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Commissioning of the NED cryostat

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General description and requirements

The NED cryostat is designed to perform heat transfer experiments primarily in superfluid helium in the temperature range of 1.6 K to 2.1 K at atmospheric pressure. But its design allows performing experiments at different thermodynamic state such as in normal helium with a temperature around 4.2 K and a pressure around the atmospheric pressure and also in supercritical state at a pressure higher that 2.5 Atm. These experiments demand a fine temperature regulation of the helium bath (reference bath) where the tested sample will be located. In superfluid helium state, the temperature of the reference bath must be regulated within 1 mK over the duration of the test, i.e. an hour. In normal helium the temperature stability of the reference bath is ten times higher i.e. around 10 mK over the duration of the test. For these two thermodynamic states the pressure has to be regulated with few mbar. For the supercritical state only pressure will be regulated within 10 mbar.

Pressurized superfluid helium is produced from normal helium refrigerated by a saturated superfluid helium (He II) bath located around it. A Pumping system, composed of several ROOTS pumps in series and a roughing pump, is used to generate saturated He II (for example: 1.8 K – 16 mbar). The cryostat is based on the principle of the "Claudet bath" described in *Figure 1*. The pressurized He II bath is maintained at constant temperature by heat exchange with the saturated He II bath located around it and a temperature regulation system. The pressurized He II bath is separated from the 4.2 K bath by a "lambda plate". The saturated He II bath is filled with helium from the 4.2 K helium bath through a thermal heat exchanger. The thermal heat exchanger (gas-liquid: 4.2/1.8 K) is located in the pumping line, for sub-cooling liquid helium I and placed before a cryogenic expansion valve (Joule-Thomson valve). The cryostat should be able to maintain a pressurized He II bath (and also the 4.2 K bath) up to 3 bars.

CEA Saclay established the specifications of the cryostat in a document edited in 2004 [1]. The design and fabrication of the cryostat was realized and provided by Kriosystem in Poland under supervision of Wroclaw University of technology [2]. Kriosystem and WUT were responsible for the design and the thermal and mechanical calculations necessary to build the cryostat. They were also responsible for manufacturing the cryostat, assembly, instrumentation, packing and expedition. The thermal heat exchanger was designed by CEA Saclay and described in a document [3]. Kriosystem manufactured it. Integration of the heat exchanger was under the responsibility of Wroclaw University. Furthermore, leak tests in

