Measurement of drag coefficients of underwater vehicles using the power consumption method

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Abstract - *The most widely used method of measuring the drag of an underwater object is to attach a sensor directly to the object. In addition, the classic method of measuring drag by attaching a rope or string to an underwater object is also used. However, these methods are known to be accurate in measuring the drag of a moving body at sea level in the form of a general ship, but they are not used in measuring the drag of a moving body in the deep sea where water pressure acts or an underwater moving body where a supercavitation phenomenon occurs. For that reason, this study conducted to develop a drag measurement method for underwater vehicles that is not subject to these limitations. In this study, we measure the power used by an underwater vehicle and measure the drag of the underwater vehicle from the power.*

***Key Words*: Drag coefficient, Drag force, Power consumption method, Underwater vehicle, Supercavitating vehicle**

1.INTRODUCTION

Several studies have been conducted to study the hydrodynamic forces, especially drag, acting on moving underwater bodies. These trends demonstrate the importance of developing drag prediction method. Additionally, these drag measurement studies were conducted in conjunction with drag reduction methods [1-6].

Over the past two decades, various methods have been proposed to measure the drag coefficient of moving underwater objects. Yao *et al.* [7] and Jourdan *et al.* [8] proposed a method of measuring the drag coefficient of an underwater moving object in a specific Reynolds number range using a speed sensor and a pressure sensor in a water tunnel. Venukumar *et al.* [9] proposed a method to measure the drag coefficient of an object in a supersonic flow using an acceleration sensor, a speed sensor, and a pressure sensor. Sridhar and Katz [10] used the PIV system to find acceleration and velocity and devised a method to measure the drag coefficient of an object. In addition to these studies, various methodologies were proposed to measure the drag coefficient of underwater vehicles, but most used speed sensors and pressure sensors. Accordingly, this study presents a method to measure the drag coefficient of an underwater vehicle using power consumption. The power consumption method proposed in this study was used in Chung and Cho's study [4], which studied the underwater supercavitation phenomenon, and this paper presents a more specific methodology for the power consumption method.

2. Experimental set-up

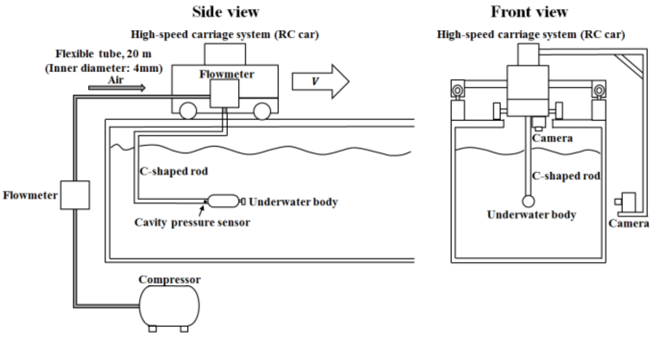


Fig -1: Experimental setup

To measure the drag coefficient of an underwater vehicle, an experiment was conducted using a tank designed as shown in Figure 1. The tank size is 19.2 m in length, 1 m in width, and 1 m in height, and the side walls of the tank are made of transparent glass for external observation. The towing system is a combination of a modified battery-powered remote-controlled (RC) car and two straight rails laid along the entire length of the tank. The RC car runs along the rails at a maximum speed of 10 m/s, and the RC car and the underwater body are rigidly attached to each other via a right-angled C-shaped connecting bar. Therefore, the underwater vehicle moves with the camera at the same speed as the RC car.

In this study, the drag force (F_D) of the underwater vehicle is obtained from the power consumption of the battery consumed when the RC car is running. As shown in Figure 2, the power consumption was measured using a voltage sensor and a current sensor.

$$F_D = P / V \qquad (1)$$

$$P = \text{Voltage} \times \text{Current} \qquad (2)$$

In the equation (1) above, P represents the power consumption and V represents the speed of the underwater vehicle.

