Development of bearing-less motor with non-contact power supply -Levitation performance-

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***Abstract*— This paper presents a new type of bearing-less motor. A unique feature of this bearing-less motor is an operation without the utilization of permanent magnets. The rotor magnetized by a current of a non-contact power supply, which consists of a bridge rectifier circuit and coils. In previously report, the levitation is archived through attractive forces generated by inclinations on the edges of the rotor and the stator. Hence, this paper shows the experimental result of the levitation and rotation control of a bearing-less motor with non-contact power supply. In addition, the design descriptions of a new rotor improvement for achieving the target rotation performance is given.**

I. INTRODUCTION

Bearing-less motor is defined as a motor which consists of the unified magnetic bearings [1]. It has received attentions among researchers due to its definite advantages of frictionless, non-abrasion, and unnecessary maintenance. It is used to produce artificial hearts with high performance blood pumps. Recently, a number of bearing-less motors have been researched and developed. However, permanent magnets have been used as their requiring element. In particular, permanent magnets have the properties of demagnetization and curie temperature limit. Therefore, this paper aim to solve this problem by enhancing the performance of the previously developed bearing-less motor [2-4] which is usable in much environment.

In this paper, we focus on the control performance enhancement of our previously developed bearing-less motor . The rotor is magnetized by a current from magnetic resonances of non-contact power supply which consists of a bridge rectifier circuit, capacitor and coils. In the previous study, the current was used to control only one side of the coils of the XY-axis. However, an inclination control of rotor requires the current apply to both the upper coils. In this paper, full control system and levitation experiment are conducted. In addition, we also address the problem of rotor rotation and a new rotor is designed using 3D-FEM analysis for solving the rotor rotation problem.

This paper is organized as follows, Section II gives a brief overview of hardware components and their configurations. Section III shows an experimental result of the levitation control. Section IV shows experimental results the rotation control. Finally, conclusion is given.

II. HARDWARE COMPONANTS AND THEIR CONFIGURATIONS

A. *Structure*

A structure of the bearing-less motor and its side view are shown in Fig.1 and Fig.2, respectively. The specification of the bearing-less motor is shown in Table I. In Fig.1, the bearing-less motor consists of three major components, that is rotor, stator and a power transmission coil. The power receiving coil is installed at the center of the rotor. Both rotor and stator are composed of two layers as shown in Fig. 2. The stator has two kinds of coils for levitation and rotation, and each coil has 100 turns.

B. *Sensor*

5 sensors are installed for position and orientations measurement of the rotor as shown in Fig. 3. The horizontal displacement is measured with a thru beam type laser sensor. The inclination of the rotor is measured by eddy current sensors which are attached to the upper part of the rotor.

When the rotor is tilted, the amount of light received from the laser sensor is decreased by the inclination of the sensor target. However, the horizontal position of the rotor can not be accurately measured. Hence, a program for correcting an inclination measurement is unavoidably required.

TABLE I. THE SPECIFICATION OF BEARING-LESS MOTOR

Parameter	Rotor	Stator
Material	SS 400	SS 400
Teeth number	32×2	24×2
Winding number of coil	100	100＋100
Mass	772 g	-
Outside diameter	142 mm	220 mm
Inside diameter	100 mm	144 mm
Bias current	1.5 A	
Air gap	1 mm	
Taper angle of teeth edge	7.6°	

