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Design and Research of Industrial Permanent Magnetic Bearing

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Abstract. Because of that the permanent magnetic bearing (PMB) has the advantage of no wear, low cost and simple structure, the industrial design concept of PMB has been put forward in this paper. Radial and axial permanent magnetic levitation technology has been studied, and the aforementioned design is done based on these two kinds of technologies. During the experiments on the mechanical characteristics of PMBs, the capacity and stiffness of the bearings are researched.

Introduction

Magnetic bearing is a kind of high performance bearing which set the rotor suspended in the air by magnetic force， in that case there is no any mechanical contact between stator and rotor. There are three kinds of magnetic bearing, including active magnetic bearing, passive magnetic bearing and mixed magnetic bearing. PMB belongs to a kind of passive magnetic bearing.

According to Earnshaw's law, we can know that PMB can not be achieved stability in all degrees of freedom [1]. Therefore, there is one degree of freedom needs to be supported by other bearing at least. In this paper, radial and axial industrial PMB have been designed.

The PMB has many advantages: simple structure, free-friction, low-cost etc, and various forms of magnetic bearing systems are constituted through combining electromagnetic bearing, mechanical bearing, and superconducting magnetic bearing. So it has broad application prospect [2].

1 Basic Structure of PMB

PMB can be used as radial bearing and thrust bearing (axial bearing), both the two kinds of bearings can be designed by suction type and repulsion type. According to the magnetization direction of magnetic ring and the differential of the relative position, PMB has variety of different magnetic structure [3]. Axis magnetizing which is currently used more often is technically easy to implement than radial magnetizing.

In accordance with the different supporting structure, we can get two basic kinds of PMB which can be divided into axial permanent magnet bearings and radial permanent magnet bearings. The two figures below just show the basic structure of these two common kinds of bearings.

Fig. 1 shows the structure of radial PMB unit, in which (a) is a suction-type PMB, (b) and (c) is the repulsive type of PMBs.

Fig. 2 shows the axial PMB unit structure, which (a_1) is the repulsive type of PMB, (b_1) and (c_1) is the suction type of PMBs.

In the actual design, in order to adapt to different conditions, there are many choices on the structure of PMB. More magnetic rings can be superimposed to increase bearing capacity and stiffness of PMB.

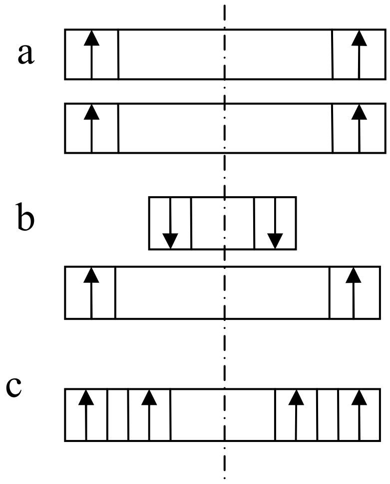

Fig. 1 Structure of radial PMB unit

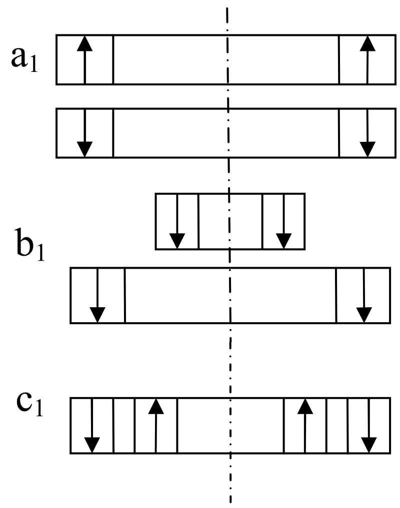

Fig. 2 Structure of axial PMB unit

2 Structural Design of Industrial PMB

2.1 Structural Design of Radial PMB

Fig. 3 shows the structure of radial PMB, where 1 is the motionless outer ring, 2 is the static magnetic ring, 3 is the dynamic magnetic ring, 4 is distance ring, 5 is the auxiliary thrust bearing and 6 is the kinetic inner ring. Both static and dynamic magnetic rings are made up with raw materials NdFeB.