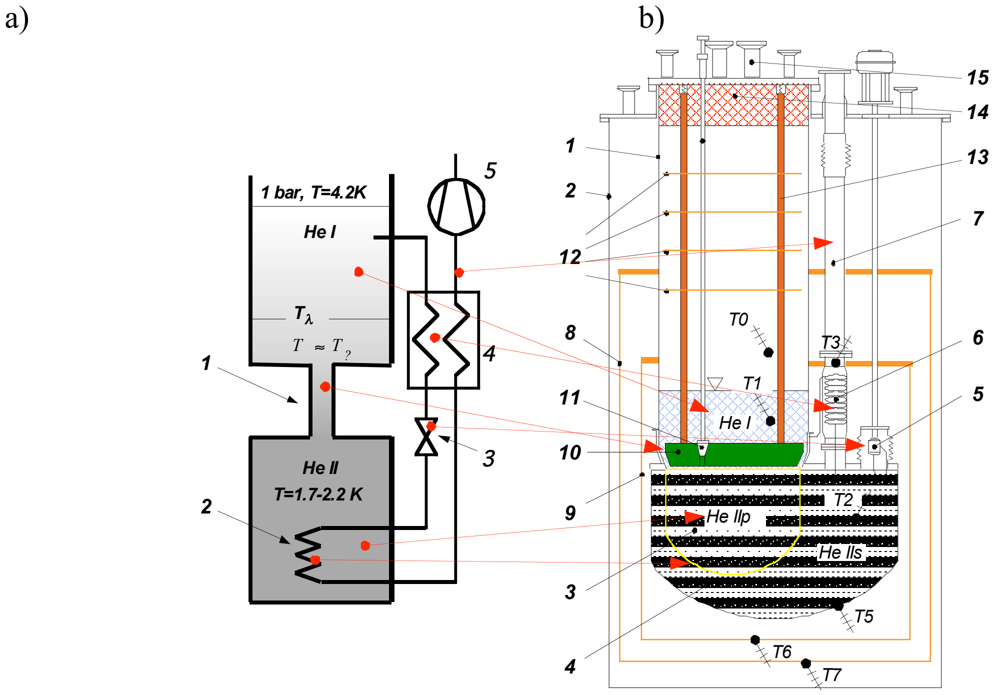


Figure 1. a) Claudet bath principle: 1 – constriction, 2 – He IIs/He IIp heat exchanger, 3 – J-T valve, 4 – recuperative heat exchanger, 5 –vacuum pump; b) NED cryostat scheme: 1 – He I vessel, 2 – vacuum container, 3 – He IIp vessel, 4 – He IIs vessel, 5 – J-T valve, 6 – recuperative heat exchanger, 7 – heat exchanger pipe, 8/9 – external/internal radiation shield, 10 – λ-plate, 11 – λ-valve, 12 – insert radiation shields, 13 – λ -plate supports, 14 – foam insulation, 15 – instrumentation ports, T0 – T7 temperature measurement points

liquid helium was done on the cryostat with the heat exchanger at Wroclaw. Factory test at 4.2 K and provisional acceptance was performed at Wroclaw University before shipping

Vacuum, pressure and helium leak tests

All the parts of the cryostat containing helium in contact with a vacuum space or all the parts under vacuum in contact with atmosphere have been tested to helium leak.

The parts that contain liquid helium or gaseous helium in contact with vacuum space have tested at room temperature and at helium temperature (4.2 K). Figure 2 shows the cryostat without its vacuum container to be prepared for the pressure and helium leak test.

The helium leak has been measured to 3 10^{-8} mbar.l.s^{-1} in the vacuum container with a pressure in the leak detector of 3 10^{-5} mbar, which is under the requirements specified in [1]. The pressure in the vacuum container reached 5 10^{-5} mbar.

The main vacuum vessel, and all the parts connected to (pumping line, heat exchanger and filling tube), has been tested at room temperature up to 3 bars in the helium vessel and the helium leak was measured to 3.5 10^{-8} mbar.l.s^{-1}, which is under the requirements specified in [1].

Figure. 2. Preparation of the Cryostat for Vacuum test and leak detection.
The picture shows the inner vessel with super-insulation to be removed for the tests.

Cool down tests

The cool down tests have shown neither pressure increase in the vacuum space nor increase of helium leak in the system.

The cryostat time constant from 300 K to 4 K is around 7 hours which is compatible with the size of the cryostat and the method of cool down. A typical temperature evolution with time during the cool down is shown in Figure 3.

Liquid helium is introduced from a 500 liters helium dewar in the main helium vessel above the lambda plate. The lambda valve stays open, connecting the He I and the pressurized He II vessel, during the cool down until 4.2 K. The pumping system is running in order to create a small depression in the filling tube to avoid any plugging and a small mass flow rate in the heat exchanger to cool down the piping. When a temperature of 4.2 K is reached in the he vessel (TT4 and TT2 temperature) and that the liquid level in the He I vessel is high enough to feed the piping and therefore the saturated He II vessel, the lambda plate is closed. The JT valve is controlled to feed up the saturated He II vessel and the pressure is lower to reach superfluid helium temperature. When the liquid level of He I vessel is regulated, it takes around an hour to reach superfluid temperature.

The lowest temperature achieved is 1.5 K (TT4 and TT2 in Figure 3) without any regulation and at this temperature no sign of leak nor pressure increase in the vacuum container has been noticed.

Figure 3. The NED Facility at CEA Saclay. The Automation and data acquisition system is located on the left. The cryostat it self is located in the middle of the Photo and on the right side of the picture one can see the 500 litres Dewar and the insert where the Lambda plate can be seen.

