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Noncontact Spinning Mechanism Using Linearly Actuated Magnets

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Abstract This paper describes a noncontact spinning mechanism which spins a object levitated by a magnetic suspension system. The magnetic suspensionlevitation system uses a permanent magnet and a linear actuator. And the proposed spinning mechanism also uses permanent magnets and linear actuators. The levitated object is an iron ball which is suspended by a magnet in the vertical direction and is spun by four magnets in the horizontal direction. Principle of the spinning mechanism is explained. A prototype system is introduced and a spinning control strategy is proposed. An experimental result of spinning the iron ball verifies the feasibility of the proposed mechanism.

Keywords: maglev system, permanent magnet, linear actuator, spinning control, noncontact control, remanent

1. Introduction

Magnetic suspension systems that control attractive forces by adjusting the air gap has been developed [1][2]. The suspension mechanism featured the use of permanent magnets and linear actuators. As the suspension mechanism uses permanent magnets not electromagnets, there was no heat generation, no need for a coil, and easier teleoperation by using long rod for permanent magnet movement. Consequently, this suspension mechanism seemed suitable for micromanipulation.

Micromanipulation has many difficulties of positioning, handling, and so on. When an end effector with mechanical contacts manipulates very small object, the friction causes that the object adheres to the tip. Noncotact manipulation technique is one of the solution for it.

Manipulation of the object needs many degrees of freedom. However, the researches have been carried out in the one degree of freedom(DOF) system. It is insufficient for manipulation. A multi-DOF suspension system seemed necessary. Recently, two DOF system which has vertical and horizontal DOF has been developed [3].

In this paper, a spinning DOF control in a magnetic syspension system with permanent magnets and linear actuators is proposed. The spinning DOF means the rotation about the vertical axis. The system is one of the system for multi-DOF micromanipulation. First, the outline of the proposed system which are already made as a prototype is introduced. Second, the principle of the spinning control is explained. Third, control system for suspension and spinning is introduced. Last, the experimental result of spinning is shown, and the feasibility of multi-DOF manipulation is verified.

2. Prototype of Suspension System

Magnetic suspension system with the spinning control

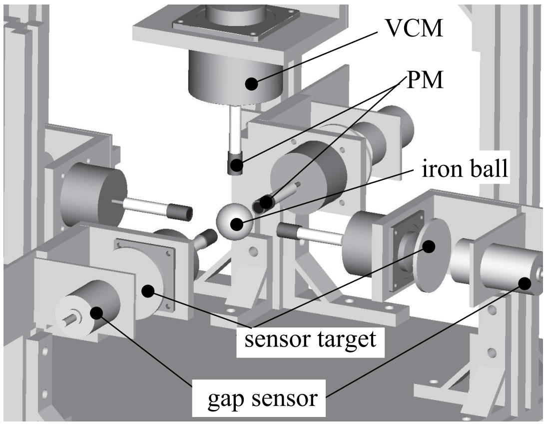

Fig. 1. Illustration of Spinning Mechanism.

mechanism using permanent magnets and linear actuators is illustrated as shown in Fig 1. And a photograph which shows a suspended object and permanent magnets is in Fig. 2. The levitated object is an iron ball which is located in the center of the magnets as shown in Fig. 2. The iron ball is suspended by a permanent magnet in the vertical direction and is spun by four permanent magnets in the horizontal direction. These magnets are indicated as the black small cylinder parts in Fig. 1. Magnets are driven by voice coil motors (VCM) which are indicated as large cylinders and are connected to magnets. Magnet movements are measured eddy current sensors which is located behind the actuators. For the iron ball, only vertical movement is measured by a eddy current sensor which is located under the iron ball as shown in Fig. 2.

