Assessing phase variations in gradient induced spatial modulation of magnetization (SPAMM)

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Introduction: Spatial modulation of magnetization (SPAMM) allows macroscopic tagging of tissue and therefore is commonly used for motion tracking of the heart or other organs. Most recently, microscopic SPAMM has also been proposed for a new super-resolution technique [1]. The modulation function achieved by applying a magnetic field gradient in between a binomial RF pulse strongly depends on the linearity of the gradient field but also on B_0 inhomogeneities. The correction of the resulting phase shifts is possible provided the modulation function is clearly visible in the tagged image [2]. Unfortunately, this is not the case for microSPAMM [1]. The aim of this work therefore was to develop a new method for assessing phase variations of the SPAMM caused by nonlinearities of the gradient field. This new approach also works with very high modulation frequencies and therefore is of high interest for correcting high resolution images that have been acquired with the microSPAMM technique.

Methods: The proposed method is based on shifting the modulation of the magnetization over one single period in small steps by cycling the phase of the tagging RF pulse over 360°. The longitudinal magnetization *Mz* in a single voxel in the resulting series of images then can be described by:

$$Mz(\theta)|\,\alpha,\phi\ const = \sin(\alpha)^2 * \cos(\theta + \phi) + \cos(\alpha)^2, \qquad (1)$$

where α is the flip angle of the tagging RF pulse, θ is the phase of the RF pulse that is stepwise increased to shift the modulation function, and ϕ is the phase shift induced by the modulation gradient. Note that one image for each θ has to be acquired. As B_1 and the gradient nonlinearities are time invariant, α and ϕ can be considered as constant. The SPAMM phase shift in each voxel can now be obtained by pixelwise fitting *Mz* over the image series, because *Mz* represents a sinusoidal function with a constant frequency. The effect of gradient induced phase shifts is illustrated in Figure 1.

The method was implemented on a 3T Tim Trio system (Siemens Medical Systems, Erlangen) and evaluated with a large cylindrical phantom (380mm). The body-coil was used for signal reception. SPAMM with a period of 3mm was generated with two non-selective 90° pulses and a modulation gradient in between followed by a readout with a spoiled FLASH sequence (FOV: 480mm, matrix: 256x256 matrix, THK = 4 mm, TE: 4,3 ms). The phase offset θ of the tagging pulse was cycled over 360° in steps of 10° which resulted in 36 differently tagged images. A gradient induced phase variation was calculated pixelwise by fitting the magnitude of a sinusoidal function into the image series according to (1). With this procedure the effect of the readout gradient and phase encoding gradient was mapped.

Results: Figure 2 shows a representative image out of the series of 36 images and the calculated phase error corresponding to the profile in the middle of the phantom. While gradient induced phase shifts seem to be only modest in the centre of the gradients (-5° to 5°), a more pronounced effect can be observed at the border of the phantom (-15° to 17°). A 2D profile of the gradient induced phase shift can be seen in Figure 3 which was reconstructed by tagging in phase encoding direction and readout direction. The smooth function was obtained by fitting a 2D polynomial function of 5th order.

Discussion: This study demonstrates that it is possible to assess phase-shifts that are induced by gradient-nonlinearities. The proposed method shows a high sensitivity even for small phase variations. In addition, it works also with high modulation frequencies and therefore is expected to help to increase resolution in microSPAMM images. The fact that the resulting phase shift is proportional to the gradient field makes this method also a promising candidate for direct mapping of the gradient field. Further work will follow this direction and will also focus on reducing the acquisition time by using fewer shifts and a faster readout.

References: [1] S. Ropele et al. MRM. 2010; 64: 1671-1675. [2] R. Bridcut et al. Phys Med Biol. 2001; 46: 1357-1367.

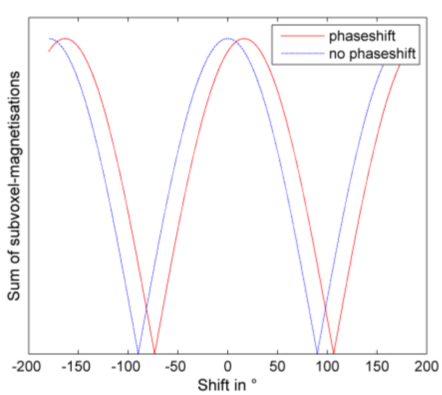

Fig. 1: Effect of gradient induced phase shift. The magnitude of Mz for a single voxel is shown (corresponding to (1)).

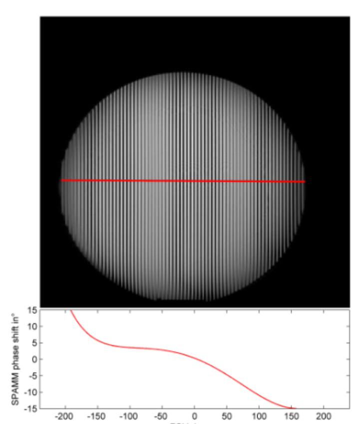

Fig. 2: SPAMM image of the phantom (top) and corresponding phase error (bottom)

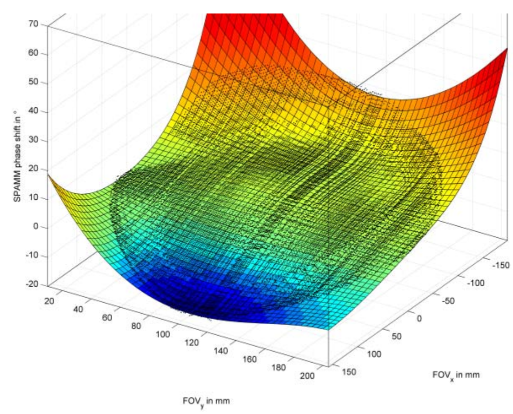

Fig. 3: 2D profile of reconstructed phase shifts due to non-linearities of the readout and phase encoding gradient.