Research of Prevention Measures for Root Cavitation Erosion

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ABSTRACT

For small high speed ships, which operate over 22 knots, cavitation phenomena called as root cavitation are happened easily on the root of propeller blades and boss, and then collapsed sequentially. Consequently, erosion can be happened at root area. This phenomenon is root cavitation erosion. Ship owners often regard the erosion as problem for safety side judging by that poor appearance. Accordingly, we need to suppress root cavitation erosion as small as possible. As the general prevention measures for the erosion, one or two holes called anti-cavitation hole are drilled on root of propeller blade to supress the root cavitation erosion. Taking this measure, the root cavitation erosion can be somewhat supressed but it cannot be completely prevented under severe operational condition. In this research, the original propeller with two anti-cavitation holes is machined additional anti-cavitation hole to reduce erosion. In order to compare the situations of root cavitation erosion of the propeller with three anti-cavitation holes and original propeller with two holes, full scale observation with actual ship equipped with these propellers were examined for 24 to 30 months. In addition, the effects of anti-cavitation holes are estimated by numerical calculations. As a result, it was confirmed that the drilling anti-cavitation holes can reduce the amount of root cavitation, and additional anti-cavitation holes can be effective measure for suppress the root cavitation erosion.

Keywords: Propeller, Root cavitation erosion, Small high-speed ship, Numerical calculations

NOMENCLATURE

V	Inflow velocity [m/s]
θ	Rotation angle [deg]
ψ	Shaft inclination angle [deg]
r	Radius direction position [m]
$\Delta\alpha$	Difference of attack angle [deg]
K_T	thrust coefficient [-]
α	Cavity void fraction [-]
p	Local pressure [Pa]
p_v	Vapor pressure [Pa]
CFD	Computational Fluid Dynamics

1. INTRODUCTION

In recent years, the small high-speed ships, which operate over 22 knots, are generally used as fisheries patrol ship, customs ship, high-speed ferry and so on. For such ships equip high power engine, and propeller which limited diameter for convenience of placement. Due to these factors, absorption horsepower per propeller blade area is high, therefore cavitation is theoretically happened.

In high-speed ships with inclined shaft arrangement, which tends to cause a problem called as root cavitation erosion (the following root erosion), which occurs at the root of the propeller blade. Therefore, it is common to drill one or two holes, called anti-cavitation holes, in the blade root to reduce root erosion risk. However, for many ships in service, two anti-cavitation holes are not adequate to prevent erosion risk.

In this study, it is developed that a propeller with two anti-cavitation holes and one additional anti-cavitation hole, for a total of three holes, to prevent further erosion risk. The erosion suppression effect of this proposed countermeasure is verified through full scale observation. In addition, by using CFD, the pressure on the propeller blade surface with and without the anti-cavitation hole is calculated to verify the suppression effect of cavitation and erosion.

2. THE PROPELLER FOR SMALL HIGH-SPEED SHIP

Aluminum monohull and catamaran types are often built in small high-speed ships, and these are often planned with a shaft inclination of 7 to 10 degrees.

Figure 1 shows the shaft arrangement of a typical small high-speed ship. Most of the small high-speed ships use two shafts, and two units fixed pitch propeller.

In addition, propellers with five blades are increasingly being used with a large blade area, which area ratio of 1.0 or more to prevent excessive cavitation.

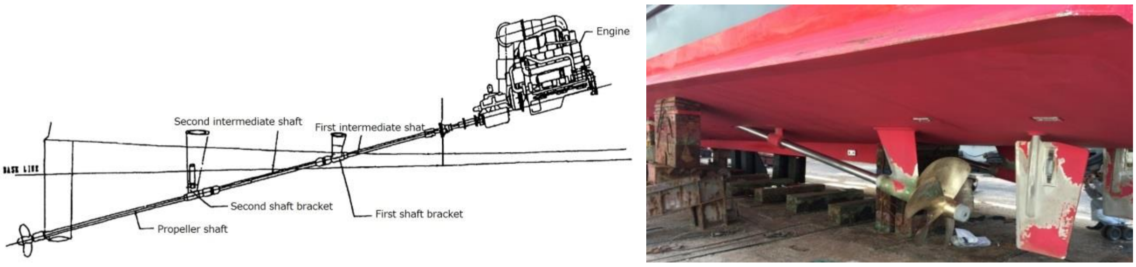


Figure 1. Shaft arrangement of high-speed ship. (Suzuki, 1998)

2.1 Root cavitation erosion

Figure 2 shows an example of root erosion at the blade root seen in propeller for small high-speed ship.

