PROPOSAL OF A GROOVE CAVITATOR ON A SUPERCAVITATION PROPELLER

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Abstract

A supercavitation propeller (SCP) that has high efficiency under supercavitating condition is expected as one of the most suitable propulsors for a high-speed vessel. To design a SCP with higher efficiency, a thinner cavity is recommended. However, less supercavitation sometimes occur contrary to the designer's expectation, thus the thrust becomes less than the design value and the efficiency becomes lower. In order to obtain the predicted thrust and high efficiency, it is necessary to let stable cavitation occur from the leading edge as predicted by theory. The authors propose a new cavitator that stimulates cavitation by a thin groove near the leading edge on the backside surface. Through the present comparative tests between propellers with and without the cavitator, it was clarified that the proposed cavitator is effective in stimulating and stabilizing a supercavity, and that it increases the propeller efficiency.

1 Introduction

Under high-speed condition, a large cavitation occurs on a conventional propeller so that its thrust and efficiency go down. A supercavitation propeller (SCP. In this paper a 'supercavitation propeller' means a propeller designed for the use under supercavitating condition distinguished from a 'supercavitating propeller' which is a propeller running under supercavitating condition.) is designed for use under such a high-speed condition, that is, it will display high efficiency under the supercavitating condition.

An SCP is designed on the assumption that a sheet cavitation covers the propeller blade from leading edge to its wake. In order to expect high efficiency, the SCP must be designed so that the sheet cavitation will be thin to the utmost (Kudo 1994a, Ukon 1994). On the designed SCP, however, unexpected condition often occur, that is, the cavitation does not start from the leading edge (Kudo 1998), or the cavitation separates to some streak cavities. This causes thrust and torque unexpected by the theoretical prediction (Kudo 1994b), and it sometimes leads unstable cavitation and fluctuating forces. Stable sheet cavitation occurrence is necessary to prevent such an unexpected condition.

It is well known that the sheet cavitation generally starts at the laminar separation point (Arakeri 1975, Yamaguchi 1981). Based on the idea that stable separation will make the cavitation stable, the present paper proposes a 'groove cavitator' that stimulates cavitation by a thin groove near the leading edge on the backside surface, and verifies its effectiveness by model tests.

2 Figure and Principle of the Cavitator

In cavitation test, in order to prevent the unstable cavitation, some techniques have often been taken to stimulate the leading edge separation, for example trip wire method (Yokoo 1960) or leading edge roughness method (Kuiper 1981). However, things attached at the leading edge in these methods tend to make cavitation thicker, and it causes the increase of section drag or propeller torque (Sumino 1991). In the

*The Ship Research Institute has changed to National Maritime Research Institute in April, 2001

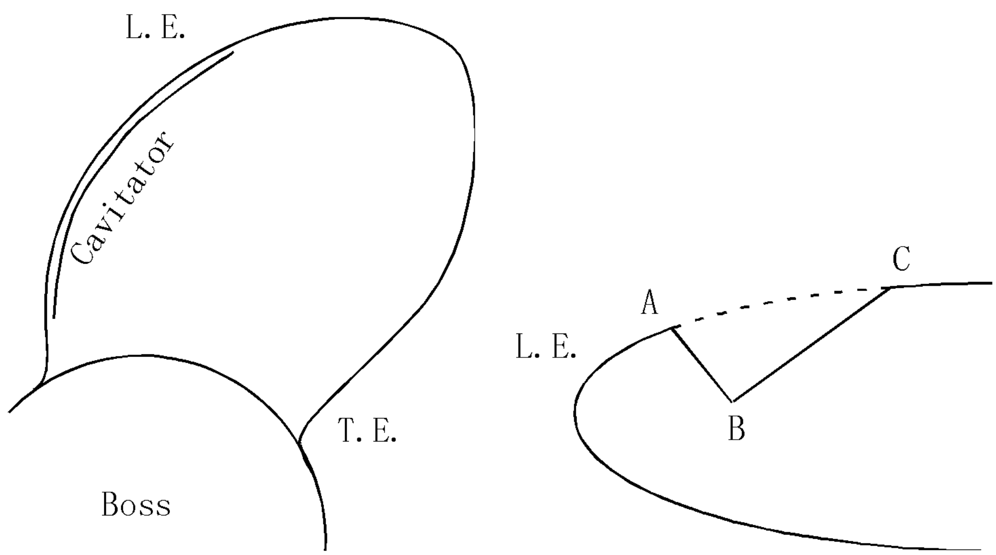

Figure 1: Groove Cavitator. Left: Over view. Right: Section.

cavitation test for special purpose, for example the pressure fluctuation test, stable cavitation will be desirable even if the torque may increase. In such a case, the cavitation stimulating techniques will be adopted. For the real propellers, however, increase of torque must be avoided because it leads decrease of efficiency.

