Analysis of thermal stability of background phase errors in phase-contrast flow imaging

Julia Busch[1], Signe Johanna Vannesjo[1], Christoph Barmet[1,2], Klaas Paul Pruessmann[1], and Sebastian Kozerke[1,3]

[1]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, [2]Skope Magnetic Resonance Technologies, Zurich, Switzerland, [3]Division of Imaging Sciences and Biomedical Engineering, King's College London, London, United Kingdom

Introduction:

Phase-contrast magnetic resonance imaging (PC-MRI) provides multi-directional velocity data of blood flow at high spatial and temporal resolution [1]. The accuracy of PC-MRI data, however, is limited by background phase errors of various spatial [2] and temporal orders [3]. Concomitant field effects can be corrected for by analytical calculation and subtraction of the field term [4]. Field errors arising from eddy-currents are addressed by gradient pre-emphasis [5]. Nevertheless, significant residual phase offsets may remain in phase-contrast flow imaging compromising its accuracy [2,3]. It has been shown that oscillatory field fluctuations can lead to significant 0^{th} and 1^{st} order phase offsets depending on the choice of echo time [3]. Besides standard correction techniques where the residual phase error is corrected using data from an additional scan in a stationary phantom, an approach using software pre-emphasis and retrospective phase corrections based on measured gradient impulse response functions (GIRF) has been proposed [6]. A key prerequisite for all these approaches to work, however, is sufficient temporal stability of the gradient chain. Recently, Gatehouse et al. [7] have reported that background phase errors are reproducible across scanning sessions, however temporal stability during longer scanning periods with high gradient duty cycle may be of concern.

The objective of the present work was to analyze the stability of background phase errors under thermal changes of the gradient system during high duty-cycle as present in PC-MRI. To this end, gradient impulse response functions were measured using magnetic field monitoring and compared to background phase offsets of 2D PC-MRI sequences under various thermal conditions.

Methods:

Thermo-sensors were mounted onto the epoxy of the x-gradient coil of a 3T Philips Achieva system (Philips Healthcare, Best, The Netherlands). Temperatures were recorded using a Luxtron 790 fiber optic temperature measurement setup (LumaSense Technology Santa Clara, CA, USA) during all scans. Gradient impulse response functions [8] were determined for three different temperatures using a 3^{rd} order dynamic field camera (Skope Magnetic Resonance Technologies, Zurich, Switzerland). A 2D PC-MRI sequence with 1D flow encoding with an encoding velocity (venc) of 150 cm/s (for all three gradient axes separately) was monitored at the same gradient temperatures and phase differences were calculated up to 2^{nd} spatial order [9]. One heart phase was acquired with a spatial resolution of 2 x 2 mm^2 and 10 mm slice thickness. To ensure constant temperature over the duration of the scan cardiac triggering was disabled (TE: 2.6 ms, TR: 15 ms, Flip-angle: 10°). Measurements in a stationary phantom using the same PC-MRI sequence were used to validate the background phase errors for the different temperature steps.

Results:

Figure 1 shows the gradient impulse response function for the x, y and z gradient axes (A-C) measured on the system at room-temperature and upon a 10 and 20K temperature increase of the gradient coils. While eddy-currents are thermally stable, it is seen that center frequencies of field oscillations shift with increasing temperature. Amplitude, phase and time constant, however, show only minor changes. In the time-domain (Figure 2), the shifts in frequency modify 0^{th} and 1^{st} order phase development. For short echo times (2.6 ms), the resulting 0^{th} and 1^{st} order phase offsets remain unchanged for flow encoding along y. There are, however, shifts in the 1^{st} order phase from 0.5 to 0.78 rad/m for flow encoding along x and from -1.6 to -0.9 rad/m for flow encoding along z at ΔT of 20K. The 0^{th} order phase offsets changed from -0.03 to -0.08 rad for the x gradient axis. The same thermal effects were reproduced in a stationary phantom for flow encoding along x, y and z (Figure 3). Assuming standard phantom calibration at room temperature vs. measurement at 20K increase errors up to 6% (z gradient axis) of the encoding velocity occur in a 20 cm field-of-view.

