CAV2021
11th International Symposium on Cavitation
May 10-13, 2021, Daejon, Korea

Accuracy Verification of Cavity Shape Measurement Using Combination Line CCD Camera Measurement Method

Koichiro Shiraishi[1], Yuki Sawada[1], Junichi Fujisawa[1]

[1]National Maritime Research Institute, National Institute of Maritime, Port, and Aviation Technology, Japan

Abstract: Increasing the accuracy of the theoretical prediction of propeller cavitation requires an investigation of unsteady propeller blade cavitation. Authors have recently developed a combination-line-CCD camera method can measure three-dimensional shapes that is faster and more accurate than conventional methods. In this paper, model experiments have been conducted in the National Maritime Research Institute (NMRI) large cavitation tunnel using a model propeller of 749GT coastal ship to verify the system's effectiveness. The authors show measurement results of cavity shapes and effectiveness of the developed measurement system.

Keywords: Marine propellers, Cavitation, 3D shape measurement, Cavity shape measurement, Pressure fluctuation

1. Introduction

Cavitation generated by a propeller operating in a ship's wake can cause hull vibration, thrust reduction, and erosion. To address these problems, developing theoretical and numerical calculation methods for estimating cavitation with high accuracy at the design stage is necessary. Estimating cavitation with high precision requires measurements of cavity volume, as this has a strong correlation with pressure fluctuation. Previously, various cavity shape measurement methods have been studied, including the use of stereo photography and laser beam scattering [1-3]. Recently, the authors have developed a system for measuring cavity shape on model propeller blades using a combination of line charge-coupled device (CCD) cameras [4-5]. The authors conducted model experiments on the propeller of "Seiun Maru I Highly Skewed Propeller" in the large cavitation tunnel at NMRI. Through the experiments the developed system can measure the shapes of cavitation on the model propeller blades.

In this paper, for further accuracy validation of the developed method, model experiments on the 749GT coastal ship have been conducted in the large cavitation tunnel at the NMRI [6-7]. The authors discuss the measurement results obtained for a model propeller blade and cavity shapes and show the effectiveness of the developed measurement method.

2. Combination-line CCD camera measurement method

The authors used a combination of line CCD camera method to measure cavity shapes on the model propeller [4]. In this method, a laser beam is irradiated onto a measurement object and light scattered from its surface is photographed using three-line CCD cameras. Based on the resulting image data, the three-dimensional surface of the object is reconstructed via triangulation. In line CCD cameras, the image-receiving elements are arranged in a row. Such cameras have the advantage of much higher scan rates and resolution than area CCD cameras. The configuration and a photo of the camera system used in this study for three-dimensional shape measuring are shown in Figures 1 and 2, respectively. The authors used a green laser (532 nm), a wavelength with high penetration ability in water.

* Corresponding Author: Koichiro Shiraishi, shiraishi@m.mpat.go.jp

The specific measurement procedure of the developed system is outlined as follows. First, the laser beam is used to irradiate a position to be measured, with laser light scattered from the surface of the measurement object passed through a semi-cylindrical lens and focused onto the image sensor of the line CCD cameras. Triangulation is then used to extract the three-dimensional coordinates of the laser light spot position from the peak coordinates of the luminance distributions of the images captured by the cameras. Figure 3 shows the measurement principle of the combination line CCD camera method.

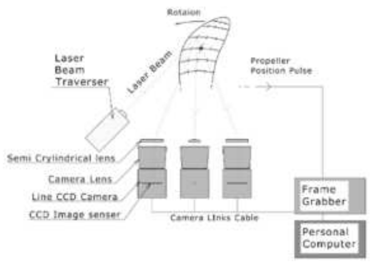

Figure 1 Outline of measurement system.

Figure 2 Photo of measurement system

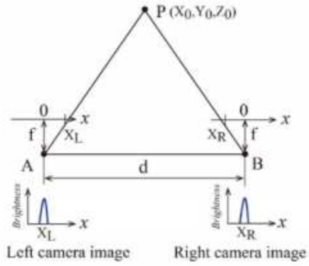

Figure 3 Illustration of the combination line CCD method

3. Experiments

3.1. Experimental setting

The experiments were performed in the No.1 working section of the NMRI large cavitation tunnel. Figure 4 shows the model propeller used in the experiments (Figure 4). The principal particulars of the propeller are given in Table 1. The cavity shape measurement was conducted in a non-uniform flow generated by a wire mesh screen. The axial wake distribution of this screen is shown in Figure 5. To verify the measurement accuracy, shape measurements of the model propeller was performed under a non-cavitation condition. The measurement results are shown in Figure 6. The contours indicate the errors between the measurement results and the shape of the propeller blade. This figure shows the error is less than 0.5 mm. In this respect, the developed method can measure the 3D shape with high accuracy.

Figure 4 Photo of the model propeller.

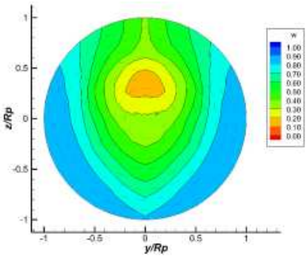

Figure 5 Wake distribution of Axial Direction.

