Development of a Solar Photovoltaic Magnetic Suspension System

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Abstract

Extra low-power suspension in gravitational field is achieved by a magnetic suspension system whose power source is solely solar photovoltaics. Presently, solar photovoltaic cells become more efficient and cost-saving year by year. In this study, solar photovoltaic generation technique is combined with the zero-power magnetic suspension. The zero-power control achieves the steady state in which the attractive force produced by the permanent magnets balances the weight of the floator and the control current converges to zero. In this system, the power necessary for generating the suspension force is very small. However, the peripheral devices including sensors and a controller need power for operation. The power consumed in the peripheral devices becomes dominant in the total power in the steady state. In this work, dedicated power-saving peripheral devices are newly fabricated. The average power consumed in the electromagnet is 20[mW] to suspend a 90-glam mass, while the power consumed in the peripheral devices is 24[mW]. The photovoltaic cells used in the apparatus has a maximum power capacity of about 2[W] in the summer sunlight of 120[kLx]. The system achieves stable suspension even under the illuminance of a fluorescent lamp of 7[kLx].

1. Introduction

Magnetic suspension is widely used in various fields. Active magnetic suspension needs energy supplied from an external power source for the operation. In applications such as space instruments and carrier systems in clean room, low energy consumption is strongly required. Virtually zero-power magnetic control has been used to minimize the energy consumption during operation. It is applicable to magnetic suspension systems using a hybrid magnet for generating suspension force[1,2]. This control achieves the steady state in which the attractive force produced by the permanent magnets balances the weight of the suspended object (floator) with the electromagnets used to achieve stabilization and the control current converges to zero. There is no steady energy consumption to achieve stable suspending. Since there is no steady energy consumption for achieving stable levitation, it has been applied to space instruments [3,4]. However, some external power supply is still necessary for the operation. So the power source will be discussed in the next.

Solar photovoltaic generation systems have been widely used in houses recently. Solar photovoltaic cells become more efficient and cost-saving year by year as a countermeasure against global warming. The fluctuation of photovoltaic power is large because its output power depends on illuminance. Therefore, a power storage and buffered system including batteries or capacitors is necessary to photovoltaic power generation system when it is used in standalone. The electric double-layer capacitor is an electrochemical capacitor with relatively high energy density and high-current charge-discharge characteristics. Their energy density is typically almost two or three orders of capacity greater than conventional electrolytic capacitor of the same dimensions.

In this study, extra low-power magnetic suspension system is actualized by combining solar photovoltaic generation technique with the zero-power magnetic suspension. In addition, dedicated power-saving peripheral devices are newly fabricated to reduce the consumed power in the whole system as much as possible. Meanwhile, more power is necessary to levitate the floator at starting up than at steady state. An electric double layer capacitor is used to supply such power transiently. Since the leak current increases as the capacitance increases, the capacitor is carefully chosen to have an appropriate capacitance. The fabricated system achieved stable suspension even under the illuminance of a fluorescent lamp.

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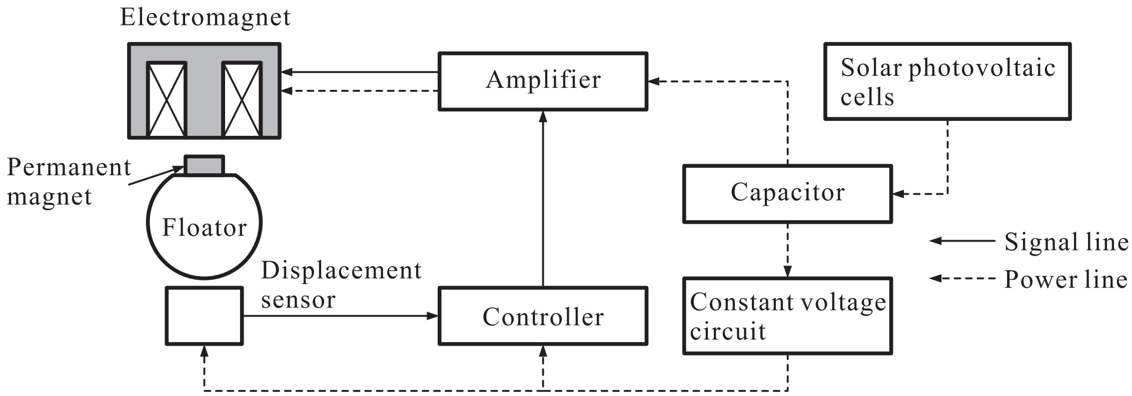

Fig. 1 Outline of solar magnetic suspension system.

