PhD thesis proposal 2024-2027
University of Lorraine - LEMTA laboratory – Team "MRI for Engineering"

TITLE

"Optimization of magnetic resonance velocimetry (MRV) methods for flow studies".

SUPERVISION

Jean-Christophe Perrin (thesis supervisor)
Other people involved (LEMTA): Sébastien Leclerc / Laouès Guendouz / Tien Dung Le / Christophe Morlot

CONTEXT

The LEMTA laboratory's "MRI for Engineering" cross-disciplinary team is developing a research axis concerning the development of velocity field measurement methods (magnetic resonance velocimetry - MRV) with applications in the field of porous media, multi-phase transport, complex fluid flows, processes... etc.

The PhD work of Feryal Guerroudj (2019-2022) has highlighted limitations in the use of "standard" MRI methods for characterizing sub-millimeter-scale flows [1-3]. Other limitations arise when flows are unsteady, as the time required for measurement (a few milliseconds) is too long compared with the characteristic time scale of the phenomena probed. In order to better understand these limitations, a numerical simulation of the behavior of nuclear magnetization based on Bloch's equations was initiated as part of a Master II internship [4]. The results have already allowed us to simulate some of the measurements, but the simulation needs to be extended to take account of the full complexity of MRV methods.

In addition, the installation of a new MRI system (first half of 2024) will open up new possibilities for developing measurement sequences, better adapted to needs of the the laboratory (open source software, collaboration with the manufacturer).

PROPOSAL

The PhD work will initially involve developing a simulation tool for "standard" MRI velocimetry experiments using bipolar field gradients (a continuation of the Master II work [4]). This tool, which will need to be validated by measurements on the new 3T imager and on the 14.1T micro-imaging system at the NMR platform of the University of Lorraine, will enable the limits of currently employed methods to be identified quantitatively (continuation of thesis [3]).

Secondly, the work will concentrate on optimizing measurements by programming and using new sequences. One of the possible directions is that of optimal control theory. This approach, already introduced in the fields of NMR [5] and medical MRI [6], is beginning to be applied to MRV. Initial work using optimal control in MRI velocimetry is encouraging, as it demonstrates that measurement time can be shortened by encoding molecule velocity directly during the initial RF pulse [7] and not during bipolar field gradient pulses.

REFERENCES

[1] F. Guerroudj *et al.*, "3D magnetic resonance velocimetry for the characterization of hydrodynamics in microdevices: Application to micromixers and comparison with CFD simulations," *Chemical Engineering Science,* vol. 269, Apr 2023, Art no. 118473, doi: 10.1016/j.ces.2023.118473.

[2] F. Guerroudj *et al.*, "Low-cost MRI devices and methods for real-time monitoring of flow and transfer phenomena in milli-channels," *Pure and Applied Chemistry,* 2023 Jun 2023, doi: 10.1515/pac-2023-0105.

[3] Feryal Guerroudj, PhD thesis, University of Lorraine (2022). https://docnum.univ-lorraine.fr/public/DDOC_T_2022_0273_GUERROUDJ.pdf

[4] Vincenot, M. "Simulation de micro-mélanges par IRM". Rapport de stage de Master II Energie, Université de Lorraine, Septembre 2023.
[5] Tosner, Z. et al., "Optimal control in NMR spectroscopy: Numerical implementation in SIMPSON", Journal of Magnetic Resonance, vol.197, 2009, 120-134.
[6] Van Reeth, E. et al. Optimal control design of preparation pulses for contrast optimization in MRI, Journal of Magnetic Resonance, vol. 279, 2017, 39-50.
[7] Jouzdani, M. A. *et al.,* "Optimal control flow encoding for time-efficient magnetic resonance velocimetry", Journal of Magnetic Resonance, vol. 352, 2023, 107461.

WORKING CONDITIONS

The thesis work will take place at the LEMTA laboratory in Vandoeuvre-lès-Nancy, within the "MRI for Engineering" team currently comprising 6 researchers, 2 engineers, 1 PhD student, 1 Postdoctoral fellow and 3 Master students (https://lemta.univ-lorraine.fr/irm-ingenierie/).
Collaboration with the CREATIS laboratory (INSA Lyon, Université Claude Bernard Lyon 1, UMR CNRS 5220, Inserm U1294, Université Jean Monnet) will be envisaged to work on the use of the optimal control approach (https://www.creatis.insa-lyon.fr/site/fr).

The LEMTA laboratory has access to two MRI imagers (2.34T and 14.1T) from the NMR platform of the University of Lorraine (https://crm2.univ-lorraine.fr/plateformes/plateforme-rmn/), and is in the process of acquiring a new 3T device to be installed on its site.

The thesis is funded by a three-year doctoral contract (french Ministry of Higher Education and Research). Remuneration, set by the LPR, will be between €2,100 and €2,300 gross. The starting date is set for October 1, 2024.

CANDIDATE PROFILES

Candidates must hold (or will hold during the 2023-2024 academic year) a Master's 2, engineering degree (or equivalent) in physics, engineering, chemical engineering, process engineering or a related discipline, and will have an intermediate level of French and English. Knowledge of NMR and/or MRI and laboratory experience are not mandatory, but will be considered an asset.

APPLICATION PROCEDURE

Candidates should contact the thesis supervisors directly by e-mail (jean-christophe.perrin@univ-lorraine.fr) and provide a detailed CV, a cover letter and a list of at least two references who can be contacted by telephone or e-mail. The deadline for applications is June 28, 2024.