Fabrication of a New Wind Tunnel for Spinning Body Using Magnetic Suspension

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Abstract

A wind-tunnel system for spinning body has been proposed to measure hydrodynamic forces acting on the body. In the proposed system, a ferromagnetic sphere (body) is suspended and rotated by electromagnets. The forces acting on the body are measured from the control signal for suspension. In this work, a wind-tunnel system with 60×60 mm was fabricated. It has eight electromagnets placed around the wind-tunnel, and a newly fabricated 3-axis optical sensor that operates in the fully differential mode. Stable suspension and three-dimensional positioning of the body were achieved in the developed system. Spinning of the body was realized by superimposing two-phase AC signals on the control signal. The hydrodynamic forces acting on the spinning body are measured successfully.

1 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 been making very rapid progress, the details of the dynamics have not been clarified sufficiently. The main difficulty is that the target phenomenon is a complex mix of macro-scale and micro-scale dynamics. Therefore, ideal wind tunnel tests are required for more precise and reproducible observation. 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 [1, 2].

We have proposed a wind-tunnel system for spinning body to measure hydrodynamic forces acting on the body [3]. In the proposed system, the body is suspended and rotated by electromagnets. The forces acting on the body are measured from the control signal for suspension. An experimental apparatus with a 40×40 mm wind tunnel was fabricated which has eight electromagnets around a wind-tunnel and an optical displacement sensor for detecting the three-dimensional positions of the body. Stable suspension, three-dimensional positioning and rotation of the body were achieved [4]. However, the free space around the body was too small for precise wind tunnel tests. In addition, the motion of the body was rather oscillatory mainly because of poor performance of the sensor along the axis of non-differential mode.

In this work, a new apparatus with a 60×60 mm wind tunnel is fabricated. In addition, a new 3-axis optical sensor operating in a fully-differential mode is also fabricated. This apparatus achieves more stable suspension and rotation than the previous one. The hydrodynamic forces acting on the spinning body are measured actually.

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2 Experimental Apparatus

Figure 1 shows a photograph of the newly fabricated apparatus. The size of the total system is $360 \times 1200 \times 440$ mm, approximately. It consists of a magnetic suspension mechanism, a three-axis displacement sensor, a controller and a wind-tunnel. The outline of Each component will be explained in the following.

2.1 Magnetic Suspension Mechanism

A schematic drawing of the mechanism for magnetic suspension is shown in Figure 2 where the nearest electromagnet is removed for a better view of the inside poles. The size is $244 \times 244 \times 296$ mm. The suspension system has eight electromagnets for controlling the three-dimensional position of a sphere body made of ferromagnetic material. Each electromagnet has five 300-turn coils. The impedance of the electromagnet can be adjusted by the connections of the coils. The distance of the poles are kept long enough for a 60×60 mm wind tunnel to be inserted.

2.2 Sensor

The operation of the newly fabricated optical sensor is illustrated in Figure 3. It combines a pair of unit with a LED (light source), four collecting lens and four phototransistors. It can detect the three-dimensional positions of the body in the full-differential mode. When the output of the phototransistor k ($k = 1, \cdots, 8$) is denoted by S_k, the displacement in each direction is estimated from

