Fabrication of Non-contact Carrier System using Solar Magnetic Suspension

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***Abstract*— A solar-powered magnetic suspension carrier system is fabricated which achieves noncontact power supply to the carrier. There are two conventional methods of supplying power to a carrier. One is through wires or contacts such as pantograph and the other is a battery in the carrier. However, the noncontact characteristics are lost in the former, and stations for charging the battery are necessary in the latter. These problems are overcome by the proposed carrier system using solar magnetic suspension that can achieve continuous levitation. In rooms like in factory, the generation of power by solar cells is low so that the magnetic suspension needs power saving. A zero power control system is applied to the suspension of the floator. In addition, low-power peripheral devices are also fabricated.**

I. INTRODUCTION

Solar power generation systems need no mechanical motion, conventional fuel consumption and operating cost. These systems are widely used in houses recently because it is a countermeasure against global warming. Consequently, solar cells are becoming a popular and cost-saving green power generation source year by year[1]. Solar power systems are suitable for small outdoor standalone apparatus where electric power transmission infrastructure is not available. However, the power generated by a solar cell is sensitive to solar conditions because the generated solar power fluctuates due to illuminance. Hence, standalone systems powered by solar energy need buffered capacitors or batteries to operate even in low-illuminance environments including night and cloudy weathers while they are charged during daylight. Such buffered techniques regarding energy storage have been also progressive and lower in cost recently.

Magnetic suspension systems [2] are widely used in non-contact and friction-free suspension. Magnetic suspension has various fields of applications such as ultra high rotational speed bearings [3], rapid-transit carrier [4], guide for high-speed elevator [5], carrier systems in clean room [6], rotating gyroscopic sensors [7], space instruments [8] and blood pumps [9]. To control them, various control methods are proposed and applied. Among them, the zero-power control [10], [11] has been used in suspension system with combined electromagnet and permanent magnet (hybrid magnet). The zero-power control achieves the steady states in which the attractive force produced by the permanent magnets balances the weight of the suspended object (floator) the control current converges to zero. Because there is no steady energy consumption at the stable levitation, this method is used in energy saving devices.

A single-degree-of-freedom solar magnetic suspension system has been developed [12]. The system is combined with solar power generation and zero-power magnetic suspension technique. Dedicated power-saving peripheral devices are newly fabricated for solar magnetic suspension system. The system achieved the stable suspension of a 90-gram floator even under a fluorescent lamp of 5[klx].

This paper proposes to apply solar magnetic suspension to a carrier system. The conventional magnetic suspension carrier systems can be categorized into two types: guide rail with magnetic coils and magnetic coils on board the car. The former does not need supply to the car for suspension. However, this system needs a lot of magnetic coils along the rail. Therefore, this system is disadvantageous in installing cost. On the other hand, latter type needs a power supply to the carrier. There are two conventional methods of supplying power to the carrier. One is through wires or contacts such as pantograph and the other is a battery in the carrier. However, the non-contact characteristics are lost in the former, and stations for charging the battery are necessary in the latter. These problems are overcome by the proposed carrier system using solar magnetic suspension that can achieve continuous levitation without any external power supply. Therefore, this system keeps the non-contact property permanently.

In this paper, the magnetic suspension carrier system is assumed to be used in an indoor condition. Usually the illuminance of indoor is darker than sunlight. The solar cells produce small generation power. Therefore, it is necessary for the magnetic suspension system to become extremely power saving.

II. SOLAR MAGNETIC SUSPENSION CARRIER

A. Outline

Figure 1 shows the outline of the solar magnetic suspension carrier including the power supply flow. In this figure, solid and dashed lines represent signal and power flows, respectively. The unit of the magnetic suspension consists of an electromagnet with a permanent magnet, a displacement sensor, a power amplifier and a controller.

The carrier has three magnetic suspension units to control three degrees of freedom of motion. The power supply for the magnetic suspension units is common. The power supply has solar cells, a buffered storage device and a constant voltage circuit for the peripheral devices. The electric power generated by the solar cells are charged to the storage devices. The constant voltage power supply is for the displacement sensor and the controller.

