine applications. In addition to these anatomical distinctions, gradient induced peripheral nerve stimulation (PNS) thresholds are known to increase with decreasing gradient linearity volume [1], and therefore, the ability to adjust gradient linearity volume size would permit a greater range of PNS-constrained performance. Some solutions for adjusting gradient linearity volume have already been described [2,3]. We introduce here a novel, more general gradient design capable of software-controlled gradient linearity regions of arbitrary size and location in order to fully exploit the performance/linearity/PNS trade-off.

Methods

The design concept is exemplified 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. Conventional target field algorithms then solve for the required conductor distribution on a single coil surface to achieve this specified field. Our approach is to approximate this desired field profile by a sum of its first three or four Fourier harmonics. We then design a different winding pattern for each separate Fourier harmonic profile using a minimum inductance target field method [4], and assume that each layer in a set of nested winding layers 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

In this work, a 3 layer Fourier harmonic transverse gradient coil with an inner bore diameter of 65cm and 130cm length was designed, and gradient performance simulated in three operational modes corresponding to region of linearity lengths equal to 28cm, 54cm, and 78cm respectively (defined using extent of 50% deviation from linearity at center).

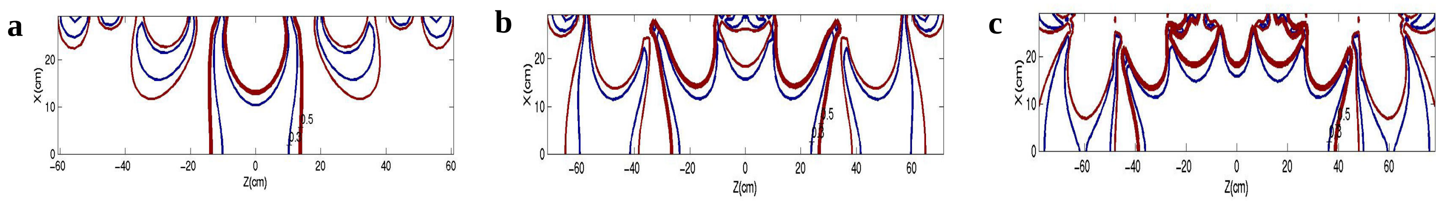

Figure 1. Contour plots of 30% and 50% (thickened lines) deviations from gradient linearity at center for (a) 28cm DSV mode, (b) 54cm DSV mode, and (c) 78cm DSV mode.

Table 1. Combined gradient strength and operating currents for 3 DSV operating modes with matched individual layer inductances of 1400 μH.

		DSV 28cm	DSV 54cm	DSV 78cm
G [mT/m]		106	52	38
I [A]	Layer 1	300	300	300
	Layer 2	280	0	-280
	Layer 3	284	-283	283

Conclusion

We have introduced a novel multi-layer harmonic gradient coil design concept, which provides in a single gradient coil the ability to continuously span a wide range of gradient linearity region lengths, with continuous trade-off between linearity and gradient strength. Simulation results suggest that a range of linearity size and corresponding gradient performance can be achieved which exceeds present day conventional or "twin" gradient coil systems. The multi-layer harmonic gradient coil could provide a single coil solution to a broad spectrum of imaging applications, including those which are most PNS-constrained.

References and Acknowledgements

1.B Zhang, YF Yen, BA Chronik, BK Rutt, PISMRM, 54 (2002). 2. R. Kimmlingen et al. MRM, 47(4), 800-808 (2002).
3. R. Kimmlingen et al. MRM, 47(4), 800-808 (2002). 4. G. DeMeester, M. Morich, Sh. Shvartsman. ISMRM Honolulu 2002.
The authors acknowledge financial asupport from CIHR, NSERC, ORDCF.