A new Magnetic Baering-Rotor system

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0 Abstract

The technology of the Active Magnetic Bearing is developed so fast that it can be utilized in many field. In order to reduce the size of the magnetic bearing to fit the artificial heart, magnetic suspended hard disk, gyroscope and etc, a new minitype Magnetic Bearing-Rotor system is successfully designed by improving the mechanical structure and control technique of the bearing. It also can suspend stably. Experiments have already proved that this design can not only effectively reduce the size of bearing but also simplify the structure of bearing.

1 Introduction

Traditional Active Magnetic Bearings (AMBs) usually have two radial bearings and a thrust bearing to control five degrees of freedom actively [1]. The size of AMBs is difficult to be reduced to a scale in order to be applied. So the number of bearings and sensors are optimized to reduce the size of the AMBs. Considering the related design experience [2-3], Only two groups of AMBs are adopted as the support to actively control two degrees of freedom inside a single plane, which is named as the main control plane. The other three degrees of freedom of the rotor suspended passively, whose support is offered by the component forces of two groups of bearings inside the main control plane. Its principle is demonstrated in Fig. 1.

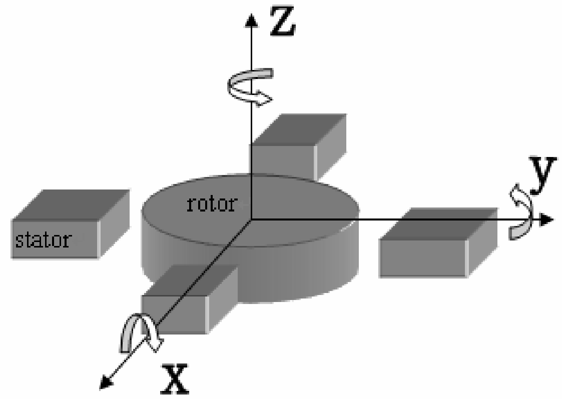

Fig. 1 Scheme of bearing

Plane x-y is the main control plane. In this plane, the bearing is stabilized in its balance place by active control. One degree of freedom turning around z axes is controlled by electric machine .The other three degrees of freedom which include translating around z axes, turning around x axes and y axes are passively stabilized by the component forces of bearings inside the main control plane. Its principle is demonstrated in Fig. 2. when the rotor departures from the main control plane, bearing force will make component force which is contrary to the direction of displacement to pull the rotor back to realize the stable suspensions in these three degrees of freedom.

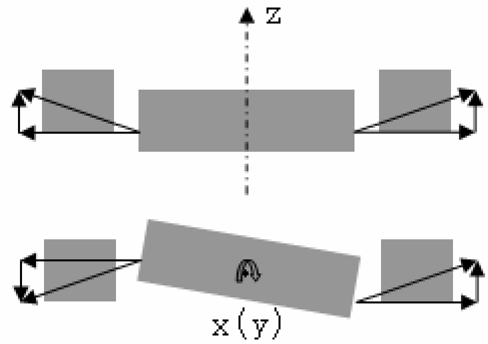

Fig. 2 Scheme of passive stabilization principle

2 The disposal of magnetic pole

In order to decrease magnetic hysteresis loss， Magnetic poles are put along the axes of rotor and magnetic flux parallel the axes of rotor. Rotor adopt the integrative magnet conductive material to enhance the strength and bring convenience in the machining process. The disposal of the magnetic poles is demonstrated in Fig. 3.

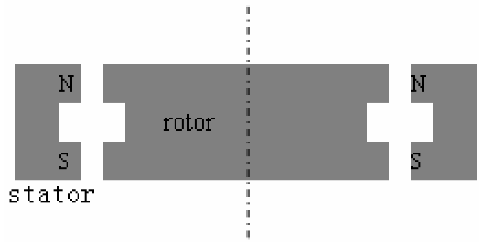

Fig. 3 Schematic view of magnetic pole disposal

3 Sensors

Two groups of inductance sensors are adopted. The iron cores of both inductance sensors and magnetic poles are alternatively disposed (Fig. 4). After the signals of sensors are processed, we can get coordinates of the rotor in the main control plane and displacements of the rotor plumbing the main control plane.

