AN EXPERIMENTAL INVESTIGATION OF VERTICALLY VIBRATING AEROSTATIC CIRCULAR POROUS THRUST BEARINGS

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Abstract

In this paper, the dynamic characteristics of the vertically vibrating aerostatic circular porous bearings are investigated by the experimental approach. A special experimental apparatus was made for this purpose where both the mass supported by the aerostatic bearing and the bearing itself can vibrate vertically together, which is actual situations in most industrial applications. The experimental results show that the vertically vibrating aerostatic porous bearing has lower dynamic stiffness than the fixed bearing case, and it seems to be very important results for design engineers in industry.

INTRODUCTION

Recently externally pressurized circular porous thrust air bearings have been widely used in many industrial applications because of their advantages, i.e. higher load capacity and stiffness, and high damping characteristics [1]. A lot of researches have been done in order to investigate the dynamic characteristics of those aerostatic porous bearings by using not only analytical approaches but also experimental approaches [2-8]. In most previous experimental approaches the aerostatic porous bearing has been fixed and only the mass supported by the bearing is allowed to move vertically [6-8].

The dynamic stiffness obtained by using those experimental setups, however, may be different with the real case where the mass and the bearing move (vibrate) together in the vertical direction. The dynamic stiffness of the aerostatic bearing can be determined by the flow characteristics in the clearance of the bearings. The possible reason that the dynamic stiffness for vertically moving aerostatic bearing may be different with the fixed bearing case is that the flow characteristics inside the bearings and also in the bearing clearance may be different between these two cases.

In this paper, the dynamic characteristics of the vertically vibrating aerostatic circular porous bearings are investigated by the experimental approach. A special feature of the experimental apparatus designed for this study is that the mass supported by the aerostatic air bearing and the bearing itself can vibrate vertically together, which is actual situation in most industrial applications. In addition, three different guiding surface materials (granite, lapped steel, and ceramic) for air bearings are also used in order to investigate the effect of the guide materials on the bearing stiffness.

EXPERIMENTAL APPARATUS AND PROCEDURE

Fig.1 shows a schematic diagram and the picture of the experimental device used to measure the characteristics of the aerostatic circular porous thrust bearings.

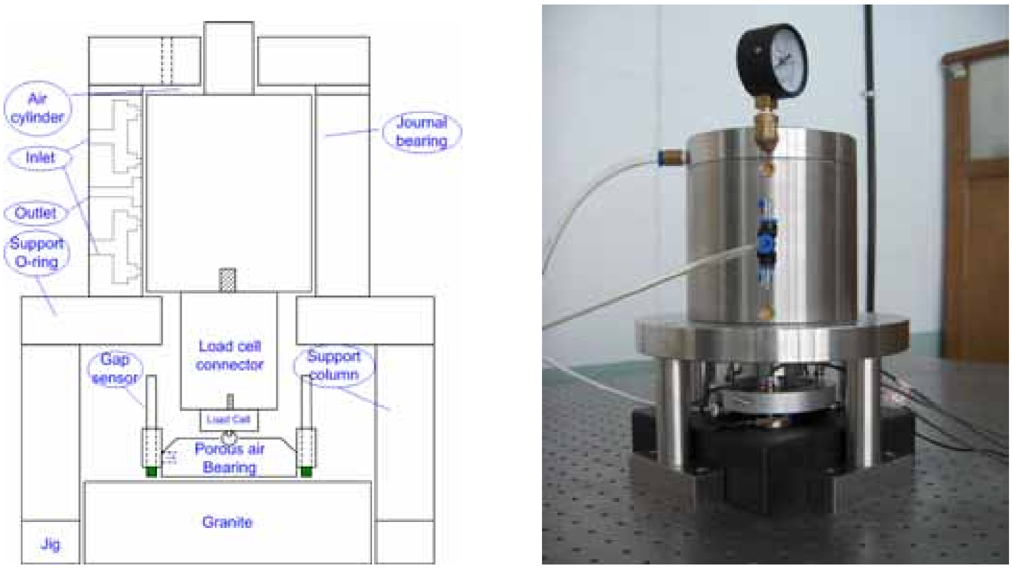


Fig.1 Schematic Diagram and Picture of Experimental Device

The finite element analysis has been performed to predict the possible deformation of the device, and the finally optimized devise had deformation less than 2 micrometers under the maximum loading conditions. The device was made from stainless steel and designed big enough to test from the 40mm air bearing up to the 125mm one.

The test bearing was connected to the load cell and the shaft in series and the bearing surface was set downward. The shaft has mass of 10kg and was guided by the two journal air bearings so that the shaft was allowed to move only in the vertical direction. In addition, a steel ball was used between the load cell and the bearing in order to keep the bearing surface in parallel with counter (granite) surface.

