Study on Bearingless Motor with Rectified Circuit Coil

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***Abstract*—This paper represents the research finding of levitation and rotation control on bearingless motor with rectified circuit coil. Rectified circuit coil is functioned as transmitting and receiving coil of wireless electric power transmission, and supplies direct current to rotor coils. Rotor coils are used as rotor magnets not using permanent magnets. Even if magnetic force of magnet is strong, normal force will not be generated if magnets are horizontally configured on straight line. So as to generate vertical axial force, the tip form of rotor and stator is made to incline and levitation force (vertical axial force) is acquired using this inclination.**

I. INTRODUCTION

The permanent magnet is used for the stator or the rotor of bearingless motor in plenty of researches [1-5]. A permanent magnet has problem which cannot be used under high temperature environment and is demagnetized by the external magnetic field. In recent years, there are several magnets which can be used exceeding 100 centigrade degrees [6-8], however other problem has not been solved.

If the number of turns of coil is the same, the magnetic force of an electromagnet is proportional to the current of coil. In order to be stabilized levitating and rotating rotor, powerful magnetic force is required. Therefore, it is needed to feed much electric power for rotor coil. If a magnet size is small, the magnetic force of an electromagnet is small than a permanent magnet. Therefore, in order to levitate a rotor by small magnetic force, it has to generate magnetic support force efficiently. On that, it is effective that Z-axis inclination exists in the tooth edge face.

The authors have previously reported a bearingless motor with rectified circuit coil of half wave rectification type[9-11]. In this type, to acquire large magnetic force of rotor, magnetic saturation of rotor and stator core will occur. In order to solve this problem, we propose a method of wireless power transmission for rotor by full wave rectification type and an inclination of teeth of stator and rotor.

In this paper, generating levitation force by inclination of teeth and control method are proposed; basic principle of generating force and the calculated results of the three-dimensional finite element method (3D-FEM) and the experiment result of power transmission by full wave rectification type are presented. We assume that the motor is used as pump for material transfer used in high environment temperature, such as food and medicine.

II. PRINCIPLE OF RECTIFIED CIRCUIT COIL

A rectified circuit coil of half wave rectification type is shown in Figure 1, and that of full wave rectification type is shown in Figure 2. The rectified circuit coil transforms the electromotive force by electromagnetic induction into a direct current using diode, and fixes the generated magnetic pole in a coil. A difference between half wave rectification type and full wave rectification type is existence of power transmission coil. In half wave rectification type, the rotor coils receive electric power directly from the stators. In other hand, in full wave rectification type, the rotor coils receive electric power from power transmission coil. However, in both of the types, a direct current flows in rotor coils, and the fixed magnetic pole appears in the both sides of a coil. Therefore, it means attaching a permanent magnet in a rotor.

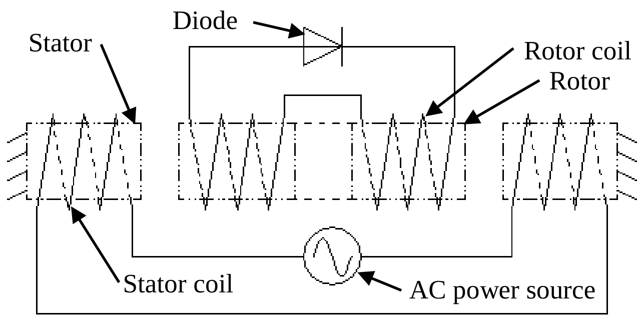


Figure 1. Half wave rectification type.