Now authors propose a new cavitator which does not increase cavity thickness and make stable cavitation. Its appearance is shown in Figure 1.

The present cavitator is a groove near and parallel to the leading edge of the propeller blade, and has a 'V' shape section. The leading edge of the groove (point A in Figure 1 Right) has almost right angle to the blade surface, and the trailing edge (point C in Figure 1 Right) joins smoothly to the blade surface.

The principle of the groove cavitator is as follows. The flow separates compulsorily at the leading edge of the groove (point A), and a separation bubble is formed in the rear. If the pressure is low enough, cavitation occurs in this separation bubble. This cavitation is stable, or doesn't disappear, because it is originated by the forced separation. Based on the potential theory, upper surface of this cavity is the same surface of the cavity starting from the point A without the groove cavitator. Therefore the groove cavitator doesn't increase the cavity thickness. The clearest difference between cavities with and without the groove cavitator is stability.

In order to use the groove cavitator the most effectively, it is thought proper to adjust the leading edge of the groove to the starting point of the cavity calculated by the potential theory.

3 Experiment

To certify the effectiveness of the groove cavitator, some tests were performed using a 3-bladed propeller. Principal dimensions of the propeller are shown in Table 1. Two models of this propeller were made, one with the groove cavitator and the other without it. The interval between the leading edge of the blade and the groove was $2mm$ measured parallel to the propeller shaft, and the depth of the groove was $0.2mm$ measured right to the propeller shaft.

The test was performed in the large cavitation tunnel of National Maritime Research Institute (the Ship Research Institute at that time) with the main dynamometer (K&R J26; maximum thrust $600kgf$, maximum torque $30kgf - m$). Air content ratio was controlled between 32% and 35%.

Photos of cavitation observed in the tests are shown in Figure 2 and 3. Figure 2 is cavitation on both propeller models under the design condition. (See Table 1.) Both propeller models ran under almost supercavitating condition, that is, hole blades except for the root were fully covered with supercavity. Observing in detail, on the model without the groove (in the left figure), marking lines of $0.8R$ and $0.9R$ are visible,

Table 1: Principal dimensions and design conditions of tested propeller models

Diameter	D_P	$250.00mm$
Number of blades	Z	3
Pitch at $0.7R$	H/D	1.8816
Expanded area ratio	EAR	0.5047
Boss ratio	X_B	0.3046
Rake angle		$30.00deg$
Skew angle		$32.28deg$
Direction of rotation		right
Material		Alminum alloy
Advance coefficient	J	1.546
Cavitation number	σ_V	0.250
Thrust coefficient	K_T	0.138

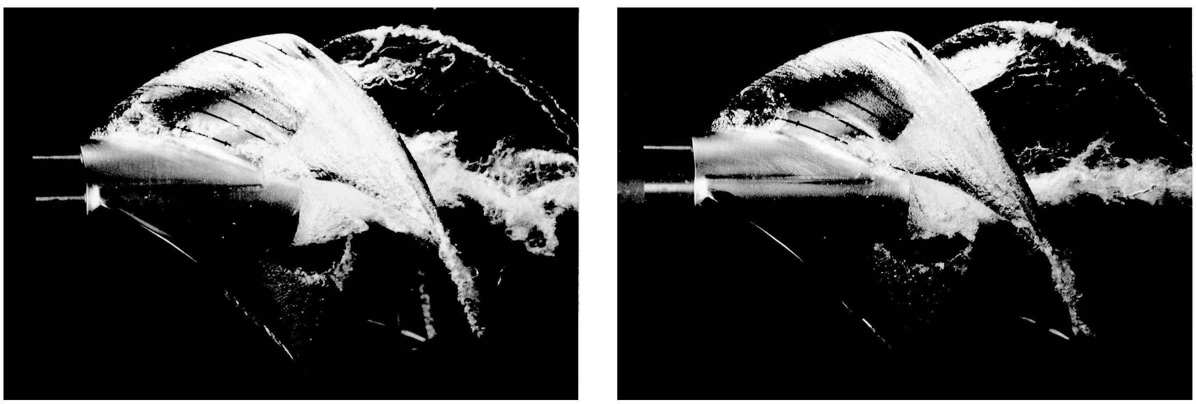

Figure 2: Cavitating propellers under $\sigma_V = 0.250$ condition. Left: Without the groove cavitator. Right: With the groove cavitator.

