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Design and experimental validation of a slit-type gas journal bearing

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Abstract

An aerostatic gas journal bearing is proposed with a gas supply orifice in the form of a narrow slit along the circumferential direction. The narrow slit provides in theory a more uniform distribution of gas inside the bearing, resulting in a lower error motion of the shaft when compared with porous or orifice gas bearing. Despite the possible application of such slit bearing in precision machines and instruments, literature on this type of bearing is surprisingly rare. This paper covers some of the remaining questions around slit bearings by describing the design and used fabrication method of a 20 mm prototype bearing. Error motion measurements on the prototype bearing shows an error motion below 60 nm, even for a heavily out-of-roundness rotor.

Gas journal bearings, metrology, precision machining

1. Introduction

Gas journal bearings are often used in high precision machines and instruments to obtain an accurate axis of rotation with minimal radial error motion. Well-designed porous gas bearings can reach an error motion on the order of nanometers, which is far better than any rolling-element bearing where the error motion is primarily bounded by the roundness of the bearing races [1]. In aerostatic gas bearings however, the gas film will 'smooth out' the geometric imperfection of the shaft and bearing surfaces. This means that, under the condition of a sufficiently uniform gas supply, the error motion of the shaft will be significant lower than its out-of-roundness [1].

In an orifice bearing, the uniformity is pursued by having multiple orifices in one or more rows tangential to the bearing surface. Machining all these orifices to the same size can however be difficult and costly [2]. Porous bearings have in essence already many small orifices distributed across the surface. Local deviations in the permeability of the porous material are unfortunately quite common and will degrade the precision of the bearing [1].

This paper presents therefore a slit type gas bearing where the precision or uniformity of the gas film will not depend on the homogeneity of a porous material, or on the capability to machine many individual orifices to strict tolerances, but only on the width-uniformity of a single circumferential slit. The required tolerance on the slit can be easily obtained with a conventional turning machine, as is shown in this paper with the fabrication and experimental validation of a Ø20 mm sized slit bearing.

2. Slit bearing concept

The conceptual idea of a slit type bearing is to have a narrow circumferential slit in the centre of the bearing acting as a laminar restrictor for the gas flow. Inside the slit the gas will move in radial direction inwards while its pressure drops from the supply pressure p_s to the bearing entrance pressure p_o as depicted in Figure 1. After the gas has entered the bearing gap, it will move further on in the axial direction where it exits the bearing at a pressure of p_a.

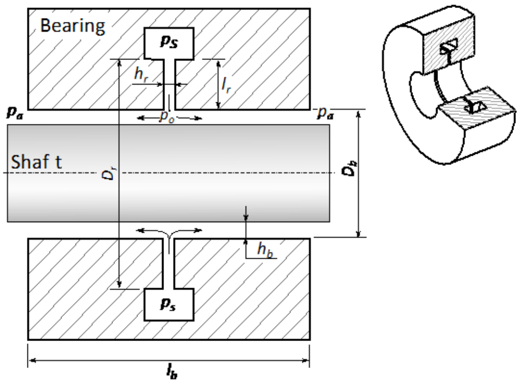

Figure 1. Conceptual drawing of a slit bearing.

By assuming a fully developed viscous flow with a parabolic velocity profile and negligible tangential flow inside the bearing, the bearing entrance pressure p_o can be simple derived from the one dimensional Reynolds equation as:

$$p_o = \sqrt{\emptyset p_s^2 + (1-\emptyset)p_a^2} \tag{1}$$

with the pressure ratio coefficient ø given as

$$\emptyset = \frac{\alpha}{\alpha+4\beta} \quad \text{with} \quad \alpha = \frac{2h_r^3}{D_b \cdot \ln(D_r/D_b)}, \quad \beta = \frac{h_b^3}{l_b} \tag{2}$$

A near optimal stiffness is obtained if the bearing and restrictor gap size h_b, h_r and their lengths l_b, l_r respectively are such that $\emptyset \approx 1/3$. In general this means that the restrictor gap hight h_r must be of the same order as the bearing clearance gap h_b. That is, on the order of 10 µm for a typical aerostatic bearing.

2.1. Prototype design and fabrication

A simple 20 mm prototype slit bearing is made for assessing the possibility of machining such narrow slit in practice. The decision was made to fabricate the bearing out of two parts, each forming one half of the bearing as showed in Figure 2. In this way, the two bearing parts can be machined on a diamond turning machine while the slit can be obtained by giving one of the two halves a small recess. The final restriction slit is then formed by bolting the two halves together.

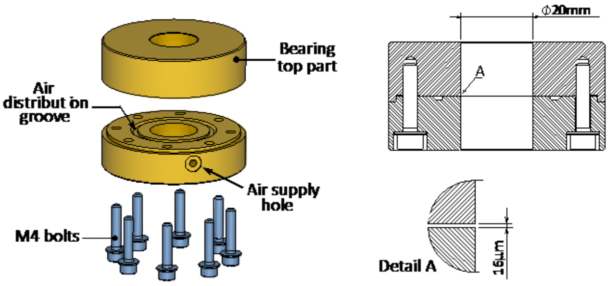

Figure 2. Prototype slit bearing design.