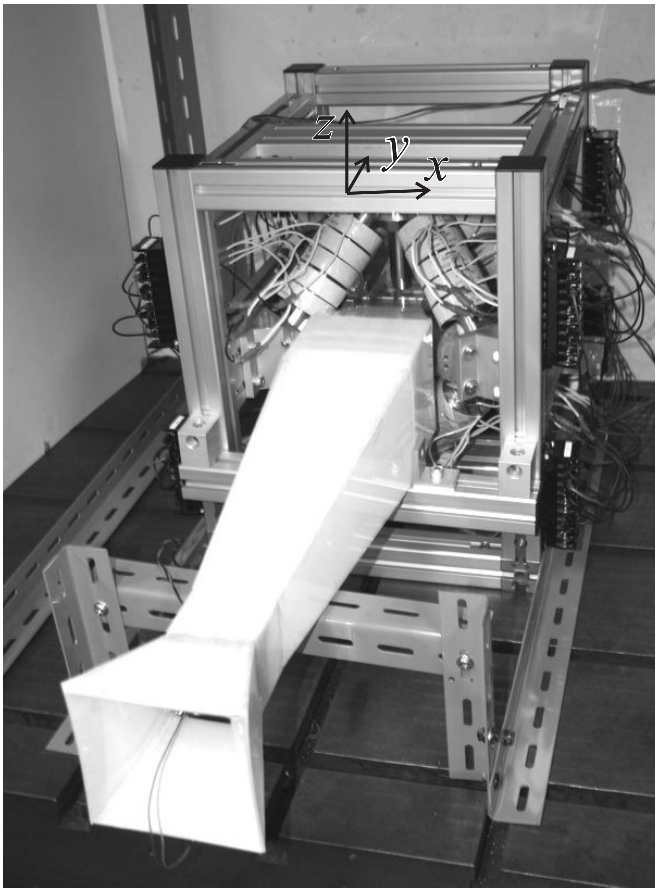

Figure 1: Fabricated Wind Tunnel Using Magnetic Suspension

$$\begin{cases} x-axis:(S_1+S_2+S_3+S_4)-(S_5+S_6+S_7+S_8) \\ y-axis:(S_2+S_4+S_5+S_7)-(S_1+S_3+S_6+S_8) \\ z-axis:(S_1+S_2+S_5+S_6)-(S_3+S_4+S_7+S_8) \end{cases} \quad (1)$$

This sensor is expected to be superior in linearity and resolution, especially as to the *x*-direction, to the sensor used in the previous work [4] because the latter operates in a single mode in this direction.

2.3 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.

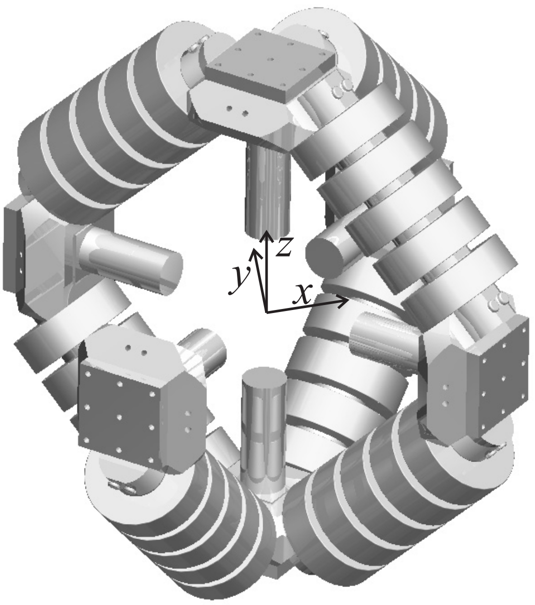

Figure 2: Schematic Drawing of Magnetic Suspension Mechanism

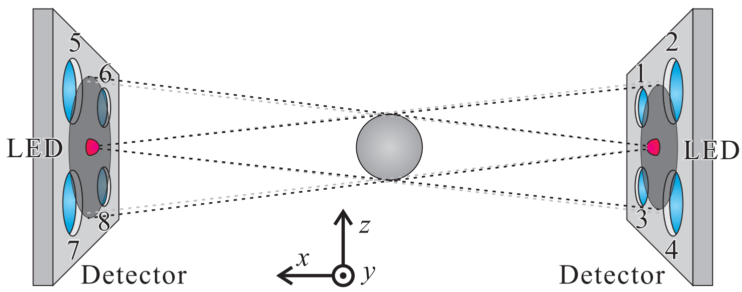

Figure 3: Three-Dimensional Differential Optical Displacement Sensor

2.4 Wind tunnel

Figures 4 and 5 show a photograph and a schematic section view of the wind-tunnel for producing uniform flow around the body. It is made of acrylic plates. It consists of a air intake duct, a fan, a diffuser, a settling tube and chamber, a nozzle, a test section and an outlet duct. A cooling fan for PC is used as the flow source. The air flows along the *y*-axis.