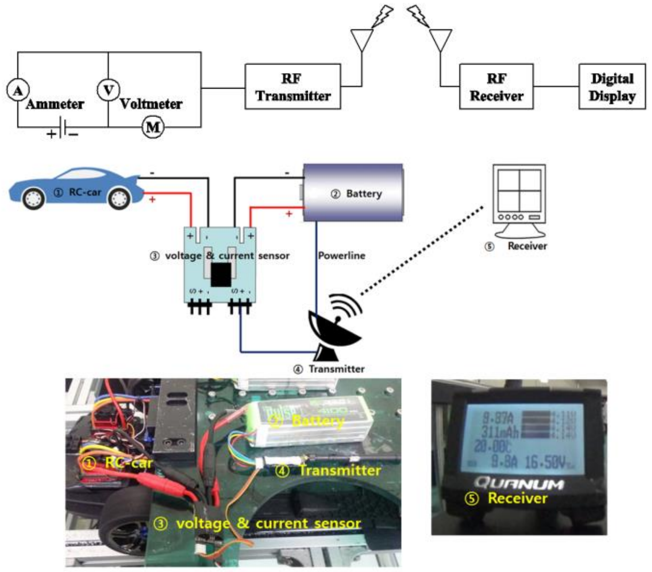


Fig -2: Measurement of power consumption

3. Experimental results

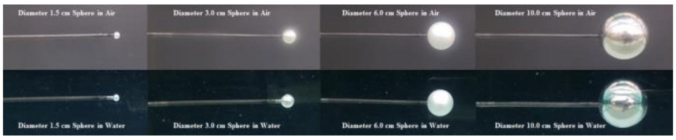


Fig -3: Moving spheres in water and air

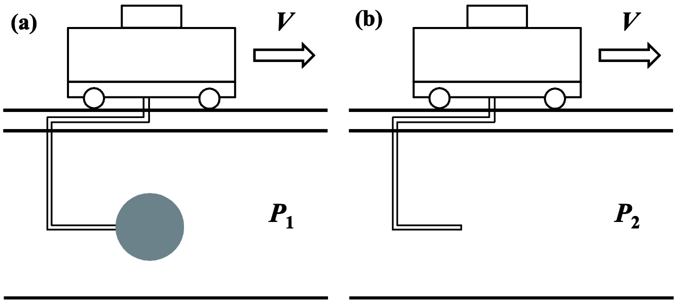


Fig -4: Measurement of power consumption
(a) with a sphere, (b) without a sphere

In order to verify the drag measurement by the power consumption method proposed in this study, the drag coefficient was measured for a sphere-shaped moving body, such as Figure 3, moving in water and air. As shown in Figure 4, the power consumption of the entire towing system required to move at a certain speed in water and air was measured, and then the power consumption of the towing system excluding the sphere was measured. The drag of the sphere was then obtained as shown in Equation 3 below. In Equation 3, P_1 is the power consumption of the entire towing system, and P_2 is the power consumption of the towing system excluding the sphere.

$$F_D = \frac{P_1 - P_2}{V} \tag{3}$$

Equation 4 shows how to obtain the drag coefficient (C_d) of a sphere using the drag obtained from Equation 3. In Equation 4, ρ represents the density of the fluid, and d_s represents the diameter of the sphere.

$$C_d = \frac{F_D}{\frac{1}{2}\rho V^2\left(\frac{\pi}{4}{d_s}^2\right)} \tag{4}$$

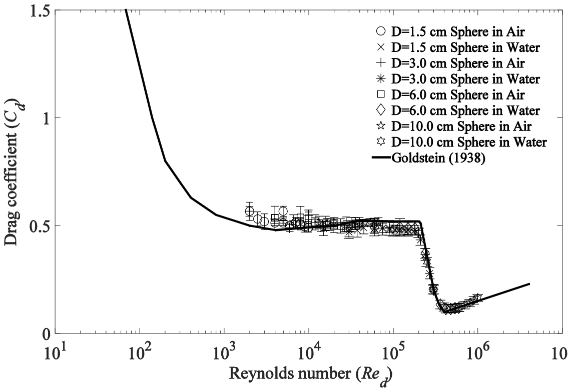


Fig -5: Drag coefficient according to the diameter-based Reynolds number

Figure 5 shows the drag coefficient of the sphere obtained using Equations 3 and 4. In order to verify the drag coefficient measurement method by the power consumption method proposed in this study, the results of Goldsteian's study [11] were compared. As can be seen in Figure 5, the drag coefficients from the Reynolds number range of about 10^3 to 10^6 in this study were confirmed to be almost similar to the results of previous studies. After that, the drag coefficient measurement for an elliptical underwater vehicle was performed using the above method.

