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Zero Power Control for Mechanical Magnetic Suspension System Using Spring Force

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Abstract. This paper describes a zero power control method for a mechanical magnetic suspension system that suspension forces are controlled by motion of permanent magnets. A spring is installed in the magnetic suspension device to counterbalance the gravity force of the suspended object. An inner integral feedback loop is introduced to achieve zero actuator current in a balance state. The principle of the suspension mechanism is explained and modelled, and numerical simulations and experimental results are shown for the feasibility study and confirmation of the proposed zero power control method.

1. Zero Power Suspension System

Conveyance vehicles have been in increasing demand because of the need for an ultra-clean environment in many fields, such as semiconductor processing, biotechnology experiments and material processing. Magnetic suspension mechanism is useful for such an environment. From a view point of cost, when we use a magnetic suspension system as a conveyance vehicle, the magnetic suspension system including magnets, controller, battery, and amplifier have to be implemented on the vehicle. And as the vehicle is driven by a battery installed on the vehicle, the energy consumption becomes a big problem. As a counter measure, a zero power control system using a hybrid magnet has been proposed [1]. A hybrid magnet is combined of a permanent magnet and an electromagnet, and a zero power control means that there is no energy loss when the system is the equilibrium state. In this paper, a new type of zero power control system which uses a permanent magnet, a linear actuator, and a spring.

An outline of the suspension system is shown in Fig. 1 [2]. The suspension system consists of a permanent magnet, an actuator and a mass. The permanent magnet (PM) generates the suspension force; the actuator performs the suspension control; and the ferromagnetic ceiling acts as a track. The suspension device is hung from the ferromagnetic ceiling by the attractive force of the PM. When the suspension device is suspended, the suspension direction is vertical, and the PM attractive force has to be balanced to the gravitational force of the suspension device. And the actuator maintains the stability of the system by adjusting of the distance between the PM and the mass so as to keep the proper air gap. When the gap is larger than the balance gap, the actuator increases its distance in response to the magnet's motion from the equilibrium position towards the ceiling and when the gap is smaller than the balance gap, the actuator decreases its distance in response to the magnet's motion away from the ceiling. In this way, the suspension mechanism is able to levitate stably without contact.

2. Principle of Zero Power Suspension System

A model of the levitation system is shown in Fig. 2. The model consists of a permanent magnet part and a frame part. Two parts are connected by a spring and a dumper. Actuator force acts both two part in the opposite directions. According to the model, the motion equations of the frame part and the magnet part are indicated as

$$m_0\ddot{z}_0 = k_s(z_1 - z_0) + c(\dot{z}_1 - \dot{z}_0) - f_a - m_0 g \qquad (1)$$

$$m_1\ddot{z}_1 = k_s(z_0 - z_1) + c(\dot{z}_0 - \dot{z}_1) + f_a + f_m - m_1 g \qquad (2)$$

where, m_0 and m_1 represent the masses of the frame part and the magnet part, z is the displacement, f_a is the force of VCM, f_m is the attractive force of the permanent magnet, which is assumed as the inverse proportion to the square of the air gap.

Sum of (1) and (2) indicates that in the equilibrium state the attractive force f_m has to be balanced to the gravitational force of the whole suspended device $(m_0+m_1)\,g$. And from (1), if there is no spring installed in parallel to the actuator; that means the spring constant k_s is zero, the actuator force f_a supports the frame part weight $m_0 g$. Consequently, the actuator requires continuous current, and vast energy consumption is produced.

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However if there is a spring, m_0g can be supported by the spring force of the first term in the right side of (1) and f_a can be controlled to zero. This is the principle of the zero power control method for magnetic suspension system as shown in Fig. 1.

