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Performance of additively manufactured surface ground porous metal aerostatic bearings

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Abstract

Aerostatic bearings are commonly used in high-speed and high-precision applications. Porous aerostatic bearings utilize porous material restrictors to distribute operating gas supplied from external pressure source to the gap between the bearing and the opposing surface. The friction is negligible due to the low viscosity of gases. The variation in material properties of graphite can result into inconsistent bearing performance. Laser-based powder bed fusion of metals (PBF-LB/M) has been proposed as a method for manufacturing porous metal restrictors for aerostatic bearings. The PBF-LB/M enables the manufacturing of porous material where the permeability of the porous restrictor can be adjusted with the manufacturing parameters. In this study, the static performance of aerostatic bearings with porous metal restrictors manufactured with PBF-LB/M was investigated experimentally. The load capacity, stiffness and air consumption were measured. The results were compared to a porous graphite aerostatic bearing.

gas bearing, externally pressurized bearing, laser-based powder bed fusion of metals

1. Introduction

Aerostatic bearings are commonly used in high-speed and high-precision applications. Porous aerostatic bearings utilize porous material restrictors to distribute operating gas supplied from external pressure source to the gap between the bearing and the opposing surface [1]. The friction is negligible due to the low viscosity of gases. Porous graphite is commonly used as the restrictor due to the tolerance for contact with opposing surface [1, 2]. The variation in material properties of graphite can result into inconsistent bearing performance between bearing samples [2-4]. The optimal permeability for porous aerostatic bearing is between 10^{-14} m^2 to 10^{-16} m^2 [2].

Manufacturing of the porous restrictor with laser-based powder bed fusion of metals (PBF-LB/M) additive manufacturing (AM) method has been studied by Schoar et al. [5] and Sadahiro et al [6]. The manufacturing of controlled porosity metal restrictors has been achieved by decreasing the volumetric energy density (VED) by either increasing the hatch spacing [5] or decreasing the laser power [6]. Decreased VED leads to incomplete melting of the powder. The AM enables the bearing to include zones of varying permeability [5-6]. Additionally, the whole bearing can be manufactured as one part, eliminating commonly required adhesive joint between bearing body and the porous restrictor.

In this study the static performance of porous metal restrictor aerostatic bearings was measured, and the results were compared against a porous graphite aerostatic bearing

2. Methods

In a previous study by Leutonen et al., a batch of porous metal restrictors were manufactured with EOS M 290 from PH1 stainless steel powder, and the permeability was varied by adjusting the hatch spacing parameter [7]. The porous restrictors were made as a 37 mm diameter disks with height of 5 mm and 0.5 mm solid outer edge. The infill hatch spacing was adjusted to form a grid of pores where the powder was left unscanned by the laser. Upskin and downskin were not used to leave the infill exposed. Parameters used were layer height of 40 µm, laser spot diameter of 80 µm and scan speed of 1083 mm/s. The porous infill was made with an aligned meander pattern with 90˚ rotation.

The samples were removed from the build plate with wire electrical discharge machining (EDM), the restrictor surfaces were joined to a metal bearing body with adhesive, and the restrictors were turned and ground. The sample geometry is presented in Figure 1. Four samples within the optimal permeability range of 10^{-14} m^2 to 10^{-16} m^2 were selected for analysis. The permeabilities of the four AM samples and the reference porous graphite bearing are presented in Table 1.

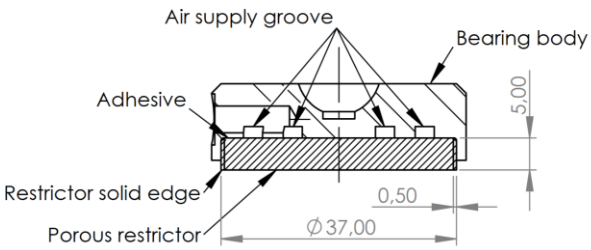

Figure 1. Sample geometry [7]

Table 1 Investigated bearing permeabilities. Porous graphite bearing permeability by Miettinen et al. [3].

