DESIGN OPTIMIZATION OF MAGNETIC BEARING COMPOSED OF PERMANENT MAGNETS FOR THE BEARING-LESS MOTOR

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ABSTRACT

Bearing-less motor causes large mechanism or complicated control system. We suggest a simple bearing-less motor composed of disk motor and magnetic using only permanent magnet. Our model makes better use of the attractive force of motor and the repulsion force of permanent magnet and attempts magnetic levitation. We make an experimental device to measure torque and attractive force and measured them. We calculate the repulsion force of a pair of cylindrical permanent magnet bearing using the equivalent surface current model. On the basis of the results above, this article finally studies the relationship between the attractive force of the motor and the repulsive force of the magnetic bearing to realize the stable levitation.

INTRODUCTION

A centrifugal pump has been expected to be used in special environments, as in vacuum or in the human body. The problems that we have to consider are the mixing impurities or inferior in quality of carrying liquid caused by mechanical contact. Magnetic bearing is therefore useful for sharply decreasing the friction, tremor and noise of the motor. In the case of artificial blood pump, it keeps off the occurrence of thrombosis. For the reasons mentioned above, a considerable number of studies have been conducted on the bearing-less motors, which are the magnetic- bearing-adopted motors [1], [2].

Bearing-less motor, however, causes large mechanism or complicated control system. We propose to use the disk motor to solve these problems. Disk motor makes better use of magnetic flux exist in the gap, because the rotary torque and the attractive force can be controlled at the same time. Passive stability simultaneously exists for radial direction. We are aiming at constructing bearing-less motor system, in which the repulsion force of permanent magnet bearing contradicts the attractive force generated by the motor. Permanent magnet bearing makes the control system much easier.

We propose the bearing system in which permanent magnets are only adopted. The radial stiffness should be considerably higher in this case, because otherwise the unsymmetrical force generated by the disk motor spoils the advantage that the system has passive stability in radial direction. According to Earnshaw's theorem, stable levitation can be realized with controlling only the attractive force of the motor, and this system decrease the control system and equipments.

We calculate the repulsion force of a pair of cylindrical permanent magnet bearing using the surface current model. As the results of the calculation, it appears that certain region surely exists that has negative stiffness at radial direction.

The purpose of this study is to constitute a bearing less motor using disk motor. And design optimization of magnetic bearing composed of permanent magnet for the bearing-less motor.

THE BEARING-LESS MOTOR

Conventional radial gap motor generates only the rotating torque. On the contrary, attractive forces are generated in the axial gap disk motor. Fig.1 shows magnetic flux flow at motor gap. These two forces are originally caused by the same magnetic flux, and they should be independently determined and controlled. Furthermore passive stability simultaneously exists for radial direction.

As has been noted, disk motor has proper ability at the bearing-less motor. We propose the bearing system in which permanent magnets are only adopted. The radial stiffness should be considerably higher in this case, because otherwise the unsymmetrical force generated by the disk motor spoils the advantage that the system has passive stability in radial direction. Therefore, we suggest magnetic bearing system in which the growth of radial displacement never occurs. That constructed a pair of cylindrical permanent magnet. According to Earnshaw's theorem, stable levitation can be realized with controlling only the attractive force of the motor, and this system decrease the control system and equipments. We calculate the repulsion force of a pair of cylindrical permanent magnet bearing using the surface current model. As the results of the calculation, it appears that certain region surely exists that has negative stiffness.

In addition, the force in thrust direction is always repulsive. That is why rotor can levitate on the condition that controlling the attractive force in disk motor. As mentioned above we propose the bearing-less motor that the combination of the disk motor and the magnetic bearing which composed a pair of cylindrical permanent magnet can be realized stable levitation. The structure of the bearing-less motor is shown in Fig.2.