B. Experimental apparatus

Figure 2 shows a photograph of the fabricated magnetic suspension carrier. The size of the apparatus is 340×200×160[mm]. The loading platform has six solar cells in three side two in each. The solar cell is amorphous silicon type, the shape is rectangular and the size and thickness are 167.5×148 [mm] and 0.4[mm], respectively. Table 1 shows the ratings of the solar cell [13]. The three magnetic suspension units are installed on the top plate of the carrier. They are used to control the three motions of the carrier: like perpendicular direction (*z*), rotation about the horizontal axis (*pitch*) and rotation about the rail direction (*roll*). The units are independently controlled. Horizontal direction (*x*) and rotation about the z axis (*yaw*) are passively stabilized by the edge effect of the magnetic fluxes.

Figure 3 shows a photograph of the magnetic suspension unit. The size of the unit is 60×50×55[mm]. It has a hybrid magnet, a pickup coil for displacement sensor and four touch down bearings. Figure 4 shows a flow diagram of magnetic suspension unit. Each magnetic suspension unit has a peripheral electric circuit.

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 an oscillator IC, a resonator, a diode rectifier and a RC smoothing circuit. The oscillator produces a rectangular-wave with a frequency of 1[MHz] and an amplitude of 3.3[V] (Fig. 4 (A)). The resonator consists a single FET, a pickup coil and a capacitor . The inductance of the pickup coil decreases as the gap between the pickup coil and the rail increases. The gap becomes larger when the carrier moves up. The resonance frequency increases as the inductance of the pickup coil decreases. The resonance frequency set to be lower than the oscillation frequency at any distance. The resonant frequency approaches the carrier frequency 1[MHz] when the gap increases. Thus, the output of the resonator decreases as the gap decreases (Fig. 4 (B)). The output is transmitted to the controller through a rectifier circuit (Fig. 4 (C)) and a low path filter (Fig. 4 (D)). This principle of rectifier and smoothing circuit is same as that of AM demodulating circuit.

A peripheral interface controller (PIC) is used as a controller. PICs are popular to industrial developers, hobby users and students due to their low consumed power, wide availability and low cost. The pin function of PIC is selectable by programing. The PIC for magnetic suspension controller uses a single-channel A/D converter, a single-channel enabled signal from the power supply circuit for active mode, two-channel direction signal of the coil current via amplifier and a single-channel PWM output. It implements the zero-power control. The zero-power control is realized by feeding back the integral of the control voltage. The controlled period is 1[msec]. The supplied voltage for the sensor circuit and PIC are 3.3[V].

Table 1 Nominal ratings of solar photovoltaic cell [13].

Parameter	Ratings
Typical open circuit voltage	4.7[V]
Typical open circuit current	175[mA]
Reference maximum power	517[mW]

Solar simulator 50 [kLx] nominal condition.

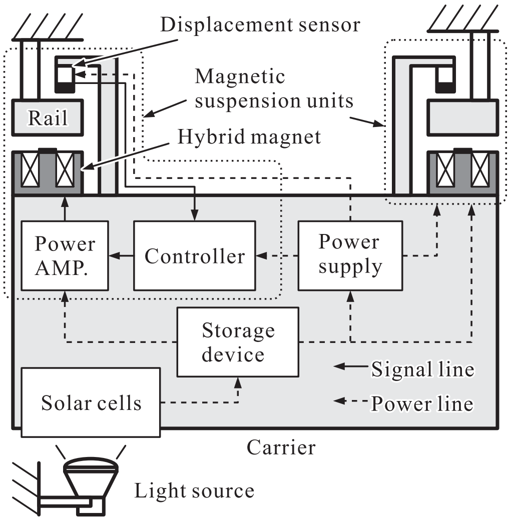

Fig. 1 Outline of solar magnetic carrier with signal and power flow.

