Quantitative comparison of minimum inductance and minimum power algorithms for the design of small animal shim coils

P. Jamali[1], and B. A. Chronik[1]
[1]Physics and Astronomy, University of Western Ontario, London, Ontario, Canada

Introduction: Advanced magnetic resonance imaging and spectroscopy at high magnetic fields benefit directly from improvements in shimming capability. We are interested in high power, dynamic shimming for small animal imaging applications at 9.4T. In this abstract we report on the quantitative comparison of shim coil performance obtainable using minimum power versus minimum inductance design algorithms. The specific goal was to determine exactly how much smaller shim coil inductance was in coils designed using the minimum inductance method as compared with the minimum power method, and similarly, by how much resistance was reduced in coils designed using minimum power methods as compared with those designed using minimum inductance methods. These specific, quantitative comparisons are critical first steps in the optimization of practical high power, high order shim coil sets.

Methods: Minimum inductance and minimum power target field methods were implemented and applied to the design of a series of gradient and shim coils for small animal imaging at 9.4T. The magnetic field constraints were identical for the two methods, and specified over the region +/- 5 cm. The following 10 separate axes were designed using both methods: X, Y, Z, XY, X2-Y2, YZ, XZ, Z2, Z3, Z4. Inductive merit (ML) was defined to be eta/sqrt(L). Resistive merit (MR) was defined to be eta/sqrt(R). L is coil inductance, R is coil resistance and eta is the field efficiency of the respective coil. The resistive merit equation is based on the assumption that the radial thickness of the conductor layer used for the coil fabrication is constant, while the width of the conducting path is determined by the minimum wire spacing. Both merits were calculated in two ways. Analytic expressions were implemented that allowed the evaluation of the inductance and resistance directly from the continuous current density. In addition, discrete wire patterns were generated from the current densities and used to numerically evaluate both inductance and resistance for the specific wire patterns. The absolute values of MR and ML as defined above cannot be compared between different shim axes; however, they can be used to compare designs for any given shim axis.

		Inductive Merit		Resistive Merit	
Axis	Analysis	Min Power Method	Min. Ind. Method	Min. Power Method	Min. Ind. Method
Z	Numerical	0.0939	0.0990	0.00490	0.00460
	Analytical	0.0932	0.0994	0.00620	0.00570
Z2	Numerical	1.24	1.30	0.0510	0.0500
	Analytical	1.12	1.27	0.0680	0.0634
Z3	Numerical	10.4	11.3	0.420	0.400
	Analytical	10.1	11.1	0.534	0.492
Z4	Numerical	86.6	91.5	3.13	2.83
	Analytical	85.2	90.7	4.34	3.96
X and Y	Numerical	0.0835	0.0913	0.00370	0.00330
	Analytical	0.0830	0.0912	0.00560	0.00500
XY and X2-Y2	Numerical	0.763	0.807	0.0293	0.0253
	Analytical	0.754	0.797	0.0490	0.0423
YZ and XZ	Numerical	1.11	1.10	0.0355	0.0319
	Analytical	0.991	1.09	0.0410	0.0370

Table 1: Performance values for shim axes designed using different algorithms

Results and Discussion: Example wire patterns for an (X2-Y2) axis are shown in Figure 1, for both minimum inductance and minimum power design algorithms. The basic features characteristic of the two methods are apparent: minimum inductance designs tend to feature oscillations within the current density; minimum power designs tend to feature longer, less rapidly-varying current densities. These features are consistent across all shim axes designed using these two methods. The field profile produced by the two designs over the region defined by the field constraints is shown in Figure 2. The fields in this region are identical for the two design methods. Table 1 summarizes the ML and MR values for the 10 different shim axes obtained. In all cases, regardless of numeric or analytic evaluation, coils designed using the minimum inductance method have higher ML values, while coils designed using the minimum power method have higher MR values. However, it is equally clear that the differences between the design algorithms are small. In every design case, the improvement in ML provided by the minimum inductance method is less than 15% of the value obtained using the minimum power method. Similarly, the improvements in MR provided by the minimum power method are less than 15% of the values obtained using the minimum inductance method. At constant coil efficiency, these differences would result in differences of approximately 30% in inductance and resistance respectively.

The results summarized in Table 1 are specific to the particular case of 10cm radius shim coils that correct for field over an imaging region of 10cm. We are currently extending these results to compare shim coil axes designed over a wider range of uniformity parameters. However, these results do indicate that differences between design methods are rather small. In our view, a potential decrease of 30% in dissipated power probably greatly outweighs the benefits of reduced inductance; however, this judgement is one that can be made on an application specific basis, using this form of analysis.

References, Acknowledgements:

[1] Turner, MRI v11, p903-920 (1993).

This work was supported by NSERC of Canada. BAC is supported by the CRC program of Canada.

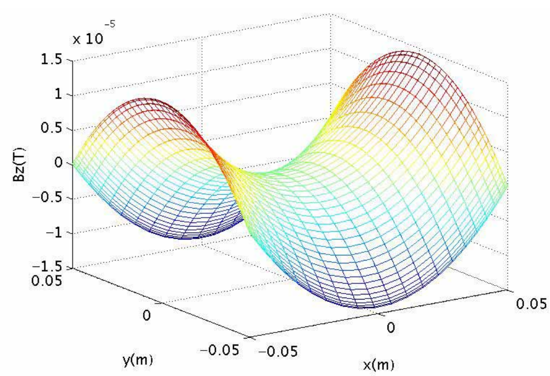

Fig. 2. Magnetic field variation in the x and y directions of the **X2-Y2** shim coil.

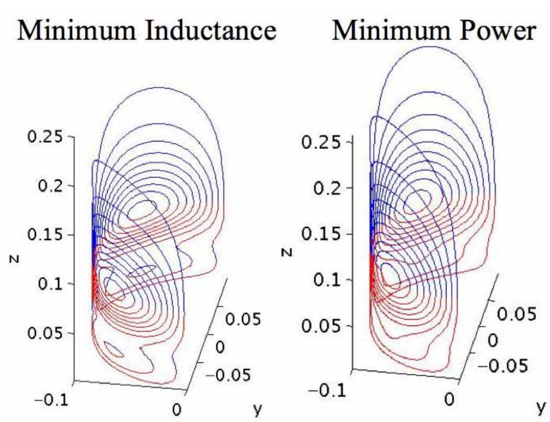

Fig. 1. Quarter of wire pattern for **X2-Y2** shim coil given by Minimum Inductance and Minimum Power methods.