Velocity-slice selection

L. de Rochefort[1], E. Durand[1], X. Maître[1], J. Bittoun[1]

[1]CIERM - Unité de Recherche en Résonance Magnétique Médicale, CNRS - Université Paris XI, Le Kremlin-Bicêtre, France

Introduction : A useful approach was introduced by Pauly *et* al. to design RF pulses based on a k-space analysis of small tip angles [1]. This technique was extended by Sersa *et* al. to design any shape of selection in any spatial direction [2]. Following this idea, Kerwin *et* al. fully described tagging [3]. A slice selection is performed by a frequency-selective excitation. It can be achieved by a modulated waveform given by the Fourier transform of the desired spatial slice profile. By incorporating velocity-encoding gradient pulses within RF pulse trains, Norris *et* al. could select either moving or still protons [5]. Here, a pseudo-spectral selection is presented, so that a selective excitation along a "velocity-direction" is made possible with a preset "velocity-thickness" and centre velocity. This work shows both simulated profiles and experimental images acquired with this technique.

Theory : The presented excitation scheme is based on a succession of hard pulses and bipolar dephasing gradients (see Figure 1), as introduced for Fourier velocity encoding (FVE) [4]. It corresponds to discretisation of a selective pulse. Here, $M = M_x + j\,M_y$ is the transverse magnetisation. In the small angle approximation ($\cos\alpha_i \approx 1$, $\sin\alpha_i \approx \alpha_i$), we have $\theta_i = 2\pi(i-1)\times u_0/\mathrm{FOS}$, where u_0 represents the selected velocity within the range $[-\mathrm{FOS}/2\ ,\ +\mathrm{FOS}/2]$, and FOS is the chosen Field Of Speed. The increment in RF phase makes it possible to focus on the selected velocity u_0. For velocity u after step n, we have:

$$M(u) \approx M_0 \cdot \exp\left[2j\pi\left(\frac{n}{2}-1\right)\frac{u_0}{\mathrm{FOS}}\right]\sum_{i=1}^{n}\alpha_i \cdot \exp\left[2j\pi\left(\frac{n}{2}-i\right)\frac{u-u_0}{\mathrm{FOS}}\right]$$

The sum is the Discrete Fourier-Transform of α_i, thus enabling any profile over the velocity direction.

Materials and methods: Simulations were made on Scilab Software [6] without the small angle approximation, for various values of n and of total flip angle $\alpha = \sum \alpha_i$ from 5° to 90° and for a 2-lobe hamming filtered sinc envelope. Even for a total angle of 90°, the small angle approximation is valid because individual flip angles remain small. Figure 2 shows a velocity-slice profile centred on null velocity ($\theta = 0$) simulated with $\alpha = 10°$ and $n = 20$.

This velocity-selection pulse was implemented in a 2D FLASH sequence so as to replace the usual slice selection pulse. Images were taken with a 200-mm diameter, receive-only, surface coil in a 1.5 T Signa GE imager fitted with a 2.2 mT/m gradient set (slew rate of 120 T/m/s). Plexiglas tubes (Ø 11 mm and 19 mm) were imaged with flowing water at a controlled rate.

Results: The images presented in figure 3 show 2D-images acquired after a through-plane velocity-slice selective pulse on water flowing in Poiseuille flow condition. The selective pulse (40 ms-long) was built with 20 hard pulses and a FOS of 2 m/s, resulting in a 0.4 m/s slice thickness.

Conclusion and discussion: A method based on the small-tip-angle approximation was applied to select a specific velocity class to image only spins within the chosen class. This technique could be especially useful when validating flow models. It provides information on spins with a specific velocity and the acquisition is faster than phase-contrast velocimetry. Moreover, this technique is not hindered by spins with velocities within the same voxel outside a chosen range. Therefore, it may compete FVE strategies, as spatial slice-selection does with 3D imaging. A long time is needed to apply the pulse but recent improvements in gradient sets may help, as well as optimisation techniques like the ones proposed by Sersa *et al.* [2]. Further studies are on the way to compare velocity slice selection with FVE.

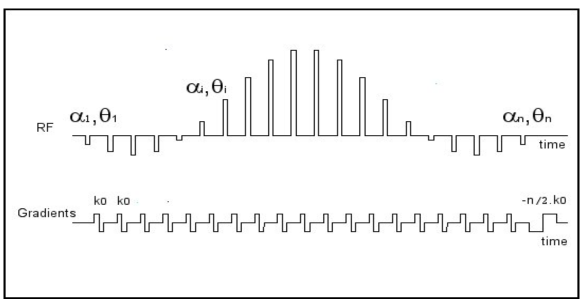


Figure 1- Excitation pulse for the pseudo-spectral selection: series of *n* small tip angles α_i (phase θ_i) under a 2-lobe Hamming filtered sinc envelope with bipolar dephasing gradients on the velocity direction (k_0 refers to the distance achieved in "k-space along velocity direction"). At the end, an ultimate bipolar pulse, with opposite sign, rephases the magnetisation.

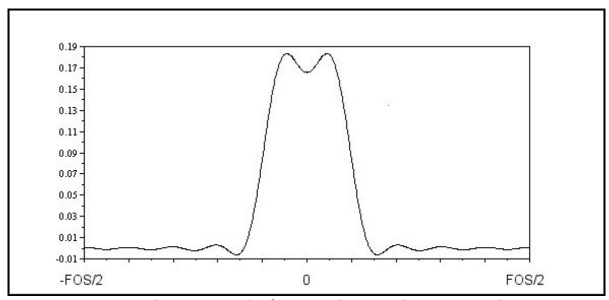
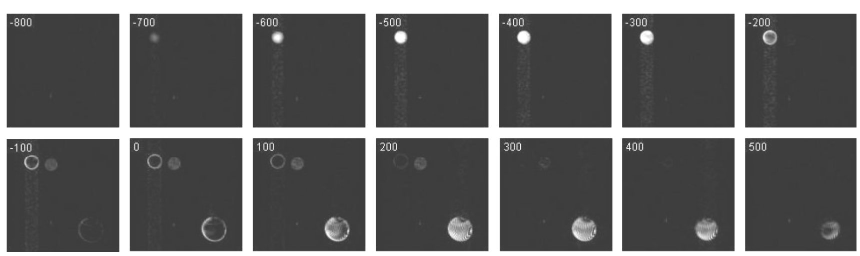


Figure 2 – Simulation result for a velocity-slice centred on zero with the scheme of Figure 1 (n=20 and α =10°). The real part of the transverse magnetisation is plotted along the velocity, expressed as a fraction of the initial magnetisation. The imaginary part of magnetisation was smaller than 0.1% of the total magnetisation. Full Width at Half Maximum was 0.2×FOS.

Figure 3- MR 2D-images achieved after a through-plane velocity-selective RF pulse on a Poiseuille flow in opposite directions through 2 tubes. The numbers written above is the position of the velocity-slice in the velocity-space (from -800 to 500 mm/s). The field of velocity was 2 m/s and the "slice thickness" was 0.4 m/s. Spatial FOV was 8 cm, with a 128² matrix (readout BW = 32kHz). Note the rings of null velocity corresponding to water along tube walls for null velocity-slice.



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