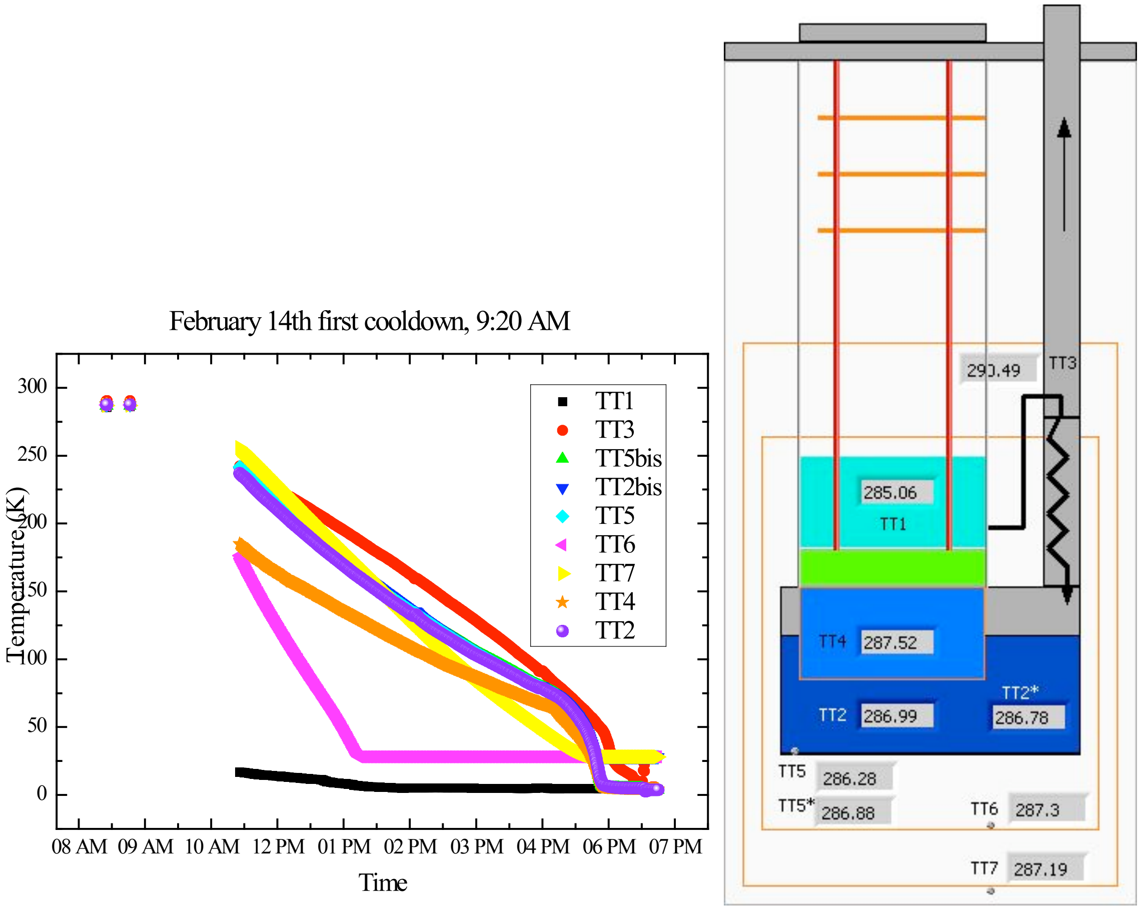


Figure 4. Temperature evolution during the cool down of the cryostat and temperature references in the cryostat.

Automation and regulation

The cryo-system has been designed to be fully automated.

The cryostat is connected to a 500 l Dewar to feed the main helium vessel (He I) above the lambda plate. The level in this He I space is controlled by a regulation system in opening of a valve located in the transfer line.

