Study of new aerodynamic foil thrust gas bearing with elastic support for cryogenic turbo-expander

Chen C.Z., Lin S.N., Hou Y., Zhu Z.H.

Institute of Refrigeration and Cryogenic Engineering, Xi'an Jiaotong University, Xi'an 710049, China

In order to meet requirements of the gas bearing cryogenic turbo-expanders development, a new type of aerodynamic foil gas thrust bearing with elastic support was proposed and developed. The experimental study has been conducted on the gas bearing test rig. The factors affected on the main performances of the gas bearing have been analyzed and the ranges of optimum bearing parameters have been obtained.

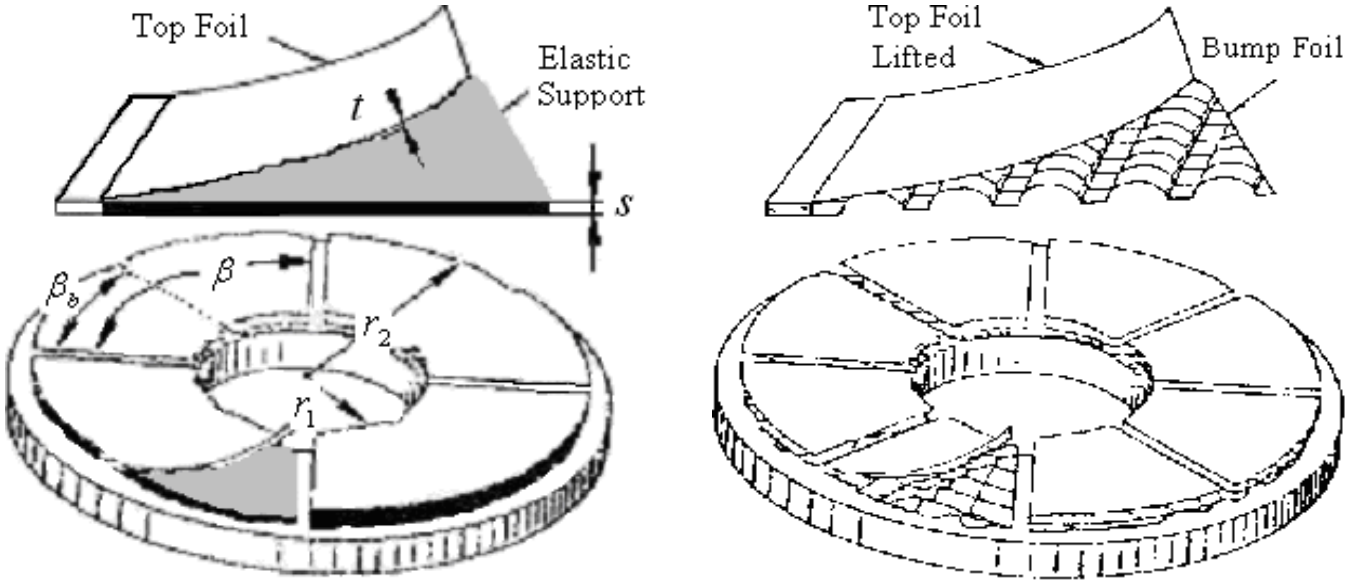
INTRODUCTION

With the development of small and miniature cryogenic turbo-expander in some fields, the high speed gas bearing has become the key part of evaluating the turbo-expander performance. Compliant foil bearing is one of the innovative bearing technologies for supporting cryogenic turbo-expander. The bearing with elastic support can adjust itself according to the changes of speed and load. It has strong self-adaptability. While the bearing is operating, it can absorb some excess energy by the function of the foil distortion and coulomb friction. It can keep high steady condition at high rotation speed even if it suffers vibration and whirling motion. The Cryogenic turbo-expander, using the foil gas bearings with elastic support, has better development potential and wide application foreground. In recent years, two types of new self-acting foil thrust bearings have been proposed and developed. The foil bearing is supported with double layers copper wires and elastic material respectively. And the domestic experiments have been conducted on the gas bearing test rig. The features of the new aerodynamic foil thrust gas bearing with elastic support are given briefly in this paper.