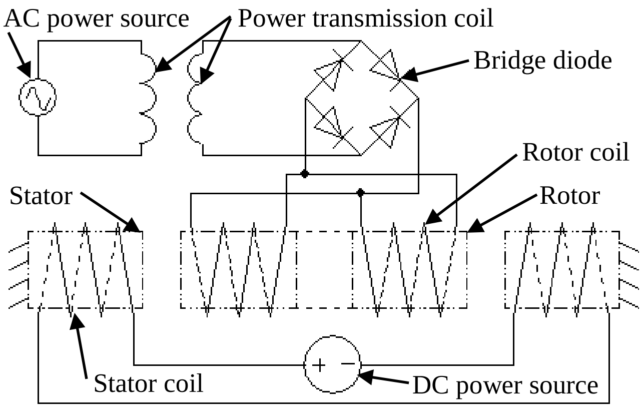
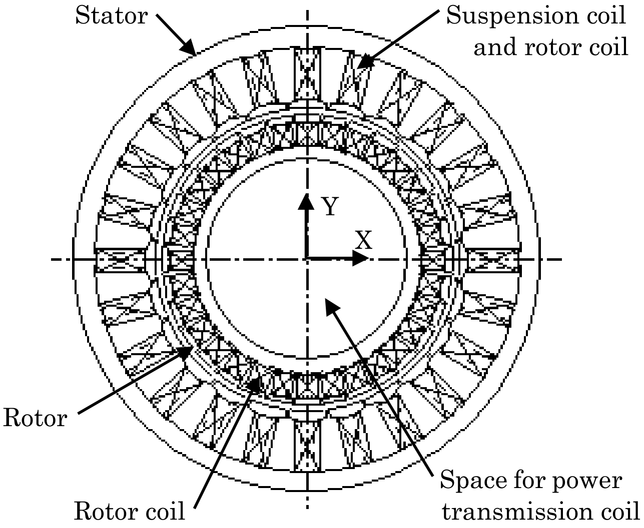


Figure 2. Full wave rectification type.

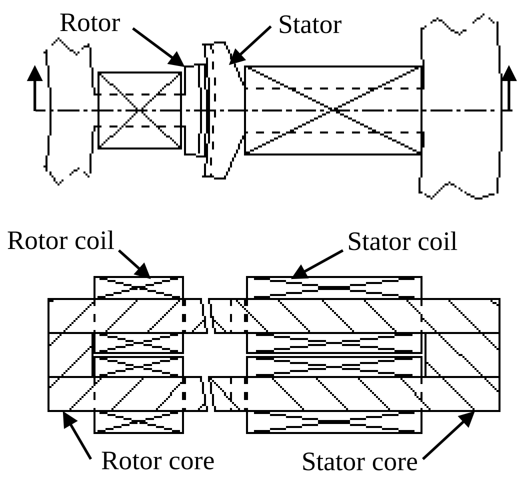
III. BEARINGLESS MOTOR WITH RECTIFIED CIRCUIT COIL

A. *Structure*

A bearing loess motor is classified into one axis to five axis control type according to the number of axes controlled actively. In case of two axis control type motor, the structure and control can be simplify, therefore we selected it. Figure 3 shows a structure of the proposed bearingless motor with two layers flat-shaped rotors. If a coil on one tooth has a small winding number and the coil current is small, it cannot generate strong magnetic force. In order to solve this problem, the tooth edge face is inclined for generating strong levitation force. Furthermore, to supply much electric power to rotor coils, it was considered as the full wave rectification type. In one layer, the number of the stator tooth is 24 pieces and the rotor tooth is 32 pieces. Suspension coils and motor coils are wound in stator core, and rotor coils are wound in rotor core. An electric power transmission coil is configured to space of the center of the rotor.



(a) Top view



(b) Detail of teeth

Figure 3. Structure of proposed bearingless motor.

B. *Principle of generating magnetic force*

The rotor coils are connected to bridge diode for the monopolar of N pole or S pole in one layer. The stator is fixed as a different magnetic pole from the rotor. The attractive force occurs between the stator and the rotor, and the force is used for levitation of the rotor. If the same current is supplied to the stator coils, the rotor received force from the stator in X-axis and Y-axis is zero when it integrates the vector of magnetic force over all circumferences, therefore, the rotor axis is located at the center of the stator axis.

