

A 1.8K refrigeration cryostat with 100 hours continuous cooling

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Abstract. A refrigeration cryostat has been developed to produce continuous cooling to a sample below 1.8 K over 100 hours by using a cryocooler. A two-stage 4K G-M cryocooler is used to liquefy helium gas from evacuated vapor and cylinder helium bottle which can be replaced during the cooling process. The liquid helium transfer into superfluid helium in a Joule-Thomson valve in connection with a 1000 m³/h pumping unit. The pressure of evacuated helium vapor is controlled by air bag and valves. A copper decompression chamber, which is designed as a cooling station to control the superfluid helium, is used to cool the sample attached on it uniformly. The sample connects to the copper chamber in cryostat with screw thread. The cryostat can reach the temperature of 1.7 K without load and the continuous working time is more than 100 hours.

1. Introduction

The λ -transition in ⁴He has been one of the most studied phase transitions. The transition at saturated vapor pressure (SVP) is a vapor He I/He II triple point, and is recognized in the International Temperature Scale of 1990 (ITS-90)[1]. A sealed cell which can realize ⁴He superfluid-transition point temperature plateau has been created by Lin Peng[1]. To maintain the state of coexistence of helium and superfluid helium in the cell, the system needs the liquid helium supplement every three hours. Therefore the primary problem of this system is consuming is high consumption of liquid helium, given that the heat leak from the environment. But the price of the helium raises. In order to solve this problem and provide a more stable temperature. A 1.8K refrigeration cryostat with continuous working time more than 100 hours has been developed and assembled. In this paper, the detailed designing process and structure will be presented.

2. Cryostat design



The refrigeration cryostat with closed-cycle cryocooler is a pretty cost-effective manner to reach the superfluid helium temperature. Recent papers have describe cryostats in this scheme. A refrigeration cryostat design by Wang and co-workers[2], helium is first liquefied by the cryocooler then stored in a large reservoir holding 1L of liquid helium at 4K. The liquid helium from this reservoir is further cooled after it pumped through a Joule-Thomson valve, filling into a pot at a temperature near 1K. This system provides a cooling power (100mW at 1.74K). The temperature stability at the 1K stage was 24mK peak-to-peak. Without the consideration of vibration in the system, we choose G-M cryocooler to cool down the system. This system contains two main process, the liquefying process with the G-M cryocooler and the liquid helium further cooled through a needle valve and a mechanical pump. The working time of this cryostat is aim to over 100 hours without load.

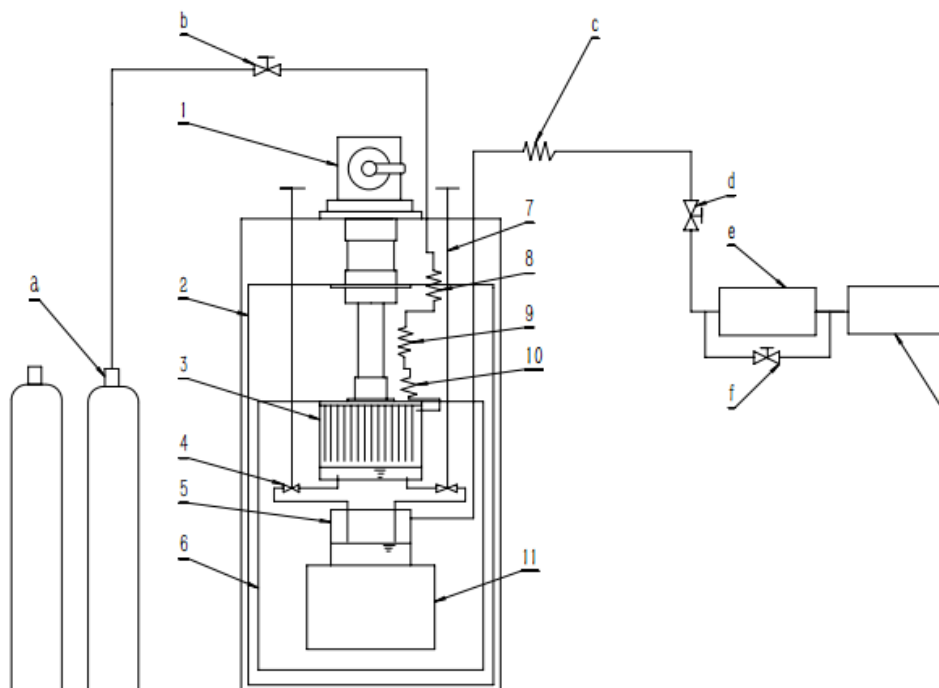


Figure 1. Schematic of the refrigeration cryostat. (1) KDE415 cryocooler; (2) the first thermal radiation shield; (3) helium condenser; (4) needle valve; (5) superfluid helium pot; (6) the second radiation shield; (7) the needle valve support rod; (8) the first cold head heat exchanger; (9) heat regenerator; (10) the second cold head heat exchanger; (11) sample cell; (a) standard helium cylinder; (b) valve; (c) heat exchanger; (d) valve; (e) mechanical pump; (f) valve; (g) air beg.