CHARACTERISTICS OF THE MOTOR

Experimental Device

As mentioned earlier the disk motor generates the attractive force, stable levitation is available using the characteristics. In addition, it can be make use of stable levitation. Moreover, it controls the rotor for stable levitation. In the case of control, the problem that we have to consider is the attractive force fluctuation. In one of technical skill of improvement in the motor structure, we experiment two kinds of rotors having 4 and 8 magnetic poles. What if the member of magnetic poles changed at disk motor? We examine torque and attractive force in that case. The examination appears the behavior at torque and attractive force with adopting same (BH)Max and volume of permanent magnet. The examination gropes for most suitable structure at bearing-less motor too. Table1 shows Specifications of The Disk Motor. We designed an experimental device that can measure the torque and attractive force at the same time. Experimental device is shown in Fig.3. As shown in Fig.3, the experimental device detects the torque and the attractive force using the torque meter and the load cell. And the rotary encoder finds rotary position. Fig.4 shows picture of the experimental device. The motor size is shown in Figs.5. The input is 3 phases AC by PWM Amplifiers.

Experimental Result

We measured the torque and the attractive force with the experimental device as mentioned above. The next is the attractive force of this motor with the drive system. Fig.6 shows the characteristics of

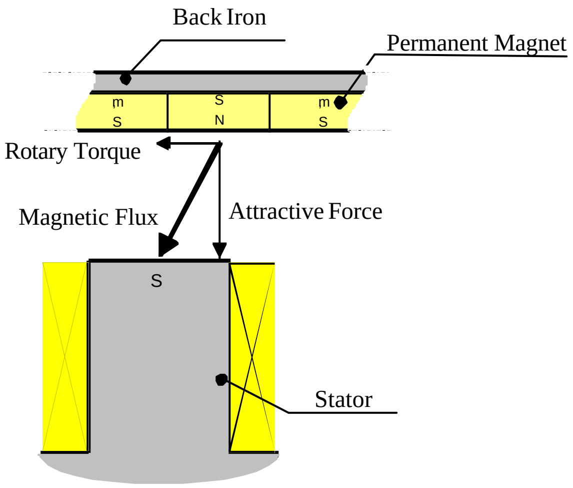


FIGURE 1: Magnetic Flux at Motor Gap

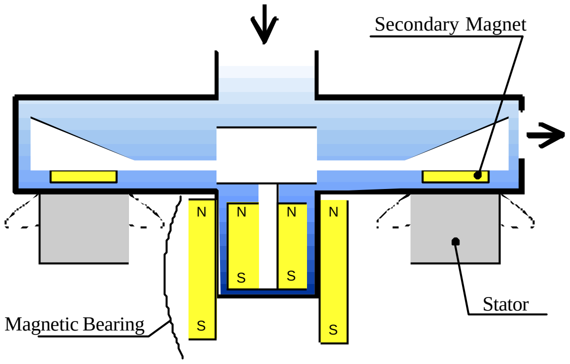


FIGURE 2: Bearing-less Motor Adopt Disk motor

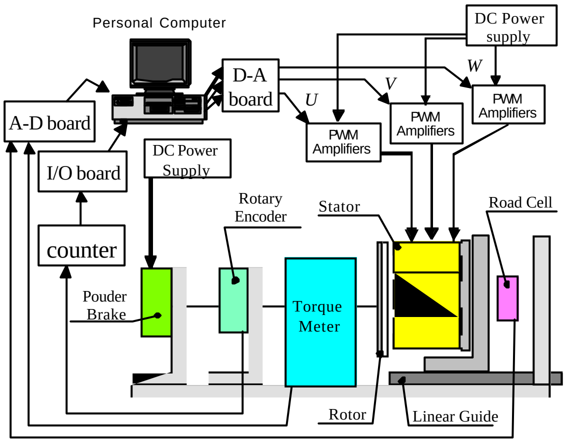


FIGURE 3: Experimental Device

attractive force at 1800[rpm], 0.05[N-m] load. It shows that the attractive force has fluctuations. Average attraction force is calculated from the waveform, together with the fluctuation.

Fig.7 shows attractive force in which rotation speed is kept at 1500[rpm]. It can be said from the results of the experiments that the attractive force fluctuation depends on the load as shown in Fig.11. The decrease of the attraction is caused by the increase of the load angle. Attractive force has decided on the load angle alike static characteristics. The result appears that attractive force is decided on the load angle in static and dynamic one. An attractive force fluctuation decreases with raising the load. The result is caused by decreasing pulsating rotary speed attended with raising the load.

