# Development of MC Type Magnetic Levitation System Using Resonance Type Contactless Power Supply

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***Abstract*— This research focuses on A MC type Lorentz force magnetic levitation system using resonance type contactless power supply. A novel prototype of the levitation system is designed and implemented. In addition, control analysis and experimental verification of a practical levitation system are conducted to demonstrate the validity of the proposed system.**

## I. Introduction

Magnetic levitation systems have received much attention among researchers over the last two decades. The system is used for support the target objects by non-contact force. i.e., electromagnetic force. The system has many valuable applications. e.g., transportation system, floating devices in special environment, vacuum or clean room, to solve the problems of dust, friction and so on.

In general, magnetic levitation systems use their levitation force by an attraction force between electromagnets and its fellow magnetic bodies. In particular, the magnetic force is very large. Hence, the target position of the object is easy to control using the attractive force of electromagnets. However, the force is nonlinear to the input current and the position of the object.

There are types two types of moving object in magnetic levitation system, that is, Moving Coil (MC) and Moving Magnet(MM). In our system design and implementation, MC type magnetic levitation system is chosen because it is one of the most practical application and the floating a coil is easy to control.

This paper presents a novel MC type of magnetic levitation system. The method of floating is using Lorentz force between permanents magnet and a floating coil, Electromagnets are used for stability. And the current for the floating force is supplied by wireless power transfer. The prototype of floating system is introduced, and noncontact floating examinations verify the feasibility of the proposed floating system.

This paper is organized as follows, Section II gives a brief overview of prototype of floating system. Section III demonstrate the components details of the proposed system. Section IV gives a system analysis based on an inspection of the floating device. Section V demonstrates the stability of the levitation system. Section VI describes the control method which applied to the system. Section VII summarize the control system. Section VIII, describes a reading method of the sensor. Section IX shows the experimental examinations in both vertical and horizontal directions. Finally, conclusion is given.

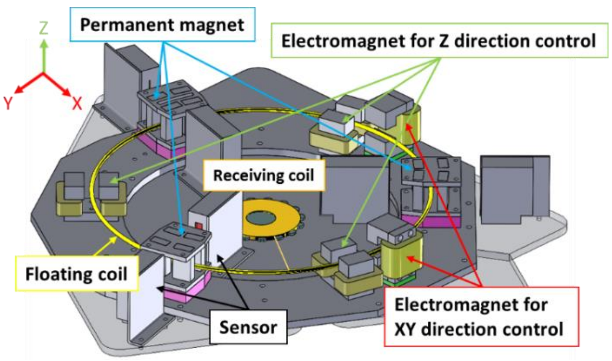


Figure 1. The proposed design of magnetic livitation system

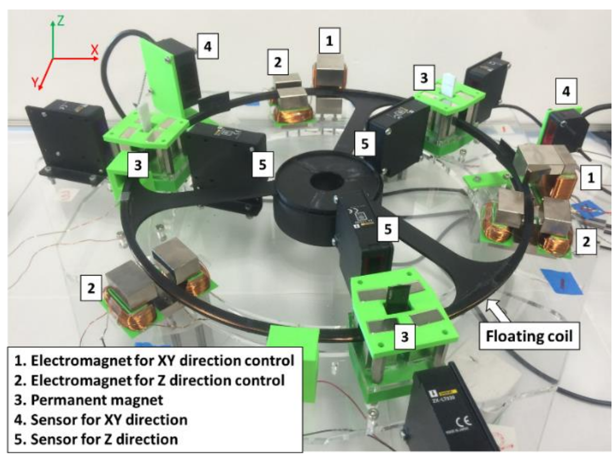


Figure 2. Photograph of prototype proposed structure

## II. PROTOTYPE FLOATING SYSTEM

An illustration of the magnetic levitation system design is shown in Fig. 1. Fig. 2 shows the proposed hardware implementation prototype. In the figure, Current of the floating coil is supplied from the receiving coil through wireless power transfer which is converted to direct current by rectifier circuits. Floating coil is installed between electromagnets and permanent magnets. Using this setup, Lorentz force is generated between magnets and the current of the floating coil, floating coil is able to levitate. Three permanent magnet sets are used in order to support the weight of the floating coil, three electromagnet pairs are used for the vertical position control and two electromagnets is used for the horizontal position control.