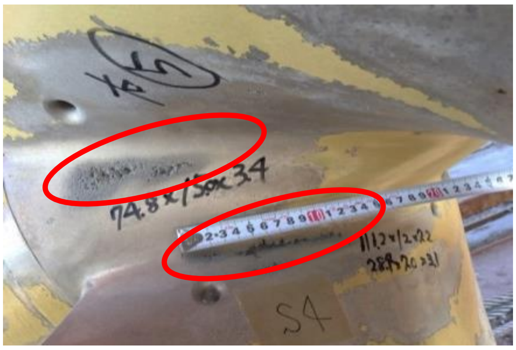


Figure 2. Conditions of root erosion.

Though root erosion may occur immediately after sea trials and erosion progresses even after the occurrence of root erosion, it has been reported that the erosion rate proceeded gradual deceleration with time (Ouchi *et al*, 1998).

Propellers for small high-speed ships are designed with a sufficient blade thickness margin compared to normal designs, so there have been no cases of breakage accidents caused by root erosion. However, there are cases where the shipowner questions the safety of the propeller, and it is desirable to avoid root erosion if possible. In addition, there are concerns about efficiency reduction due to the surface roughness caused by root erosion, but since the contribution to thrust by the blade root is small, it is considered that root erosion has almost no effect on propeller efficiency.

2.2 Principle of root erosion generation

The occurrence of root erosion is attributed to the fact that the angle of inflow into the propeller fluctuates greatly during one rotation due to inclined shaft.

Figure 3 shows the change in the velocity of inflow into the blade elements of a propeller for high-speed ships. The velocity component working on the propeller in diagonal flow due to inclined shaft can be divided into $Vsin\psi$ and $Vcos\psi$ using the ship's speed V and shaft inclination angle ψ. When the top position is set to 0 degrees of rotation angle and the propeller blade is at θ degree of rotation angle, the tangential velocity change due to inclined shaft can be expressed as $Vsin\psi \cdot sin\theta$.

When the propeller blade rotates from the top to the bottom, the angle of attack increases and cavitation occurs on back side of the blade. On the other hand, when the propeller blade rotates from bottom to top, the angle of attack becomes smaller (or negative) and cavitation is more likely to occur on face side of the blade. Therefore, both the face and back side of the blade are at risk of cavitation erosion under severe operational conditions.

In particular, at the blade root of the propeller, the circumferential velocity $r\omega$ is small compared to the tangential velocity change $Vsin\psi \cdot sin\theta$, so the angle of attack fluctuation $\Delta\alpha$ during one rotation becomes larger. Therefore, cavitation repeatedly occurs and disappears at the blade root, and root erosion is caused by the collapse pressure when cavitation collapses.

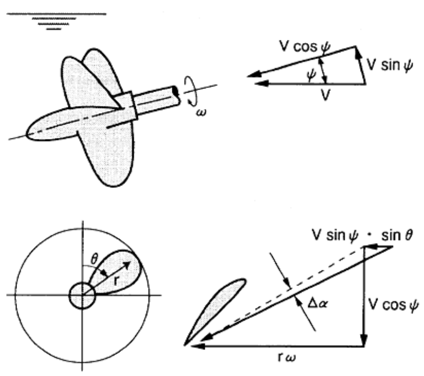


Figure 3. Fluctuation of propeller inflow speed for high speed ship.(Okada, 1998)

3. PREVENTION MEASURES FOR ROOT EROSION

In designing a propeller for a small high-speed ship, to reduce the amount of cavitation in the blade root, the pressure distribution on the blade root is calculated within the assumed range of angle of attack fluctuation. Then the negative pressure area below the vapor pressure is examined, and the pitch is determined with zero lift angle of attack averagely not to bring negative pressure as possible.

