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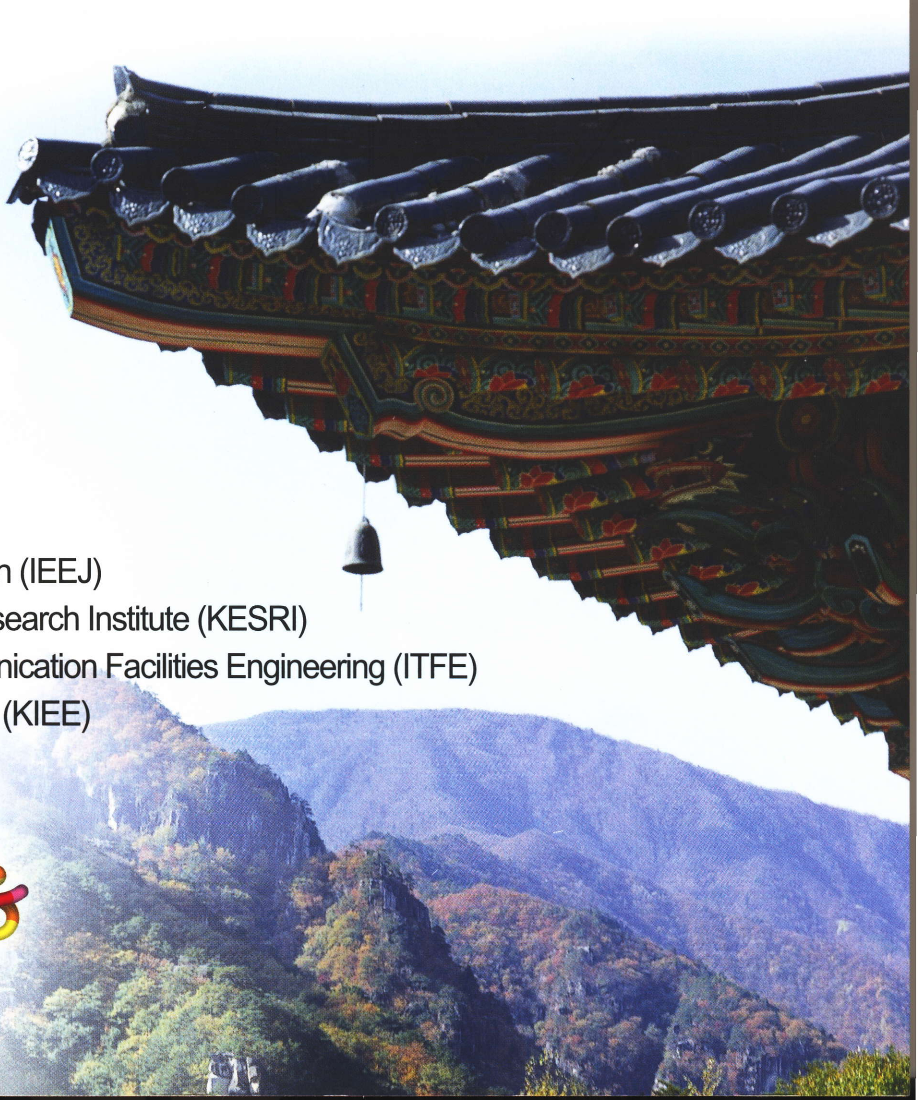

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Noncontact Spinning Mechanism Using Rotary Permanent Magnets

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Topics: 42

1. Introduction

A noncontact spinning mechanism has been developed using permanent magnets and linear actuators for a magnetically suspended object [1]. In the system, four magnets driven linearly in horizontal plane approach to the object in turn and the object is spun. This spin mechanism, however, pulsates the object vertically and fast rotation speed can not be realized. The reason is supposed that the flux distribution does not altered smoothly.

This paper proposes a new type of noncontact spinning mechanism using disk magnets and rotary actuators in place of magnets and linear actuators. Depending on the arrangement of the numbers of magnets and the phases of their magnetic poles, the levitated object has an equilibrium attractive force in the horizontal plane. The principle of rotation mechanism is explained, a prototype of spinning system is introduced, some experimental results are shown, and consequently, there is no pulsation in the spinning suspension state and faster rotation speed can be realized

2. Noncontact Spinning System

2.1. Spinning Principle

The principle mechanism of the spinning system is shown in Figure 1. The figure is a plane view from the top of the device. An iron ball which is the spun object is located in the centre of four disk magnets. The iron ball is suspended in the vertical direction by a permanent magnetic suspension system. The four disk magnets are arranged around the levitated ball and in the same horizontal plane as the ball. Each magnet has two magnetic poles in the radial direction. The magnetic poles of the four disk magnets are arranged in a parallel configuration, and reverse between two adjacent magnets. All the disk magnets rotate in the same speed.