## III. Details of Components

### A. Permanent Magnet

The permanent magnet is made from the neodymium magnet. The magnet dimension is given as follows: height 40[mm], width 20[mm], and thickness 10[mm]. The magnetized direction of the magnet is 10[mm], the gap of magnetized direction is 15[mm], the gap between magnetized direction and vertical is 10[mm]. Four permanent magnets were grouped into one permanent magnetic component. Three of them were placed around the floating coil. The position of each permanent magnet was fixed by the jig which made from machined acrylic board and 3D printer.

### B. Electromagnet

The electromagnet used rolled steel for general structure. The coil of the electromagnet used UEW line of 0.5[mm] in diameter and wound up 150 times. Three electromagnets for XY direction control and two electromagnets for Z direction control were placed around the floating coil.

### C. Floating Coil

The floating coil used UEW line of 0.5[mm] in diameter, form a circle of 0.5[mm] in diameter, and wound up 50 times. The floating coil was wound up the bobbin which were made from 3D printer. This is because, the distortion could occur without using bobbin which caused unreliable Lorentz force between magnets, integration of a floating coil and receiving coil.

### D. Sensor

The surface position of the XY direction is detected by three transmissivity laser sensors. The surface position of the Z direction is detected by two reflecting laser sensors. The detection of the sensor was enable once the shield is attached to the bobbin.

### E. Contactless Power Supply

Resonance type contactless power supply consists of two parts that transmission circuit and receiving circuit as shown in Fig. 3. Table1. shows the specification of the circuit diagram. In the figure, receiving parts of contactless power supply is placed in the center of the bobbin and float with the floating coil.

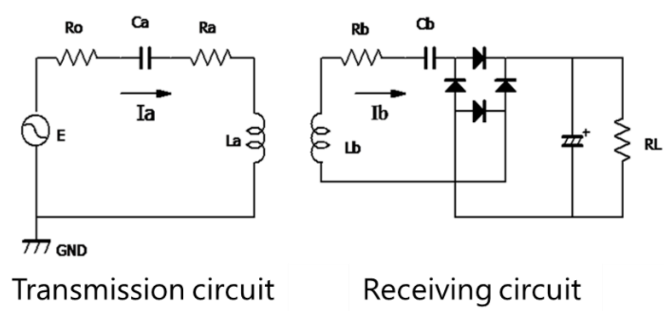


Figure 3. Circuit diagram of the device

TABLE I. SPECIFICATION OF THE CIRCUIT DIAGRAM

| Name | Sign |
|---|---|
| AC voltage | $E$ |
| Internal resistance | $R_0$ |
| Condenser transmission side | $C_a$ |
| Inductance transmission coil | $L_a$ |
| Resistance transmission coil | $R_a$ |
| Electric current transmission circuit | $I_a$ |
| Inductance receiving coil | $L_b$ |
| Resistance receiving coil | $R_b$ |
| Condenser receiving side | $C_b$ |
| Electric current receiving circuit | $I_b$ |
| Resistance of a floating coil | $R_L$ |

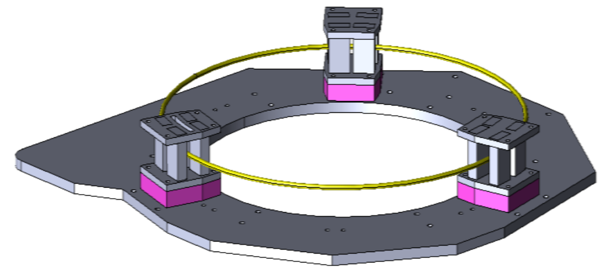

Figure 4. Analytical model

## IV. Inspection of the Floationg

It is necessary to generate Lorentz force more than 2.1[N] between a floating coil and permanent magnets in order to levitate the floating and receiving coils, and receiving circuit follows:

$$F \geq (m_{b1} + m_{b2} + M)g \times 10^{-3} \tag{1}$$

where $m_{b1}$is mass of the receiving coil,
$m_{b2}$is mass of the receiving circuit,
$M$ is mass of a floating coil.

The total mass , $m_{b1} + m_{b2} + M$, in Eq. (1) is 215 [g]. The sufficient Lorentz force is required to levitate the receiving parts between a floating coil and permanent magnets. Therefore, current that flow through the floating coil was examined. To do that, a relationship between size and corresponding Lorentz force, which occur between permanent magnets and current to flow a floating coil, is next investigated through electromagnetic field analysis software JMAG.

