Towards dynamic shimming in a 31cm bore 9.4T system: analysis of shim-shim inductive interactions

D. W. Haw[1], and B. A. Chronik[1]
[1]Physics and Astronomy, University of Western Ontario, London, Ontario, Canada

Introduction: Preclinical MRI and spectroscopy applications at very high field demand improved shimming capabilities. Our goal is to improve shimming techniques in a 31cm bore 9.4T MR scanner with the development of an optimized high strength dynamic shim system. There are two types of challenges surrounding dynamic shimming: one is shim-shim interactions, and the other is interactions between the shim coils and the rest of the system. Attempts have been made to alleviate the problem of shim-shim interactions with limited success [1]. In this abstract we report on the severity of shim-shim interactions for all axes up to 2nd order in tesseral and 3rd order in zonal. We also investigate a method to reduce the interactions between shims that exhibit significant coupling.

Methods: Shim axes of various orders and predetermined fixed lengths were designed using a Fourier series method [2]. This method expresses current density over a specified interval as a truncated Fourier series. Outside the interval the current density is set to zero. Magnetic field and resistance are expressed in terms of current density, and a functional that includes these coil parameters is minimized. This algorithm was first used to design a realistic shim set containing: Z^0, X, Y, Z, XY, XZ, YZ, X^2-Y^2, Z^2, and Z^3. All shim coils were individually designed using a minimum power technique. A mutual inductance term was then added to the functional and used to design decoupled shims. The inner most shim coil, Z^0, has a radius of 10cm. The radius of each coil, preceding radially outward, is 1cm larger than the previous shim coil. All coils had a fixed aspect ratio (diameter/length) of 2.5, a self-inductance of 200μH and were designed to have the same field uniformity over a 10cm DSV. The mutual inductances between all shim axes were calculated using a modified Neumann formula based on realistic discrete wire patterns. For mutual inductance values deemed to be significant, the higher order shim coil of the interacting pair was re-designed using the minimum mutual inductance technique.

Results and Discussion: It was determined that the majority of shim axes do not posses any significant interactions between them. In fact the only significant interactions seen were between the Z^0 and Z^2 shims, and the Z and Z^3 shims. The mutual inductance values for these two sets of interacting shims, along with the re-designed decoupled Z^2 and Z^3 shims are given in table 1. All other mutual inductance values were a factor of 10^5 less than the coupling zonal shims, and thus were deemed to be insignificant. It was also found that the new decoupled shims did not interact in any significant way with the other original shim axes. Figures 1 and 2 show the wire patterns for the original minimum power Z^0-Z^2 and Z-Z^3 interacting pairs and the corresponding re-designed minimum mutual inductance Z^2 and Z^3 shims. It can be seen that the re-designed Z^2 and Z^3 shims couple to the Z^0 and Z coils by factors of 50 and 25 less than the original designs. The effect of this reduced coupling is significant. For example, given the original Z^0-Z^2 set, if the current through the Z^0 shim is changed by driving with a 400V source, the induced voltage on the Z^2 coil is 146.2V. However, for the decoupled Z^2 shim the induced voltage would only be 2.92V, well within the ability of most power supplies to compensate.

It has been shown that mutual inductive interactions between realistic shim axes are dominated by only a few coil combinations. Furthermore, it is possible to redesign these axes to reduce this interaction to manageable levels.

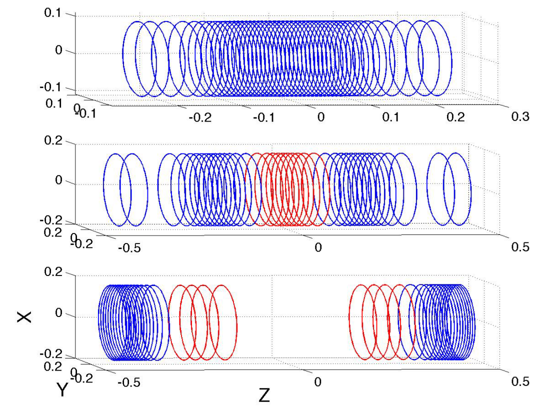

Figure 1. Minimum power Z^0 shim coil (top). Minimum power Z^2 shim coil (middle). Minimum mutual inductance Z^2 shim coil (bottom).

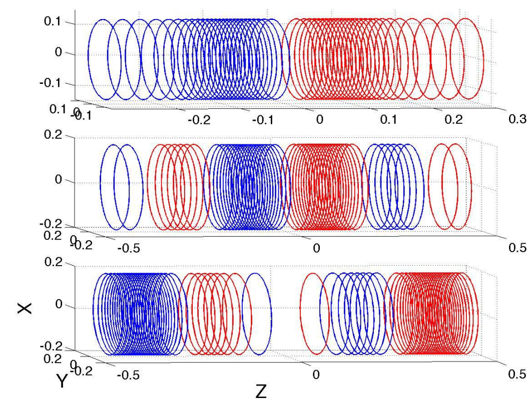

Figure 2. Minimum power Z shim coil (top). Minimum power Z^3 shim coil (middle). Minimum mutual inductance Z^3 shim coil (bottom).

Mutual Inductance (μH)		
Interacting Pair	Original Z^2 and Z^3	Decoupled Z^2 and Z^3
Z^0-Z^2	73.14	1.461
Z-Z^3	110.2	4.712

Table 1. Mutual inductance values for significantly interacting shim pairs, and the mutual inductance values for the decoupled pairs.

References:
[1] de Graaf R A et al. 2003 Magn. Reson. Med. **49** 409-416
[2] Carlson J W et al. 1992 Magn. Reson. Med. **26** 191-206