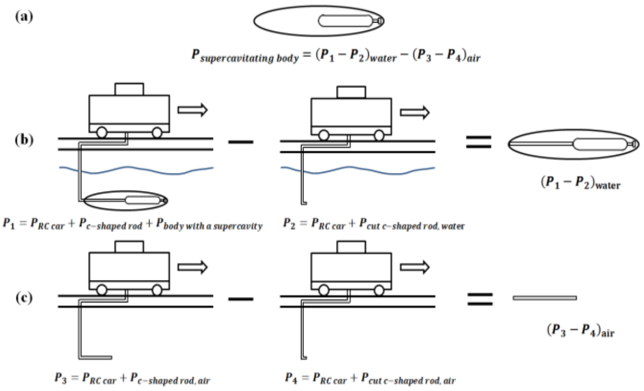


Fig -6: Method for measuring drag coefficient of an elliptical underwater vehicle and an elliptical underwater vehicle in a supercavity state. (a) Underwater vehicle in supercavity, (b) supercavity vehicle and a cut rod inside the supercavity, (c) a cut rod inside the supercavity

We measured the drag coefficient of an underwater vehicle in a supercavity state using the drag coefficient measurement method described above, and conducted four different tests for this purpose. To measure the drag coefficient of an underwater vehicle in a supercavity state as shown in Figure 6(a), we first conducted a test to measure the power consumption of the entire towing system with a supercavity formed as shown in Figure 6(b), and then measured the power consumption of only the I-shaped bar in the air formed by the supercavity as shown in Figure 6(c).

$$P_1 = P_{\text{RC car}} + P_{\text{c–shaped rod}} + P_{\text{body with a supercavity}} \quad (5)$$

$$P_2 = P_{\text{RC car}} + P_{\text{cut c–shaped rod, water}} \quad (6)$$

$$P_3 = P_{\text{RC car}} + P_{\text{c–shaped rod, air}} \quad (7)$$

$$P_4 = P_{\text{RC car}} + P_{\text{cut c–shaped rod, air}} \quad (8)$$

First, to calculate the power consumption of the underwater vehicle in the supercavity state and the I-shaped rod, as shown in Figure 6(b), the method of subtracting Equation 6 from Equation 5 was used. Then, to calculate the power consumption of only the I-shaped rod, as shown in Figure 6(c), the method of subtracting Equation 8 from Equation 7 was used.

$$P = P_1 - P_2 - (P_3 - P_4) \quad (9)$$

$$F_D = \frac{P}{V} \quad (10)$$

$$C_d = \frac{F_D}{\frac{1}{2}\rho V^2\left(\frac{\pi}{4}d^2\right)} \quad (11)$$

Thus, the power consumption in the final state as in Figure 6(a) was calculated using Equation 9, the drag was measured using Equation 10, and the drag coefficient was measured using Equation 11.

Table -1: C_d values

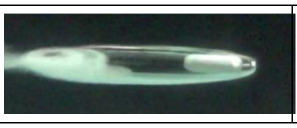
Case	Photo	Description	C_d
1		Body	0.41
2		Body with a cavitator	1.17
3		Supercavitating body with a cavitaotr	0.11

Table 1 shows the drag coefficients of a typical elliptical underwater vehicle, an underwater vehicle with a cavitator, and an underwater vehicle in a supercavity state. Case 2 in Table 1 is an underwater vehicle with a disk-shaped cavitator attached, and the drag coefficient was measured to be about 1.18. This result is almost similar to the drag coefficient of a disk-shaped underwater vehicle [12]. And as in Case 3 of Table 1, the drag coefficient of the underwater vehicle with the supercavity formed was measured to be approximately 0.11, and compared to Case 2 of Table 1, which has the same shape but no supercavity formed, it was confirmed that the drag coefficient was reduced by approximately 76% when the supercavity phenomenon occurred.

4. CONCLUSIONS

This study conducted the experiment for drag coefficient measurement of underwater moving body. To examine how much drag is reduced or not, a new drag measurement method using power consumption is proposed and the drag force of the supercavitating underwater moving body is measured. Also, in this study, the drag coefficient of underwater moving body was measured using the power consumed by underwater body without any additional equipment.

The drag coefficient measured by the drag measurement method proposed in this study was found to be almost identical to those of previous studies in the Reynolds number range from 10^3 to 10^6. However, other Reynolds number ranges could not be measured due to limitations in the experimental equipment. It was confirmed that the error rate was less than 5% in the Reynolds number range from 10^3 to 10^4, and that the error rate in the Reynolds number range from 10^5 to 10^6, where the drag coefficient changes rapidly, was less than 2%, which is almost identical.

As a result of measuring the drag coefficient of an underwater vehicle in a supercavity state by applying the proposed drag measurement method, it was confirmed that the drag coefficient was reduced by approximately 90% in the case of an underwater vehicle equipped with a cavitator.

ACKNOWLEDGEMENT

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BIOGRAPHIES

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