Shielding and energy advantages of capped elliptical coil structures

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Abstract

We have designed a capped actively shielded gradient coil on an elliptical coil form. Compared to conventional uncapped elliptical and cylindrical gradients, our design substantially reduces the fringe fields, the associated eddy currents in the inner bore and consequent acoustic noise power. In addition, there is a good reduction in magnetic energy. The fringe fields are reduced 70%, largely because of the end caps, and the magnetic energy is lessened because of the reduced cross sectional area. The magnetic energy is reduced, relative to cylindrical designs, by 35% for the z-gradient and 19% for the transverse gradients.

Introduction

Elliptic gradients are of interest because they approximate the shape of human body or head and have reduced magnetic energy compared to cylindrical gradients of similar dimensions[1]. Significant work has been done optimizing elliptical gradient coils and their advantages have been well demonstrated [2,3]. We have now designed elliptical gradients with substantially improved shielding and eddy current performance.

We have designed eddy current optimized elliptical gradients coil design with active endcaps. This includes both actively shielded axial (Z) and transverse (Y)-gradient coils. Utilizing an iterative target field algorithm, the results produce a reduction of fringe field on the cryostat inner bore by as much as 63% when compared to similar elliptical designs without end cap. No significant penalty is paid in terms of the gradient field quality and characteristics. The fringe field reduction translates into a decrease in the magnitude of eddy currents on the cryostat bore. Lower eddy currents improve image quality and also reduce the acoustic noise generated by the cryostat inner bore, which has been shown to be a significant source of acoustic noise [4].

Theory

The proposed gradient coil structure is depicted in Fig.1. The current densities for the primary (*P*), shielding (*S*), and annular endcaps (*C*) have the familiar form of a sum of the product of expansion coefficients and orthonormal vector basis functions. The basis vectors are defined to be nonzero only inside the assumed length of the primary, secondary, and cap structure. An iterative approach [5] is used to find the unknown coefficients by constructing a functional of quadratic terms and minimizing it. The minimizing functional *W* is given by

$$W = b_1 E + b_2 \sum_{i=1}^{N_{dsv}} \left[B_z(\boldsymbol{r}_i) - B_{z_i} \right]^2 + b_3 \sum_{j=1}^{N_{shield}} \left[\boldsymbol{B}(\boldsymbol{r}_j) \right]^2$$

where E is the energy of the system and terms b_1, b_2, and b_3 are the weighting parameters. The second term is the square of variance of the field from target field values B_{Zi} at N_{dsv} points inside the DSV. The variance of the field from its desired zero value at N_{shield} points on an elliptic surface at the inner cryostat bore is included in the third term. The minimum for the functional is obtained through an iteration procedure involving variations of expansion coefficients [5].

Results and Discussion

For both transverse and Z elliptical coils, the gradient field strength is set to be 25mT/m. The primary and secondary coil semimajor and semiminor axes are $2R_{P1} = 0.82$m, $2R_{P2} = 0.69$m, $2R_{S1} = 0.98$m, $2R_{S2} = 0.85$m with total lengths $2L_p$=1.0m and $2L_s$=1.22m. The annular cap extends down from the secondary cylindrical surface to $L_C = 0.0325$m in the semimajor axis direction. Inside the 0.40m DSV four constraint points were chosen to obtain a gradient field with an allowed variation range of 10% linearity and 20% uniformity. Table 1 shows the comparison of stored energy and maximum fringe field leakage for newly designed elliptic and cylindrical systems which are obtained using identical field constraints. The major ellipse axis length = the diameter of the cylindrical coil. As a typical result, for similar shielding behavior, the elliptical Z-gradient coil with a cap exhibits a 35% reduction in stored energy relative to a comparable cylindrical Z-coil with a cap. The maximum fringe field value for the new design is less than 110 µT, a 63% reduction at the cryostat inner bore with respect to a conventional capless design. Table 1 also compares the transverse capped elliptical Y gradient coil to its corresponding capped cylindrical equivalent. For similar shielding behavior, the transverse capped elliptical coil stores 19% less magnetic energy and has a 17% lower peak leakage field than the corresponding capped transverse cylindrical gradient.

Table 1. Comparison of elliptical and cylcindrical gradients

	Z-gradient			Y-gradient		
	Cylindrical	Elliptic	Compare	Cylindrical	Elliptic	Compare
Field Strength	25 mT/m	25 mT/m	------------	25 mT/m	25 mT/m	-------------
Nonlinearity	10%	9.9%	-1%	10.0%	8.8 %	-12%
Nonuniformity.	20.7%	17.0%	-18%	33.0%	19.4%	-41%
Energy(J)	35.69	23.35	-35%	67.85	55.10	-19 %
Fringe field (mT)	0.101	0.111	+10%	0.247	0.206	-17%

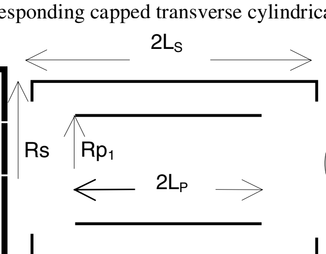

Figure 1a. Gradient longitudinal cross-section

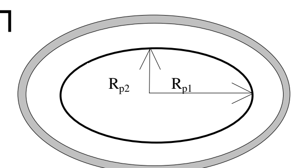

Figure 1b. Gradient transverse cross-section

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References

[1] Petropoulos, L.S. et al. *Meas. Sci.Technol.3:667-673;* 1992
[2] Liu,Q. et al. *J. Magn. Reson., 113(B): 222-227 ;*1996
[3] Yipping, P. et al. in *Mag. Res. Imag. Vol 3,2:255-262;*1997
[4] W. A. Edelstein et al., *Mag. Res. Imag.,* **20** (2002) 155-163
[5] Brown RW et al, MAGMA 2002; 13:186-192