The remanent magnetization on the surface of the iron ball is used for spin control. The iron ball has various remanent magnetizations. The strongest magnetization determines which will be the upper side of the ball during suspension. The next strong remanent magnetization, indicated in Figure 1, causes the ball to rotate about the vertical axis due to attraction to the four disk magnets. We assumed the remanent magnetization is N. In the situation shown in Figure.1, the remanent magnetization is attracted by disk magnet I, and will rotate so as to face disk magnet I. At the same time, the four magnets are each rotating. Consequently, when the remanent magnetization faces magnet I, the iron ball has rotated 90 degrees, and the four magnets have rotated 90 degrees as well. At this point, the remanent magnetization will then be attracted to magnet II. Theoretically, repetitions of this rotation cycle

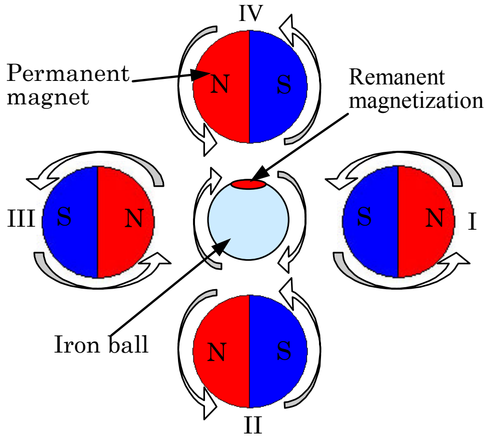


Figure.1: Principle of spinning mechanism

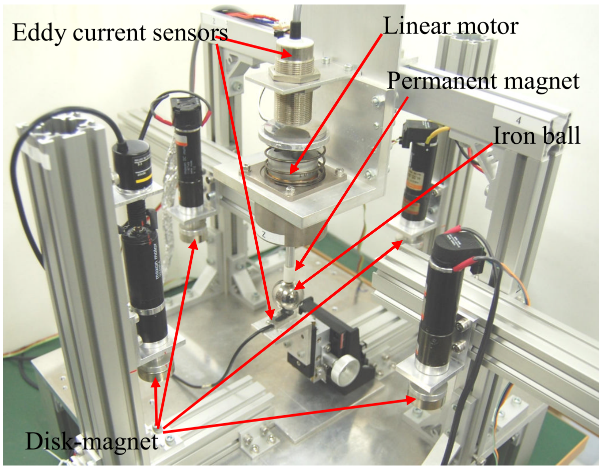


Figure 2: Photograph of noncontact spinning mechanism

can make the iron ball spin at the same rotation speed as the four magnets.

2.2. Prototype Spinning System

Figure 2 shows a photograph of the prototype of noncontact spinning system. The mechanism has two parts: one is a suspension part which consists of a permanent magnet, a voice coil motor and two eddy current sensors, and the other is a spinning part which consists of four disk-type permanent magnets and four rotary motors which are including reduction mechanisms and encoders.

In the suspension part shown in Figure 3, a cylinder permanent magnet was equipped on the lower top of the slider of the voice coil motor, and a sensor target was installed on the upper top of the slider. The permanent magnet and the sensor target were moving with the slider together. The upper sensor measured the magnet position

