Design and Test of Helium Gas Bearing Turbo Expander in 200W@4.5K Helium Refrigerator

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Abstract

Helium gas bearing turbo expander is an indispensable core component in large-scale cryogenic refrigeration systems. According to the parameters of the process design, two helium gas bearing turbo expanders have been designed for 200W@4.5K helium refrigerator. In this paper, the results of thermal design and structural design are described in detail, and the performance of the helium turbo expander are also tested. The experimental results show that both of the helium gas bearing turbo expanders run steadily at the speed of 230 krpm, and the cooling capacity of the whole machine has reached 260W under design conditions, which satisfies the design requirement of the helium refrigerator.

Introduction

In this article, two helium gas bearing turbo expander are designed for 200W@4.5K helium refrigerator. The refrigeration system was developed by FullCryo Company, and it will be applied to the KSTAR-NBI (Neutral Beam Injector) upgrade project of the National Nuclear Fusion Research Institute of Korea, which will provide cooling capacity for the cryogenic pump cold plate to ensure that the system obtains and maintains ultra-high vacuum.

Design requirements

The 200W@4.5K refrigeration system uses 80 K liquid nitrogen pre-cooling reverse Brayton cycle, and the two turbo expanders are arranged in series. The helium refrigerator process flow diagram is shown in Figure1, and the physical diagram of the cold box and the Dewar are shown in Figure 2. design parameters of the two turbo expanders are shown in Table 1.

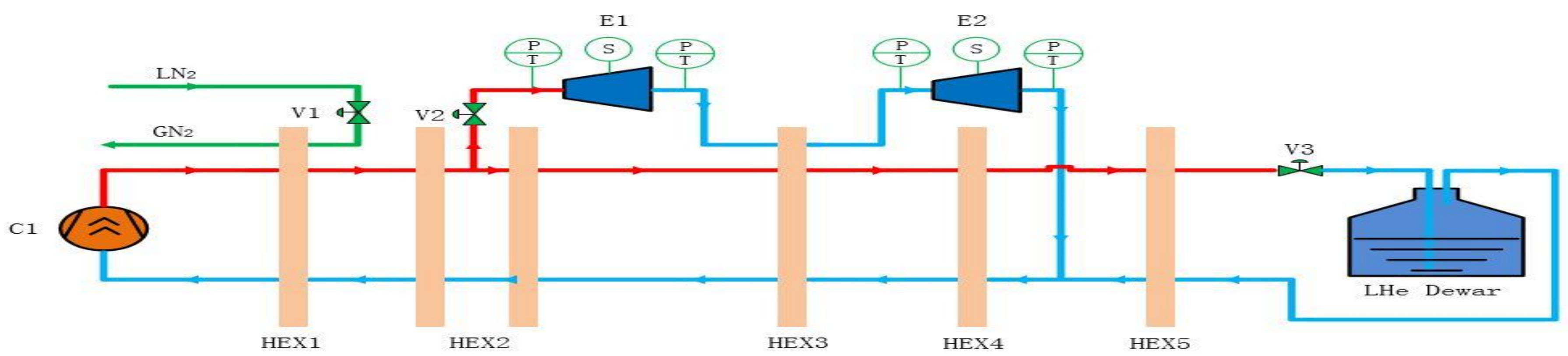

Figure 1. Process flow diagram of 200W@4.5K refrigerator

Figure 2. Physical diagram of the cold box and the Dewar

Expander Model	Inlet temperature (K)	Inlet pressure (bar)	Outlet pressure (bar)	Mass flow rae (g/s)
TE1	40.0	9	5.5	18
TE2	14.75	5.49	1.25	18

Table 1. Design parameters of the two turbo expanders

Thermal and structural design

a. Thermal design

In this paper, we design two helium gas bearing turbo expanders according to the method of one-dimensional flow. The selection of basic thermal parameters and structural parameters is based on the parameters of existing turbo expanders. The main thermal design results of the two expanders are shown in Table 2.

Table 2. Design parameters of the two turbo expanders

Expander Model	Expander Wheel Diameter(mm)	Brake Wheel Diameter (mm)	Rotor Speed (krpm)
TE1	16	29	215
TE2	14	27	226

b. Structural design

The overall structure of the expander affects the ease of assembly and disassembly, the efficiency and reliability of the expander. The outline of the whole turbo expander is shown in Figure 3. The turbo expander consists of a volute, a turbine cartridge, a brake house and a cooling water exchanger. The three parts of the cartridge, the brake house and the cooling water exchanger are assembled by bolting.

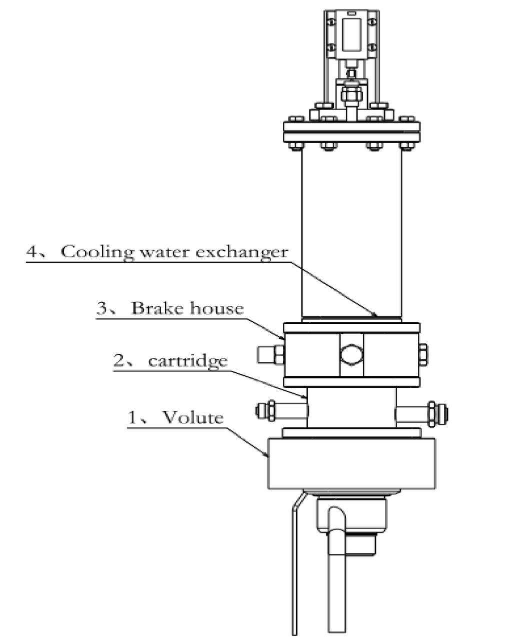

Figure 3. Structure of the turbo expander

Test Results

a. Stability test

Speed-up tests of the two turbo expanders are carried out at room temperature. The test results are shown in Figure 4. The experimental results show that both of the turbo expanders can operate continuously and steadily at the speed of 230 krpm, reaching and exceeding the design value. During the whole testing process, the bearing-rotor system showed good stability, no bearing instability and rotor jam occurred, and experienced various working conditions.