A static preload was arbitrarily applied to the bearing by supplying pressurized air into the air cylinder located in the upper part of the housing (above the mass), and the magnitude of the applied load was measured by the load cell. The average clearance of the bearing was calculated from the data measured at three equally spaced points around the air bearing by using three gap sensors. The gap sensors used in this experiment were ADE technology model 4810 which have 0.1 micrometer resolution, and the load cell was DACELL model CMM2 which has 10N resolution. To measure the dynamic characteristics, an impulsive force was applied to the top of the shaft, and the frequency response functions were measured, and finally dynamic stiffness was calculated from the natural frequency of the system.

With this experimental device, the real operating conditions of the air bearing can be realized where both the air bearing and the mass supported by the bearing can vibrate together in the vertical direction, and the bearing clearance and the load applied to the bearing can be exactly measured even if there exist the housing deformation.

EXPERIMENTAL RESULTS

Static Stiffness

The diameter of the aerostatic bearing used for experiment was 80mm, and the supply pressure to the bearing was 0.41MPa, 0.5MPa, and 0.55MPa, respectively. Fig. 2 and 3 represent the static load capacity of the bearing when the supply pressure was 0.41MPa and 0.55MPa respectively. Each figure shows the six experimental results where two of them were measured by increasing the static load in sequence, two of them measured by decreasing in sequence, and the rest measured by the random test. From the results, the hysteresis phenomenon was not found. Comparing the experimental results with the data provided by the bearing manufacturer, some difference was found. There exists about 1 micrometer difference at the manufacturer recommend ideal load (1100N). However our experimental results seem reasonable because the slope of the curve in low clearance (high load) region is steep, which is logically reasonable for the externally pressurized air bearing.

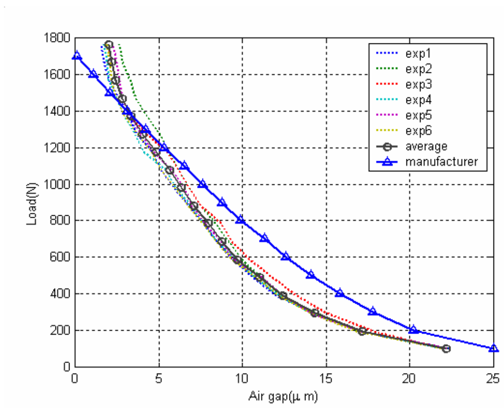


Figure 2 – Static load capacity (0.41MPa)

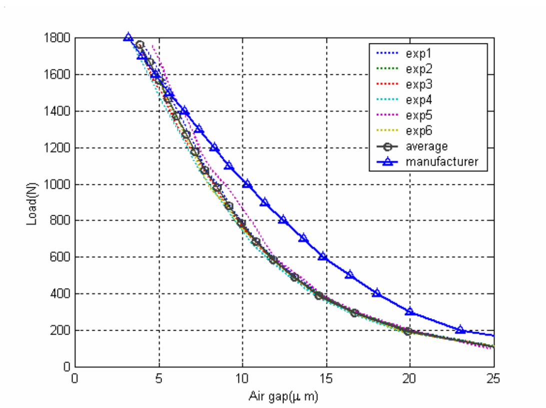


Figure 3 – Static load capacity(0.55MPa)

The six measured clearances at the specific load were averaged, and the averaged data were used for curve fitting of static load capacity. Fig. 4 shows the static stiffness curve which was obtained by differentiating the static load capacity curve for three different supply air pressure.

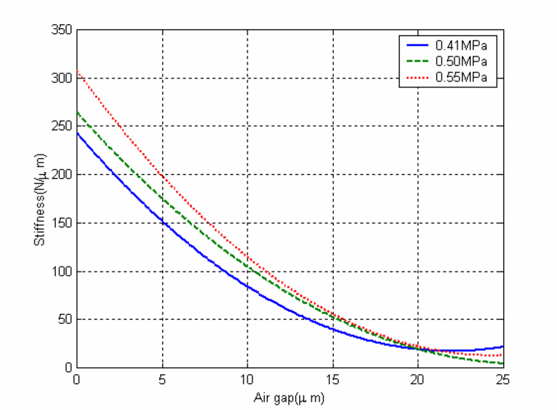


Figure 4 – Static stiffness curve

In order to identify the effect of the different guide materials on static load capacity, three different materials(granite, ceramic, and cast iron) were used. From the experimental results, the guide material which has the lower surface roughness provides the higher load capacity as shown in Fig. 5.

