CLOSED CYCLE LIQUID HELIUM REFRIGERATORS

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We have developed closed cycle liquid helium refrigerators using a Joule Thomson circuit precooled by commercially available two staged Gifford Mac Mahon cryocoolers. The Joule Thomson counterflow heat exchangers are modular and have been thermo-hydraulically characterized. Fully automatic cool down and operation are achieved by two pneumatically driven by pass and expansion valves. Several apparatus have been built or are under assembly with cooling power ranging from 100 mW up to 5 Watt, for temperature ranging from 2.8 K up to 4.5 K. A trouble free operation with several warm up and cool down cycles has been proven over 7000 hours.

INTRODUCTION

Liquid helium handling or supplying may either be a strong logistics constraint for experimentalists (remote location of the experimental plant, lack of helium liquefier or supplier) or a significant expenses source in the case of facilities with continuous operation at helium temperature. Consequently there is a need for autonomous closed cycle liquid helium refrigerators.

The goals for such refrigerators are an attractive selling price, a fully automatic operation and a proven reliability with minimum time between maintenance of a least 10 000 hours.

A development program undertaken several years ago at CEA/SBT in Grenoble has met these goals.

REFRIGERATOR DESCRIPTION

Figure 1 shows a schematic flow diagram of the refrigerator. The Joule Thomson (J.T.) loop (including a compressor, counterflow heat exchangers, by-pass and expansion valves and filters) is precooled by a Gifford Mac Mahon (G.M.) cryorefrigerator.

We use commercially available two staged GM refrigerators. A cycle sizing computer program developed in our laboratory is used to determine the precooling specifications for the GM refrigerator and JT compressor, taking into account the required temperature and cooling power of the JT loop and the thermohydraulic characteristics of the counterflow heat exchangers. Up to now we have used various precooling GM machines (l'AIR LIQUIDE, APD, CRYOMECH, EDWARDS) for which we have asked the manufacturer to fit heat exchangers on the cold stations. A small fraction of the high pressure helium flow delivered by the GM compressor is derivated to the JT circuit. The JT compressor is used to compress helium from JT loop low pressure up to the GM compressor suction pressure. We have developed a specific JT compressor specially adapted for low suction pressure operation (~ 100 mbar) when cooling temperature below 3 K and small cooling power (~ 150 mW) are required. For 4 K operation commercially available compressors are used (APD) with an additional primary vacuum pump connected in serie if 3 K operation is needed.

The counter flow heat exchangers of the JT loop are made with modular components, different numbers of which can be connected in serie or in parallel, according to the cooling power and temperature specified. As shown on figure 2, each module is made from a copper tube wounded and introduced in an annular channel made from two thin wall stainless steel tubes specially produced with embossed spacers. High pressure gas flows in the copper tube and low pressure gas in the two well calibrated annular gaps. Heat transfer capabilities and pressure drop for these modular components have been measured and compared to theoretical laws. These results are reported on figure 3 as a function of the helium mass flow rate for various temperature ranges (300 K/80 K, 80 K/20 K, 20 K/4 K).

The JT circuit is automatically operated by two specially developed pneumatically driven control valves ensuring fast cooling down from room temperature and stable operation without any manual interaction. During cool down, the last stage JT heat exchanger is by-passed by the pneumatic by-pass valve as long as its temperature is higher than about 15 K. This valve is actuated by the pressure in a metallic below acting as a gas thermometer. The JT expansion valve is controled pneumatically to maintain its exhaust pressure at a constant value. As a consequence, in normal operation, the refrigerator is operated at constant temperature level, the JT compressor working at constant suction pressure and then constant mass flow rate. A temperature stability better than 0,02 K is obtained during several thousands hours of operation. During cooling down, the JT valve is fully opened as long as the flowrate is lower than the nominal value.

To avoid plugging, gas purification is controlled by three levels of adsorbers and filters located at 300 K, 70 K and 15 K. Troubleless operation over more than 7000 hours has been obtained without any plugging or performance degradation.

