PM-Biased AC Magnetic Suspension Having Energy Transfer Function

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ABSTRACT

A novel AC magnetic suspension with a permanent magnet is proposed which has the performance of noncontact energy transfer to the suspended object (floator). The permanent magnet is used for suspending the weight of the floator. An electromagnet combined with permanent magnet operates for both stabilization and energy transfer to the floator. The principles of the proposed magnetic suspension system, an apparatus manufactured for experimental study and several experimental results are presented.

INTRODUCTION

One of the advantages of magnetic suspension is the property of being free of contact. When energy is consumed in the floator, either wire connection between the suspended object and ground facilities or the installation of a battery on the object is necessary. However, the former breaks the noncontact property. In the latter, exchanging or recharging a battery is unavoidable.

To overcome such problems, a novel AC magnetic suspension with a permanent magnet is proposed in this paper. The permanent magnet is used to suspend the weight of the floator. An electromagnet combined with the permanent magnet is used for both stabilization and energy transfer to the floator.

This paper is organized as follows. First, the principles of the proposed magnetic suspension system are presented. Second, an apparatus manufactured for experimental study is shown. Third, several experiments carried out with the apparatus are presented to demonstrate the fundamental properties of the proposed magnetic suspension system.

PRINCIPLES OF MAGNETIC SUSPENSION

Basic Structure

The basic structure of the proposed system is shown by Fig.1. The proposed magnetic suspension system has three main components. The first component is a primary circuit comprised of a primary coil and a constant voltage AC supply. The second component is a secondary circuit comprised of a secondary coil and a variable electrical load. The third component is a permanent magnet that provides main suspension force.

For energy transfer from the ground to the suspended object, the principle of transformer is utilized. When AC voltage is applied to the primary coil, the magnetic flux in the core wounded with the secondary coil has a DC component and a sinusoidal component that are produced by the permanent magnet

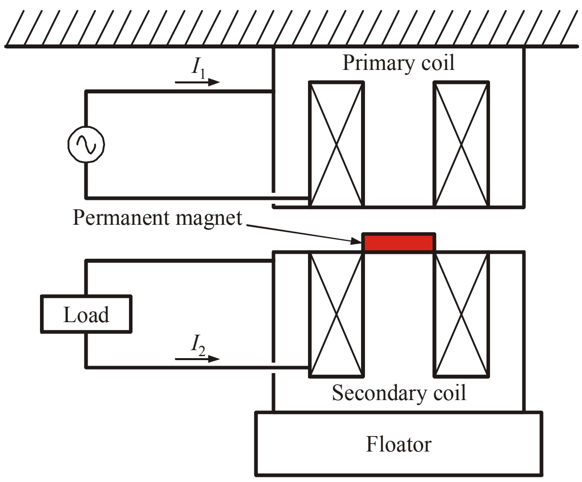

FIGURE 1: Basic structure of PM-biased AC magnetic suspension

and the primary electromagnet, respectively. An electromotive force is induced in the secondary coil due to the second component so that energy can be transferred onto the suspended object.

The secondary coil is also used for the stabilization of the suspension system. The amplitude of the secondary current changes in relation to the load of secondary circuit. When there is no DC component, therefore, the suspension force can easily be adjusted by the impedance of the secondary circuit; the suspension force becomes largest when the secondary circuit is open, and smallest when the secondary circuit is shorted [1, 2]. However, when a large DC component exists, the suspension force cannot be controlled in such a simply way because the average force is almost independent of the amplitude of the secondary current as shown in Fig.2.

