Conventional and Linked Gradient Coil Designs: a Comparative Study

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Introduction

The "gradient system"(GS), i.e., the gradient coils and amplifiers, is the second most expensive unit, after the magnet, in a whole body MRI scanner. Indeed, GS performance determines to a large extent the imaging capabilities and sensitivity to artefacts of an MRI scanner. Reduced eddy currents (shielded coils), high gradient strengths and small rise times (low inductance coils and/or high power amplifiers) and high linearity (gradient spatial uniformity and high-fidelity amplifiers) are essential ingredients of the recipe for good image quality.

Coil shielding can be accomplished using two different types of coil design: conventional and 3D or "linked" designs [1]. Although linked coils generally have better performance characteristics than conventional designs, they are often much more difficult to manufacture. Use of linked coils thus may reduce amplifier costs, but increase the coil construction costs. Here, we present a comparative study of these two types of shielded coil design. Coil performances are compared by evaluating the inductive stored energy and the resistive power dissipation as a function of field error, in three common coil configurations: (i) cylindrical [1], (ii) biplanar [2] and (iii) split [3]. In addition, a weighting factor related to cost has been introduced in the comparison.

Method

In conventional shielded coil designs, the primary and shield coils are wound on two separate surfaces. In such coils, current return paths can take up half of each surface, and are often concentrated at the extremities of the coil, thus increasing the stored energy. In linked coil designs, the primary and shield surfaces are linked through a third surface over which the current is allowed to flow (see ***Figure 1***). This eliminates the high current densities at the end of the coil and allows the gradient-generating wire paths to spread over a larger portion of the primary coil surface. In addition, undesired field contributions generated by the current return paths on the primary surface are reduced.

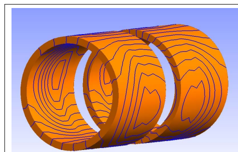

Figure 1: Example of "Linked" gradient coil for split

Multiple coil aspect ratios were evaluated in this investigation (more than 30) and the geometries considered span most of the currently available whole body scanners. For each configuration, transverse, x-gradient coils were designed using the Inverse Boundary Element Method (IBEM) [4], with both a conventional and a linked (3D) form. The internal and shielding field errors had the same weight in the IBEM optimization. In order to assess the coil performance, the inductive energy and the resistive power for a gradient field intensity of 40mT/m were calculated for each configuration whilst varying the design to produce different levels of field error. In order to define the coil cost, raw material, manufacturing and testing costs were considered. Power and hardware costs entered in the figure used for amplifier costs. Using these estimates, which were based on discussions with a range of gradient coil manufacturers, it is possible to complete a bottom line comparison between the two coil types from an engineering point of view. Of course, precise costs may vary with suppliers, volumes etc.

Results

Figure 2 shows the results for two representative cases for each configuration, varying the field error from 5% to 30%.

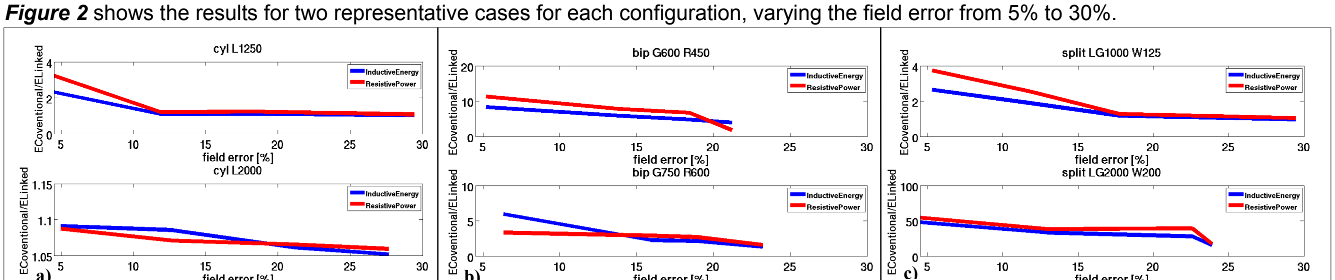

Figure 2: Relative Inductive Energy and Relative Power Dissipation of two solutions for each configuration.
Primary-Secondary Distance: 50mm, Secondary-Shielding Region Distance: 60 mm.
a) *Cylindrical configuration:* length 1250 mm – radius 350 mm and length 2000 mm- radius 350 mm, DVS 450 mm ***b)*** *Biplanar configuration:* gap 600 mm - radius 450 mm, gap750 mm radius 600 mm, DSV 400 mm ***c)*** *Split configuration:* length 1000 mm – central gap 125 mm – radius 350 mm and length 2000 mm – central gap 200 mm – radius 350 mm, DSV 450 mm

The "linked" configurations are always energetically advantageous for lower field errors, especially for configurations in which the geometry is more challenging, such as a small length to diameter ratio for cylindrical coils or a big gap to radius ratio in the planar geometry. On the other hand, as the field error increases or the space for the wire paths increases, the difference between conventional and "linked" designs becomes less significant; furthermore, in some straightforward configurations (a), the IBEM optimization technique produces designs in which the primary and the secondary coil are not linked, and there are no significant differences in the energies of the two configurations. ***Figure 3*** shows plots of the relative total cost (manufacturing and amplifier costs) and the ratio of the stored energy for the two coil types as a function of the field error. From these results one may infer that, for field errors greater than 10%, the conventional configurations may be preferable to the "linked" coils in terms of value for money.

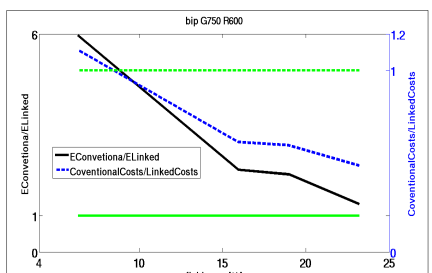

Figure 3: Performances in terms of inductive energy for a biplanar coil configuration: gap 750 mm -radius 600 mm The lines in green represent unity ratios of the respective quantity

Conclusion

In the design of a gradient coil system, the choice between conventional and "linked", 3D configurations is not trivial. In this work we provide some guidelines that cover many coil geometries which may be considered in the design phase for a gradient system. When high performance is needed, depending on the geometry of the system, the "linked" gradients can be preferable, as we show for planar and split configurations. When lower performance is sufficient or very straightforward geometries are considered (long bore magnet), the higher manufacturing costs of "linked" gradient coils could drive the choice towards the conventional design.

References

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