CONTROLLING THE LOAD CAPACITY OF AEROSTATIC BEARINGS VIA DEFORMABLE MAGNETORHEOLOGICAL-ELASTOMER NOZZLE

[1]SY-WEI LO, [2]TAI-HAO HONG, [3]KE-YU JHANG, [4]CHU-YUAN TSENG

Department of Mechanical Engineering, National Yunlin University of Science & Technology
Douliu City, 640 Yunlin, Taiwan
E-mail: [1]losw@yuntech.edu.tw, [2]M10511016@yuntech.edu.tw, [3]M10311018@yuntech.edu.tw,
[4]M10511048@yuntech.edu.tw

Abstract - Aerostatic bearing is vital to the industry of precision machines. The restrictor, which lies between air supply and bearing itself, determines the load capacity and stiffness of the bearing system. In this research, nozzles made of magnetorheological elastomer (MRE) are designed and implemented inside a commercial electromagnet. The nozzles are composed of a capillary restrictor and an air pocket (recess) at the outlet. The shape of the recess can be tweaked by changing the electric current supplied so that the outlet air pressure distribution is therefore adjusted.

Keywords - Aerostatic Bearing, Magnetorheological Elastomer, Stiffness

I. INTRODUCTION

Aerostatic bearing is vital to the industry of precision machines. The restrictor, which lies between air supply and bearing itself, determines the load capacity and stiffness of the bearing system. However, the low viscosity and compressibility of the air induce difficulties in both building the restrictor in the aerostatic bearings and holding the pressure in the air film between bearing and its mated surface. Many design ideas of restrictor for liquid lubricant, for instance, the metallic membrane restrictor, are not appropriate anymore. Besides, the variation of the air pressure in the recess of nozzle outlet decays so quickly that the restrictor must be placed right adjacent to the outlet, this imposes some extra limitations on the design of restrictor.

Böse et al. [1] developed a valve using MRE (magnetorheological elastomer) to control the gas flow. Its basic function is a laboratory device containing an MRE ring in the space between two concentric yoke parts of the magnetic circuit, leaving an inner air gap. Their device is shown inFig. 1. Recently Lo et al. [2] adopted this design and proposed a new bearing with flux control.The structure of the flux-control bearing, which is basically an "inverse" version of Böse et al. [1] flux regulator is also shown in Fig. 1. The air flows into the bearing through the intake port on the main body. The mandrel (principal axis) is coiled using copper wire. The inner brim of the MRE, shown in Fig. 2, begins to move towards the mandrel to confine the air flux when the electric power actuates. The advantage of such a design is that the heat generated on the coils can be taken away by the air. The majority of the bearing is made of low carbon steel which is suitable for gaussage conduction. While in order to enhance the intensity of the magnetic field in the MRE and reduce the weight at the same time, the disk and the bottom of the bearing are made of acrylics and aluminum alloy, respectively. The aluminum bottom surface is polished and anodized.

Each time when the bearing is disintegrated and reassembled, the gap between the inner brink of the MRE disk and the central pillar is altered, not only by the accuracy of manufacturing but also by assembly. These are the inherent flaws of such a mechanism that results in unreliable air flux.

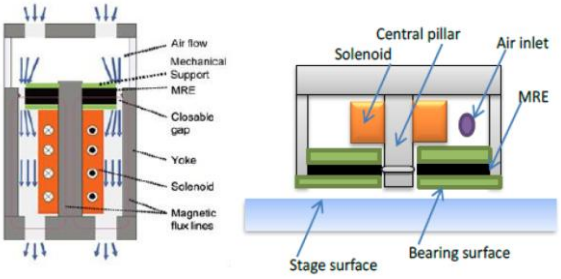


Figure 1: MRE flow controller [1](left) and the aerostatic bearing of flux control [2]



Figure 2: MRE disk used in the aerostatic bearing of flux control

Due to the drawback mentioned above, another model adopting the well-known mechanism to maintain the air pressure, say, concave bearing surface, is

thengiven by Lo et al. [2].

The pressure distribution and the structure of the curvature-control bearing is shown in Figures 3 and 4, respectively. The curvature-control type is proved to be more effective and reliable. Therefore, in this paper, two refined designs based on curvature variation are carried out as our first try.