The iron ball is held in suspension by the attractive force from a magnet positioned above it. A balance between the gravitational force and the magnetic force makes the iron ball levitate. The relationship between

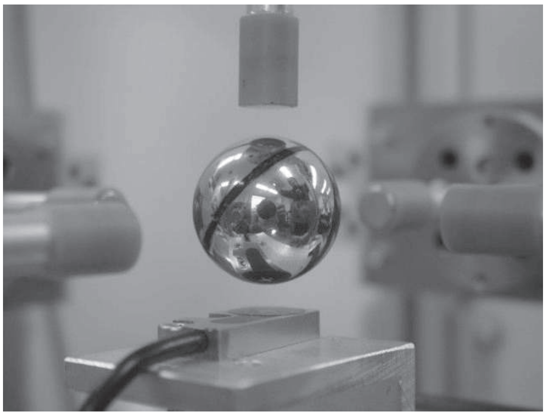

Fig. 2. Photograph during levitation

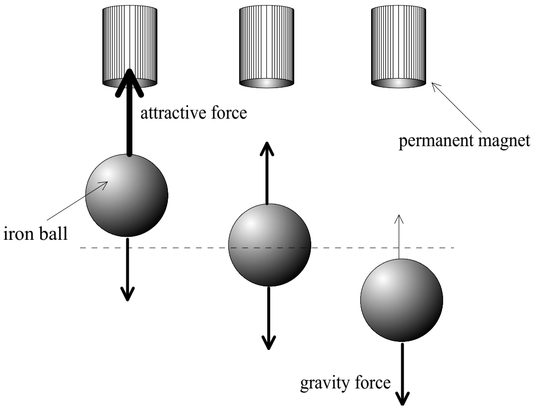

Fig. 3. Relationship between attractive force and gravitational force

the attractive force and the gravitational force is shown in Fig. 3. From consideration of the figure servo-control for the permanent magnet can make the levitation system stable.

3. Spinning Control Mechanism

Remanent magnetization is used for spinning control. The iron ball has various remanent magnetization. The strongest one determines the upper side of the ball during suspension. Next strongest remanent makes the ball rotate about the vertical axis by four magnet movements.

A view from upper side for the ball and four magnets is shown in Fig. 4. As shown in the figure, four magnets and a iron ball are in the horizontal plane. Four magnets are installed perpendicular to each other. The second remanent is also shown in the figure. The figure shows that magnet I is near to the iron ball. When a magnet is near to the ball, the remanent is attracted to the magnet. Consequently, the part involving the remanent of the ball faces with the magnets. The figure shows the situation. Next, magnet I returns to the original position, and magnet II is made to be near to the iron ball. The remanent part is attracted to the magnet II, and the iron ball rotates 90 degrees as shown in Fig. 4.

Repetitions of these approach and apartness can make the ball spin. This rotation mechanism is a kind of PM

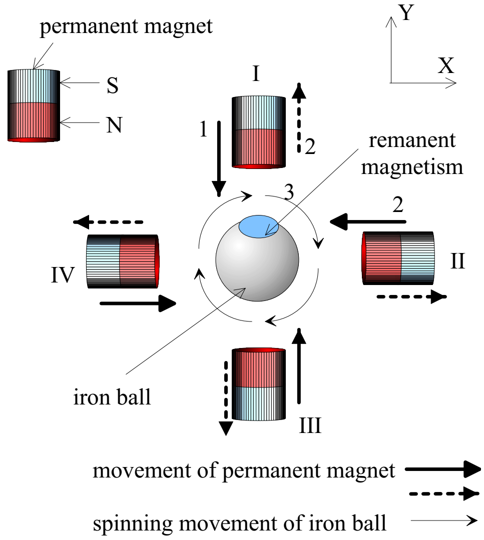

Fig. 4. Principle of Spinning Mechanism.

