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Research on the static performance of a gas thrust bearing for the eddy current brake helium turbo-expander

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Abstract. As an important refrigeration component, the turbo-expander affects the continuous operation of the helium refrigerator. In order to improve the reliability of the refrigerator, a helium turbo-expander with the eddy current brake was designed by Institute of Plasma Physics Chinese Academy of Sciences. The axial support is the critical technology to ensure the stability of the bearing-rotor system for the turbo-expander. This study is based on the static gas thrust bearing of the home-made turbine, the performance of the bearing was investigated by computational fluid dynamics simulation. The findings in this paper can provide an important guideline for the optimal design of the thrust gas bearing.

1. Introduction

The large-scale helium cryogenic system is an important subsystem for many large scientific devices such as the nuclear fusion, high energy accelerator and so on. The 2KW helium cryogenic system for the Experimental Advanced Superconductive Tokamak (EAST) was designed and built at the Institute of Plasma Physics, Chinese Academy of Sciences (CASIPP). The toroidal and poloidal field magnets in EAST device have been cooled from ambient temperature to 4.5 K by the cryogenic system.

In the process flow, four turbo-expanders are used to achieve refrigeration below 80K. As the heart of cryogenic refrigerators, the helium turbo-expander affects the stable operation of cryogenic systems. The supporting component of the turbine is the bearing, the mechanical properties of which are directly related to the reliability and safety of the turbine with the higher rotate speed.

For the optimization of the cryogenic system, CASIPP has been developing the helium turbine design and bearing research. In the initial stage, turbine expanders with the oil and gas mixed bearing were operated in the cryogenic system, which have a complex structure and the oil could pollute the system. Then the gas bearing turbine with fan brake was studied for EAST system, but it is difficult in adjustment. In recent years, in order to simplify the turbine operation and improve the system reliability, a fully static gas bearing turbo-expander with the eddy current brake has been designed for EAST cryogenic system by CASIPP.

The axial support is the critical technology to ensure the stability of the bearing-rotor system for the turbo-expander because the turbine is placed vertically. Static performance analysis is the basis of dynamic analysis, which is the guidance of machining and assembly. In this paper, the influence of gas supply pressure and film thickness as well as hold diameter on the performance of the thrust bearing of



the home-made turbine were calculated and analyzed using CFD numerical simulation. And the thrust bearing is optimized to meet the turbine design demand.

2. Gas bearing engineering design

According to the design of the expansion wheel, brake wheel and the rotor speed, the axial force was anticipated, which is the main load of thrust bearing. Then the structure of the thrust bearing was obtained based on the axial force. The multi-supply gas holes annular static thrust bearing for the eddy current brake turbine is showed in figure 1.

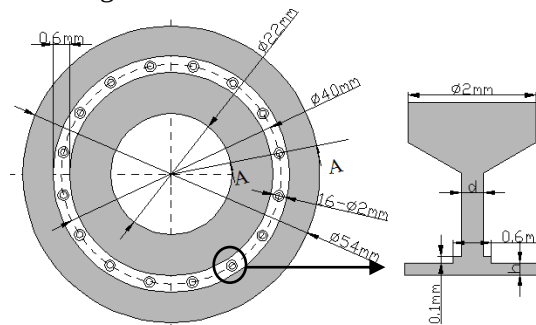


Figure 1. Structure and parameter detail of thrust bearing.

The inner and outer diameters of the thrust disc are 22 and 57mm, respectively. There is one row of 16 gas supply holds distributed in a circumference direction of 40mm diameter. In order to increase the load capacity of the bearing, a groove connecting the gas supply holes was set along the circumference for the pressure equal distribution. Due to increasing the gas volume in the film, the pressure-equalizing groove should be selected as small as possible to avoid the phenomenon of the bearing air-hammer.

3. Numerical simulation and result analysis

3.1. simulation model

The load capacity provided by the designed thrust bearing is larger than the axial load from the rotor system, but the bearing performance would be affected by the machining and assembly, such as gas supply pressure, film thickness, orifice diameter and so on. By solving the Reynolds equation, the pressure distribution in the bearing gas film is calculated, and the parameters of the bearing load capacity, stiffness and gas consumption are gained, which is an effective method to analyze the bearing performance.