Both halves are machined out of brass RG7 according to the dimensions of Table 1.

Table 1. Actual bearing dimensions

Dimension		Size
Bearing diameter	D_b	20.0 mm
Bearing width	l_b	31.0 mm
Bearing clearance	h_b	16.3 µm
Restriction diameter	D_r	30.0 mm
Restriction length	l_r	5.0 mm
Restriction slit width	h_r	16.0 µm

3. Experimental validation

The accuracy of the slit and its performance are evaluated by measuring the bearing air consumption and the radial error motion.

3.1. Experimental setup

For the experiments, a light weight titanium dummy rotor is placed inside the bearing. An aluminium outer case is machined to hold the bearing assembly and to generate a small air stream to drive the dummy rotor up to 34 rpm. The radial position of the rotor is monitored by three Lion Precision capacity probes while the bearing air consumption is measured by a mass-flow meter (Cori-Flow M54). The setup, with the exception of the PXI-1031 data acquisition system of National Instruments, is shown in Figure 3.

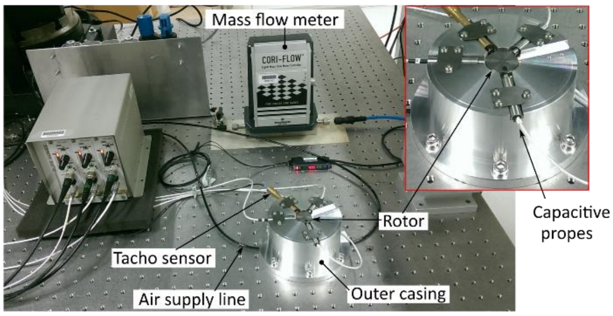

Figure 3. Experimental setup.

3.2. Air consumption

By assuming an isothermal Poiseuille flow inside the slit, an analytical expression (3) can be derived for the total air consumption of the bearing. Here Q stands for the volumetric flow rate and μ for the dynamic viscosity of the lubricating gas.

$$Q = \frac{\pi D_b}{6\mu p_a}\beta(p_o^2 - p_a^2) \qquad (3)$$

Using the remaining values of Table 1 and the known intermediate pressure p_o of equation (1), the theoretical air consumption versus supply pressure can be plotted against the experimental measured values, as depicted in Figure 4.

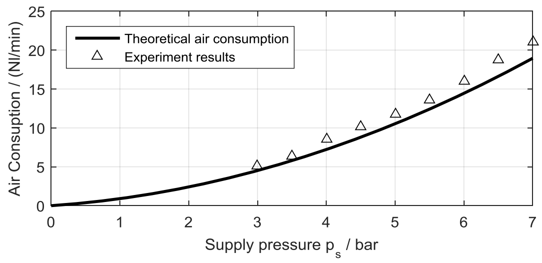

Figure 4. Bearing air consumption versus supply air pressure.

Both experimental and theoretical flow values appear to be in reasonable agreement. This suggests that the slit is machined to the correct nominal width.

3.3. Combined error motion measurement

The multi probe method [3] is used to measure the error motion of the shaft. Three sensors are positioned in radial direction to the cylindrical surface of the shaft. Radial runout measurements are taken over 20 revolutions and at a supply pressure of 5 bar. A Fourier error separation technique [3] is used in order to separate the shaft error motion from the shaft form error. This results in a combined synchronous tilt and radial error motion of 58 nm p-p and 11.4 nm rms at the sensor position. Asynchronous error motion is only 2.3 nm, which seems to be reasonable for the fact that the rotor is only supported by one bearing and has an out of roundness of at least 200 nm.

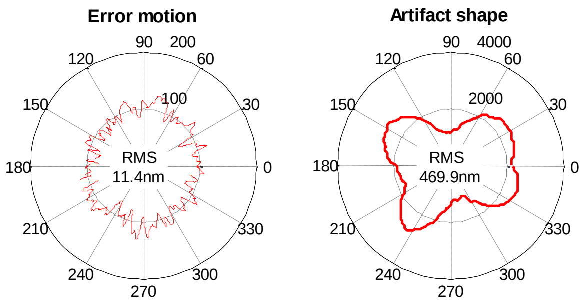

Figure 5. Shaft synchronous error motion and artifact/shaft shape.

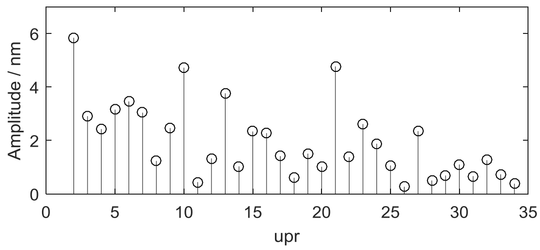

Figure 6. Synchronous error motion frequency spectrum.

4. Conclusion

A 16 µm wide slit bearing is successfully realised by using a simple design methodology and fabrication techniques. Reasonably small error motions were observed for the current single-bearing setup, suggesting that further reduction of error motion is possible by having a two bearing supported rotor and by improving its circularity.

References

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