The next, we experiment concerning the attractive force and rotary speed with maintaining the load.

Fig.8 shows the characteristics of the attractive force in which the load is kept at 0.05[N-m]. It can be said from the results of the experiments that the attractive force occurrence at a uniform rotary speed in 4 poles and 8 poles alike. In the case of 8 poles, attractive force decrease from 30[N] to 27[N] depended on the rotary speed. Eddy current is quite likely to come the results. Nevertheless, characteristics of attractive force fluctuations differ on magnetic poles. It is quite clear that the attractive force fluctuation is independent from the rotation speed but depend on the input frequency. It is inferred that the fluctuation is reflected in input frequency. In addition to that knowledge, the fluctuation hardly influences detent force, the higher rotary speed.

The characteristics of attractive force – excitation current in which the load is kept at 0.05[N-m] appears in Fig.9. As the figure indicates, the characteristic of attractive force is not change with raising the rotary speed at 4 magnetic poles. However, the characteristic is changes with changing rotary speed. Again, it is the reason that the cause of the result is eddy current with raising input frequency.

Consequently, it is possible that it keep the attractive force on the condition that the rotor has 4 magnetic poles. But in the case of 8 magnetic poles, it exists that it cannot keep attractive force constant opposite the load. The next the characteristic of attractive force – excitation current in which the rotary speed is kept at 0.05[N-m] appears in Fig.10.

Consequently, it is possible to keep the attractive force on the condition that the rotor has 4 magnetic poles. As when we have seen, those experimental result appears that the trial motor is hardly controlled. It was for that purpose that we required improvement to the characteristic. After this, changing the specification, alternating the permanent magnet and changing the cross section of the iron core etc. improve the control volume.

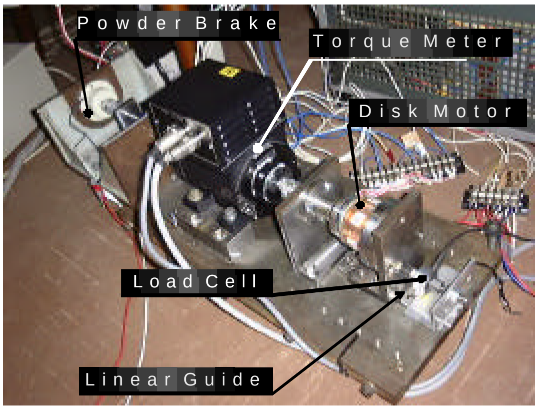
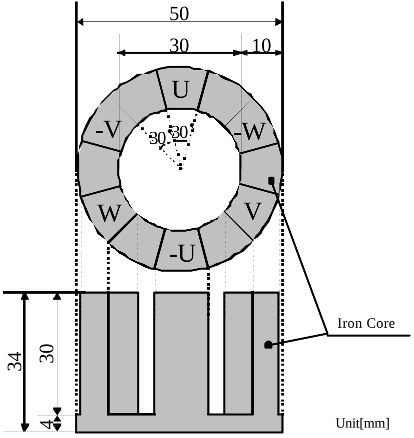


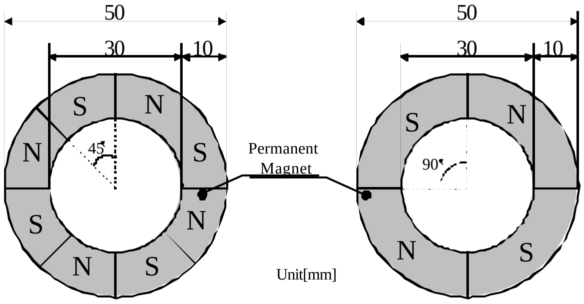
FIGURE 4 : Picture of The Experimental Device

TABLE 1: Specifications of The Disk Motor

Item	Value [unit]
Phase	3
Number of winding	180[turn]
Gap length	3X10^{-3}[m]
Winding diameter	0.4X10^{-3}[m]
(BH)max	34[MGOe]