3 Experimental Results

3.1 Position Sensing

The performance of the fabricated sensor was examined experimentally. Figures 6 show the outputs of the sensor when the object to be measured (floator) is displaced in the *x*-direction. It is found that the sensor has good linearity

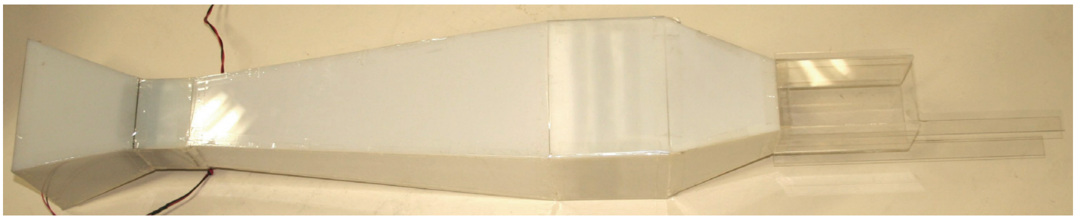

Figure 4: Photograph of Wind Tunnel

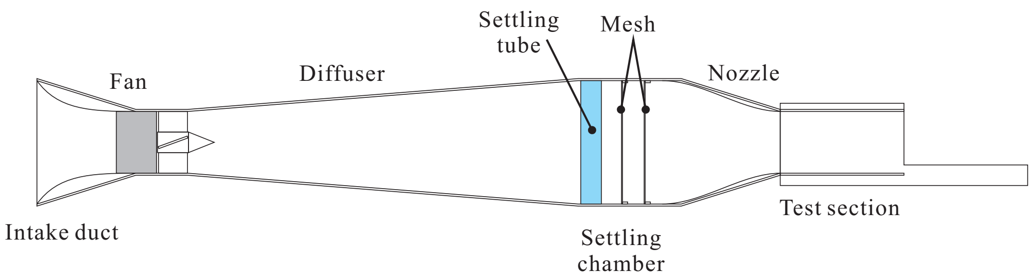

Figure 5: Cross Section View of Wind Tunnel

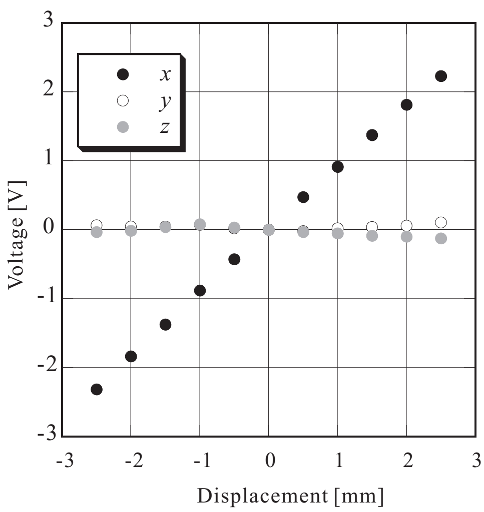

Figure 6: Sensor Characteristics for Displacement in the *x*-direction

and small interference among the axes in the measurement. The results show that the sensor has better performance than the previous one [5].

3.2 Levitation

Stable suspension was achieved by applying PID control. Figure 7 shows the motions of the floator in the wind of 8 [m/s] in the *y*-direction. It is observed that the position of the body is kept stably whereas vibratory motions were induced by a wind in the previous apparatus [5]. It is one of the results of the improvement.

3.3 Rotation

The rotation of the body is realized by superimposing two-phase AC signals on the control signals for the *x*- and. *y*-directions. The rotation about the vertical axis (*z*-axis) was achieved. The relation between the excitation frequency

