Research on Influence of Annular Magnetic Pole on Airgap Magnetic Field and Bearing Capacity of Axial Magnetic Bearing

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Abstract—**In order to enhance the radial bearing capacity of the axial magnetic bearing, the magnetic field distribution of the air gap in the double-annular magnetic axial magnetic bearing and the three-annular magnetic axial magnetic bearing is simulated and studied, and the dual-ring magnetic pole shaft is established. Based on the magnetic circuit model of the magnetic bearing and the three-ring magnetic pole magnetic bearing, the effect of the annular magnetic pole on the air gap permeability and the total magnetic flux of the magnetic circuit was analyzed. The spatial distribution of air gap magnetic field between magnetic poles was obtained by finite element simulation. The distributions of axial and radial components of the air gap magnetic induction intensity were analyzed. Compared with the traditional single annular magnetic pole axial magnetic bearing structure, the multi-annular magnetic pole structure was enhanced. With the edge effect of the air gap flux, the proportion of the edge flux increases, and the axial flux ratio decreases. After that, the axial component of the magnetic induction intensity and the radial component of the radial displacement of the two-ring magnetic structure and the three-ring magnetic structure are compared and analyzed. The results show that the annular magnetic pole reduces the axial force and enhances the radial force, that is, the radial bearing capacity increases, and the axial component of the magnetic induction intensity of the three-ring magnetic structure is larger than that of the double-ring magnetic structure. The radial component of the displacement to the displacement is reduced, which provides a theoretical and experimental reference for the radial suspension of the annular magnetic axial magnetic bearing.**

Key words: axial magnetic bearing; annular poles; radial magnetic force; magnetic equivalent circuit;fringe magnetic flux

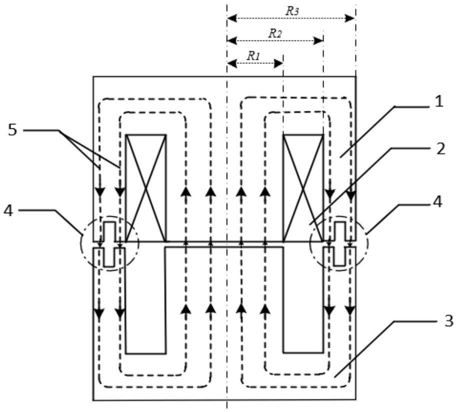
I. INTRODUCTION

Magnetic suspension bearings are used by the magnetic force between the stator and rotor, so that there is no mechanical contact between the stator and rotor, so that the bearing rotor is suspended in the bearing in the space setting position. And because there is no mechanical contact between the rotor and the stator, it greatly reduces the mechanical energy consumption and noise, and has the obvious advantages of no lubrication, no oil pollution, and long service life. It is suitable for special environments such as high speed and vacuum cleaning [1-3]has been successfully applied to high-speed electric spindle, centrifugal compressor, vacuum molecular pump, artificial heart and other equipment [4-9]. The traditional five-degree-of-freedom magnetic bearing system consists of two sets of radial magnetic bearings and a set of axial magnetic bearings. It controls four translational degrees of freedom in the radial direction and one translational degree of freedom in the axial direction. Each group of magnetic bearings passes the displacement sensors, controllers, and power amplifiers at various degrees of freedom to realize closed-loop control and provide their own freedom. Degrees of magnetic force required for suspension to achieve a five-degrees-of-freedom suspension of the rotor in space. However, the conventional five-degree-of-freedom magnetic levitation system consisting of two sets of radial magnetic bearings and one set of axial magnetic bearings has the disadvantages of large volume and high power consumption. Therefore, a certain degree of freedom of the magnetic bearing to provide multiple degrees of freedom to reduce the degree of freedom of active control, to overcome the shortcomings of the traditional five-degree-of-freedom maglev system's high power consumption and large volume has a high research value [10-11].

By consulting literature and studying the multi-freedom levitation force of the axial magnetic bearing, it was found that the radial bearing capacity of the axial magnetic bearing is generally small, and only the axial magnetic bearing is used in many cases where radial bearing capacity is required. Less than required, and the radial bearing capacity directly determines the radial levitation performance of the magnetic bearing system. Therefore, in many applications requiring an axial magnetic bearing to improve the radial bearing capacity and stiffness, a certain degree of freedom of the magnetic bearing comes Providing multi-degree-of-freedom bearing capacity to overcome the shortcomings of high power consumption and large size of the traditional five-degree-of-freedom magnetic levitation system is the key to the design of an axial magnetic bearing to achieve active control of a single-degree-of-freedom magnetic levitation system.

This paper presents an axial magnetic bearing structure with a ring-shaped magnetic pole. First, a magnetic circuit model with an annular magnetic pole axial magnetic bearing is established, and the total magnetic flux of the annular magnetic pole against the axial magnetic bearing is analyzed by the magnetic circuit method. Influence; Using finite element simulation, the magnetic induction intensity and magnetic field spatial distribution at the air gap are obtained, and the spatial distribution of axial magnetic flux and radial magnetic flux in the air gap magnetic flux is analyzed, and on the basis of the double annular magnetic pole, the In a loop, the axial and radial components of the magnetic induction intensity of the double-ring magnetic pole and the triple-ring magnetic pole are analyzed and compared, and the conclusion is obtained. The result of the air-gap magnetic field analysis is verified, and the magnetic flux of the annular magnetic pole axial magnetic bearing is realized. Provide theoretical and experimental basis for suspension.

