Optimization Design of Turbo-expander Gas Bearing for a 500W Helium Refrigerator

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Introduction

➢ The 500W@4.5K helium refrigerator for ADS project has been designed and built at the Institute of Plasma Physics, which could be used for superconducting coils testing. The refrigerator adopts the standard Claude refrigeration cycle, which has two turbo-expanders to achieve expand cooling. Our team developed the 500W helium turbine.

➢ The turbine is the core machinery of the refrigerator, which efficiency and reliability are crucial to the economy and long-term stable operation for the refrigerator. The bearing as the supporting element is the core technology to impact the turbine stability.

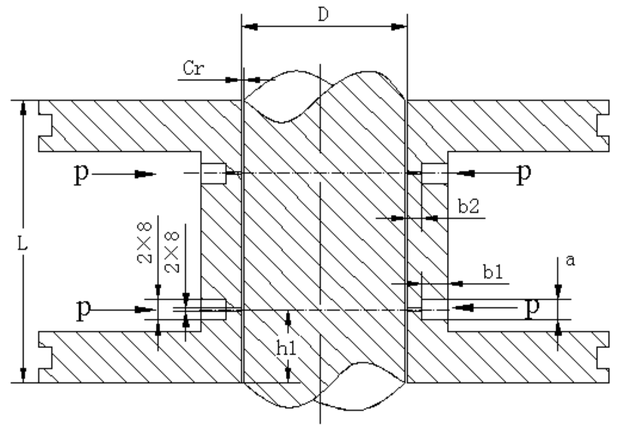
➢ The optimization design and performance study for the gas bearing are the premise to ensure the stability turbo-expander.

Gas bearing engineering design

➢ The helium turbine employs the static gas bearing. In order to avoid the bearing air-hammer, and reduce the processing difficulty, the inherent orifice was adopted.

➢ The impeller structure, rotation speed and power were obtained in the turbine design process. Then the rotor diameter was calculated and a series of the approximately reasonable ratio of length to diameter (L/D) for bearing were determined.

➢ According to the experience of engineering design, the final structure of the bearing was gained. The bearing has two rows of orifice restrictors, each with 8 and uses "O" ring to increase stability.



Numerical simulation

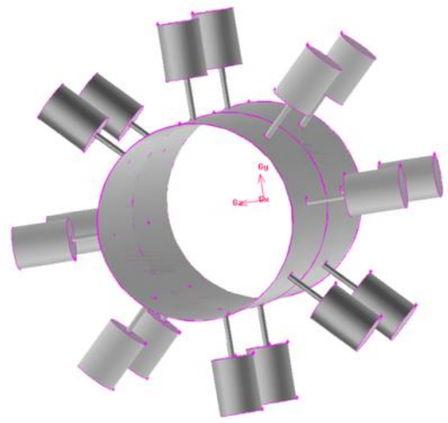
➢ In this paper, the performance study and optimization design has been presented using Fluent.

➢ Because of the good convergence effect, the laminar flow model has been adopted. The numerical model is assumed as following:

1) The surface roughness of the bearing is neglected, and the clearance is constant.

2) Nitrogen is selected as the lubrication medium, which is set as the ideal gas.

3) The outlet pressure is the atmospheric pressure, and the flow process is an adiabatic process.



Optimization design method

Calculation model

➢ The 1/4 model is adopted to simplify calculation.

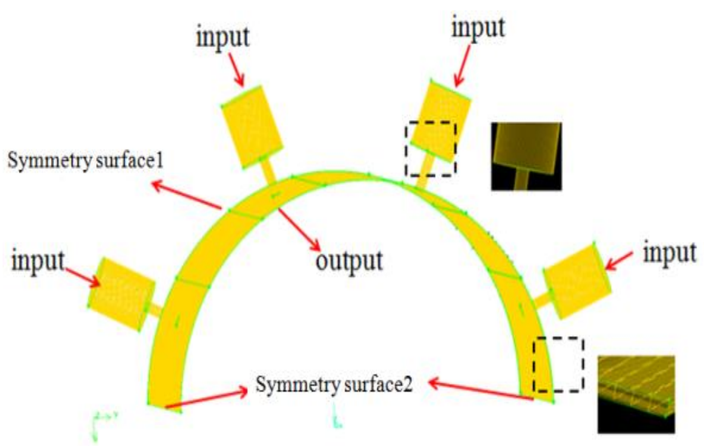
➢ Considering the mesh number and the calculation accuracy, ten layers of the mesh are selected in the thickness of the gas film. The meshes is basically hexahedral structure mesh (HEX).