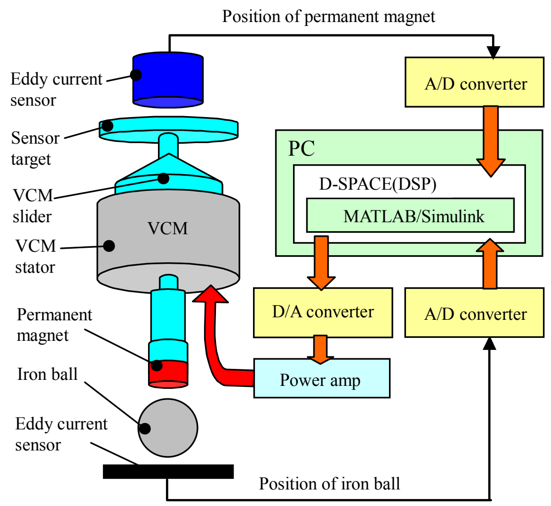


Figure 3: Configuration of Magnetic Suspension System

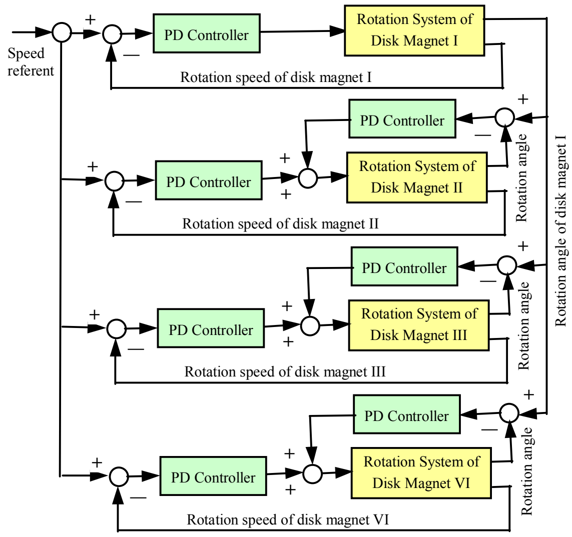


Fig. 5 Control Diagram of Spinning System

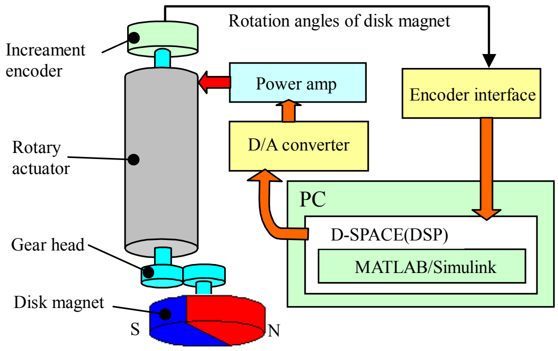


Figure 4: Configuration of One Spinning System

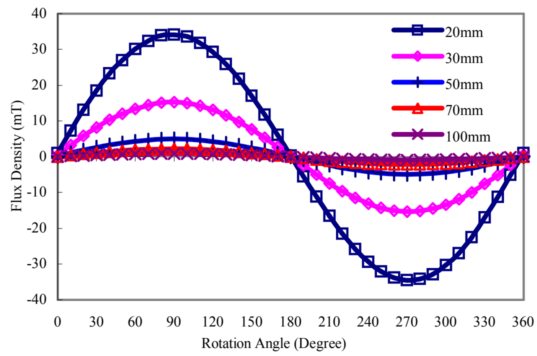


Fig. 6 Magnetic Flux Density Characteristic of Disk Magnet

through the sensor target. The lower sensor measured the position of the iron ball. Depending on the iron ball position and the permanent magnet position, the feedback control suspends the iron ball stably in the vertical direction.

In the spinning part, four same disk-type permanent magnets were installed on the rotary motor's shafts. As shown in Figure 1, the motors were installed on the rail-frames, along which the magnets positions can be adjusted in the vertical and horizontal directions. The four magnets were adjusted into the same horizontal plane with the levitated ball and the same distances between the suspended ball. The four disk-magnets were arranged as shown in Figure 1, which had been magnetized into two magnetic poles in their radial directions. One forth configuration of the control system of the spinning part is shown in Figure 4 and control diagram is shown in Figure 5.

2.3. Characteristic experiment

To examine the magnetic characteristic of the disk magnet and the influence of the distance between the magnet and the levitated ball, the magnetic flux density of the disk magnet was measured using a gauss-meter. The flux density was recorded at distance of 20 mm, 30 mm, 50 mm, 70 mm and 100 mm from the disk-magnet, as the magnet rotated. The measurement data are shown in Figure.3. From the data, it can be seen that the flux density curves resemble sine curves at all points, and smaller distance yields greater flux density. It means that the influence on the remanent magnetization on the ball surface is periodic while the magnet is rotating; the magnet generates a greater force at the point nearer the levitated ball.

3. Experimental Results

Experimental examinations were carried out for investigating the performance of the proposed spinning system. In the experiments, the centres of the disk magnets were located to the position with the distance of 75mm from the centre of the suspended object, and the velocities of the object spinning were recorded. Step responses and the velocities in steady states were examined.

3.1. Step Response

A step response was examined for three types of the different arrangements of magnet installation. One, two, and four disk magnet(s) were used for spinning. For each setup, a step velocity input of 0.5 [rps] was applied. The results were shown from Figure 7 to Figure 9. In all experiments, the object spinning can be confirmed.

