PHD PROPOSITION

« Heat transfer study in superfluid helium through confined geometry »

INTRODUCTION

The geometrical configuration of superconducting magnet for accelerators creates geometrical confinements that reduce the cooling even with superfluid helium (T < 2.2 K). The electrical insulation of the superconducting cables is one of the confined geometries that constitutes the highest thermal barrier for cooling. For NbTi magnets, these electrical insulations are composed of several layers of polymer tapes creating a network of micro-channels. These channels have characteristic dimensions in the order of 10×10 µm². Moreover the wrapping of these polymer tapes creates constrictions with cross-sectional and orientation changes. Another example is the space, between the steel collars (around 200 µm), situated around the superconducting coils to prevent undesirable movements of the conductors. During magnet « quenches » (when the coil goes from superconducting to normal state), the energy dissipation is such that helium undergoes various thermal regime changes associated with phase transitions.

Understanding the thermal phenomena of heat transfer and phase transition in superfluid helium at this level of geometrical confinement is necessary to achieve reliable design of the cooling system. It would also help apprehending the transient phenomena that arise during the quenches of these superconducting magnets such as the ones of the Large Hadron Collider at CERN, Geneva.

Experimental methods have been developed to study heat transfer from micrometer to millimeter scale channels. They are based on MEMS technology to construct micro-channels with Pyrex wafers by chemical etching (See fig. 1) and precision machining for larger ones. These channels are tested as a function of different parameters, such as the heat flux, temperature or pressure. These tests are performed in an experimental facility capable of creating a superfluid helium bath at variable pressure with a temperature controlled within millikelvin during the entire testing period (several days) (cf. fig. 2).

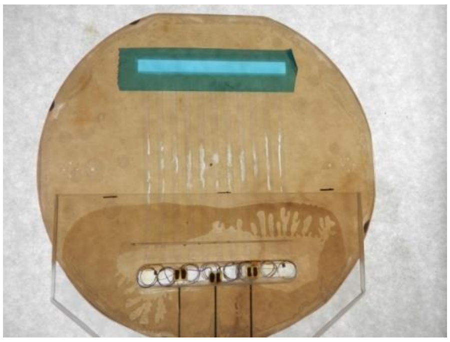

Figure 1: 11 channels Pyrex Wafer 2 mm in width and 10 µm in height. The internal superfluid helium bath (lower of the photo) includes temperature sensors and a heater; it is connect through the micro-channels to the external bath of the cryostat (exit of the channels in blue color).

Figure 2: Experimental facility allowing to create a stable superfluid helium bath from 1.4 K to 2.15 K with a constant temperature regulated to the millikelvin. At the center the cryostat and on the left, the data acquisition system and cryostat monitoring.

The transient regimes will also be studied with specific wider channels from 100 µm up to mm in height with an appropriate instrumentation to monitor the propagation of the phase changes in time and space (cf. fig; 3). These results will be used to feed the numerical modeling effort on the transient heat transfer and phase change that has been started in our laboratory using Fluent®.

LABORATORY AND SUPERVISION

Most of the PhD work will be done at the Cryogenic laboratory of the Department of Accelerators, Cryogenics and Magnetism (DACM) belonging to the CEA Paris-Saclay located 25 km south of Paris. The cryogenics laboratory has the facilities and the crews skilled to carry out the experimental tests and the machining capabilities to support the work of the PhD student.

The future PhD student will be registered at the University of Paris-Saclay. The study will be supervised by Dr. Bertrand Baudouy, an experienced researcher in low temperature heat and mass transfer, especially in superfluid helium and supported by a team of expert technicians and engineers in cryogenics.

PROPOSED WORK

The heat and mass transfer in superfluid helium in small channels in a single or network configuration will be studied experimentally. The hydraulic diameter of the channels range from mm down to micrometer. The study will cover the pure superfluid regime (régime de Landau), the turbulent regime (régime de Gorter-Mellink) and the transition regime with the apparition and development of superfluid vortices. In the transient regimes, the heat transfer at the wall and with the fluid will be studied with and without phase transition. The effects of Different parameters will be studied depending on the project advancement, such as the channel length, the hydraulic diameter, the channel entrance and exit and the pressure. The effect of a point restriction or a change of cross section present in the actual insulations is also within the scope of the proposed work.

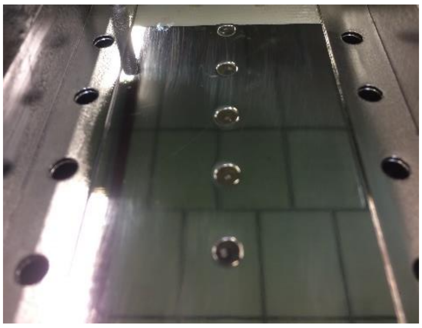

Figure 3: Lower part of the mm scale channel instrumented with several cryogenic millimetric temperature sensors.

Numerical modelling will be performed in parallel with the measurements using Fluent® or possibly OpenFoam®. The model is based on the Landau two-fluid model (Modified Navier-Stokes equations) describing the behavior of helium flow. A phase transition module to be added to the 3D-code will be a part of the work.

REQUIREMENTS

We seek for excellent and highly motivated candidates with a Masters in Physics, Applied Physics or Mechanical Engineering with hands on experience in fluids dynamics, heat transfer or condenser matter physics. She/he should have a good level in physics to comprehend the physical phenomena from heat transfer to superfluid helium physics. Experience in data acquisition and cryogenics is a plus. Moreover, the candidate must be motivated by experimental work.

SKILLS TO BE ACQUIRED

The candidate will acquire a know-how that will enable him/her to pursue a scientific career in many fields in a research lab or industry. More specifically, he/she will have the opportunities to learn useful competencies in the domains of superconducting magnets, low temperature engineering, numerical modeling, fluid dynamics, cryogenics and vacuum, instrumentation and "low level" measurements and data acquisition.

COLLABORATIONS

As a part of the EASItrain Marie Curie Project (http://easitrain.web.cern.ch/), the PhD student will collaborate with all laboratories involved in the project.

CONTACTS

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