International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 0084

INVESTIGATION ON DYNAMIC CHARACTERISTICS OF A FULL LOCALIZATION 250W@4.5K HELIUM CRYOGENIC REFRIGERATOR

Xiujuan Xie [1,*], Shaoqi Yang [1], Yunlong Wang[1], Qing Li[1,2], Wei Pan[1], Xiangdong Xu[1], Linghui Gong [1]

1 State Key Laboratory of Technologies in Space Cryogenic Propellants, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, 29 Zhongguancun East Rd., Beijing 100190, China

2 University of Chinese Academy of Sciences, No.19 (A) Yuquan Rd., Beijing 100049, China (Corresponding Author: xiexiujuan@mail.ipc.ac.cn)

ABSTRACT

In this paper, a full localization 250W@4.5K helium cryogenic refrigerator was commissioning up to nearly 470 hours. A step-by-step commissioning strategy about the stability of high and low pressure of refrigerator, cool-down processes in cold box and cooling capacity evaluation of refrigerator was carried out. Dynamic characteristics including the adjustment of pneumatic valves for the stability of high and low pressure, 300~4.5K temperature evolution of heat exchangers and turbine expanders in the cold box and cooling capacity fluctuation are experimentally discussed. The results are helpful to more precisely understand and commissioning hundred watts level helium cryogenic refrigerator.

Keywords: dynamic characteristics, commissioning strategy, cool-down process, full localization, helium cryogenic refrigerator

1. INTRODUCTION

Large scale helium cryogenic refrigerators have many critical applications in the aerospace engineering, in superconductivity, in the gas liquefaction (helium, hydrogen) industries and hydrogen energy. For instance, helium is used as a kind of coolant in hydrogen liquefaction technology, encompassing the range from laboratory liquefaction equipment to large-scale plants. The Claude cycle is the basis of most helium and hydrogen refrigeration and liquefaction systems. It may be regarded as a combination of the Linde and Brayton cycles [1]. The Large Hadron Collider (LHC) accelerates proton beams at CERN, the European Organization for Nuclear research in Geneva, Switzerland are driven by superconducting magnets, which are cooled down at 1.9K and maintained superconductivity over a 27 km ring by large scale helium cryogenic refrigerators [2-3]. The ITER cryogenic system includes three identical liquid helium (LHe) refrigerators with a total average cooling capacity equivalent to 75 kW at 4.5 K to the magnets and cryopumps [4]. In China, hundreds of watts refrigeration capacity at liquid helium temperature at TIPC/CAS has been developed to satisfy the domestic requirements. [5-6].

Large scale helium cryogenic refrigerators are continuous industrial processes, which are highly complex due to the large number of correlated variables on wide operation ranges. That is to say all thermodynamic and chemical parameters change with time and the operating characteristics of key components such as cryogenic heat exchangers, turbine expanders, and pneumatic valves are simultaneously. Therefore, dynamic characteristics on experimental commissioning of large scale helium cryogenic refrigerator are paid more and more attention by researchers. In China, a full localization helium cryogenic refrigerator including cryogenic heat exchangers, turbine expanders, and pneumatic valves is constructed. It is very necessary to investigate on dynamic characteristics of cryogenic heat exchangers, turbine expanders, and pneumatic valves in the cold box to acquire the commissioning experience. Therefore, Dynamic simulation of full localization

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

helium cryogenic refrigerator was investigated in this paper.