In the analysis condition, six permanent magnets are used, a copper wire, with 0.5[mm] in diameter and wound up to 50 times, is used as the floating coil. The floating position, which was measured the bottom of the permanent magnet, is 20[mm]. The electric current of the floating coil was approximately 2.0[A] which analyzed every 0.1[A].

The analytical result is shown in Fig. 5. In the figure, it is shown that if it could supply an electric current more than 0.8[A], then floating power is enough to levitate the floating coil.

## V. Stability of Levitation

Magnetic flux around two permanent magnets which were installed on the both side of the levitated coil is illustrated in Fig. 6. In the figure, magnetic flux flew from N pole to S pole

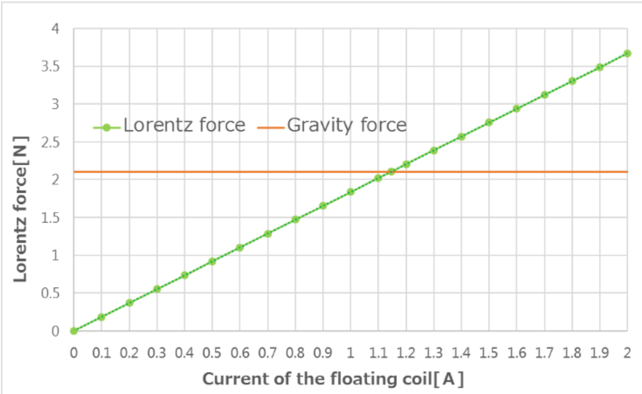


Figure 5. Analytical result obtaied from JMAG

of the other magnet between 2 magnets. The upper two magnets and the lower two magnets generate magnetic flux flowing from N pole to S pole of same magnet. Therefore, the direction of Lorentz force depends on position of the floating coil. Fig. 7 shows the direction of Lorentz force and magnetic flux in various points around two permanent magnets.

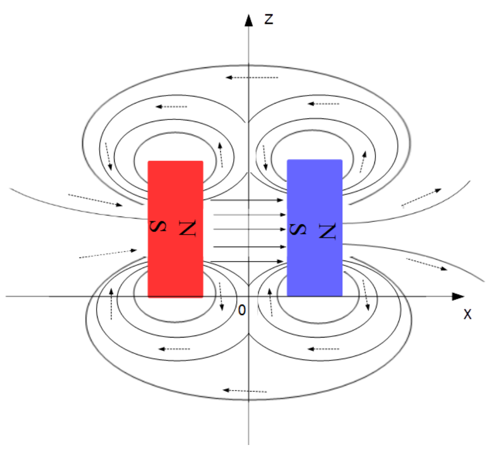


Figure 6. Lines of magnetic flux around two permanent magnets

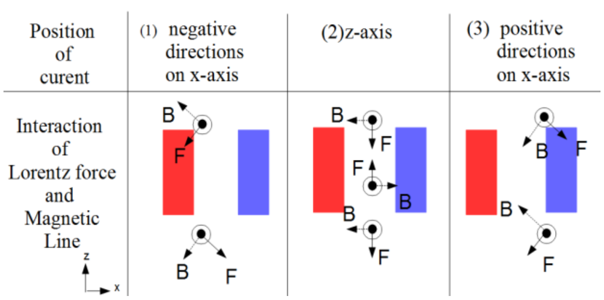


Figure 7. Direction of Lorentz force and magnetic flux in various points around two permanent magnets.

## VI.CONTROL METHOD

For the complete contactless floating, active controls for vertical direction and horizontal directions are required. For completeness, two types of electromagnets are used as shown in Fig. 8. In the figure, the left-side of figure illustrates a vertical control magnet and the right-side of figure illustrates a horizontal control magnet.

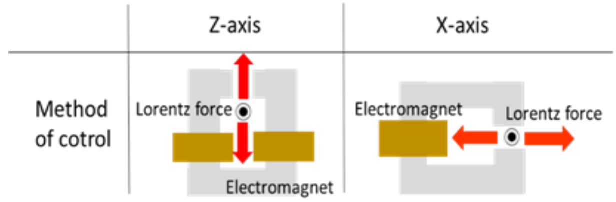


Figure 8. Control method

## VII. SUMMARY OF THE COTROL SYSTEM

Summary of the whole control system is shown in Fig. 9. Floating position of floating coil between the permanent magnets was measured by three transmissivity laser sensors. Horizontal position was measured by two reflecting laser sensors.