In this paper, the numerical simulation was carried out by Fluent software. The high pressure gas is supplied through the 16 orifices, and the ambient pressure is 1.5 bar. As shown in figure 2, the pressure distribution of thrust bearings is symmetrical, so the 1/4 model was adopted to reduce the time of calculation. To ensure the quality of meshes, the model was split to many parts for meshing, which are basically hexahedral structure (HEX). And eight layers of meshes are selected at the gas film. Figure 3 shows the meshes and boundary conditions of the thrust bearing.

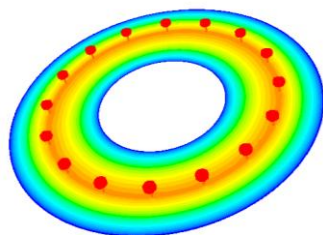


Figure 2. Pressure distribution.

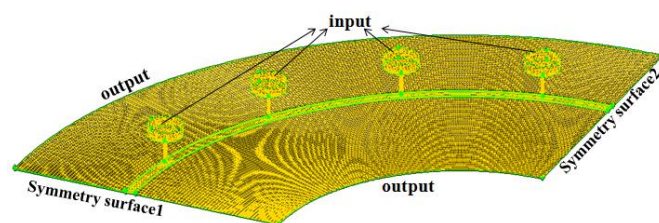


Figure 3 . Meshes and boundary conditions.

3.2 Effect of gas supply pressure variation

With other parameters consistency ($d=0.35\text{mm}$), the gas consumption and load capacity of the bearing with film thickness at 15, 20, 30, $50\mu\text{m}$ are calculated respectively when the gas supply pressure is 5, 6, 7, 8, 9, 10, 11, 12 bar. As shown in figure 4, with the increase of gas supply pressure, the load capacity and gas consumption increase gradually. When the thickness of gas film is larger, the load capacity is basically unchanged with the increase of the supply pressure. Considering the loss of compressor power and gas supply, 10 bar supply pressure was adopted.

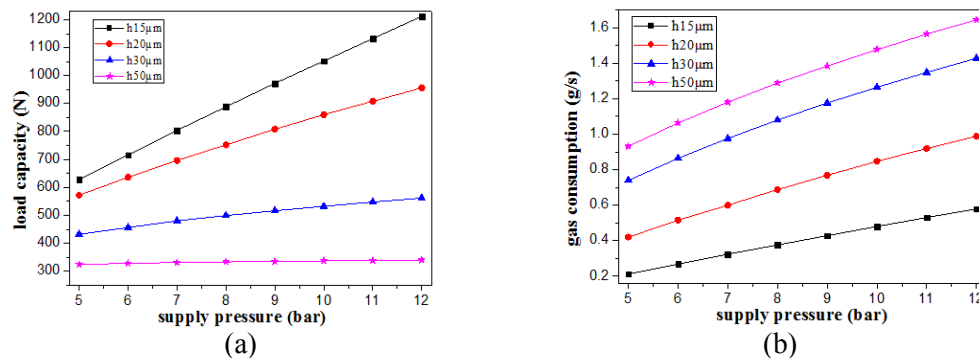


Figure 4. Bearing load capacity(a) and gas consumption(b) for different gas supply pressures.

3.3 Effect of pressure-equalizing groove

Figure 5 shows that the pressure distribution of gas film is uniform along the circumference direction with the pressure-equalizing groove. The pressure distribution of bearings with different structures in the radial direction was shown in figure 6. At the same parameters and the film thickness is $10\mu\text{m}$, with the pressure-equalizing groove, the pressure in the film decreases smoothly to the ambient pressure as a parabola. But without the pressure-equalizing groove, the gas film pressures suddenly decrease. As shown in figure 7, the load capacity and gas consumption of the bearing with the pressure-equalizing groove are larger than the other.