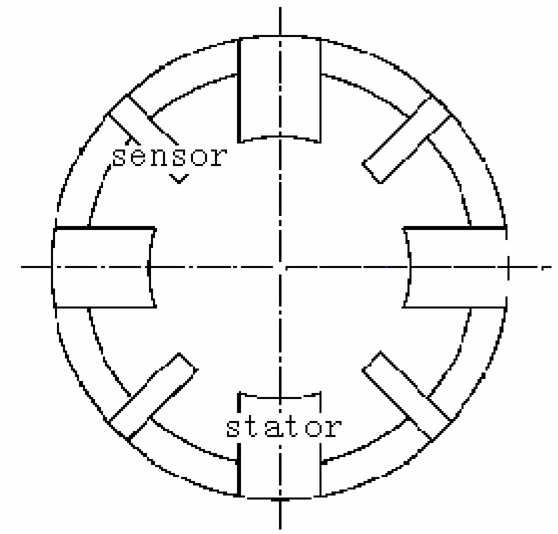

Fig. 4 Schematic view of sensor disposal

Inductance sensors detect the distance (airspace s) between the rotor and the iron cores through detecting the changes of loop sensors L. The calculation formula for the sensor loop inductance is:

$$L = n^2 \mu_0 A_l \frac{1}{2s} \tag{1}$$

L means inductance, n means number of windings of the loop, μ_0 means the magnetic constant in vacuum, s means the wide of the airspace， A_l means gas gap cross section. Taylor expansion of the equation (1) at the balance place s=s_0 and adopt the main item:

$$L = \frac{n^2 \mu_0 A_l}{2}\left[\frac{1}{s_0} - \frac{1}{s_0^2}(s-s_0) + \frac{2}{s_0^3}(s-s_0)^2 - \frac{6}{s_0^4}(s-s_0)^3 + \cdots\right] \tag{2}$$

$$L \approx \frac{n^2 \mu_0 A_l}{2}\left[\frac{1}{s_0} - \frac{1}{s_0^2}(s-s_0)\right] \tag{3}$$

Let us put a group of sensors as examples in Fig. 5. We can get the inductance difference between A and B in equation (3):

$$L_A - L_B = \frac{n^2 \mu_0 A_l}{2}\frac{1}{s_0^2}(s_A - s_B) = k\Delta s \tag{4}$$