First, the positions were measured with each sensor and consequently digitized by an A/D converter. Second, the signal was received from DSP board transmitting to PC which the data is able to calculate by MATLAB/Simulink program. Third, the digital signal is conversed analog by a D/A converter. Last, an electric current amplified by an amplifier is supplied to each electromagnet.

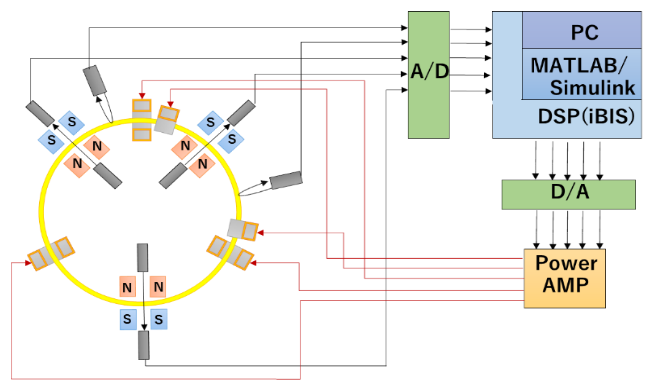


Figure 9. Summary of the control system

## VIII. READING METHOD OF THE SENSOR

Three shielding for reading a floating position between permanent magnets and two shielding for reading a horizontal position are attached to a floating coil as shown in Fig. 10.

In the case of the vertical direction reading, the amount of receiving light is indicated the change of the vertical direction obtained from three transmissivity laser sensors as shown in Fig. 11. In contrast to the vertical direction, the reading of the horizontal direction is measured by the change of the distance of reflection of light by two reflection laser sensors as shown in Fig. 12.

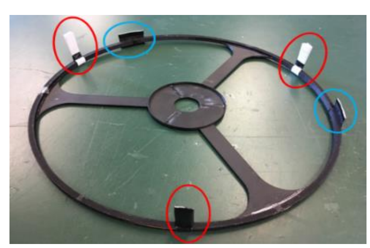

Figure 10. Shielding position

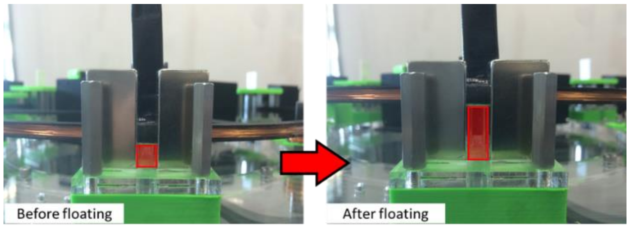


Figure 11. Reading of vertical direction

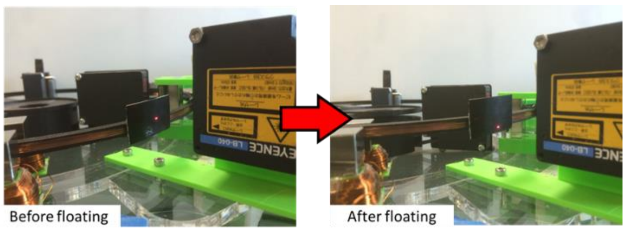


Figure 12. Reading of horizontal direction

## IX.EXPERIMENTAL EXAMINATIONS

### *A. Control in the vertical direction*

The floating coil can move up to 8[mm] range in the vertical direction. The reference position is set to 4[mm] height in this study. The current of the electromagnets is determined from PID compensation. Fig 13 shows the measurement results of the positions of the three magnets. From the result of vertical control, all the position values are converged to 4[mm]. This confirm that the experiment is succeeded. The floating coil is levitated to meet the reference position in the vertical direction.