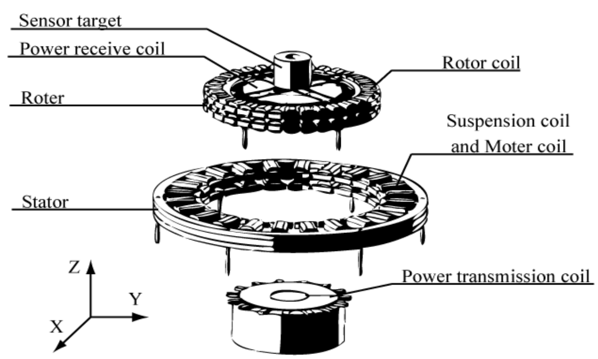


Figure. 1 Bearing-less motor construction

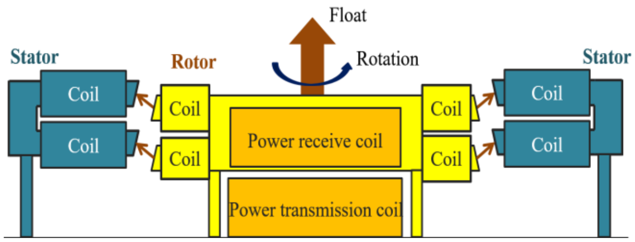


Figure. 2 Side view of Bearing-less motor

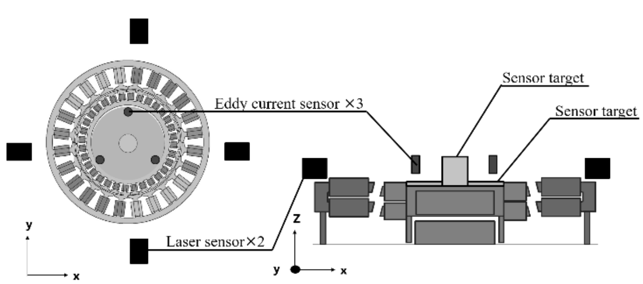


Figure 3. Sensor arrangement

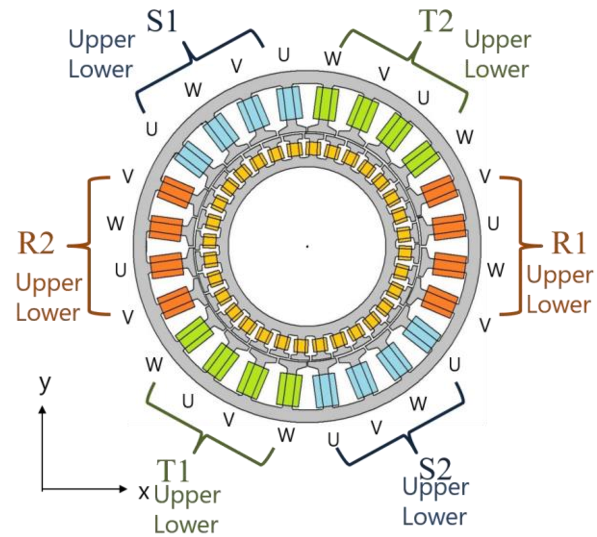


Figure 4. The configurations of the stator and rotor windings

C. *Levitation Control*

Five degrees of freedom excepts the rotation around the vertical axis are necessary to stabilize the levitation. The motions of two horizontal displacements and two rotations around the horizontal axis are controlled by the electromagnets of R, S, and T as shown in Fig.4. They are individually controlled about these horizontal displacements diagonal rotation. The rotational control method around the horizontal axis is shown in Fig.5. The control in the levitation displacement are performed by summation of all coil currents of R, S, and T.

Fig.7 shows the block diagram of the levitation system. The measured values are converted to RST-axis. Next, Partial-Derivative (PD) compensators are used to control the output currents of R, S, and T as shown in Fig.7. Those PD controller gains are shown in Table II.

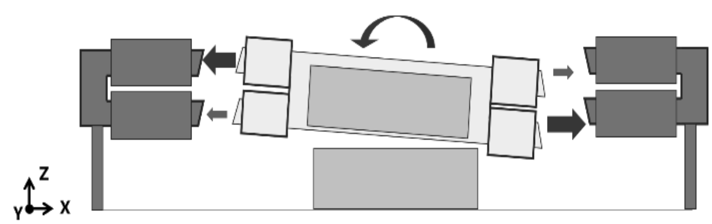


Figure 5. Image of inclination control

TABLE II. PD CONTROLLER GAINS VALUES

	k_p	k_d
Horizontal	5 A/mm	0.025 A/mm
Inclination	10 A/rad	1 As/rad
Height	0 A/mm	0.1 As/mm