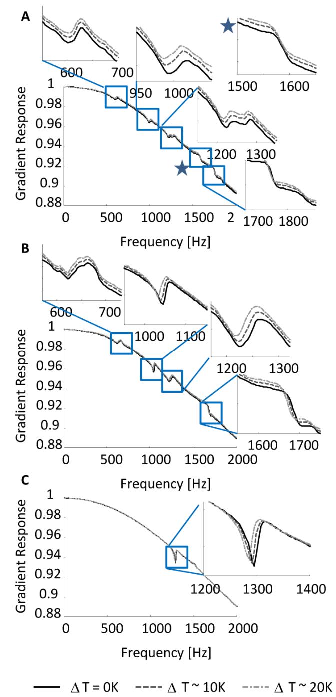

Figure 1: Gradient impulse response function for the x, y and z gradient coil (A-C) measured at three different temperatures of the gradient system.

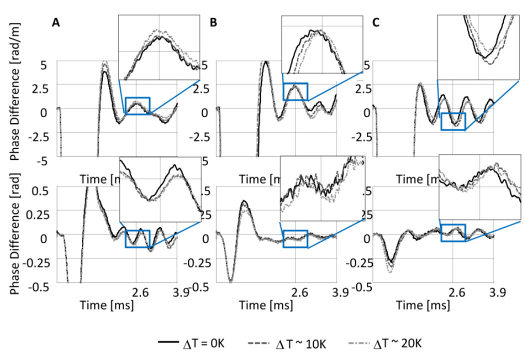

Figure 2: 0^{th} (lower row) and 1^{st} (upper row) order time domain phase differences for flow encoding along the x, y and z gradient axes (A-C) at different temperatures.

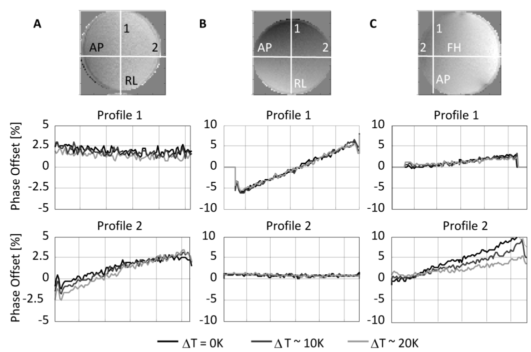

Figure 3: Comparison of background phase errors in a static phantom for different temperatures of the gradient system Flow was encoded along the x, y and z gradient axes (A-C).

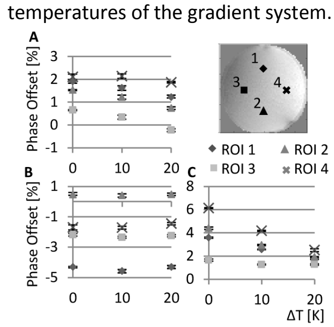

Figure 4: Mean phase error over the regions of interest 1-4 in the phantoms acquired with a phase-encoding sequence along the x, y and z axes (A-C) for different temperatures.

Discussion:

In this work it has been demonstrated that changes in background phase offsets in PC-MRI may occur depending on the temperature of the mechanical gradient system support which will render a standard phantom calibration non-effective. Differences in temperature of the gradient mount were found to change the frequency of oscillatory field fluctuations. Since the amplitude, phase and time constant of the oscillations are not affected a calibration approach by software pre-emphasis might still work. Considering this first data a linear dependence of the frequency on the temperature can be suggested, in this case a linear frequency-temperature model might be applied. Both aspects, however, remain to be analyzed.

References: [1] Markl et al., JCMR'11;13:7; [2] Gatehouse at al., JCMR'10;12:5; [3] Giese et al., MRM'11;67:1294-1302; [4] Bernstein et al., MRM'98;39:300-308; [5] van Vaals et al., JMR'90;90:52-70; [6] Busch et al., ISMRM'12, 1172; [7] Gatehouse et al., JCMR'12; 14:72; [8] Vannesjo et al., MRM'12, doi:10.1002/mrm.24263; [9] Barmet et al., MRM'08; 60:187-197