The Design of Planar Transverse Gradient Coils Using a Deformation Algorithm

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Introduction

There are two basic approaches to gradient coil design for MRI. The first is the Fourier (continuous)-space based approach; e.g. the target field method [1]. The second is the real (wire)-space based approach; e.g. the simulated annealing method [2]. Both of these approaches have pros and cons. The first approach uses analytical expressions or series expansions to describe the current densities over a specified surface. It is very efficient for regular-shaped domains but is difficult to implement for domains with arbitrary geometry. The second approach is relatively slower but has the advantage that it can handle more arbitrary geometries and additionally it is easy to incorporate real constraints. In this work we propose a modified, efficient real-space method [2] and apply it to the design of bi-planar gradient coils for open MRI systems. The proposed method permits the placement of current arcs on any desired coil surface. For the case of a planar gradient coil, the design of the z-coils is relatively straightforward; the z- and r- positions of the current 'loop' can be adjusted in the optimization process. For the transverse coils, the solution is not as straightforward because it is not feasible to move each segment of the current arcs separately. The solution that we propose in this work is to represent each arc by a closed contour described by parametric equations such that the ensemble of closed contours can be deformed/reshaped in a simple manner controllable by just a few parameters. These parameters are then used to define system rearrangements in the design procedure. An iterative optimization procedure is used to adjust the control parameters to minimize target/cost functions including gradient homogeneity, inductance and other parameters.

Method

In the defined coil plane, a series of limaçons (polar equation $r = a + b\cos\theta$) are used to represent the initial current arcs. We use the following parameterization of a limaçon to describe each contour:

$$x(t) = (a + b\cos t)\cos t + k, \quad y(t) = (c + d\cos t)\sin t.$$

The coefficients *a, b, c, d,* and *k* control the translation and deformation (scaling/shape). We treat these as unknown variables that alter/control the current-arc positions (i.e., x- and y- coordinates). Their values are determined using a quadratic optimization routine. During the optimization, the gradient field over the region of interest is calculated using the Biot-Savart Law. Given that the coil contour is a closed curve, the field evaluation can be efficiently implemented using a 1D Gaussian integration method.

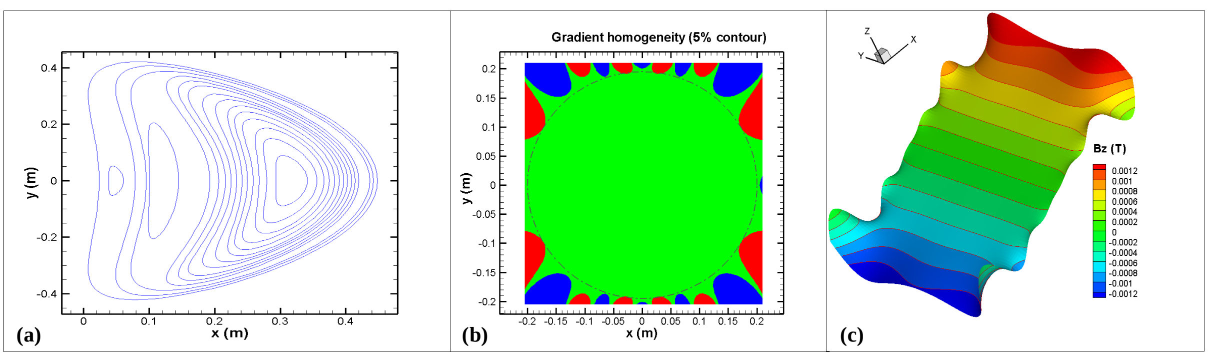

Fig.1 The coil pattern for the symmetrical gradient x-coil (a) and corresponding gradient homogeneity (b) and field profile (c)

Result

Fig.1 shows an example transverse coil pattern and corresponding gradient field homogeneity inside the DSV. It can be seen that the new algorithm can produce a well-connected coil structure and a good gradient linearity.

Conclusion

In this work we have demonstrated that a real-space algorithm can be used for complicated gradient coil design through an appropriate parameterization of the current arcs. Both a previous study for a cylindrical system [2] and the current work for a planar system demonstrate the capability of the deformation-space methodology. In the future we will refine this optimization technique; extend it to a variety of geometry domains (including 3D); and consider additional engineering constraints such as energy and inductance.

References

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