2. System

2.1. Outline

Figure 1 shows the outline of the fabricated solar photovoltaic magnetic suspension system including the power supply flow. In this figure, solid and dashed lines represent signal and power flows, respectively. The magnetic suspension system have a floator with a permanent magnet, an electromagnet, a displacement sensor, a power amplifier and a controller. The solar magnetic suspension system has solar photovoltaic cells, a buffered capacitor and a constant voltage circuit for the displacement sensor in addition to these conventional components. The electric power generated by the solar photovoltaics is used to supply current to the electromagnet and the peripheral devices via the buffered capacitors. In the steady state, the theoretical consumed power of the electromagnet is zero under the zero power control.

2.2. Experimental apparatus

Figure 2 shows a photograph of the experimental apparatus. The height of the apparatus is 310[mm], and the diameter of the central part is 88[mm]. The central part has two arms and each arm has four photovoltaic cells. In this apparatus, the single-degree-of-freedom vertical translational motion is actively controlled while the other motions are passively stabilized by the edge effects of the magnet.

The floator is made of soft iron. It is a hollow sphere with an outer diameter of 43[mm] which equals that of a golf ball approximately. A disk shaped permanent magnet is attached to the top of the floator. It is made of ferrite material. The diameter is 15[mm], and the thickness is 4[mm].

The electromagnet has a solid core made of soft iron. The smallest cross section area of the core is 180[mm^2]. This electromagnet has a 1200-turn coil. The wire is 0.3[mm] in diameter and made of copper enameled with polyvinyl. The direct-current resistance of the coil is 12[ohm].

The solar photovoltaic cell is an amorphous silicon type. The shape is rectangular and the size and thickness are 75×55 [mm] and 2.3[mm], respectively. Table 1 shows the ratings of the photovoltaic cell. It was measured under the solar simulator 50 [kLx] nominal condition[8]. The four cells at each arm are connected in parallel. Then the pair is connected in series. This solar photovoltaic section generated almost 1[W] in total.

Figure 3 show a photograph of the circuits of the peripheral devices in the cylindrical head part of the apparatus. The power storage circuit has six double layer electrochemical capacitors.

Table 1 Nominal ratings of solar photovoltaic cell [5].

Parameter	Ratings
Typical open circuit voltage	7.7[V]
Typical short circuit current	22.3[mA]
Reference maximum power	114[mW]

A peripheral interface controller (PIC) is used as a controller. PICs are popular to industrial developers, hobby users and students due to their low cost, low consumed power, wide availability and low cost. The controller has a single-channel A/D converter and a five-channel digital I/O. It implements the zero-power control. The zero-power control is realized by feeding back the integral of the control voltage. The control signal is transmitted to a power amplifier with voltage output via a pulse width moderator in the controller. The controlled period is 1 [msec].

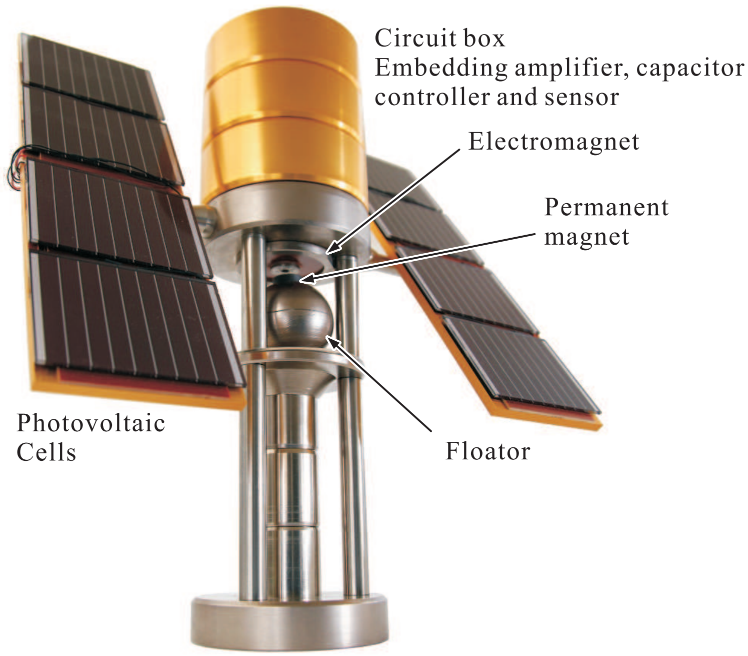

Fig. 2 Photograph of experimental apparatus.