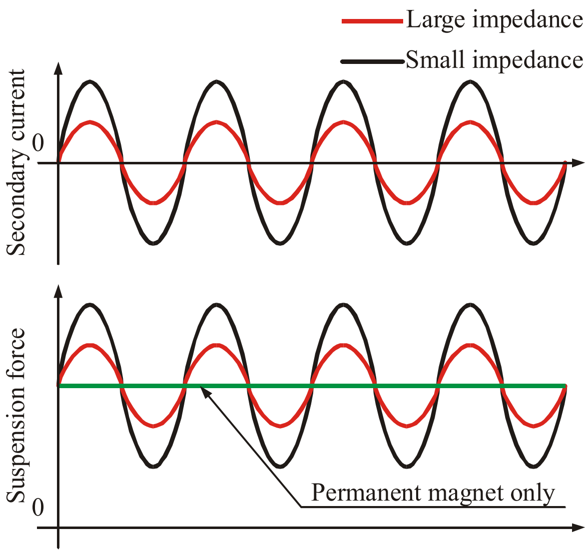

FIGURE 2: Relation between the impedance and the suspension force

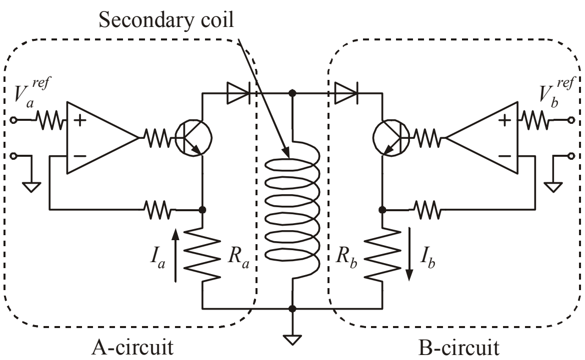

FIGURE 3: Impedance control circuit

Impedance Control Circuit

To overcome the above-mentioned problem, it is proposed to use a special impedance control circuit in which the impedance is altered according to the direction of current flowing in the circuit. It is to be noted that the suspension force becomes smaller when the direction of the secondary current is positive and larger when the direction is negative.

The proposed impedance control circuit is shown in Fig.3. It has two parts denoted by A- and B-circuit. The secondary current flows only in the direction of I_a (negative direction) in the A-circuit while it flows only in the direction of I_b (positive direction) in the B-circuit. The currents I_a and I_b are limited by the input signals V_a^{ref} and V_b^{ref}, respectively. The average of the suspension force can be adjusted by them. For example, when $V_a^{ref} > 0$ and $V_b^{ref} = 0$, the average force increases, and when $V_a^{ref} = 0$ and $V_b^{ref} > 0$, it decreases. To achieve stable magnetic suspension, V_a^{ref} and V_b^{ref} are changed according to the motion of the floater.

EXPERIMENTAL SYSTEM

Figures 4 and 5 show a photograph and a schematic drawing of the fabricated experimental apparatus. They have three pairs of primary and secondary electromagnets with permanent magnets for three-axis active control in the vertical direction. The three secondary electromagnets are fixed to the floator that is a rectangular steel plate. The locations are shown in Fig.6. When the apparatus is used for single-axis control experiments, the floator is supported by a shaft with bearings at one side to rotate about the shaft as shown in Fig.5. When it is used for three-axis control experiments, the shaft is removed so that the floator can levitate without any mechanical contact.

The primary and secondary electromagnets have a laminated core made of silicon steel plate and a 330-turn coil. An AC power supply connects with the primary coil. Its output is kept constant with amplitude of 30V and a frequency of 150 Hz in the following experiments. The secondary coil on the suspended object connects with the impedance control circuit shown by Fig.3. Forty small ring-shape permanent magnets are attached to the core of the secondary electromagnet. The diameter and thickness of a permanent magnet are 3mm and 0.6mm, respectively.

Three eddy-current gap sensors are located under the floator; their locations correspond to those of the secondary electromagnets. Their outputs are inputted to a DSP-based digital controller. The controller calculates V_a^{ref} and V_b^{ref}, and outputs them to the impedance control circuit through D/A converters.

