Influence of Collimator Insertion on Eddy Currents for different Resistivities of Tungsten

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Target audience: Physicists, gradient coils designers, MRI designers, SPECT designers, medical imaging engineers.

Purpose: Medical imaging technology has tended to become more integrated over the past decade. While combined Positron Emission Tomography and Magnetic Resonance Imaging (PET/MRI) is rapidly gaining popularity, no commercial systems for combining the complementary functional imaging techniques of Single Photon Emission Computed Tomography (SPECT) and MRI have been developed. This is mainly due to the physical space constraint, magnetic incompatibility of collimators and the required rotation mechanism inside the MRI bore [1] [2]. Some approaches investigated this integration [3] but no one focused on the development of pre-clinical SPECT systems and their integration with pre-clinical MRI without compromising image quality and taking into account the MR-compatibility of the collimator material. This study investigates eddy currents in the collimator due to the magnetic field gradients, for different resistivities of tungsten, for small animal SPECT/MRI. Collimator resistivity can be tuned nowadays through tungsten additive [4].

Methods: Gradient coils for pre-clinical systems, e.g. [5], were simulated with the collimator (Figure 1) using two state-of-the-art 3D full-wave electromagnetic simulation platforms: SEMCAD-X (Speag, Zurich) and FEKO (EMSS, South-Africa). In SEMCAD-X we used the low frequency solver, which solves Maxwell's equations in the frequency domain using the quasi-static approximation to decouple magnetic field from electric field. FEKO uses the Method of Moments (MoM) that provides full wave solutions of Maxwell's integral equations in the frequency domain. Low frequency stabilization was activated and Volume Equivalence Principle (VEP) was used for meshing the collimator. A z gradient coil is shown schematically in the Figure 1 with a pentagonal collimator of 5 parts separated by a flare of air. Z gradient coils contain 132 wires fed with +/-150 A (blue wires are fed with 150A in Figure 1). Some parameters of the gradient coils are: G_x(gradient strength for x) = 449mT/m, η_x(gradient efficiency for x)= 2.98mT/m/A, G_z(gradient strength for z)= 533.3mT/m, η_z(gradient efficiency for z)=3.55mT/m/A, 2.04 % and 0.86 % for maximum deviation in a sphere of 3cm for x and z gradient coils respectively.

Results: Figure 2 shows distributions of current density, J, over the collimator's surface for different resistivities ρ. Figure 3 shows the deviation, as a function of space along the z-axis, of the magnetic field due to the collimator's insertion in a z gradient coil. Results of the simulations showed that for higher values of resistivity, lower current densities on the collimator are obtained and thus lower eddy current effects, reducing deviations from the expected values of the gradient. The presence of the collimator inside the coils disturbs the gradient field with a maximum deviation at the external faces of the collimator (z = +/- 23 mm Figure 3).

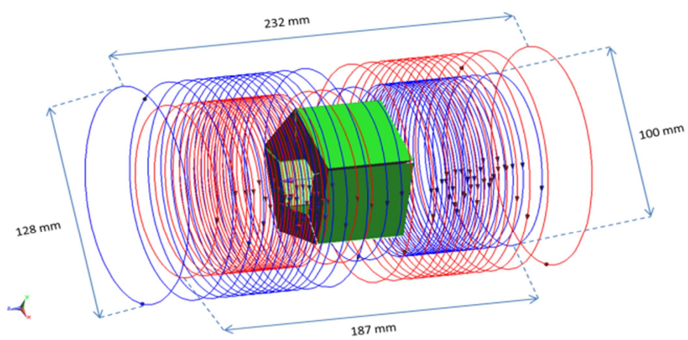

Figure 1: Z gradient coil with collimator

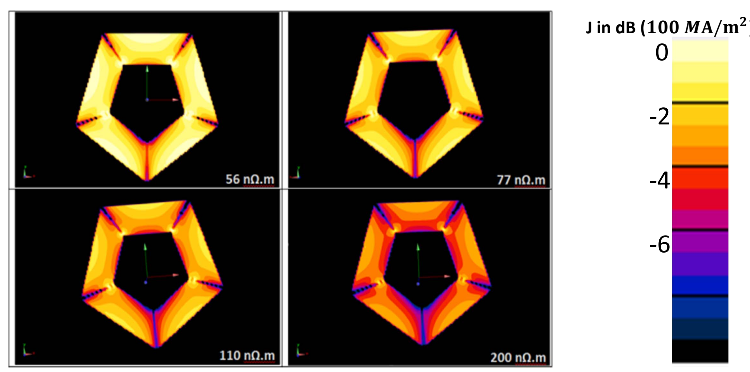

Figure 2: Current density on the collimator for different resistivity normalized to 10^8 A/m^2

Discussion: Characteristics of the modified x, y and z gradient coils fit with the requirements of the SPECT/MRI in terms of high gradient strength, a linearity of maximum 2% over a Field Of View (FOV) of 3cm and the physical space constraints. When tungsten with high resistivity (200nΩ.m) is used, the gradient field is distorted with less than 0.02%. The production parameters corresponding with this resistivity also results in lower density, which has an influence on the collimator performance. A higher density is preferred resulting in low resistivity (56nΩ.m) but with a high deviation from the expected value of the gradient field. Finally, with this characterization of the eddy currents effect on the collimator, and by using an improved design of the gradient coil, it should be possible to reduce the eddy currents in the collimator.

References: [1] L. Cai et al, Nucl. Inst. Meth. 2013. [2] B. Tsui et al. IEEE NSS-MIC Conference Record, 2011. [3] S. Shvartsman et al, ISMRM, 2009 [4] K.Deprez, et al. Medical Physics, 2013.[5] M. Poole et al. Concepts Magn Res, 2007.

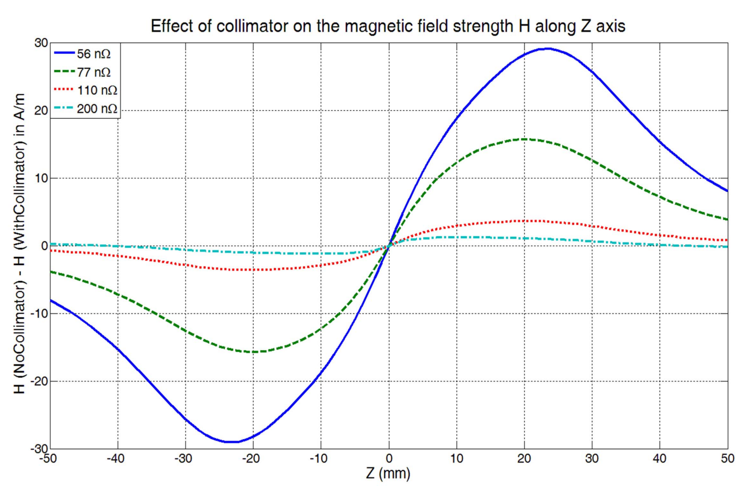

Figure 3: Deviation of magnetic field with and without collimator along z axis