Although it is difficult to prevent root erosion risk by considering the pitch, so various measures have been proposed as the following: (Kihara *et al* 1984; Okada *et al* 1998; Ukon *et al* 2006)

- Changing the shape of the leading edge of the blade root section
- Changing the thickness of the trailing edge of the wing root section
- Changing in the position of the maximum blade thickness
- Changing in the number of blades (from three to five)
- Attaching small fins, which suppress the angle of attack fluctuation, in the front of the propeller

In addition of these, there is the method of drilling one or two anti-cavitation holes per blade, which is the common measure taken.

However, even with these measures, root erosion cannot be completely solved in most of the cases. This time, in response to the shipowner's request for improvement of the root erosion situation, it is proposed to change in the number of anti-cavitation holes for countermeasure (from two to three holes).

Since erosion frequently occurs between the two cavitation prevention holes that are usually installed, it was expected that drilling additional holes could be effective.

4. FULL SCALE OBSERVATION

4.1 Full scale observation conditions

In the past, there have been five cases where the propellers were modified to three anti-cavitation holes after delivery (one case with five blades and four cases with three blades). Though those propellers were drilled two anti-cavitation holes previously, the conditions of the cavitation erosion were so severe that additional holes were drilled. In these cases, the root erosion suppression effect of the three anti-cavitation holes was evaluated by photo judges. The quantitative data for the amount of erosion over time had not been obtained.

In this experiment, the same types of propeller were installed on Kyushu Shosen Co., Ltd.’s two high-speed passenger ships for A and B (same type as A), both of which operate the same route, and compared the effect of two anti-cavitation holes and three anti-cavitation holes on preventing root erosion.

The main particulars of hull, engine and propeller are indicated in Table 1.

Table 1. The main particulars of ship and engine and propeller.

Ship		Engine (2 Sets)		Propeller (Left & Right handed)	
Length	34 m	BHP	1440 kW	Number of blades	5
Breadth	6.1 m	RPM (Engine)	2250 rpm	Diameter	1050 mm
Depth	2.5 m	RPM (Propeller)	934 rpm	Pitch ratio at 0.7R	1245 mm
				Exp. area ratio	1.10

The surface condition of the propeller was observed, and the erosion range and depth were measured during dry dock inspections every 6 months for 2 years after the ship A was in service in October 2016. Ship B was also observed, and the erosion range and depth were measured during dry dock inspections every 6 months for 2.5 years after the ship B was in service in July 2018. The propeller for Ship A was drilled two anti-cavitation holes, and the propeller for Ship B was drilled three anti-cavitation holes. The propeller installed into the ship is shown Figure 4.

The propeller with three anti-cavitation holes is shown in Figure 5.

Figure 4. Image of installed propeller.

Figure 5. Three anti-cavitation holes.

4.2 Full scale observation result

Figure 6 shows the changes in the propeller blade surface conditions of ship A and B over time. Erosion was observed between the anti-cavitation holes on the blade surface of Ship A after 6 months of service, and gradually progressed during from 6 months to 12 months of service. After 12 months, erosion progressed gradually and some new erosion was observed, but the degree of erosion was minor. As can be seen in the Figure 6, the erosion range of the propeller on Ship B (with three anti-cavitation holes) was significantly reduced compared to Ship A (with two anti-cavitation holes).

