Principle and Performance Analysis for Heterpolar Permanent Magnet Biased Radial Hybrid Magnetic Bearing

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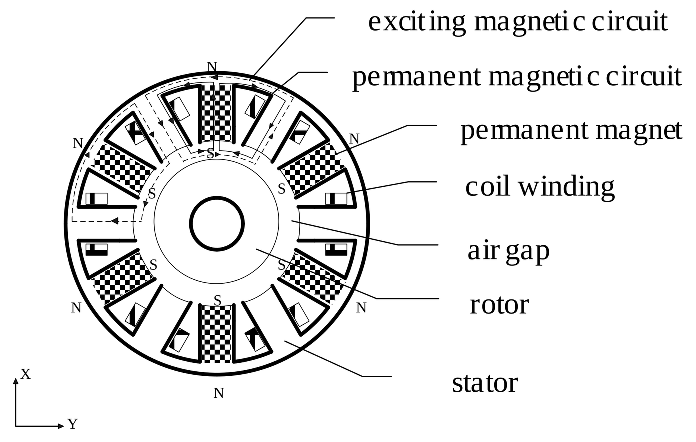
Background

Magnetic bearings are a kind of supporting device which use maxwell force to suspend the rotor stably in the balance position. The magnetic bearings have no mechanical contact between the rotor and the bearing, and have the advantages of no friction, no wear, no lubrication, no pollution, high speed, high precision, and so on. Although the inverter-fed three-pole magnetic bearing has many advantages, effective nonlinear decoupling control method must be used to realize the high performance operation, and it also increases the overall design difficulty and cost of the system. In order to solve the nonlinear problem and strong coupling of three-pole magnetic bearings, a heterpolar permanent magnet biased radial structure is proposed.

Heterpolar Permanent Magnet Radial Hybrid Magnetic Bearing

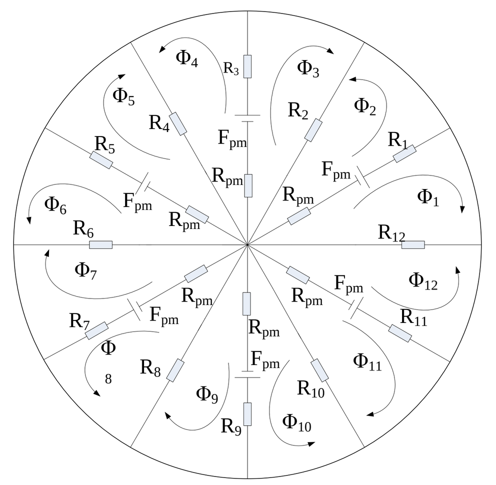
Operation Principle

- The Heterpolar Permanent Magnet Radial Hybrid Magnetic Bearing is mainly composed of a permanent magnet, stator, radial control coils and rotor.

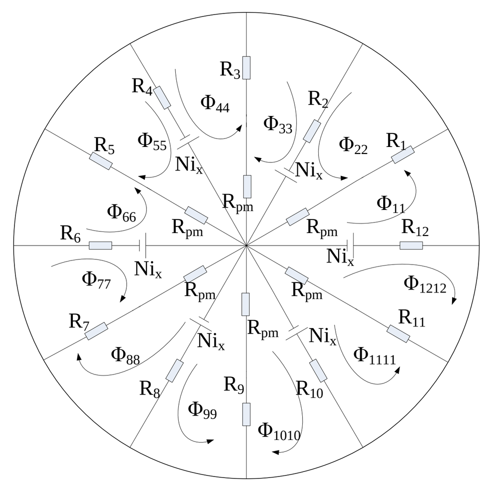


- The magnetic flux consists of bias flux and control flux, which are generated by the permanent magnet and the electrification of the control coils, respectively.

Mathematical Model



(a)the path of permanent magnetic circuit

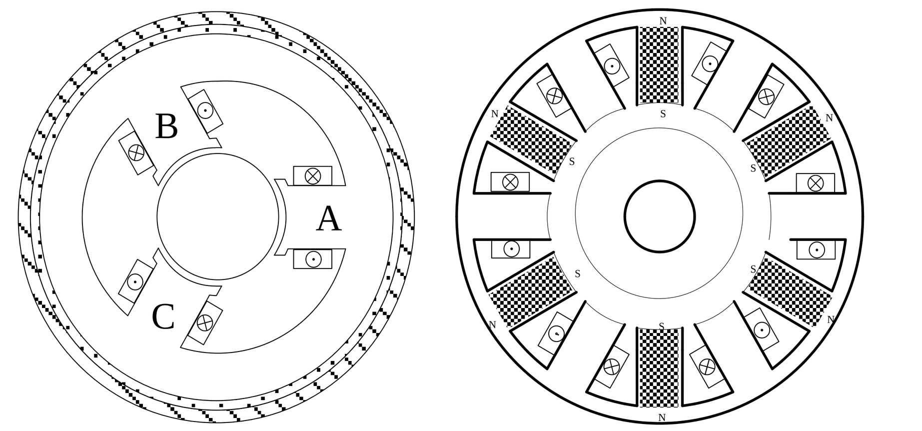


b)the path of electric magnetic circuit

Radial suspension forces can be expressed as follows:

$$\begin{cases} F_x = \dfrac{\Phi_{c1}^2 + \frac{1}{2}\Phi_{c2}^2 + \frac{1}{2}\Phi_{c6}^2 - \Phi_{c4}^2 - \frac{1}{2}\Phi_{c3}^2 - \frac{1}{2}\Phi_{c5}^2}{2\mu_0\delta} \\ F_y = \dfrac{\frac{\sqrt{3}}{2}\Phi_{c2}^2 + \frac{\sqrt{3}}{2}\Phi_{c3}^2 - \frac{\sqrt{3}}{2}\Phi_{c5}^2 - \frac{\sqrt{3}}{2}\Phi_{c6}^2}{2\mu_0\delta} \end{cases}$$

Comparative Analysis of Three-pole Structure and heterpolar permanent magnet biased radial Structure



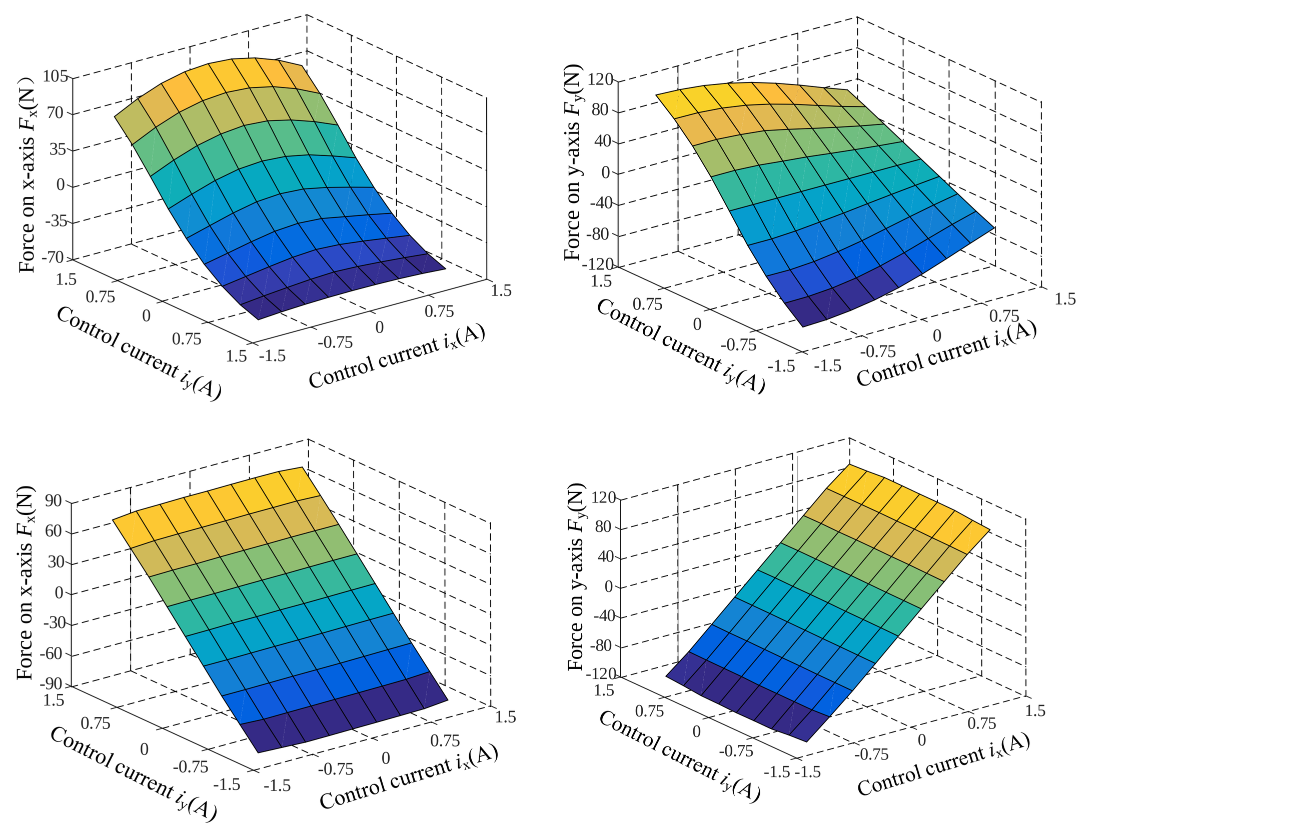
Structure contrast of three-pole and heterpolar permanent magnet biased radial

Maximum Suspension Force In Each Direction

Bearing capacity direction	three-pole structure	Suspension Force of heterpolar structure
Positive direction of x-axis	$\frac{15B_S{}^2S_r}{16\mu_0}$	$\frac{3B_S{}^2S_r}{4\mu_0}$
Negative direction of x-axis	$\frac{9B_S{}^2S_r}{16\mu_0}$	$\frac{3B_S{}^2S_r}{4\mu_0}$
y-axis	$\frac{\sqrt{3}B_S{}^2S_r}{2\mu_0}$	$\frac{\sqrt{3}B_S{}^2S_r}{2\mu_0}$

The maximum bearing capacity of the heterpolar permanent magnet biased radial structure is increased by 33.3% compared with that of the couple-piece type three-pole structure.

