Gradient waveform measurement using prephased gradient moments.

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Introduction

One of the commonly used methods for k-space trajectory/gradient waveform characterization is based on utilizing the FID phase evolution sampled from a thin slice excited at a known distance, close to the gradient isocenter, and orthogonally oriented to the examined gradient [1]. In many cases like breast or extremity imaging, there is no source of signal near the magnet's isocenter. This introduces problems with rapid phase accrual [2, 3]. Additional complications arise from measuring high gradient amplitudes when modification of this approach is necessary to avoid problems with low signal amplitudes caused by spin dephasing [4]. Here we propose alternative methods for gradient characterization based on the gradient moment mapping.

Methods

The main idea of the proposed k-space trajectory/gradient waveform measurement is shown in Fig. 1. The measurement of each of the X, Z and Y gradient channels is done separately. The spin-echo sequence is used to excite a slice with parallel orientation to the measured gradient channel. After slice excitation, a phase encoding pulse G_{PE} is applied to introduce a spin dephasing moment along the examined gradient direction. Following the refocusing RF pulse, the gradient waveform G_{MEAS} is applied with simultaneous acquisition of the MR signal. The experiment is repeated while stepping the phase encoding gradient in such way that the acquisition trajectory intersects the k-space origin at different time points of the measured gradient waveform, *i.e.*, for small phase encoding amplitudes the crossing occurs at the front lobe of G_{MEAS} while for increasing G_{PE} later. These changes in the k-space crossing can be observed as the echo time shift, *i.e.*, the signal maximum arrives at a different echo time TE. In another words, the exact time of k-space origin crossing by G_{MEAS} can be found as an echo maximum. The k-space trajectory of G_{MEAS} can be simply reconstructed from the pre-phased k-space shifts (k_1, k_n, k_p) and the corresponding arrival times of the echoes (TE_1, TE_n, TE_p) as indicated in Fig. 1. The gradient waveform can be further calculated using the rate of change of the k-space trajectrory with respect to time. For more complex gradient waveforms *e.g.* bipolar gradients, more transition across the k-space origin occurs and could be used for reconstruction.

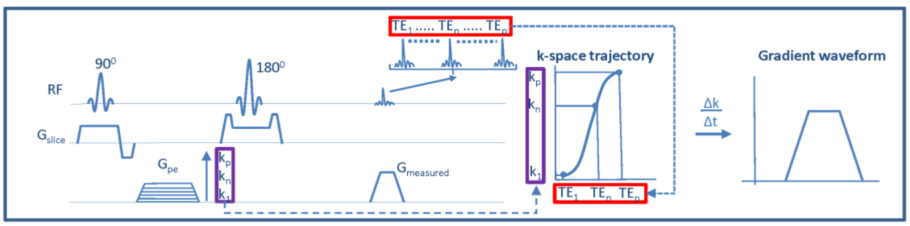

Fig.1: The pulse sequence for mapping k-space trajectory/gradient waveform. The experiment is repeated stepping the G_{PE} amplitude and acquisition of the spin-echo signal during the application of the G_{MEAS}. The information of the spin echo shift and the gradient moment of G_{PE} (or k_1, k_2, k_n) is used for reconstruction of the k-space trajectory as it is schematically shown in the figure.

Results and Discussion

The method has been implemented on a whole body 3T scanner (TimTrio; Siemens Medical Solutions, Erlangen Germany). The standard transmit/receive coil and a spherical phantom of 170mm diameter filled with $CuSO_4$ doped water was used in all experiment. A bipolar gradient (amplitude 35mT/m, ramp time 250μs, plateau time 300μs) was measured by the proposed sequence using the following parameters: TR=1500ms, TE=50ms, slice thickness = 4mm. A phase encoding pulse of 5ms duration and 100 phase encoding increments (max. amplitude ~ 5mT/m) was used to map the bipolar gradient waveform. Measurements were performed in two locations - at gradient isocenter and off-center (shifted 100 and 150mm in Y and Z axis, resp.). Additional measurements using a phase evolution method [1,5] was performed at gradient isocenter in order to evaluate the performance of the suggested method. Both measurements showed good agreement, however, the latter could not be applied away from the gradient isocenter.

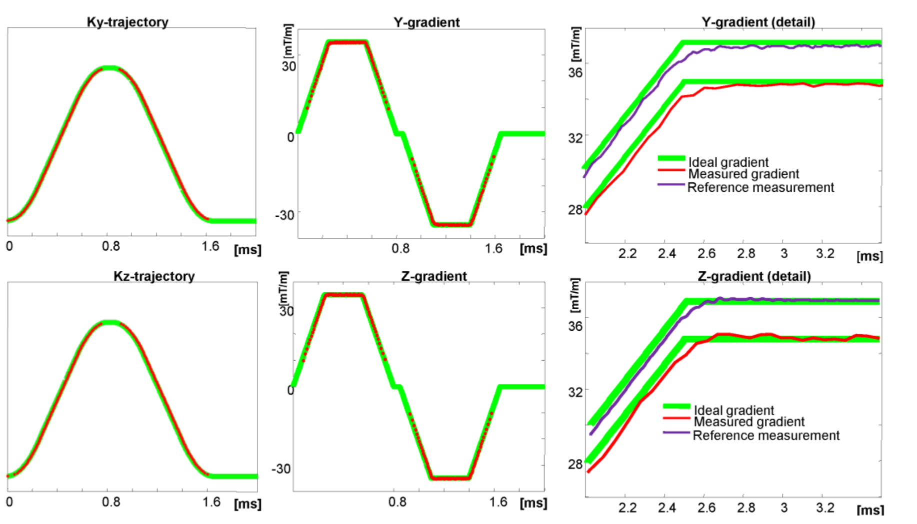

Fig.2. Results obtained from measurement of a bipolar gradient pulse (35mT/m amplitude) when coil with phantom (spherical phantom filled with $CuSO_4$ doped water) were placed at the gradient isocenter. The red dots represent the time points in which the information of the k-space trajectory/gradient waveform was obtained. Reference measurement was done with the method mentioned in [5] and is shifted up by 2mT/m for clarity

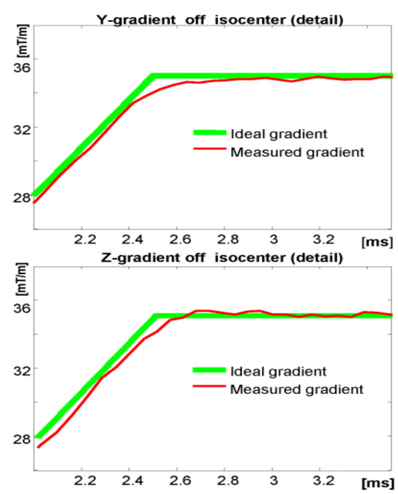

Fig.3. Experiments demonstrating the capabilities of the proposed method to measure a gradient away from magnet isocenter. Position of the coil with phantom was moved 100mm in Y and 200mm in Z direction from the magnet isocenter.

Conclusion The results showed that this new method is capable of providing information on k-space trajectory/gradient waveforms. It can even be applied for more complex waveforms, except for gradient values close to zero. However, the main advantage of the propose method is that it is not restricted to measurements close to gradient isocenter and it has no direct restrictions for large gradient amplitudes.

References

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