Adaptive Method for Gradient Coil Design

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Method

One of the obstacles in designing gradient coil is the general discretization procedure that approximates the continuous current densities by a number of current carrying conductors. The shape of the conductors' layout determines the properties of the gradient coil such as the gradient strength, field quality characteristics inside the FoV, level of shielding, coil resistance, slew rate, etc. For a self-shielded gradient coil the level of the eddy currents is very sensitive to the discretization procedure and may result in distortions of the images. When designing the gradient coil it is important to be able to minimize the net thrust Lorentz force exerted on the coil due to the presence of the main magnet field which is sensitive to the position of the current carrying conductors. The common practice of a gradient coil design is to derive the continuous current densities that provide the desired characteristics of the gradient coil. It is sometimes difficult to find a continuous solution that satisfies the trade-offs. Depending on the magnet configuration the nullification of the thrust force can lead to an energy penalty or even to reversed current patterns on either of the primary and shield coils, which in fact lead to an energy/inductance penalty. Because of the proximity of the cold shield to the magnet's coils, the forces on the cold shield due to the eddy currents could be big and should be reduced to avoid quenching. In this abstract we propose an adaptive method of design/discretization of the continuous current solution that allows satisfying the trade-offs for the gradient coil characteristics. We illustrate this adaptive method on an example of an X-gradient design. One can find coarse continuous solutions for the z-components $f_z(z)$ of the current densities that yield good approximations of the desired coil characteristics. In discretizing these solutions, we propose to use the following technique: the current paths on the primary/shield coil are defined by the following equation:

$$\phi = \arccos(S_n / f_z(z)), S_n = ((n-\sigma)/N)(f_z(z_{eye}) - \Delta) \quad (1)$$

In this equation we have introduced two parameters σ, Δ that could be varied to change the shape of the current patterns and thus the Z-intercepts [1]. These parameters could be global for the whole coil or could be local for each of the individual turns, and could be different for the primary and shield coil. The number of turns as well as the value of the current in the turns is another set of parameters. For each set of all parameters the current in the coil turns is maintained at the same magnitude on both the primary and the shield coil. This avoids discretization errors found in the standard approach [2] where the parameters are $\sigma = 0.5, \Delta = 0$.

Results

We have applied the proposed adaptive method to design an X-gradient coil that can fit a pre-existing 1.5T magnet. The FoV was chosen to be 50cm(X/Y) X 40cm (Z). Fig. 1 shows the sensitivity of one of the Z-intercepts as a function of the discretization parameters in Eq. (1). Fig. 2a shows the current patterns on the primary coil with the standard set of parameters $\sigma_P = 0.5, \Delta_P = 0$ and Fig. 2b shows the current patterns with $\sigma_P = 0.5, \Delta_P = 500$. Similar behavior is found for the current patterns on the shield. Table 1 lists a subset of possible trade-offs when all available parameters are varied. In this table the net thrust forces (F_X) on the gradient coil and the Cold Shield (CS) at the gradient strength of G=30mT/m are in N. The RECE is the residual eddy current effect over the FoV. One can see that the current in Fig. 2b is more uniformly distributed with a bigger window compared to that in Fig.2a. This feature makes the heat dissipation more uniform. The absence of the turns near the coil's eye allows reduction of dB/dt and AC self-eddy currents. For the self-shielded coil shown in Fig.2b the current for G=30mT/m is I= 473A, inductance L=417μH, and the slew-rate is equal to 160T/m/s at V=1200V. For the shield coil the parameters were $\sigma_S = 0.3, \Delta_S = 700$.

Discussion

We have demonstrated the application of the adaptive method for gradient coil design. This method allows finding optimized trade-offs for the magnetic /electric properties of the gradient coil.

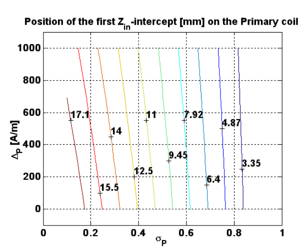

Fig.1 Sensitivity of Z-intercept positions as a function of the parameters σ, Δ

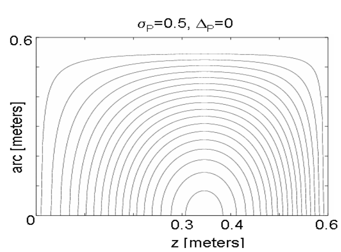

Fig.2a Current patterns on the primary coil when $\sigma_P = 0.5, \Delta_P = 0$

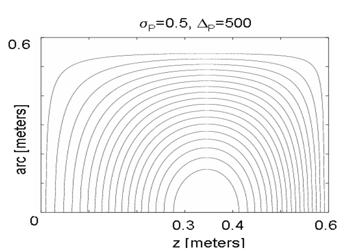

Fig.2b Current patterns on the primary coil when $\sigma_P = 0.5, \Delta_P = 500$

Table 1. Trade-offs of the design

Δ_P	σ_P	Δ_S	σ_S	Non-linearity [%]	Non-uniformity [%]	RECE [%]	F_X on Gr.	F_X on CS
0.0	0.7	0.0	0.6	2.93	-31.27	0.39	70.3	60.0
300.0	0.6	600.0	0.3	3.14	-29.45	0.20	46.7	10.3
600.0	0.4	0.0	0.6	-0.73	-29.32	0.23	89.1	40.4
600.0	0.5	300.0	0.5	1.07	-30.31	0.23	89.3	12.1

References

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