

Design and Performance Test of Large-Scale Cryopump Used in Space Environment Simulation System

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ABSTRACT: A large-scale cryopump (DN1250 LN₂) used in space environment simulation system was designed and its performance experimentally investigated by BISEE. In the design, the cryopanel of the cryopump was cooled by Brooks Model 1020 cold head which with high second stage cooling capacity of about 12W @ 20K. The thermal radiation shield and baffle were cooled by liquid nitrogen. A design method for three main technical data (pumping speed for N₂, cool down time and crossover) of the pump was introduced in this paper. A test system according to the test standards for cryopump (JB/T 11081-2011) was built to test main performance of the cryopump. The experimental results showed that the pumping speed for N₂ of the pump was up to 57,000L/s, the cool down time was about 330min, and the crossover was over than 3.0×10^5 Pa L.

KEYWORD: Cryopump; Pumping speed for N₂; Cool down time; Crossover

1 INTRODUCTION

A large-scale cryopump (DN1250 LN₂) used in space environment simulation system was designed and its performance experimentally investigated by Beijing Institute of Spacecraft Environment Engineering (BISEE). There are a number of advantages of this kind of cryopump as simple structure, oil free, high pumping rate of condensable gas, high ultra-vacuum pressure, wide range of working pressure and easy to operate & maintain etc[1]. For these reasons, cryopump was widely used in space environment simulation system as high-vacuum pump.

In this paper, a design method for three main technical data (pumping speed for N₂, cool down time and crossover) of the cryopump was introduced. A test system according to the test standards for cryopump (JB/T 11081-2011) was built to test main performance of the cryopump. The experimental results were showed at the end of the paper.

2 RESEARCH METHODOLOGY

2.1 Configuration and function of the cryopump

Cryopump pumping gas by very cold panels which was cooled by Brooks Model 1020 cold head which with high second stage cooling capacity of about 12W @ 20K. The thermal radiation shield and baffle were cooled by liquid nitrogen.

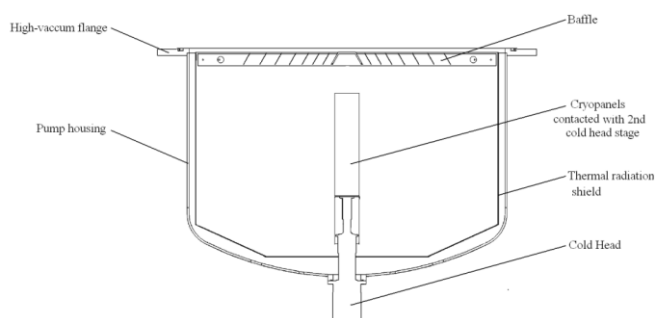


Figure 1. The diagram of the inside of the cryopump

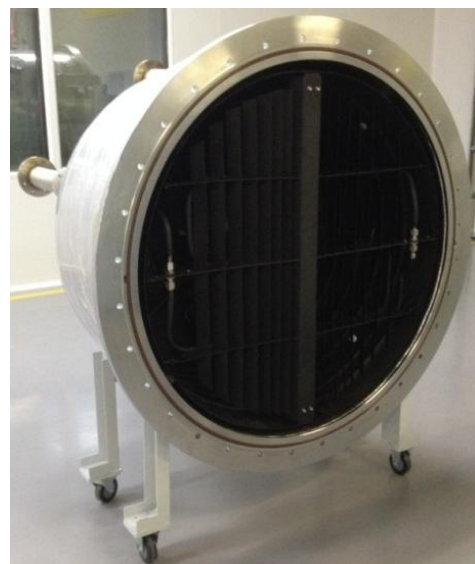


Figure 2. The photograph of the DN1250LN₂ cryopump

Three methods were used in cryopump to absorb gas inside the vacuum chamber to achieve vacuum pumping, which are cryocondensation, cryosorption, and cryotrapping, of which cryocondensation and cryosorption are the primary methods[2]. The thermal radiation shield and baffle, which will condense and cool water vapor and most hydrocarbons at temperatures below 100 K. The low temperatures for the cryopanel were generated in a cold head and compressor unit. The cold head cools the cryopanel to ≤ 12 K. The second stage of the cold head was contacted to the cryopanel. The first stage was not contacted to the cryopump. Virtually all other gases condense on the outer surfaces of the cryopanel. The gases hydrogen, helium and neon were trapped into the activated charcoal on the inner surfaces of the cryopanel.

2.2 The design method of the cryopump for main technical data

2.2.1 Pumping Speed for N_2

For DN1250 LN_2 cryopump, the pumping speed[3] for N_2 can be calculated as the following equations.

$$S = S_{th} \cdot \alpha \cdot A_1 \quad (1)$$

Where S = pumping speed of the cryopump; α = cryocondensation coefficient; A_1 = the exterior surface of the cryopanel; and S_{th} = the maximum pumping speed on the unit area of the exterior surface of the cryopanel.

$$S_{th} = 3.638 \sqrt{\frac{T_{N2}}{M}} \quad (2)$$

Where T_{N2} = The temperature of N_2 ; M = The molecular weight of N_2 .

