Cryogenic Performance Test Platform for the Gas Bearings of Helium Turbine Expanders

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Abstract. The turbo-expander is the core part of the helium refrigerator, and the gas bearing is the critical component influences the stability of the machine. There is 300 K operating temperature difference between the turbine wheel and the gas bearing regions in the helium turbo-expander. Therefore, it is necessary to consider the heat transfer between the bearing surfaces, nominally at room temperature, and the rest of the machine when studying bearing dynamic stability. This paper describes a cryogenic test platform that is being developed to analyze the dynamic performance of gas bearings with cryogenic gas supply. The system flow loop has been designed for bearing and small turbine testing at 80 K and above. The experimental method has been determined. All of the components are ready for the cold box assembly. The commissioning of the platform will be carried out in the near future.

1. Introduction

The turbo-expander is the key machine in a large-scale helium cryogenic system. It is responsible for the cool-down below 80K of the helium refrigerator. As the mechanical support for the rotating assembly of the turbo-expander, the bearings play an important role in the stability and reliability of the machine. In general, the turbine wheel and gas path are inside the cold box of the helium refrigerator, and the bearings and the brake wheel are located at the room temperature end of the machine. The working temperature of the turbine wheel can reach below 10 K, so the loss of cooling capacity from axial heat conduction is unavoidable. The behavior of the bearing shaft system of the turbo-expander involves complex heat transfer and hydrodynamic phenomena.

The Institute of Plasma Physics, Chinese Academy of Sciences (CASIPP) has been devoted to the application and research of helium turbine expanders for many years. In the research, it was found that the stability of the bearing shaft system was good in room temperature experiment tests. However, in the actual cryogenic condition, the faults had occurred, caused by the contact between the bearing and the shaft, so the influence of cryogenic heat transfer on the bearing shaft system cannot be ignored.

CASIPP had developed a cryogenic helium turbo-expander test platform. This platform was connected with the Experimental Advanced Superconductive Tokamak (EAST) cryogenic system, so the overhead cost of cryogenic experiments is high. This paper describes a standalone cryogenic test platform that uses nitrogen. This platform is being developed to analyze the dynamic performance of gas bearings with cryogenic gas supply. The platform can be used in the basic research of bearing stability and to guide the study and development of turbo-expanders.
2. Process flow of the cryogenic test platform

The design method of this experimental platform is to use the cold capacity obtained by turbine expansion to provide low temperature gas supply source for the bearing. The process flow diagram of the test platform is shown as Figure 1. The dynamic characteristics of hydrostatic gas bearings and the stability of the bearing-rotor system are studied at various gas supply pressures and temperatures at various fixed speeds. The cryogenic test platform includes the plate heat exchanger HX1, turbine expander, cryogenic valve, nitrogen compressor, cold box and related pipelines. This platform is suitable for testing of small turbines with flow rates below 100 g/s. To avoid the formation of liquid nitrogen in the bearing gas supply, the experimental temperature range of the bearing flow is 300 K to 150 K.

![Figure 1. Process flow diagram of cryogenic performance test platform.](image-url)

The high-pressure gas from the nitrogen compressors is stored in a nitrogen tank to provide 15 bar pressure for the test system. When opening valves V 301 and V 101, the high-pressure nitrogen enters the test platform. The room temperature part of the bearing supply is provided by slowly opening V 202. When the inlet pressure of the bearings is more than 3 bar, which is the minimum safe pressure for bearing operation, V102 is slowly opened to supply gas to the turbine wheel. The opening valve V 102 in combination with the amount of flow in the brake circuit fixes the turbine speed. As the opening of the valve V 102 increases, the inlet temperature of the turbine decreases under pre-cooling from the turbine expansion power through heat exchanger HX1.

In the process just described, the turbine speed is rising. The turbo-expander assembly is equipped with an independent brake wheel and braking circuit at the warm end. The heat generated by expansion work transfer from the turbine wheel to the braking wheel is taken away by cooling water in the heat exchanger HX 2. The rotational speed is controlled by adjusting V502. Valve V201 provides flow to the bearings that is cooled by HX1. If the temperature at V 201 is too low, the bypass valve V 401 can be opened. When the temperature at valve V201 is steady at a desired value, V 201 is opened. The gas supply pressure and temperature of the bearing is adjusted by the interaction between V 201 and V 202. This test platform can also be used to test mechanical properties and the thermodynamic performances above 80 K for the turbine expander.
3. **Main components of test platform**

3.1. *piston nitrogen compressor*

All of the gas supply for the cryogenic test platform comes from two identical reciprocating nitrogen compressors working together. The maximum pressure of a single nitrogen compressor is 2.5 MPa, and the flowrate is 1 m³/min. Figure 2 shows one of the nitrogen compressors. High pressure nitrogen is stored in a nitrogen tank whose storage capacity is 50 m³. The inlet gas for the nitrogen compressors is generated by liquid nitrogen vaporization, so the purity of gas supply is sufficient for the test system. In addition, many filters are installed in the test system to further ensure the purity of gas supply for the turbine and bearings.

