Transmit k-space Calibration using Magnetic Field Probes

F. Testud[1], C. Barmet[2], M. Haas[1], D. Kokorin[1], J. Hennig[1], K. Pruessmann[2], and M. Zaitsev[1]

[1]Medical Physics, Dept. of Radiology, University Medical Center Freiburg, Freiburg, Germany, [2]ETH and University, Zurich, Institute for Biomedical Engineering, Zurich, Switzerland

Introduction: Field probes [1,2] have been used in the last years for dynamic magnetic field monitoring (MFM) in order to reduce image artifacts due to imperfect gradient coils and amplifiers, eddy currents, B0 drifts and patient breathing by taking the measured field dynamics into account in the image reconstruction[3]. Parallel spatially selective EXcitation (PEX) [4-6] allows inner volume imaging where only specifically regions of interest are excited. However it relies on the exact matching of multidimensional RF pulses and the simultaneously traversed k-space trajectory which, if not fulfilled, can lead to artifacts. In [7] field probes were used for calibrating the transmit (Tx) k-space trajectory used in PEX experiments. In the present work 4 unshielded ^{1}H field probes [8] (Fig.1) are used to calibrate the Tx k-space trajectories and calculate corresponding RF pulses to excite target patterns.

Theory: The phase $\phi_P(t)$ of the acquired signals of the field probes P is reflecting the magnetic field evolution at their respective positions x_P, y_P, z_P as described by Eq.1. The initial value of the phase and the linear drift has to be subtracted to account for off-resonances $\omega_{\mathrm{ref},P}$. The field evolution $\vec{k}(t)$ can then be estimated in the least square sense from the unwrapped phases using Eq.2.

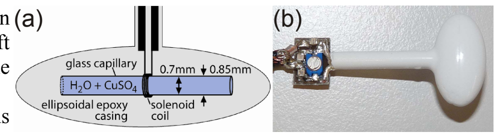

Fig.1: (a) sketch of the field probes used [8], (b) image of a field probe with tune and match circuit.

$$\phi_P(t) = \mathbf{P}\vec{k}(t) + \omega_{\mathrm{ref},P}t \quad \text{(Eq.1)}$$

$$\mathbf{P} = \begin{pmatrix} 1 & x_1 & y_1 & z_1 \\ 1 & x_2 & y_2 & z_2 \\ 1 & x_3 & y_3 & z_3 \\ 1 & x_4 & y_4 & z_4 \end{pmatrix}, \vec{k}(t) = \begin{pmatrix} k_0(t) \\ k_1(t) \\ k_2(t) \\ k_3(t) \end{pmatrix}$$

$$\vec{k}(t) = (P^T P)^{-1} P^T [\phi_P(t) - \omega_{\mathrm{ref},P} t] \quad \text{(Eq.2)}$$

Methods: The experiments in this study were done on a 3T human Tim TRIO MR scanner (Siemens Healthcare, Erlangen, Germany) with an 8 channel TxArray parallel transmit body coil. The field probes were arranged on a tetrahedron placed in the isocentre of the magnet. All probes were connected to the scanner via a customer-build T/R switch and a low-noise preamplifier (Siemens Healthcare, Erlangen, Germany). The probes were operated in receive mode. The trajectory measurements were performed separately from the PEX experiment. First B0 shimming was performed on a large bottle containing doped water to obtain a homogenous B0 field over a large region. The 12 channel head coil used for reception and the phantom were tightly fixed and then removed. The field probes were placed inside the bore with the same B0 shim and the transmit voltage of one channel of the TxArray was empirically adjusted to obtain maximum signals from the field probes. The field probes were excited with a non-selective rectangular pulse and the designed k-space trajectory was recorded. A fully sampled 3D shell trajectory (Tra1) (8 shells, 8 revolutions, gradient pulse duration TD=41 ms), a 3D rosette trajectory (Tra2) with an acceleration factor of 2.67 (20 radial oscillations, 5 azimuthal turns, 8 polar turns, TD=16 ms) and a rosette trajectory (Tra3) with an acceleration factor of 3.7 (20 radial oscillations, 5 azimuthal turns, 8 polar turns, TD=11 ms) were calculated for a field of excitation of 18cm³ and a matrix size of 16³. The fastest trajectory used a slew rate to 168 T/m/s. 32 and 64 repetitions were acquired for the first and the last two trajectories, respectively, to reduce noise in the phase evolutions. The probes positions were determined by projection scans in the 3 spatial dimensions. Free induction decay signals (20 repetitions) were acquired prior to the k-space trajectory measurement to calculate $\omega_{\mathrm{ref},P}$ from the phase evolutions by linear regression. The field probes were then removed and the head coil with the phantom was replaced inside the magnet bore at the same position as at the beginning to perform the PEX experiments. Multi-slice B_1^+ mapping was performed on the phantom and used for calculating the pulses. The nominal and the reconstructed k-space trajectories were used to calculate excitation pulses for a specified target. A smoothed 3D letter L Fig.2 (a) was used as a target. A 3D FLASH sequence was used for imaging (flip angle=15°, TR=100 ms, FOV 18x18x26 cm³, matrix size 64x64x44). One experiment was performed with the pulse calculated using the expected k-space trajectory and in comparison another experiment using the measured trajectory.