The result of the experiment using only one magnet is shown in Figure 7. As shown in the figure, the velocity

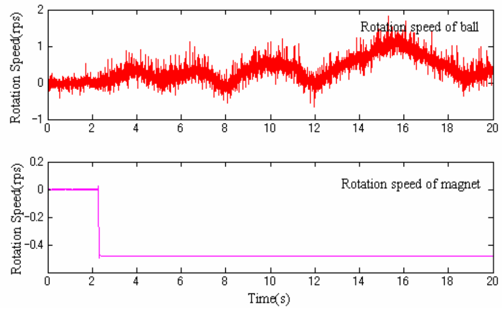
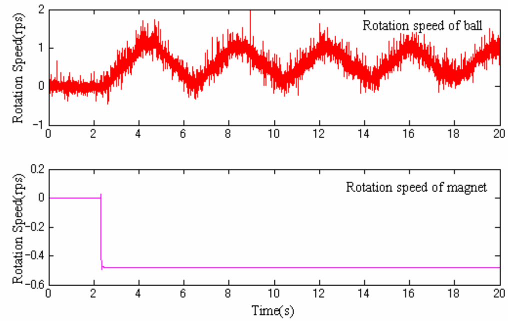


Fig. 7 Step response of iron ball using only one disk magnet



Figurer 8: Step response of iron ball using two disk magnets

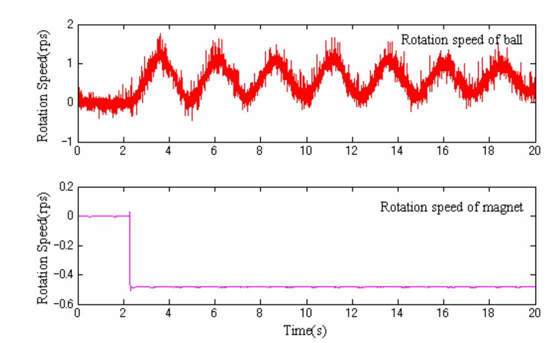


Figure 9: Step response of iron ball using four disk magnets

response does not follow to the input. It means that the object does not rotate, but vibrates. We can see, however, the vibration becomes large.

When two magnets were used for spinning, the result is shown in Figure 8. As shown in the figure, the spinning movement starts as the input and the output velocity is about 0.5 [rps] as same as the input. However, the velocity vibrates of the period of about 4 seconds.

When four magnets were used for spinning, the velocity step response is shown in Figure 9. As shown in the figure, the velocity responses as the input changes. And the mean of the velocity is about 0.5 [rps] as same as the input. Compare with the result using two magnet the quick response can be seen. The velocity vibration also occurs and the period is shorter than the result of Figure 8.

These results indicate the spinning can be realized

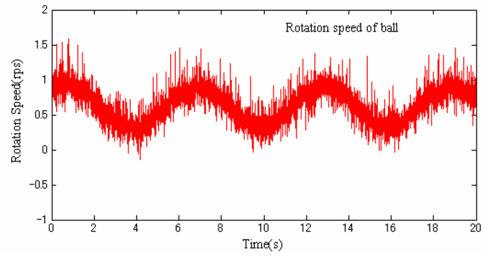


Figure 10: Steady state velocity of iron ball using one disk magnet

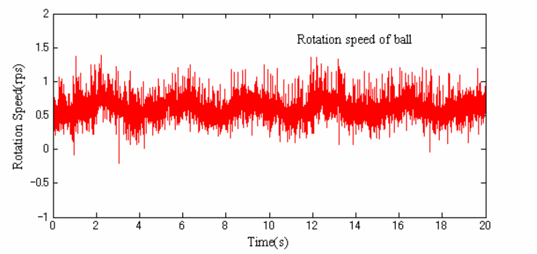


Figure 11: Steady state velocity of iron ball using two disk magnets

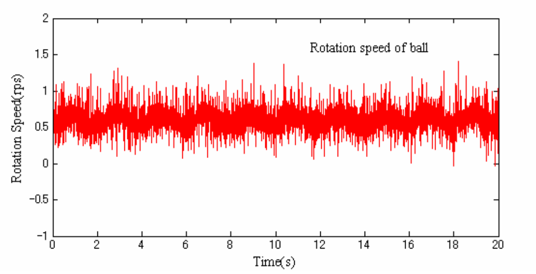


Figure 12: Steady state velocity of iron ball using four disk magnets

without respect to the number of the magnets.

3.2. Velocity in Steady State

Same as step response examination, when three types of arrangements were used, the velocities were recorded. The results are shown in Figure 10 to Figure 12.

As shown in these figures, we can see that the velocities are almost 0.5 [rps] as same as the input velocity. A small velocity error can be seen in all figures. This may be caused by the sensor gain error. We can be also seen that as the more number of magnets is installed, the iron ball spins more smoothly.