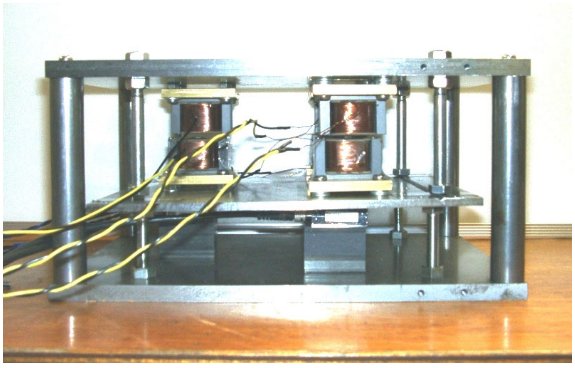

FIGURE 4: Photograph of the fabricated experimental apparatus

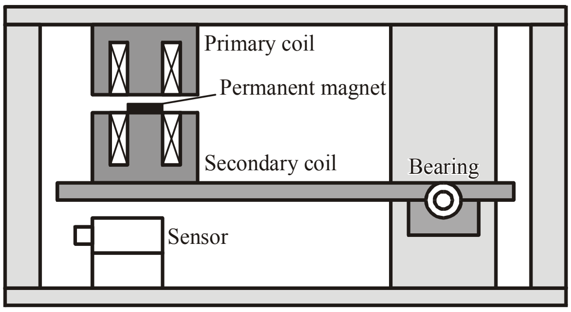

FIGURE 5: Schematic diagram of the fabricated experimental apparatus for single-axis experiments

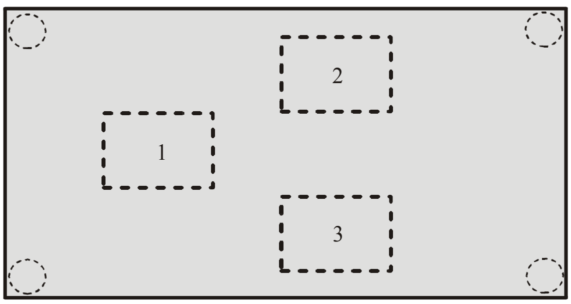

FIGURE 6: Locations of the suspension magnets (top view)

EXPERIMENTAL RESULTS

Measurement of Suspension Force

The suspension force of one magnet driven by the impedance circuit is measured. In measuring, the secondary electromagnet is fixed to a force sensor. The relation of the secondary current and the suspension force is shown in Fig.7. In this graph average current and average force are shown. As mentioned in the Section of Impedance Control Circuit, the suspension force increases when $I_a > 0$ and decreases when $I_b > 0$. It is found that the ratio of decrease in force to I_b is about eight times that of increase to I_a.

Realization of Suspension

First, single-axis control experiments were carried out. Only the electromagnet 1 was operated. The inputs to the impedance control circuit V_a^{ref} and V_b^{ref} were changed according to PD control. Figure 8 shows the displacement of the floator and the secondary current when stable magnetic suspension is achieved. Since the

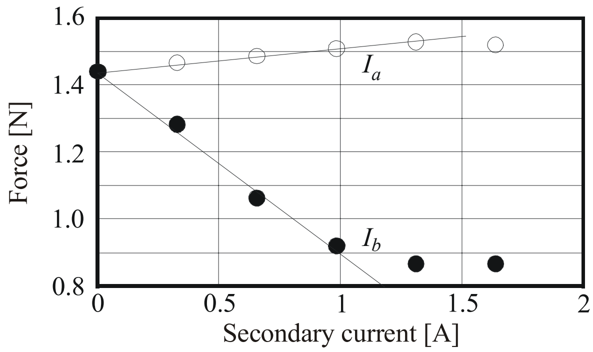

FIGURE 7: Relation between the suspension force and the secondary current

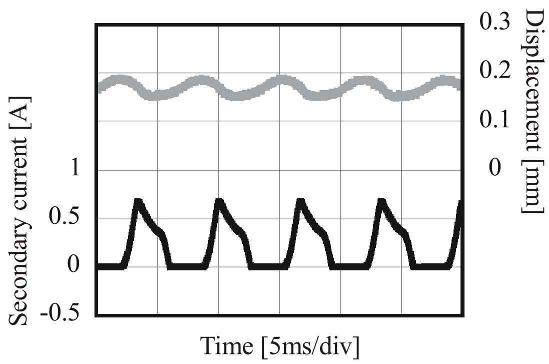

FIGURE 8: Displacement of the floator and the secondary current in the single-axis control