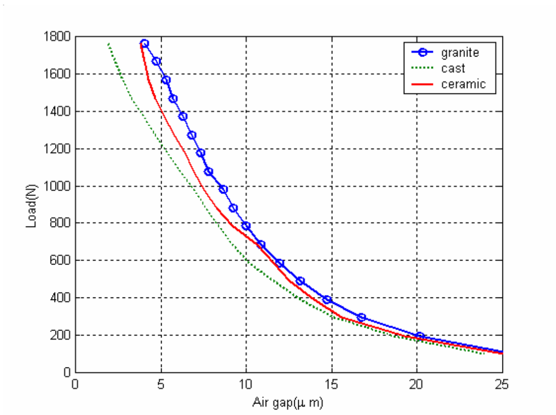


Figure 5 – Effect of different guide

Dynamic Stiffness

In order to investigate the dynamic characteristics of the aerostatic porous bearing, impulse was applied at the top of the shaft by the impact hammer, and the averaged impulse response measured by the gap sensors were shown in Fig. 6. When applied the impulse, the magnitude of the impulse should be as low as possible because the nonlinear effects of the air bearing system should be minimized in the response signal. The FRF of the air bearing was then obtained as shown in the right of Fig. 7, where unexpected several peaks (60Hz, 185Hz) were observed.

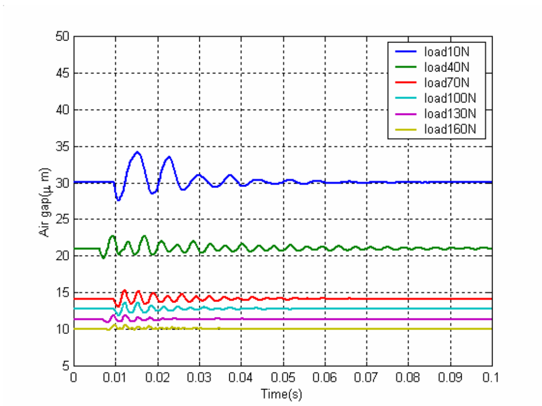


Figure 6 - Vibration displacement signal

In order to investigate those peaks, the modal analysis was performed for the table, the experimental device, and the guide structure, respectively, and the results are presented in the left of the Fig. 7. From the results, it was found that the unexpected vibration modes were caused by the flexible vibration mode of the table surface where the experimental device was mounted on, therefore the vibration mode of the aerostatic porous bearing could be distinguished.

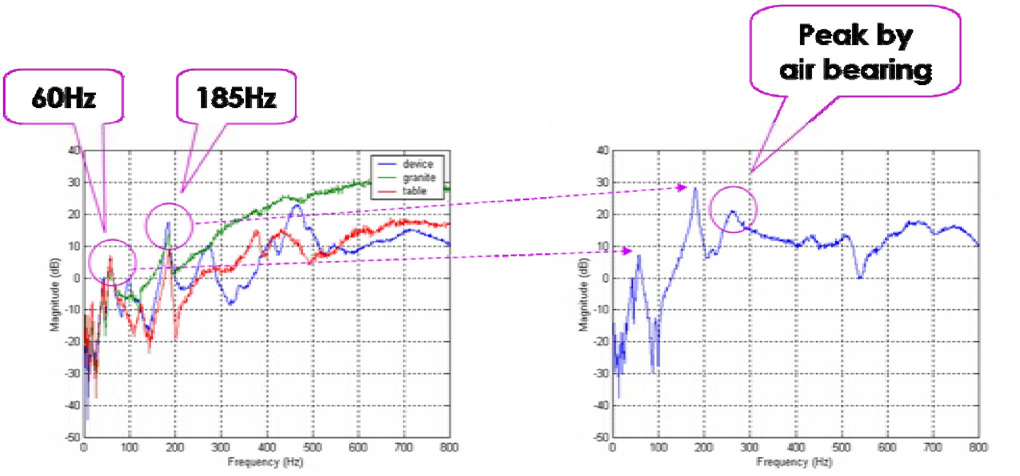
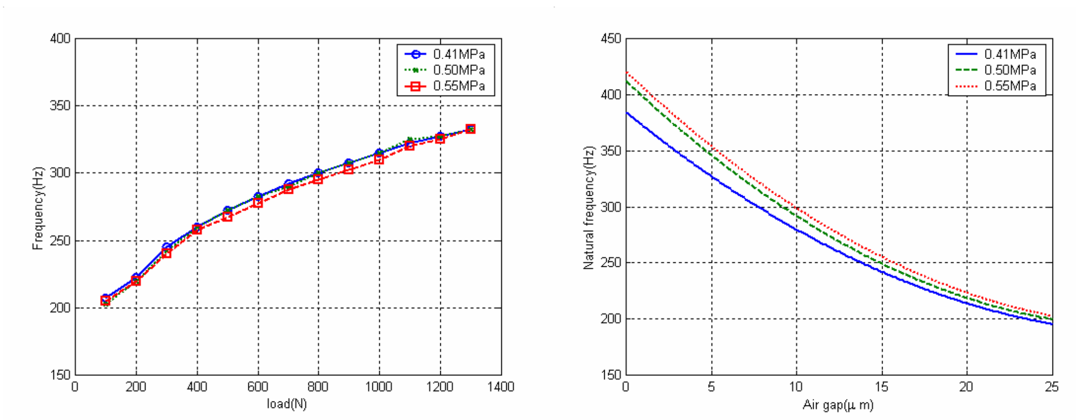