![Figure 2. Reciprocating nitrogen compressor.](image)

![Figure 3. Bearing shaft system for testing.](image)

3.2 *The test object*

When the turbine is starting, all of the mating rotating parts and bearings surfaces match each other at the correct clearances. Testing the bearings separately at this condition does not account of the thermal and mechanical interaction between bearings and other components, which are key to true turbine operation. This test platform takes the bearing system and complete rotating assembly as a whole system to analyze and research, and integrates them in the turbo-expander unit to test together. This not only displays the dynamic characteristics of bearings correctly, but also avoids heat transfer between the bearings and external environment and prevents frost in the cryogenic gas supply. The turbo-expander is the key part of the whole platform for cool down of the system. The turbo-expander developed by ASIPP will be adopted. The gas bearings and rotor system are shown in Figure 3. Some key design parameters of turbo-expander for helium operation are listed in Table 1. As shown in Figure 4, the full hydrostatic gas bearing system and the brake wheel were adopted along with the turbine, and the thrust disk was placed in the middle of the two bearings.

![Figure 4. The diagram of testing turbine and bearing.](image)
Table 1. Design parameters of the turbine expander.

| Parameter                  | Values |
|----------------------------|--------|
| Inlet pressure (bar)       | 12.45  |
| Inlet temperature (K)      | 34.5   |
| Mass flowrate (g/s)        | 34.8   |
| Rotor speed (krpm)         | 243    |
| Bearing diameter (mm)      | 17 mm  |
| Bearing length (mm)        | 28 mm  |
| Orifice rows               | 2      |
| Orifice number in one row  | 8      |

3.3 The cold box

The cold box is cylindrical structure and made of 304 stainless steel. Figure 5 illustrates 3-D design of the cold box. The top of the box is a cover plate with multiple penetration, and the bottom is a flat flange cover structure. The cold box includes a plate heat exchanger, a turbo-expander, low temperature valves, and temperature and pressure sensors. All the pipes and components in the cold box are suspended from the top cover, and have a certain distance from the top flange, which is convenient for lifting and maintenance. In order to reduce heat loss, all pipes are covered with multilayer insulation. Due to a section of the bearing gas supply pipe being outside the cold box, the length of that pipe is shortened to avoid frosting, and all top flange penetrations are well insulated.

Table 2. Parameters of the cold box.

| Diameter (mm) | Height (mm) | Design pressure (MPa) | Working pressure (Pa) | Shell thickness (mm) |
|---------------|-------------|-----------------------|-----------------------|----------------------|
| 900           | 1650        | 0.1                   | $10^3$                | 6                    |

Figure 5. 3-D schematic diagram of the cold box design.  
Figure 6. The vessel.

The test platform is designed as a multi-functional and comprehensive cryogenic test platform for turbo-expanders and bearings, so multiple holes were reserved on the top cover for testing different turbo-expander and bearing designs for future improvements. The design parameters of the cold box are in Table 2. The shell thickness is selected according in the vacuum vessel design manual. The cold
box vessel shown in Figure 6 has been fully-fabricated and pressure tested. The next step is to install the internal components of the cold box.

3.4 Date acquisition and analysis
In this test platform, National Instruments data acquisition card is used for the continuous recording of pressures, flowrates and temperatures. The host computer uses Labview soft to store and display the data in real time. The key points in the flow loop of Figure 1 are set up for pressure and temperature measurement, including the four ends of the heat exchanger HX1, the inlet and outlet of the turbine, and the inlet for the bearing gas supply. An eddy current shaft displacement sensor was used. Through the linear relationship between sensor out signal and displacement, the rotor speed and shaft center-line orbits are obtained. Figure 7 shows the dynamic characteristic test display for the bearing.

![Figure 7. Dynamic characteristic test interface for the bearing](image)

4. Conclusion
This paper describes the development of a cryogenic test platform to evaluate the dynamic characteristics of gas bearings and small turbo-expanders. The effect of different temperatures and pressures of the gas supply on bearing stability will be studied using the platform. At present, the cold box vessel has been received from its vendor. In the future, the internal parts of the cold box will be installed and the data acquisition system will be checked out. The inlet pressure and temperature of the bearing gas supply are regulated by two valves to achieve a given test condition. These valve settings also interact with the brake circuit valve setting to fix the turbine speed. Testing will be carry out as soon as possible to commission the platform.

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