$$\Delta s = s_A - s_0 = s_0 - s_B \tag{5}$$

$$k = \frac{n^2 \mu_0 A_l}{s_0^2} \tag{6}$$

Fig. 5 Scheme of sensor principle

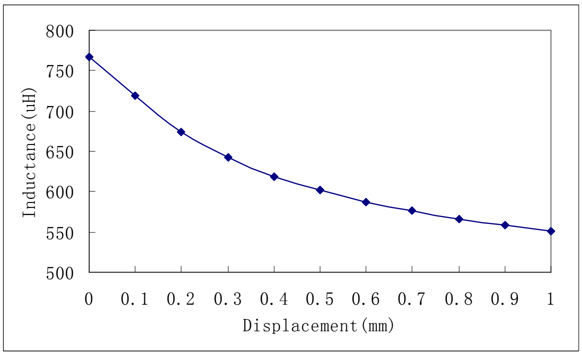

Fig. 6 Measured curve of sensor A

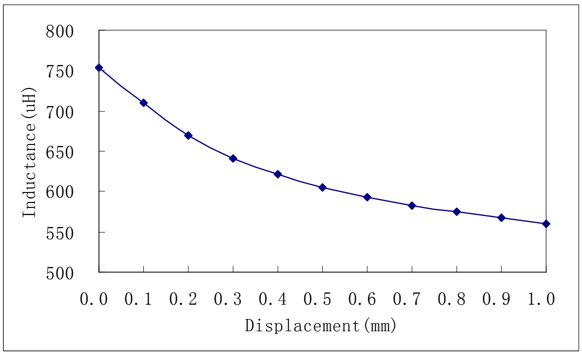

Fig. 7 Measured curve of sensor B

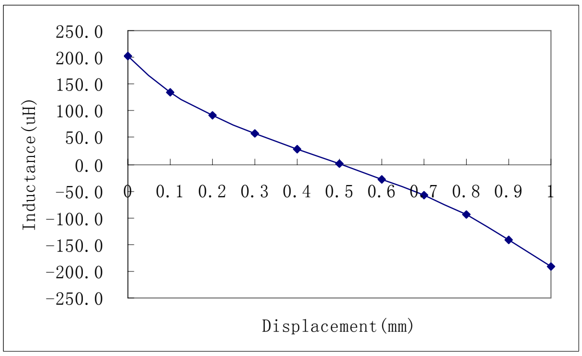

Fig. 8 Curve of differential of sensor A and B

The result that a group of sensors A and B do the differential is to prorate with the place change (Δs) at the balance place. The proportion modulus is k. The true measurement of the inductance A, B and the place change curve is demonstrated in Fig. 6 and Fig. 7.The differential curve of the sensor A and B is shown in Fig. 8. At the balance place, the inductance difference shows linear relationship with the place of rotor. It inosculates well with the theoretically analytical results.

Due to the certain angle formed between sensors and magnetic poles, the signal measured by sensors should map to the coordinate directions in which magnetic poles are located, the mapping connection of $(x, y) \rightarrow (x', y')$ is:

$$x' = x \cdot \cos\theta + y \cdot \sin\theta$$
$$y' = y \cdot \cos\theta - x \cdot \sin\theta \qquad (7)$$

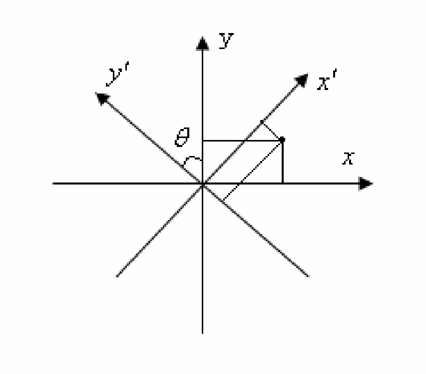

Fig. 9 Schematic view of coordinate conversion

4 Control

For this application, the power consumption of the system is very little and do not require high power amplifying efficiency. So linear power amplifier is adopted. The circuit is simple and responds quickly. No high frequency interferes with it. Based on this unusual structure, control current should satisfy certain restriction conditions to improve the stability of three degrees of freedom suspended passively. The control arithmetic is optimized.

Based on this unusual structure, control current should satisfy certain restriction conditions to improve the stability of three degrees of freedom suspended passively.

Let us put a group of magnetic poles as examples in Fig. 10. If ordinary differential control mode is adopted, the electricity in the 1, 3 magnetic loop is shown in equation (9), i_0 is offset electricity, Δi is control regulated quantity.

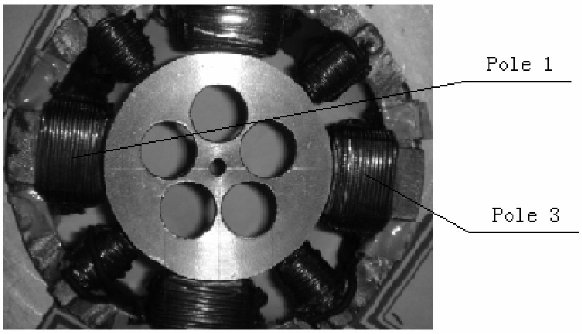

Fig. 10 Scheme of magnetic pole

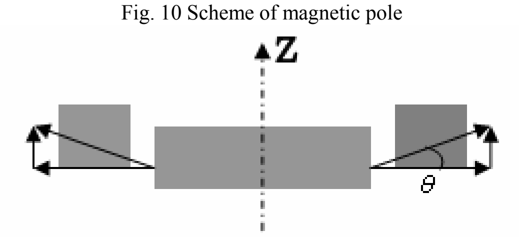

Fig. 11 Diagram of axial force

$$i_1 = i_0 - \Delta i$$
$$i_3 = i_0 + \Delta i \qquad (8)$$

The calculation formula of the electromagnetism force generated by the electricity in the magnetic poles is $f = \mu_0 A_l (\frac{ni}{2s})^2$, n means number of windings of the loop, μ_0 means the magnetic constant in vacuum, s means the wide of the airspace, *i* means the electricity in the loop. Let us put situations in Fig.13 as examples, the magnetic force along Z axes suffered by the rotor is :

$$f_z = \frac{n^2 \mu_0 A_l}{4} [(\frac{i_1}{s_1})^2 + (\frac{i_3}{s_3})^2] \qquad (9)$$

$$f_z = \frac{n^2 \mu_0 A_l}{4} [(\frac{i_0 - \Delta i}{s_0 - \Delta s})^2 + (\frac{i_0 + \Delta i}{s_0 + \Delta s})^2] \qquad (10)$$

In the equation (10), Δi and Δs are changing measures in the control process. f_z will change accordingly. That means shock excitation force will be produced in Z axes, which will destroy the balance of the rotor outside of the main control plane. As a result, the previous differential control mode is improved.