Figure 7 – Effect of table vibration

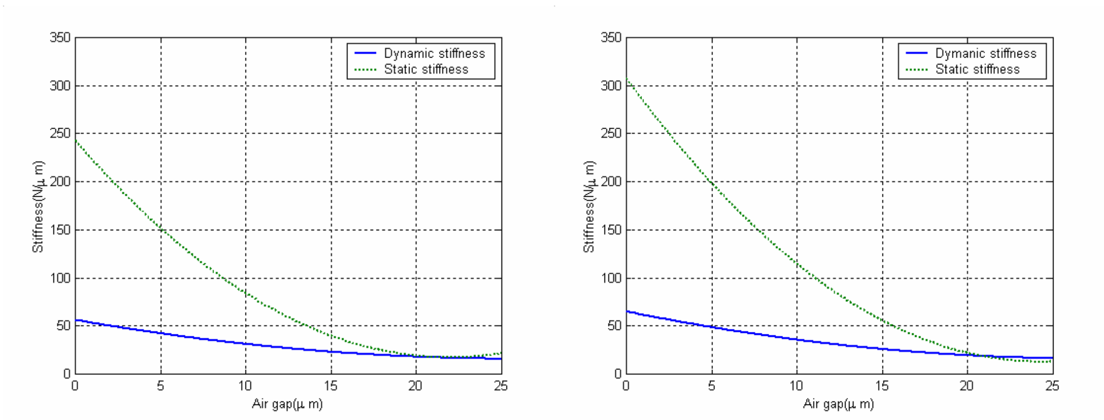
Fig. 8 shows the natural frequencies of the bearing system with respect to the preload and the clearance in each supply air pressure. It was observed that the natural frequencies were not changed regardless of change the supply air pressure because the stiffness decreases due to grow of clearance when increase the supply air pressure.



(a) *(b)*

Figure 8 – Natural frequency with respect to (a) load, (b) clearance in each air pressure

The dynamic stiffness of the aerostatic porous bearing could be finally calculated by using the natural frequencies, and the results were presented in Fig. 9. From the figure, it was found that the dynamic stiffness of the aerostatic porous bearing is much smaller than the static stiffness, almost one third for ideal load.



(a) *(b)*

Figure 9 –Dynamic and static stiffness in air bearing pressure (a) 0.41MPa, (b) 0.55MPa

The experimental results in reference [7], where the tested bearing was fixed and only the mass supported by the bearing could vertically vibrate, was used for the comparison. The results were presented in Fig.10, and from the figure it could be concluded that the dynamic stiffness of vertically vibrating porous bearing is much lower than the dynamic stiffness of the fixed bearing.

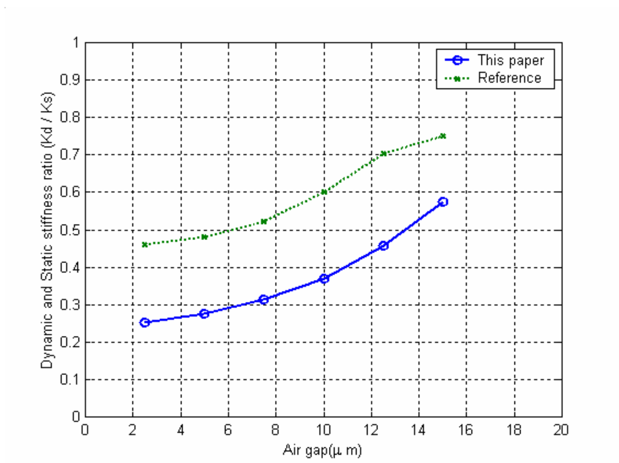


Figure 10 –Dynamic and static stiffness ratio

CONCLUSION

In this paper, the dynamic characteristics of the vertically vibrating aerostatic circular porous bearings were investigated by the experimental approach. From the experimental results, the followings observations could be made.

(1) The dynamic stiffness of vertically vibrating aerostatic porous bearing is much lower than the static stiffness, which is almost one third of the static stiffness.

(2) The dynamic stiffness of vertically vibrating aerostatic porous bearing is lower than the dynamic stiffness measured when the bearing is fixed and only the mass supported by the bearing is vertically vibrating.

(3) The guiding surface which has smaller surface roughness can provide higher load capacity of the bearing.

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