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Air gap pressure distribution measurement device

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Abstract

Aerostatic bearing operating principle is based on a thin air film between the bearing and the opposing surface. Air film thickness varies commonly in the range of 1 to 10 µm. Pressure and the pressure distribution in the airgap are important factors when estimating the performance of aerostatic bearings. The pressure distribution influences the stiffness and the overall load capacity of the aerostatic bearing. The pressure distribution in the air gap varies due to the type and geometry of the bearing. This study investigates an automated test device for the measurement of the pressure distribution in the air gap. The measuring setup consists of a measurement rig to load the aerostatic bearing and to measure the air gap height. The load for the bearing is applied with low-friction pneumatic cylinder and the force conducted to the sample is measured with a load cell. The investigated bearing is supported with a four-bar linkage where all joints are flexure hinges. Parallel alignment of the bearing against its counter surface is ensured with a separate two axial flexure joint. The height of the air gap is measured with three linear gauges.

The pressure distribution in the air gap was measured using a moveable bearing counter surface where a 0.10 mm diameter hole was located. The moving countersurface was used to position the hole at various radial locations in the air gap of the aerostatic bearing. The counter surface had two parallel spring guides in series to provide guiding for linear displacement with minimal parasitic error motions.

The results show that the pressure in the air gap varies in relation to the distance from the bearing edge. Furthermore, it is shown that increasing the bearing load increases the pressure in the air gap until overload of the bearing is reached. Overloading brings the bearing close to or in contact with the guiding surface and significantly restricts air flow, thus decreasing pressure in the air gap. The results of the present study give corroborative evidence on the feasibility of the pressure measurement method and usefulness of the automated test device.

Aerostatic bearing, pressure measurement

1. Introduction

Aerostatic bearings are commonly used in precision motion and positioning applications. Because aerostatic bearings form a thin film of air between the bearing and the guide surface, the bearings are nearly frictionless, have no stick-slip phenomena and tolerate high rotating speeds without notable heat output. On the other hand, aerostatic bearings are rather limited by their load capacity. [1]

Aerostatic bearings operate by feeding externally pressurised gas to a gap between the bearing and the guiding surface. To limit the gas flow, and to increase the stiffness of the bearing, a restrictor is used. Restrictors vary in type, with the most common ones being orifice, groove, slot, and porous material restrictor. From these, porous restrictors are usually preferred, since it offers higher stiffness with better load capacity over larger range of air gap heights [2].

Porous material aerostatic bearings are more resistant to external disturbances such as impurities in gas supply, scratches on the bearing surface and errors on the opposing surface. These properties results in a wide range of suitable applications for porous material aerostatic bearings.

The current body of knowledge lacks measurement results of the pressure distribution in the air gap with high spatial resolution. Previously presented measurement setups have been manual and thus the measured results are pressure values in the air gap in singular positions instead of pressure distribution. [3]

Plante et. al. has presented pressure distribution in the air gap as a result of developed simulation [4]. The presented measurement device allows for generation of datasets for validation of simulation models.

2. Methods

In a previous publication, the authors developed a measurement device with multi-point data acquisition system [5]. To study the pressure distribution in the air gap, the measurement device was augmented with a movable guide surface for the bearing. The device is presented in figure 1. The guide surface has a 0.1 mm diameter hole that connects a pressure sensor to the bearing gap. Displacing the guide surface allows positioning of the pressure measurement hole at variable radial distances from the bearing centreline. The stainless-steel plate used as the bearing guide surface included two monolithic parallel spring guides in series in order to implement linear motion for the surface. The movable surface was displaced with a lead screw and a stepper motor. The position of the surface plate was measured with a Heidenhain MT-25 linear probe.

A porous aerostatic bearing with a 38 mm diameter bearing face was used in the tests. The measurement of the gap pressure distribution was started from outside of the bearing at 0 mm relative position after which the pressure measurement hole was moved past the centre line of the bearing in 0.1 mm increments. At each increment, a delay of 10 seconds was introduced before measurement in order to settle the system to steady state conditions. The air gap pressure was measured with SMC PSE540A pressure sensor. The measurements were repeated with 0.4 and 0.6 MPa bearing supply pressures and loads between 200 and 600 N at 100 N increments. Additionally, air gap height was measured.