(A)The Stator



(B) The Rotor

FIGURE 5 : The Stator and The Rotor of The Disk Motor

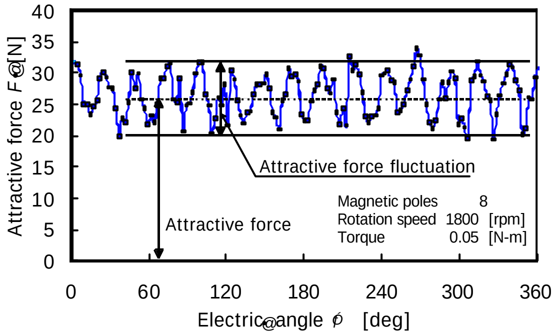


FIGURE 6: Attractive Force and its Fluctuation

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The way of formularization for repulsion force examines on the supposition that surface current on permanent magnet occurs. Magnetization of permanent magnet appears **J** [T], densely of surface current appears **K** [A/m^2] and current densely appears Eq.(1)(2).

$$\mathbf{I} = \nabla \times (\mathbf{J} / m_0) \ [\mathrm{A/m^3}] \qquad (1)$$

$$\mathbf{K} = -\mathbf{n} \times (\mathbf{J} / m_0) \ [\mathrm{A/m^2}] \quad (2)$$

$\mu_0=4\pi\times10^{-7}$[H/m]

n is unit vector vertical to the surface of permanent magnet. Permanent magnet has been equally magnetized at the inside of it. In addition, recoil line supposes straight line. Permanent magnet volume current densely **I** equals zero, and surface current **K** it rounds on the side of it. In the case of the model, we calculate the magnetic flux on supposition that surface current exist outside and inside it. Repulsion force F is calculated integral calculus of electromagnetic force between B_2 to lateral current of PM1. Eq.3 gives the whole repulsion force.

$$\mathbf{F} = \frac{J_2 r_2}{m_0} \int_{h-c_2}^{h+c_2} \left\{ \int_0^{2p} \left(B_{1z} \mathbf{a}_r - B_{1r} \mathbf{a}_z \right) \mathrm{d}f \right\} \mathrm{d}z_2$$

Repulsion force is calculated the following size.
a=48[mm], b=20[mm], e=17[mm], g=7[mm]
C_1=12[mm]
Magnetizing Force of PM1, J_1=0.974[T].
Magnetizing Force of PM2, J_2=0.974[T].

The prerequisite of stable levitation must be show at Z and R each axis. Nevertheless, magnetic bearing composed permanent magnet cannot control at r axis. In our model, the bearing-less motor should be shown negative stiffness at R axis only magnetic bearing composed permanent magnet. The characteristics of z direction repulsion force **Fz** and r-direction stiffness **Kr** as shown in Fig.13. The r-direction stiffness

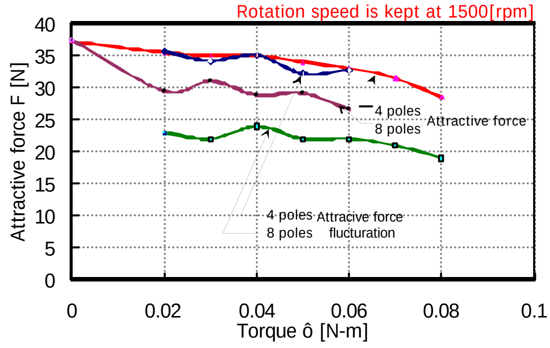

FIGURE 7 : The Characteristics of Attractive Force and its Fluctuations(rotation speed is kept at 1500[rpm])

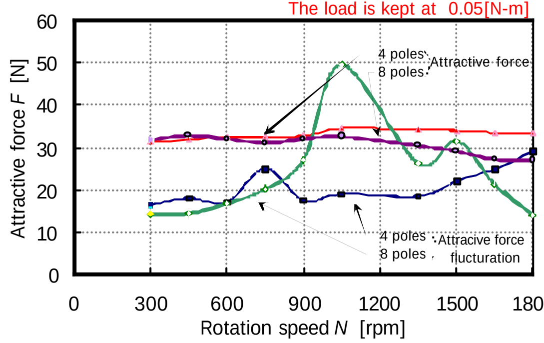

FIGURE 8: The Characteristics of Attractive Force and its Fluctuations(the load is kept at 0.05[N-m])