EXAMPLES OF APPLICATIONS AND PERFORMANCES

Up to now, several refrigerators have been built or are under assembly for various applications with temperature ranging from 2.8 K to 4.5 K and cooling power from 150 mW to 5 Watt. Some examples are given hereafter with corresponding performances. Typical thermal characteristics of refrigerators are also reported on figure 4 : the net cooling power available at each of the three cold stations is represented versus their temperature. The third stage cooling power is a direct function of the second stage temperature for a given JT loop mass flow rate (and consequently given third stage temperature) regulated by the pneumatic JT expansion valve.

(I) Cooling of SIS junctions mixers on millimeter wavelengths radio-telescopes for IRAM [1] : five receivers are cooled at 2.75 K (~ 120 mW) with intermediate cooling at 15 K of FET amplifiers. The cryostat can be tilted over a ± 90° angle. Continuous operation without any trouble has been obtained with this apparatus for over 7000 hours with several warm up and cool down and with a temperature stability of 10^{-2} K. Six apparatus are in construction by L'AIR LIQUIDE in the framework of a technology transfer agreement.

(II) Sample cooling for neutron scattering goniostats [2] : two refrigerators have been developed (500-750 mW/4.5 K) allowing for three rotating degrees of freedom for the sample.

(III) In situ condensation of cryogenic targets (He^3, He^4, H_2 and D_2) for 4π detectors [3] : a refrigerator with cooling power of 1,5 Watt at 4.5 K or 3 K is used for condensation in about 4 hours of 1 liter targets. More than 5000 hours of troubleless operation have been cumulated.

(IV) Cooling of superconducting coils :
Two superconducting coils for neutron spin echo experiments at ILL [4] are cooled by thermosiphon circulation using two JT refrigerators as recondensers (1.5 to 2 Watt at 4.5 K per refrigerator). Pneumatic dampers are used to minimize vibrations transmission from the GM expander (2 Hz) to the coils. These machines have cumulated several thousands hours of test and are expected to be run continuously over 10 months a year.
A refrigerator to be run 11 months a year with a cooling power of 5 Watt at 4.5 K is under assembly for the cooling of two superconducting coils used as magnetic lens on the heavy ions beam of the GANIL accelerator [5] (SISSI Experiment) with 3 cooled current leads of 175 A.
A preliminary sizing study for the cooling of a superconducting wiggler at ESRF [6] as also been performed with a calculated cooling power of 2.6 Watt at 4.5 K with 2 cooled current leads of 160 A.

(V) Cooling of samples for physics experiments.
Systems with a cooling power of about 700 mW at 4.2 K are proposed for sample cooling in solid state physics at low temperature.
A specific system has been developed [7] for the loading and the cooling from room temperature down to 4.2 K of Silicon waffers in a photoluminescence apparatus delivered to IBM.

CONCLUSION

The development in our laboratory of several prototypes for various applications in the last few years has shown the interest of closed mechanical liquid helium refrigerators. They have proven to be highly versatile (fully automatic operation, adjustable cooling temperature and power, tilting cryostat...) and reliable (more than 7000 hours of troublefree operation is proven - minimum time between maintenance of 10 000 hours is expected).

A helium liquefier (calculated liquefaction rate of 1 to 1.5 liter/hour) based on this refrigeration technology is presently under development.

REFERENCES

[1] Claudet G., Lagnier R., Blum C., 3 K closed cycles refrigerator for SIS receivers at millimeter wavelengths, *Proceedings of ICEC* **12** (1988), Development for l'Institut de Radio Astronomie Millimétrique (IRAM, Domaine Universitaire - 38046 Saint-Martin d'Hères, France).

[2] Development for Departement de Recherche Fondamentale , Laboratoire de Magnétisme et Diffraction Neutronique (DRF/MDN), CEN Grenoble, BP 85X, 38041 Grenoble, France and Laboratoire Léon Brillouin (LLB), CEN Saclay, 91191 Gif sur Yvette, France.

[3] Development for Departement de Physique Nucléaire (DPhN), CEN L'orme des Merisiers, 91191 Gif-sur-Yvette, France.

[4] Development for l'Institut Laue Langevin (ILL, rue des Martyrs, 156X, 38042 Grenoble Cédex, France).

[5] Development for SISSI instrument - GANIL, BP 5027, 14021 Caen Cedex, France.