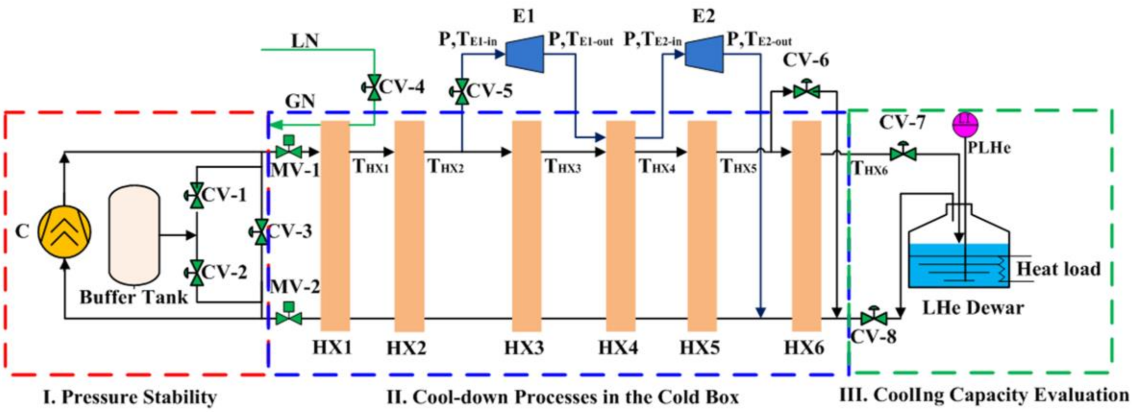

Fig 1 Process flow diagram of the 250W@4.5K helium cryogenic refrigerator

2. A STEP-TO-STEP COMMISSIONING STRATEDY

The process flow diagram of full localization 250W@ 4.5K helium cryogenic refrigerator is present in fig. 1. The system is described as a helium screw compressor (C), six heat exchangers (HX1~6), two turbine expanders (E1 and E2), pneumatic valves (CV-1~CV-6 and CV-8), electromagnetic valves (MV-1 and MV-2), a J-T valve (CV-7) and LHe Dewar with a heat load (HL). The working process has been described in ref [5] in details. A step-by-step commissioning strategy is proposed, shown in fig 1. The first step is the stability of high and low pressure of refrigerator. The stability of high pressure is controlled by matching of the discharge valve (CV-1) and the charge valve (CV-2), while the stability of low pressure is controlled by the pneumatic valves (CV-3). By long-running operation of the compressor cycle, the purification of H_2O, N_2 and C_xH_x in helium gas decreases to the level of less than 1 ppm. At this time, the electromagnetic valves (MV-1 and MV-2) are opened and then the second step: the cool-down processes in the cold box starts. Heat exchanger HX1 is pre-cooled by liquid nitrogen and gradually cooled down to 80K. The turbine expanders (E1and E2) start to work by adjusting the opening of CV-5. When the temperature at the end of HX6 T_{HX6} is lower than 35 K, CV-7 and CV-8 are opened. The temperature in LHe dewar is further cooled down up to 4.5 K, and the liquid level of LHe is stabilized at 30%. The third step: cooling capacity of refrigerator at the liquid helium is evaluated by heat load. By this step-to-step commissioning strategy, the PID parameters of CV-1~CV-8 can be acquired and optimized, and then start-stop remote control can be further realized.

3. DYNAMIC CHARACTERISTICS ANALYSIS OF FULL LOCALIZATION 250W@4.5K HELIUM CRYOGENIC REFRIGERATORS

3.1 Dynamic analysis of the pressure stability

A helium screw compressor with 150 kW rated power and variable frequency driver 20~50 Hz is used to supply 0~57 g/s mass flow rate. In the commissioning, it experienced 8 times experiments and the operating time was nearly 470 h by recording the frequency of compressor, shown in fig 2. The maximal high pressure is up to 14 bar (A) and low pressure is 1.05 bar (A).

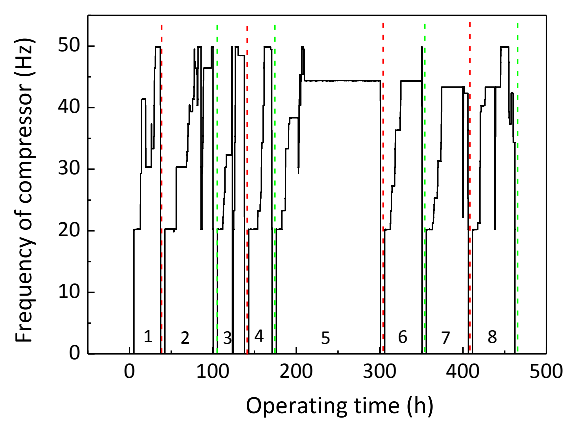

Fig 2 the operating time vs. frequency of compressor

Experimental opening of pneumatic valves CV-1~CV-3 and pressures of helium screw compressor for 24 hours operation are shown in figures 3 and 4. The function of CV-1 is to discharge the overpressure helium gas of high-pressure pipeline, in order that it can be prevent instantaneous overpressure at high pressure. So the opening of CV-1 is closed in most of time, seen in fig 3. The pneumatic valve CV-2 is a charge valve to fill with the high purified helium gas from buffer tank.

When the cool-down process of heat exchangers in 4K cold box is happened, CV-2 is opened frequently. On one hand, the quantity of high purified helium gas become bigger in the helium liquefaction stage than in the cool-down stage, which has to increase the opening CV-2, and then increase high pressure. On the other hand, the high pressure should be stabilized by decreasing the opening of CV-2, which results in the oscillation of opening of CV-2 and high pressure of system, shown in the enlarge parts of figures 3 and 4. CV-3 is a by-pass valve, which could bypass the helium gas to avoid the lower pressure in case of emergency. PI parameters to control the opening of pneumatic valves CV-1~CV-3 are experimentally optimized further. Therefore, high and low pressure of refrigerator system can be smoothly stabilized to 10.5±0.6 bar (A) and 1.05±0.1 bar (A) within few minutes, shown in figure 4.