NEW AERODYNAMIC FOIL THRUST GAS BEARING WITH ELASTIC SUPPORT

The new aerodynamic foil thrust gas bearing with elastic support developed by Institute of Refrigeration and Cryogenic Engineering of Xi'an Jiaotong University is composed with some sectorial bearing housings and elastic foils. The surface of sectorial bearing housings is formed from incline and plane. The import gas film clearance between the surface and elastic foils is defined h_1; the export gas film clearance is defined h_2.When the bearing moves relatively with thrust surface, the supporting load is created by the aerodynamic effect. The aerodynamic foil thrust gas bearings with four bearing housing pads are shown in Figure 1(a). The other geometric structural parameters are defined as follows: r_1: inside radius of pad, r_2: outer radius of pad, β: field angle of pad, β_b: field angle of sectorial incline, S :thickness of the elastic material, t: thickness of the top foil, $b = \beta_b / \beta$: pitch rate.

The top foil is made of Beryllium-bronze, which is a kind of better bearing material. Its shape is sector and the size is suitable to bearing housing pad. Its dimensions are follows: field angle of pad 90º, inside radius 8mm, outer radius19mm and thickness 0.05～0.10mm. To improve the quality and lubricating property, the surface of the top foil is treated to form the composite coat or wiped by the lubricating material such as MoS_2.



(a) (b)

Figure 1 (a) The foil thrust gas bearing with elastic support
(b) The foil thrust gas bearing with bump foil

The support is made of the elastic material that has better elasticity and damp property and can endure high temperature. The shape of it is also sector and the dimensions are follows: field angle of pad 90º, inside radius 9mm,outer radius 18mm and thickness 0.2～0.5mm.The abridged general view of the new foil thrust gas bearing with elastic support is shown in Figure 1(a). Compared to the bump foil gas thrust bearing shown in Figure 1(b), which is widely used in high speed turbo machines, the support in our scheme is replaced by a kind of new elastic material. Its construction is simple, and it is easy to manufacture. And its surface structural stiffness is more uniform. So it has good practicability and extensibility.

EXPERIMENTAL APPARATUS

The experiments of the new aerodynamic foil thrust gas bearing with elastic support have been conducted on the multifunctional gas bearing test rig shown in Figure 2.The thrust gas bearing test rig is made up of the bearing-rotor system and the load system of the axial piston. The rotor system of the static gas bearing is driven by a reaction wheel. And its rotor speed and axial force can be adjusted by changing the mass flow or pressure. The load system of the axial piston includes piston shaft, cylinder, connecting piece, static journal bearing and eddy current displacement sensor. The experimental foil thrust bearing is mounted on the piston shaft by the connecting piece. The piston shaft is supported by the gas film, which is supplied by a pair of gas bearing. There is no friction in the axial motion. And the axial load is adjusted easily through changing the loading gas pressure of the cylinder.

The GYG01 high precision pressure sensor is adopted in the experiment to measure the axial loaded-gas pressure. In order to measure the motion and amplitude of vibration, the SJ4-1 eddy current sensor and the fore magnifier are used. And using FFT method, the rotor speed can be obtained by analyzing the vibration signal which can be measured by two eddy current type displacement probe

mounted on expander housing in X-Y direction respectively.

