A k space measurement technique with single point excitation

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INTRODUCTION

In fast MR acquisitions, high gradient slew rate and amplitude are inevitable. This can result in artifacts from eddy current, cross-coupling of gradients, or scanner instability etc. One way to overcome this is to measure the actual k space trajectory and include it in the image reconstruction scheme. Many trajectory measuring methods have been introduced [1-5]. However, these methods did not account for errors in trajectory due to inhomogeneity in measurement object [1,2], measured the target gradients separately ignoring the cross coupling [1,4,5], or required extra encoding steps for longer scan time from minutes up to hours[1-3,5].

In this work, we introduce a new method to measure k space trajectory with increased accuracy by fully compensating for field inhomogeneity and allowing for calculation of gradient cross coupling all within reasonable scan time.

METHOD

Figure 1 shows the gradient waveform we played. To measure a readout gradient in the X channel, a slice selective 90 degree pulse in x at a location X_0 and 180 degree pulse in y at Y_0 are played. A pair of spoiling gradient around 180 degree pulse is included to ensure a point (actually a bar in z direction) is excited (Figure 2(a)).

The data is collected while both of the gradients are played. The received signal is $S(t) \cong \exp(-i2\pi(k_x(t)X_0 + k_y(t)Y_0)) \int_{-\Delta z/2}^{\Delta z/2} M(X_0, Y_0, z)\cdot \exp(-i\omega(X_0, Y_0, z)t)dz \cdot$ To get rid of the field inhomogeneity and z related term, the data without readout gradients is also collected as in [4], and S(t) is divided by this FID signal. Since the true iso-center is not accurately known, the measurement was repeated for another spatial location at $(-X_0, Y_0)$, and the unwrapped phase difference of the two measurements is divided by $-2\pi 2X_0$ to get an estimate of *Kx*.

Field drifts can cause extra linear phase accrual in the estimated trajectory, because of the time gap between measurements (~4 sec). This extra term was linearly regressed out using the following model $k_{true}(t) = \alpha \cdot k_{measured}(t) + \beta \cdot t$, and the final estimated trajectory ($k_{estimated}$) is determined as the measured trajectory plus the linear term.

In a similar way, the y readout gradient can be measured by exciting a location at (X_1, Y_1) and $(X_1, -Y_1)$.

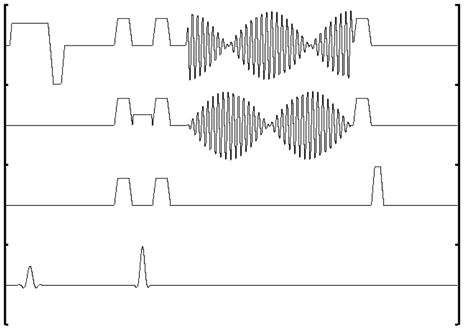

Figure 1. The gradient waveforms

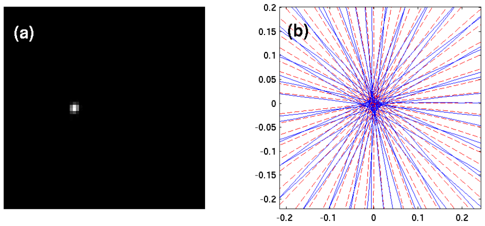

Figure 2. (a) the point excitation (b) the measured trajectory (blue), and the true trajectory (red dashed)

EXPERIMENT

We scanned a sphere phantom (NiCl2 solution, 17cm diameter) in a GE 3T scanner. The point locations were (4cm,0),(-4cm,0),(0,4cm),(0,-4cm), and TE=25ms, TR=4s, slice thickness = 3mm, flip angle = 90 degrees, FOV=20cm, spatial resolution=3.125mm . The readout sequence was rosette trajectory where $k_{true}(t) = \sin(2\pi f_1 t)\exp(i2\pi f_2 t)$, f1=1.10KHz and f2=34.57Hz. For comparison, we also performed the measurement with only one gradient on to measure the cross coupling of gradients.

RESULTS AND DISCUSSION

Figure 3 (a) and (b) show the error in the measured x and y trajectory. The Normalized Root Mean Square Error (NRMSE) was 0.0133 and 0.0115 respectively. Most of the error was from the scaling of the trajectory and phase shift, which are common types of eddy current distortion for sinusoidal gradient waveforms. Figure 3(c) shows the difference between the measured trajectories Kx(t) with both gradients on and only one gradient on. From the high correlation of the peaks with Ky(t), we can conjecture that this is the cross coupling component in Kx(t). This implies that measuring k trajectories separately can cause extra significant error in the measurement from absence of cross coupling of gradients.

In this method, a phase unwrapping was necessary as the phase accrual exceeds [-π, π] interval. Since a single point source is imaged, the SNR is low in general, and this can affect the quality of measurement.

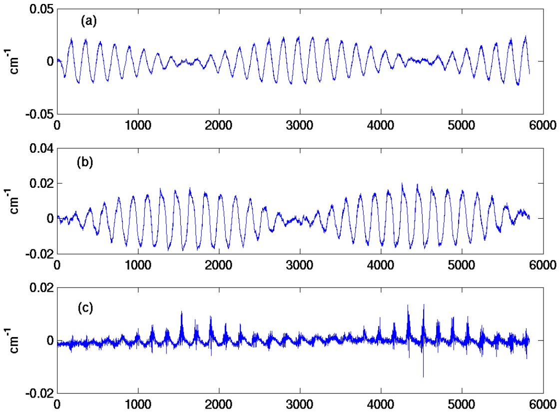

Figure 3. (a) $Kx_{estimated} - Kx_{true}$ (b) $Ky_{estimated} - Ky_{true}$ (c) Cross coupling in Kx

REFERENCES

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