Proposal of Wind Tunnel for Spinning Body using Magnetic Suspension

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Abstract: A wind-tunnel system for spinning body is proposed to measure hydrodynamic forces acting on the body. In the proposed system, the body is suspended and rotated by electromagnets. The forces are measured from the control signal for suspension. An experimental apparatus is fabricated to demonstrate the feasibility. In the apparatus, eight electromagnets are placed around the wind-tunnel. A photo sensor using four lens and phototransistors was manufactured for detecting three-dimensional positions of the body. In the experiment, stable suspension and three-dimensional positioning of the body were achieved. Spinning of the body was realized by superimposing two-phase AC signals on the control signal. The fluid drag force was measured from the control input of PID controller. It was ascertained that the drag force increases as the flow velocity increases.

Keywords: Magnetic Bearing, Magnetic Suspension, Wind Tunnel, Spinning Body, Hydrodynamic Force, Force Measurement

Introduction

Magnetic suspension provides an ideal way of supporting a model for wind tunnel tests because there is no support interference problem arising with mechanical model-support [1, 2]. The forces and moments to support the model are generated by electromagnets arranged outside the test section. In addition, aerodynamic forces acting on the model are estimated from the control current of the electromagnets.

Aerodynamics around a spinning body such as golf ball is still an intriguing topic in both academic and industrial fields. Although simulation-based analysis has made rapid progress, it has not been clarified sufficiently mainly because it is a complex mix of macro- and micro-scale phenomena. Therefore, ideal wind tunnel tests are required to make more precise and reproducible observations. However, conventional wind tunnels using magnetic suspension were not designed to test a spinning body so that they lacked the function of rotating the body.

In this paper, a wind-tunnel system for spinning body is proposed to measure aerodynamic forces acting on the body without any ill effects due to mechanical support. In the proposed system, the body is suspended and rotated by electromagnets, and the forces are measured from the control signal for suspension [3]. The basic concept and an experimental apparatus fabricated for demonstrating the feasibility are presented.

Concept

A schematic drawing of the proposed wind tunnel using magnetic suspension is shown in Fig.1. It has a wind tunnel and a magnetic suspension system for a spinning body. The body itself or its core is made of ferromagnetic material. It is suspended and rotated by the electromagnets arranged outside the tunnel. The aerodynamics forces acting on the body are estimated from the control signals for maintaining the position of the body. In such configuration, wide-gap suspension and position sensing are necessary because both the electromagnets and sensing devices are set outside of the tunnel. In designing apparatuses, therefore, they are critical points.

