HECAL: A cryostat for calibration of hot wires

S Kharche1, J P Moro2, C Baudet3 and A Girard4

1Université Grenoble Alpes, CEA IRIG-DSBT, F-38000 Grenoble, France
2CEA-DEN-DANS-STMF, F-38000 Grenoble, France
3Université Grenoble Alpes, LEGI, F-38041 Grenoble, France

Corresponding author: alain.girard@cea.fr

Abstract. The Laboratory SBT (“Systemes à Basse Température”) has studied Fundamental Turbulence at High Reynolds Numbers for many years. Different experiments were performed, which allowed to study high Reynolds Number flows, and also to compare these (normal helium) turbulent flows with superfluid flows driven under the same conditions. First section describes the interest of hot wire anemometry to characterize the turbulent flows. Hot wires were used already in Hejet, and more recently in SHREK. However, the hot wires should be calibrated, which is not always possible in situ. Therefore, we built a facility dedicated to the test and calibration of hot wires. This original facility is described in second section; instead of having a fixed hot wire in an incoming flow, which is the usual situation for hot wire calibration devices, the hot wire to calibrate is installed on a support part, which can be rotated in a fluid at rest. In order to calibrate the hot wires in the same velocity domain as in the SHREK and Hejet experiments, the support of the hot wire can reach velocities of a few meters per second. The first results obtained with Hecal are presented in third section. Fourth section describes the future work to be performed in the CEA facilities.

1. Introduction: turbulence studies at CEA/SBT; hot wires for turbulence, and the Hejet facility

CEA/SBT has worked in the field of turbulence for more than ten years [1-5]. The main contribution of the laboratory had consisted in building and operating the flow cooled with the large refrigerator available at CEA [6], while partner laboratories mainly contributed in the characterization of the flows. However, it appeared early that CEA/SBT should also be involved in the characterization of the cryogenic flow. Therefore, as hot wire anemometry is one of the most commonly used diagnostic tool for turbulent flows, we decided to develop this particular technique [4], and adapt it to cryogenic flows. This work started in the Hejet facility (shown in Figure 1), where hot wires were used in cryogenic helium, both in normal and superfluid helium [7].

However, it was shown that the operation of hot wires in He-II was not straightforward. Indeed, heat transfer in He-II is fundamentally different as what occurs in a normal fluid. Therefore, we decided to go one step further, and study the connection between the velocity of the flow, and the signal of a hot wire in superfluid helium. For this we decided to modify the Hejet facility. This facility is a liquid helium jet, pressurized via the valve 17, driven by a turbine (6) rotated by a motor (1), and whose temperature is fixed by a heat exchanger (12) where pressurized liquid is cooled in the saturated bath pumped through valve (3) and pump (4); the jet expands into the pressurized bath through a nozzle (10). A rupture disk (13) prevents the pressure to increase above the limit of 8 bars. For cost reasons, we decided to modify
this facility by simply changing the pressurized volume and by using the rotating axis which drives the turbine.

![Image](a)

![Image](b)

**Fig. 1: The Hejet facility** (a): Picture of the facility; (b): Schematic drawing

2. **Description of HeCal and of the experiments.**

The objective of the HeCal facility is to study the relation between the velocity of the flow and the signal of a hot wire, both in normal and superfluid helium. Indeed, this is a calibration tool for hot wires working in cryogenic helium. Usually, hot wires are calibrated in a laminar flow with known velocity (commercially available for room temperature operation). At cryogenic temperature, there is no such device available. Therefore, we prefer to move the hot wire with a known velocity in a fluid at rest. This is performed in the HeCal facility.