II. DOUBLE ANNULAR MAGNETIC POLE AXIAL MAGNETIC BEARING STRUCTURE



1-Stator core 2-Coil 3-Rotor core 4-Annular magnetic pole 5-Magnetic flux

Fig.1 Axial magnetic bearing structure diagram with double annular magnetic pole

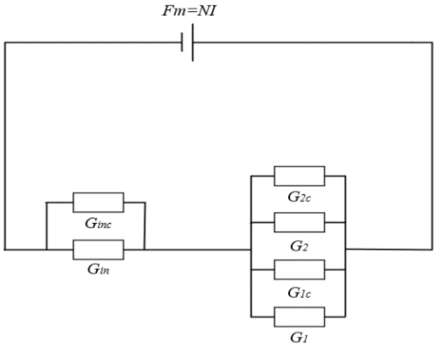
As shown in Fig.1, it is a schematic diagram of a double-ring magnetic pole axial magnetic bearing structure composed of a stator iron core, an electromagnetic coil wound around the stator iron core and a rotor iron core. A current flows through the coil to generate a magnetomotive force, which is generated in the magnetic circuit. The magnetic flux, in turn, passes through the stator core, the outer air gap, and the rotor core, and the inner air gap forms a magnetic flux return, as shown by the arrows in the figure. The magnetic flux passes through the air gap between the stator and the rotor to establish an air gap magnetic field. The magnetic force generated at the interface between the stator and the air gap can be decomposed into an axial component force Fy and a radial component force Fr. At the outer magnetic pole of the axial magnetic bearing, the double annular magnetic poles change the magnetic induction intensity and magnetic field distribution of the air gap magnetic field, thereby affecting the axial and radial forces of the axial magnetic bearing.

When there is no radial displacement between the stator and rotor, the stator and the rotor shaft coincide, and the air gap flux distribution is symmetrical along the axis of the shaft. There is only axial force between the stator and rotor, and the radial force is zero. When radial displacement occurs between stators and rotors, the rotating shaft of the stator and rotor is no longer coincident, and the magnetic field between the inner and outer magnetic poles is no longer axisymmetric. In addition to the axial force between the stator and the rotor, there is a radial force opposite to the radial displacement. Pointing to the axis of the stator, the role is to return the rotor to the equilibrium position. Axial magnetic bearings control the current in the coil, change the magnetic induction strength of the air gap magnetic field, control the axial force and radial force, and realize the axial and radial suspension of the rotor.

III. MAGNETIC CIRCUIT MODEL OF DOUBLE ANNULAR MAGNETIC POLE AXIAL MAGNETIC BEARING

According to the double annular magnetic pole axial magnetic bearing structure shown in Fig.1, Fig.2 is an equivalent magnetic circuit diagram, which mainly considers the air gap magnetoresistance, ignoring the magnetic resistance of the core material, mainly considering the air gap at both ends of the pole and side Magnetic flux leakage between other magnets is ignored.

Fig.2 Double annular magnetic axial magnetic bearing equivalent magnetic circuit



In the picture, G_{in} is air gap magnetic surface between inner pole faces, G_{inc} is Leakage between the inner side of the magnetic pole. G_{1c},G_{2c} is the leakage magnetic flux between the double annular magnetic pole sides, respectively.

According to the calculation formula of air gap permeance, the expression for the magnetic permeability of each part is:

$$G_{in} = \mu_0\left(\frac{\pi R_1^2}{g} + 1.26R_1\right) \tag{1}$$

$$G_{inc} = \frac{2u_0R_1L}{0.22g + 0.4L} = 3.92u_0R_1 \tag{2}$$

$$G_1 = \mu_0\left[\frac{\pi(R_2+t)^2 - \pi R_2^2}{g} + 1.26(2R_2+t)\right] \tag{3}$$

$$G_2 = \mu_0\left[\frac{\pi R_3^2 - \pi(R_3-t)^2}{9} + 1.26(2R_3-t)\right] \tag{4}$$

$$G_{1c} = 3.92\mu_0(2R_2+t) \tag{5}$$

$$G_{2c} = 3.92\mu_0(2R_3-t) \tag{6}$$

Where R_1 is the inner magnetic pole outer diameter, R_2

and R_3 are the outer magnetic pole inner and outer diameters respectively,g is the length of the air gap,t is the radial thickness of a single annular magnetic pole, andμ_0 is the vacuum permeability.

The magnetic conductance of the inner and outer magnetic poles is：

$$G_i = \mu_0\left(\frac{\pi R_1^2}{g} + 5.18R_1\right) \tag{7}$$

$$G_0 = \mu_0(R_2 + R_3)\left(\frac{2\pi t}{9} + 5.18\right) \tag{8}$$

When the radial displacement is r，the gap g can be expressed as：

$$g = \sqrt{z^2 + r^2} \tag{9}$$

In the formula, z is the axial distance between the rotor and the stator；r is the radial relative displacement between the stators of the rotor.