[6] Feasability study (internal document : Note SBT/CT/92-05) for the European Synchrotron Radiation Facility (ESRF, BP 220, 38043 Grenoble Cedex, France.

[7] Development for SCANTEK, Immeuble Delta, 10 avenue Guy de Collongue, 69130 Ecully, France.

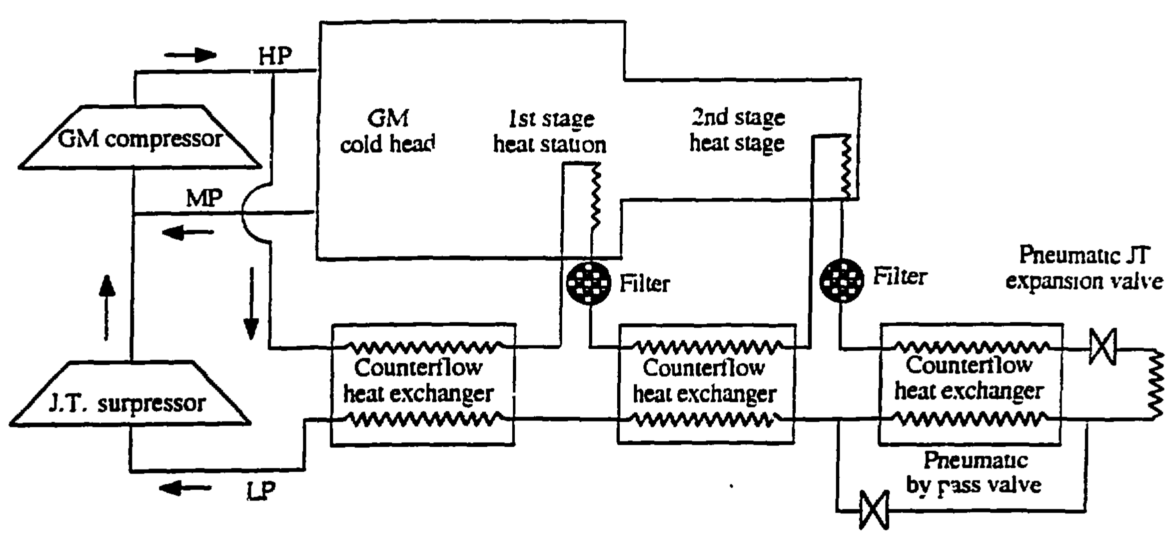

Figure 1: Schematic flow diagram of the refrigerator