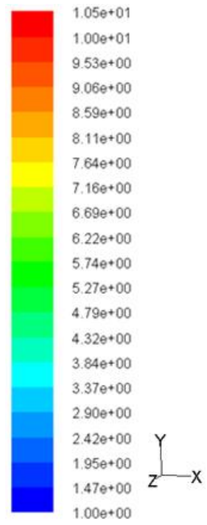
➢ There are four kinds of boundary conditions in the calculation model:

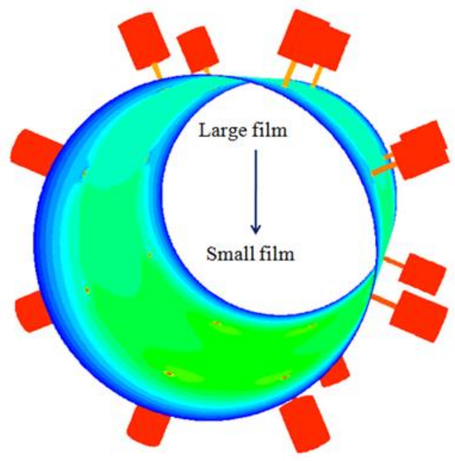
1). Inlet pressure of gas supply holes;

2) pressure outlet of the gas film;

3) Symmetry surface; 4) Wall surface.







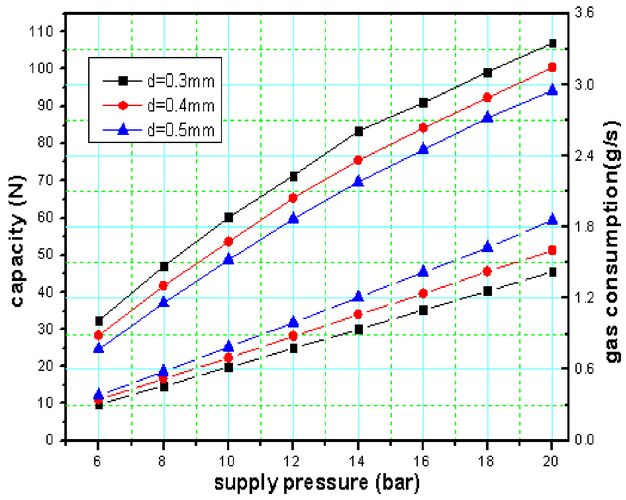
Optimization design method

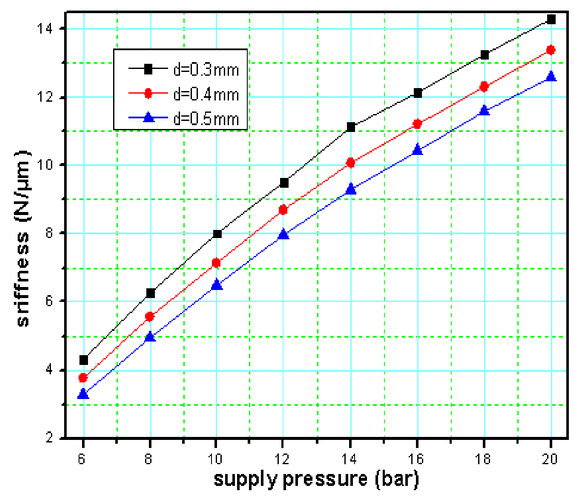
Effect of gas supply pressure variation

➢ The bearing capacity , stiffness and gas consumption increase.

➢ The pressure after the orifices is increasing, but the outlet pressure remains constant, so the pressure differential of the film increases. Then the capacity W strengthens.

➢ The increase of gas consumption Q will consume the compressor high pressure flow, and reduce the refrigerator COP value. So 10 bar supply pressure was adopted.



