MRI Transverse Gradient Coil for Reduced Peripheral Nerve Stimulation

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Introduction.

Peripheral nerve stimulation (PNS) sets limits on time changing magnetic fields. These limits are related to the time derivative of the magnetic field produced by gradients. The associated electric field induced within the patient is tissue and anatomy dependent and may result in PNS for the patient. We introduce a method that allows reducing the gradient magnetic field (and thus the induced electric field) in the region that can be sensitive to PNS. It assumes asymmetric adjustment of the currents in the coils of a shielded gradient and allows shifting the region where |**B**| and |**E**| are maximum.

Method.

References [1,2] describe a combination of two transverse coil arrangements that are capable of reducing the total field on one side of a region of interest and increasing the total field on the other side. One coil acts as a gradient coil, while an additional "concomitant" coil produces a uniform vertical field over a selected region. A disadvantage of [1,2] is that it requires extra coils for each axis of a shielded gradient. In this abstract we propose a transverse gradient coil that is driven asymmetrically as shown in Fig. 1. This Figure illustrates the schematics of the unfolded primary (p) and shield (s) coils in the z-ϕ plane. We suggest a transverse shielded gradient coil that is capable of gradient strength G=40mT/m and has the coils connected and driven by two gradient amplifiers as shown in Fig. 1, where current on the left amplifier is scaled by a factor $\alpha<1$. This method achieves the goals of [1,2] without introducing "concomitant" coils. As an example, we assume that the region sensitive to PNS is at z<0. It should be mentioned that asymmetric current driving introduces some problems. If initially the gradient coil was designed with $\alpha=1$ such that the thrust forces and net torque due to the magnet are balanced, then when $\alpha<1$ the thrust forces and net torque will become unbalanced. (It should be pointed out that the concomitant coils such as [1,2] also have forces and torques). When $\alpha<1$ the residual eddy current and gradient distortions will become asymmetric as well.

We propose to account for the force, torque balancing, and symmetric eddy current as follows. We use the modification of the Turner [3] approach when the constraints such as the desired field behavior in the FoV, zero net thrust force and torque are imposed. To avoid spatial residual eddy current asymmetry we introduce additional constraints for uniform distribution of the residual eddy current effect within the FoV similar to [4,5]. Also we allow the coil to be asymmetric in geometrical length, if necessary. This will depend on the magnet that the gradient coil will be used with. The z-component of the current density on the primary/shield coil in terms of cylindrical coordinates is assumed to be of the following form

$$J_z(\mathbf{r}) = f(z)\cos(\varphi)\delta(\rho - R), \qquad f(z) = \begin{cases} f_1(z), z > 0 \\ \alpha f_1(z), z < 0 \end{cases} \qquad (1)$$

Here $f_1(z)$ is an anti-symmetric function of z. This expression does not contradict the continuity equation for the total current density. As an example we present the results when $\alpha=0.8$.

Results and Discussion.

Figure 2 shows a comparison of the magnetic field magnitude as a function of z at $\rho=0.2$m produced by two gradient coils: $\alpha=1$ and $\alpha=0.8$. It shows that for $\alpha=0.8$ the maximum values of **B** field in the region z<0 is reduced by 24.6% compared to that when $\alpha=1$, while the gradient strength is reduced by only 15%. The net thrust force and the net torque exerted on the coil in both cases are balanced. In both cases the residual eddy current effects are uniformly distributed over the volume of the 40cm DSV and may be corrected with pre-emphasis. We have performed the analysis of the electric field induced within a long conductive ($\sigma=0.2$ S/m) cylindrical phantom of radius 20cm placed inside the gradient, using the method similar to [6]. The electric field magnitude reduction follows the same pattern as the magnetic field: for $\alpha=0.8$ the electric field in the region z<0 is reduced by 23% compared to that in the region z>0. Fig. 3 illustrates the unfolded current paths in the z-ϕ plane in two quadrants on the primary coil for $\phi>0$. There are 20 turns for z>0 and 16 turns for z<0 carrying the same current. The shield coil is not shown.

Conclusion.

Asymmetric driving of various coils of the transverse gradient repositions the maximum values of the magnetic and electric fields. It allows reduction of the magnetic field and may reduce the onset of PNS in a selected region of the coil. This is verified by computing the electric fields produced by the gradients in a phantom. Our approach uses only a single shielded gradient coil and does not require additional coils. The parameter α fixes the coil design and therefore the magnetic and electric fields behavior. A similar approach can be used for an axial gradient.

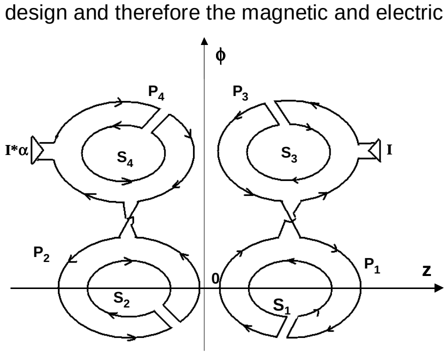

Fig. 1

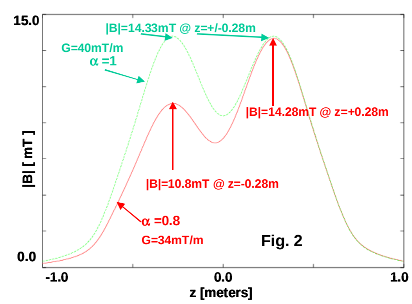

Fig. 2

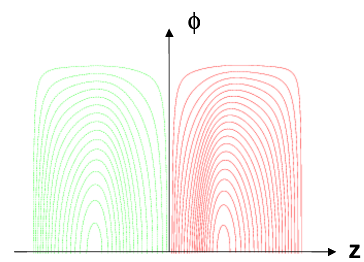

Fig. 3

References.

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