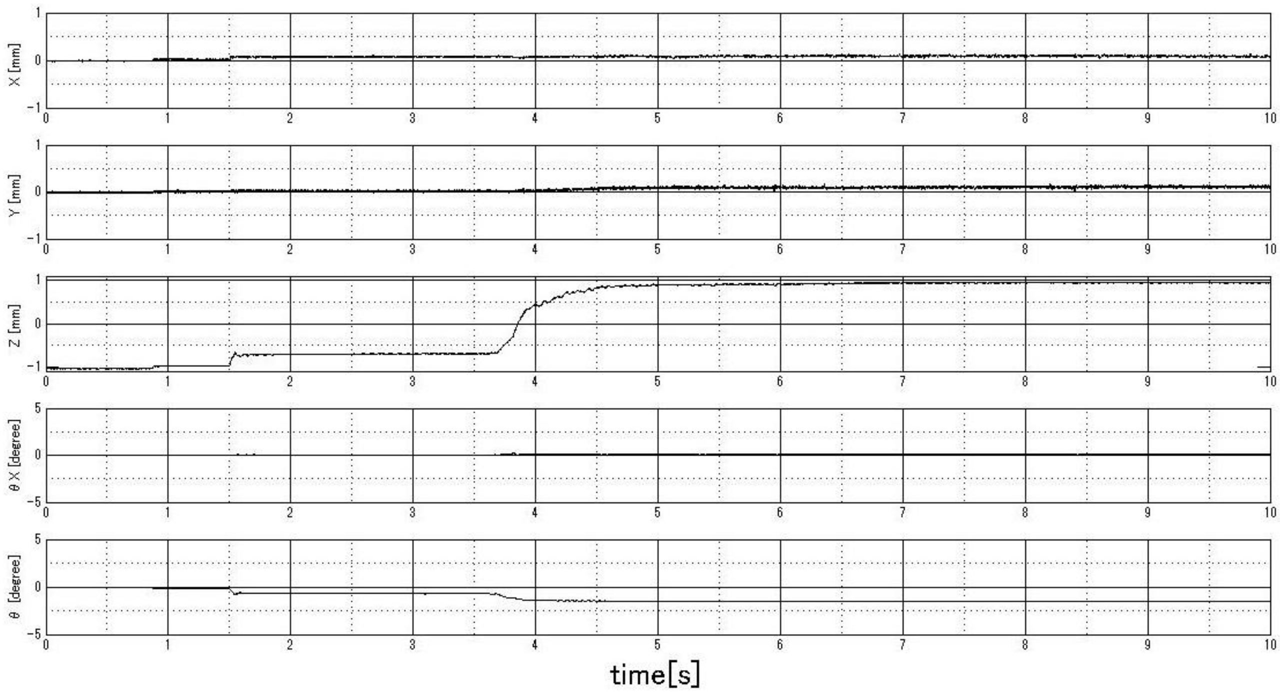


Figure 6. The result of levitation experiment

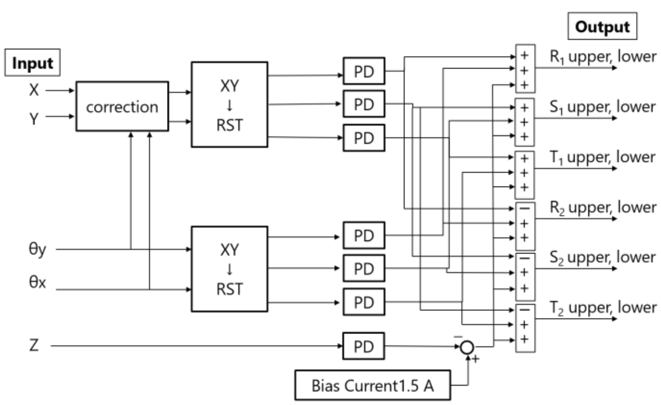


Figure 7. Levitation controller

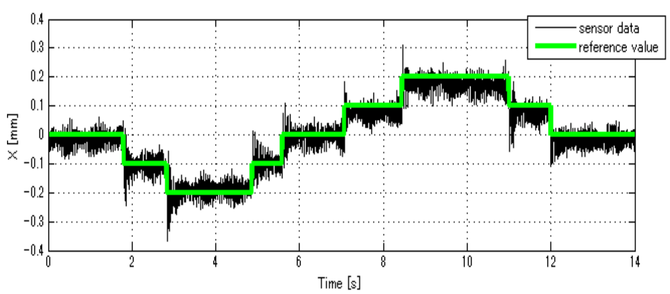


Figure .8 The result of followability

III. EXPERIMENTAL RESULT OF THE LEVIATION CONTROL

A. Levitation examination

Fig.6 shows the result of the levitation experiment. In the figure, the electromagnets of stators were switched at 1.5 seconds and non-contact power supply for rotor coil was started at 4 seconds. From the result, the rotor was levitated nearly 2mm after 4 seconds. It is confirmed that sufficient levitation force could be given to the rotor.

In addition, when the target value of X-axis was changed while levitating, the corresponding rotor displacement is shown in Fig.8. In the figure, the system can control the position of the rotor and the measured data from sensor was faithfully followed the reference command.

B. Discussion

From the results above, we confirm that the bearingless motor can be stabilized during the levitation.