floator is suspended at positions higher that the reference point, the controller produces a control signal to decrease the suspension force so that the secondary current flows only in the positive direction (I_b). The deviation of the floator position is due to the applied AC voltage to the primary circuit. Figure 9 shows a step response of the suspension system; a stepwise signal is superimposed upon the control signal. It is shown that the secondary current is controlled according to displacement of the suspended object. When the position of the floator is lower than the reference point, the secondary current flows only in the negative direction for the suspension force to increase. When the position is higher, in contrast, the secondary current flows only in the positive direction. These results demonstrate that the developed impedance control circuit works well as described in the previous section.

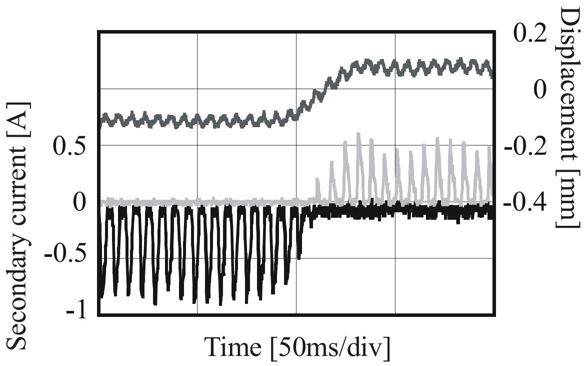

FIGURE 9: Step response of the single-axis suspension system

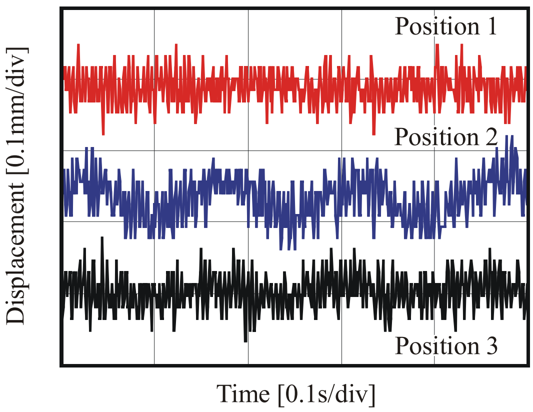

FIGURE 10: Vertical displacements of the three-axis suspension system

Second, three-axis control experiments were carried out. The shaft was removed from the apparatus and the three electromagnets were operated. An individual PD control was applied for stabilization. Figure 10 shows the displacements of the floator at the sensor positions. This result demonstrates that the floator has been actually suspended without any mechanical contact by the proposed AC magnetic suspension system.

CONCLUSION

A new AC magnetic suspension system with the performance of energy transfer to the floator was studied in this paper. It uses permanent magnets for suspending the weight of the floator. It was shown that the average suspension force can be adjusted with an impedance control circuit in which the amplitude of the positive secondary current and that of the negative secondary current are separately controlled. An experimental apparatus was fabricated which has three pairs of primary and secondary electromagnets with permanent magnets for three-axis active control in the vertical direction; the three secondary electromagnets are fixed to the floator that is a rectangular steel plate. The efficacy of the fabricated impedance control circuit was confirmed by the single-axis control experiments. By operating the three secondary electromagnets, the floator was successfully suspended without any mechanical contact.

Further study is under way for improving both suspension and energy transfer performances.

REFERENCES

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