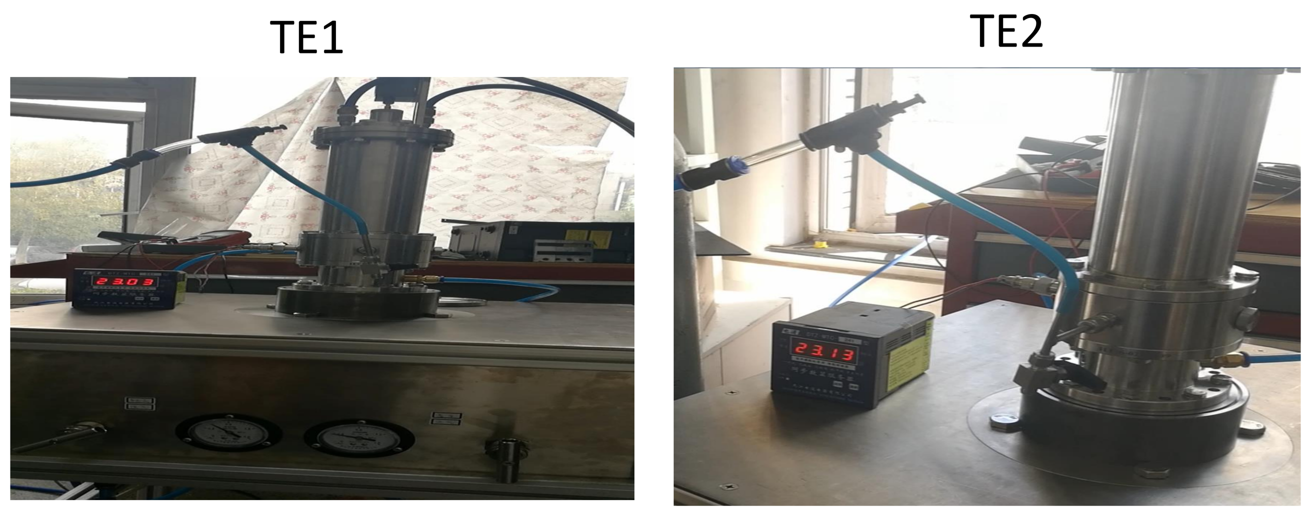

Figure 4. Stability test results

b. Thermal performance test

Under design conditions, the inlet and outlet parameters of the turbo expanders are shown in Fig. 5. The isentropic efficiency can be calculated according to the inlet and outlet temperature and pressure of the turbo expander. The isentropic efficiency of TE1 and TE2 are 66% and 59% respectively. During the commissioning process of the 200W@4.5K refrigeration system, the helium turbo expander experienced multiple starts and stops, cooling and long-term low-temperature operation tests, and the rotor bearing system has excellent dynamic performance. The maximum test cooling capacity of the entire system reached 260W, fully meet and exceed design requirements.

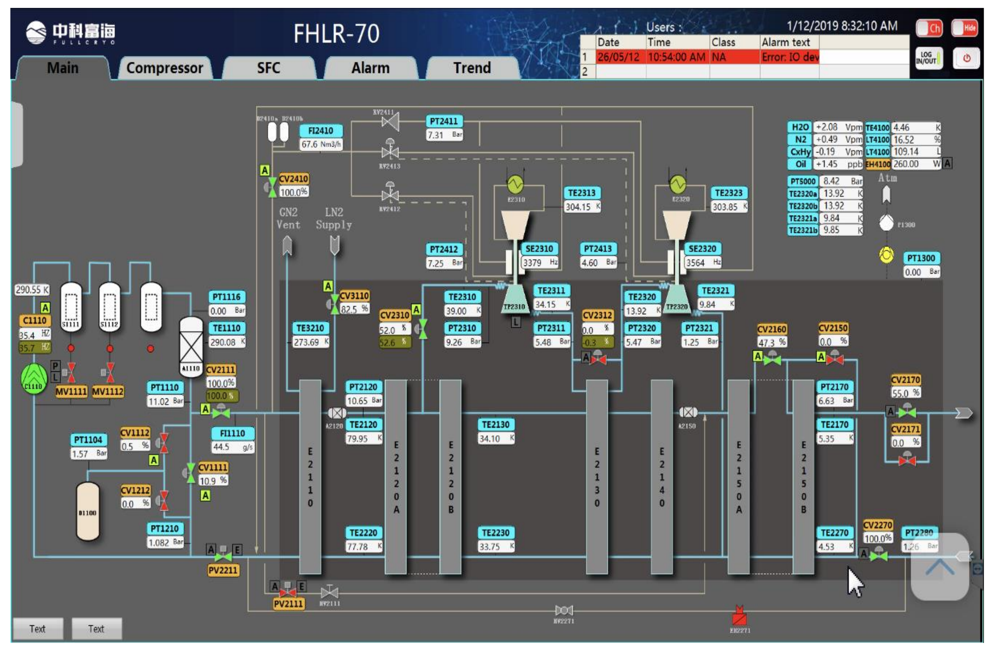

Figure 5. Experimental results of turbo expander under design conditions

Conclusions

According to the process parameter design requirements of large-scale cryogenic refrigeration systems, two helium gas bearing turbo expander are designed. The test results of normal temperature and low temperature show that the two turbo expanders have excellent performance. The two turbo expanders rotor system can always run smoothly at high speed or even over speed. This fully shows that the performance index of the turbine expander meets and obviously exceeds the original design requirements.

References

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