2.2.2 Cool down time

In the design of DN1250 LN_2 cryopump, consider that the pressure in the cryopump was less than 10^{-1} Pa before the cryopump cools down, the conduction and the convection and the latent heat of the gas condensation could be ignored. Thus the heat of the cryopanel was divided into three parts: The heat provided by the second stage of the cold head Q_1 ; The radiant heat of the thermal radiation shield and baffle Q_2 ; And the leak heat Q_3 . The heat in effect of the cryopanel could be expressed as the following equation.

$$Q_{eff} = Q_1 + Q_2 + Q_3 \quad (3)$$

Where Q_1 = the heat provided by second stage of the cold head, the value could be got by Figure 3. which was provided by Brooks.

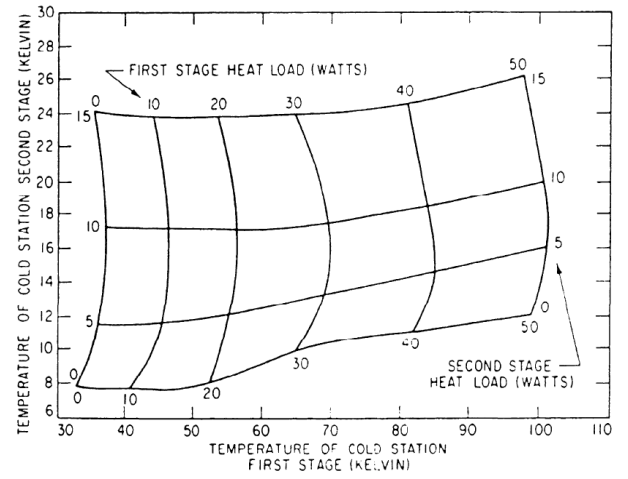


Figure 3. The cold power of the cold head(Model-1020)

Q_2 was the radiant heat of the thermal radiation shield and baffle.

$$Q_2 = \frac{5.67 A_1 \left[\left(\frac{T_2}{100} \right)^4 - \left(\frac{T_1}{100} \right)^4 \right]}{\frac{1}{\epsilon_1} + \frac{A_1}{A_2} \left(\frac{1}{\epsilon_2} - 1 \right)} \quad (4)$$

Where A_2 = the inner surface of the thermal radiation shield and baffle; ϵ_1 = the emissivity of the exterior surface of the cryopanel; ϵ_2 = the emissivity of the inner surface of the thermal radiation shield and baffle; T_1 = the temperature of the cryopanel; T_2 = the temperature of the thermal radiation shield and baffle.

Q_3 was the leak heat of the cryopump.

$$Q_3 = \sigma \cdot A_1 \cdot \epsilon_1 \cdot l \left[\left(\frac{T_h}{100} \right)^4 - \left(\frac{T_1}{100} \right)^4 \right] \quad (5)$$

Where σ = Stefan Boltzmann's constant; l = heat leak rate; T_h = the temperature of the pump housing.

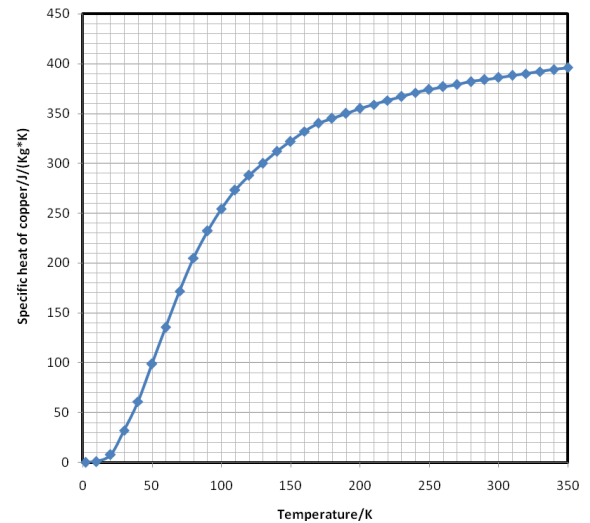


Figure 4. The specific heat c of copper

Consider that the specific heat c of the copper (the material of the cryopanel) was the function of the temperature T of the cryopanel, as shown in

Figure 3. The cool down time t of the cryopump was considered as the following equation.

$$t = m \int_{T_c}^{T_a} \frac{c(T)}{Q_{eff}(T)} dT \quad (6)$$

Where m = the mass of the cryopanel; T = Temperature; T_a = init temperature of the cryopanel; T_c = the terminal temperature of the cryopanel which could be calculated by Eq. (7); $c(T)$ = the specific heat of cooper at temperature T ; $Q_{eff}(T)$ = the heat in effect of the cryopanel at temperature T .