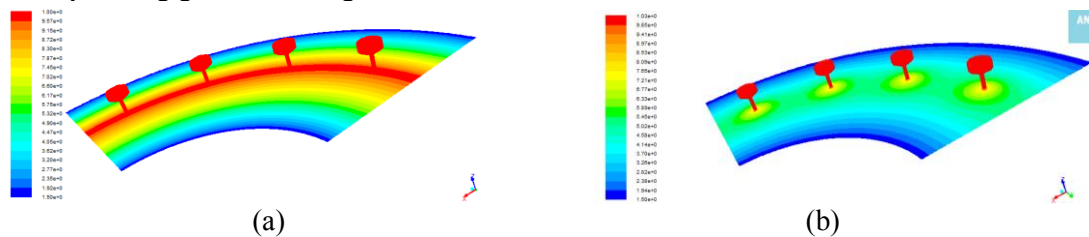


Figure 5. A-A cross-section pressure (a) with groove (b) without groove.

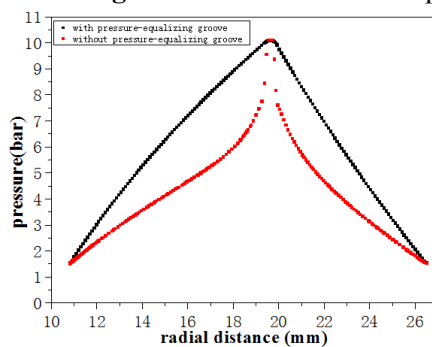


Figure 6. A-A cross-section pressure.

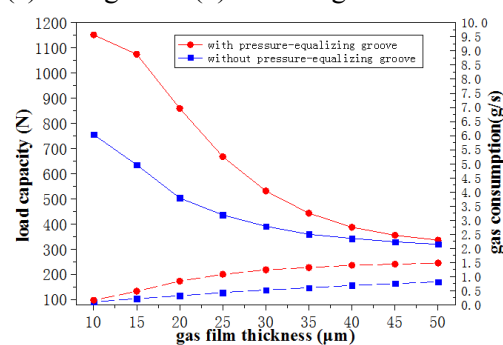


Figure 7. Bearing load capacity and gas consumption for different structures.

3.4 Effect of gas film thickness variation

As shown in figure 8, the load capacity and gas consumption of the thrust bearing were compared with the different gas film thicknesses. When the orifices diameter were fixed, with the increase of film thickness, the load capacity decreases rapidly, then decreases gradually. And the gas consumption increases gradually and then remains basically. The thrust bearing stiffness is the slope of the load capacity curve. Figure 9 shows that the stiffness increases first and then decreases, and a wave peak appears.

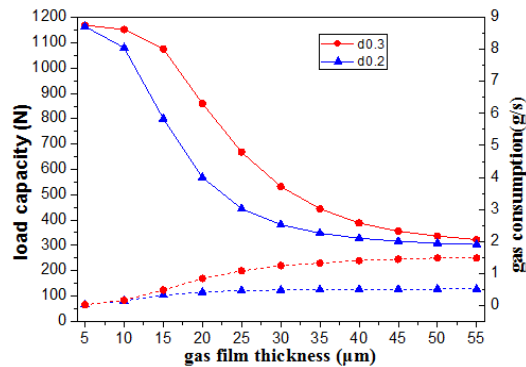


Figure 8. Bearing load capacity and gas consumption for different gas film thicknesses.

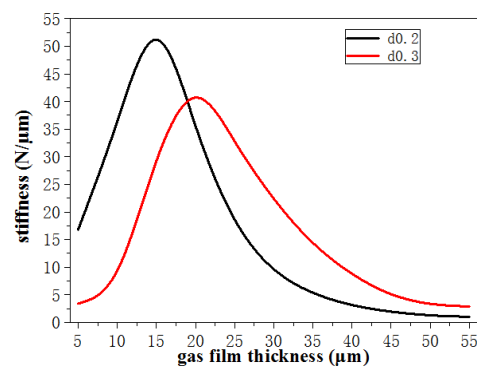


Figure 9. Bearing stiffness for different gas film thicknesses.

3.5 Effect of hole diameters variation

The bearing load capacity and gas consumption for different hole diameters were displayed in figure 10. When the gas film thicknesses were fixed, with the increase of hole diameters, the load capacity and gas consumption increase and then level off. Therefore, the orifice diameter should not be too large, moderate hole diameter was choose to avoid the processing difficulty.