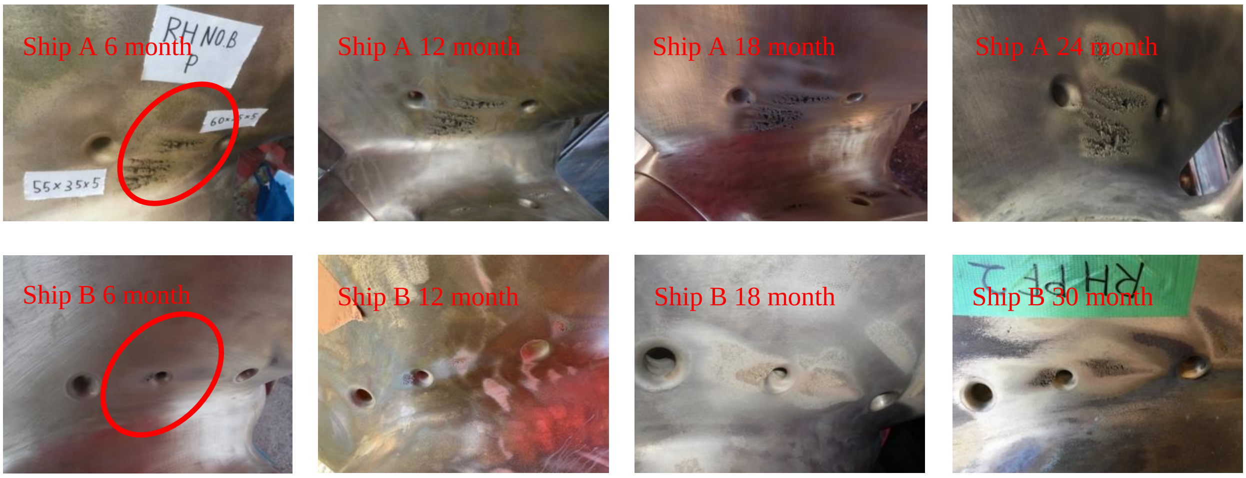


Figure 6. Conditions for propeller surface.

The relationship between the maximum erosion depth on back and face side of the per propeller blades of ship A and B and the operation time is shown in Figure 7 and Figure 8, respectively. it can be seen that the erosion progresses differently between ships A and B. In ship A, deep erosion occurs on the blade surface, while in ship B, the erosion depth on each blade surface is smaller than in ship A.

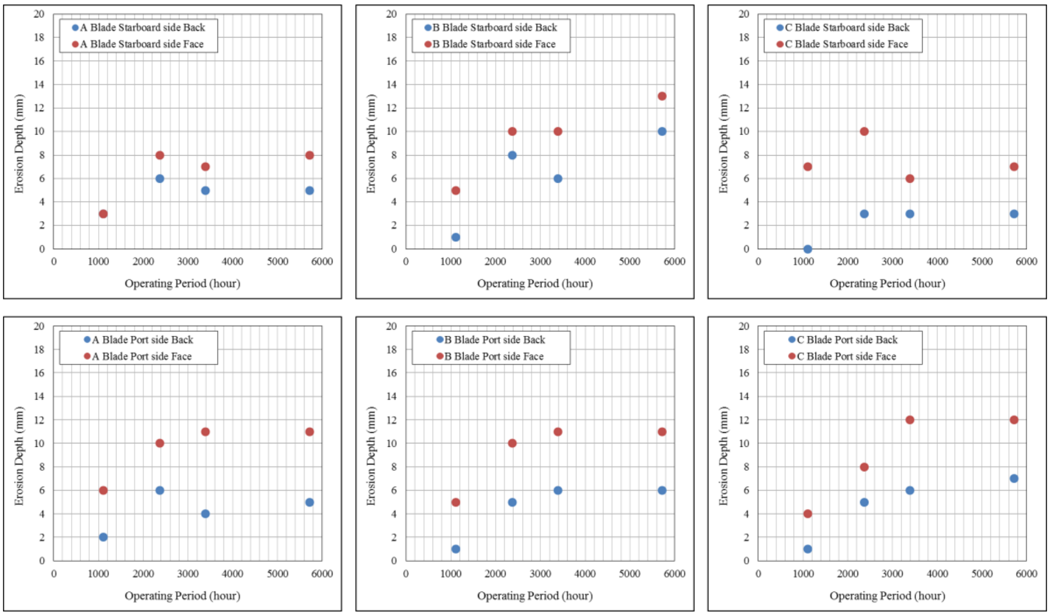


Figure 7. Erosion time series for ship A propeller.

