Design of an Axial Electric Pump with Permanent Magnetic Levitation

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Abstract

A new axial electric pump with permanent magnetic levitation was presented. First the basic structure, working principle and characteristic of the axial electric pump are introduced. Then the generation of magnetic suspension force, electromagnetic torque and axial force of the motor pump was analyzed. The research results may provide a theoretical foundation for the electromagnetism design of axial induction motor pump.

Keywords: permanent magnet, magnetic levitation, axial electric pump, electromagnetism design.

1. Introduction

With the development of the world economy and the increasing of people's living standards, electric pump has entered into people's work and life widely. Compared with other structural pumps, such as plunger pump, centrifugal pump, gear pump, rotary plate pump, etc., the electric pump has compact structure, excellent performance, low vibration and noise, long life and other characteristics. The electric pump is mainly composed of three parts: the pump body, the permanent magnet motor and the outer shell. The working principle of the permanent magnet motor is that after the permanent magnet motor is electrified, the pump body is rotated, and the liquid is sucked from the inlet, then flows through the inner part of the electric pump, and then is pressed out from the outlet to achieve the working control of liquid flow rate and pressure.

The electric pump common uses ordinary bearings. These bearings can reduce the friction and heat phenomenon in the rotation process, but they cannot completely eliminates the power loss of bearing friction, component wear, component heat and other adverse factors, and it is difficult to achieve high-speed running requirements. So a novel axial electric pump is proposed, which use the

permanent magnetic bearings to replace the ordinary bearings for supporting the electric pump. Therefore, in addition to the advantages of ordinary electric pumps, electric pump with magnetic levitation could also eliminate friction and wear of supporting rotor, and has no need of lubrication, no pollution and long service life, so it can improve the speed and output power. Now the magnetic bearings have been successfully applied to high-speed and ultra-high-speed rotary machine, such as ultra-high speed camera, cutting machine and faster centrifuge. It has also been widely applied to centrifugal compressors, pumps, driving motors, steam turbines and gas turbines ^[1].

2. Basic Structure of the Axial Electric Pump with Permanent Magnetic Levitation

The axial electric pump with permanent magnetic levitation is mainly composed of permanent magnetic bearings, axial motor, pump, mechanical seal devices and so on, which is shown in Figure 1. The permanent magnet bearings support the rotating shaft, and the axial motor outputs the torque, which is composed of rotor shaft, rotor disc and two stators. Two stators are installed symmetrically on both sides of the rotor disc. The rotor disc is shown in Figure 2, and the stator is shown in Figure 3.

Fig. 1 structure profile of the axial electric pump with permanent magnetic levitation

Fig. 2 the rotor disc

Fig. 3 the stator

3. Mechanism Analysis of the Axial Electric Pump with Permanent Magnetic Levitation

3.1 The Radial Force and Axial Force of Permanent Magnetic Bearings

The axial electric pump with permanent magnetic levitation uses two pairs of permanent magnet bearings to achieve radial support. According to the literature 2, the selection of axial magnetized permanent magnet bearings is better than radial magnetized permanent magnetic bearings, and permanent magnetic bearings can provide an axial force by biased the permanent magnetic ring pairs. The permanent magnetic bearing structure is shown in Figure 4.

Fig. 4 structure diagram of permanent magnetic bearings

If the radial permanent magnet bearings have axial displacement, and at the same time the radial displacement occurs. Because the radial clearance between permanent magnet rings is no longer uniform, the radial force and axial force can be calculated by magnetic charge method. While any point magnetic charge on the inner surface of the outer magnetic ring and any point magnetic charge on the outer surface of the inner magnetic ring are selected, the interaction force between the two magnetic charges is ^[3]:

$$dF = \frac{(\sigma_1 r_1 d\beta dr_1) \cdot (\sigma_2 r_3 d\alpha dr_3)}{4\pi\mu_0 |r|^3} \cdot r \quad (1)$$

Where σ_1 and σ_2 are the magnetic charge density on the end surface of the outer magnetic ring and the inner magnetic ring. α and β are the polar coordinates of any point charge on the end surface 1 and 3. μ_0 is vacuum permeability. r_1 is the radius vector of any point on the end surface 1 of the outer magnetic ring, and r_3 is the radius vector of any point on the end surface 3 of the inner magnetic ring. R_1 and R_2 are the outer diameter and inner diameter of the outer magnetic ring, and R_3 and R_4 are the outer diameter and inner diameter of the inner magnetic ring. d is the offset. e is the radial clearance. h is the width of ring. r is the radius vector between two point magnetic loads.