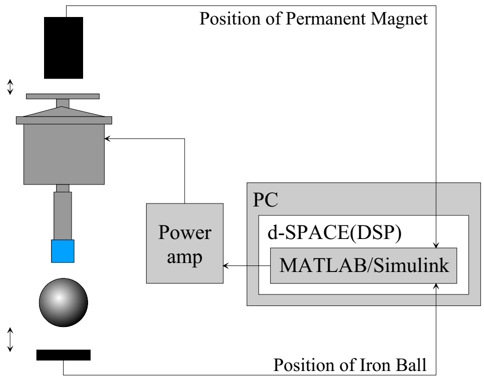

Fig. 5. Suspension system in the vertical direction.

stepping motor.

4. Control System

4.1 Control system in the vertical direction

A control system in the vertical direction is shown in Fig. 5, and a block diagram is shown in Fig. 6. This control system has the function of suspension of the iron ball.

The vertical system has two sensor feedback loop. One is for the displacement of the permanent magnet, and the other is for the displacement of the suspended object. Both feedback loops have PD controllers. The outputs from PD controllers are added and output to the amplifier. The amplifier controls the currents of the VCM. So the controller calculate the force for the permanent magnet. The state variable is the displacements and velocities of the magnet and the iron ball. As the control system is state feedback, the feedback gains can be calculated by linear control theory, eg LQR. The controller is DSP computer.

4.2 Control system in the horizontal direction

A control system in the horizontal direction is shown in Fig. 7, and a block diagram is shown in Fig. 8. Fig. 7 shows one system of four horizontal magnet control systems and indicates the view from the vertical direction. Fig. 8 shows all horizontal magnet control sys-

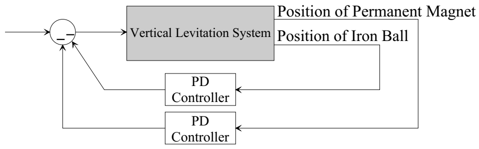

Fig. 6. Block diagram of the system in the vertical direction.

tems. They are independent. This control system has the function of spinning of the ball.

Each horizontal control system has a feedback loop of a permanent magnet respectively. As each magnet is controlled by high gain PD controller, the error of the position of the magnet disturbed by the attractive force and/or the friction can be neglected. The controller is a DSP computer same as the vertical system.

Four controller references are sine waves which has same amplitude and same frequency. But the phase is different. One reference of the magnet and next differ by 90 degrees as shown in Fig. 8. Consequently, four magnets approach the iron ball by turns. The difference of the phase makes the iron ball to rotate. Rotation speed is ideally same as the reference frequency.

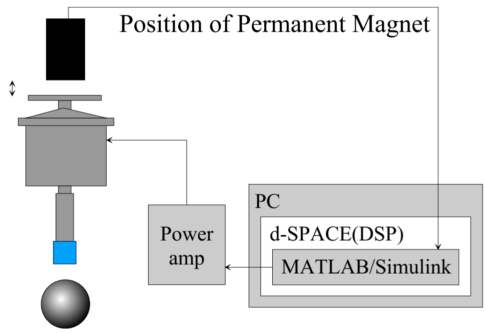

Fig. 7. Suspension system in the horizontal direction.

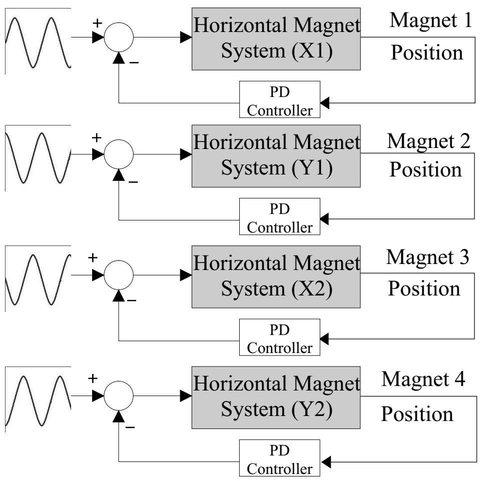

Fig. 8. Block diagram of the system in the horizontal direction.