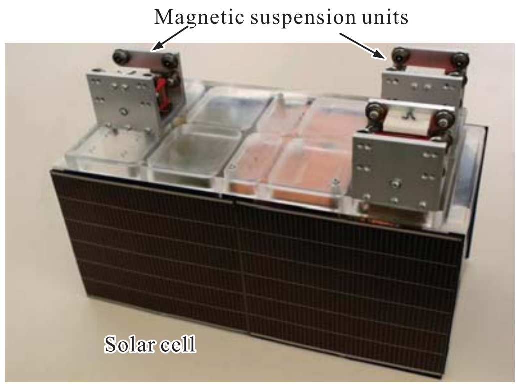

Fig. 2 Photograph of a magnetic suspension carrier.

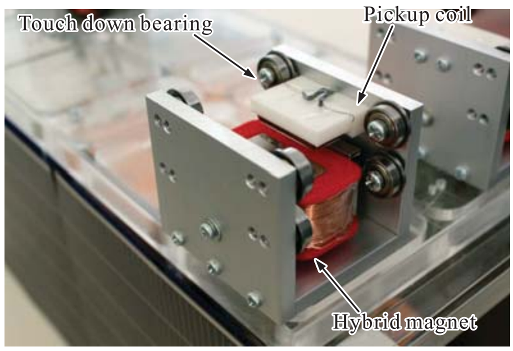

Fig. 3 Photograph of a magnetic suspension unit.

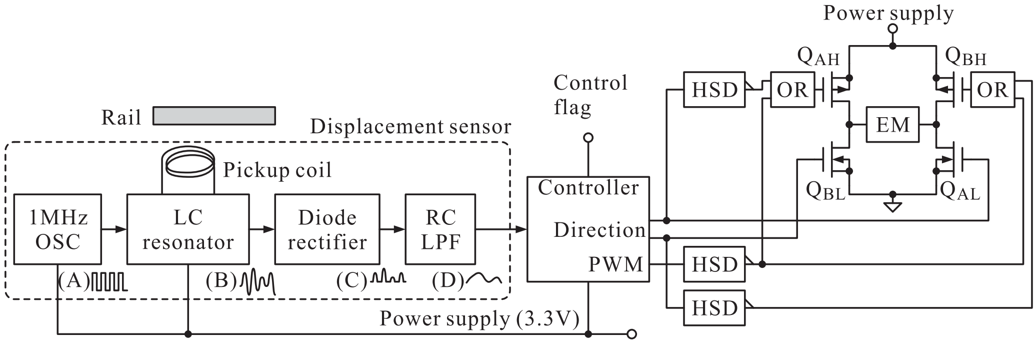

Fig. 4 Flow diagram of magnetic suspension unit.

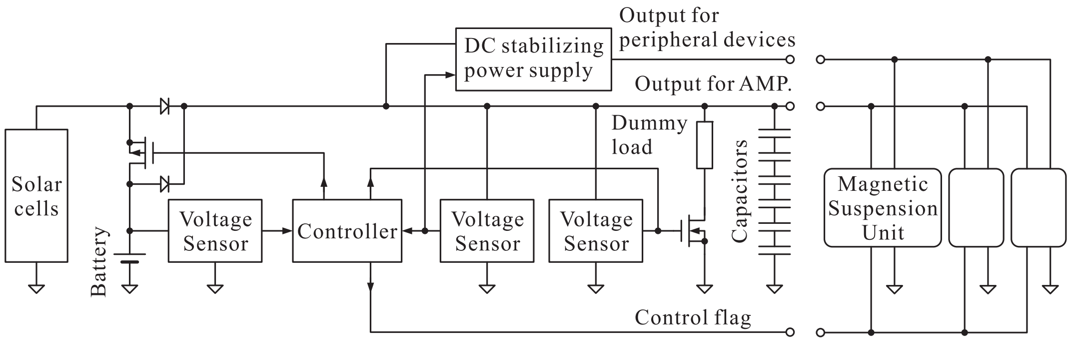

Fig. 5 Flow diagram of power supply circuit.