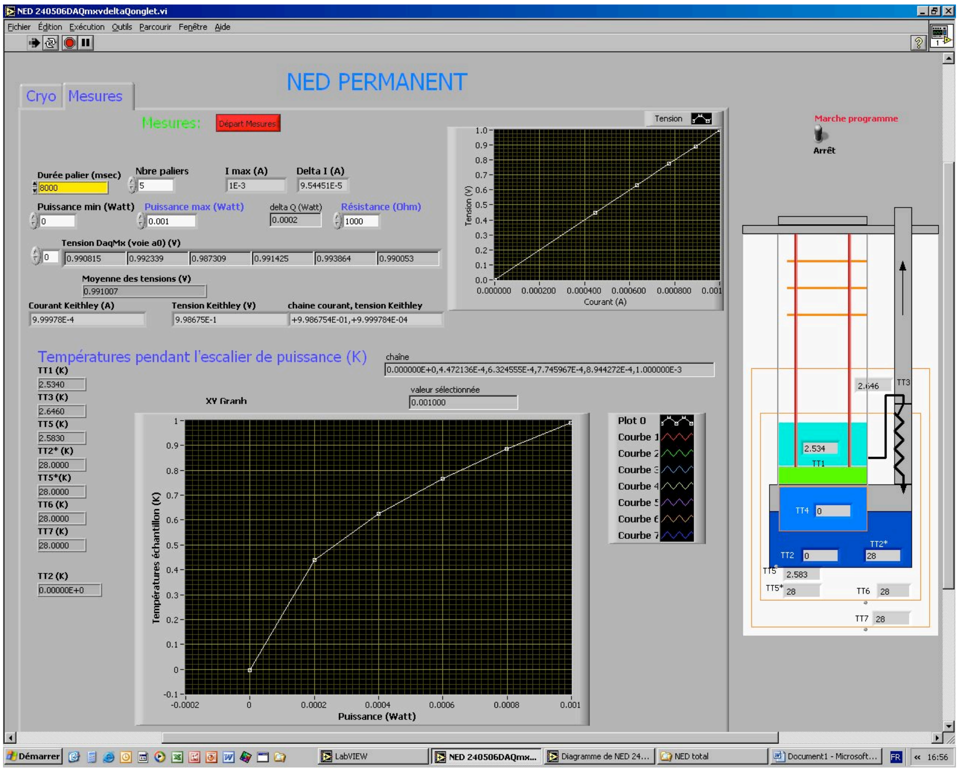
The liquid level in the saturated He II vessel is controlled by regulated in opening the JT valve located after the heat exchanger in the pumping line.

The pressure in the saturated He II vessel is controlled by a regulator with a pressure sensor (MKS Baratron) in opening a butterfly valve located in the pumping line via a MKS regulation controller. This pressure regulation is also a temperature regulation since the helium _in this vessel is in a saturated state.

All the regulation systems described above have been tested during cool downs and normal operation modes and worked properly.

A computer based program has been developed to monitor all the temperature sensors and to regulate some of them as shown in Figure 5.

This software is also capable of controlling the temperature in the pressurized He vessel (TT4) by controlling a cryogenic regulation system via a GPIB connection. The temperature regulation is based on heat exchange between the He II saturated vessel (TT2) and the pressurized one (TT4). A heater is used to control the temperature (TT4) in the pressurized He II vessel while the saturated he II temperature (TT2) is controlled by the pressure regulation.



Durée palier (msec) 8000
Nbre paliers 5
I max (A) 1E-3
Delta I (A) 9.54451E-5
Puissance min (Watt) 0
Puissance max (Watt) 0.001
delta Q (Watt) 0.0002
Résistance (Ohm) 1000
Tension DaqMx (voie a0) (V) 0 | 0.990815 | 0.992339 | 0.987309 | 0.991425 | 0.993864 | 0.990053
Moyenne des tensions (V) 0.991007
Courant Keithley (A) 9.99978E-4
Tension Keithley (V) 9.98675E-1
chaine courant, tension Keithley +9.986754E-01,+9.999784E-04

Températures pendant l'escalier de puissance (K)
TT1 (K) 2.5340
TT3 (K) 2.6460
TT5 (K) 2.5830
TT2* (K) 28.0000
TT5*(K) 28.0000
TT6 (K) 28.0000
TT7 (K) 28.0000
TT2 (K) 0.00000E+0
chaîne 0.000000E+0,4.472136E-4,6.324555E-4,7.745967E-4,8.944272E-4,1.000000E-3
valeur sélectionnée 0.001000

TT3 2.646
TT1 2.534
TT4 0
TT2 0
TT2* 28
TT5 2.583
TT5* 28
TT6 28
TT7 28

Figure 5. Computer based program monitoring and regulating system. A two windows parallel mode is possible: monitoring of the temperature and testing samples. The figure shows the test samples window.

For example if a temperature of 1.8 K is desired in the pressurized He II vessel, a lower temperature is maintained in the saturated He II vessel (1.75 K for example) and the system energized a heater located in the pressurized He II vessel to maintain the temperature within a desired precision.

The software is also capable of performing the heat transfer tests by controlling a heater in the pressurized He II vessel and measuring different temperatures; heater and temperature sensor located in the test sample.

Finally since a temperature can be maintained during a long period of time (over the night) without any operator; it is considered that the cryostat fully automated system is validated. The measuring system has been tested without any sample but since it is a master slave mode and passive measurement (resistance measurement), the authors do not see any reasons for a malfunctioning with a real test sample.

