

Effective and Flexible Eddy Current Compensation for Delta Relaxation Enhanced MR Imaging

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Introduction: Delta relaxation enhanced MR (dreMR) [1] is a new imaging method which allows acquiring information about the magnetic field dependence of the relaxation rate (dR1/dB, relaxation dispersion). This quantity has shown promise for contrast agent imaging. One major problem in dreMR imaging is the occurrence of eddy currents which drastically reduce the quality of the resulting images. A common practice against eddy currents is waveform preemphasis [2]. However this method is expensive and difficult to implement because it requires high fidelity amplifiers and sophisticated control. This abstract presents a different approach which can easily be implemented in the scanner software, does not require any additional hardware and can be used for any imaging sequence.

Methods: dreMR imaging acquires two images with contrast from different magnetic field strengths for subtraction in one MR scanner. The shift in B_0 is achieved by a cycling coil which is placed at the isocenter of the scanner. It increases or decreases the B_0 field during image acquisition (e.g. in a clinical 1.5T scanner from 1.4T to 1.6T).

The field cycling induces eddy currents in the cold bore of the scanner which result in a temporally varying (but spatially homogeneous) offset in the Larmor frequency. This offset between Larmor frequency and system reference frequency shifts the field of view (FOV) along slice and read encoding axes (displayed in sketch in Fig. 1 a)). The shift varies with the parameters of the B_0 cycling field. If subtracting images acquired with two different B_0 cycling fields, they will have slightly different FOVs and hence the resulting image comprises subtraction artifacts which make proper interpretation of the dreMR image impossible (shown in Fig. 1 b)).

The approach of this eddy current compensation method is to keep the offset between Larmor frequency and system reference frequency as small as possible by dynamically adjusting the system frequency. The temporal behavior of eddy currents is well predictable and can be calculated for the whole imaging sequence. The calculated offset in frequency is used to in- or decrease the system frequency by just the same amount at each moment in time. Both frequencies now vary with time but the difference between them is kept at zero.

These changes in system frequency usually are on the order of 100Hz and can easily be introduced into any imaging sequence by software means. A time varying phase is added to all radio frequency (RF) pulses and acquisition windows (ACQ) resulting in the desired dynamic frequency adjustment. Due to the additive nature of phases this additional phase does not disturb any other use of the system phase like e.g. for the tip angle orientation in the rotating frame or RF spoiling. Fig. 2 a) shows an example spin echo sequence where 90° and 180° pulses are along perpendicular axes in the rotating frame. Φ_{norm} shows the usual phase for the sequence, $\Phi_{\text{correction}}$ shows the phase for a corrected sequence with the sum of usual phase and a time varying phase for frequency adjustment.

Experiments: A measurement with a phantom containing 19 glass tubes demonstrates the effect of the eddy current compensation. Two tubes are filled with a substance which is bright in conventional images and dreMR images (dreMR active), all other tubes contain substances which are only bright in conventional images but vanish in dreMR images (dreMR inactive). A conventional, T_1 weighted image of the phantom is shown in Fig. 2 b) with circles marking the dreMR active substances. One dreMR image is acquired with the presented eddy current compensation and one without compensation. The images are shown in Fig. 3 a) and b) respectively.

Results: The dreMR image with eddy current compensation (Fig. 3 a)) shows signal merely at places with dreMR active substances and is dark at the places with dreMR inactive substances. Faint halos around the positions of the tubes indicate minimal subtraction artifacts. The dreMR image without compensation (Fig. 3 b)) shows severe subtraction artifacts, especially along the read encoding direction (left – right). The artifacts are so much brighter than the dreMR signal that it cannot be distinguished from the background. dreMR signal usually is about a factor of 20 smaller than T_1 weighted signal, however the subtraction artifacts have the same signal level like T_1 weighted signal. This fact renders interpretation impossible. It is not feasible to correct for the subtraction artifacts after image acquisition because the acquired data does not comprise all necessary information. To some degree the misalignment along the read encoding axis can be compensated, but the shift of the FOV along the slice encoding axis cannot be reversed.

Conclusion: We have demonstrated an eddy current compensation for dreMR imaging which can easily be implemented in software and does not need any additional hardware. It can be introduced into any imaging sequence by a dynamic adjustment of the system reference frequency. The compensation yields almost artifact free dreMR images where a missing compensation results in severe artifacts which make the images useless for interpretation.

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References: [1] Alford et al., Mag Res Med, 2009, 61, 796-802, [2] Jehenson et al., JMR, 1990, 90, 264-278

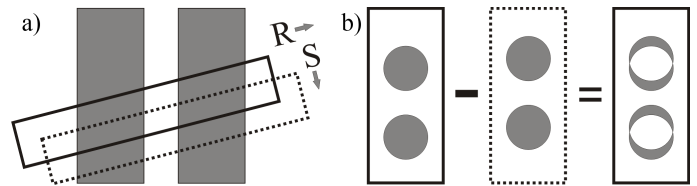


Fig. 1: a) shift of the FOV along read and slice encoding direction due to frequency offset, phantom with two tubes, b) images with shifted FOV have equal intensities but different signal locations, subtraction leads to artifacts

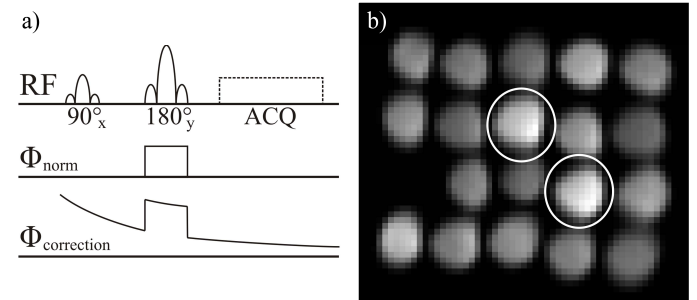


Fig. 2: a) spin echo sequence with perpendicular 90° and 180° pulses, Φ_{norm} is the usual phase for the sequence without correction and $\Phi_{\text{correction}}$ the phase with eddy current compensation, b) T_1 weighted image of phantom, circles mark dreMR active substances

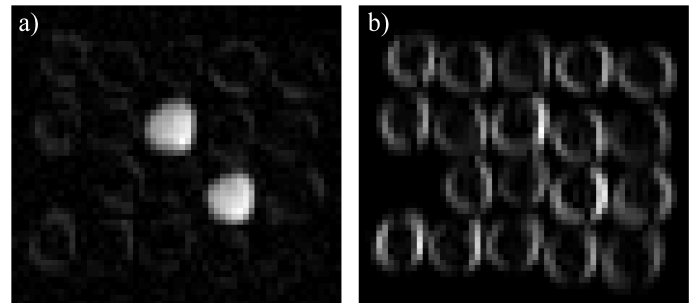


Fig. 3: a) dreMR image with eddy current compensation (normalized), b) dreMR image without eddy current compensation, dreMR signal is much smaller than the artifacts and cannot be identified