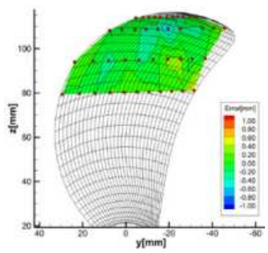

Figure 6 3D shape measurement results of model propeller

Table 1 Principal particulars of model propeller

	M.P.No.700
Diameter [m]	0.240
Pitch ratio at 0.7R	0.6059
Expanded area ratio	0.4791
Boss ratio	0.1750
Number of blade Z	4
Skew angle [deg]	25.0
Rake angle[deg]	4.13
Blade section	NACA
Direction of rotation	Right

3.2. Cavity shape measurement on model propeller

Cavity shape measurement was conducted under the cavitation condition on the he 749GT coastal ship. The experimental conditions were $K_T = 0.124$, $n_p = 42.0$ [rps] and $\sigma_n = 1.37$. Thrust coefficient K_T and cavitation number σ_n are defied as following equation.

$$K_t = T/\rho n^2 D_p^4, \quad \sigma_n = (P_0 - P_v)/(\tfrac{1}{2}\rho n^2 D_p^2) \tag{1}$$

* Corresponding Author: Koichiro Shiraishi, shiraishi@m.mpat.go.jp

where, n_p: number of revolutions of propeller, T: propeller thrust, ρ: the water density, D_p: the propeller diameter, P_0: the static pressure at the propeller position P_v: the vapor pressure. Cavity shape measurement was performed at six propeller phase angles: 0.0, 10.0, 20.0, 30.0 40.0 and 50.0 [deg.].

Figure 7 shows photos of the cavitation patterns taken with a steel camera (left) and cavity shapes measured with the developed system (right). From Figure 7, the developed method can measure the cavity shapes over a wide range of phase angles. The region near 0.9 R at which the cavity thickness increases is also captured. The figure sequence demonstrates the thickness of the cavity increasing and the cavitation growing toward the trailing edge. From this figure, the developed system can measure thin cavitation around the leading edge at 0.8R. These results confirm that the developed system can measure the cavity shape a wide range of propeller phase angles.

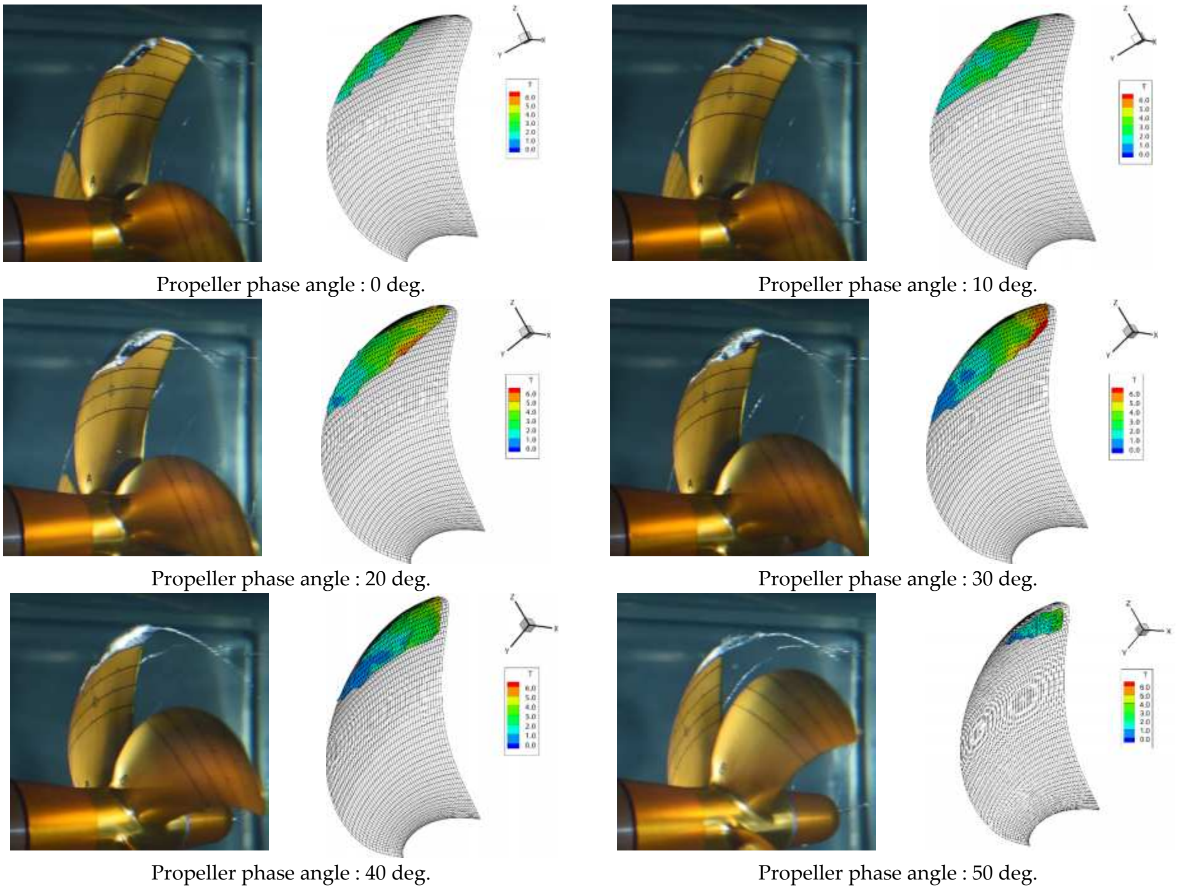

Figure 7 Image of cavitation patterns and measured cavity shapes and thickeness distribution on the model propeller ($K_T = 0.124$, $\sigma_n = 1.37$).