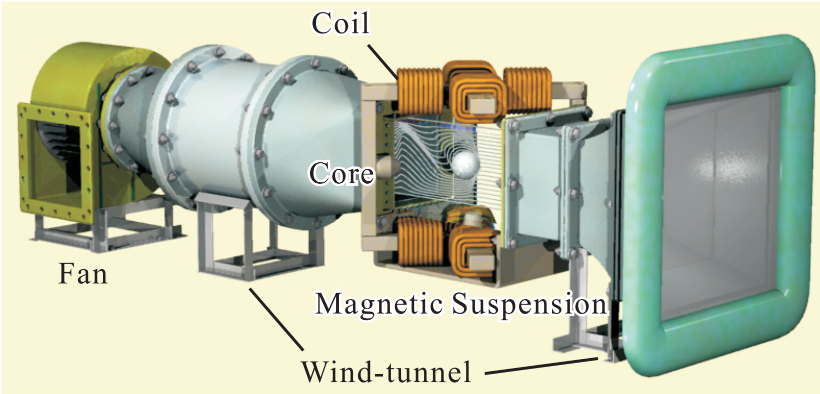

Fig.1 Coceptual drawing of the proposed wind-tunnel usign magnetic supension

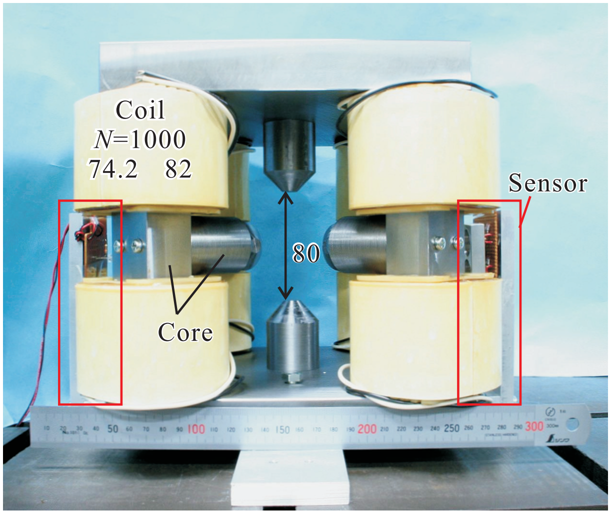

Fig.2 Photograph of the fabricated apparatus

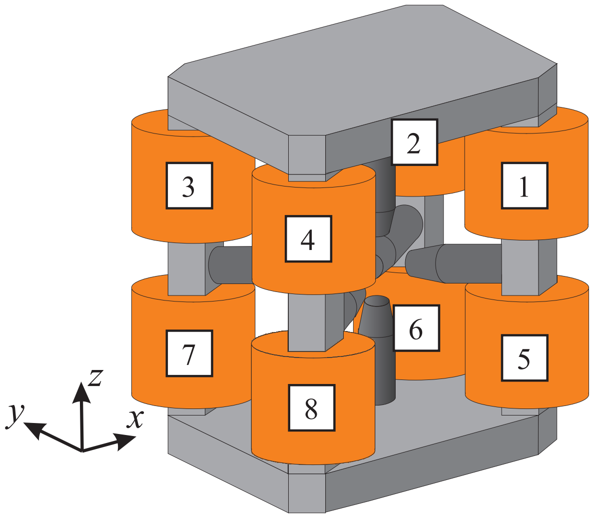

Fig.3 Arrangement of the coils

Experimental Apparatus

Outline. Figure 2 shows a photo of the fabricated magnetic suspension for wind tunnel. It has eight electromagnets for controlling the three-dimensional position of a body and rotating the body in any direction. The arrangement of the coils are shown by Fig.3. A permanent magnet is attached to the head of magnetic pole in the vertical direction for compensating the gravitational force acting on the body. The distance between the facing heads is 80mm. The turn of each coil is 1000. The diameter of the coil is 1mm. The suspended body is a spherical iron ball whose distance and mass is 19.5mm and 28.4g, respectively.

Operation. The operation of the electromagnets to control the motions of the floator is explained in the following. To control the vertical motion, the upper four electromagnets 1 to 4 and the lower four magnets 5 to 8 are operated differentially. For example, to increase the upward force, the currents of the upper electromagnets 1 to 4 are increased and those of the others 5 to 8 are decreased both equally. To control the lateral motion, the four electromagnets in the same plane are operated differentially. For example, to increase the force in the *x*-direction, the currents of the electromagnets 1 and 5 are increased and those of the electromagnets 3 and 7 are decreased both equally. The block diagram of the control system is shown by Fig.4 where e_x, e_y and e_z are reference signals.

