Phase error correction to velocity-encoded single-point-imaging measurements using a sawtooth gradient waveform

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Introduction: Pure phase encoding imaging sequences can be modified to include motion-sensitisation by superimposing bipolar pulsed field gradients (PFG) during the encoding intervals. In particular, motion-sensitised SPRITE has been shown to be an effective tool for measuring the flow field in fast, turbulent, and two-phase flows [1, 2]. Rapidly-switching, large-amplitude magnetic field gradients introduced by the bipolar PFG produce significant eddy currents. Therefore, the sample experiences an undesired gradient waveform, resulting in k-space and phase errors (image artefacts and incorrect velocity values).

Existing methods for correcting these errors can result in considerable additional measurement time [3]. We propose a motion-sensitised, pure phase encoding SPI measurement with a simple, repeating sawtooth gradient waveform [Fig.1]. Sequence timing is chosen such that the sample experiences a linear gradient ramp during the phase encoding interval, thus eliminating the k-space and phase errors prior to data acquisition, unlike motion-sensitised SPRITE.

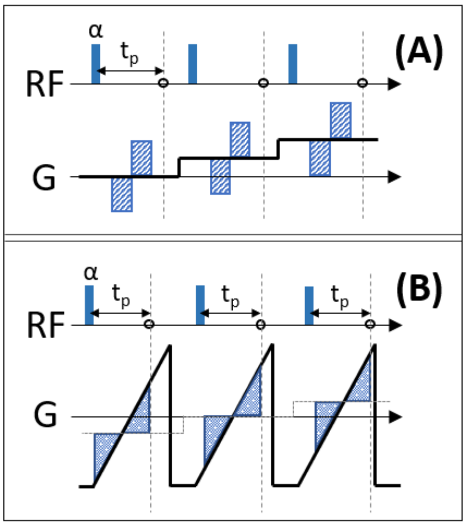

Fig. 1: (A) SPRITE pulse sequence with superimposed bipolar PFG for motion-sensitisation (B) Motion-sensitised SPI sequence with a sawtooth gradient waveform. The linear gradient ramp gives PFG with triangular lobes (as shown). Different k-space points are selected by changing the start time of the phase-encode interval t_p relative to the start of the linear ramp.

Methods: A water sample flowed through a pipe constriction placed in a 4.7 T superconducting magnet. The motion-sensitised SPRITE measurement was repeated with different amplitudes of the PFG. Velocity maps were created from these data for three cases: (i) no eddy current correction, (ii) correction using images of stationary fluid, and (iii) correction by adjustment of the relative areas of the bipolar PFG lobes (“trimming”) [2, 3]. A measurement was then performed using the motion-sensitised sawtooth gradient waveform sequence with the same flow parameters. Different q-space points were acquired by varying the slope of the linear gradient ramp.

Results and discussion: Velocity maps of water flowing through the pipe constriction show expected results. When no eddy current correction is used, the velocity values are nonsensical due to the phase errors. Motion-sensitised SPRITE with stationary data correction and trimming correction gives velocity values that agree with theoretical expectations (although both require significant additional measurement time). Motion-sensitised SPI with the sawtooth waveform produces velocity maps, which are compared with the trimmed measurements.

Conclusions: Significant eddy currents produced during motion-sensitised SPRITE measurements cause the sample to experience an undesired magnetic field gradient waveform, resulting in k-space and phase (velocity) errors. A linear gradient ramp during the phase-encoding interval ensures that the bipolar PFG is balanced about the midpoint of the phase-encoding interval, thus mitigating k-space and phase errors. Velocity maps created using a sawtooth gradient waveform are presented.

References: [1] Sankey, et al., J. Magn. Reson. (2009). [2] Adair, et al., Magn. Reson. Imaging (2018). [3] Adair, et al., J. Magn. Reson. (2019).