The total magnetic flux Ga of the magnetic circuit is obtained according to the parallel relationship between each series of magnetic fluxes in the magnetic circuit and equations (1)-(9):

$$G_a = \frac{1}{\frac{1}{\mu_0\left(\frac{\pi R_1^2}{g}+5.18R_1\right)}+\frac{1}{\mu_0(R_2+R_3)\left(\frac{2\pi t}{g}+5.18\right)}} \tag{10}$$

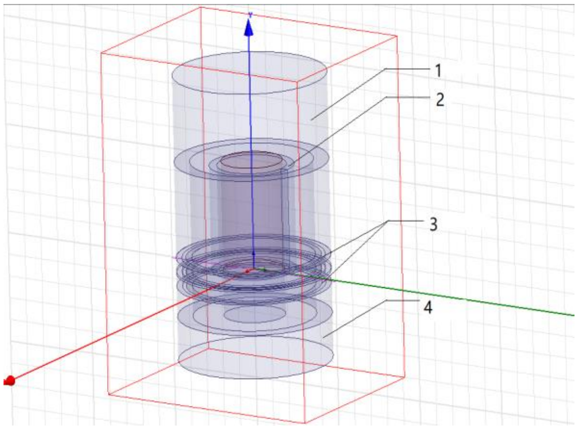
When the current i is applied to the coil, the magnetic flux of the magnetic circuit is Fm=Ni, so the total magnetic flux of the magnetic circuit is：

$$\Phi = F_m G_a = \frac{Ni}{\frac{1}{\mu_0\left(\frac{\pi R^4}{g}+5.18R_1\right)}+\frac{1}{\mu_0(R_2+R_3)\left(\frac{2\pi t}{g}+5.18\right)}} \tag{11}$$

According to the formula (11), compared with the conventional magnetic bearing, the inner magnetic conductance of the double-ring magnetic magnetic bearing does not change, the outer magnetic pole is changed from the original single-ring magnetic pole to the double-ring magnetic pole, and the outer magnetic conductance becomes smaller, so the total Magnetic flux becomes smaller. At the same magnetomotive force, the magnetic flux of the annular magnetic bearing decreases.

IV. FINITE ELEMENT SIMULATION OF MAGNETIC FIELD OF DOUBLE ANNULAR MAGNETIC AXIAL MAGNETIC BEARING

The three-dimensional model of the axial magnetic bearing is constructed in finite element analysis software. As shown in Fig.3, it is mainly divided into four parts: stator core, stator coil, ring-shaped magnetic pole surface and rotor core, and its magnetic field is simulated. For comparison, the simulation and comparative analysis of a conventional single-loop magnetic pole axial magnetic bearing and multiple sets of double-ring magnetic pole magnetic bearings with different annular magnetic pole widths were performed.



1-Stator core 2-Stator coil 3-Ring surface 4-Rotor core
Fig.3 Double annular magnetic pole axial magnetic bearing finite element simulation model

The parameters of the axial magnetic bearing constructed except for the parameters of the outer ring-shaped magnetic pole surface are the same. The other parameters are the same. The specific parameters are shown in Table 1.

Tab.1 Ring magnetic pole magnetic bearing structure parameters

Structural parameters	Value			
	Conventional single-ring magnetic axial magnetic bearing	Double ring magnetic pole magnetic bearing 1	Double ring magnetic pole magnetic bearing 2	Double ring magnetic pole magnetic bearing 3
Inner pole radiusR1/mm	8	8	8	8
Outside pole diameterR2/mm	16	16	16	16
Outside pole diameterR3/mm	20	20	20	20
Ring magnetic radial widtht/mm	无	1.5	1	0.5
Rotor core axial length /mm	20	20	20	20
Rotor core groove depth /mm	10	10	10	10
Stator core axial length /mm	45	45	45	45
Stator core groove depth /mm	25	25	25	25
Number of solenoid coils	400	400	400	400
Coil maximum currentImax/A	10	10	10	10
Axial air gapg/mm	0.5	0.5	0.5	0.5
Radial displacement △r/mm	0.5	0.5	0.5	0.5

A. Magnetic circuit distribution and finite element simulation of double annular magnetic pole axial magnetic bearing

In the finite element simulation software Maxwell, using the double-ring magnetic pole magnetic bearing 1 as an example, the simulation model is shown in Fig.4. In the figure, the spatial distribution of the magnetic field loop can be clearly seen. The magnetic flux passes through the stator core, air gap and rotor. The core forms a magnetic circuit, and the magnetic flux leakage is mainly distributed between the inner and outer magnetic pole surfaces and the stator core.

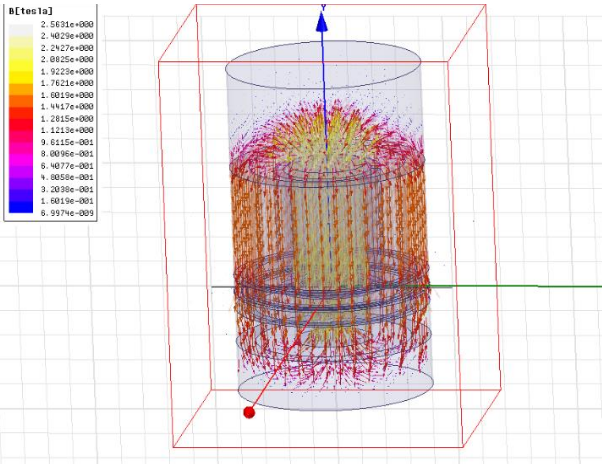
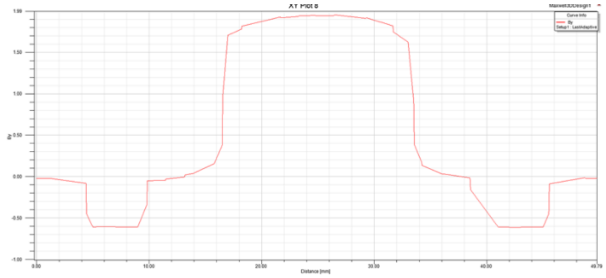
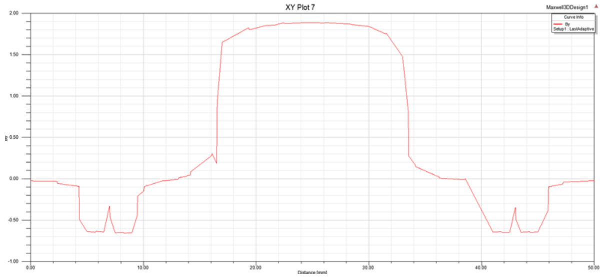