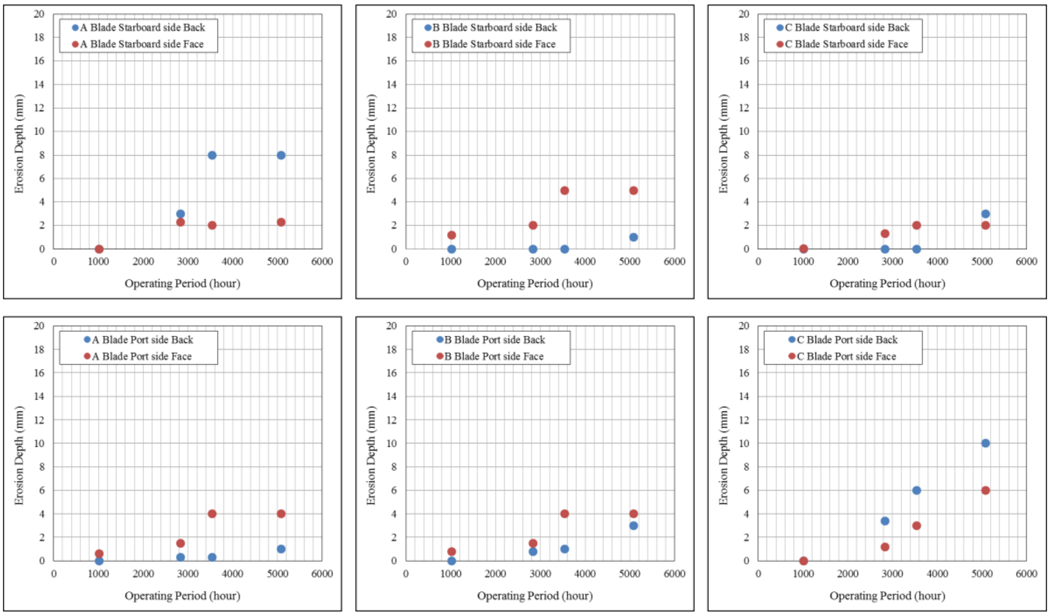


Figure 8. Erosion time series for ship B propeller.

The average, maximum and minimum erosion depth of all the propeller blades on its both surfaces at each time of dry dock are shown in Figure 9. After approximately 5000 hours of operation, this measurement data shows that the three anti-cavitation holes reduced the maximum erosion depth by about 38% and the average depth by about 52% compared to the two anti-cavitation holes. As for the progress of erosion with time, Ship A showed significant progress of erosion depth until around 2000 hours, but the progress slowed down after that. On the other hand, in the case of ship B, the erosion progressed from 1000 to 4000 hours, but the progress was slower than that of ship A. After that, the erosion progressed more slowly.

Judging from the trend of the erosion depth progress, it is expected that the erosion progress rate will continue to slow down in the future. Therefore, drilling the three anti-cavitation holes will be also more effective in slowing down the erosion depth progress than the two holes drilling.

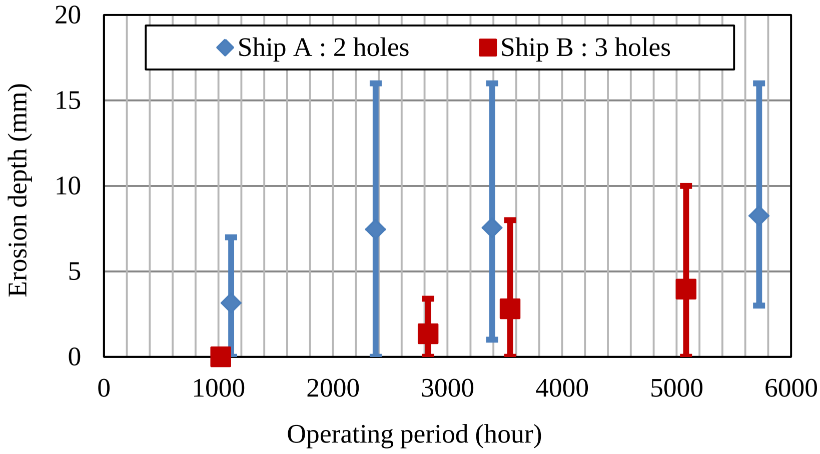


Figure 9. Erosion time series comparison.

5. ESTIMATION BY CFD

5.1 Numerical calculation conditions

It was performed that numerical calculations of the pressure on the propeller blade surface operating in diagonal flow to confirm the erosion suppression effect of anti-cavitation holes. The target propeller model is based on the propeller shape used in the full scale observation, and it was compared between a propeller without anti-cavitation hole and a propeller with two holes. The numerical calculations were performed using SC/Tetra Ver.10, a general-purpose CFD solver based on the finite volume method. The MP k-ε model was used as the turbulence model, and unsteady calculations were performed with a thrust coefficient of K_T= 0.1856. The analysis domain consists of a rotating part including the propeller and a stationary part outside the propeller, and the axial inlet velocity distribution considering the shaft rake is given as a boundary condition. The analytical mesh and computational domain are shown in Figure 10.

