Tapered Head Gradient Coil Design Using the Wave Equation Method

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Introduction: Gradient coil design for specific purposes has been the focus of much recent research [1-4]. The aim is to produce gradient coils that have large imaging regions, high field strengths and low associated torque [5]. Although many different approaches exist for the design of gradient coils, the process can be tedious and time consuming, which is generally independent of the design method employed. Numerical simulation strategies [1, 3, 6-8] pose a number of advantages over classical analytical approaches [9, 10], mainly allowing for more flexibility in the design. In this work the wave equation method is used for x-gradient head coil design [1], whereby a number of different optimization approaches have been investigated for the winding patterns of the conductive wires.

Theory & Methods: The theory of the wave equation technique is outlined in Vegh [1]. In this work on x-gradient head coil design, differential evolution has been incorporated to compare the results obtained using the method of simulated annealing to that obtained using differential evolution. To illustrate the flexibility of the approaches, the simulated annealing method is used to obtain optimum windings, whereby wires are wound on a single layer without end correction paths. The differential evolution algorithm is used with end correction paths. The total number of primary wire paths is the same for both design strategies.

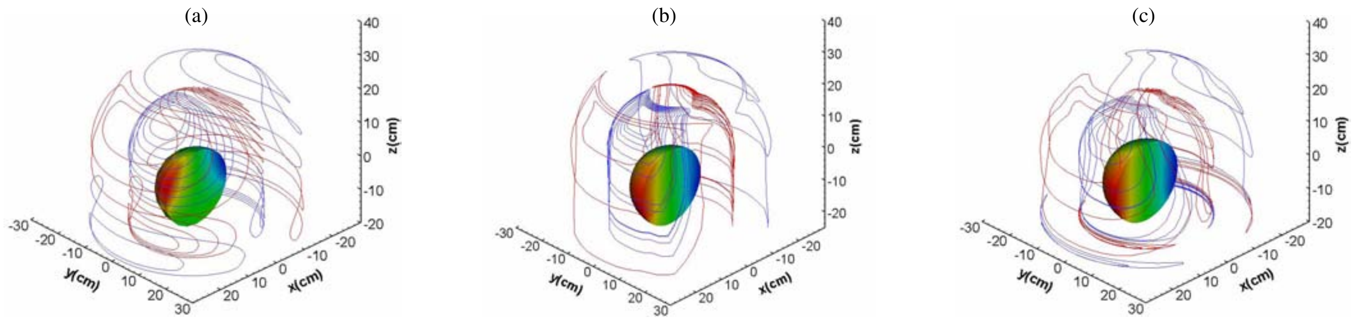

Figure 1. Illustration of the actively shielded x-gradient coil windings as obtained for (a) the seed data, (b) simulated annealing and (c) differential evolution. Red wires represent a current direction opposite to that of the blue wires. The magnetic field produced by the wires is illustrated by the hemisphere in the middle.

Description	Figure	Inductance $[L](\mu H)$	Torque $(NmA^{-1}T^{-1})$	Efficiency $[\alpha](Tm^{-1}A^{-1}\times10^{-3})$	$\alpha^2/L(\times10^{-3})$
Seed data	(a)	24	0.038	0.102	0.434
Simulated Annealing	(b)	27	0.302	0.110	0.448
Differential Evolution	(c)	25	0.302	0.113	0.511

Table 1. Tabulated results of different parameters obtained using the strategies described in this work.

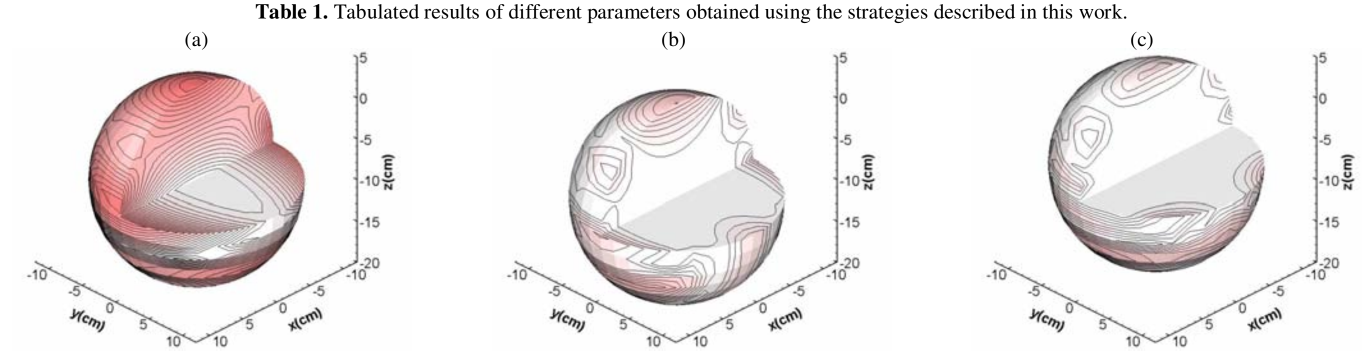

Figure 2. The x-gradient field error plots with 5% contour lines for the respective windings of Figure 1.

Results & Discussion: Through the simulations the imaging volume was constrained to be as close to the end of the coil windings as possible, with the limitation on torque that it had to be less than 0.31. It is well known that coil windings with lower torque can be obtained by shifting the imaging volume further inside the coil, but in this work the aim was to try and place the imaging volume in a more accessible region, while maximising the overall size of this imaging volume. Using the simulated annealing and differential evolution optimization strategies, imaging volumes of approximately 15cm in diameter were obtained. Figure 1 illustrates the winding patterns for the starting winding, the wire paths obtained using simulated annealing and differential evolution. Table 1 highlights some of the more important parameters as calculated by the algorithm. It can be seen from Table 1 and Figure 2 that as the winding patterns evolve the imaging volumes greatly increase, at the cost of increased torque. In general the group has found that a time saving of a factor of four can be accomplished by using differential evolution as opposed to simulated annealing for the generation wire winding patterns for x-gradient head coils. The wave equation technique for x-gradient head coil design has proven to generate high quality results, for which the imaging volume is large and is close to the open end of the winding pattern for more accessibility.

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