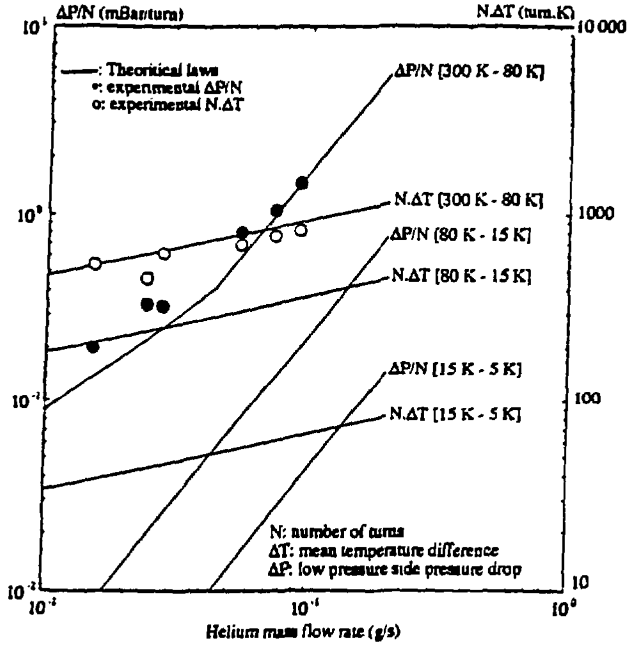

Figure 3: thermohydraulic characterization of counterflow heat exchangers

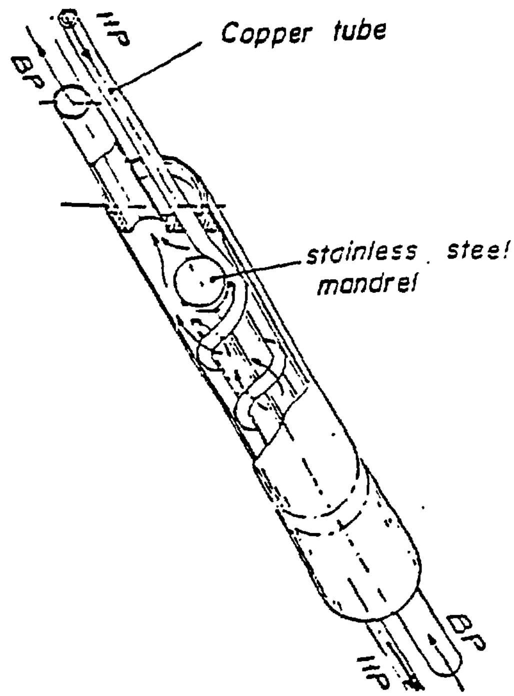

Fig.2. J.T. Heat exchanger

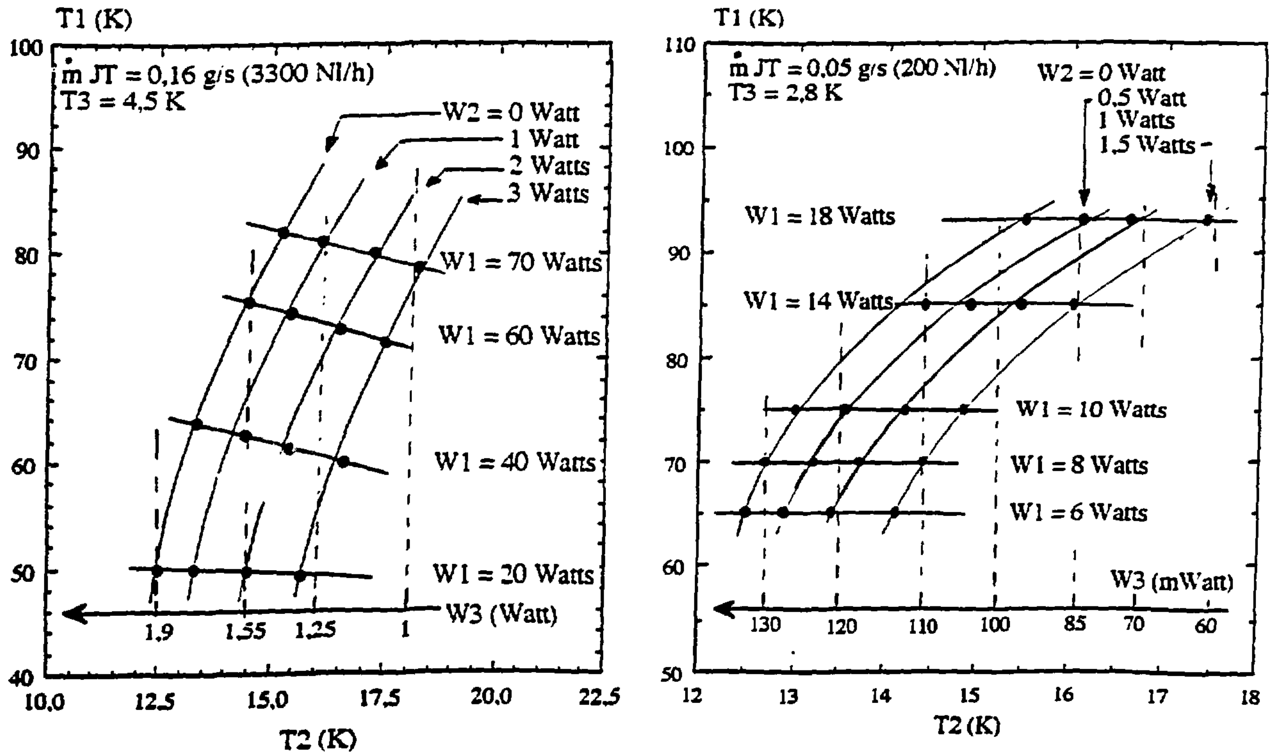

Figure 4: Typical thermal characteristics of close cycle liquid helium refrigerator