Fig.4 Magnetic Field Spatial Distribution of Simulation Model of Double Annular Magnetic Axial Magnetic Bearing 1

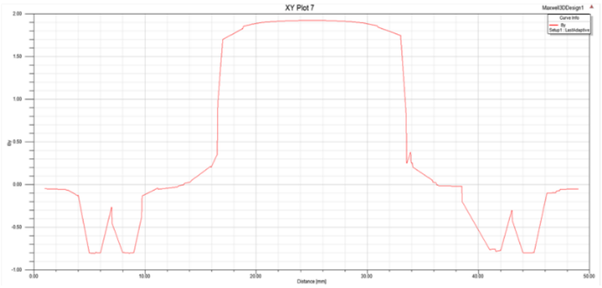
In the finite element simulation software, simulate the traditional single-ring magnetic magnetic bearing and double-ring magnetic axial magnetic bearing simulation respectively, observe the axial component of air gap magnetic induction of the inner magnetic pole and the outer magnetic pole when there is no radial displacement, and There is an axial component and a radial component of the magnetic flux density of the air gap when it is radially displaced, and then a comparative analysis is performed. The axial component of the air gap magnetic induction strength of the conventional magnetic bearing and the annular magnetic pole magnetic bearing 1, 2, 3 without radial shift is shown in Fig. 5.



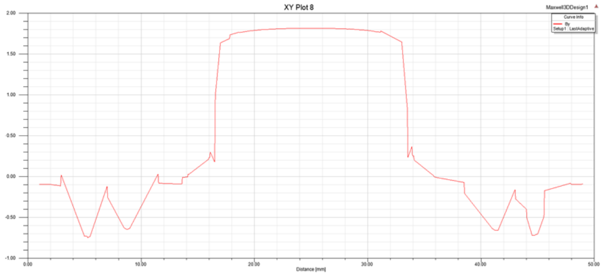
(a) Conventional single-ring magnetic axial magnetic bearing



(b) Double ring magnetic pole magnetic bearing 1



(c) Double ring magnetic pole magnetic bearing 2



(d) Double ring magnetic pole magnetic bearing 3

Fig.5 Axial component of magnetic induction in air gap of axial magnetic bearing without radial displacement Spatial variation curve

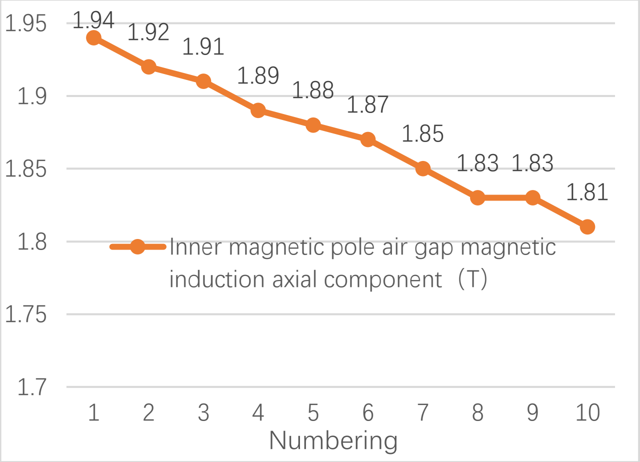
According to Fig.5, the axial component of the magnetic flux density of the air gap of the conventional single-ring magnetic pole axial magnetic bearing and the three-ring magnetic pole axial magnetic bearing with three different magnetic pole widths can be obtained. A good conclusion is that between the conventional single-ring magnetic bearing and the double-ring magnetic pole magnetic bearing 1, between the double-ring magnetic pole magnetic bearing 1 and the double-ring magnetic pole magnetic bearing 2, the double-ring magnetic pole magnetic bearing 2 Several simulation experiments were performed between the double-ring magnetic magnetic bearing 3 and the specific experimental data shown in Tab.2.

Tab.2 Axial component simulation data of air gap magnetic induction without radial displacement

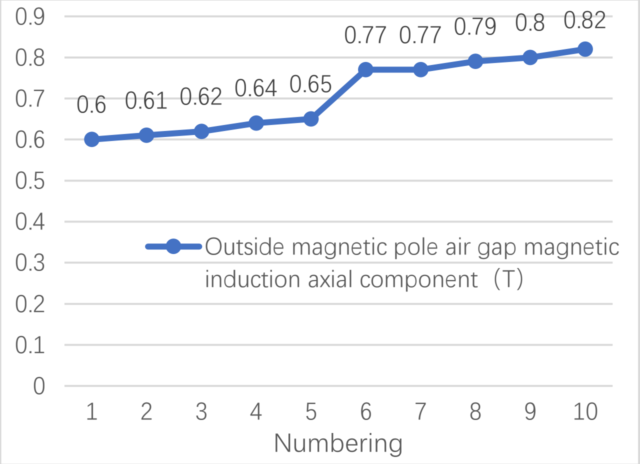
Numbering	Magnetic bearing type (pole width)	Inner magnetic pole air gap magnetic induction axial component （T）	Outside magnetic pole air gap magnetic induction axial component （T）
1	**Conventional single-ring magnetic axial magnetic bearing**	1.94	0.6