When the cryopump achieve thermal equilibrium,

$$Q_{eff} = 0 \quad (7)$$

The terminal temperature T_c could be got from Figure 3.

2.2.3 Crossover

In cryopump, the crossover was defined by the maximum amount of nitrogen gas (in Pa L) which could be admitted to the cryopump over a short time with the temperature of the second stage remaining at or below 20K during the test gas flow [4].

For DN1250 LN₂ cryopump, the heat of condensation of the DN1250 LN₂ cryopump could be expressed as following equation.

$$Q_{c,N_2} = Q_{0,c} \quad (8)$$

Where Q_{c,N_2} = The heat of condensation of the DN1250 LN₂ cryopump; $Q_{0,c}$ = The heat of the cryopanel and the cold head from the terminal temperature up to 20K.

The saturation vapor pressure of liquid nitrogen versus temperature was shown as Figure 5.

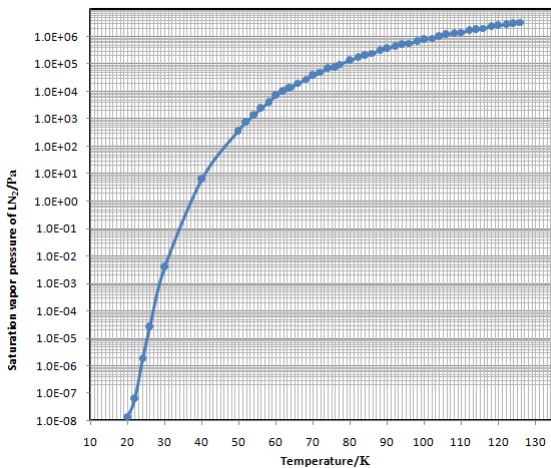


Figure 5. Saturation vapor pressure of LN₂

At 20K, saturation vapor pressure of LN₂ was approximate 1.44×10^{-8} Pa, under this condition, the left hand in Eq.(8) could be divided into two parts: N₂ cool down from room temperature to temperature of the cryopanel Q_{rt} ; And the heat of N₂ solidification Q_s .

$$Q_{c,N_2} = Q_{rt} + Q_s \quad (9)$$

Where,

$$Q_{rt} = \int_{T_r}^{T_{cr}} m_{N_2} c_{N_2}(T) dT \quad (10)$$

Where T_r = the room temperature; T_{cr} = the maximum temperature of the cryopanel when test the crossover; m_{N_2} = the mass of N₂; $c_{N_2}(T)$ = the specific heat of N₂ at temperature T ; Q_s = the latent heat of the N₂ solidification.

If ignore the effect of the temperature uniformity of the cold head and the cryopanel, the right hand in Eq. (8) could be expressed as follows.

$$Q_{o,c} = m \int_{T_c}^{T_{cr}} c(T) dT \quad (11)$$

3 TEST SYSTEM FOR CRYOPUMP

The test system was shown in Figure 2. The system was consisted of cryopump, dry pump, test dome, vacuum gauge, gas flow meter, and valve etc [5-6]. The Pirani gauge, Bayard-Alpert gauge and gas flow meter were sent to Beijing Aerospace Institute for Metrology and Measurement Technology for N₂ calibration prior to the experiment. The silicon diode sensor and cryogenic temperature monitor were sent to Center of Cryogenic Metrology (Technical Institute of Physics and Chemistry, CAS). Four silicon diode sensors were installed separately on the Baffle and the cryopanel. Three PT-102 sensors were installed separately on the thermal radiation shield. To simplify the display for the temperature of the second stage and the Baffle and the radiation shield the temperature curves illustrated for this study were average means measured by the sensors. The test dome was constructed according to the test standards for the cryopump JB/T 11081-2011. This paper uses flow meter method to investigate the pumping characteristics of the cryopump under different gas flow rates.