Sample	Permeability (m^2)
Graphite	1.44×10^{-15}
190 µm	2.67×10^{-15}
200 µm	2.39×10^{-15}
210 µm	5.90×10^{-15}
220 µm	3.30×10^{-15}

The static load capacity, stiffness and air consumption of the bearings were measured at 0.6 MPa supply pressure with measurement setup developed by Miettinen et al. [3]. The bearing was placed on a natural stone surface in a loading frame. The bearing was loaded with pneumatic cylinder guided by a parallel flexure guide. The force was measured with a load cell. The air gap between the bearing and the opposing natural stone surface was measured with three capacitive sensors around the bearing.

3. Results and discussion

The results of the measurements are presented in Figure 2 in three graphs. The graphs share the horizontal axis representing the air gap height. The top graph is the load capacity, the middle graph is the stiffness, and the bottom graph is the air consumption of the bearing.

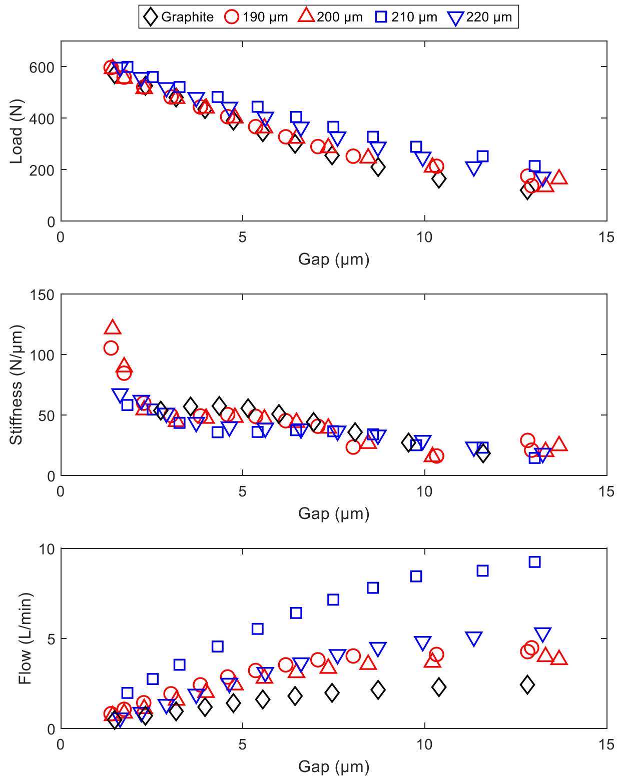

Figure 2. Bearing load capacity, stiffness and air consumption at 0.6 MPa supply pressure. Four AM samples with 190 µm, 200 µm, 210 µm and 220 µm hatch spacing. A reference measurement of a graphite restrictor aerostatic bearing by Miettinen et al. [3].

The load capacity and stiffness of all the AM restrictor bearings were comparable to the reference porous graphite bearing. The high measured stiffness of the AM samples at low air gap height may be due a non-ideal geometry of the restrictor surface causing contact between the bearing and the opposing surface. The air consumption of the AM restrictor bearings was higher than the reference. Some instability of the AM restrictor bearings was observed at approximately 200 N load. The instability was most significant on the 210 µm hatch distance restrictor load possibly due to the high flow rate.

The restrictor permeability did not increase with increasing hatch spacing as the surface was further processed. This is likely due to the limited control of the turning and grinding process to the surface of the restrictor leading to variation in permeability. The smearing of the ductile material closes the pores and forms a thin restrictive layer. The thin restrictive layer can be beneficial but the turning and grinding of the restrictor surface may not be controllable enough for repeatable manufacturing process. Larger batch size should be studied as only one sample per hatch spacing parameter was investigated in this study.

The turning and grinding process may bring excessive amount of heat and mechanical power to the delicate structure of the porous restrictor. More controllable methods such as wire EDM could be used to manufacture the final restrictor surface.

4. Conclusions

PBF-LB/M is suitable method for the manufacturing of porous metal restrictors for aerostatic bearings. The static performance of the AM restrictor bearings is comparable to porous graphite restrictor aerostatic bearings. However, the air consumption of the AM restrictors was higher than the graphite bearing, and some instability of the bearings was observed at approximately 200 N load. The instability was most significant with the 210 µm hatch distance restrictor load possibly due to the high flow rate.

The repeatability of the manufacturing process could be studied further with a focus on the permeability of the restrictors. In this study only one sample per parameter value was made. Variation of the porous material permeability is an issue with the current graphite based aerostatic bearings.

5. Acknowledgements

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