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Permeability influences on the performance of porous aerostatic bearing with micro-holes array restrictive layer

Kuo-Yu Chien[1], Yu-Ting Lyu[2], Yan-Ting Chen[3], Chung-Li Tsai [4]

Micro/Meso Mechanical Manufacturing R&D Department, Metal Industries Research & Development Centre (MIRDC), Taiwan

benson@mail.mirdc.org.tw

Abstract
High permeability often results from large pore size and uncertain properties in porous materials, which limits the application of porous aerostatic bearing. The new mechanism of dual-layer porous aerostatic bearing developed by MIRDC could break through the limitation of porous aerostatic bearing application. In this research, porous material's permeability determines a great part for the performance of porous aerostatic bearing, and could be further analysed by experiment. The experiment result shows that the dual-layer mechanism avoids the unstable vibration phenomenon sometimes happened while using porous materials with large permeability. These results also confirmed the basic design principle for the dual-layer porous aerostatic bearing. Higher loading capacity could be obtained by choosing high permeability porous material, and dynamic stability and stiffness could be obtained by adjusting the geometric parameters of micro-holes array to control permeability.

Porous Aerostatic bearing, Permeability, Micro-holes array

1. Introduction

For the demand of miniature module in micro/meso machining systems, precision aerostatic stage has become an important technology to achieve the sub-micron accuracy performance which is required in the development of micro/meso machining systems. Such as the micro factory [1] at AIST in Japan, the micro/meso machine tools (mMTs) at UIUC, NWU in USA [2], and the reconfigurable micro/meso machining system at MIRDC in Taiwan [3].

Porous type aerostatic bearing with high loading efficiency, good stiffness and excellent self-stable property is often applied in such high precision equipment. However, high cost and manufacturing difficulties limit the applications of porous type aerostatic bearing. The properties of porous materials are usually not very stable among each manufacturing batch process, resulting in variation of the characteristics including pore size, pore distribution, and permeability. These situations lead to uncontrollability and unexpected dynamic performance failure of aerostatic bearings.

2. Porous aerostatic bearing with micro-holes array restrictive layer

MIRDC has developed a new mechanism of porous type aerostatic bearing with a micro-holes array restrictive layer on the bearing surface to solve the performance inconsistency. The dual-layer porous bearing configuration was shown in Fig.1 and Fig.2 This dual-layer design successfully overcomes the problem of inhomogeneity of the porous materials and also improves bearing loading capacity, efficiency, stiffness and stability effectively compared to traditional porous air bearing. By controlling the numbers and geometric design of micro-holes to limit flow rate, bearings have stable dynamic property and high loading capacity performance. The previous experiment result shows that aerostatic bearing based on porous graphite with 50um micro-holes array and pitch 0.2mm has higher stiffness more than 3.6 times, and the efficiency of load capacity could be improved up to 45% [4]. Verification the load capacity and stiffness of bearing could be enhanced by the new mechanism of micro-holes array restrictive layer.

In this research, porous ceramic with higher permeability was being chosen to analyse the permeability influences on the performance of dual-layer porous aerostatic bearing. The bearing's specifications are shown in table 1., and properties of the used porous materials are shown in table 2.

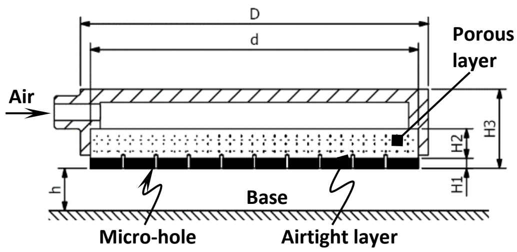

Figure 1. Configuration of the dual-layer porous aerostatic bearing

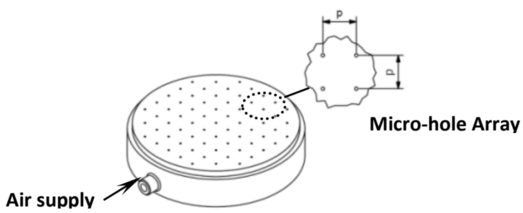

Figure 2. Surface configuration of the dual-layer porous aerostatic bearing

Table 1 Specifications of the dual-layer porous aerostatic bearing

Geometric parameters of air bearing	(1) D : ϕ 53 mm (2) d : ϕ 50 mm (3) H2 : 6 mm (4) H3 : 12 mm
Geometric parameters of micro-holes array layer	(1) H1 : 40 μm (2) Diameter of Micro-holes: Graphite/ϕ 60 ± 15 μm Ceramic /ϕ 110 ± 20 μm (3) Pitch of Micro-holes array : Graphite/1.0 & 0.5 & 0.2 mm Ceramic /1.0 & 0.6 & 0.4 mm
Quality of bearing surface	(1) Flatness : <1.0 μm (2) Roughness (Ra): <0.1 μm