2	Double ring magnetic pole（1.85mm）	1.92	0.61
3	Double ring magnetic pole（1.75mm）	1.91	0.62
4	Double ring magnetic pole（1.65mm）	1.89	0.64
5	**Double ring magnetic pole 1（1.5mm）**	1.88	0.65
6	Double ring magnetic pole（1.25mm）	1.87	0.77
7	Double ring magnetic pole（1.15mm）	1.85	0.77
8	**Double ring magnetic pole 2（1.0mm）**	1.83	0.79
9	Double ring magnetic pole（0.75mm）	1.83	0.80
10	**Double ring magnetic pole 3（0.5mm）**	1.81	0.82

According to the experimental data shown in Table 2, the axial component of the inner magnetic pole and the outer magnetic pole of the magnetic gap without magnetic displacement under radial displacement is shown in Fig. 6 as a variation of the magnetic pole width.



(a) Inner magnetic pole air gap magnetic induction axial component

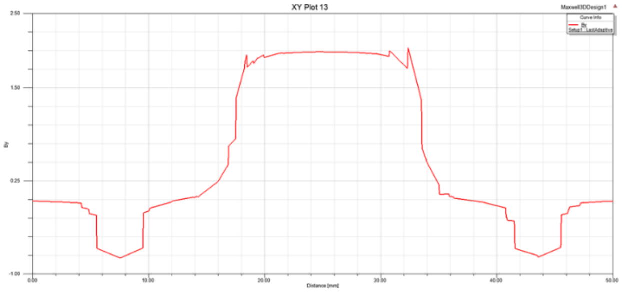


(b) Outside magnetic pole air gap magnetic induction axial component

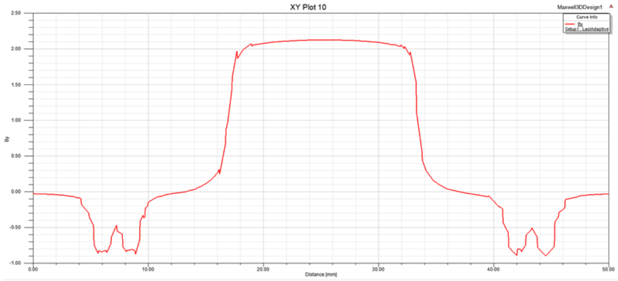
Fig. 6 Variation of the axial component of the inner magnetic pole and the outer magnetic pole of the air gap magnetic induction without radial displacement

From the four simulation charts in Fig.5 and the data in Tab.2 and the line graph in Fig.6, we can see that the axial component of the magnetic induction intensity is mainly distributed on the magnetic pole surface, and the axial component on the same magnetic pole surface remains basically unchanged. It is approximately zero at the non-pole surface. With the same magnetomotive force and axial clearance, as the annular magnetic pole width of the axial magnetic bearing increases, the axial magnetic gap magnetic induction intensity of the inner magnetic pole decreases continuously, and the axial air gap of the outer magnetic pole decreases. Magnetic induction continues to increase. This is because the design of the annular magnetic pole makes the total magnetic conductance of the magnetic circuit decrease, the total magnetic flux decreases, and the area of the inner magnetic pole does not change, so that the axial magnetic gap magnetic induction intensity of the inner magnetic pole is reduced, and the area of the outer magnetic pole is also reduced. The decrease and the total magnetic flux decrease cause the axial magnetic induction intensity component at the annular magnetic pole to increase and increase as the thickness of the annular magnetic pole decreases.

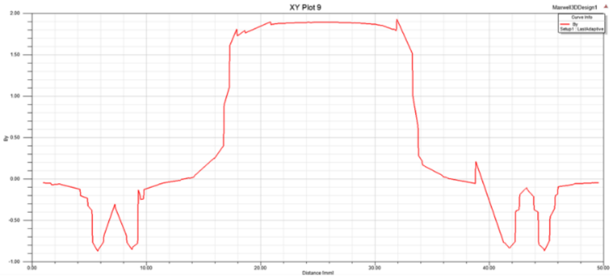
When radial displacement occurs (r=0.5mm)， The axial air gap magnetic induction intensity curve of the conventional axial magnetic bearing, double annular magnetic pole 1, double annular magnetic pole 2 and double annular magnetic pole 3 is shown in Fig.6.



