DESIGN STUDY FOR MAKING SPLIT GRADIENT COILS MORE ROBUST

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Target Audience

This work will be of interest to those researchers and engineers who are involved in the design and manufacture of gradient coils and hybrid MR systems, such as MR-PET and MR-guided radiotherapy.

Purpose

In 2008, Green *et al.* reported the design and construction of a split gradient coil for MR-PET [1] and with successful integration into the system [5] Poole *et al.* reported the results of the coil design and showed simultaneously acquired MR and PET data [2]. The coil recently failed during an EPI sequence due to a suspected mechanical failure of one of the 432 soldered joints. Due to the complicated design of the coil, there was no room to bind the solder joints for mechanical strength and this known weakness of the coil, combined with the rapid switching of the EPI sequence, is the suspected cause of coil failure. Impedance measurement in the 1T field shows a magneto-mechanical resonance at approximately 1.2kHz. New gradient coils must be built for the system and, of course, we must ask "what can be done to the design and manufacture of the coils to increase their robustness?". In the previous design we considered simplifications to the design, but the inevitable performance loss was deemed too great. This study looks at the effect on coil performance of various design changes to provide information with which to decide the design criteria for the next set of coils to build.

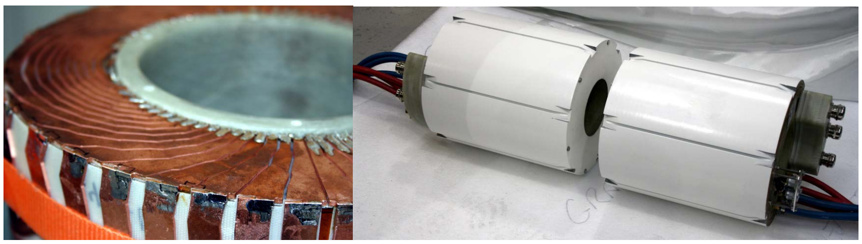

Figure 1. The original split gradient set for hybrid MR-PET. Left is a close-up of the annular and shield wires of the X-gradient coil showing the soldered connections. Right is the finished coil (which has had the company logo removed) illustrating the central gap.

Methods

We designed new X-gradient coils (Z coils are relatively easy to design for this system) with the same dimensions as previously reported [2]. Using an inverse boundary element method with triangular elements [3], a suite of coils was designed to assess the effect of design changes on the coil performance. Design requirements were based on those previously reported [2] where the coil strength is dictated by the number of wires used to approximate the current density while ensuring a minimum wire spacing of 4.2mm. In some coils, close wires were spread by minimising the maximum current density [4].

How can we design a more robust coil?

Eliminate the annulur wires.
Make the annular wires radial only.
Ensure torque is balanced on each half.
Balance torque with the real magnet field.
Different construction techniques.

How can we mitigate the performance loss?

Reduce the gradient field linearity.
Change/reduce the active shielding.
Use wire-spreading design methods.

Results

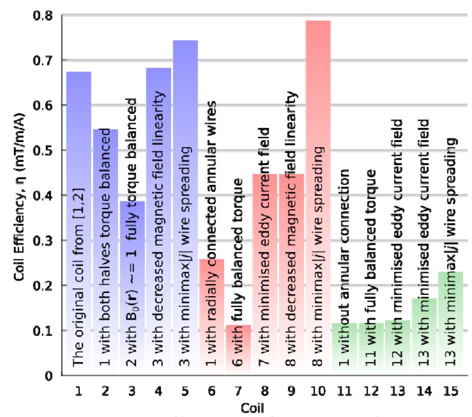

Figure 3. The efficiency of several of the coils designed in this study. Blue, red and green bars refer to fully connected, radially connected and unconnected annuli, respectively. A brief description of each coil is also overlaid.

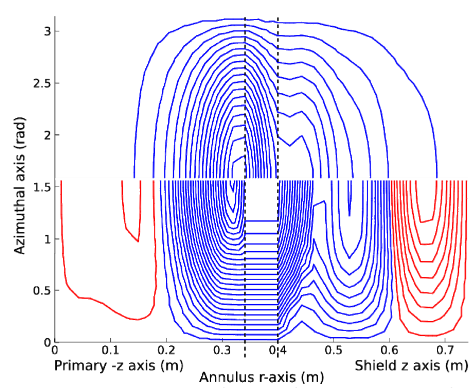

Figure 2. An example of 1/8th of the wire pattern for the original coil (top) and a fully balanced, radially connected X-gradient coil (bottom).

Discussion and Conclusion

A reduction in useful design surface yields a reduction in coil performance – in the present study, the removal of linking annulus. An increase in the number and severity of constraints placed on the design further reduces the performance – in the present study, by the imposition of radially connected annulus wires and torque balancing both halves of the coil separately. Other design criterion must be relaxed to recoup this performance loss, such as relaxing the field linearity.

Coils with radially connected annulus wires have greatly reduced efficiency due to the increased constraints and consequentially increased maximum current density. Much of this can be recovered by spreading these few close wires out and altering the shielding to minimise the eddy current field reflected from the magnet rather than simply minimising the escaping field, see coil 8, Fig 2. Resistance of coil 8 is approximately double that of coil 1. Coils with no connection between primary and shield have very low efficiency, which cannot be recovered by any method.

This initial design study gives an idea of the trade-offs one can expect when simplifying the build complexity in this split gradient coil. More simulations and experiments are required, as well consideration of the amplifier and cooling systems and construction techniques, before a final design can be built.

References

[1] D Green et al. *Proc ISMRM*, (2008), **16**, 352. [2] M Poole et al. *Magn Reson Med*, (2009), **62**, 1106-1111.
[3] S Pissanetzky. *Meas Sci Tech*, (1992), **3**, 667-673. [4] M Poole et al. *J Phys D*, (2010), **43**, 095001 (13pp).
[5] A Lucas et al. *MR System Technology in Cancer Research and Treatment*, (2006), **5**, 826-830.

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