The cavity area and volume calculated from the cavity shape measurements are shown in Figure 8 and Figure 9, respectively. The cavity area is the projection of the cavitation area onto the blade surface. Comparing Figure 8 and Figure 9, the increasing trend of the cavity area is different from the increasing trend of the cavity volume. From 10.0[deg] to 20.0[deg] at propeller phase angle, the cavity area increases slowly, on the other hand, the cavity volume increases rapidly. This means that the cavity thickness increases more than the cavity area. These results confirm that the importance of capturing not only the

* Corresponding Author: Koichiro Shiraishi, shiraishi@m.mpat.go.jp

cavity area but also the cavity volume and the cavity shape in order to improve the accuracy of cavitation estimation through numerical calculations.

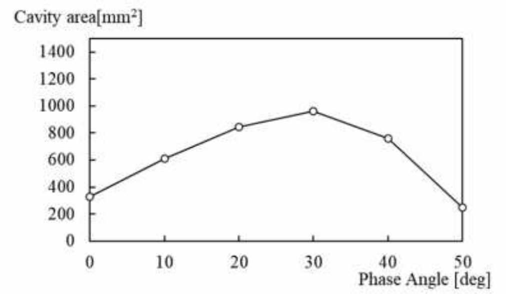

Figure 8 Result of cavitation area calculated from measured cavity shapes

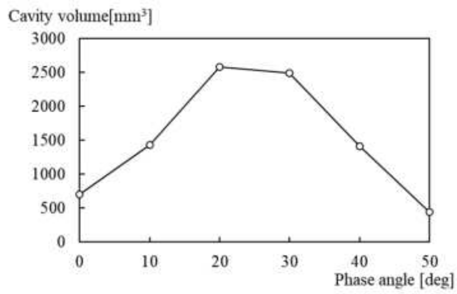

Figure 9 Result of cavitation volume calculated from measured cavity shapes.

4. Conclusions

In this paper, to verify the accuracy of the developed system, the model propeller shape and cavity shape measurements of the model propeller of 749GT coastal ship were conducted. The results of the model propeller shape measurements show the developed measurement system can measure the 3D shape with an accuracy of 0.5 mm or less. The results of the cavity shape measurements show that the developed system can measure the cavity shape a wide range of propeller phase angles and can capture the increasing and decreasing trends of cavitation. From these results, the developed system can also be applied to the propellers of general merchant ships with high accuracy.

Acknowledgments: This research was partially supported by Japan Society for the Promotion of Science (JSPS) Grant-in-Aid for Scientific Research (C) JP 19K04871.

References

1. Ukon, Y., Kudo, T. and Kurobe, Y. (1991), "Measurement of Cavity Thickness Distribution on the Blade of Propeller Models by Laser-CCD Method", Proceedings of CAVITATION'91, ASME, FED-Vol. 116, pp.99-104.
2. Luca S., Michele V., Francesco C. and Marco F.; Application of computer vision techniques to measure cavitation bubble volume and cavitating tip vortex diameter, Proceedings of the 7th International Symposium on Cavitation, 2009, pp. 737-748.
3. Luca S., Michele V. and Marco F; Propeller Cavitation 3D Reconstruction through Stereo-Vision Algorithms, International Conference Advanced Model Measurement Technology for EU Maritime Industry (AMT'09), 2009, pp.116-131.
4. Hoshino, K. and Tamura, K.; Development of Three-Dimensional Shape Measurement Method of the Object in Water, OCEANS '04. MTTS/IEEE TECHNO-OCEAN '04, 2004, Vol.3, pp.1240-1247.
5. Shiraishi, K., Sawada, Y. and Hoshino, K.; Cavity Shape Measurement Using Combination-Line CCD Camera Measurement Method, Proceedings of International Symposium on Marine Propulsors 2017, 5th SMP.
6. Kawakita, C., Shiraishi, K., Fujisawa, J., Sawada, Y., & Arakawa, D.; Development of Fixed Pitch Propellers for Coasting Vessels. Conference Proceedings of the Japan Society of Naval Architects and Ocean Engineers, 2017, Vol.24, pp. 169-174.
7. Arakawa, D., Shiraishi, K., Sawada, Y. & Kawakita, C.; Study on Experiment on Pressure Fluctuation Induced by Propeller and Cavitation. Conference Proceedings of the Japan Society of Naval Architects and Ocean Engineers, 2018, Vol.26, pp. 563-568.

* Corresponding Author: Koichiro Shiraishi, shiraishi@m.mpat.go.jp