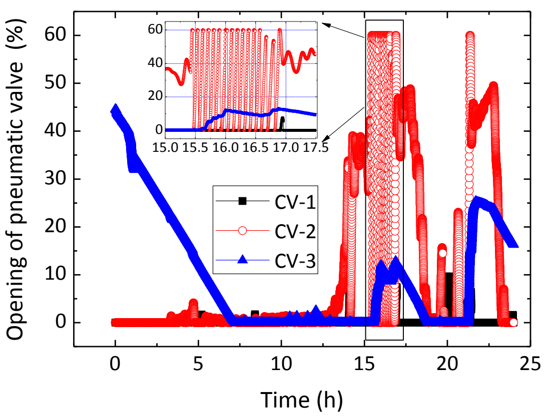

Fig 3 experimental opening of pneumatic valves CV-1~CV-3 for 24 hours operation

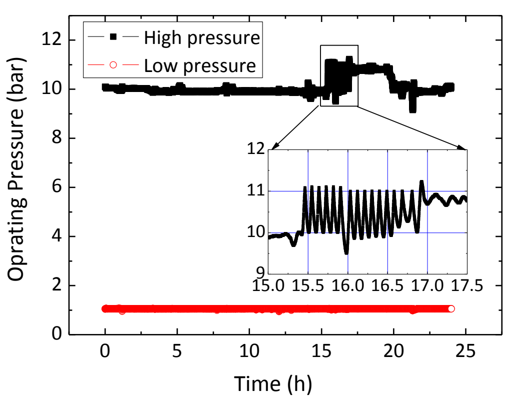

Fig 4 high and low pressures of helium screw compressor for 24 hours operation

3.2 *Temperature evolution in the cold box*

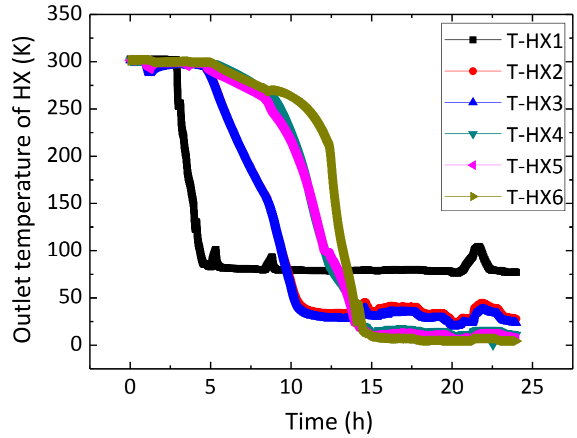

Fig 5 outlet temperature evolutions of heat exchangers at the high-pressure side for 24 hours operation

The outlet temperature evolutions of heat exchangers at high-pressure side and of turbine expanders for 24 hours operation are presented in figures 5~6. The pre-cooling rate 1 K/min is controlled for HX1 by adjusting the opening of CV-4, shown in figure 5. Furthermore, by matching of the turbine expanders E1 and E2, the cooling rate of HX2 &HX3 and HX4&HX5 are controlled nearly as the same，which is lower than HX1. The cooling rate 0.5~0.8 K/h of HX2~HX6 is preferred. Even though, the temperatures of HX1~HX6 reach to the set point, the minor oscillations at the quasi-steady stage are happened due to the variation of the opening of CV-5 and CV-6, shown in figures 5~6.

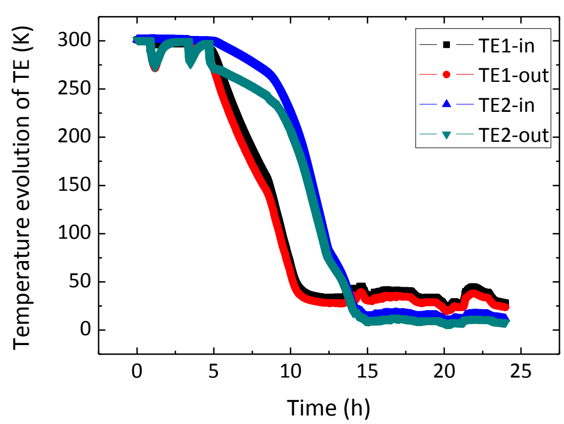

Fig 6 temperature evolutions of turbine expander for 24 hours operation

3.3 *Dynamic process of cooling capacity evaluation with heat load*

Dynamic process of the cooling capacity evaluation including cooling temperature and cooling power of helium cryogenic refrigerator is presented in figure 7. The descriptions of the measurement and heat load in details are referring to [6]. Combining the figures 3~6, liquid helium is produced and transferred to the Dewar with heat load during 15.4 to 17 h, while the temperature of Dewar is continuously cooled down to liquid helium temperature. By maintaining the high pressure of system and the liquid helium level of the Liquid Helium Dewar stable, the heat load in LHe Dewar starts to increase from 0W to the maximal power at 17.8 h. The cooling power and the cooling temperature are measured by thermometer TI4100 and heat load EI4100, respectively. The maximal cooling capacity of this helium cryogenic refrigerator is up to 317 W and maintain stable at 4.45 K temperature for 1 hour. After that, by adjusting the electricity power of the heat load, the cooling power is larger than 250 W while the cooling temperature is controlled at the range of 4.19K to 4.45K. The cooling capacity of 250 W @ 4.5 K is strictly evaluated for three times, which all reached the design target, and then to assess the dynamic characteristics of this helium cryogenic refrigerator further.