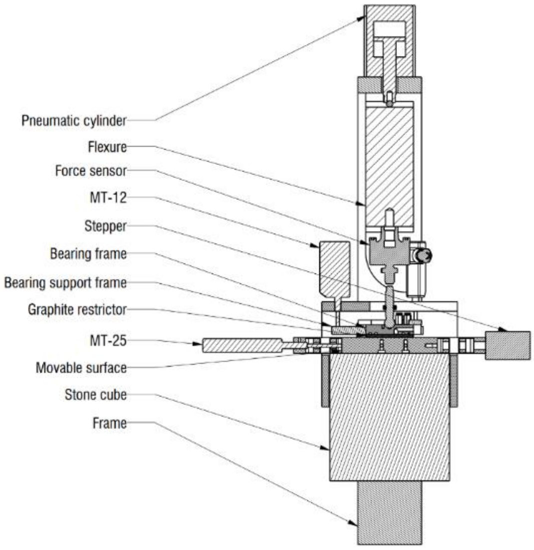

Figure 1: Measurement device. The moveable guide surface of the bearing included the air gap pressure profile measurement channels seen below the bearing restrictor. The pressure measuring sensor (not visible) is connected to pressure measuring channels.

The air gap height at each measurement point was determined by the relative displacement of the bearing with the air supply on and off at that position of the guide surface. The gap height is the average of the displacement of the three sensors. During displacement of the opposing surface, there was 0.6 MPa bearing supply pressure and zero load applied.

3. Results

The pressure distribution in air gap is presented in Figure 2**.** Applied bearing pressures were 0.4 and 0.6 MPa and the applied load was from 200 to 600 N at 100 N increments. Horizontal axis represents the distance from bearing edge. Air gap height at each sample point are presented in figure 3.

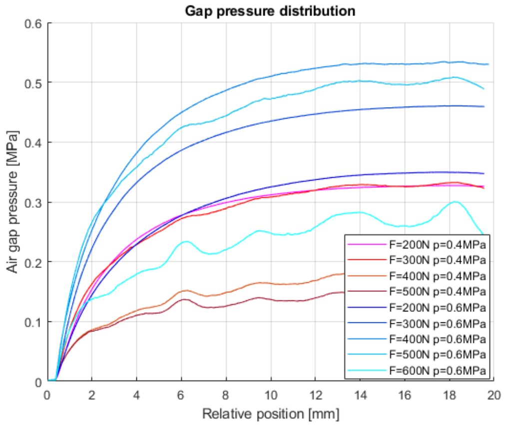

Figure 2. Air gap pressures with bearings pressures 0.4 and 0.6 MPa and with 200, 300, 400, 500 and 600 N loads applied to the bearing. Relative position is the position from the outer edge of the bearing.

4. Discussion

This study investigated aerostatic bearing gap pressure distribution measurement in order to validate the developed measurement setup. The presented pressure distribution measurement results agree well with the current body of knowledge.

As seen from the figure 2, with all of the measured bearing supply pressure and load combinations, pressure in the air gap decreases rapidly near the edge of the bearing. The maximum pressure in the gap is dependent on the load and the supply pressure. It is logical since the bearing edge acts as a transition zone between pressurized air and atmospheric pressure. This behaviour is in line with, for example, the simulation model created by Plante [4].

However, above a certain load level, the air gap collapses as the maximum air gap pressure is limited by the supply pressure. This indicates overloading of the bearing. While load compared to bearing air supply is too high, air gap pressure starts to become unstable and, presumably, the scratches on the bearing surface can be seen as increased gap pressures at various points. This implicates that under too high load is not axially symmetric or smooth. The collapse of the overloaded air film in the bearing gap can also be observed from the figure 3, where the air gap height for the overloaded conditions is drastically lower. However, the drift in the gap height measurement through the measured points is on a reasonable level, especially on the measurements done in non-overloaded conditions. Thus, the results show that the stiffness of the movable bearing surface and the measurement setup is sufficient to produce good data.

This study focused on the conceptual testing and verification of the developed measurement device. The results show that the measurement device produce useful information for investigation of aerostatic bearings. In further studies, the measurement device can be used to investigate the performance of aerostatic bearings and to generate datasets for validation of simulation models.

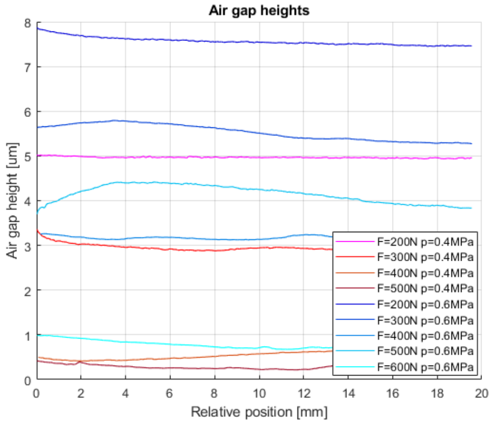

Figure 3. Air gap heights with bearing air supply pressures 0.4 MPa and 0.6 MPa and 200, 300, 400, 500 and 600 N loads.

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