IV. EXPERTIMANTAL RESULT OF THE ROTATION CONTROL

A. Principle

By using the difference between the number of teeth in stator and the rotor, we consider a method for rotation as shown in the Fig. 9. That is, the current is sequentially apply to the stator. In the experiment, it was found that the rotor did not rotate even if the rotating current is applied. Hence, we next performed a magnetic field analysis using software JMAG investigate the rotation problem.

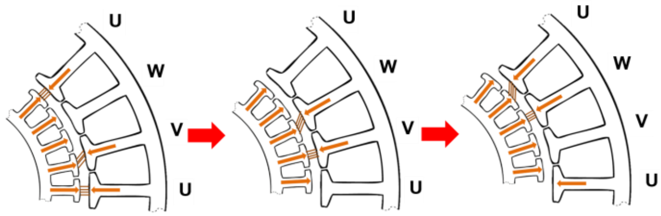
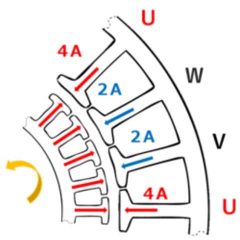


Figure 9. Principle of rotation

B. Analysis

The analysis conditions are shown in Fig. 10. From the experiment, current 2 [A] is required to supply all stators as a current for levitation and the flow of a current for rotation to an arbitrary stator. In addition, the relationship between the rotational torque and the phase of the rotor is rotated by two cycles.



Analysis soft	J-MAG
Analysis method	3D-FEM
Mesh size	0.1mm

Figure 10. Situation analysis

C. Torque simulation

Fig.11 shows the result of an analysis using a conventional rotor. The torque that the rotor turns in the positive direction is positive. It can be seen that a number of stability points exist where the rotational torque changes from positive to negative while requiring large restoring force. However, it was not able to attract any tooth of the rotor. In addition, a waveform of one period at 90 degrees is shown and that the rotor could not be rotated. This happened because the magnetic force of the teeth of the rotor was uniform.

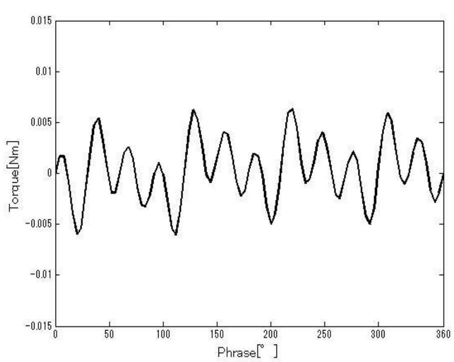


Figure 11. The analysis result of 100T-100T

Therefore, a new rotor was manufactured as the same shape as the conventional model. However, the difference of magnetic forces between the teeth were considered which was done by alternately changing the number of turns in the coil. Therefore, the number of coil turns in a new rotor was analyzed in the same way as for 100T - 100T. Considering this property, 100T-75T, 100-50T and 100-25T were analyzed. The results are obtained as shown in Fig.12. In the figure, it can be seen that the stable points are decreased by showing the waveforms of the same shape but the difference in the number of turns are increased. However, at 120 degrees,150 degrees and 200 degrees are not clearly seen. That is, the stability point cannot be eliminated.

D. The result of Levitation Force

By changing the number of turns of the rotor coil, the magnetic force was weaken and the rotor was not able to levitate. Therefore, the levitation force was also analyzed.

The mass of the conventional rotor was 772[g], it was estimated to be 700[g] for 100T-50T, and 665g for 100T-25T. The force required to float each rotor is 7.52N, 6.86N and 6.52[N]. In Fig.13, the height of the floating conventional rotor is the 0[mm]. If 2[A] of the bias current is applied to the stator as the same as the conventional one, the rotor cannot generate the sufficient output force for levitation. However, it can be seen that if the bias current of the stator is 2.5[A], it can be levitated at both 100-50T, and 100T-25T. Considering the controllability at the time of the levitation and the stability of levitation force, we thus decided to produce a new rotor 100T-50T.