The block diagram of the suspension system is shown in Fig. 3. There are two large PD feedback loops and a local integral feedback loop. Two PD feedback loops make the suspension system stable. The lower loop is for the displacement of the frame part and the upper loop is for the relative displacement between the magnet part and frame part. The inner current integral feedback loop is used to implement zero power control. When current flows through the VCM circuit, this integral feedback loop reduces the current. The current reduction affects the distance between the frame part and the magnet part, and the resulting distance variation causes the spring length and the generating force to change. When the spring force becomes equal to the frame part weight the VCM current reaches zero.

3. Experimental Examination

Fig. 4 shows the results of the experiments that a 10 grams weight was removed from the frame part as a step disturbance. Figure (a) shows the result without zero power control, and (b) shows the result with zero power control. From the current graph of (a), after removing the weight, the current value is converged to about −0.005 (A). However in (a), the current is converging to zero, and the variation values of the displacements z_0 and z_1-z_0 are greater than (a). It can be verified that the integral feedback loop acted and the currents of the VCM was reduced. Consequently the zero power control can be realized.

4. Conclusion

A zero power control method for a mechanical magnetic suspension system was proposed. It can be seen that a parallel spring to the actuator and a local integral feedback loop realizes zero power control. Experimental examinations were carried out and they support the feasibility of the proposal.

References

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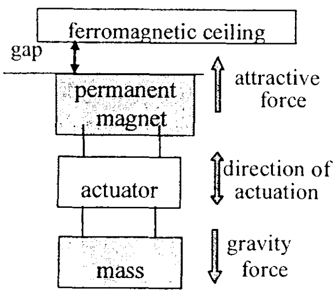


Fig. 1 Outline of suspension system

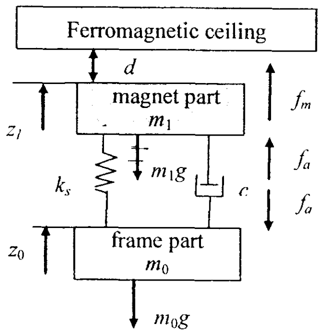


Fig. 2 Model of suspension system

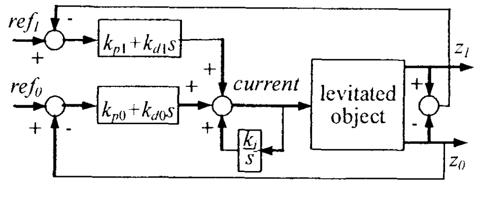
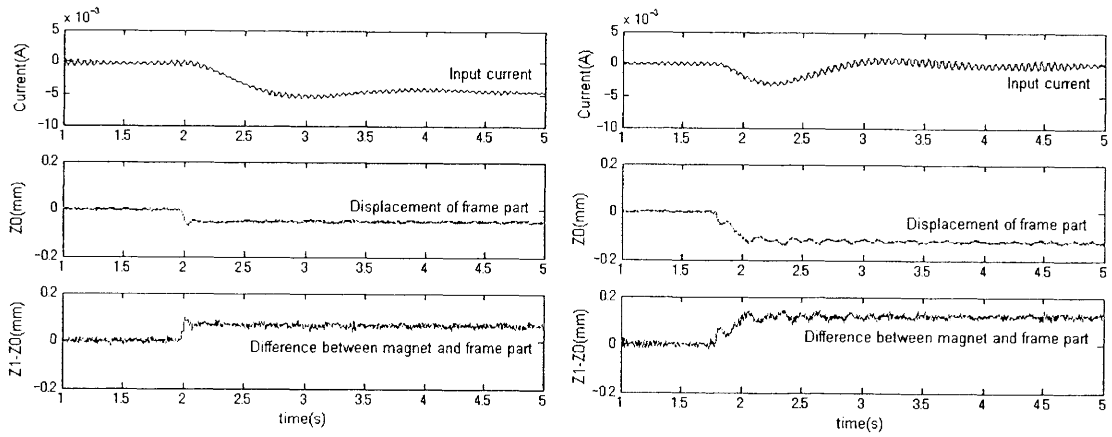


Fig. 3 Block diagram of suspension system



(a) without zero power control

(b) with zero power control

Fig. 4 Experimental result