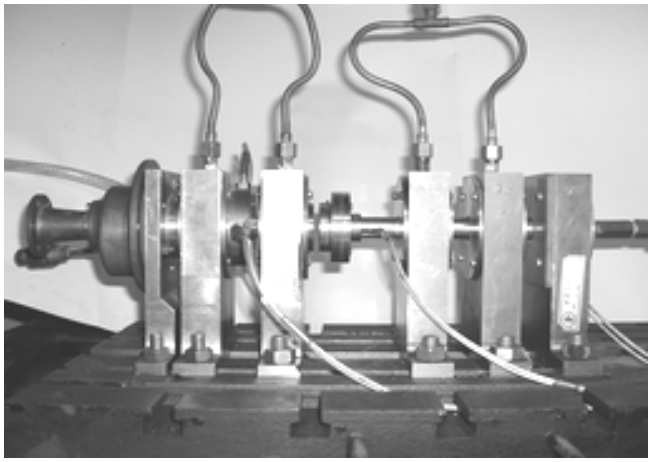
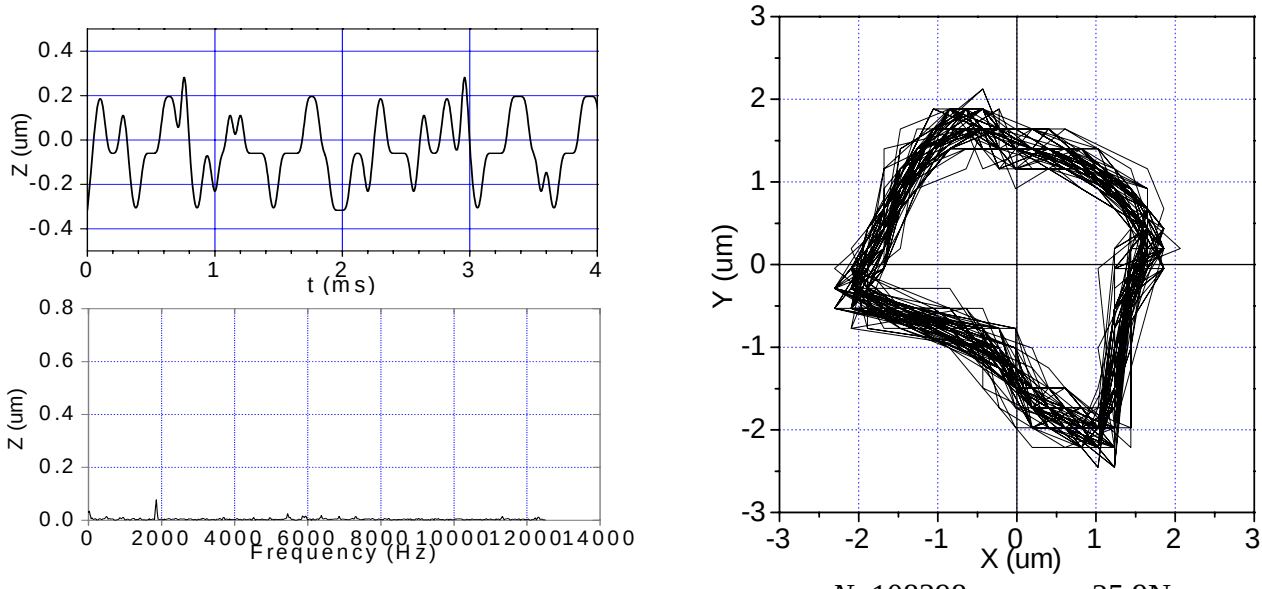


Figure 2 The multifunctional gas bearing test rig

EXPERIMENTAL RESULTS AND ANALYSES

Many thrust gas bearings of this new elastic support type with different structural parameters have been tested. The better results of the dynamic performance in the experiment are presented. The orbits of rotor center, the time-base and frequency-domain records of the rotor vibrations in the thrust force loading course are shown in Figure 3.The orbits of rotor center are clear and the amplitudes of vibration are small even when the sub-synchronous resonance occurs. The main portion of the rotor response is synchronous. The sub-synchronous resonance is not significant and its frequency is very low. The changes of the shaft vibration amplitudes are rather smooth in the operation. The results indicate that the new aerodynamic foil thrust gas bearing with elastic support is quite stable, and it seems to be suitable for small cryogenic turbo-expander.



N=108398rpm, *w*==25.9N

(*s*=0.25*mm*, *t*=0.07*mm*, *b*=0.7)

Figure 3 The vibration characteristics of the foil thrust gas bearing

Figure 4 illustrates the axial clearance of the foil thrust bearing as a function of bearing load at the speed 100,000rpm.As shown in the figure, the axial clearance reduces correspondingly with increasing the bearing load when the speed fixed. And the amplitudes reduce slowly and gradually at the greater load.

The results indicate the good damping characteristics.