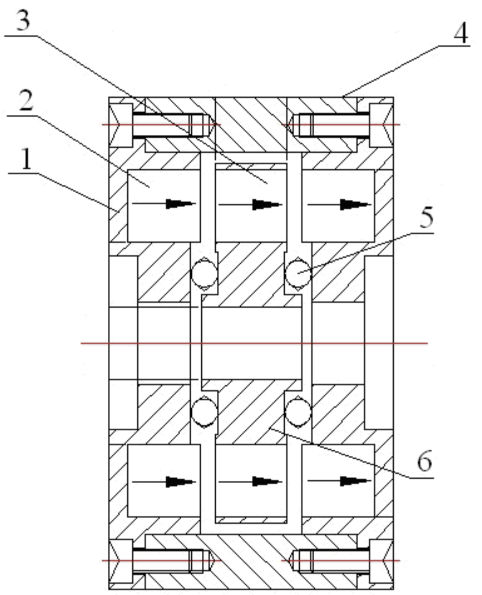

Fig. 3 Structure of radial PMB

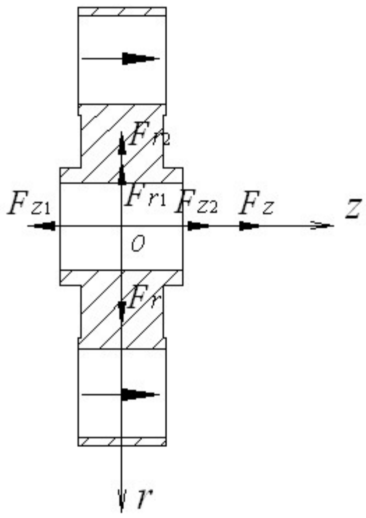

Fig. 4 Force diagram of dynamic magnetic inner ring

The working principle is: when radial migration of the dynamic magnetic inner ring acted by F_r occurs, resilience F_{r1} and F_{r2} would be generated between the dynamic and static magnetic rings in the opposite direction of the motion to move back to the original balance location.

$$F_r = F_{r1} + F_{r2} \quad (1)$$

F_z is the force of the auxiliary thrust bearing:

$$F_z = F_{z1} - F_{z2} \quad (2)$$

Then the radial stiffness could be obtained:

$$K_r = \frac{dF_r}{dr} \tag{3}$$

In order to seek the total magnetic force on the dynamic ring, we needs to make summation on magnetic force in air around dynamic ring. By using the method of virtual work in the finite element software ANSYS, the magnetic force can be obtained by the differential of magnetic energy to displacement of moving parts. The basic formula of magnetic force in radial direction in air layer is:

$$\{F_{ri}\} = \int_{vol_i} \left[\{B\}^T \left\{ \frac{\partial H}{\partial r} \right\} \right] d(vol) + \int_{vol_i} (\int \{B\}^T \{dH\}) \frac{\partial}{\partial r} d(vol) \qquad \text{(i=1,2)} \tag{4}$$

F_{ri} is the magnetic force on r direction, $\left\{ \frac{\partial H}{\partial r} \right\}$ is the differential of magnetic field intensity to displacement, r is the virtual displacement of the node coordinates in the r-axis direction, vol_i is unit volume.

$$\{F_{zi}\} = \int_{vol_i} \left[\{B\}^T \left\{ \frac{\partial H}{\partial z} \right\} \right] d(vol) + \int_{vol_i} (\int \{B\}^T \{dH\}) \frac{\partial}{\partial z} d(vol) \qquad \text{(i=1,2)} \tag{5}$$

F_{zi} is the magnetic force in z direction, $\left\{ \frac{\partial H}{\partial z} \right\}$ is the differential of magnetic field intensity to displacement, z is the virtual displacement of the node coordinates in the z-axis direction, vol_i is for unit volume.

2.2 Structural Design of Thrust PMB

Fig. 5 shows structure of thrust PMB, where 1 is the shaft ring, 2 is the housing ring, 3 is the static magnetic ring, 4 is the dynamic magnetic ring, 5 is distance ring and 6 is the auxiliary radial bearing.

