New Gradient Coil Design Method Using Loop-Current Elements

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Purpose: The Purpose of this paper is to propose a new gradient coil design method using loop-current elements and to apply the scheme to the design of head-only actively-shielded gradient coils. The design scheme can be used for either the minimum-inductance or the minimum-power design or even for a combined, weighted minimization of the two. The design scheme seems to be useful for the minimum-power as well as minimum-inductance design of arbitrarily-selected coil shapes.

Materials and Method: An asymmetric head-only gradient coil has been designed using the proposed method. The loop current elements are defined as square-shape clockwise loop currents. A total of N_φ(φ-direction)$\times N_z$(z-direction) current elements are defined and a combined cost of the stored energy and the power consumption is minimized under the constraints of target field intensities. The z-directional magnetic induction at (x_0,y_0,z_0), $B_z(x_0,y_0,z_0)$, can be written as :

$$B_z(x_0,y_0,z_0) = \int_z\int_\phi i_p(z,\phi)[B_z(x_0,y_0,z_0 : r_p,\phi,z)$$

$$+ \int_{z'}\int_{\phi'} i_s(z'-z,\phi'-\phi)B_z(x_0,y_0,z_0 : r_s,\phi',z')d\phi' dz']d\phi dz$$

where r_p, r_s are the radii of the primary and shield layers, respectively. $B_z(x_0,y_0,z_0{:}r,\varphi,z)$ is the z-directional magnetic induction at (x_0,y_0,z_0) from the current elements at (r,φ,z) in the cylindrical coordinates on the surface of an r(cm) diameter cylinder. The $i_s(z,\varphi)$ is the shield pattern to shield the unit current element of primary located at z=0. The cost e^2 for the combination of minimum-power and minimum-inductance is calculated as a weighted sum of the power and the stored energy using i_p. The constrained minimization can be done easily by using matrix equations and Lagrange multipliers.

Results: Both transverse and axial gradient coils have been designed and constructed. A 3.0 G/cm/200A of gradient intensity can be obtained with appropriate gaps between wires. The shielding effect by discrete shield layer is almost 98.5%.

Conclusion: A new gradient coil design method using loop-current elements has been proposed and applied to the design of head-only actively-shielded gradient coils. Experimental results show the effectiveness and utility of the design method and the constructed head-only gradient coil.

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