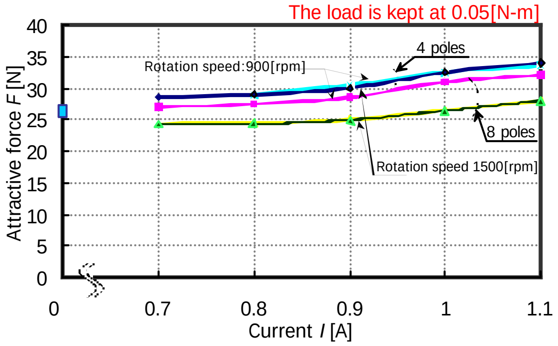

FIGURE 9: The characteristics of attractive force

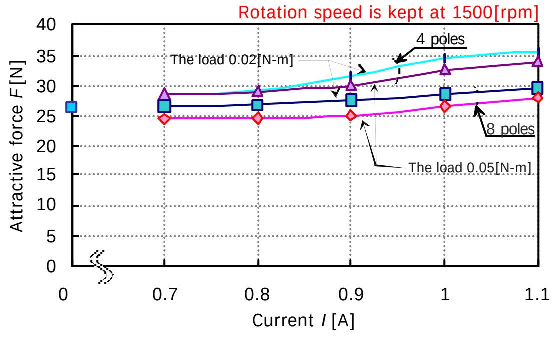

FIGURE 10: The characteristics of attractive force

would be positive on the condition that PM1 sprang out of PM2. The z-direction attractive force is maximum on the terms of the position that the upper end of PM1 is aligned with PM2. The r-direction stability is secured at the position.

Moreover, we calculate the z-direction spiffiness and the repulsion force with changing the ratio C2/C1 and holding the position the upper end of PM1 are aligned with PM2. Fig.14 shows calculate model. Fig.15 shows calculation result. Repulsion force **Fz** is maximum in C2/C1=0.5 as shown in Fig.15. The higher the ratio of C2/C1, the bigger stiffness **Kz** considering the circumstances mentioned above, the rate of C2/C1 equal to 0.5 is selected in our model. Fig.16 appears the characteristics of attractive force of motor compared with repulsion force of permanent magnet. To be levitate, it is required that attractive force of motor equals repulsion force of permanent magnet. Moreover, controllable area expends on the condition that the r-direction stiffness is low. Those things considered, it is very important things which is the way of decision that the size of C1 and relative position.

CONCLUSION

We are aiming at constructing bearing less motor the way using permanent magnet's restitution force compete with absorb force. Therefore, we make an experimental device to make the point of it clear. And we experimented with the motor which rotor has 4 or 8 magnetic poles.

The result appears that the static torque and attractive force are decided on the load angle in static and dynamic characteristics. As when we have seen, those experimental result appears that the trial motor is hardly control. We examine the structure of the magnetic bearing with changing the rate of the size. As a result, attractive force of the motor is max on the condition that the rate the height of inside to outside is 0.5. It is important that the relative position between the motor gap and the magnetic bearing.

After this, we examine the control system on the motion equations. In addition, to be concrete, the motor structure improves the control volume.

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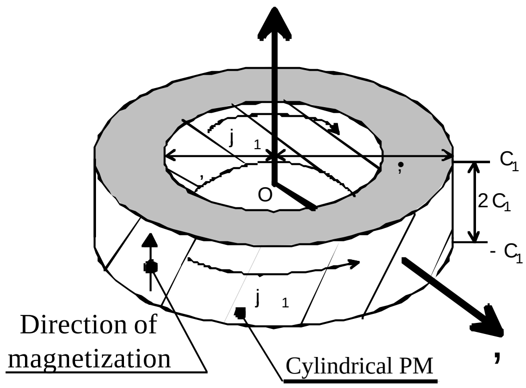