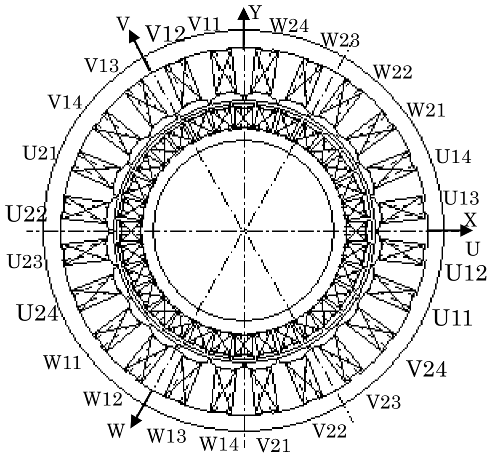


Figure 4. Principle of radial suspension force generation.

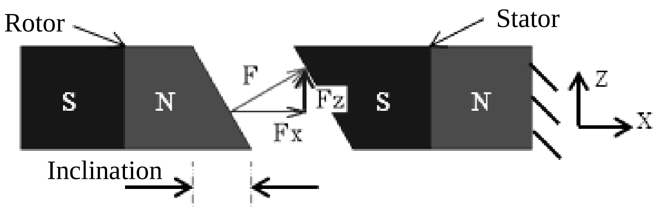
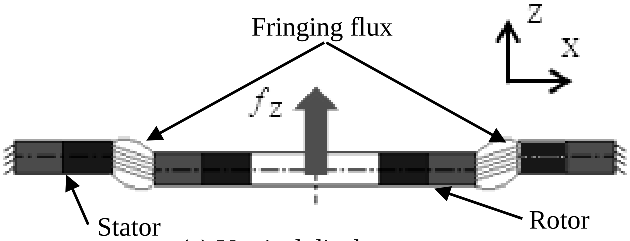
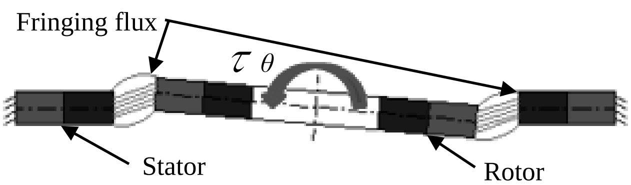


Figure 5. Principle of axial suspension force generation.



(a) Vertical displacement



(b) Tilting displacement

Figure 6. Principle of axial and tilting restitutive force generation.

The suspension coils of the stator are configured on 3 axis of U, V and W axis, as shown in Figure 4. The position of XY coordinates can be displaced to the position of UVW coordinates. A displacement in XY axis of the rotor is displaced into UVW axis by 2-phase/3-phase conversion, and the magnetic force of UVW axis of the stator is controlled; magnetic force can be generated in radial by integral of the vector of applied force to the rotor. Radial position control of the rotor is attained by the disequilibrium of this force.

Principle of generating Z-axis magnetic suspension force is shown in Figure 5. Generally, it is difficult to acquire sufficient suspension force with short electromagnet of shaft orientation. Then, it is considered as the edge form of tooth which has inclination angle to the Z-axis, and the levitation force of Z-axis is acquired. Direction of the magnetic-flux line of the air-gap is perpendicular to the edge surface of the direction of magnetization. Even if the position of the rotor and the stator is the same on the Z-axis, Z-axis force will occur.

Figure 6 shows the principle of restitutive force of rotor when a displacement of the rotor occurs in shaft orientation and tilting. Magnetic couplings between the rotor and the stator provide stability in the axial and tilting directions.

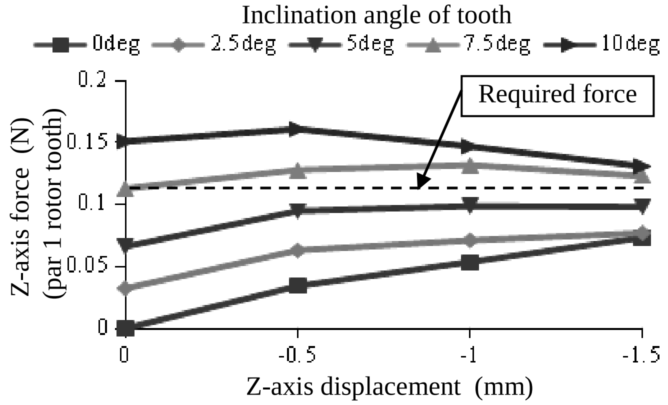


Figure 7. Compare of force by teeth inclination angle.