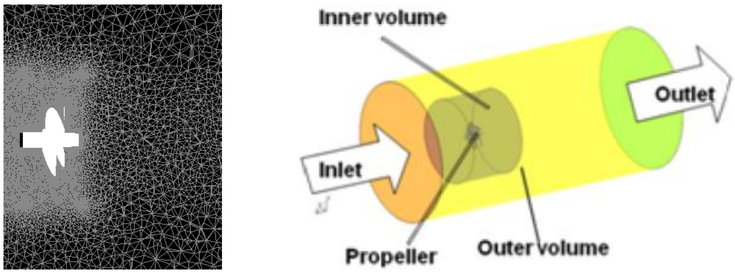
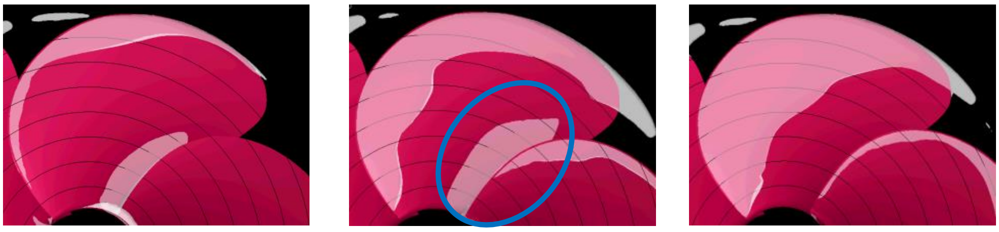


Figure 10. Numerical domain.

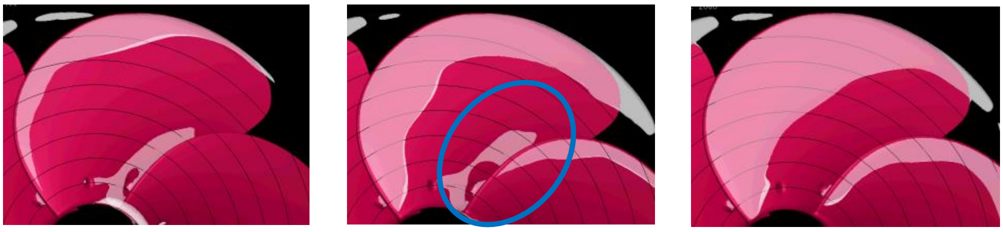
5.2 Numerical calculation result

Cavitation simulations were performed using the calculation results obtained by CFD. Then, the contour of the cavity void fraction $\alpha = 0.2$ was used for comparison in this research. Figure 11 shows the cavitation patterns at 0, 45, and 90 degrees of rotation angle when the top position is set to 0 degree. Comparing the cavitation patterns of the propeller blades with and without the anti-cavitation holes, the cavitation pattern with the anti-cavitation holes showed less cavitation at 45 degrees of rotation angle. This indicates that drilling the anti-cavitation holes can suppresses the amount of cavitation.



0deg 45deg 90deg

Figure 11. Cavitation pattern of the propeller without anti-cavitation hole.



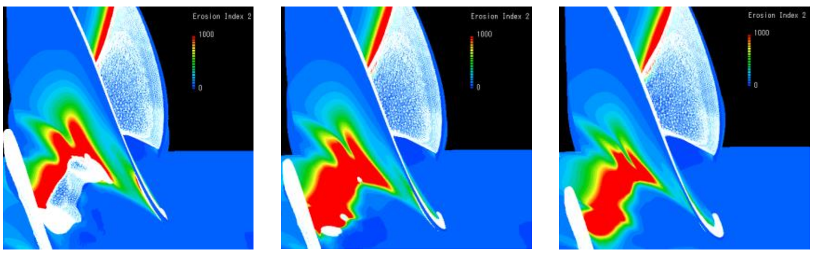
0deg 45deg 90deg

Figure 12. Cavitation pattern of the propeller with anti-cavitation hole.

Comparative evaluation of erosion risk with and without anti-cavitation holes was conducted using the erosion index2 Expression (1) proposed by Nohmi and Hasuike (Nohmi *et al*, 1999 ;Hasuike *et al*, 2009).