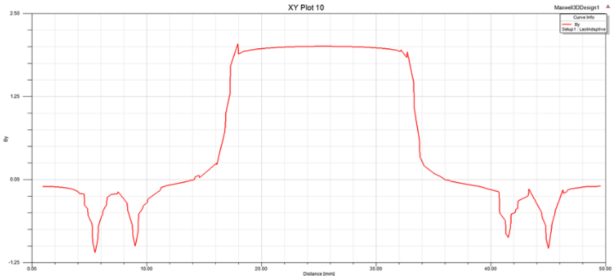
(a)Traditional magnetic bearings



(b)Double ring magnetic pole magnetic bearing 1



(c)Double ring magnetic pole magnetic bearing 2

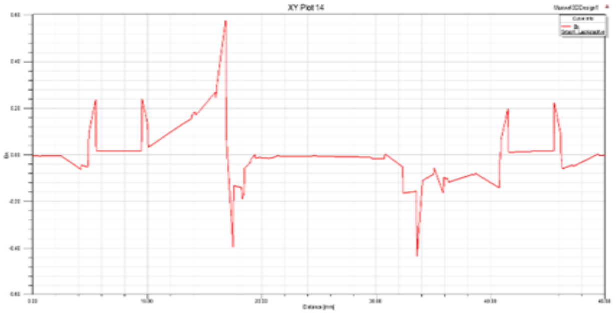


(d)Double ring magnetic pole magnetic bearing 3

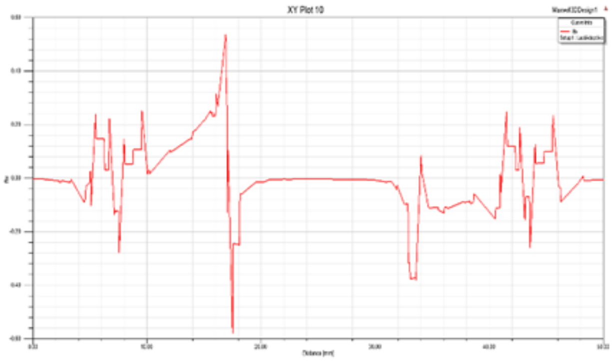
Fig.7 Spatial variation of axial component of air gap magnetic induction in the presence of radial displacement

Comparison between Fig.7 and Fig.5 shows that when there is a radial displacement, the axial component of the magnetic flux density of the air gap on both the inner magnetic pole surface and the outer magnetic pole surface is basically constant with no radial displacement, but increases with the radial displacement. Small peaks appear at the edges of the magnetic poles, and the annular magnetic poles also become sharp. This is due to the fact that the radial displacement results in a reduction of the positive area of the magnetic pole and a decrease in the ratio of the axial magnetic flux between the magnetic poles.

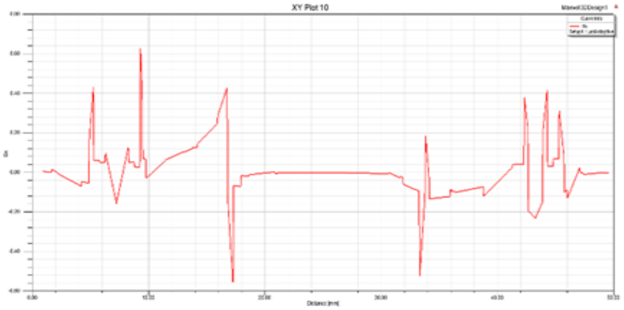
In the presence of radial displacement (r = 0.5 mm), the radial component of the air gap magnetic induction for conventional single annular magnetic pole axial magnetic bearings, double annular pole 1, double annular magnetic pole 2 and double annular magnetic pole 3 For simulation analysis, the direction of spatial change is radial displacement direction. The simulation results are shown in Fig.8.



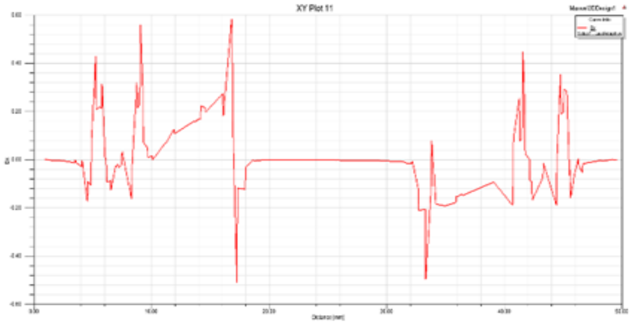
(a)Traditional magnetic bearings



(b)Double ring magnetic pole magnetic bearing 1



(c)Double ring magnetic pole magnetic bearing 2



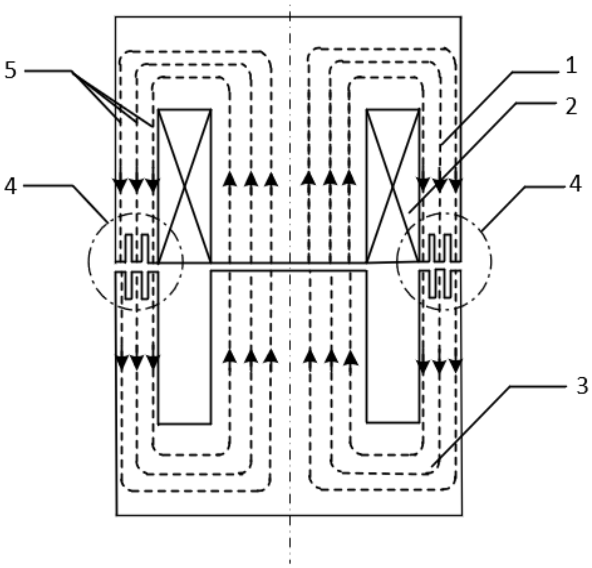
(d)Double ring magnetic pole magnetic bearing 3

Fig.8 Spatial variation of radial component of air gap magnetic induction

It can be seen from Fig.8 that the radial component of the air gap magnetic induction intensity is mainly distributed at the magnetic pole edge. The radial component of the air gap magnetic field of the conventional single annular magnetic pole magnetic bearing is mainly distributed on the outer edge of the inner magnetic pole, the inner and outer edges of the outer magnetic pole, and on the magnetic pole surface. The right part is almost zero. In addition to the above parts, the double-ring magnetic pole bearings 1, 2, and 3 also have a relatively strong radial magnetic induction intensity distribution at the edge of the annular magnetic pole. As can be seen from the four figures in the figure, when a radial displacement (0.5 mm) occurs The double annular magnetic poles obviously increase the magnetic flux density of the air gap between the outer magnetic poles in the radial direction. It can be seen that the double annular magnetic poles will increase the radial bearing capacity of the axial magnetic bearing.

