Gradient Coil Induced Eddy Current Computation Using the Boundary Elements Method

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Synopsis

The Boundary Element Method “Faraday” software, developed by Integrated Engineering Software Inc., Winnipeg, Canada, was employed for analysis of 3D eddy currents induced by both transverse and axial MRI gradient coils. We applied this method to a split whole-body gradient coil designed for a MRI guided Radiation Therapy device. The device requires three multi-leaf collimators to be positioned in the gap of the split gradient coils. The presence of the collimators results in eddy current asymmetry that should be characterized and accounted for in image reconstruction to provide imaging adequate for treatment planning.

Method

Commercially available software “Faraday” based on the Boundary Element Method (BEM) [1] was employed for the analysis of 3D eddy currents induced by the whole-body split gradient coil designed by “Magnex Scientific” for use in MRI guided Radiation Therapy [2]. The software “Faraday” is based on the boundary integral equation formulation with magnetic currents and electric charges as unknowns. Linear shape basis functions, defined over a quadrilateral element, are used for the Galerkin’s type of integral equations. The whole system under investigation consists of the split gradient coil and the multi-leaf collimator (MLC) made from Tungsten for shaping the radiation beams delivered to the patient. The gradient coil was designed to produce 20mT/m gradient strength with 400A output of the power amplifier in the absence of the MLCs. The three sets of MLCs (positioned 120^{o} apart from each other as shown in Figure 1) can simultaneously be rotated with the Gantry about the axial direction to deliver optimized radiotherapy treatment plans. Based on 2D AUTOCAD drawings of the split transverse gradient coil, gradient current patterns were modeled in the 3D “SolidWorks” CAD software and loaded into the “Faraday” software. In addition, the “SolidWorks” model of the three MLCs was also added to the system (leaving out the detail of individual leaves). The 3D model of the MLCs is illustrated in Figure 1. Because of the axial symmetry only half of the system is used to find the solution. The current carrying conductors of the split gradient coil were assigned the corresponding current magnitude and directions. These conductors were meshed with 280 brick-elements in each of the current loop that are used as source elements. The MLCs were assigned the electrical properties of Tungsten and meshed using 10000 triangular surface elements. The system was solved at frequency range starting from 100 Hz up to 2.5 kHz with 100 Hz step. The solutions were post-processed for further analysis. For a given frequency it takes approximately 35 minutes to solve the system with a single Core PC having 32GB of RAM. The solution allows computing all components of the eddy currents inside any conducting volume or on its surface, all components of the magnetic and electric fields anywhere in the model, and power losses in the eddy current carrying conductors.

Results

We have considered six azimuthally different positions of the three MLCs (rotated by the step of 5degrees) and found the corresponding solutions. It was found that the gradient strength decreases as the driving frequency increases. For example at the frequency f=1.0 kHz the gradient strength at the isocenter was reduced from 20mT/m to ~18.4mT/m due to the eddy currents induced in the MLCs. The solutions show that at each particular frequency the gradient strength is insensitive to the rotational angle of the MLCs as illustrated in Figure 2 for f=1.0 kHz. Due to the discrete azimuthal symmetry of the MLCs positions the non-linearity of the gradient strength is sensitive to the rotational angle of the MLCs as shown in Figure 3. This results in eddy current asymmetry. Figure 4 shows the power losses in the MLCs as a function of the rotational angle. The “Faraday” software was also employed to compute the eddy currents in the Warm Bore and the Radiation Shield of the magnet. We also computed eddy currents induced by the gradient coil in the Magnet’s current bundles and found extremely low effect of the eddy currents on the central frequency. Similar analysis was performed for the axial split gradient coil.

Discussion

We have demonstrated the application of the BEM for computing the 3D eddy currents induced by the pulsing split gradient coil used in MRI guided Radiation Therapy. This method allows computing all properties of the magnetic /electric field generated by the gradient coil and the eddy currents.

References

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Acknowledgment

We thank Dr. Dan Green (Magnex Scientific, Varian, Inc.) for providing the AUTOCAD drawings of the Gradient Coil.

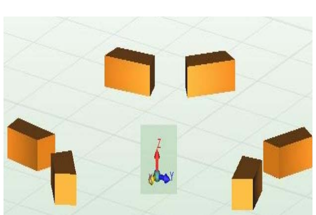

Fig.1 Half of the MLC structure used in the analysis

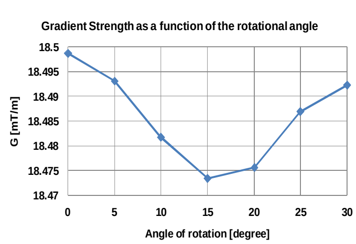

Fig.2 Gradient strength as a Function of rotational angle

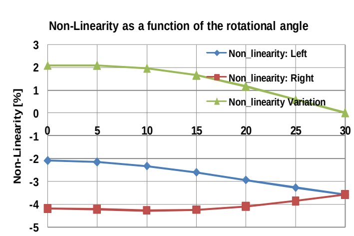

Fig.3 Gradient field non-uniformity as a function of rotational angle

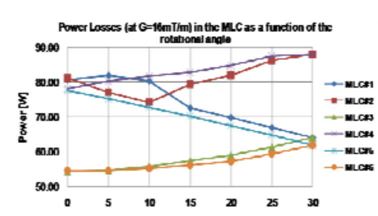

Fig. 4 Power losses in MLC as a function of rotational angle