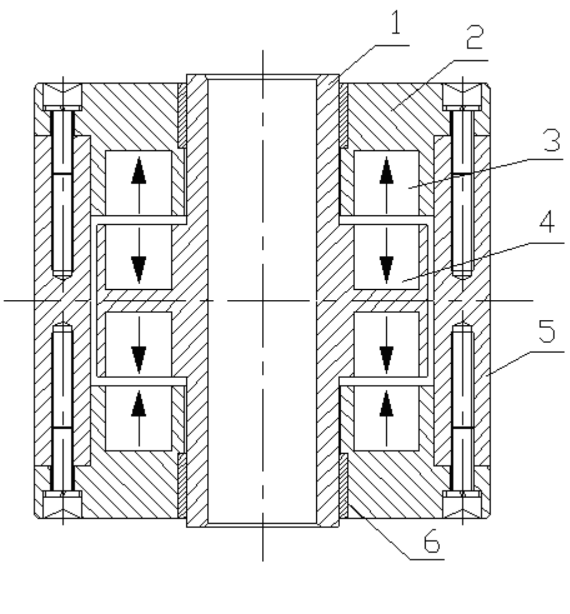

Fig. 5 Structure of thrust PMB

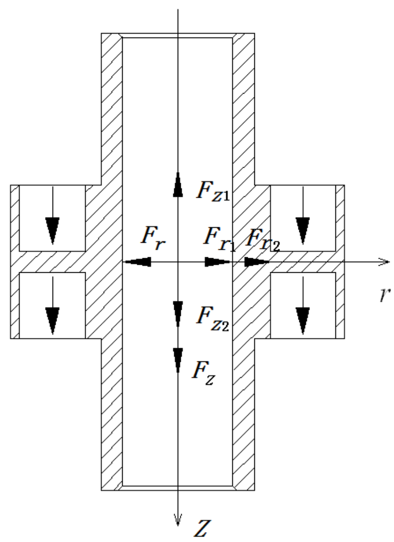

Fig. 6 Force diagram of dynamic magnetic ring

The working principle is: there are two static magnetic rings in housing rings which are on the top and bottom side of the bearing. The dynamic magnetic rings are kept in the shaft ring. The two static magnetic rings have the same magnetizing direction, which have the opposite magnetizing direction to the adjacent dynamic magnetic ring. The repulsive forces F_{z1}, F_{z2} between the dynamic and static magnetic rings generates the restoring force in the opposite direction when the dynamic magnetic ring is acted by force F_z. That stabilize suspension.

$$F_z = F_{z1} - F_{z2} \tag{6}$$

F_r is the force of the auxiliary radial bearing:

$$F_r = F_{r1} + F_{r2} \tag{7}$$

Then the axial stiffness could be obtained:

$$K_z = \frac{dF_z}{dz} \tag{8}$$

3 Experimental Study of PMB Static Characteristics

3.1 Experiment of Radial PMB

As is shown in Fig. 7, a pressure is given through the nut to the strength block. There are two linearity springs between the two blocks, which would pass the pressure to the test rotor. Then dial indicator can be measured by the radial displacement of test rotor, and then the radial load curve of PMB would be obtained.