A fabricated amplifier is a voltage-controlled H-bridge constructed from two low side N-ch FETs (Q_{AL}, Q_{BL}), two high side P-ch FETs (Q_{AH}, Q_{BH}), three pre-high-side-driver FET (HSD in the figure) and two OR gates. The direction signal has 3 states of a positive, minus and zero. The high side FETs are driven by the compared signals. The signals compared direction signals with the PWM signal. When the direction signal is positive, Q_{AH} in PWM operation, Q_{AL} is turned on, and other side FETs (Q_{BH} , Q_{BL}) are kept turned off, and vice versa. When the control value is zero, all the transistors are turned off.

Figure 5 shows a flow diagram of power supply circuit. A power storage device is needed to a standalone active system using solely solar energy. The fabricated system uses electric-double-layer-capacitor and a nickel-hydrogen secondary battery for power storage. The energy density of typical electric-double-layer capacitors is hundreds to thousands times greater than that of a conventional electrolytic capacitor of the same dimensions [14]. The storage circuit of the fabricated system has six series-connected capacitors with parallel-connected balanced registers individually. The leakage currents are different among the capacitors. The voltage of the series-connected capacitors vary individually according to the leakage currents. The balancing registers balance the voltage for each capacitor. The capacity of the secondary battery is 200[mAh]. As shown later, magnetic suspension system consumes 350[mW]. Therefore, the expected levitation period is 4.8hours without solar power supply. The secondary battery has a constant voltage characteristic. Therefore, the output voltage of the power supply for the amplifier is approximately constant. When the generation power of the solar cells exceeds consumption power, the output voltage is raised and the current is decreased. If output voltage exceeds a threshold voltage, surplus power is consumed by a dummy load. When overvoltage or undervoltage, power supply circuit stops suspension control and charging for the battery.

III. Experimental Result

A. *Consumption power of peripheral devices*

The consumption power of the suspension unit was measured. The power of the H-bridge amplifier is 2.7[mW] with an applied voltage of 8.4[V] and no load. The power is consumed mainly in charging the gate-source capacitor in the FET and high-side-driver (HSD). The consumption power in the amplifier becomes zero when the coil current of the electromagnet is zero. The consumption power of PIC is 1.8[mW]. The average consumption power of displacement sensor is 0.7[mW]. Commercially available displacement sensors with similar dimensions consume electric power of more than 200[mW] [15]. The consumption power of peripheral device in the unit is 5.2[mW].

The consumption power of the power supply circuit was measured. The power loss due to leakage current of the electro-double-layer-capacitor circuit is 1[mW] in the case of 10[V].

When the charging voltage is high, the leakage current is large. The consumption power in the power supply circuit depends on the output voltage. The power consumption is 1.9[mW] at the other than the zero. The power of peripheral devices for floating is less than 20[mW] in the suspension system.

B. Consumption power at the floating

The consumed power of the experimental apparatus was measured. In this measurement, an 8.4-V power supply is substituted for the solar cells. The current is measured through a sensing resistor inserted into the circuit. Figure 6 shows an experimental result of the consumption power for hybrid magnet in the steady suspension. The average consumption power is approximately 330[mW] for the suspension. The total of suspension system consumption power is 350[mW]. Illuminance of approximately 15[klx] is necessary for the magnetic suspension system.

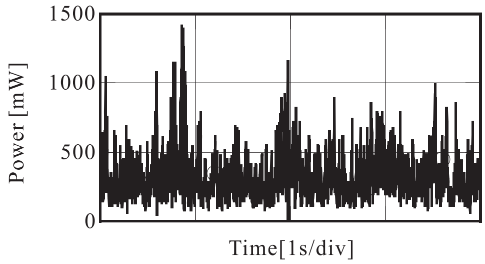

Fig. 6 Consumption power characteristic for electromagnet at the steady state floating.

IV. Conclusions

A non-contacted carrier system using solar magnetic suspension was fabricated. The carrier was controlled vertically passively stabilized horizontally. Dedicated power-saving peripheral devices were newly fabricated. The consumed power of the fabricated system was measured. The total consumed power was approximately 350[mW] in the steady-state suspension.

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