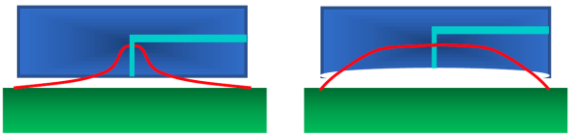


Figure3: Air pressure distributions for uniform (left) and concave (right) air gaps

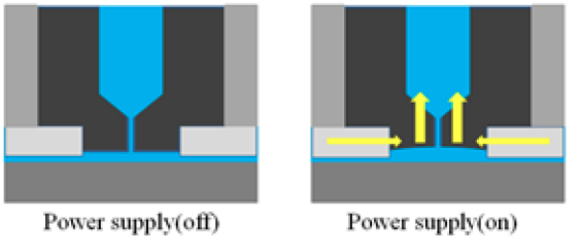


Figure 4: Create concave air pocket using MRE

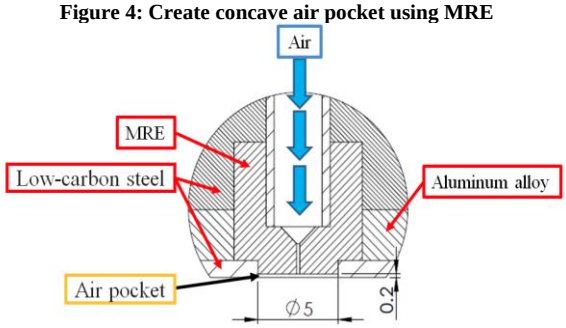


Figure 5: Refined bearing without central needle

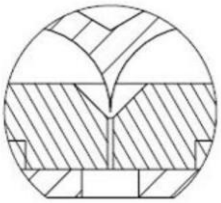


Figure 6: Refined bearing with central needle above MRE

II. DESIGNS OF NOZZLES

As shown in Figure 5 for the first design: the magnet lines go from the bearing surface, through the wall of the MRE tube to the low carbon steel support. Besides, various shapes of air pocket are produced; For the second model in Fig. 6, a steel needle is centered above the capillary of MRE tube, so that the magnet lines will concentrate and flow through the tip of needle, back to the low carbon steel. In this case, the air pocket is fixed, say, diameter of 2 mm and 1 mm deep.

The bearing is tested in the way shown in Fig. 7. The gap, also called the elevation of the bearing, is measured by the indicator with resolution of 1 micron.

In the MRE tube, there is a 12 mm capillary of with diameter of 10 mm. The bottom of the MRE tube is brought up by the magnetic force and thus alters boththe shape and size of the air pocket and the capillary. However, the air flux is found to be much greater than that of the conventional nozzle. The load carry ability is also terribly low. It is surmised that high air pressure not only causes the expansion of the soft MRE capillary, inducing abnormally high air consumption, but also pushes the MRE tube out to touch the mating surface, as shown in Fig. 8.

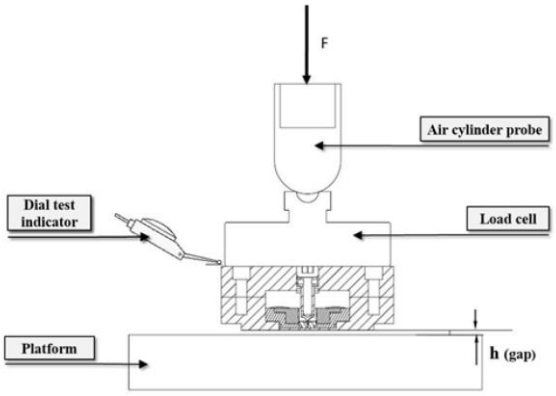


Figure 7: Test rig for static load capacity

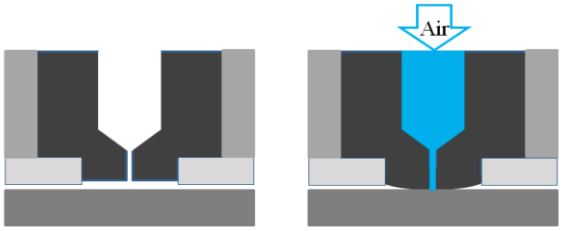


Figure 8: Collapse of MRE tube under high supply air pressure

III. MODIFIED MODELS

In order to avoid the collapse of air pocket and the complex interaction between the contraction of MRE body and the capillary diameter, some special procedures must be considered to maintain the capillary and tube dimensions.