B. *Comparison and Analysis of Axial Magnetic Bearings with Double-Ring and Three-Ring Magnetic Pole*

In order to investigate the influence of the number of annular magnetic poles on the magnetic flux density of the axial magnetic bearing, the number of annular magnetic poles is increased to three under the condition that the area of the annular magnetic pole surface is constant, as shown in Fig.9. As shown.



1-Stator core 2-Coil 3-Rotor core 4-Tricyclic magnetic pole 5-Magnetic flux

Fig.9 Schematic diagram of an axial magnetic bearing with double annular magnetic poles

Fig. 10 shows the comparison of the structure of three-ring magnetic poles and double-ring magnetic poles of structure 4. t1, t2, t3 are the radial widths of three annular magnetic poles respectively. Other conditions are the same as before, and the previous simulation experiments are performed respectively. Measure the axial component of the air gap magnetic induction and the radial component of the air gap magnetic induction when the radial displacement occurs. Analyze the experimental results.

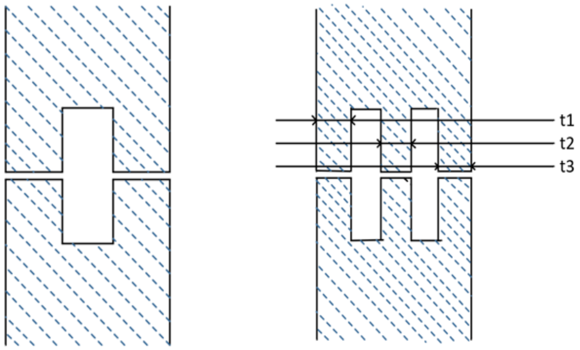


Fig.10 Comparison of the number of ring-shaped magnetic poles 2 and 3

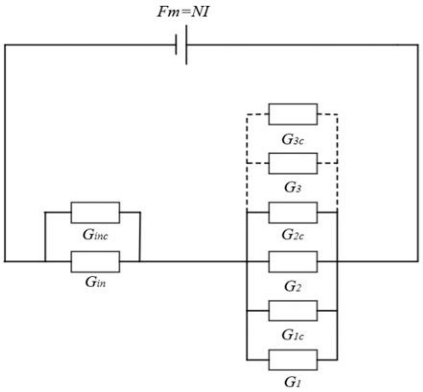


Fig.11 Magnetic circuit model when the number of ring magnetic poles is 3

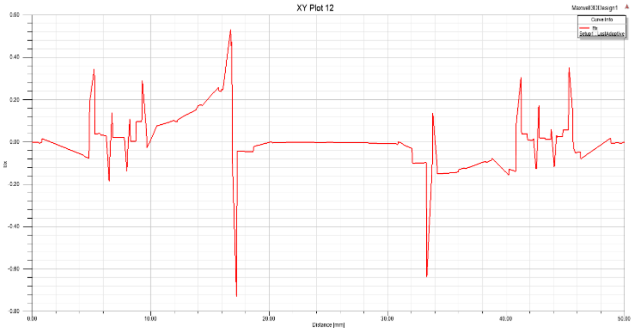
By comparing the axial component of the magnetic induction axial force of the double-ring magnetic pole and the triple-ring magnetic pole axial bearing, the experimental data shown in the following Tab.3 are obtained.

Tab. 3 Axial magnetic bearing axial component experimental data of 2 and 3 annular magnetic poles

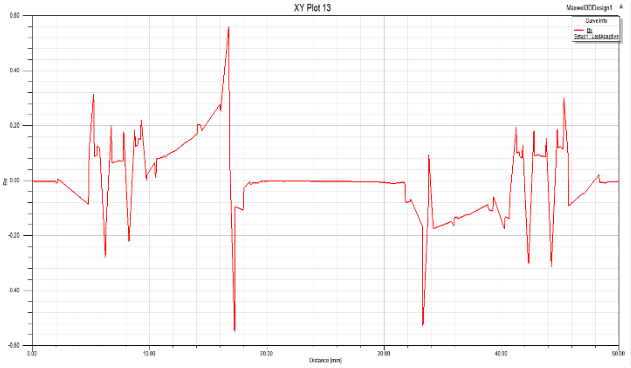
Double annular magnetic axial magnetic bearing	Inner pole （T）	Outside magnetic pole （T）
Double ring magnetic pole magnetic bearing 1	1.88	0.65
Double ring magnetic pole magnetic bearing 2	1.83	0.79
Double ring magnetic pole magnetic bearing 3	1.81	0.82
Three-ring magnetic axial magnetic bearing（t1 t2 t3/mm）		
Three ring magnetic pole magnetic bearing 1（1 1 1）	2.31	0.86
Three ring magnetic pole magnetic bearing 2（0.5 1 0.5）	1.89	0.81
Three ring magnetic pole magnetic bearing 3（0.25 0.5 0.25）	1.84	0.85