2.1. Helium liquifaction heat exchanger

A schematic of the helium flow through the system is shown in fig1. The GM cryocooler is an easycool KDE415 with a cooling power 1.5W at 4.2K. High-purity(99.99%) helium is provided by a standard compressed gas cylinder(a). In order to cool down the helium gas efficiently, a heat exchanger circle the cryocooler including with a copper pipe on the 1st stage(8), 2nd stage(9) and the 2nd stage cylinder(10). The helium gas from the cylinder first goes through the tubular heat exchanger. In order to use the cryocooler efficiently, the pipe circling on the first stage cylinder act as regenerator. The tubular heat exchanger is made of copper and

the regenerator is made of 304 stainless steel according to the material of the cryocooler. The heat exchanger weld on the cryocooler which make good thermal contact to the cryocooler.



Figure 2. Assembled refrigeration cryostat.

The system consists three layers of flange. Before the helium gas went in the heat exchanger, a cold trap on the extended 30K first cold head stage(the second flange), the helium precooled and the residual impurities in the gas can be freezing out.

2.2. Helium condenser and superfluid helium pot

Under the helium gas heat exchanger, the helium condenser(3) with a diameter of 193mm and 102mm height make sure all the helium gas liquified. It is also act as a liquid helium reservoir and connects to the second stage cold head mechanically. At the top of the condenser is lined with parallel fins(5mm width, 5mm long, 15mm high), the helium gas was all liquified by the fins. The amount of the liquid helium was detected by the differential pressure between the top and bottom liquid helium reservoir, so at the top and the bottom of the liquid helium reservoir set pipes and connected to a gauge (NIVOPRESS). At the bottom center of the condenser, a pipe with two branches are linked to the superfluid helium pot(5) with a diameter of 103mm and 55mm height. Each pipe pass through the needle valve(4). The needle valve is used as a Joule-Thomson impedance. The two tunnel from the liquid helium pot are for the purpose of making sufficient amount of the superfluid helium. The pot is pumped through a stainless steel tube. The mechanical pump decompress superfluid helium pot. The bottom of the superfluid helium pot performs as a cold plate to cool the sample, at the bottom of which a screw was placed for the convenience of sample installation(11).

2.3. The thermal radiation shield

In order to reduce radiation losses, we add two stages of radiation shield. The two thermal radiation shields is made of copper. The flange of the two shields are thermal link to the first and second stage which reaches 52K and 5K. At each radiation shield, in order to reduce the heat leak, two layers of aluminized paper wrapped on the each copper shield. The assembled refrigeration cryostat is shown in figure 2.

3. Heat load

The cryostat provides vacuum environment for the thermal insulation to device of transition point of superfluid helium operating at 4.2K and the first stage radiation shield is 50K and the second radiation shield is 4.2K. The steady-state heat load, whether radiative or conductive, are driven by the temperature difference between the vacuum vessel and the helium tank. In order to realize producing the long durable 1.8K environment, minimizing the heat leak and thus minimize active cooling power requirements and the consuming of the helium.

One important source of heat is radiation from the room temperature to the superfluid helium transition device. The heat leak through the vessel could be calculated from the Lockheed equation[3], the results are shown in table1.

Table 1. Heat Load

item	Heat leak(W)
Radiation	0.43
Support	0.63
total	1.06

$$q = \frac{C_s (\bar{N})^{2.56} T_m}{N_s + 1} (T_m - T_c) + \frac{C_r \varepsilon_{RT}}{N_s} (T_H^{4.67} - T_c^{4.67}) \quad (1)$$

Where

$$C_r = 5.39 \times 10^{-10}$$

$$C_s = 8.95 \times 10^{-8}$$

\bar{N} = radiation shield layer density, layers/cm

N_s = number of radiation shields

q = heat flux, W/m²

T_c = cold boundary temperature, K

T_H = warm boundary temperature, K

T_m = mean insulation temperature, K

ε_{RT} = room temperature (300K) total hemispherical DAM emittance

$$Q = F A q \quad (2)$$

Where

A = inner surface area

F = degradation factor

4. Conclusion

The 1.8K cryostat with G-M cryocooler provides the necessary environment for the sealed cell used to realize ^4He superfluid-transition point temperature plateau for 100 hours continuously. The using of cryocooler reduces the consumption of liquid helium. The cryostat design in this paper has been validated for the structure. The performance of the cryostat is going to test in the next step and the result will published in the future.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Grant No.51522705), the National Magnetic Confinement Fusion Science Program (Grant No.2015GB121001). The found of Key Laboratory of Cryogenics, CRYOQN201505. The found of the State Key Laboratory of Technologies in Space Cryogenic Propellants, SKLTSCP1504.

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