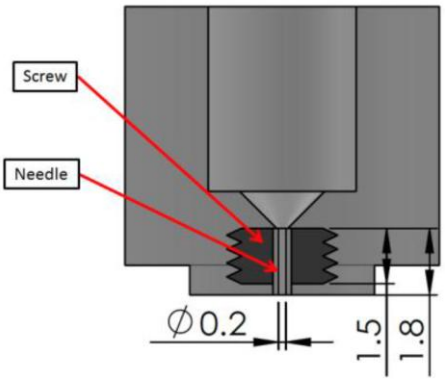


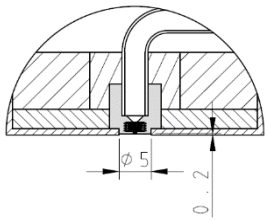
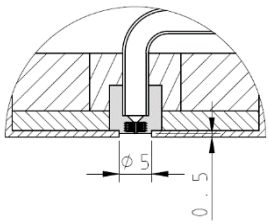
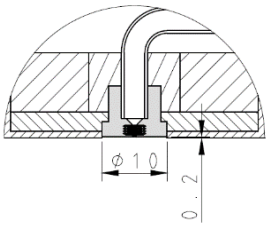
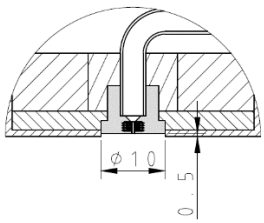
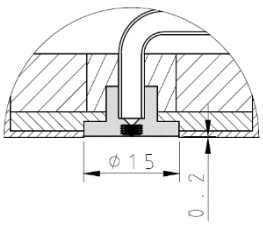
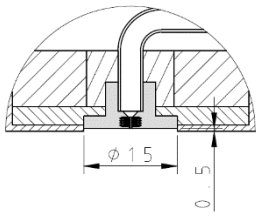
Figure 9: Steel screw buried in MRE tube to enhance the rigidity and magnetic force

A. MRE tube without central needle

Firstly, a 0.5-mm diameter/2.5-mm long hole is drilled in a M3 screw. A needle with 0.2-mm capillary is then buried in the MRE tube. The

important dimensions are shown in Fig. 9. Recesses of different diameters and depthsare listed in Table 1, that is, three diameters: 5, 10, and 15 mm and two depths: 0.2 and 0.5 mm.

Table 1: Different air pockets

Symbol	Structure
Tybe-SN502	
Tybe-SN505	
Tybe-SN1002	
Tybe-SN1005	
Tybe-SN1502	
Tybe-SN1505	

The major change in the modified model is that a steel screw with capillary made of steel needle is embedded in the MRE tube so that the capillary will not expand. Besides, the steel screw helps in the conduction of magnetic force. The deformation of the recess is therefore magnified. Someexamples of the relations between the elevation of the bearing and the external loading for different air pockets are shown in Fig. 10 to Fig. 13.

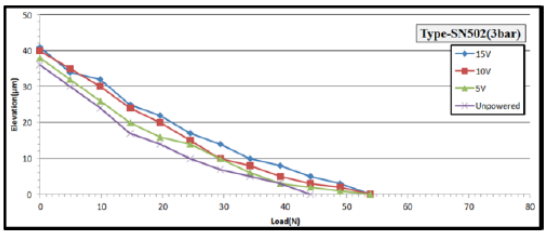


Figure 10: Bearing elevation vs. load for air pocket of 5 mm-diameter and 0.2 mm-depth.

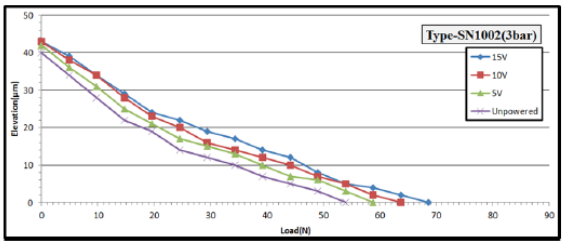


Figure 11: Bearing elevation vs. load for air pocket of 10 mm-diameter and 0.2 mm-depth.

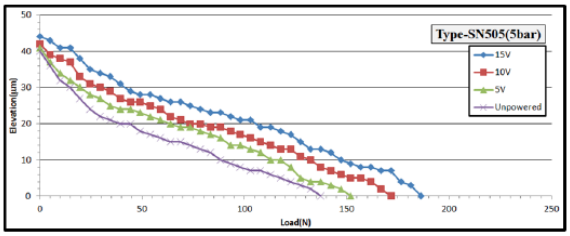


Figure 12: Bearing elevation vs. load for air pocket of 5 mm-diameter and 0.5 mm-depth.