From Tab.3, it can be concluded that when the other conditions are unchanged and the number of magnetic poles is increased from 2 to 3 without changing the area of the magnetic pole, the axial magnetic bearing magnetic induction intensity of the inner magnetic pole or the outer magnetic pole is the same. The axial components all have different degrees of increase. This is because when the number of annular magnetic poles is increased, the magnetic circuit model is changed as shown in Fig. 11 below. Among them, G_1, G_2, and G_3 are the magnetic conductances between the ring-shaped magnetic pole faces, and G_{1c}, G_{2c}, and G_{3c} are the leakage magnetic guides between the annular magnetic pole sides, and it can be seen that increasing the number of the annular magnetic poles increases the total magnetic conductance of the magnetic circuit, making The magnetic flux of the magnetic circuit increases, and finally the axial component of the magnetic induction intensity of the inner magnetic pole and the outer magnetic pole increases, and as can be seen from the magnetic circuit model, the annular magnetic poles are ensured with the magnetic pole surface area constant and the manufacturing process permitting. The more the number is, the greater the axial component of the magnetic induction intensity of the side magnetic pole and the outer magnetic pole is, ie, the greater the axial bearing capacity of the axial magnetic bearing.

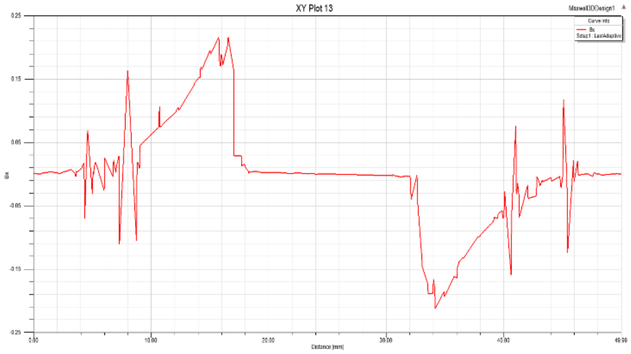
In order to investigate and compare the radial bearing capacity (0.5 mm) of the radial displacement of the three-ring magnetic axial magnetic bearing and the double-ring magnetic axial magnetic bearing, three types of three-ring magnetic poles shown in Table 3 The bearing is subjected to a simulation analysis and then the magnitude of the radial strength of the magnetic induction is compared.The simulation results are shown in Figure 12 below.



(a)Three ring magnetic pole magnetic bearing 1



(b)Three ring magnetic pole magnetic bearing 2



(c)Three ring magnetic pole magnetic bearing 3

Fig.12 Spatial variation of radial component of air gap magnetic Induction

By comparing Figs. 12 and 8(b)(c)(d), it can be seen that the three-ring magnetic pole is significantly larger than the ratio of the magnetic flux between the outer magnetic poles of the double-ring magnetic poles with the magnetic pole area unchanged. The specific data is shown in Table 4 below.

Tab.4 Radial component of magnetic flux density of double-loop magnetic pole and triple-ring magnetic pole

	Radial component of air gap magnetic induction （T）		Radial component of air gap magnetic induction （T）
Double ring magnetic pole 1	0.032	Tricyclic magnetic pole 1	0.029
Double ring magnetic pole 2	0.041	Tricyclic magnetic pole 2	0.036
Double ring magnetic pole 3	0.053	Tricyclic magnetic pole 3	0.046

By comparing the axial component and the radial component of the magnetic flux density of the air gap of the double-ring magnetic pole axial magnetic bearing and the three-ring magnetic pole axial magnetic bearing of Table 3 and Table 4, it can be concluded that the magnetic pole area remains unchanged. Compared with the three-ring magnetic pole axial magnetic bearing, the axial component of the air gap magnetic induction strength is correspondingly reduced, the radial component is correspondingly increased, and as the magnetic pole area is reduced, The radial component of the magnetic flux density of the air gap gradually increases, that is, the three-ring magnetic pole has better radial bearing characteristics than the double-ring magnetic pole.

V. CONCLUSION

In this paper, the simulation and analysis of the air-gap magnetic field distribution of the double-ring magnetic pole axial magnetic bearing and the three-ring magnetic pole axial magnetic bearing is carried out, and the magnetic properties of the double-ring magnetic pole axial magnetic bearing and the triple-ring magnetic pole magnetic bearing are established. Based on the road model, the effect of the annular magnetic pole on the air gap permeability and the total magnetic flux of the magnetic circuit was analyzed. Afterwards, the three-dimensional finite element simulation was used to obtain the spatial distribution of the magnetic flux density of the air gap magnetic field, and the axial and radial components of the air gap magnetic induction intensity were obtained. The results showed that the annular magnetic pole reduced the axial component of the magnetic induction intensity at the inner magnetic pole. The axial component and the radial component of the magnetic induction at the outer annular magnetic pole both increase, the proportion of the axial magnetic flux between the magnetic poles decreases, and the proportion of the fringe magnetic flux in the total air gap magnetic flux increases. At the same time, the two-ring magnetic pole and the three-ring magnetic pole axial magnetic bearing are compared and analyzed. Through the establishment of the magnetic circuit model and the finite element simulation analysis, it is concluded that the magnetic pole surface area is not changed and the manufacturing process is allowed. Under the double-circle magnetic pole axial magnetic bearing and the three-ring magnetic axial magnetic magnetic bearing, the axial component of the magnetic induction strength of the inner magnetic pole and the outer magnetic pole is reduced, that is, the axial bearing capacity is reduced, but radial displacement occurs. At this time, the radial component of the air gap magnetic induction will increase. The annular magnetic pole is beneficial to enhance the radial support characteristics of the axial magnetic bearing, and provides theoretical and experimental basis for the radial suspension of the axial magnetic bearing.

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