Results: In Fig.3 details of 2 of the measured k-space trajectories are shown. The mean deviation between the nominal and the measured k_z component of the fully sampled shell trajectory is -7.1±0.6 m^{-1} over duration of 41.6 ms (Fig.3 (b)) which is very small compared to k-space values of up to 300 m^{-1}. In general, this agreement between the nominal and the measured trajectory was observed for all the trajectories Tra1, Tra2 and Tra3. In Fig.2 (b) & (c) the excitation volume is shown with RF pulses calculated based on the theoretical and the measured trajectories. No visual improvement was observed between PEX experiments using the nominal or the measured k-space trajectories as visible in Fig.2 (b) & (c), respectively. The maximum and minimum difference is only about 4.7% and -2.8% in Fig.2 (d), respectively.

Conclusion: It is shown that it is possible to successfully perform MFM. The signal life time of the probes is about 150 ms [8] which is long enough for typical pulse durations used in PEX (≤50ms). No overall artifact reduction could be observed for the presented experiments here. In general it is possible to use 3D shells (not shown here) or 3D rosette Tx k-space trajectories. Further improvements might be achieved by using a separate Tx chain for exciting the field probes.

References:

[1] Barmet C. et al. MRM 62:269 (2009) [2] Sipliä P. et al. Proc ISMRM 2010:217 [3] Wilm J. et al. Proc ISMRM 2010:190 [4] Katscher U. et al. MRM 49:144 (2003) [5] Zhu Y. MRM 51:775 (2004) [6] Ullmann P. et al. MRM 54:994 (2005) [7] Schneider J. et al. Proc ISMRM 2010:4926 [8] Barmet C. et al. Proc ISMRM 2009:780

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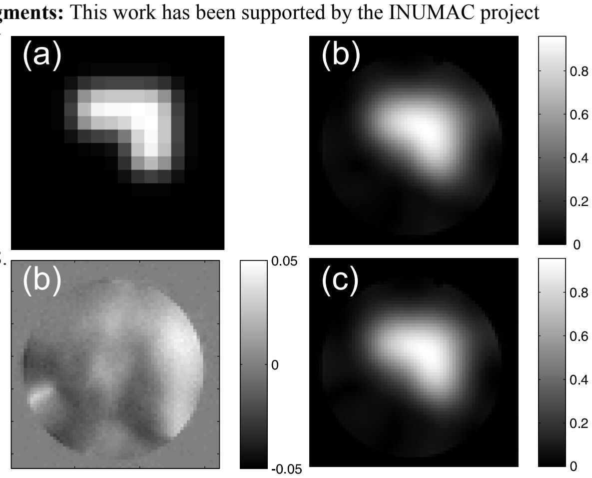

Fig.2 (a): target pattern; Middle slice of the 3D parallel excitation on the target using (b) pulses calculated with the nominal k-space trajectory Tra3 and (c) pulses calculated with the measured k-space trajectory (Tra3); (d) difference between (b) and (c).

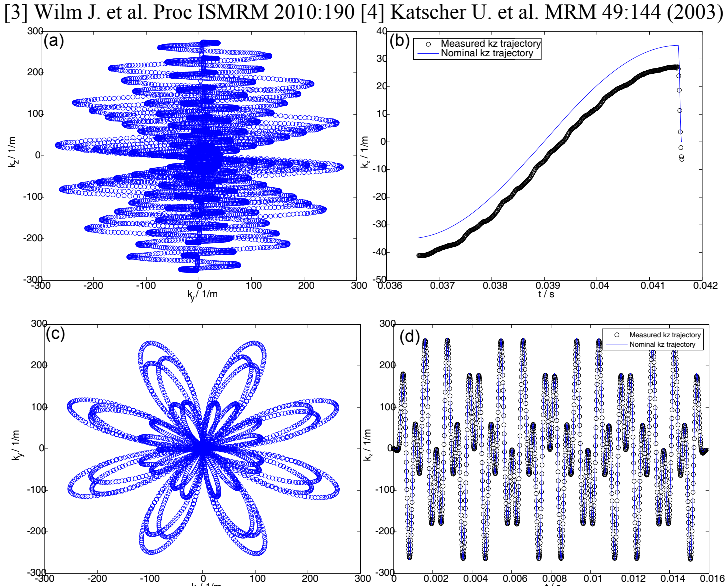

Fig.3: Shell trajectory Tra1: (a) Measured k_y–k_z projection (b) last 5ms of the measured and nominal k_z components. Rosette trajectory Tra2: (c) Measured k_x–k_y projection (d) last 5ms of the measured and nominal k_z component.