Design and Simulation of a Double Stator Type Axial Magnetically Levitated Motor

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***Abstract*—A magnetically levitated axial motor that has tilt control function is proposed. The rotor has eight permanent magnets on each side (sixteen PMs in total). The two states have twelve poles each which include three-phase eight-pole motor windings and two-phase six-pole suspension windings. The operating principle was clarified by FEM, and the prototype device was designed. According to the analysis, the device had sufficient magnetic force to control the rotor. Moreover, it was clarified that the proposed motor can control the translation motion, inclination motion and rotational motion independently.**

***Index Terms*—Magnetic levitation, Magnetic device, Magnetic analysis, Magnetic forces.**

I. Introduction

A magnetically levitated motor (maglev motor) can realize the non-contact support and rotation of a rotor by magnetic force. Therefore, it has many advantages over conventional mechanical bearing supported motors [1], [2]. In order to accomplish complete magnetically levitation of the motor, however, it is necessary to control five axes actively. Two radial magnetic bearings, one axial magnetic bearing and brushless DC motor are usually required. However, this gives rise to major issues such as complicated control system and associated electronics, resulting in enlarged equipment size.

This paper proposed a double stator type magnetically levitated motor that has axial translation motion and tilting motion control function.

II. Operation Principle

A schematic of the proposed maglev motor is shown in Fig. 1. Eight pole permanent magnets (PMs) are located on each side of the rotor. The stator has twelve poles. Each stator pole has three-phase eight-pole winding for rotational and axial motion control, and two-phase six-pole windings for tilting motion control. The rotor is installed in the center of two identical stators as shown in the figure.

The operation principle of the proposed maglev motor is based on a conventional axial bearingless motor. The operation principle of the upper side airgap is hereby described. In order to simplify numerical analysis, leakage flux is ignored. The flux density distribution B_{pm} in the upper side airgap produced by the rotor PMs is described as follows.

$$B_{pm}(\theta,t) = B_P \cos(\omega t - 4\theta) \tag{1}$$

Where, B_P is the maximum flux density of the PM, ω is rotating speed, t is time, θ is the angle. To generate the rotating torque, an eight-pole rotating magnetic field of phase difference ψ should be generated by the motor windings.

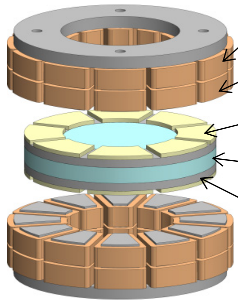


Fig. 1. Schematic of the proposed maglev motor.

In addition, to control the axial translation motion, a eight-pole magnetic field of the same phase of the PM should be generated. Meanwhile, to control the tilt motion, a six phase magnetic field should be generated. Therefore, the flux density generated by the rotational control current B_m, by the axial control current B_s, and by the tilt motion control $B_{\theta x}$ and $B_{\theta y}$ are as follows.

$$\begin{aligned} B_m(\theta,t) &= B_M \cos(\omega t - 4\theta + \psi) \\ B_s(\theta,t) &= B_S \cos(\omega t - 4\theta) \\ B_{\theta x}(\theta,t) &= B_\Theta \sin(\omega t - 3\theta) \\ B_{\theta y}(\theta,t) &= B_\Theta \cos(\omega t - 3\theta) \end{aligned} \tag{2}$$

Where, B_M, B_S and B_Θ is the peak value of the flux density produced by the motor current, the suspension current and the tilt control current, respectively.

Magnetic energy ΔW in the infinitesimal volume of the airgap ΔV is as follows.

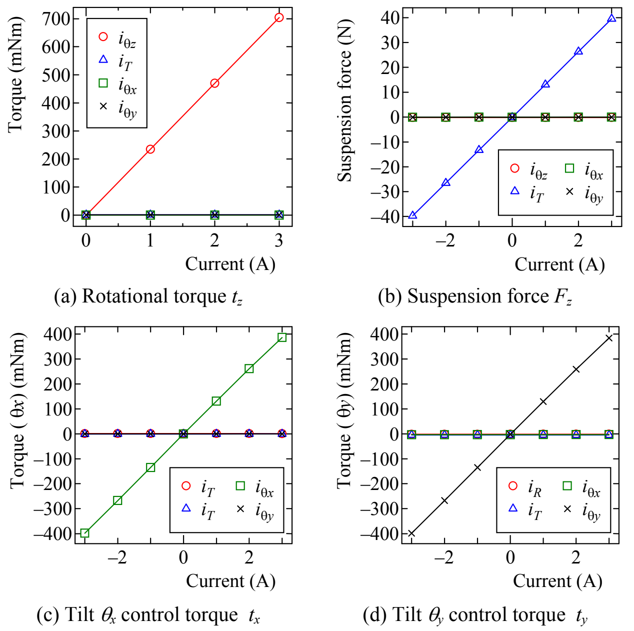
$$\Delta W = \frac{B^2}{2\mu_0}\Delta V = \frac{B^2}{2\mu_0} \cdot z\pi(r_o{}^2 - r_i{}^2) \tag{3}$$

Where, μ_0 is the permeability of the vacuum, and r_o and r_i are outer and inner diameter of the stator, respectively.