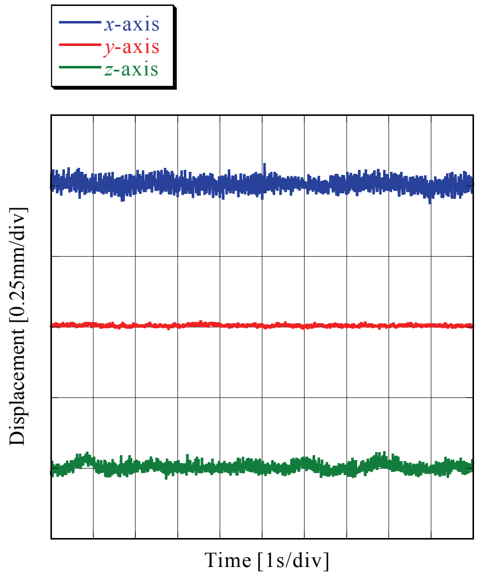

Figure 7: Displacements of the floator in wind

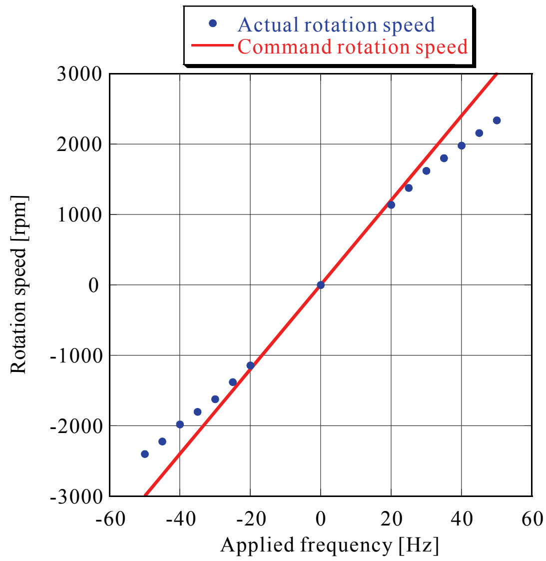

Figure 8: Relation between Driving Frequency and Rotation Speed

and the rotational speed was studied experimentally. The results are summarized in Figure 8. The body is driven up to 3000rpm. Since the principle of rotation is same as that of induction motor, the slip is observed in higher frequency regions.

3.4 Aerodynamic Force Measurement

Several wind tunnel tests are carried out. PID control is applied in this experiment. The fluid drag and lift forces are measured from the control input. Figure 9 shows a relation between drag force and wind speed. The drag force is proportional to the square of the wind speed approximately. Figure 10 show a relation between lift force and wind speed when the rotation speed of the ball is 2300 rpm. The lift force also increases as the wind speed increases.

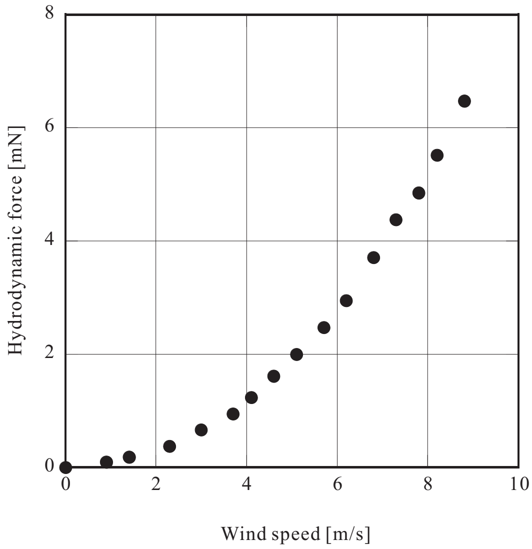

Figure 9: Drag Force Characteristics

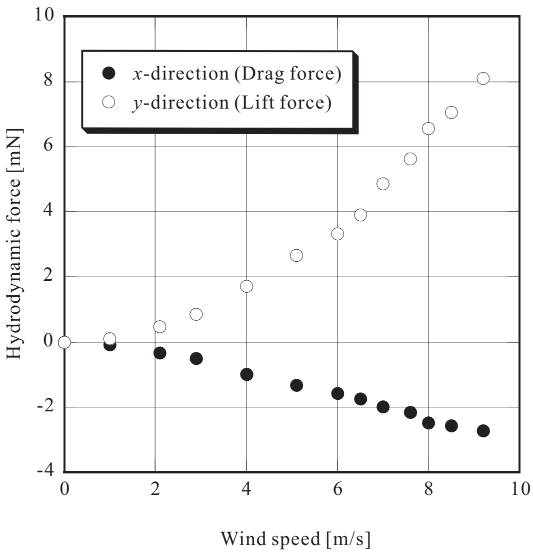

Figure 10: Drag and Lift Forces Characteristics at the Rotation Speed of 2300rpm.

4 Conclusion

A wind-tunnel system with 60×60 mm was fabricated. It has eight electromagnets placed around the wind-tunnel, and the 3-axis optical sensor operating in the fully differential mode. The performance of the sensor was studied experimentally. Stable suspension was achieved even in the presence of wind in the developed system. Spinning of the body was realized by superimposing two-phase AC signals on the control signal. The hydrodynamic forces acting on the spinning body were measured from the control inputs.

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