3.3. Relationship Between Input Velocity and Output Velocity

The relationship between input velocity and output velocity was examined for verification of the linearity of the system. In the experiments, every 0.1 [rps] input velocity was applied to the system until the iron ball could not be stably suspended. For each experiment, after becoming the steady velocity state the average velocity for ten seconds was measured by a laser speed sensor. The results are shown in Figure 13 to Figure 15.

The result using only one magnet is shown in Figure 13. During this experiment, other 3 magnets are removed from the system. The spinning velocity is increasing as

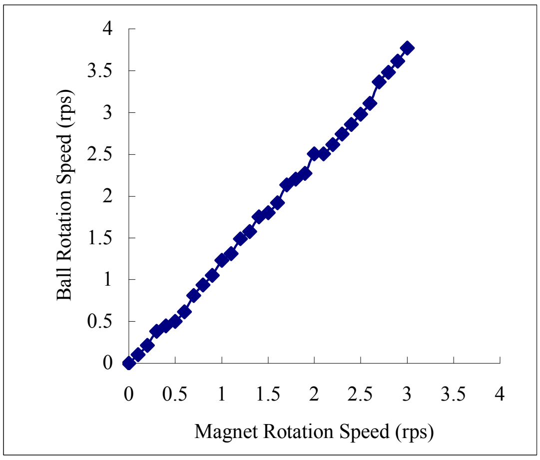


Figure 13: Relationship between magnet velocity and iron ball velocity (one magnet)

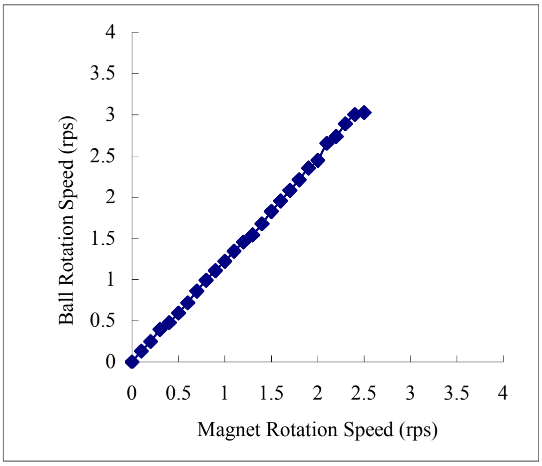


Figure 14: Relationship between magnet velocity and iron ball velocity (two magnets)

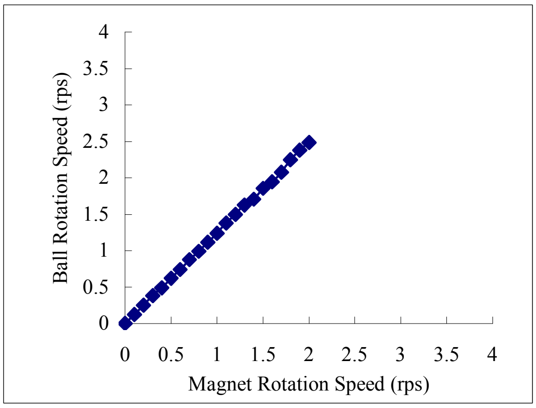


Figure 15: Relationship between magnet velocity and iron ball velocity (four magnet)

the input velocity as shown in the figure. Input and output velocity is different and the gradient is not 1. However the number of the rotation of the magnet is same as that of the iron ball. So, the difference is supposed to be caused by the sensor gain error. The correct velocity is represented by the magnet rotation velocity. The iron ball can be spun up to 3 [rps].

The result using two magnets is shown in Figure 14. During this experiment, we use opposite two magnets and other 2 magnets are removed from the system. Other conditions are same as Figure 13. In this case, the iron ball can be spun up to about 2.5 [rps].

When four magnets were used for spinning, the result is shown in Figure 15. As shown in the figure, the iron ball velocity is up to 2 [rps]

As shown in these three figures, as the number of the magnet increases the limit velocity becomes slower. We have supposed that four magnets

Compare with the limit velocity in previous prototype spinning system [1], the system can be spun up to 1 [rps]. So we can conclude that this proposed spinning system has better performance than the previous system.

4. Conclusion

A noncontact spinning method using disk magnets and rotary motors has been proposed. A prototype of the spinning system was constructed to verify the proposed method. Noncontact spinning experiments using the prototype were performed. The examination results indicate that a levitated iron ball can be spun using the remanent magnetizations and the rotation disk magnets.

References

[1] Oka, K., Fujiwara, Y., Cui, T.S. and Chen, L., "Noncontact Spinning Mechanism Using Linearly Actuated Magnets", in Proc. Int. LDIA2005 Symp., pp.552-555, 2005.