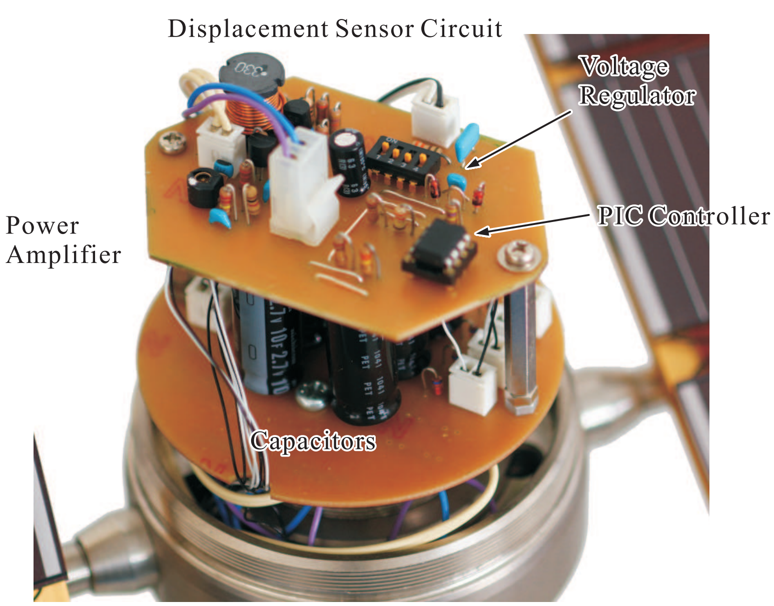

Fig. 3 Photograph of embedded electric board.

The fabricated amplifier is s voltage-controlled H-bridge constructed from two N-ch FETs, two P-ch FETs and two pre-driving resistor-equipped transistors for the P-ch FETs.

An inductive-type displacement sensor was fabricated for power saving. A typical commercially available eddy-current displacement sensor consists of an oscillating circuit, a resonator, a rectifier, a smoothing circuit, a linearizer and a stabilized power supply. The fabricated displacement sensor only uses two bi-polar transistors for resonation and rectifier. A stabilized power supply for the sensor is shared with the PIC. It is comprised of a fabricated constant regulative diode and a shunt regulator.

3. Experimental result

3.1. Consumption power

The consumed power in the experimental apparatus is measured. In this measurement, a 12-Volt constant power supply is substituted for the solar photovoltaic cells. The current is measured through a sensing resistor inserted to the circuit. Figure 4 shows an experimental result of the transient consumed power response when suspension starts. In this figure, the horizontal axis indicates time. The control for suspension starts at a time of 0[s]. The total consumed power of the peripheral devices is 24[mW] before the control starts. The consumed powers in the peripheral devices is 5[mW] in the PIC, 5[mW] in displacement sensor and 14[mW] in the power supply circuit. Commercially available displacement sensors with similar dimensions consumes electric power of more than 200[mW]. The fabricated sensor is more power-saving them.

The quiescent power of H-bridge amplifier is below 2[μW]. It is caused by the leak current of FETs, which is approximately 0.1[μA]. When the suspension control starts, the apparatus uses 800[mW] at maximum for the main suspension by the electromagnet transiently. Figure 5 shows an experimental time response of the consumed power in the steady-state suspension. The average total consumed power is 45[mW] approximately. The consumed power of the electromagnet is calculated by subtracting the peripheral devices power and the operating power amplifier from the total value. The consumed power of the electromagnet for the static magnetic suspension is obtained as approximately 20[mW]. In addition, the apparatus in the standalone operation has a power loss of 10[mW] due to 0.5[mA/F] leak current of capacitors in the typical value. Therefore, this system uses approximately 60[mW] achieve suspension in the steady state.

3.2. Magnetic suspension by solar photovoltaic generated power

Figure 6 shows a experimental scene of suspension under a fluorescent lamp. The average illuminance of under 300 [mm]of a fluorescent lamp is 7[kLx]. Figure 7 shows a time response of voltage charged in the capacitor in the steady-state suspension. The capacitors start to charge from 10.1[V]. This figure shows generated power exceeds the consumed power during stable suspension so that the charged voltage rises with time. This apparatus can achieved static suspension by the solar photovoltaic power even under the 7[kLx] illuminance of a fluorescent lamp.

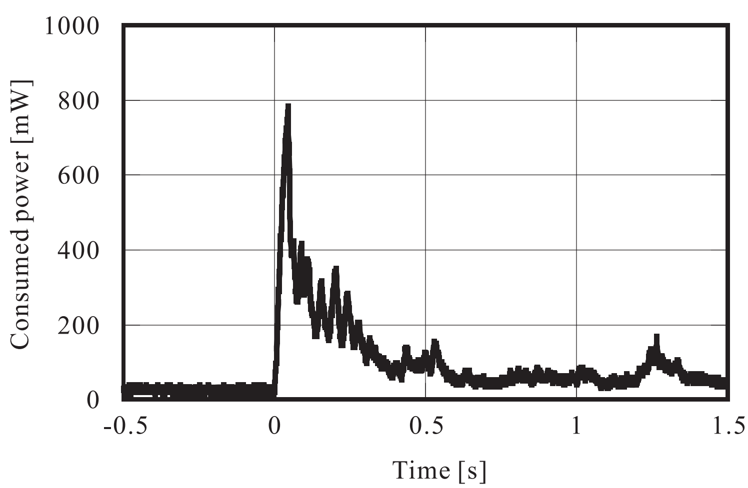

Fig. 4 Transient response of the consumed power when the suspension control start at 0[s].