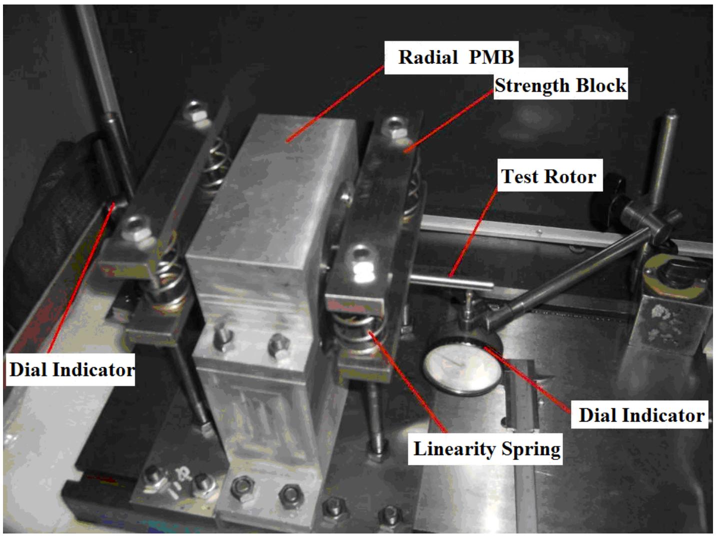

Fig. 7 Loading test-bed of radial PMB

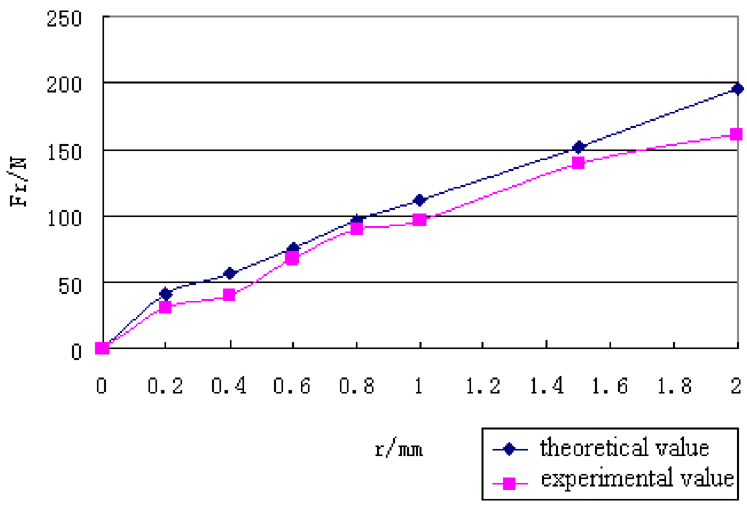

Fig. 8 Mechanical characteristics curve of radial PMB

As is shown in Fig. 8, theoretical analysis and experimental data has got the same trend, which proves the fact that the radial force of radial PMB would keep growing with the increase of radial displacement. We can also notice that the experimental data is less than the theoretical data. Radial stiffness calculated by finite element method is approximately K_r = 110N/mm, while the measured value is K_r = 90N/mm.

3.2 Experiment of Thrust PMB

The capacity and stiffness of thrust PMB are measured by acting axial load on bearing in this experiment. Put the nominal measurement weights on the thrust PMB which is axial placed.
Adjust the magnetic ring gap, we can record the result of mechanical characteristics curve of thrust PMB which is shown in Fig. 9.

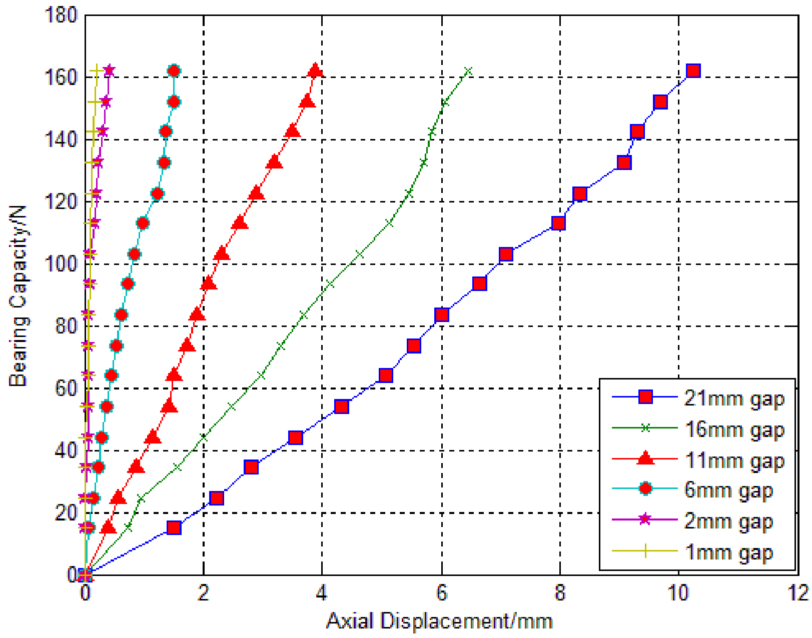

Fig. 9 Mechanical characteristics curve of thrust PMB

It can be seen from Fig.9, the axial resilience of the thrust PMB increases with the increasing of axial displacement. Experimental results show that the bearing stiffness could be up to 400N/mm when the gap is 2mm.

4 Conclusions

The industrial PMB is simple and reliable, which avoids the inconvenience of the self-assembly parts. The advantage of the bearing is good for the quantity production. The industrial PMB has broad application prospect.

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