PhD Position at the Institut Clément Ader (ICA), Toulouse, France

Development of a Knudsen micropump for integration in a Pulsed tube Cryo-cooler

Key-words

Microfluidics, Rarefied Gas flows, Temperature Driven Micropump, Miniaturized Cryo-cooler

Context

For many processes in science or applications, low temperatures far less than 273K are either beneficial or mandatory. For instance, temperatures of 100K-150K or less are requested for superconductors, specific chemical processes, electromagnetic systems or several infrared (IR) sensors as well as other sensor systems. In numerous cases, liquefied gases can be used to reach those temperatures, but this solution is more or less limited to stationary systems. One alternative is the use of cryo-cooling machinery such as pulsed tube Cryo-coolers (PTCC) which are versatile systems for different applications, ranging from sample preparation in biology and medicine to application of sensors in science and industry.

PTCC works in principle like a Stirling engine combined with a regenerator [1]. The system consists in a tube with a cold point and normally two hot points, a regenerator heat exchanger material of large heat capacity and, regularly, a big volume between the cold point and one of the hot points as well as a buffer volume and a compressor (Fig. 1).

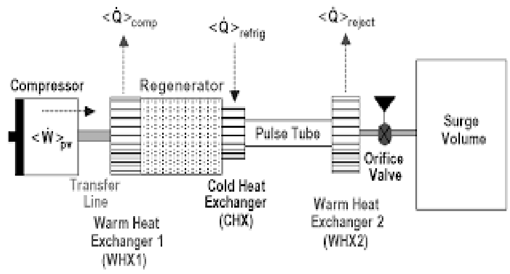

Fig. 1: Schematic of a PTCC. from: www.CryoCooler.org

In the last decades, miniaturization has been at the centre of many research and development fields. Scaling to mini, micro or even nano scales allows integration of a multitude of specific functionalities into a single device, or improves the performances of devices (i.e. time or spatial resolution of sensor devices, sometimes by orders of magnitude).

However, all PTCC need a compressor, which causes vibrations transferred by the tubing into the system. For macro scale devices this is not much of a problem, because damping arrangements can be implemented, cutting off the vibrations. This changes when the system dimensions are scaled down to the microscale. Due to the decrease of dimensions, vibrational distortion cannot be settled with any regular known counter-measures anymore. This is especially true for miniaturized measurement and sensing systems, in which the spatial resolution is in the range of some µm or below, and the time resolution is in the µs or even ns range. Thus, the implemented compressor has to work without moving parts, generating neither friction nor vibrations in any way.

For this purpose, Knudsen pumps (KP) are good candidates as they can generate gas movements by thermal transpiration obtained by temperature differences only [2-11]. A mass flow is obtained from a cold to a hot region when their connecting channel is small enough. By combining in a cascade system several hot and cold spots with alter-natively small and large channels, as schematically shown in Fig. 2, a net mass flow is generated and a significant pressure difference between inlet and outlet can be reached.

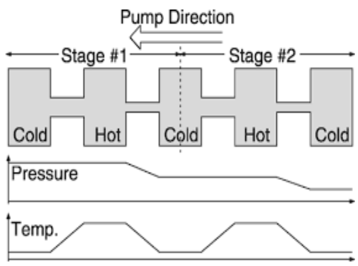

Fig. 2: Schematic working principle of a Knudsen pump [3]

Objectives of the study

This PhD thesis is part of an international project, Pulsed tube Cryo-cooler with integrated Knudsen micropump – PuCK, funded by the French and German Research Agencies, and involving two research teams from the Institut Clément Ader in Toulouse, France and from the Karlsruhe Institute of Technology, Germany. The general aim of the project is to develop, manufacture and test a modular micro PTCC (mµPTCC), including a Knudsen pump (KP) acting as vibration-free compressor, as proof-of-concept device.

In this framework, the objectives of the present PhD thesis will be first to develop of a numerical model, based on a lumped-parameter approach, for pre-design of the whole µPTCC. The numerical design and optimization of the KP will then be performed using complementary numerical approaches [12-15]. Based on the results of the modelling and simulations, Knudsen Pump prototypes will be manufactured using different processes ranging from lithography to micromachining, available within the Karlsruhe Nano Micro Facilities for information-driven material structuring and characterization Network (KNMFi) and/or at the micro and nanotechnologies platform of the Laboratory for Analysis and Architecture of Systems (LAAS) in Toulouse. The KP prototypes will then be tested on an experimental facility designed and fabricated at ICA, before to be integrated in the whole µPTCC which will be experimentally characterized in a test bench developed at KIT. The results will be evaluated and compared to the simulation results obtained from the lumped-parameter model. This final integration and testing step will be performed in close collaboration with a PhD fellow hired at KIT for the design and development of the micro heat exchangers and other elements of the µPTCC.

Methodology

The planed steps for this project will consist in:

1- Developing of a numerical model, base on lumped parameter approach, for the pre-design of the whole mµPTCC – *Task performed in collaboration with KIT PhD fellow*
2- Designing, using different numerical models, a Knudsen pump addressing the specifications provided in task 1
3- Manufacturing the Knudsen micropump prototypes using processes available at the KNMFi in Karlsruhe and/or at the LAAS in Toulouse
4- Experimental testing of the prototypes on an experimental facility specifically developed at ICA
5- Assembling of all the µPTCC components and experimental characterization of the whole system on a specific test bench developed at KIT - *Task performed in collaboration with KIT PhD fellow*

International collaborations

This PhD position is part of the PuCK German/French Project coordinated by Prof. Juergen Brandner at the Institute of Microstructure Technology of the Karlsruhe Institute of Technology (https://www.imt.kit.edu/) and Prof. Lucien Baldas at the Institut Clément Ader (https://ica.cnrs.fr/home/). The work will mainly be performed at ICA in Toulouse, but frequent interactions will be needed with the team at KIT, in particular with the PhD fellow hired in Germany for this project. Several travels and short stays in Karlsruhe are thus expected, in particular for running some of the experimental campaigns planned in the project.

Requirements

- Master-level degree in Mechanical Engineering, Process Engineering, Physics or similar,
- Communication skills and good written/verbal knowledge of the English language, good presentation skills,
- A good background in fluid mechanics and/or heat transfer,
- Experience in experimental techniques and/or numerical simulations in fluid dynamics would be helpful.

Duration and Starting date:

3 years from March 1st, 2023

Financial information / Salary

Annual gross salary: 36 k€

Application

Interested candidates should send their detailed CV, cover letter and last transcript of records **before December 23rd, 2022**, to the two supervisors:

Dr. Christine Barrot - christine.barrot@iut-tlse3.fr

Prof. Lucien Baldas – baldas@insa-toulouse.fr

References

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