euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
www.euspen.eu

Differential supply pressure to increase load capacity of an air bearing spindle

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Abstract

For ultraprecision applications that require a rotary axis with nanometer-level error motions whilst supporting large loads, a differential pressure between opposed thrusts of an air bearing spindle is demonstrated to provide as much as twice the axial load capacity compared to the capacity with both thrusts at the same pressure. The differential pressure, or bias, between the thrusts is realized through unique separated flow paths and porting design. Further, the separated flow path can be used to provide an integral non-influencing brake, or pneumo-lock, suitable for metrology applications. Finally, for applications which require a rotary degree of freedom combined with fine linear positioning, the differential pressure is used to demonstrate 3 µm controlled axial motion with a resolution less than 10 nm.

Air bearing design

1. Introduction

The air bearing spindle used in this work features opposed thrust plates with a relatively short, stiff shaft connecting them as shown in Figure 1. Nanometer-level error motions are achieved through a kinematically correct design in which the relatively large thrust bearings support axial and moment loads applied to the spindle [1]. With 5 µm air films and inherent compensation, the spindle exhibits stable operation over a wide range of supply pressures without pneumatic hammer.

Figure 1. A 10R Blockhead (Professional Instruments Company) is the subject of this work.

The air bearing structure described by HEG Arneson [2], commonly known as the Blockhead design, provides unrestricted (full line pressure) to both the journals and the thrusts. As such, the flow restriction necessary to support loads and provide stiffness is provided through grooves in the bearing surfaces and precise control of the air film thickness (inherent compensation) [3].

Furthmore, novel porting features incorporated into the structure permit supply of different pressures to each thrust as shown in Figure 2. The benefit of this design feature lies in the ability to increase axial load capacity for vertical axis applications by providing higher pressure to the upper thrust than to the lower thrust. In this work, the effect of differential thrust pressure on axial load capacity is demonstrated for a 10R Blockhead air bearing spindle. In addition, bias pressure supplied to the thrusts can also provid a metrology brake and a means to provide a few micrometers of axial motion without the need for an additional linear axis.

2. Design

Blockhead spindles may be equipped with a porting arrangement which allows the spindle to be biased for increased axial load capacity, to prevent rotation pneumatically, or provide micrometer-level axial motion.

2.1. Bias supply pressure to increase capacity

Blockhead spindles have internal porting which normally allows one inlet to feed both sides of the spindle. This porting can be easily modified to separate the flow to the two sides of the spindle. The modified path is shown in Figure 2. Air flows from the A side inlet and enters the air films without restriction at the corner of the A side thrust and radial bearing. The air flows across the films whilst being restricted by inherent compensation (grooves and bearing geometry). The radial films exhaust to atmosphere at the center of the journal and the thrust films exhaust at the outside of the thrust plate. The B side flow follows the same path for the opposite side of the spindle. This porting arrangement makes it possible to supply different pressures to the upper and lower thrusts. In particular, lower pressure on the lower thrust increases the axial load capacity.