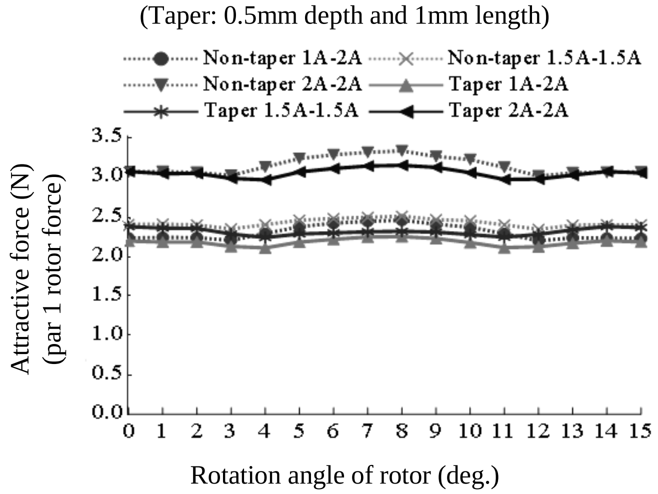


Figure 8. Compare of force by teeth inclination angle.

IV. DESIGN OF BEARINGLESS MOTOR

A. Levitation force

Figure 7 shows the relation between inclination angle of teeth and generated Z-axis force (levitation force) with stator and rotor is calculated by 3D-FEM with 75% in design current. If inclination angle is large, generated force is also large. However, if the displacement of Z-axis is greater than 0.5mm, the force will become low rate of increase or will decrease. The Z-axis force for levitating the rotor in design is approximate 0.11N per the rotor tooth. Therefore, the inclination angle of the rotor and the stator is decided to be approximate 7.5 degrees.

B. Form of tooth edge

A taper of tooth edge is applied to reduce a change of the magnetic force by angle of rotation of the rotor. Calculations by 3D-FEM ware carried out using design dimension. Figure 8 shows a comparison of attractive force in case of 0.5mm depth and 1mm length of taper and in case of without taper, and indicates that the taper is functioning, and change of magnetic force is decrease. The variation of force becomes small with the increase in current, therefore the taper is acting effectively.

C. Power transmision to rotor

The coil for electric power transmission shown in Figure 9 is attached in the center of rotor not as the method of exciting rotor coil directly but as the method of transmitting electric power to rotor coil indirectly. In order that an electric power transmission coil may increase transmission efficiency, Spider winding applies a coil winding method, and uses resonance by

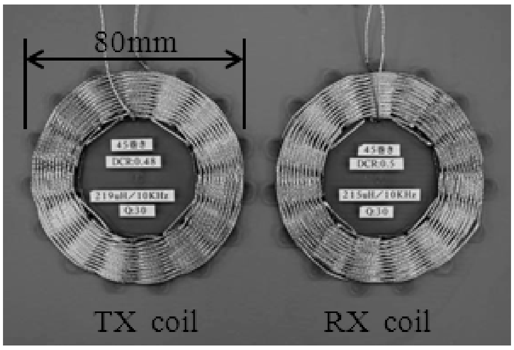


Figure 9. Wireless power transmission coil.

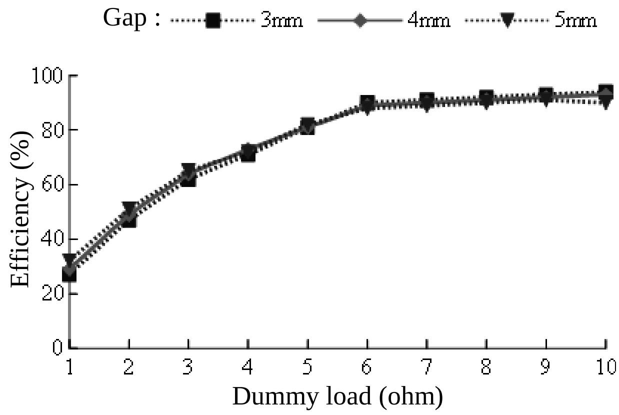


Figure 10. Power transmission efficiency.