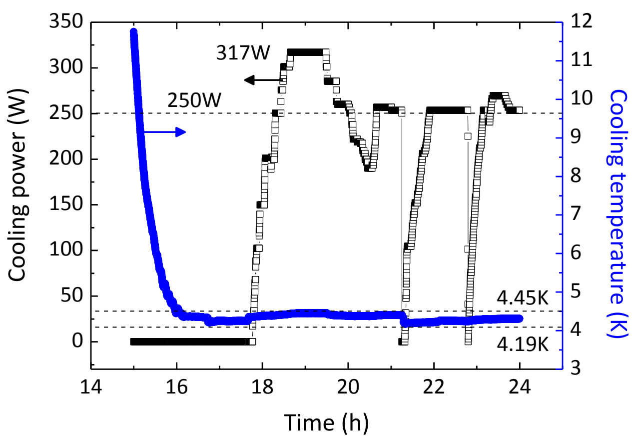

Fig 7 Dynamic process of the cooling capacity evaluation including cooling temperature and cooling power of helium

3.4 Conclusions

In this paper, a step-by-step commissioning strategy of a full localization 250W@4.5K helium cryogenic refrigerator: pressure stability of refrigerator, cool-down processes in cold box and cooling capacity evaluation of refrigerator was developed and carried out. Dynamic characteristics including the adjustment of pneumatic valves, 300~4.5K temperature evolution of heat exchangers and turbine expanders in the cold box and cooling capacity fluctuation are experimentally discussed. High and low pressure of refrigerator system can be smoothly stabilized to 10.5±0.6 bar (A) and 1.05±0.1 bar (A) within few minutes. The pre-cooling rate 1 K/min is controlled for HX1 by adjusting the mass flow rate of liquid nitrogen. By adjusting the opening of CV-4~CV-6 and the matching of E1 and E2, the cooling rate of HXs in the cold box can be controlled as 0.5~1 K/min. While maintaining the high pressure of system and the liquid helium level of the Liquid Helium Dewar stable, the cooling power is larger than 250 W at the range of 4.19K to 4.45K. The maximal cooling capacity of this helium cryogenic refrigerator is up to 317 W at 4.45 K temperature. The results are helpful to more precisely understand and commissioning hundred watts level helium cryogenic refrigerator.

ACKNOWLEDGEMENT

This work was supported by the fund of the State Key Laboratory of Technologies in Space Cryogenic Propellants of China (SKLTSCP 1801) and National Research and Development Project for Key Scientific Instruments of China (ZDYZ2014-1).

REFERENCE

[1] Hands BA, Alii. Cryogenic Engineering. London: Academic Press, 1986.

[2] Ph. Lebrun. Cryogenics for the large hadron collider. IEEE Transactions on Applied Superconductivity, 1999; 10: 1500–1506.

[3] Ph. Lebrun, L Tavian, Beyond the Large Hadron Collider: a first look at cryogenics for CERN future circular colliders, Physics Procedia, 2015; 67: 768 – 775.

[4] Fauvea E, Bonnetona M, Chalifoura M, Changa H S, Chodimellaa C, Monnereta E, Vincenta G, Flavienb G, Fabreb Y, Grillotb D, ITER LHe Plants Parallel Operation, Physics Procedia, 2015; 67: 42 – 47.

[5] X J Xie, S Q Yang, B C Deng, W Pan, Y L Wang, W P Zhu, J H Wu, Q Li, L H Gong, Y Zhang, Integration and commissioning of a full localization 250W@4.5K helium refrigerator at TIPC, IOP Conf. Ser.: Mater. Sci. Eng. 502 (2019) 012013.

[6] Shaoqi Yang, Xie Xiujuan, Bicai Deng, Wei Pan, Qing Li, Cool down results from a full localized 250W@4.5K helium refrigerator at TIPC, IOP Conf. Ser.: Mater. Sci. Eng. 502 (2019) 012014.

[7] R. Maekawa, K. Ooba, M. Nobutoki, T. Mito, Understanding dynamic behaviors of a large scale cryogenic plant, Advances in Cryogenic Engineering, 2008, 985,483-490.