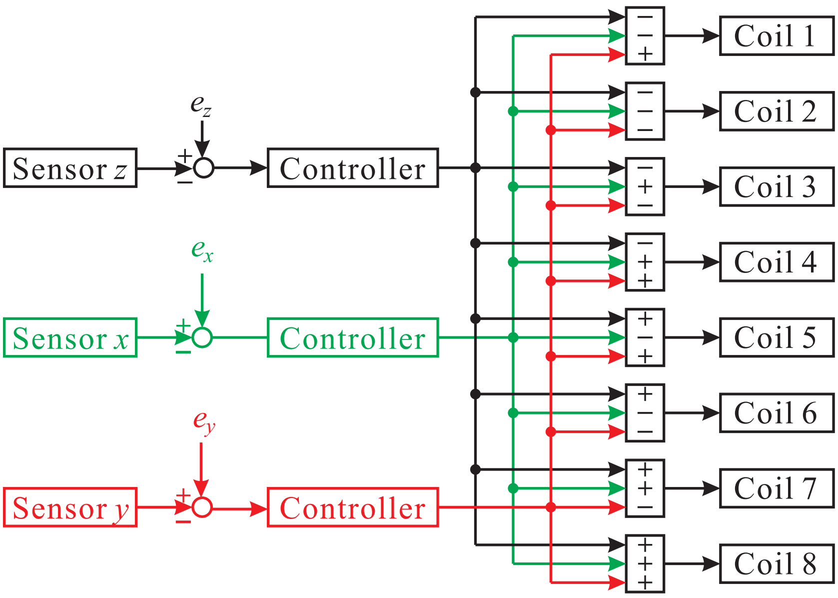

Fig.5 Block diagram of the 3-axis control

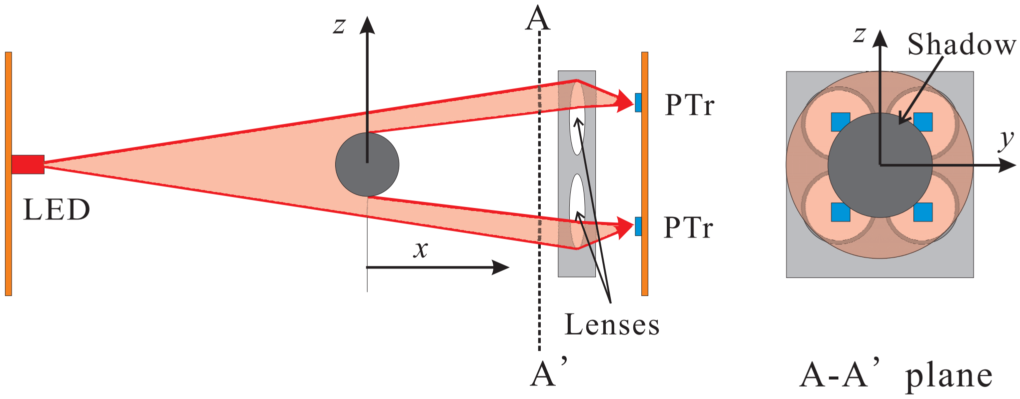

Fig.6 Principles of the fabricated 3-axis position sensor

Sensor. Figure 6 shows the principle of the fabricated photo sensor. It consists of a LED (light source), four collecting lens and four phototransistors (PTr's). It can detect the three-dimensional positions of the body. The displacement in the x-direction is estimated from the sum of the outputs of the four PTr's. The displacement in the y- and z-directions are estimated from the differences of those in the corresponding directions.

Control and Measurement. Since the suspended body is inherently unstable, stabilization using active control is required. The outputs of the sensors are inputted into a DSP-based digital controller. The controller calculates control signals and send them together with excitation signal for rotation to eight power amplifiers for the electromagnets through D/A converters. The aerodynamics forces acting on the body are estimated from the control signals for maintaining the position of the body.

Experimental Results

Sensor. The performance of the fabricated sensor was examined experimentally. Figure 7 shows the outputs of the sensor when the object to be measured (floator) is displaced in the y-direction. It is found that the sensor has good linearity and small interference among the axes in the measurement

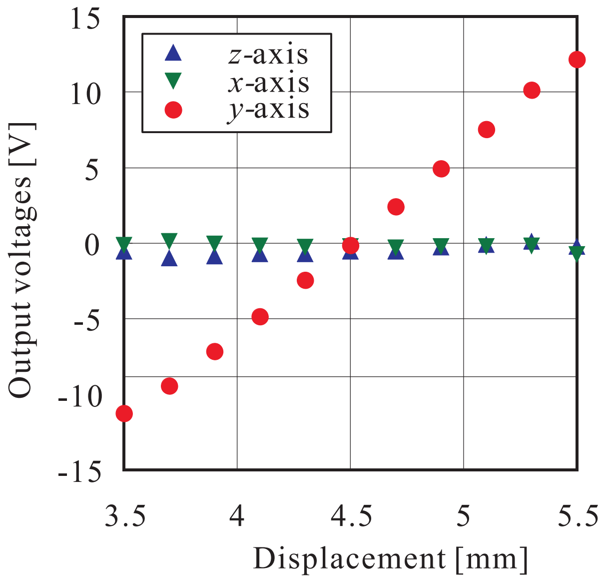

Fig.7 Characteristics of the position sensor for displacement in the *y*-direction.