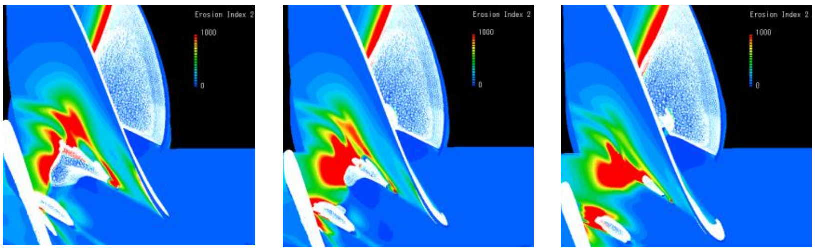
$$Index2 = \alpha \cdot max[(p - p_v), 0], \#(1)$$

Figures 13 and 14 show the evaluation by erosion index with and without anti-cavitation hole. The image shows the view from the top of the propeller, and the rotation angle indicates the angle of rotation of the front blade. High erosion index values are shown in red contours, indicating rapid pressure recovery. Comparing the results of two cases of the calculations, in the case where the propeller is not drilled anti-cavitation hole, there is a wide area of high erosion risk around the root cavitation indicating white color. Then, the cavitation disappears rapidly from -5 degrees to 0 degree of rotation angle. These indicate that there is a possibility of sever erosion occurrence. On the other hand, in the case where propeller is drilled anti-cavitation holes, the high erosion risk area around the root cavitation is smaller than the propeller without anti-cavitation hole. Comparing Figure 13 with Figure 14 at the rotation angle of -5 degrees and 0 degree, the cavitation collapse is slower and disappears more gradually on the propeller with anti-cavitation hole than on the propeller without anti-cavitation hole. Therefore it is considering that the possibility of sever erosion occurrence on the propeller with anti-cavitation hole is less likely compared with that without anti-cavitation holes. This evaluation indicates that the anti-cavitation hole is effective in reducing the range of rapid pressure fluctuation and suppressing erosion.



-5deg 0deg 5deg

Figure 13. Erosion Index of the propeller without anti-cavitation hole



-5deg 0deg 5deg

Figure 14. Erosion Index of the propeller with anti-cavitation hole

About the location of high erosion risk areas on the propeller blade surface with anti-cavitation holes, these are mainly found between the holes, and cavitation is observed to collapse between the holes. This is similar to the results of the full scale observation. Therefore, it is considered that this numerical calculation method can predict the areas of erosion risk to some extent, and it can be a tool to consider the design of anti-cavitation holes, including the size and location of holes in the future.

6. CONCLUSIONS

The following results were obtained from full scale observation and numerical calculations aimed at preventing root erosion of propellers for small high-speed ships.

- By drilling three anti-cavitation holes, the erosion range and depth, and rate of progress could be suppressed compared to the conventional measures.
- By numerical calculations, it was verified that the anti-cavitation holes is effective in reducing the amount of cavitation and the risk of erosion.
- It was confirmed that the CFD using this research can be used as a tool for erosion risk study and anti-cavitation holes design.

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REFERENCES

Hasuike, N., Yamasaki, S., and Ando, J. (2009). Numerical Study On Cavitation Erosion Risk of Marine Propellers Operating in Wake Flow. *Proceedings of the 7th International Symposium on Cavitation*, No.30

Kihara, K. and Nakamura, N. (1984). Actual Ship Test of Changing the Blade Number of a Propeller for High-speed Ship. *The West-Japan Society of Naval Architects*.

Nohmi, M., Iga, y., and Ikohagi, T. (2008). Numerical Prediction Method of Cavitation Erosion. *Conference Proceeding of turbomachinery Society of Japan*, vol.59

Okada, Y., Yoshioka, M., and Kubo, H. (1998). Development of New Propeller for High Speed Ships, Effective for Prevention of Root Cavitation Erosion. *The Society of Naval Architects of Japan*, Autumn lecture meeting

Ouchi, K., Kawati, F., and Ueda, K. (1998). Long-term Examination of Propeller Root Erosion, *Marine Engineering Academic meeting*, pp.85-88.

Suzuki, K. (1998). Shafting System of High-speed Ships. *Japan Institute of Marine Engineering*, 33 vol.9.

Ukon, Y., Fujisawa, J., Kawanami, Y., Sakoda, M., and Yamasaki, S. (2006). About the Prevention Measure of Root Erosion. *Symposium on Cavitation*