Thermal stability tests and Performance

The results of stability test are presented in the Figure 6. For the temperature range studied, the difference between the temperature set-point and the measurement is within 3 mK (Curve). The stability of each point is around 2 mK (error bars) over a duration of several tens of minutes (white frame). The stability test has to be extended to an hour in the near future, which is the average duration of a test. Nevertheless, the authors do not see any reason for not reaching a hour range stability duration for the cryostat NED, specified in [1].

Performance tests have been also realized. The results are presented in the Figure 6 in the orange frame for each temperature. The power presented in the figure 6 corresponds to the power dissipated in the heater, located in the pressurized He II vessel, to maintain the temperature (TT4). This power is therefore the power available on the he II vessel to perform a test, i.e. the power that can be dissipated in the test sample. This power was expected to be between 5 and 10 W and decreasing with temperature.

The stability and the performance obtained with the NED cryostat are acceptable.

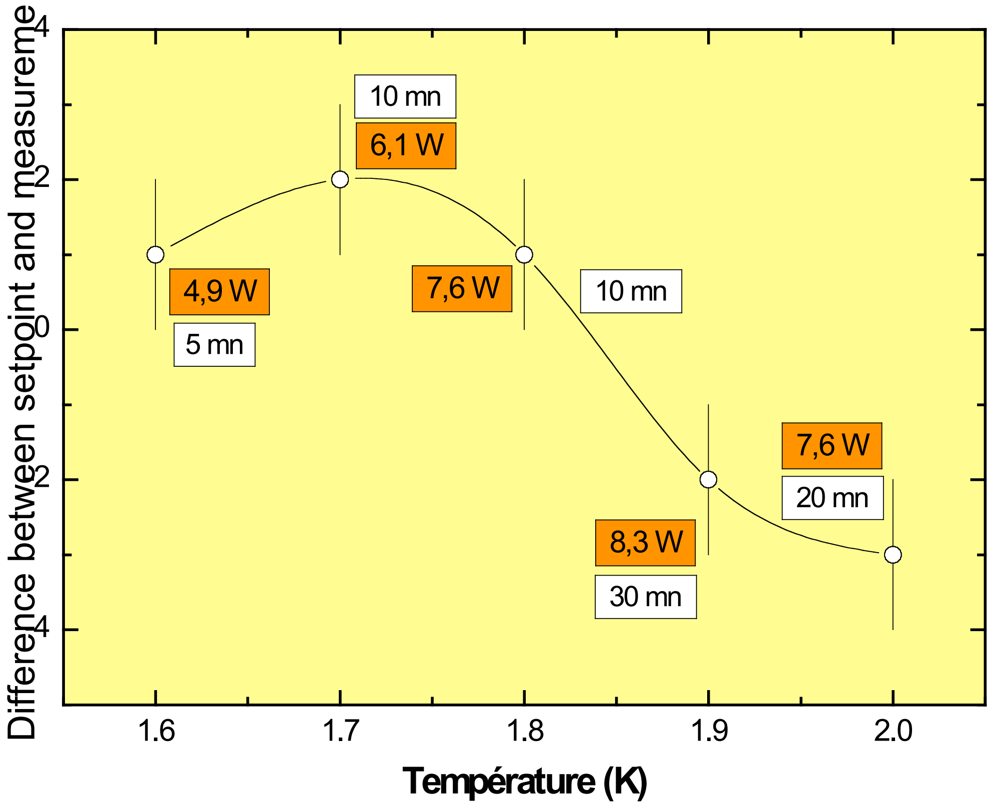


Figure 6. Performance of the NED Cryostat

Conclusions

Since the automation system is validated and the temperature stability and the performance obtained are acceptable, the NED cryostat meets the requirements of [1, 3] and is accepted.

References

[1] F. Michel, B. Baudouy, and H. Hervieu, "Technical Specifications for the pressurized He II cryostat (V.2) (task 2.2.1)," CEA Saclay 08/06/2004 2004.

[2] M. Chorowski, J. Polinski, B. Baudouy, F. Michel, and R. Van Weelderen, "Optimization of the NED cryostat thermal shielding with entropy minimization method," presented at International Cryogenic Engineering Conference, Prague, Rep. Czech, 2006.

[3] F. Michel and B. Baudouy, "Technical Specifications for the Sub-cooling Heat Exchanger," CEA Saclay 14/06/2004 2004.