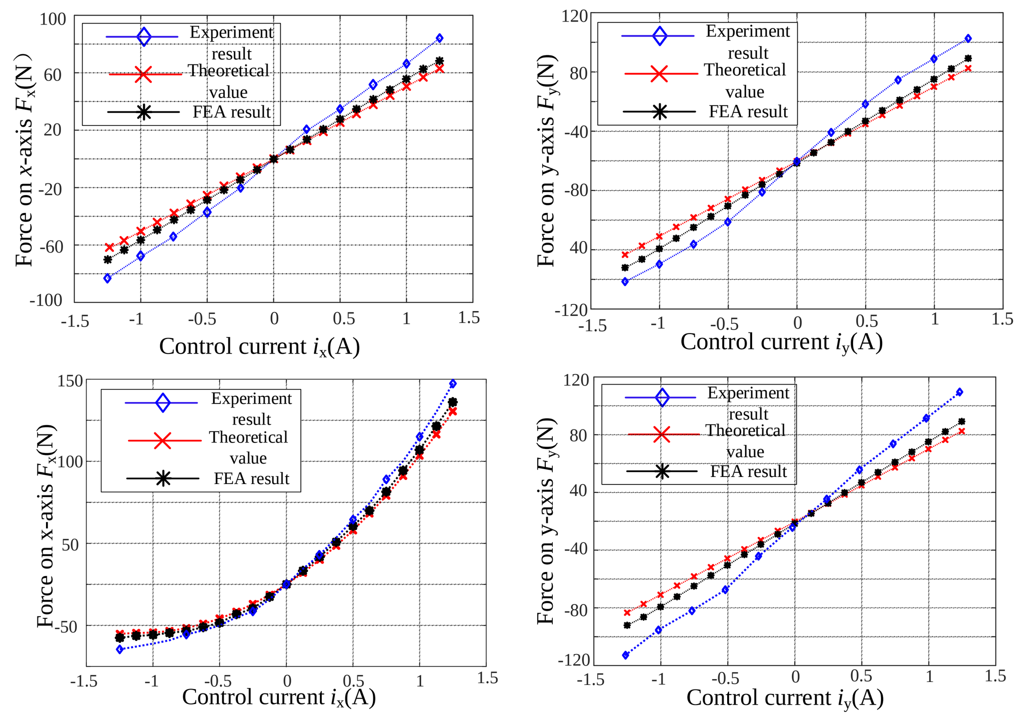
Simulations



Because of the spatial asymmetry in the couple-piece type three-pole structure, the force-current characteristic curve in the x-direction is not centrosymmetric. And the symmetry of the y-axis makes that its force-current characteristic curve is symmetric with the center point. However, the linearity of the force-current characteristic curve of x-axis and y-axis is very poor.

The heterpolar permanent magnet biased radial structure benefits from the symmetry of its spatial structure. The force-current characteristic curves of the x-axis and y-axis are symmetric and have good linearity, which verifies the validity of the theoretical analysis.

Experiments



The maximum suspension force of magnetic bearings is determined by the minimum of the maximum suspension force, so the maximum bearing capacity of the three-pole structure is 72 N, and the heterpolar permanent magnet biased radial structure is 91 N. Therefore, through the experiment, the maximum bearing capacity of the heterpolar permanent magnet biased radial structure is increased by 26.3% compared with the three-pole structure, which verifies the validity of the theoretical analysis.

Conclusions

In view of the asymmetry of the three-pole structure, a heterpolar permanent magnet biased radial structure is studied. According to the theory analysis, finite element analysis and verification experiments, the conclusions can be drawn as follows:

The characteristic curves between the suspension force and the control current are obtained by experiments, and compared with the finite element analysis results and the theoretical value. The experimental results show that there is a linear relationship between the suspension force Fx, Fy and the control current ix, iy in the heterpolar permanent magnet biased radial structure, and the experimental results are consistent with the theoretical analysis and the simulation results.

In the case of the same volume and the same ampere-turns, the maximum bearing capacity of the heterpolar permanent magnet biased radial structure is 26.3% higher than that of the three-pole structure, and the unit volume utilization ratio of the magnetic bearing is improved.