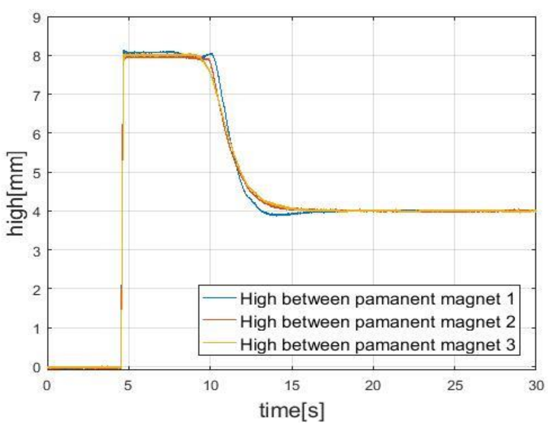


Figure 13. Result of vertical control

### *B. Control in the horizontal direction*

The floating coil can move up to 6[mm] range in the horizontal direction. The reference values are set to 4[mm] in this study. The current of the electromagnets is also determined by PID compensation. The horizontal sensors are located as shown in the Fig. 14. Due to the limited space on the prototype, electromagnets controlling in the horizontal directions are thus located on the axes of X and Y. We calculate the following equations and obtain the position of each X and Y axes as follows:

$$X = (-\textcircled{1}) \times \cos 15 + \textcircled{2} \times \cos 45 \qquad (2)$$

$$Y = (-\textcircled{1}) \times \sin 15 + (-\textcircled{2}) \times \sin 45 \qquad (3)$$

The results are shown in Fig. 15. In this experiment, we first controlled the vertical direction, then the control of the horizontal direction was activated at 20 seconds. Horizontal position control made a floating coil to move approximately 1~2[mm] in the vertical direction. In particular, all the position values are converged to the reference values. This confirms that the experiment was indeed succeeded. The reason of vertical movements is that the distance between vertical electromagnets and horizontal electromagnets is very near and the generation force of horizontal magnets affects the force of the vertical electromagnets.

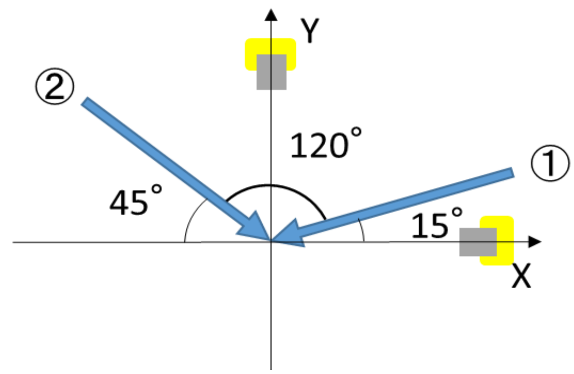


Figure 14. Input value to the electromagnet

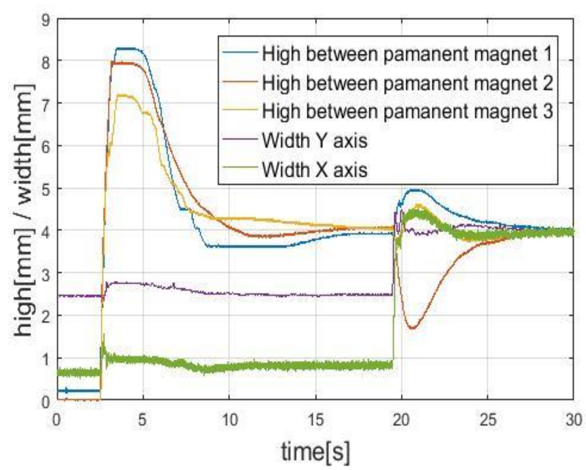


Figure 15. Result of horaizontal control

## X. CONCLUSIONS

A magnetic levitation system using Lorentz force was proposed. The vertical and the horizontal control method were investigating and the experiment of the noncontact levitation was succeeded.

## XI.FUTURE WORK

As the final goal, we consider that a floating coil can turn like a motor by adjustment direction of the Lorentz force to work on a floating coil. Therefore, it is thought that it is necessary to perform the design of an electromagnet producing the Lorentz force that can turn a floating coil. In addition, the shape of the current floating coil is interfered with magnets and sensors and cannot turn it. Therefore, it is necessary to design the new floating coil.


## *ACKNOWLEDGEMENTS*

*I am deeply grateful to Chiramathe Nami.*


## REFERENCES


[1] Masako Tanaka, Yuto Oguri, Koichi Oka and Akinori Harada, "Magnetic Levitation System Using Wireless Power Supply and Lorentz force – Experimental Examination of Levitation Performance –", The 5th Japan-Korea Joint Symposium on Dynamics & Control, program J3.