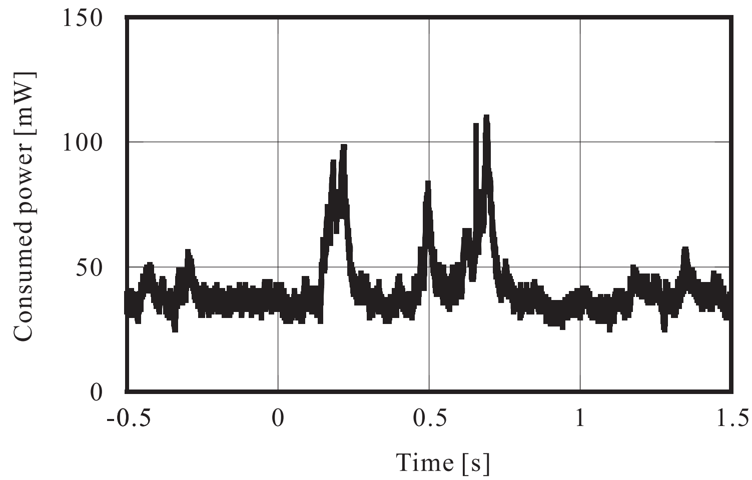

Fig. 5 Time response of the consumed power in the static suspension.

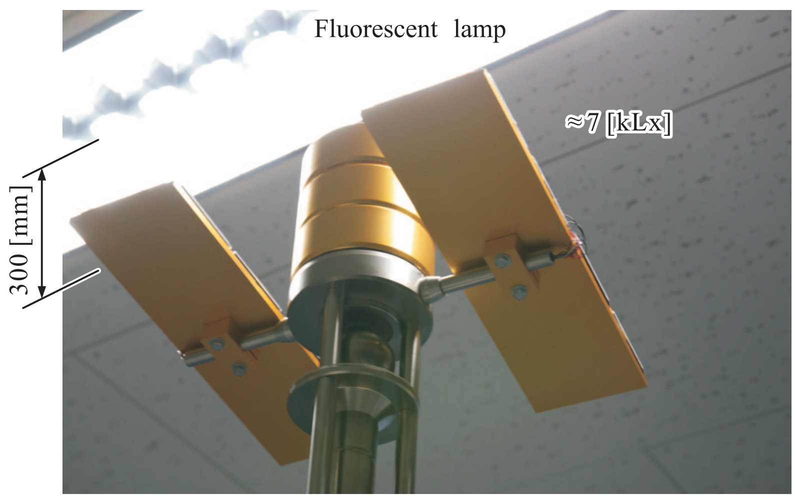

Fig. 6 Photograph of the magnetic suspension system under a fluorescent lamp.

4. Conclusions

A solar photovoltaic magnetic suspension system was fabricated. Dedicated power-saving peripheral devices were newly fabricated. The consumed power of the fabricated system was measured. The total consumed power was approximately 60[mW] in the steady-state suspension. The system achieved stable suspension even under the illuminance of a fluorescent lamp of 7[kLx].

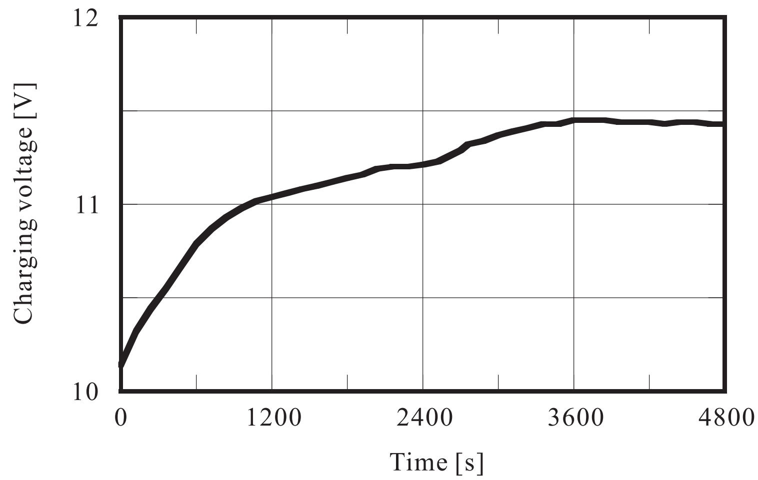

Fig. 7 Time response of the charging voltage at under the illuminance of the fluorescent lamp.

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