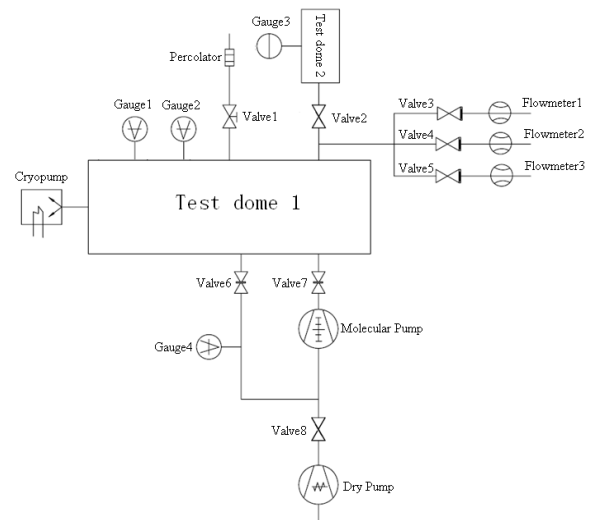


Figure 6. The test system for cryopumps

4 RESULTS AND DISCUSSIONS

Figure 7. shows the pumping speed relative to the pressure. The test curves above show that pumping speed constant from the magnitude of 10^{-4} Pa to 10^{-3} Pa, but during the magnitude of 10^{-2} Pa, the pumping speed increases. The value of the pumping speed for the cryopump was about 57500L/s to 58000L/s, which can be seen as a constant.

Figure 8. shows the cryopanel's temperature and the temperature of the buffer and the radiation shield relative to the operating time. The cool down time to 20K was about 330min.

Figure 9. shows the cryopanel's temperature relative to the time when test the crossover. The crossover value was 3.0153×10^5 Pa L, the gas in test dome2 should be admitted within 3s. The curve shows that the temperature of second cold head rises to 19.7K from 12K, but for no more than 10 minutes the temperature went back to about 12K, and the cryopump reached its normal operating mode again. The results showed the crossover value of the cryopump tested was about 3.0×10^5 Pa L.

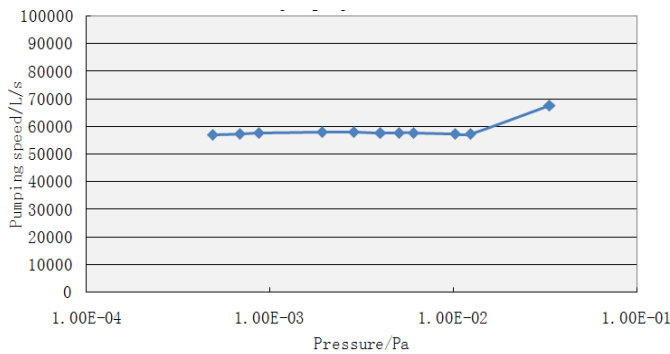


Figure 7. Pumping speed test result of DN1250LN₂ cryopump

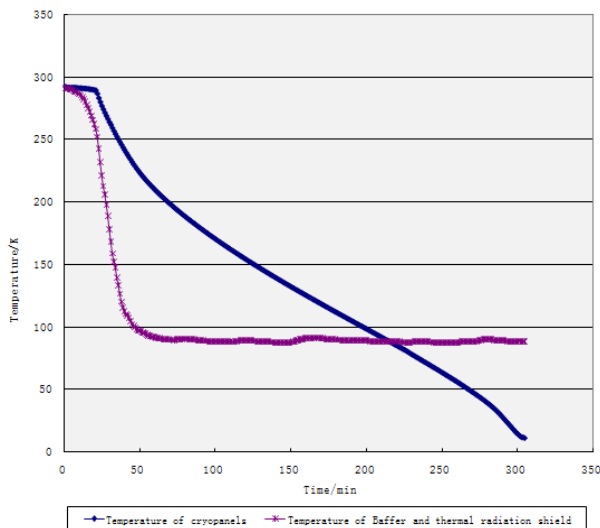


Figure 8. Cool down time test result of DN1250LN₂ cryopump

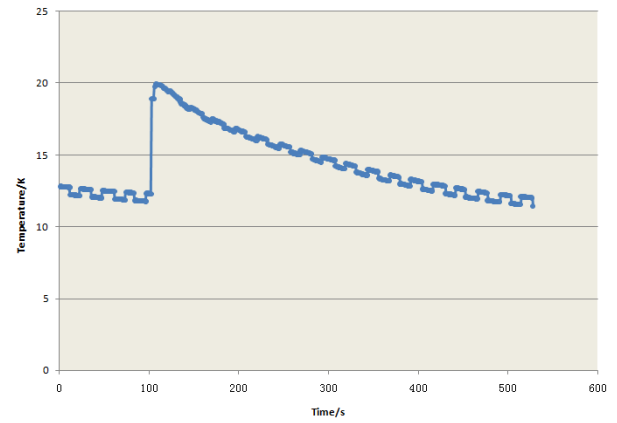


Figure 9. Crossover test result of DN1250LN₂ cryopump

5 CONCLUSIONS

A design method for three main technical data (pumping speed for N₂, cool down time and crossover) of the cryopump was introduced in this paper. The method was validated by the main performance test of DN1250LN₂ cryopump. The pumping speed (for N₂) was up to 57,000L/s, the cool down time was about 330min, and the crossover was over than 3.0×10^5 Pa · L. All the performance was satisfied the target of the design and the cryopump was successful used in space environment simulation system.

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