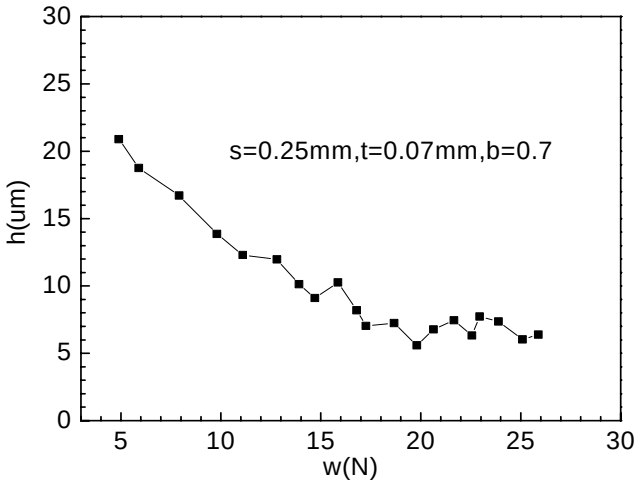


Figure 4 The axial clearance of the foil thrust bearing with bearing load

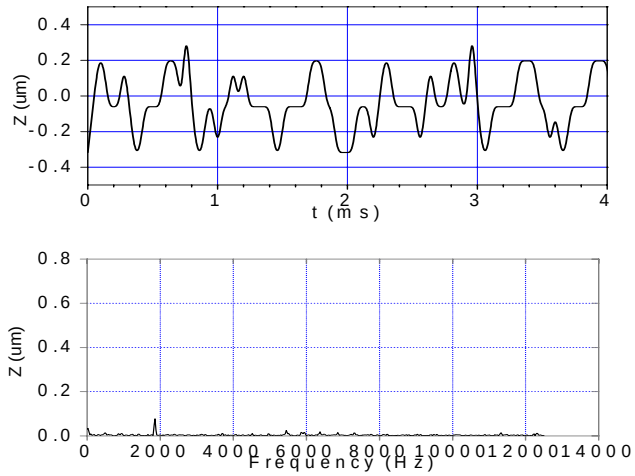


Figure 5 The time-base and frequency-domain records at the highest load

The relation between the maximum thrust bearing capacity and the structural parameters of foil bearing is obtained in the experiments. It is shown that the thickness of elastic material affects mostly the thrust bearing load. Generally speaking, the thinner the elastic material is, the higher the thrust bearing load is. But the thickness of the material can't be unrestrictedly reduced. On one hand, the restriction of material processing technique in existence must be considered; on the other hand the stability of the bearing is affected with reducing the material damping characteristics because of reducing the elastic support thickness. The highest thrust bearing load 25.9N is obtained (with s=0.25mm, t=0.07mm and b=0.7).The records of the time-base and frequency-domain of the foil bearing at the highest thrust bearing load are shown in Figure 5.Moreover, the material of elastic support is studied preliminarily and some factors affecting the performance of the new foil thrust bearing are obtained.

CONCLUSION

The experimental results indicate that the new aerodynamic foil thrust gas bearing with elastic support possesses good stability and operation performance. The good damping characteristics of the elastic support material restrain the rotor's vibrations and the growth of whirling amplitudes. And the flexible surface of the bearing decreases the damage to the rotor and the bearing surface effectively. The good damping characteristics of the elastic support and the good performance of the bearing are presented sufficiently. With the proper choice of the elastic support material and the parameters, the foil thrust bearing presented here can achieve high stability and high load capacity. The experiments of the cryogenic turbo-expander with new aerodynamic foil thrust gas bearing have also been conducted and some remarkable achievements are obtained. Due to its simplicity and good performance, the new aerodynamic foil thrust gas bearing with elastic support is hopeful to be applied to a small high speed cryogenic turbo-expander successfully.

REFERENCES

1. Chen C. Z., Self-acting Foil Journal Bearing with Elastic Support, 1998, Chinese Patent No. 98233296.3.

2. Xiong L.Y., Wu G, Hou Y. Development of aerodynamic foil journal bearing for a high speed cryogenic turboexpander, Cryogenics (1997) 37(4) 221-30.