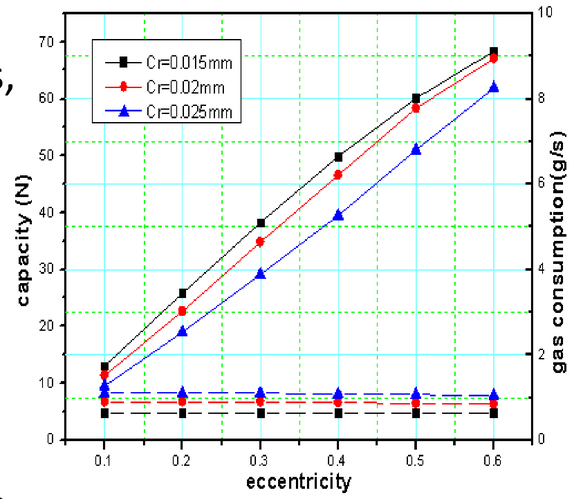


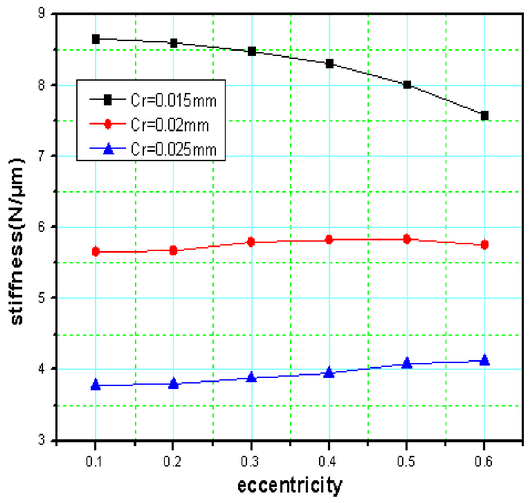
Effect of eccentricity variation

➢ The bearing capacity increases, and gas consumption reduces.

➢ The eccentricity leads to the difference of the gas-flow resistance, which is increasing at the minimum film, but decreasing at the maximum. So the pressure difference of the gas film increases, then the bearing capacity strengthens.

➢ The distance between the bearing and axis become larger, so the stiffness decreases slightly. The simulation model is used 0.5 eccentricity.





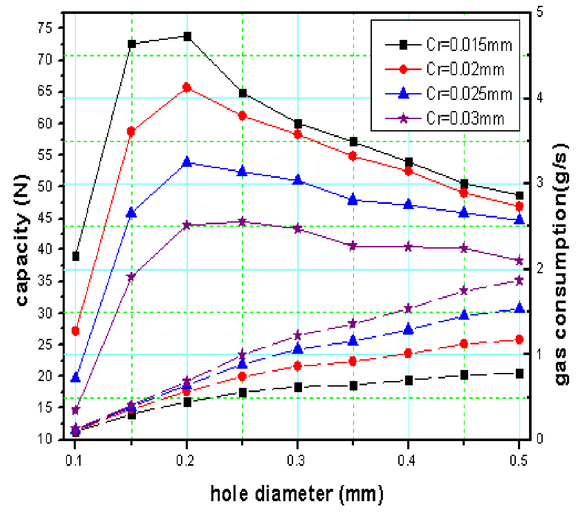
Effect of hole diameter variation

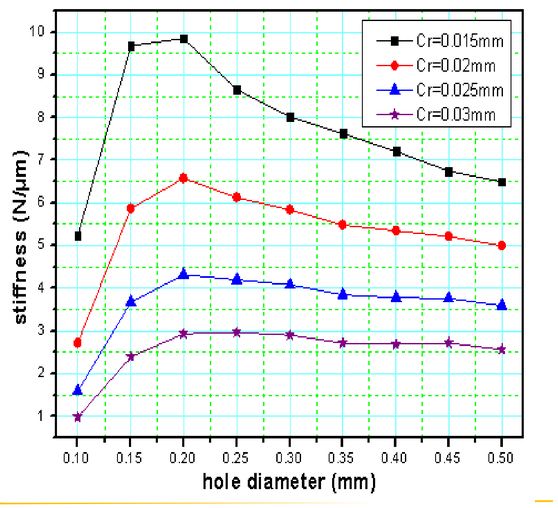
➢ The capacity and stiffness increase first and then decrease, there is an optimum diameter.

➢ The gas consumption increases because the gas flow area increases.

➢ The smaller hole will lead to difficulty in processing, which tend to clog up.