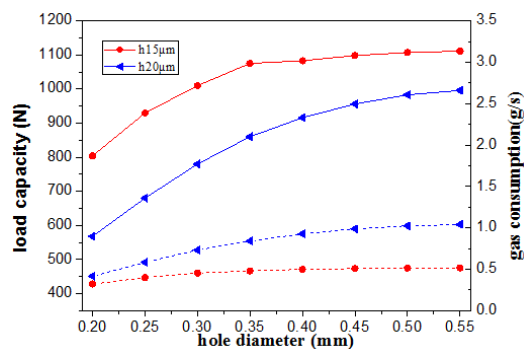


Figure 10. Bearing load capacity and gas consumption for different hole diameters.

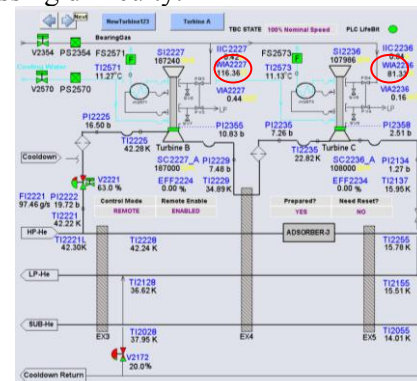


Figure 11. Supervisory interface of ATEKO turbines in EAST helium refrigerator.

4. Application analysis on the thrust bearing

At present, the turbine with eddy current brake from ATEKO Company were adopted in EAST helium system for many times of cryogenic experiments. The turbine rotor is supported by fully dynamic gas bearings. But the lower thrust gas bearing is static to increase the thrust carrying capacity. As shown in figure 11, axial load capacity is a critical monitoring parameter in EAST cryogenic experiment. Figure 12 shows the relationship between axial load and inlet, outlet and internal pressure of the turbine. And the rotation of the spindle could change the gas film thickness of the thrust bearing, which affect the axial load capacity. Therefore, it is necessary to make a detailed performance analysis for the thrust bearings before processing and testing of the turbine. In contrast from the designed bearing, the bearing gas supply of the ATEKO turbine is not lower than 5bar.

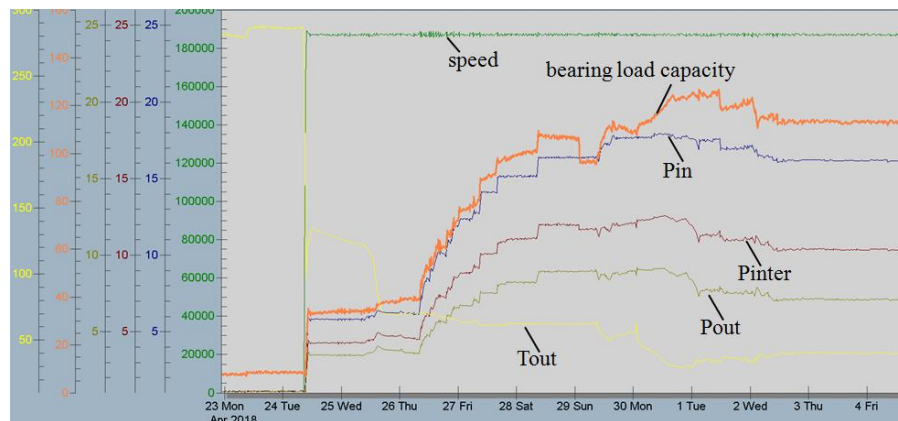


Figure 12. Operation curves of startup process for ATEKO turbines.

5. Conclusion

In this paper, the static performance of the thrust bearing for the self-designed turbine has been studied using CFD numerical simulation method. The simulation results prove that the gas film thickness is an important parameter to affect the performance of thrust bearings. With the gas film thickness decreasing, the bearing load capacity will increase, but the stiffness peaks is between 10-25 μ m. And the bearing capacity can be improved by increasing the gas supply pressure and hole diameter. According to the actual situation, the bearings with hole diameter 0.35mm were machined, and the gas supply pressure 10bar was adopted. Due to the simplification and assumptions for the simulation model, the performance of thrust bearing needs to be verified by some test in future work and then optimized.

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Acknowledgments

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