Experimental validation of modal gradient coil design methodologies

Elliot Charles Smith[1], Hector Sanchez Lopez[1], Michael Poole[2], and Stuart Crozier[1]

[1]ITEE, The University of Queensland, Brisbane, Queensland, Australia, [2]Institute of Neuroscience and Medicine, Jülich, Jülich, Germany

TARGET AUDIENCE

The work covers the validation of a modal coil designed to study eddy current spatial-temporal behaviour. This work is of benefit to those involved in gradient coil design and those investigating shielding methods for MRI.

PURPOSE

Eddy currents are an unavoidable phenomenon in the presence of rapidly switching magnetic fields. Such fields, often found in MRI, can cause an increase in heat, noise, and image degradation which compromises the primary function of MRI scanners. Methods to reduce the effects of eddy currents on the system and image include pre-emphasis and shielding. Pre-emphasis involves modifying the drive current of gradient coils such that the combination of primary field and the secondary field, produced by the eddy currents, matches the profile of the desired field[1]. In order for pre-emphasis to be effective the spatial distribution of the primary and secondary field must be similar within the region of interest (ROI). By decomposing the secondary field into independent spatial basis functions the interaction between primary and secondary field can be analysed and tailor gradient coils to account for the most prevalent basis functions, generated by surrounding conductive structures. This modal analysis has been studied previously and shows strong promise for gradient coil design and analysis but, to the best of the author's knowledge, these results have yet to be fully validated[2-4]. Field measurements of a coil designed to excite two independent eddy current modes will confirm the previous theoretical work and validate the proposed design and analysis methodologies.

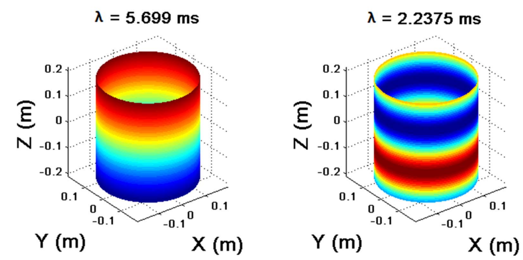

Figure 1: Dominant modes and their decay constants

METHODS

In order to test the validity of the modal design a coil was made which excited two predominant spatial modes. The dominant mode was constant along the axis of the cylinder whilst the secondary mode varied symmetrically around the canter of the coil's axis (Figure 1). The strength and time constants of the eddy currents, induced when the coil was excited with a trapezoidal pulse (2ms rise and fall time, 20ms peak), were simulated and the decay curve fitted to a double exponential decay (1). The time constants of the fit were calculated at 49 points along the central axis of the 400mm long coil. The physical coil was then excited with the same trapezoid and the resulting magnetic field was measured with and without the 2.5mm thick aluminium shield (Figure 3). The measurement was taken using a Magnetic tunnelling Junction (MTJ) sensor which was precisely moved using a 3 axis CNC machine. Combining these results the field from the eddy currents was determined and fit to the same double exponential formula. The goodness of fit between the data and the simulation was recorded to determine how well the data conformed to the prediction.

$$\boldsymbol{a} \cdot \boldsymbol{e}^{-\boldsymbol{kt}} + \boldsymbol{b} \cdot \boldsymbol{e}^{-\boldsymbol{lt}} \quad (1)$$

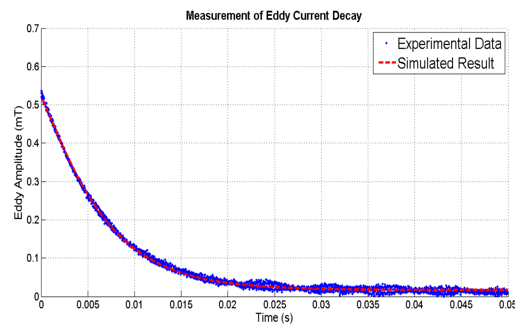

Figure 2: Simulated Decay and Experimental Measurements

RESULTS

Measurements were taken at 49 points along the central axis of the coil. This was done with and without the shield in order to determine the eddy current contribution. Figure 2 shows the eddy current decay at one point along the axis. The eddy current decay curves were then fit to the simulated double decay function and the root mean square error (RMSE) was calculated. The two exponential decay functions had a calculated time constants of 5.699ms and 2.2375ms. The RMSE at all points along the axis was below 0.012 with a mean value of 0.0066. This shows a strong correlation between the simulated and experimental results.

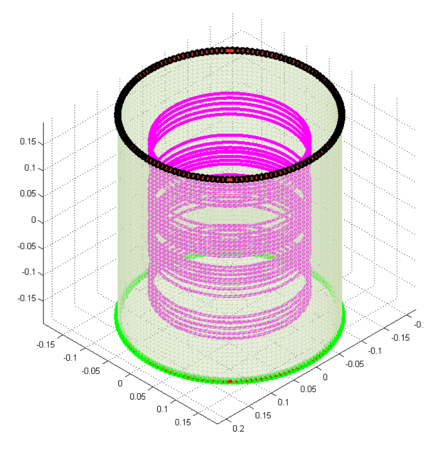

Figure 3: Coil Shield Setup

DISCUSSION & CONCLUSION

The experimental results reflect the simulation and allow the methods to be used in future design and analysis of gradient coils and eddy currents. Experimental data matched the simulation very closely (Figure 2) at all points along the z axis confirming the simulated results. Determining the primary modes of surrounding structures can assist in the design of more efficient coils and shielding systems in MRI. Investigation into the modification of shielding surfaces to excite certain modes shows promise in reducing the negative effects of eddy currents.

REFERENCES

1. Glover, G., & Pelc, N (1987) US Patent 4,698,591. **2.** Lopez, H. S., Poole, M., & Crozier, S (2010). Eddy current simulation in thick cylinders of finite length induced by coils of arbitrary geometry. Journal of Magnetic Resonance, 207(2), 251-261. **3.** Lopez, H. S., Poole, M., Trakic, A., & Crozier, S (n.d.). Can we re-design the gradient coil to make the eddy current field match the primary gradient field? ISMRM 2010 **4.** Lopez, H. S., Freschi, F., Trakic, A., Smith, E., et al (2013). Multilayer integral method for simulation of eddy currents in thin volumes of arbitrary geometry produced by MRI gradient coils. Magnetic Resonance in Medicine.