The rotating torque and the suspension force are derived from partially differentiating magnetic energy ΔW with regard to phase difference ψ and gap length z, respectively. According to (2) and (3), the rotating torque t_z and the suspension force F_z are as follows.

$$\begin{aligned} \tau_z &= \frac{\partial W_M}{\partial \psi} = \frac{2z\pi(r_o{}^2 - r_i{}^2)}{\mu_0} B_P B_M \sin\psi \\ F_z &= \frac{\partial W_S}{\partial z} = \frac{\pi(r_o{}^2 - r_i{}^2)}{4\mu_0}\left\{B_P{}^2 + 2B_P B_S \cos\psi + B_S{}^2\right\} \end{aligned} \tag{4}$$

The restoring torque is a product of the attractive force by the tilt control current and the distance from the center of the



(a) Rotational torque t_z (b) Suspension force F_z

(c) Tilt θ_x control torque t_x (d) Tilt θ_y control torque t_y

Fig. 2. Analytical result of interference of control current

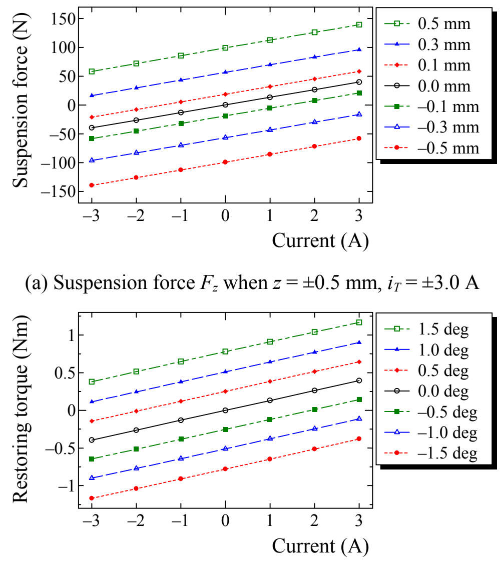
Gravity to point of application of the force. According to (4), the restoring torque t_x and t_y are as follows.

$$\tau_x = \frac{\partial W_\theta}{\partial z} \times \frac{r_o + r_i}{2}$$
$$= \frac{\pi (r_o + r_i)(r_o^2 - r_i^2)}{16 \mu_0} \left\{ B_P^2 + 2 B_P B_\theta \sin \theta + B_\theta^2 \right\} \quad (5)$$
$$\tau_y = \frac{\pi (r_o + r_i)(r_o^2 - r_i^2)}{16 \mu_0} \left\{ B_P^2 + 2 B_P B_\theta \cos \theta + B_\theta^2 \right\}$$

It is therefore theoretically apparent that rotating torque, suspension force and restoring torque can be controlled independently.

III. Magnetic Analysis

In order to clarify the torque and suspension force characteristics, an FEM magnetic field analysis was carried out. The rotor was located at the geometric center of the both stators. The airgap was 1 mm for each side. The control current for each coil windings were changed as follows. Rotating current i_R: 0 to 3 A, translation current i_T: ±3 A, tilt current $i_{\theta x}$ and $i_{\theta y}$: ±3A. Then, rotating torque τ_z, suspension force F_z and restoring torque τ_x, τ_y were calculated. Analytical results are shown in Fig. 2. According to the result, torque τ_z and force F_z were generated only by the current that is related to them ($i_{\theta z}$ and i_T, respectively). It was clarified that rotation control, translation control and tilt control ware not cross coupled. In addition, the relationship of suspension force F_z versus current i_T and displacement z and restoring torque τ_x versus current $i_{\theta x}$ and tilt angle θ_x were also calculated. Analytical results are showed in Fig. 3. When the z was changed + 0.20 to −0.20 mm, a control current i_T of −3.0 A to +3.0 A would generate enough suspension force to cancel the PM's negative spring force. (attractive force). Meanwhile, the rotor was tilted +0.78° to −0.78°, the control current of –3.0 A



(a) Suspension force F_z when $z = \pm 0.5$ mm, $i_T = \pm 3.0$ A

(a) Restoring torque τ_x when $\theta x = \pm 0.5°$, $i_{\theta x} = \pm 3.0$ A

Fig. 3. Relationship between displacement (tilt) and current.

to +3.0 A generated enough restoring torque to cancel the negative toque by the PM.

IV. Conclusion

A double stator type magnetically levitated motor was proposed. By the FEM magnetic field analysis, it was clarified that rotation control, translation control and tilt control show no interference. These four axes are therefore, able to be controlled independently. In addition, a controllable range of ±0.2 mm and ±0.78° was obtained.

As a future work, the experimental setup is in the process of fabrication. In order to confirm the operating principle and to clarify the control performance, levitation rotation control will be carried out by the fabricated experimental setup.

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