2017 STLE Annual Meeting & Exhibition, May 21-25, 2017
Hyatt Regency Hotel, Atlanta, Georgia, USA

Two magnetorheological elastomer devices for the control of aerostatic thrust bearing: Thru regulating air flow or surface curvature

Category: Fluid Film Bearings

Sy-Wei Lo[1], Jyun-Lin Li[1], Tsung-Ti Shu[1], Wan-Tsun Tseng[1], Tsuo-Fei Mao[2]
[1]Department of Mechanical Engineering, National Yunlin University of Science & Technology; losw@yuntech.edu.tw
[2]Department of Mechanical Engineering, Chienkuo Technology University; tfmau@ctu.edu.tw

1. Introduction

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 are not appropriate anymore. Moreover, 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.

Recently, Böse et al. [1] developed a valve using MRE (magnetorheological elastomer) to control the gas flow. Its basic function is a laboratory device containing a MRE ring in the space between two concentric yoke parts of the magnetic circuit, leaving an inner air gap. In this paper, their design is modified to design a new bearing with flux control. Another well-known mechanism to maintain the air pressure, say, concave bearing surface, is also adopted in the present research by using MRE. The two devices are tested for evaluating their performances under static/dynamic loadings.

2. Designs of MRE Aerostatic Thrust Bearings

2.1 Design of Flux-Control Bearing

The structure of the flux-control bearing, which is basically an “inverse” version of Böse et al. [1] flux regulator is shown in Fig. 1. The air flows into the bearing through the intake port on the main body. The mandrel (principal axis) is coiled 333 circles using copper wire of 0.5-mm diameter since the magnetic density is saturated for more circles. The inner brim of the MRE 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 to have roughness R_a equal to 0.097 μm.

The electric current is generated by two ways: for lower magnetic intensity at the mandrel end, the computer together with a power amplifier are used; On the other hand, the commercial power supply unit is adopted to provide higher gaussage. Note that the variation of gaussage is not monotonically increasing with the current ranging from 0.6A to about 2A. Different ways of power supplying lead to different magnet intensities in spite of the identical readout of electric current. This strange behavior might origin in the fact that the bearing has been reassembled between these two experiments. Each time when the bearing is disintegrated and reassembled, the gap 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 as will be shown in the following section. The gap between mandrel and MRE (marked by the circle in Fig. 1) is changed and the contact condition influences the magnetic field in turn.

2.2 Design of Curvature-Control Bearing

The structure of the curvature-control bearing is shown in Fig. 2. A flexible air pipe is inserted into the top cover, bent, centered through the mandrel, and then connected to the top MRE tube, which is fixed by an acrylics ring and a bottom cap made of low carbon steel. The purpose of the acrylics ring is to intensify the magnetic field by forcing the magnetic lines to flow through the thinner bottom cap. The polymer air pipe, MRE tube and the acrylics can be glued together easily and perfectly without air leakage; However, to prevent the air from leaking through the gap between the acrylics ring and the cap, an O-ring serves as the seal. The flat surface of the bottom cap is adopted as the bearing surface, which is finely polished and hardened with Ni-coating to get the final roughness R_a 0.076 μm.

An orifice type of restrictor is arranged in the MRE tube, which is 12-mm long and has an diameter of 10 mm. The details around the tube is illustrated in Fig. 3. In order to avoid the complex interaction between the contraction of MRE body and the capillary diameter, some special procedures must be considered to maintain the capillary dimensions. Firstly, a 0.5-mm diameter/2.5-mm long hole is drilled in a M3 screw. To produce a 0.2-mm capillary, the screw is then buried in the MRE tube and a spring steel of 0.2-mm diameter is stretched and centered through the hole during the process of solidification. A recess of 2-mm diameter and 1.5-mm depth can be formed after the MRE tube has been integrated with the acrylics and the bottom cap. It is noteworthy that the bottom of the tube is slightly shorter than that of the cap in order to accommodate any error in dimensions caused by curing.

Again, the mandrel is coiled 333 circles using copper wire of 0.5-mm diameter since the magnetic density is saturated for more circles. As the coils are empowered, the magnetic field is built up and the whole tube is hardened and contracted upwards. A concave bearing surface is thus generated at the 10-mm diameter circular end of the tube. The electric current is generated by two ways: for the greater magnetic intensity, the commercial power supply is used to produce 459-1100 Gauss at the end of the recess for current from 1.03 A to 3.13 A; On the other hand, the computer together with a power amplifier are adopted to provide gaussage below 428

Gauss. For the convenience of recording, the voltage instead of the current, which is shown on the panel of either the power supply or the PC-amplifier unit, is marked in the following illustrations. Monotonically simple relationship is observed. Compared with the flux-control mechanism, the curvature-control one is more promising in the aspect of the gaussage/current response.