The axial coordinate axis is selected as the X axis, and the projection in the direction of the X of the force between the end surface 1 of the outer magnetic ring and the end surface 3 of the inner magnetic ring is F_{13}^x , which is calculated by the formula 2.

$$F_{13}^x = \frac{\sigma_1 \sigma_2}{4\pi\mu_0} \int_0^{2\pi} \int_0^{2\pi} \int_{R_2}^{R_1} \int_{R_4}^{R_3} \frac{-x_0 r_1 r_3}{|r_{13}|^3} d\alpha d\beta dr_1 dr_3 \quad (2)$$

Where $|r_{13}| = \sqrt{(-x_0)^2 + (e \cos \theta + r_3 \cos \alpha - r_1 \cos \beta)^2 + (e \sin \theta + r_3 \sin \alpha - r_1 \sin \beta)^2}$, x_0 is the axial displacement of the inner magnetic ring to the outer magnetic ring. θ is the angle that the inner magnetic ring deviates from the outer magnetic ring in the radial coordinate axis Y. r_{13} is the radius vector from 1 to 3.

In the same way, the projection in the direction of the X of the force between the end surface 1 of the outer magnetic ring and the end surface 4 of the inner magnetic ring is as following:

$$F_{14}^x = \frac{\sigma_1 \sigma_2}{4\pi\mu_0} \int_0^{2\pi} \int_0^{2\pi} \int_{R_2}^{R_1} \int_{R_4}^{R_3} \frac{-(l+x_0) r_1 r_4}{|r_{14}|^3} d\alpha d\beta dr_1 dr_4 \quad (3)$$

Where r_4 is the radius vector of any point on the end surface 4 of the inner magnetic ring. r_{14} is the radius vector from 1 to 4.

The projection in the direction of the X of the force between the end surface 2 of the outer magnetic ring and the end surface 4 of the inner magnetic ring is as following:

$$F_{23}^x = \frac{\sigma_1 \sigma_2}{4\pi\mu_0} \int_0^{2\pi} \int_0^{2\pi} \int_{R_2}^{R_1} \int_{R_4}^{R_3} \frac{-(l-x_0) r_2 r_3}{|r_{23}|^3} d\alpha d\beta dr_2 dr_3 \quad (4)$$

Where r_2 is the radius vector of any point on the end surface

2 of the outer magnetic ring. r_{23} is the radius vector from 2 to 3.

The projection in the direction of the X of the force between the end surface 2 of the outer magnetic ring and the end surface 4 of the inner magnetic ring is as following:

$$F_{24}^x = F_{13}^x.$$

When the axial magnetization is magnetized, the magnetic force provided by the permanent magnetic bearings is the algebraic sum of the interaction forces between the 4 ends. The projection force in the direction of the X is:

$$F_a = F_{13}^x + F_{24}^x - F_{14}^x - F_{23}^x = 2F_{13}^x - F_{14}^x - F_{23}^x \quad (5)$$

3.2 Electromagnetic Torque and Axial Magnetic Levitation Force Produced by the Magnetic Levitation Motor

(1) electromagnetic torque

If the current frequency in the stator winding is f , and the angular frequency $\omega = 2\pi f$, then the electromagnetic torque T_d could be calculated with the equivalent circuit:

$$T_d = \frac{P_d}{\omega} = \frac{1-s}{\omega} (I_2')^2 \frac{R_2'}{s} = \frac{(I_2')^2 R_2'}{s\omega_s} \quad (6)$$

Where P_d is the power of each phase; R_2' is the rotor resistance; I_2' is the rotor current. s is the slip ratio. ω_s is the synchronous angular frequency. According to the de Venan equivalent circuit and the partial voltage principle, $(I_2')^2$ can be obtained [4].

(2) axial magnetic attraction force

Fig. 5 calculation diagram of axial magnetic attraction force

Under the hypothetical condition^[5], the small area ds on the disc is taken as shown in Figure 5. Then the axial magnetic attraction force of the rotor is as following.

$$F = \int_s \frac{B^2}{2\mu_0} ds = \frac{1}{2\mu_0} \int_{r_1'}^{r_2'} \int_0^{2\pi} B^2 r' dr' d\alpha = \frac{r_2'^2 - r_1'^2}{4\mu_0} \int_0^{2\pi} B^2 d\alpha \quad (6)$$

Where r_1' and r_2' are the inner and the outer diameter of rotor disc. r' is the radius of the position of the small area on the disc. B is the flux density through ds .

When the rotating magnetic potential of the base wave in the stator air gap is produced^[6], the axial magnetic attraction force is obtained.

$$F = \frac{(r_2'^2 - r_1'^2) \mu_0 m_1^2 N_1^2 I_1^2}{\pi \delta^2}$$

Where m_1 is the number of phases, the N_1 is the turn number, the I_1 is the current, and the δ is the axial gap between the rotor disc and the stator.

4. Conclusions

On the basis of the existing magnetic levitation electric pump, the design and analysis of the permanent magnetic levitation axial electric pump. The following conclusions are drawn:

(1) the passive magnetic levitation mode of permanent magnetic bearings is used, and the structure is simple and easy to control.

(2) the axial size of the motor is reduced by axial motor, and it is convenient to be used in the case of small axial space.

(3) when the axial rotor size, axial force and stator winding with the number, number of turns and the excitation current is proportional to the square of.

(4) both sides of the rotor disk have the same axial magnetic force on the rotor, so it can ensure the rotor shaft's stable suspension in the axial direction under the axial support of the permanent magnet bearing..

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