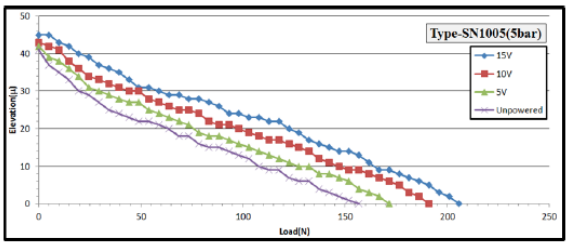


Figure 13: Bearing elevation vs. load for air pocket of 10 mm-diameter and 0.5 mm-depth.

It can be seen that the elevation can be controlled by the supply power to the electromagnet. Basically, the bearing is elevated higher under more intensive magnetic field. From Fig. 10 and Fig. 11 where the depth of the air pocket is as shallow as 0.2 mm, the greatest supply pressure is set as 3 bar since the MRE tube is pushed out and the recess is believed to collapse when the pressure is beyond 3 bar, in spite that the tube has been enforced by the screw already. The greater supply pressure such as 5 bar can be adopted when the diameter of the pocket is enlarged, like those shown in Fig. 12 and Fig. 13.Together with the wider pocket, greater load capacity can be achieved.

B. MRE tube with central needle

The details of the bearing and the loop of the magnetic lines (indicated with red lines) are given in Fig. 14. Figure 15 and Fig. 16 show the comparisons of elevation and air flux between designs with and without the screw. The supply pressure is 5 bar.

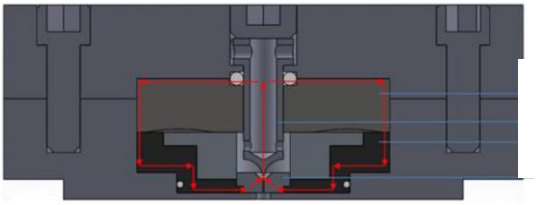


Figure 14: Details of structure and loop of magnetic lines.

Both the designs w/wo the screw can endure such a high pressure since the recess is deep enough. Both models demonstrate the ability of capacity adjustment with respect to magnetic intensity. The screw offers uniform and fixed capillary shape, resulting in minor ability of elevation adjustment since some tuning elements associated with the deformation of capillary have already been exterminated. The elevation of the one with screw is much higher than that of the one with no screw.It is believed that the expansion of the capillary and the extrusion of the MRE bottom in the "soft" design might lessen the outlet pressure and weaken the pressure distribution. On the other hand, Fig. 16 shows that the soft model has the greater air flux. It onlybecomes lower than the model with screw when the load is beyond about 60 N, where the gap (bearing elevation) drops below 10 microns. It turns out to be difficult for the air to flow through.

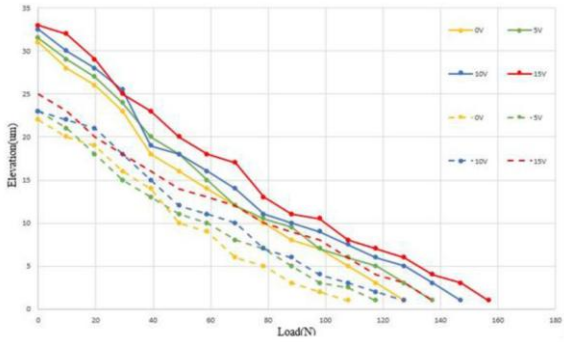


Figure 15: Bearing elevation vs. load for models having central needle. Solid lines: with screw; dash lines: without screw.

After eradicating the factor of capillary deformation in the screw model, altering the supply magnetic intensity should change the space between the needle tip and the MRE tube, which results in the variation in air flux. However, from Fig. 16, it can be seen that the air flux is barely influenced by the voltage supplied. It implies that the tweaking of elevation in Fig. 15 is mainly a result from the deformation of air pocket.

Finally, both the designs with and without the central needle demonstrate comparable ability of elevation control. Note that the superior load capacity of the no-needle model is a consequence of the wider and shallow recess.