➢ After considering various factors and the actual situation, the smaller diameter is properly adopted.



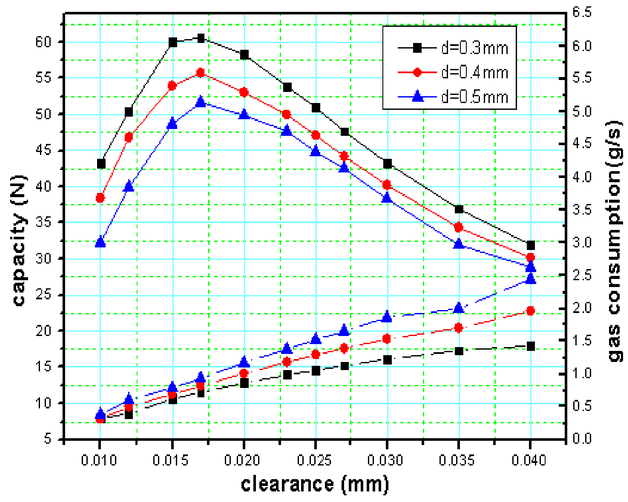


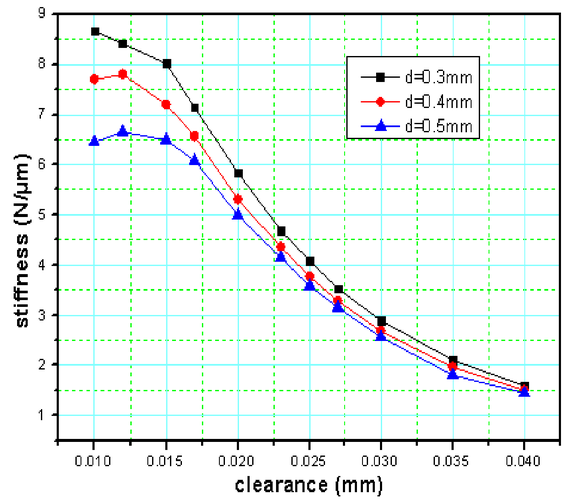
Effect of clearance variation

➢ There is a maximum capacity at Crm=0.017mm, but the capacity and stiffness decrease dramatically at Cr<0.015mm.

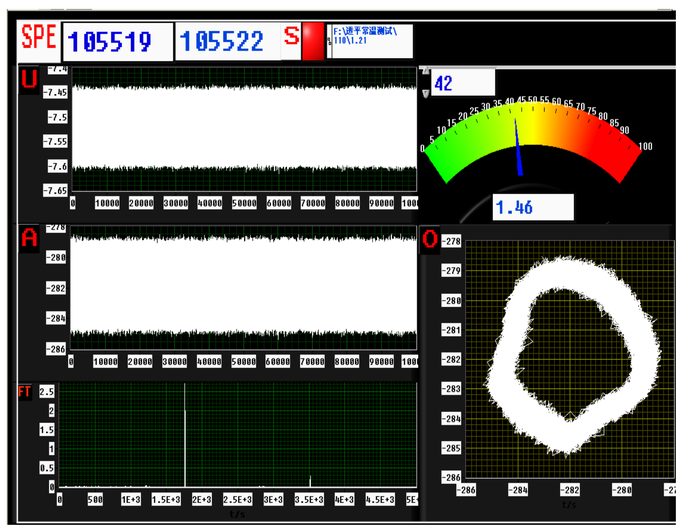
➢ Because of the clearance increase, the distance between the bearing and axis become larger, so the capacity and stiffness decreases. The gas consumption increases because of the increase of the gas flow area.

➢ The optimum clearance should be chosen at the maximum bearing capacity or less than Crm.





Ordinary temperature test



➢ The helium turbo-expander and its gas bearings have performed ordinary temperature testing several times.

➢ The rotation speed of the turbine is at 158 krpm, and the maximum amplitude is only 7~10 μm.

➢ The gas bearing has good stability and the mechanical properties of the turbine expander get the requirements.

Conclusions

➢ In the paper, the bearing capacity, stiffness and gas consumption are analyzed, and the corresponding relationship have been obtained.

➢ In the engineering pressure range, with increasing the supply pressure and eccentricity, reducing hole diameter and adjusting the clearance, the bearing capacity and stiffness can increase.