2.1. **Description of HeCal**

The principle is the following: hot wires to calibrate are mounted on a supporting part connected to a rotating axis. The motor is driven to the maximum velocity desired within the adequate time, so that the maximum calibration velocity is reached within less than one turn (this is to prevent turbulence generated from the wake of the supporting part). HeCal uses the main vessels of Hejet (for liquid nitrogen pre-cooling and for the saturated helium bath). The thermal shields are those of Hejet as well (Figure 2). The turbine which generates the flow in Hejet is removed, and the pressurized volume is considerably simplified. Indeed this volume hosts the hot wires installed on the supporting part which is connected to the end of the rotating axis (Figure 3a & 3b). Three or four hot wires can be installed in the volume, each of them being placed at a different radial position. As a consequence, hot wires that are installed at small radii will be calibrated up to a smaller velocity than those placed at large radii. The maximum of four hot wires can be mounted on the support at a radius of 35.5, 48.5, 60, 73.5 mm; out of which the results presented here deals with the hot wire mounted at a radius of 60mm. In order to avoid the pressurized rotating seal (Figure 1b, 18) which was used in Hejet, the motor is installed in a (room temperature) vessel which is at the same pressure as the cold pressurized vessel. These two vessels are however connected through a high pressure drop, which is mandatory to have a reliable operation in superfluid helium. In order to have a good heat exchange in superfluid helium, a copper tube is installed...
at the end of the pressurized vessel. This tube has led to excellent heat exchange in He-II. The
temperature in the bath is measured via a thermometer (Cernox type). As the hot wires are in a rotating
frame, it is necessary to use rotating electrical contacts (commercially available) to bias the wires, and
measure their voltages.

![Figure 2: The Hecal facility.](image)

2.2. Procedure of test of hot wires.
The calibration is a transient process: in order to have a fluid at rest, the hot wires should be calibrated
before one turn of the supporting part. In order to estimate the velocity of each hot wire, we record the
instantaneous rotation velocity of the motor. This frequency is measured via a commercial tachometer
connected to the motor, whose time constant is in the range of a few tens of microseconds, by far
sufficient for our measurement. The motor is driven by a power supply digitally controlled, which
enables quick rise of the current, so that the conditions for reaching the maximum desired velocity within
one turn is fulfilled. This procedure is applied in air at room temperature, and in He-I and He-II. We

![Figure 3: (a) Hot wires installed in Hecal (b) Hot wire support connection](image)
have also performed measurements of the thermal time constant of the hot wires. These results are shown below.

3. First results

3.1. Calibration of hot wires

The hot wires are of Wollaston type, 1.27 µm in diameter and length of a few hundreds of microns. Such a small radius makes the hot wire very fragile; in particular a special attention should be paid to the cool down phase, when differential contractions may lead to the destruction of the hot wire. To prevent this, a special procedure is applied, and the hot wire is curved during the fabrication process [8], to compensate for the contractions at low temperature. Figure 4 shows the signals of the hot wire and of the tachometer (tachometer: 1 V = 2.38 Hz instantaneous rotation frequency). Hot wires are operated in constant current mode (i.e. a constant current is injected in the hot wire, and the voltage is measured to account for its resistance). These figures show the procedure explained above: the motor is driven so that its rotation frequency increases, and then it is stopped once the necessary velocity is reached. This occurs within typically one or two seconds. It is important that this procedure lasts for a short period of time, in order to avoid an increase of the temperature of Helium. Figure 4a shows a signal of hotwire in normal helium, while figure 4b shows the same signals in superfluid helium. The temperature of the hot wire in both conditions was similar (i.e. the resistance of the hot wire was the same). It is worth mentioning that it was necessary to inject more current in the hot wire when working in superfluid helium, than in normal helium (16 mA in He-II, 13 mA in He-I).

The signals of figure 4 can be interpreted as follows: at t=0, the hot wire is cooled via natural convection, which is less efficient than forced convection. So the resistance (dependent on the temperature) of the wire is high, and consequently the voltage as well. When the motor starts accelerating, the hot wire is cooled, and its temperature drops, and the voltage as well. The maximum relative velocity between the flow generated by the supporting part (wake flow) and the hot wire is reached at 1.1 second. Then the voltage starts increasing, which shows that the relative velocity between the generated flow and the hot wire starts decreasing. At t=1.7 seconds, the signal of the hot wire stops to increase, as the relative velocity between the generated flow increases because the velocity of the hot wire becomes close to zero, while the fluid has reached its maximum velocity. This behaviour is observed both in normal and superfluid helium.