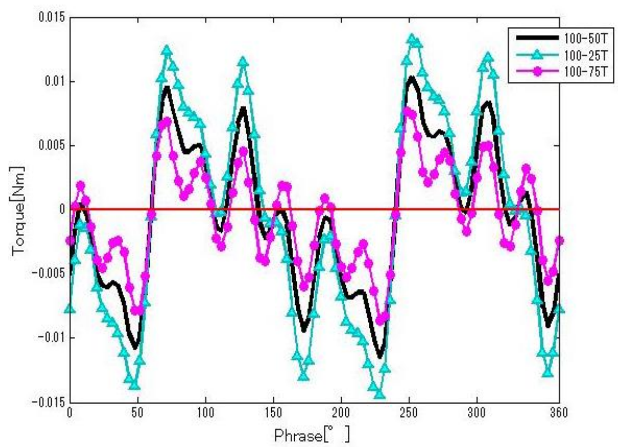


Figure 12. The analysis result of 100T-50T,100T-25T,100T-75T

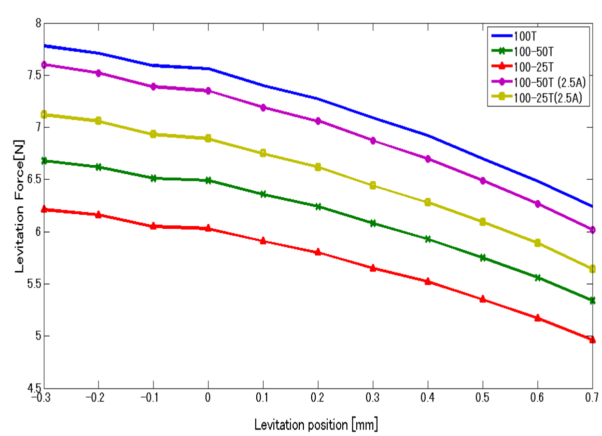


Figure 13. The result of float power

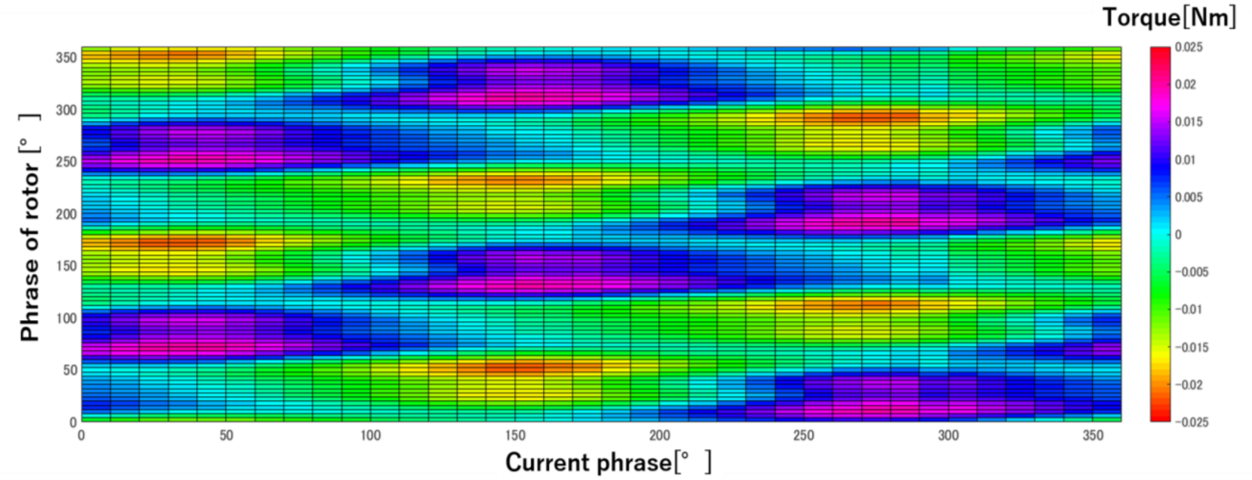


Figure 14. Three-phrase control

E. The result of 3 phrase control

As shown in Fig.14, it was found that there was an unnecessary stable point for the rotation of the rotor. Therefore, we next analyzed the rotation control of the rotor. Considering that the rotor can be rotated by changing from on-off pulse wave control to three-phrase alternating current using sin wave, it is seen that the stable points does not appear smoothly. In order to smoothly express the stable point, the reconstruction of the rotor shape is required.

F. Discussion

From the analysis, the rotation problem of the rotor caused by turn number of rotor coil. Therefore, we propose a method for changing turn number of rotor coils as well as increase magnetic force. That is, we decided to manufacture new rotor at 100-50T to solve the levitation force problem.

V. Conclusion

By using inclination control, the rotor can float and stabilize. In addition, good the tracking performance of the rotor is obtained. In addition, we show that the number of coil turns in rotor caused the rotation problem. We proposed a method to change the number of turns of the coil alternately and conducted 3D-FEM analysis. As a result, we show the possibility to rotate the rotor by controlling the rotation using 3-phrase control.

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