

Rheo-NMR micro-imaging in natural coordinates

Uri Nevo, Evren Özarslan, Peter J. Basser

Section on Tissue Biophysics and Biomimetics, NICHD, NIH, Bethesda, MD, USA

Abstract:

The Rheo-NMR is a unique device for non-invasive measurement of molecular displacements and spectra under controlled shear conditions [1]. By harnessing advantages of NMR spectroscopic methods and imaging, Rheo-NMR has found important niches in materials sciences and hydrodynamics [1].

An added benefit of Rheo-NMR is in imaging the medium under shear flow. Conventionally, MR images are sampled using a Cartesian k-space trajectory, and reconstructed in a Cartesian framework, (even if sampled in a non-Cartesian way). Here we suggest sampling and reconstructing the Rheo-NMR data in the natural coordinate system defined by the direction of fluid stream-lines, (i.e., cylindrical coordinates for the Couette cell and spherical coordinates for a cone-plate geometry).

In the Couette cell, the k-space samples, $M(k, \phi_k)$, are related to the local magnetization $M(r, \phi_r)$ by the Fourier relation:

$$M(k_r, \phi_k) = \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dy M(x, y) e^{-i(k_x x + k_y y)} = \int_0^{\infty} dr r \int_0^{2\pi} d\phi_r M(r, \phi_r) e^{-ikr \cos(\phi_r - \phi_k)}$$

$M(r, \phi_r)$ can be obtained by inversion and by expansion of the exponential factor, such that:

$$M(r, \phi_r) = \sum_{m=-\infty}^{\infty} i^m e^{im\phi_r} \int_0^{\infty} dk k J_m(kr) \int_0^{2\pi} d\phi_k M(k, \phi_k) e^{-im\phi_k}$$

where $J_m(kr)$ is the m^{th} -order Bessel function of the first kind. This combined radial sampling and reconstruction scheme is advantageous over the Cartesian framework by providing: (a) similar partial volume artifacts in all voxels, (b) identical angular and linear resolution for all voxels and at all angles, (c) no ghosting artifacts in the velocity plane (no phase-encoding [2]), (d) homogeneous spatial frequency content in r and ϕ , (e) convenient presentation for further analysis. This framework is a particular case of the general concept by which the sampling and reconstruction parameters are uniquely tailored to exploit the specific symmetry, geometry and other characteristics of the sample.

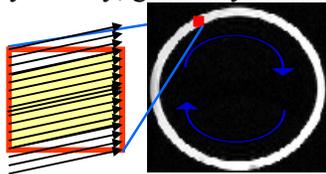


Figure 1: An axial cross section of the Rheo-NMR with 'zoom' on a Cartesian voxel. Notice that the partial volume of different stream-lines depends on the direction of flow within each voxel

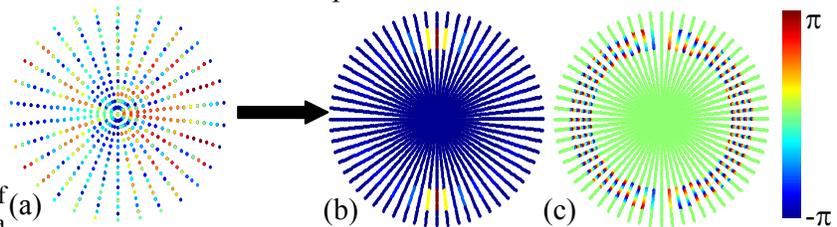


Figure 2: Simulation of a micro-imaging experiment of a rotating Rheo-NMR. (a) The sampled cylindrical k-space data. (b) The resulting cylindrical magnitude image, and (c) phase images.