![Figure 4: Time evolution of the hotwire voltage and tachometer signal. a: He I; b: HeII](image)

The signals of Figure 4 are used for calibration of the hot wires. In order to verify that the procedure is valid, we apply it at room temperature (in air), with hot wires overheated by a factor of 40%. Figure 5 shows a calibration curve obtained in air. The experimental fit (pink curve) shows that King’s law is well fulfilled. This curve shows that Hecal can be used as a calibration system for hot wires, similarly to conventional laminar wind tunnels.
Figure 5: Calibration curve obtained with hot wires at room temperature

Kings’s law is a robust law for hot wires. Figure 6 shows that, in normal Helium, it is also well fulfilled (curve 6a), while it is by far less satisfactory in superfluid helium (Figure 6b). This is not surprising, as heat transfer in superfluid helium is very different from heat transfer in normal helium. However, we can see that there is still a dependence on the velocity in superfluid helium; but the signals exhibit more fluctuations than with normal helium.

Figure 6: Calibration curve at low temperature. a: He-I; b: He-II

3.2. Evaluation of the time constant

In Constant Current Anemometry, the time constant of the measure is directly related to the thermal time constant of the hot wire (which is not the case in Constant Temperature Anemometry, nor Constant Voltage Anemometry). This time constant can be measured by quickly applying a small additional current step di to the hot wire, as shown in figure 7. This thermal time constant is of course dependent on the cooling mechanism, and hence on the velocity of the flow with respect to the hot wire.
Figure 7: Principle of measurement of the thermal time constant: an additional step of current $dI$ is applied at $t=5$ ms and cancelled at $t=20$ ms; the time constant here is $0.3$ ms for pedagogical purpose.

All quantities are approximated to first order in $dI/I$.

The voltage of the hot wire (temperature $T$, resistance $R(T)$, initial current $I$, and initial voltage $RI$) then increases immediately by a factor $dV=R(T)dI$, and later increases as the additional current heats progressively the hot wire, leading to a resistance $R+dR=R(T+DT)$ after an exponential growth of time constant $\tau$. When the current step is stopped, the voltage drops immediately by $R(T+DT)dI$, and later with an exponential decay of time constant $\tau$ down to the initial value $RI$. The results obtained at 2.0 K are summarized in table I.

| Temperature (K) | Velocity (m/s) | Time constant (µs) |
|----------------|---------------|--------------------|
| 2.0            | 3.1           | 22.6               |
| 2.0            | 4.4           | 20.7               |
| 2.0            | 5.6           | 18.6               |

Table I: Time constant measurement in He-II.

As expected, the time constant decays as the velocity increases. Indeed, such measurements were already performed in the SHREK experiment [5], but we needed then to assume a solid rotation of the liquid medium to derive an absolute calibration of the velocity. The main interest of Hecal is precisely to avoid this assumption. This measurement of time constant in Hecal was made in He-II only, at 2.0 K only. Only large (> 3 m/s) velocities were analysed. Similar studies will be pursued by varying experimental conditions.

4. Conclusion and future work.

In this article we have shown the first results obtained with the Hecal experiment. Calibration curves can be obtained in He-I as well as in He-II. In He-II King’s law is not well fulfilled, which can be accounted by the differences in heat transfer in He-II and He-I. We still need to perform many additional experiments: the dependence of the calibration curve in superfluid helium needs to be carefully studied at different temperatures and heating powers. The evolution of time constant versus temperature (in He-II, He-I) will also be studied. How the fluctuations of the hot wire can be interpreted as a turbulent cascade in He-II will be also studied.

5. References

[1] Rousset B et al 2008 *AIP Conf. Proc.* 985 633
[2] Duri D et al 2015 *Rev. Sci. Instrum.* 86 025007
Acknowledgments
We acknowledge Bernard Rousset and Pantxo Diribarne for fruitful discussions and contributions. We acknowledge the technical support of Bertrand Rollet (design) and Jérôme Chartier (construction and operation). This work was supported by the EUHIT European FP7 program (Grant Agreement No. 312778), by the french ANR project “Ecouturb” (ANR-16-CE30-0016-01), and by the french ANR project “LANEF” (ANR-10-LABX-51-01).