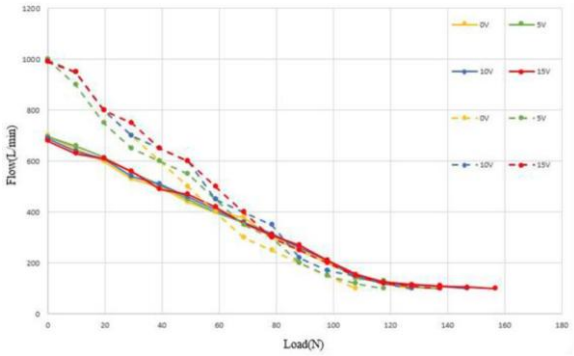


Figure 16: Air flux vs. load for models having central needle. Solid lines: with screw; dash lines: without screw.

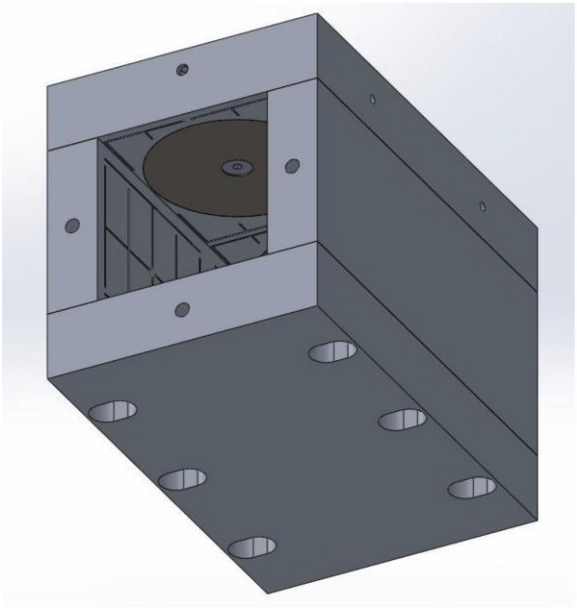


Figure 17: 3D illustration of rectangular hollow bearing for linear guideway.

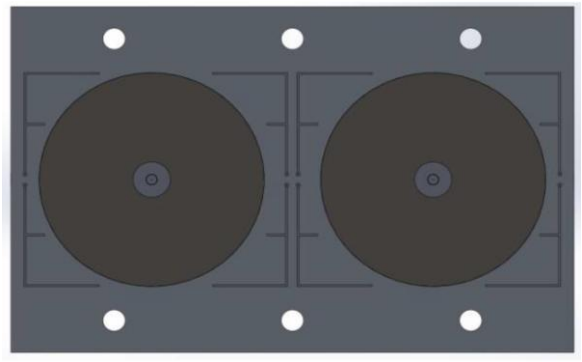


Figure 18: Combining conventional and new nozzles for industrial application.

The new nozzles proposed in this paper offer the capability of force adjustment. However, their load capacities arejust too low for practical application. They can be integrated with conventional nozzles, as

shown in Fig. 17 and Fig. 18 to gain sufficient load capacity while retain the flexibility for elevation adjustment. Figure 17 is a three-dimensional illustration of rectangular hollow bearing for linear guideway. Figure 18 shows that two MRE nozzles are combined with four conventional orifices and some micro ditches. Most of the external force is balanced by the orifices, which distribute the high air pressure along the micro ditches.

CONCLUSION

In this research, aerostatic nozzles made of magnetorheological elastomer (MRE) are designed and implemented inside a commercial electromagnet. The nozzles are composed of a capillary restrictor and an air pocket (recess) at the outlet. The shape of the recess can be tweaked by changing the electric current supplied so that the outlet air pressure distribution is therefore adjusted.

It is found that the MRE tube and the capillary inside deform seriously, causing poor loading ability and abnormally high air flux. To overcome these drawbacks, a steel screw with metallic capillary is buried in the MRE tube to enforce the rigidity of nozzle. In addition, an alternative design having a needle tip near the capillary inlet is made. It is supposed that the existence of the needle not only can change the distribution of the magnetic field but alsoadjust the size of capillary inlet.

A series of experiments verifies that the elevation can be controlled by the supply power to the electromagnet. Basically, the bearing is elevated higher under more intensive magnetic field. For the design having central needle, the screw generally offers minor ability of elevation adjustment while consumes less air since the deformation of capillary have already been exterminated.The elevation of the one with screw is much higher than that of the one with no screw. The deformation of the air pocket is the major factor influencing the load capacity of nozzle.
The new nozzles must be combined with the conventional ones to obtain load capability for practical industrial applications.

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