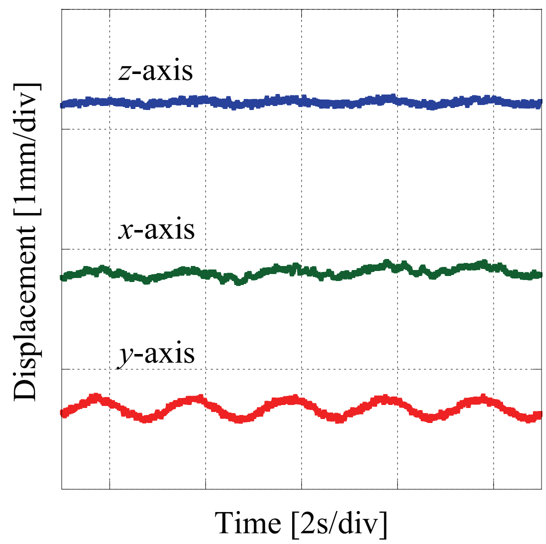

Fig.8 Response to a sinusoidal reference in the *y*-direction

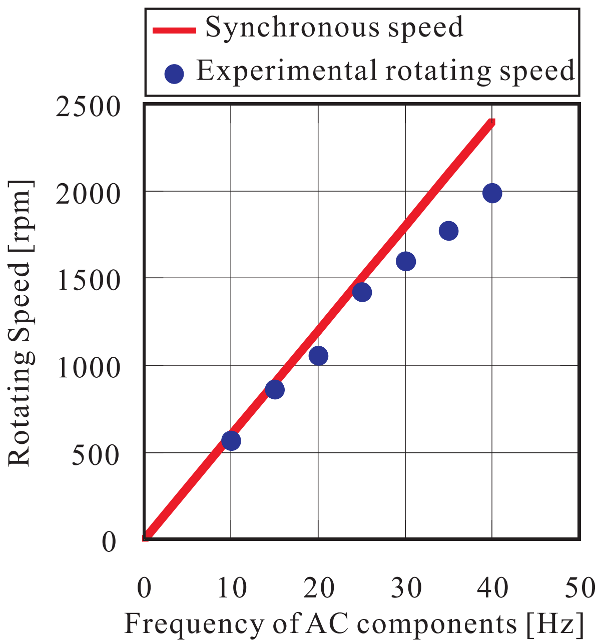

Fig.9 Rotational speeds

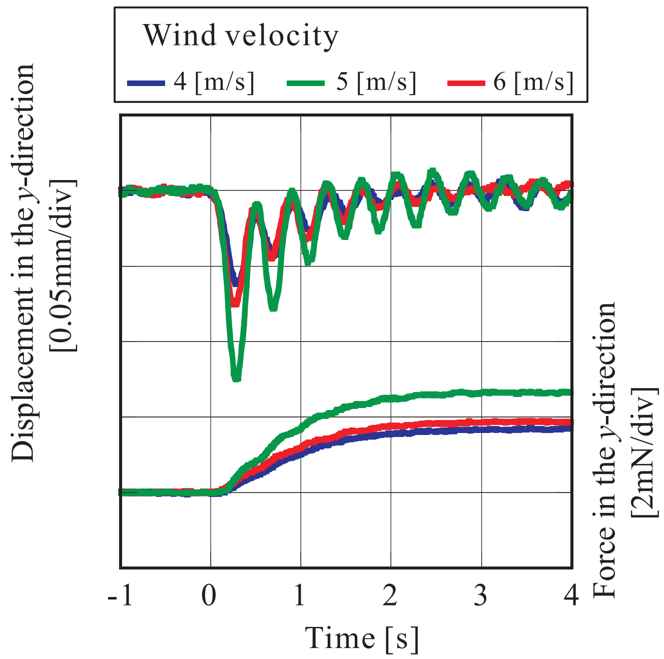

Fig.10 Response when wind in the *y*-direction is added

range of $\pm 1\,\text{mm}$. Similar results were obtained when the object was displaced in the *x*- and *z*-directions.

Levitation. First, stable suspension was achieved with PD control. Figure 8 shows the motions of the floator when the reference e_y is a sinusoidal signal with a frequency of 0.5Hz and an amplitude of about 0.2mm. It is found that there is small interference among the axes. Second, PID control was applied instead of PD control. This control is effective in measuring aerodynamic forces acting on the body because the forces can be estimated from the control signals when the position of the body is maintained at the original position.

Spinning. The spinning of the body was realized by superimposing two-phase AC signals on the control signal. The relation between the excitation frequency and the rotational speed was studied experimentally. The result is shown by Fig.9. The body is driven up to 2000rpm. Since the principle of rotation is same as that of induction motor, slip is observed.

Measurement of Aerodynamic Force. Several wind-tunnel tests were carried out. Figure 10 shows the responses of the control system when wind with various speeds was added. In this experiment, the floator was not rotated. The floator moved to the same direction as the wind just after the wind started. It returned to the original position in 2.5 seconds. The drag force can be estimated from the control signal at the steady state. It is ascertained that the drag increases as the flow velocity becomes higher.

Conclusions

A new wind tunnel for spinning body was proposed. It was characterized by using magnetic suspension to suspend and rotate the body without any mechanical contact. In addition, the aerodynamic forces were estimated from the control input for suspension. This ability was confirmed experimentally by the fabricated apparatus.

Since the proposed system can perform ideal wind tunnel tests, it will make a contribution to clarifying aerodynamics around a spinning body.

References

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