Characterization and Compensation of Eddy Current Induced by Insertable dreMR Magnet

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INTRODUCTION

Delta relaxation-enhanced magnetic resonance (dreMR, [1]) imaging is a B_0-cycled MR technology that produces contrast from intended targets only. While ΔB can be achieve with an insertable field-cycling magnet, mutual coupling to MR structure induces eddy current (EC) that cause unintended change to the effective main field. In this framework, there is a need for a thorough characterization of coupling effects with the main bore and other magnet structures. Here, we present an imaging strategy to characterize and compensate for the induced EC on a clinical imaging system.

MATERIAL AND METHODS

MR systems Experiments were conducted using a 1.5T Philips system. A fast-field cycling solenoidal coil with a dual layer magnet capable of supplying $\Delta B = \pm 0.5$T was fixed to the imaging bed and centered in the main field within 1 cm of the main magnet isocenter. The FFC magnet external dimensions were 17cm in diameter and 30cm in length. It was capable of producing $\Delta B = \pm 0.5$T for 320A current with ramp times of 1-2ms, and was cooled by perfluorocarbon. A quadrature birdcage coil was inserted inside the FFC magnet and interfaced to the Philips system in transmit/receive mode using an active transmit/receive switch. The effective imaging region was 28mm in diameter, into which was placed a phantom comprising different NMR tubes filled with solutions of dispersive and non-dispersive contrast agent.

Pulse sequence A multi-phase spoiled gradient echo imaging sequence was modified to allow triggering of the FFC magnet amplifier. The pulse sequence could control amplifier blanking and waveform triggering such as depicted in fig. 1. After shimming and scout imaging, a transverse slice was applied with the following parameters: Flip angle = 10°, Field-Of-View = 5 cm, matrix size = 100x100, slice thickness = 5 mm, TE = 7 ms, TR = 14 ms, pixel bandwidth = 96 Hz. 50 phases were acquired to cover signals up to 700 ms. The FFC pulse and multi-phase train was repeated every 2 s. FFC pulses were applied with various amplitudes and durations. To measure eddy currents outside the FFC magnet as well, the RF coil was placed in between the FFC magnet and the main bore border.

Data analysis Dicom images were reconstructed on a 112 x 112 matrix using standard reconstruction. The dominant effect of the B0 pulse is a B0 offset which will induce a frequency shift resulting in a spatial shift in the readout encoding direction. To measure this effect, the magnitude image corresponding to the last phase was used as a reference position. Cross-correlation between each magnitude image and the reference image was calculated allowing for sub-voxel shifts (as small as one tenth of a voxel) to determine the spatial shift in each of two in-plane directions between image and reference. This spatial shift was then converted to frequency shift with a maximum precision of 8.6 Hz. The frequency shift evolution with time was fitted to a mono-exponential decay to extract a time constant and amplitude characterizing the eddy current behavior.

RESULTS

As can be seen in fig.2, a spatial shift in the frequency direction is obtained right after the application of a B0 shift waveform as compared to 700 ms later. Eddy currents occurring during an observation time of ~10 ms did not significantly affect image quality; image deformation was limited to a rigid-body spatial shift. This indicates that the field variation is uniform and that the temporal decay is small enough to be neglected during individual acquisitions. The temporal evolution of the eddy current induced frequency shift followed a mono-exponential decay (fig.3) with a time constant of 90.6±3.3 ms (reproducibility over the various experiments). The amplitude of the frequency shift was linear with ΔB, allowing the complete modeling of the eddy current induced frequency shift as 165Hz/MHz*exp(-t/90.6). Fig.4 summarizes the various experiments for Field amplitudes between ±15MHz and application times up to 400 ms. Results obtained with RF coil and phantom outside the FFC magnet gave exactly the same behavior indicating that eddy currents were not induced within the FFC magnet nor the RF coil, but were a result of the interaction with the MRI main magnet.

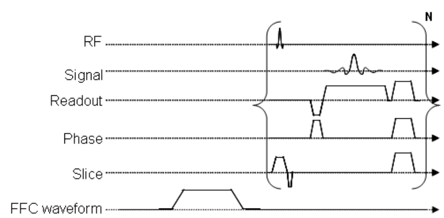

Fig. 1: Schematic of the FFC magnet control followed by the multiphase imaging sequence (N phases). The Philips system is used to enabled the FFC system and trigger the B0 shift start and stop.

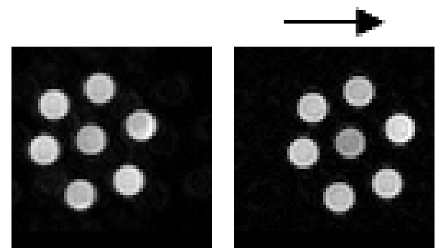

Fig. 2: Images obtained for the first and last phases evidencing the spatial shift in the readout direction.

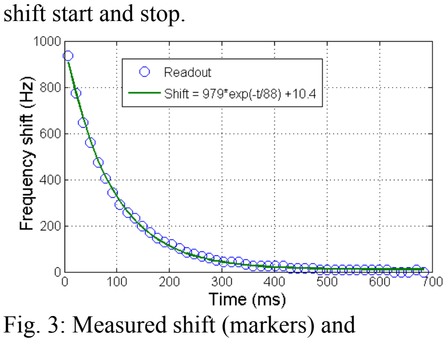

Fig. 3: Measured shift (markers) and exponential shift (line) obtained after a 100 ms long 235 mT pulse.

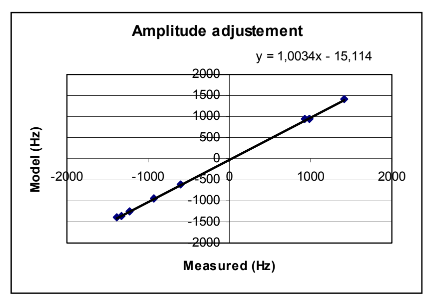

Fig. 4: Measured initial EC amplitude as a function of the modeled amplitude.

DICUSSION AND CONCLUSION

FFC setup on and interfacing with a Philips 1.5T system is feasible. Using a multi-phase imaging strategy similar to the acquisition of repeated spoiled FIDs but with the additional spatial localization, we have shown that eddy currents resulted only from coupling with the main imaging system and followed a mono-exponential decay. Eddy current induced field shifts were homogeneous within the entire bore and linear with waveform amplitude. Consequently, they only induced rigid-body spatial shifts and image quality was not degraded significantly. These results indicate that eddy currents induced by the FFC insert coil can be compensated by using pulse sequence adaptations and post-processing.

REFERENCES 1. Alford, JK et al. MRM 2009;61(4):796-802