Rapid Network Calculation for Active-Passive Gradient Shielding

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Abstract

We have modeled the effect of passive copper shielding applied to the outside of an actively shielded, axisymmetric z-gradient, with the aim of substantially reducing induced eddy currents in the cryostat inner bore that create acoustic noise. The cylindrical cryostat inner bore and the passive copper shield are sliced into thin ring sections. The thin cylindrical sections thus formed become elements in an electrical network that includes the actively shielded gradient coil. The network calculation is about 30 times as fast as the finite element calculation

Introduction

Eddy current calculations using finite element methods (e.g. [1]) are time consuming. A fast, accurate method would be useful for getting rapid answers and also to further improve system performance, for example, to simultaneously optimize gradient and shielding design. In the present work we have applied an electrical network method [2-4] that has advantages in speed and flexibility.

To apply the network method to this configuration, the cryostat inner bore and the copper passive shield are divided into a number of narrow circular sections. The self-inductance and resistance of each section are calculated, as are the mutual inductances of all thin sections with each other and with the gradient coil. The simultaneous coupled differential equations for the electrical circuit including cylinders and gradient coil can be written

$$j\omega[M]\bullet\{\mathrm{I}\}+[R]\bullet\{\mathrm{I}\}=-j\omega[M_0]\bullet\mathrm{I}_0 \quad (1)$$

where $[M]$ and $[R]$ are the inductance and resistance matrices for the cylinders, $[M_0]$ is the mutual inductance vector between the cylinder sections and the gradient coils, $\{\mathrm{I}\}$ is the eddy current vector in each cylinder section and I_0 is the applied gradient current.

Results

We have calculated the power deposited in the cryostat inner bore, by eddy currents, for 100 A peak gradient harmonic excitations at a series of frequencies. Two Cu passive shield configurations were considered: Cu shield applied to the outside circumference of the gradient cylinder [5]; and cylindrical Cu shield extended over the ends of the gradient and inward to the gradient clear bore [1].

The inner gradient winding has radius 33 cm and length 99 cm, the outer winding has radius 42 cm and length 125.8 cm and the gradient assembly is 160 cm long. The copper shield has an average radius of 44.2 cm, and length 160 cm. The cryostat inner bore has radius of 45.15 cm, length 170 cm, and thickness 3.18 mm. We extended the copper down to the radius of the inner gradient to get more power reduction.

Inductances were obtained using formulas from Grover [6] and Jackson [7]. Calculations were carried out using Matlab on a 3.4 GHz PC running Windows XP or Linux; computation times were similar for the two operating systems. Calculations were done with up to 500 slices each on the cryostat bore and the Cu shield, but no significant change was observed from the configuration with 100 slices each on bore and shield. Table 1 below displays those results and compares them to finite element outcomes.

Table 1. Cryostat bore power deposition reduction in dB, for single frequency gradient excitation, relative to scanner with no Cu shield. "1mm Cu" has a 1mm copper passive shield, "1mm Cu cap" has a 1mm copper passive shield with a cap extended down to clear bore of the gradient assembly. These calculations were done with the cryostat bore and copper shield each divided into 100 parts.

Frequency (Hz)	1mm Cu		2mm Cu		4mm Cu		1mm Cu wrap		2mm Cu wrap		4mm Cu wrap	
	FE	N	FE	N	FE	N	FE	N	FE	N	FE	N
10	1.1	1.1	2.9	3.1	5.8	6.3	1.3	1.5	3.6	4.5	7.4	8.3
30	4.6	5.0	8	8.6	11.8	12.5	5.9	6.5	10.4	11.9	14.9	16.6
100	10.7	11.4	14.6	15.2	18.3	18.5	13.7	15.1	18.0	19.9	22.4	24.5
300	15.2	15.2	18.4	17.7	20.5	19.1	18.9	20.4	23.7	25.2	29.0	29.9
1000	14.8	13	15.9	13.5	16.5	13.8	22.0	22.4	27.4	26.7	32.6	29.0
3000	12.6	10.2	12.9	10.2	13.0	10.1	24.5	23.2	29.4	25.5	30.8	26.0
10000	12.4	10.0	12.5	9.9	13.1	9.1	28.2	24.2	30.5	24.9	29.2	25.1

Discussion and Conclusions

The network method is much faster than the FE approach. For each frequency and scanner configuration, the FE calculation takes 10-15 minutes. The network result for Cu and warm bore cylinders divided into 100 sections requires about 20 s at each frequency. The results are in good agreement, particularly at low frequencies, and both procedures clearly indicate trends. At high frequencies (3 kHz and 10 kHz) and thick shields, the network results tend to indicate less shielding than do the FE results. Since shielding requires a high degree of cancellation of fields from the gradient coils plus all portions of the shield, the precision of inductance values is critical. We are investigating methods to improve inductance calculations.

References

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