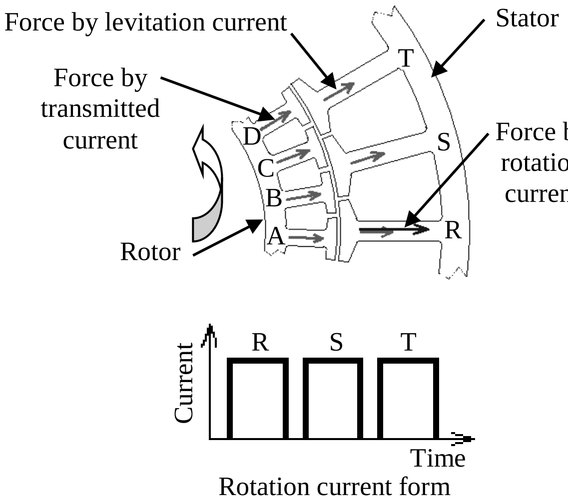


Figure 11. Principle of rotation.

a capacitor for primary side (fixed side). The result of having measured the electric power transmission efficiency in which load resistance and a coil gap were changed is shown in Figure 10. The estimate value of rotor coil resistance is about 5.5ohms, and transmission efficiency of 5.5 ohms is 80% or above showed in Figure 10.

D. Levitation and XY position control

If large displacement of Z-axis rotor position does not occur, since the rotor position restores to an initial position passively, the levitating position of Z-axis of the rotor is controlled to the initial position. On the other hand, the displacement of XY-axis of the rotor is controlled actively. XY-axis position of the rotor is measured by displacement sensors, and the positions are controlled using the measured value. Specifically, if a X-axis displacement of the rotor occurs, the current of U2x coils in Figure 4 is fixed and the current of U1x coils in Figure 4 is changed. The relative force of X-axis between the rotor and the stator is changed, accordingly the rotor moves by this action of the force. In case of Y-axis, it carries out by the same method with V1x, V2x, W1x and W2x coils in Figure 4.

E. Rotation control

The magnetic pole of the stator on one layer which opposes the rotor is fixed N pole or S pole. By moving the tooth of N pole or S pole with the strong magnetic force of the stator, a force works between stator and rotor then the rotor rotates by difference of force on the rotor teeth shown in Figure 11. In Figure 11, the generated force between tooth A of the rotor and tooth R of the stator is largest, therefore the tooth A of the rotor is rotated to front of the tooth R of the stator. Rotation control coils of the stator are arranged to rotate the rotor, and resupplied rectangle wave current one by one as shown in Figure 11. Figure 12 shows the rotation force by calculation with 3D-FEM. The rotate angle by one pulse is 3.75 degrees, therefore 96 pulses are required for one rotation.

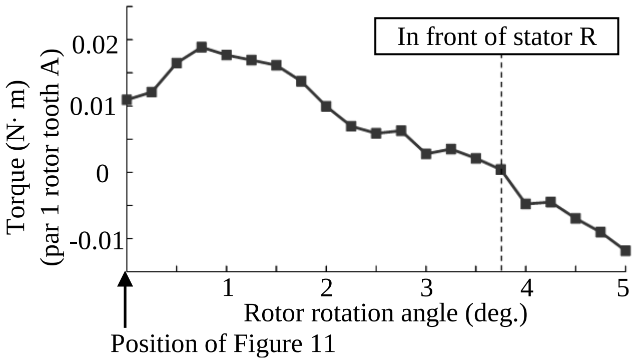


Figure 12. Calculated rotation force (1/8 model).

V. Conclusion

The tow layer flat monopolar type bearing loess motor using full wave rectification circuit which does not use permanent magnet was proposed. It was shown from the experiment and the simulation result that levitation force can be efficiently acquired by that it is possible to send electric power efficiently with an electric power transmission coil and using inclination of the tooth of the opposite side of the rotor and the stator. We think it is possible to realize the proposed bearing loess motor from these results. After this, a proto type motor will make for experiment, and the details of these proposal will verify.

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