FIGURE 11: Surface Current Model

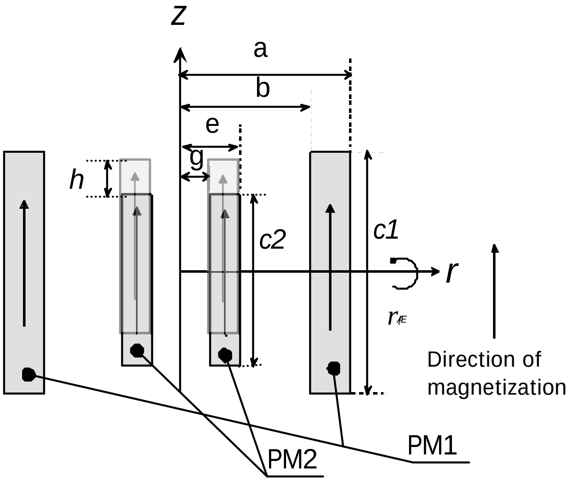

FIGURE 12: Size of the Analysis Model

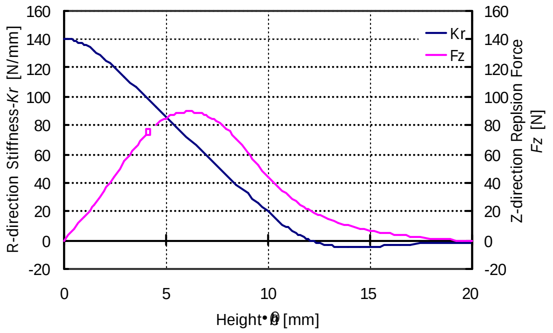

FIGURE 13: Relationships to Kr and Fz

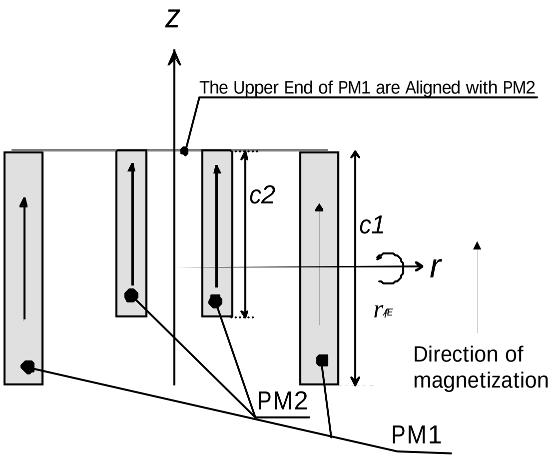

FIGURE 14: The relationships of PM1 toPM2

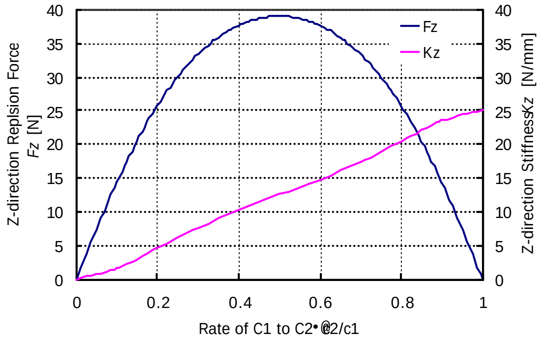

FIGURE 15: The Characteristics of Attractive Force

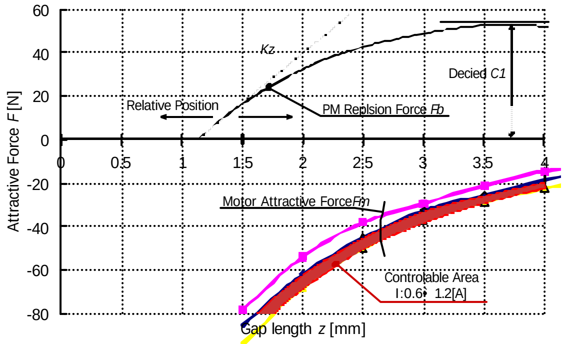

FIGURE 16: The Relationships of Motor and Magnetic Bearing