In order to restrain shock excitation force, $(\frac{i_1}{s_1})^2 + (\frac{i_3}{s_3})^2$ should be fixed, the control policy is improved:

$$i_1 = \frac{s_0 - \Delta s}{s_0} \sqrt{i_0^{\ 2} - 2 i_0 \Delta i}$$
$$i_3 = \frac{s_0 + \Delta s}{s_0} \sqrt{i_0^{\ 2} + 2 i_0 \Delta i} \qquad (11)$$

So it guarantees f_z will not interfere with Δi and Δs in order to eliminate the origin of shock excitation force.

5 The experimental device

Through initial mechanical structure design and finite element analytical calculations, an experimental system is made to fulfill the stabilized suspension in the static state. And it works well.

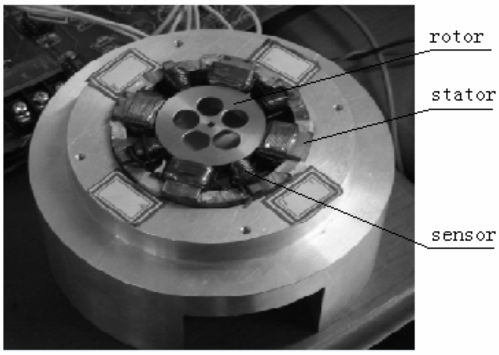

Fig. 12 Photo of experimental system

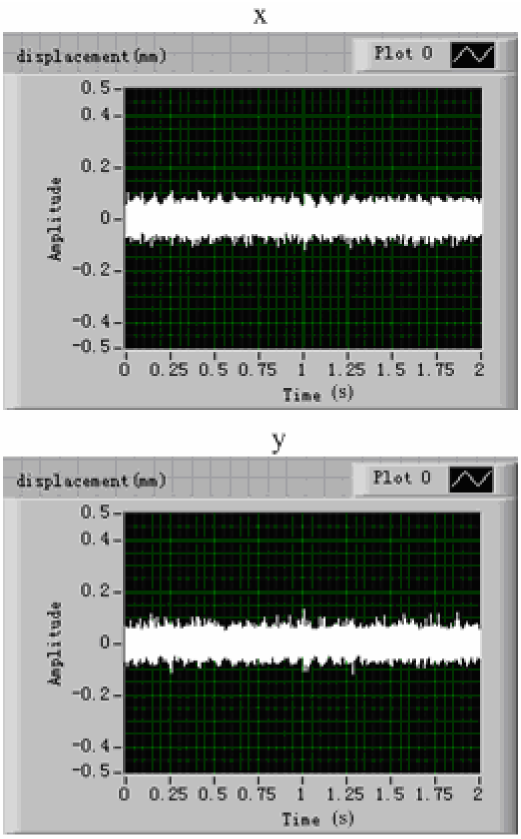

Fig. 13 Waveform of radial sensor

The electricity vortex is installed in axial direction, the axial direction waveform is shown in Fig. 14.

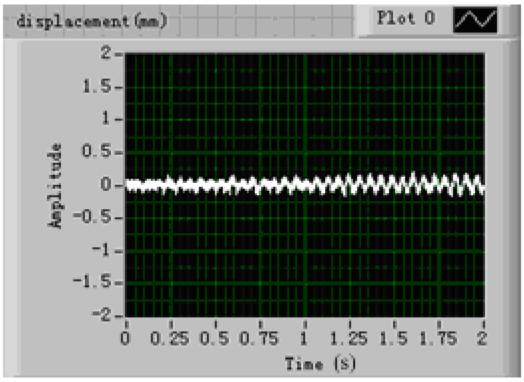

Fig. 14 Waveform of axial sensor

6 Conclusion

Experiment demonstrates this optimized design not only effectively reduces the size of bearing, but also does not affect the effect of suspension. The disposal method of magnetic poles and sensors benefits renewed size reduction and control and necessarily restricts control current to favor the stabilized suspension of the other three degrees of freedom outsider the main control plane.

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