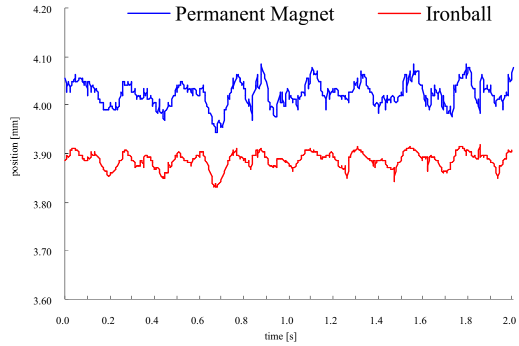

Fig. 9. movement of magnet and iron ball during levitation.

5. Examination

5.1 Levitation Examination First, the levitation examination was carried out to verify the performance of the levitation. Only the horizontal control system is used. The result is shown in Fig. 9. In the figure, the displacements of the magnet and ironball is recorded during the iron ball levitate. The upper line indicates the permanent magnet movement, and the lower line indicates the iron ball. During the levitation, the iron ball has the vibration of 50 μm amplitude, but the system is stable.

5.2 Spinning examination An experimental examination of spinning has been carried out. We gave 1 Hz references to the horizontal control systems. The result is shown in Fig. 10. The result was measured after the sufficient time has passed. As the result, the spinning examination has succeeded.

However there are some problems. As the remanent of the iron ball is very weak, open loop control for the spinning function has a tendency to become unstable spinning. And the cycle of magnet movements is difficult to select when the spinning starts. A feedback control of the iron ball angle is necessary for improvement of the spinning.

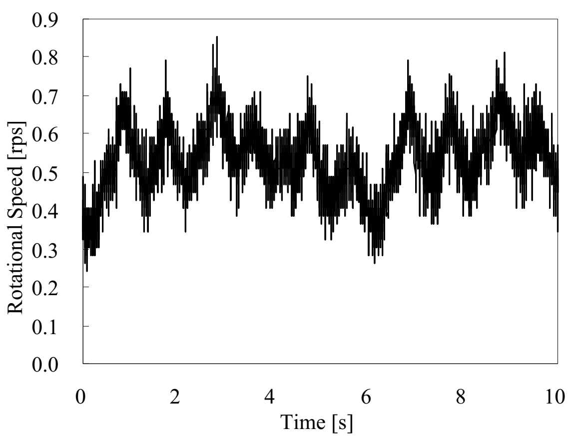

Fig. 10. Rotation speed of suspended iron ball.

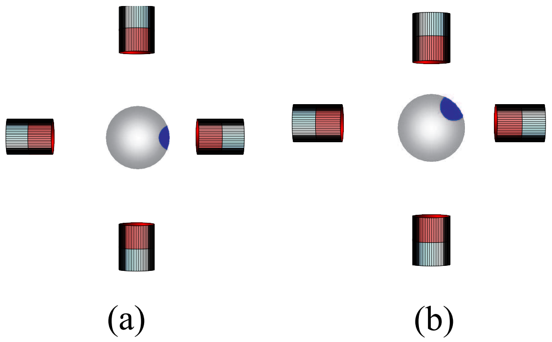

Fig. 11. Angle control system.

6. Conclusion

As the one step of the development of the noncontact manipulation mechanism, a noncontact spinning mechanism with linear actuators and permanent magnets has been proposed. The mechanism consists from four linear actuated magnets. And the remanent magnetization of the iron ball is used.

Summaries in this paper are as follows.

(1) A noncontact spinning control method using remanent magnetization was proposed.
(2) A prototype of spinning system to verify the proposed method was made.
(3) Control system for spinning system was made.
(4) An experimental examination of spinning was carried out and it was succeeded.

As Further works, the angle control of the iron ball may be realized as shown in Fig. 11. The adjustments of the positioning of the permanent magnets makes the iron ball to be positioned in arbitrary angle.

References

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