Table 2 Properties of porous materials used in the bearings

Porous material		**Graphite**	**Ceramic**
Density	**g/cm^3**	1.76	1.9
Pore size	**μm**	5-7	1-2
Porosity	**%**	-NA-	40
Permeability	**m^2**	1.1247×10^{-14}	6.4872×10^{-14}

3. Bearing performance for different porous material

3.1. Permeability

Permeability refers to the ratio of fluid penetrates material under certain pressure difference, and porous material's permeability determines a great part of the performance of porous aerostatic bearing. In traditional type porous bearing, the flow rate of porous graphite was measured as 7.4 l/min and porous ceramic as 40.8 l/min at 0.55 MPa, while the porous ceramic have higher permeability about 5.8 times of graphite ones. The permeability performances cannot be controlled without changing bearing geometries. Dual-layer porous bearing could control its permeability by the micro-holes array layer.

Fig.3 shows the micro-holes array and cross section drilled by ultrafast laser with pitch 0.6mm. Ultrafast picosecond laser was efficient and convenient when applied on micro-machining with great machining quality. The micro-holes were over-drilled depth more than 200 μm to ensure the air channels to surfaces. However, the sealing method may have problems, such as non-uniformity of the epoxy resin, and the attachment conditions possibly differ among micro-holes due to the porous material structure. Those uncertain factors may cause difference of the profiles and restrict performance of the micro-holes on the airtight layer.

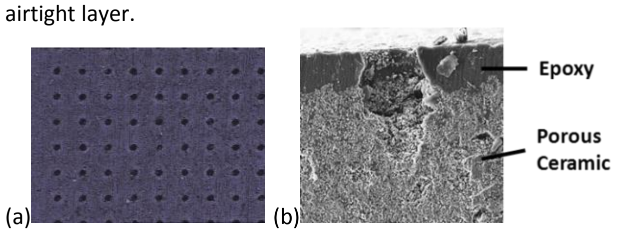

Figure 3. (a) Surface of micro-holes array ;
(b) SEM image of the cross section of micro-hole

3.2. Bearing performance experiment discuss

Traditional porous ceramic aerostatic bearing exists serious air hammer phenomenon with too large flow rate. Micro-holes array layer lowers flow rate and solve the unstable problem. Detail bearings' loading capacity and stiffness tendency at 0.55 MPa as shown in Fig. 4 and Fig. 5. Due to higher permeability, the new mechanism porous ceramic aerostatic bearing's loading capacity was higher than graphite one.

New porous graphite aerostatic bearing with lower permeability have more stable characteristics and better stiffness, especially with floating gap below 10 μm, that was common operating range in precision aerostatic equipment. These advantages show the possibilities applied precision equipment with higher position accuracy and dynamic property.

On the other hand, in Fig.4 the ceramic bearing with larger pitch and lower permeability shows a loading capacity tendency similar to graphite bearing. That means dual-layer porous ceramic aerostatic bearing is possible to get more stable and higher stiffness by adjusting the geometric parameters of micro-holes array layer.

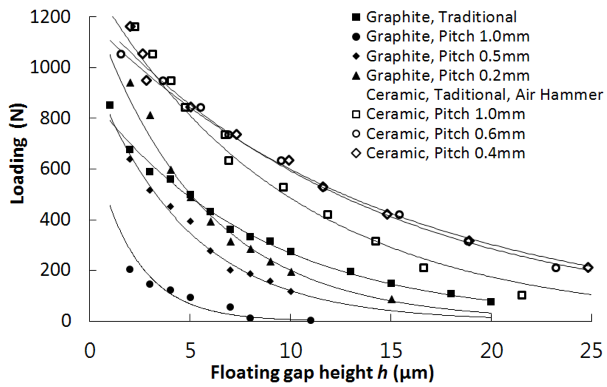

Figure 4. Bearing loading capacity tendency compared at 0.55 MPa.

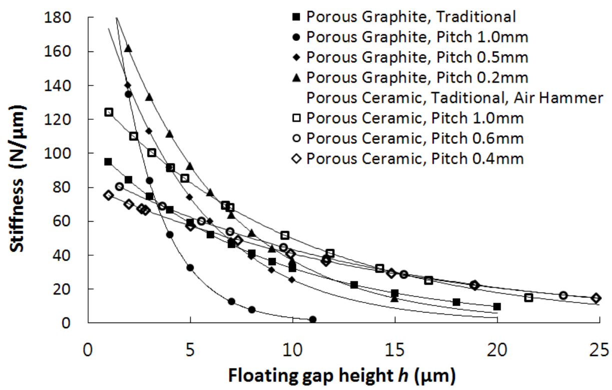

Figure 5. Bearing stiffness tendency compared at 0.55 MPa

4. Conclusion

These results confirm the basic design principle for the dual-layer porous aerostatic bearing. Higher loading capacity could be obtained by choosing high permeability porous material, loading capacity and stiffness could be obtained by adjusting the geometry parameters of micro-holes array to control permeability. The design also enables the possibility to reduce air hammer phenomenon under same air supply pressure.

References

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