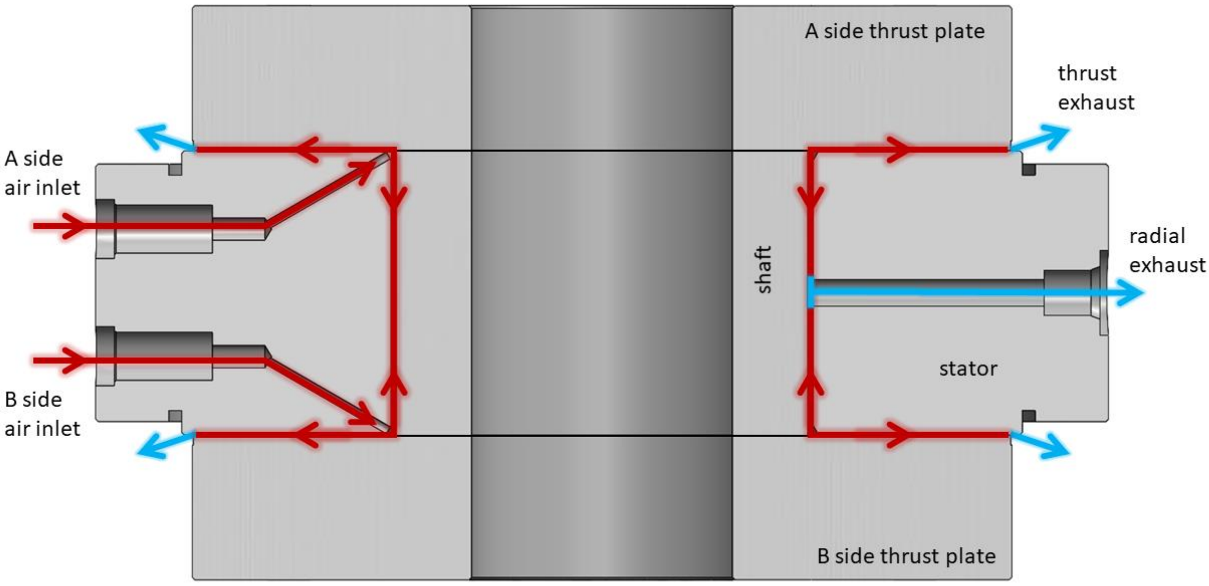

Figure 2. A side and B side flow paths are separated enabling a differential pressure, or bias.

2.2. Pneumatically locked metrology brake

When air pressure to one side of the spindle is completely removed, the rotor is held against the thrust surface of the stator. The holding force is enough for very light finish cuts or as a metrology brake with 6 Nm torque using 1 MPa differential pressure.

2.3. Controlled axial motion

A bias between the upper and lower thrust films causes the rotor to shift in the axial direction. This integral feature of all 10R Blockheads is ideal for micrometer-level adjustments. The recommended maximum axial motion is about half of the nominal air film which provides travel of about 3 µm. The axial motion is linearly proportional to the differential pressure.

3. Results

Measurement results using bespoke metrology tooling has been previously described [4]. Using this apparatus, a significant increase in load capacity is demonstrated using a bias pressure feed. With 0.7 MPa supplied to the upper thrust, the axial capacity increased 58% when the lower thrust pressure was reduced 0.2 MPa. This is especially useful since it provides enhanced load capacity without increasing the supply pressure, but reducing it. In addition, the bias feed can be used to move the spindle rotor in the axial direction. The displacement as a function of differential pressure is shown in Figure 3. Assuming a typical pressure resolution of 0.3 kPa, the calculated resolution of the axial motion is less than 10 nm.

3.1. Load capacity

Table 1 Measurement results demonstrate a 58% increase in axial capacity with 0.2 MPa bias for 10R Blockhead SN 657.

	Upper pressure	Lower pressure	Differential pressure	Ultimate axial capacity
Without bias	0.7 MPa	0.7 MPa	0.0 MPa	781 kg
With bias	0.7 MPa	0.5 MPa	0.2 MPa	1232 kg

3.1. Axial motion

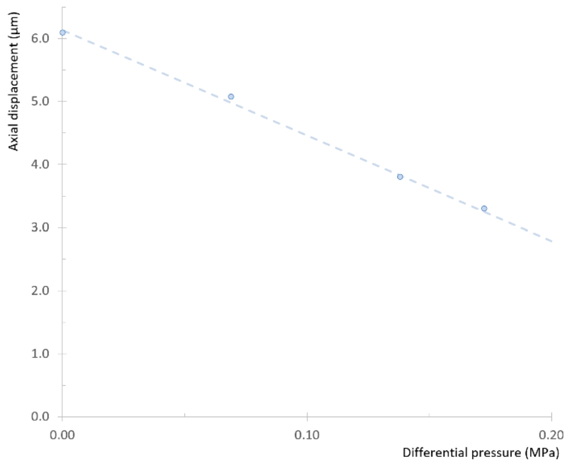

Figure 3. Controlled axial infeed provides 3 µm motion that is linearly proportional to the differential pressure.

4. Conclusion

The advantages of a differential pressure, or bias, between the opposed thrusts bearings of an ultra-precision air bearing spindle are demonstrated. The primary benefit is increased axial load capacity by reducing the supply pressure to the lower bearing. The bias can be used also as a pneumatic brake and to provide micrometer-level axial motion with resolution better than 10 nm.

References

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