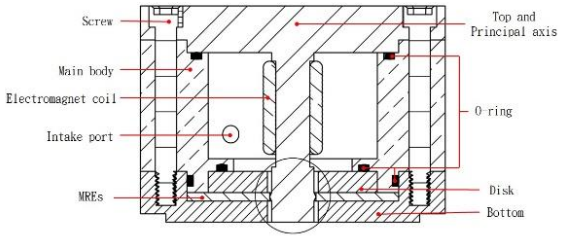

Fig. 1: Structure of flux-control MRE bearing

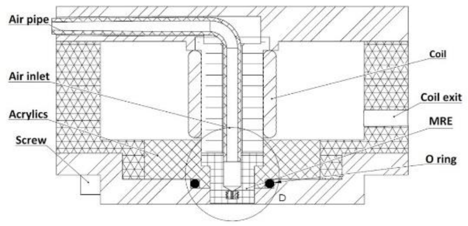

Fig. 2: Structure of curvature-control MRE bearing

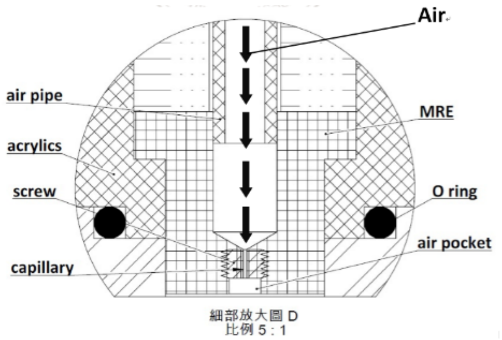

Fig. 3: Details of the MRE tube and restrictor

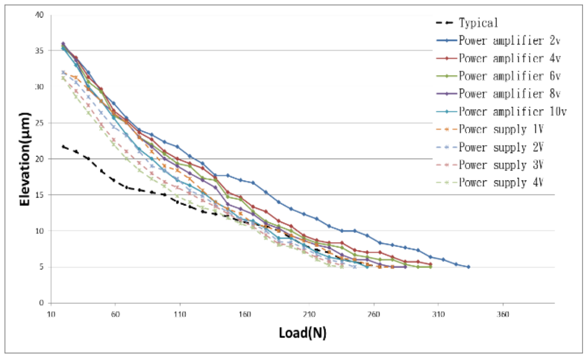

Fig 4: Flux-control using different power sources (Flux-control)

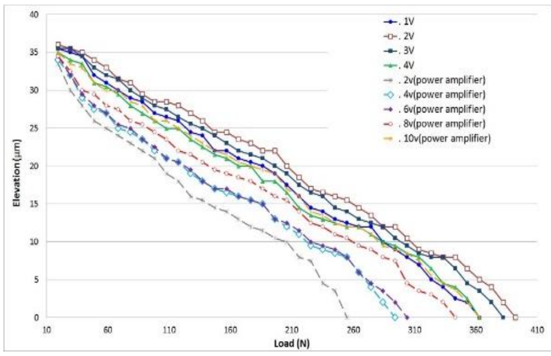

Fig 5: Curvature-control using different power sources

3. Static Experiment

3.1 Flux-control bearing

The pressure for the air supply is 0.5 MPa (5 bar). Figure 4 shows the relationship between elevation and load for the flux-control mode. The air flux for the typical bearing is 1 L/min and the unpowered new bearing is 2.1 L/min. Generally speaking, the load capacity for a given elevation of the new bearing is better than the typical one when the floating height is above 10 μm. On the other hand, the static stiffness is similar to, or even worse than that of the typical design. When the voltage is increased, the MRE disk shrinks to yield a smaller gap between mandrel and disk. The air flux and the floating height are therefore reduced. The variation is monotonic. It can be seen that the PC power amplifier unit produces a broader range of control while the distribution of elevation variation activated by power supply is much narrower due to the saturation of magnetic effect. The most pronounced “controllable” elevations are among 10 to 17 μm using the power amplifier unit. It covers, for example, a wide variation of load ranging from 180 N to 250 N for elevation 10 μm. In addition, the load capacity changes substantially when the voltage is enhanced from 2 V to 4 V. It is noteworthy that the air flux, thus the load capacity, is very sensitive to the gap between MRE and the mandrel. Accuracy of assemble and the precision of MRE dimension play a key role in flow control. However, the MRE dimension is not only influenced by the solidification process but is also deformed subjected to a kind of “squeeze” action when it is integrated with the other parts in bearing. Strictly speaking, the “flux-control” model will face definitely many problems in practical applications. The discrepancy between the two sets of curves by power amplifier and power supply, respectively, at the low load region clearly reflects the defect mentioned above.

3.2 Curvature-control bearing

Figure 5 gives the results for the curvature-control design using power supplier. The air consumption varies from 1.6 L/min to 1.9 L/min. The higher the load, the smaller the air flux. Both the load capacity and the static stiffness outplay the typical one. Different from the “monotonic” flux-control bearing, the behavior of the curvature-control model is more complex, due to the subtle relation between the geometry of recess and the load capacity. The curves from power supplier show the tendency that there exists an optimal electric current, called the “reverse point” of current, capable of generating the greatest load capability. While Fig. xx implies that when a PC power amplifier is adopted, no “reverse” point is found. It is interesting to note that the effect of voltage on bearing elevation almost vanishes between 4 V and 6 V. The lower electric current, which is provided by power amplifier, can produce a broader band for elevation control if the external load becomes unstable while a constant elevation is in demand. However, a superior ability of elevation control can be achieved if a wider variation of electric current is provided.

4. Dynamic Experiment

In the present test a shaker is used to create maximum output of 17.8 N, operating from 5 Hz to 13 kHz. The force exerted by the air cylinder is 10 N. The shaker oscillates 60 seconds for each scanning frequency.

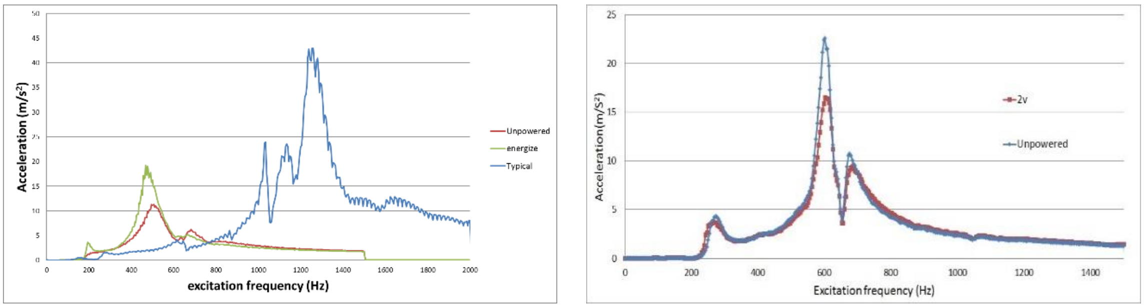

Fig 6: Acceleration vs. frequency for flux-control bearing (left) and curvature-control bearing (right)

4.1 Flux-control bearing

The flux-control bearing has the greatest air flux and thus the highest load capacity when the bearing is not powered. Therefore, in the experiment we will record the acceleration against excitation frequency of shaker for the typical bearing, the unpowered new bearing, and the new one charged with an arbitrary chosen voltage, say, 3 V by power supplier. The results are shown in the left of Fig. 6. The typical bearing displays the most serious resonance at 1260 Hz where the acceleration is 43 m/s^2. Its damping ratio is 3.3%. The resonance of the new bearing is, however, substantially alleviated to 11 m/s^2 at 496 Hz due to the softer, viscoelastic property of elastomer and the damping ration increases to 10.0%; On the other hand, the charged elastomer is “hardened” and raises the peak value of acceleration up to 19 m/s^2 at 468 Hz. The damping ratio becomes 6.6%. In conclusion, the flux-control design can bring down both the resonance frequency and the severity of resonance.

4.2 Curvature-control bearing

Since the static tests show that the bearing driven by voltage 2 V from the power supplier demonstrates both the best load capacity and static stiffness, it is chosen for the dynamic experiment. Figure 6 (right) shows that the resonance frequency, 600 Hz, is smaller than that of the typical bearing, 1260 Hz, and is barely affected by the electric power. At the resonance frequencies, the responding accelerations are equal to 22.6 m/s^2 for unpowered bearing and 16.5 m/s^2 for the charged one, respectively. Meanwhile the damping ratio changes slightly from 3.0% to 3.4%. Both are close to the typical bearing 3.3%. In conclusion, the concave MRE surface helps cut the resonance acceleration and frequency except the damping ratio.

5. Conclusions

In this paper two novel controlling elements made of magnetorheological elastomer (MRE) for aerostatic thrust bearing have been developed. An electromagnet was integrated in the bearing to trigger the contraction of the elastomer. In the mode of “flux control”, the performance of the bearing depends on the air flux flowing through the gap between a MRE ring and the central mandrel. While in the mode called “curvature control,” changing the magnetic field can bend the MRE orifice shape and deepen the recess of the bearing. The air pressure distribution and the load capacity of the bearing are altered accordingly. The load-elevation relationships can be manipulated. In spite that the flux-control design yields a more monotonic relation between control voltage and load capacity, the performance is very sensitive to the accuracy of assembly and dimension of the MRE part. On the other hand, the curvature-control one shows a more complex performance while keeps the better repeatability of experimental results.

A simple dynamic test showed that the MRE bearings have both the acceleration and frequency of resonance less than that of the typical design. However, the first two resonance frequencies of the curvature-control bearing are higher than that of the flux-control one. Another interesting finding is that when the MRE is charged, the acceleration of the flux-control bearing upsurges, but it plunges for the curvature-control one.

Acknowledgement

The support from the Ministry of Science and Technology under grant MOST105-2221-E-224-016-MY3 is gratefully acknowledged.

References

[1] Böse H., Rabindranath R., Ehrlich J., 2012, “Soft magnetorheological elastomers as new actuators for valves”, *Journal of Intelligent Material Systems and Structures*, **23**, pp. 989-994.