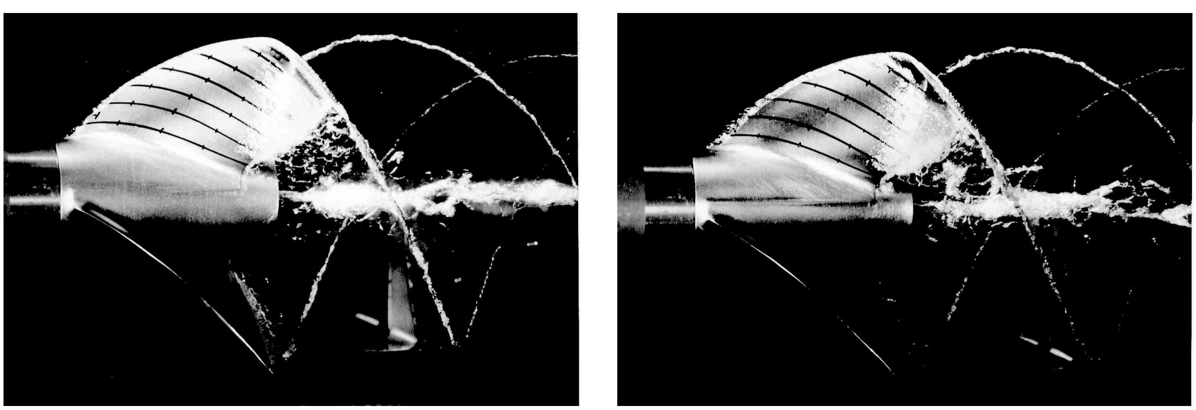

Figure 3: Cavitating propellers under $\sigma_V = 0.500$ condition. Left: Without the groove cavitator. Right: With the groove cavitator.

which means that there is no cavity in this area. On the other hand, on the model with the groove (in the right figure), marking lines are invisible because of cavitation.

Figure 3 shows propeller cavitation with higher cavitation number ($\sigma_V = 0.50$). It is clear that length of cavity at the propeller leading edge is different between both propellers.

Comparisons of propeller characteristics between the two propeller models are shown in Figures 4 to 9. Figures 4 to 6 are with constant cavitation number $\sigma_V = 0.250$, while Figures 7 to 9 are with constant propeller advance ratio $J = 1.546$.

In Figures 4 and 5, the thrust and torque of both models don't show remarkable difference bellow the design point $J = 1.546$. On the other hand, over the design point, although thrust and torque increase without the cavitator, both decreases with the cavitator. Thrusts under the design condition are less than the design value in Table 1. The errors from the design value were -6% without the cavitator while -4% with the cavitator. Although the efficiency without the cavitator reaches its maximum at larger J than the design J, that with the cavitator is the maximum at the design J (Figure 6). The efficiency with the cavitator at the design J is higher than that without the cavitator by 1.7%.

Against any cavitation number, the torque in Figure 8 shows little difference between with and without the cavitator, while the thrust with the cavitator in Figure 7 is slightly larger than that without the cavitator. In Figure 9, the efficiency with the cavitator is higher than that without the cavitator, and their difference becomes smaller as the cavity becomes smaller with high cavitation number.

4 Conclusion

The groove cavitator was proposed to stimulate and stabilize the cavitation for the purpose of the same cavitating condition with enough thrust and high efficiency as expected in the theoretical design of a super-cavitating propeller. Model tests confirmed the effects of the present cavitator, that is:

1. The groove cavitator stimulates sheet cavitation starting from the propeller leading edge.
2. The groove cavitator increases propeller thrust and decrease its error from the design value.
3. Differing from other cavitators, the groove cavitator doesn't increase propeller torque.
4. A supercavitation propeller with the groove cavitator shows its maximum efficiency at the design point, and it is higher than efficiency without the cavitator.

The processing method, the most suitable figure and arrangement, and applicable condition of the groove cavitator are necessary to be studied as future works.

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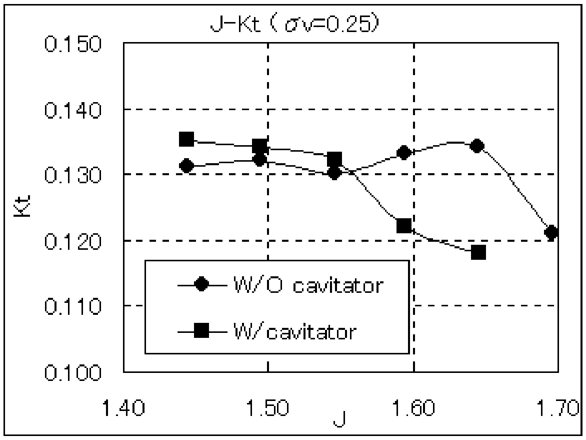

Figure 4: Comparison of thrust coefficient against propeller advance ratio between with and without cavitator

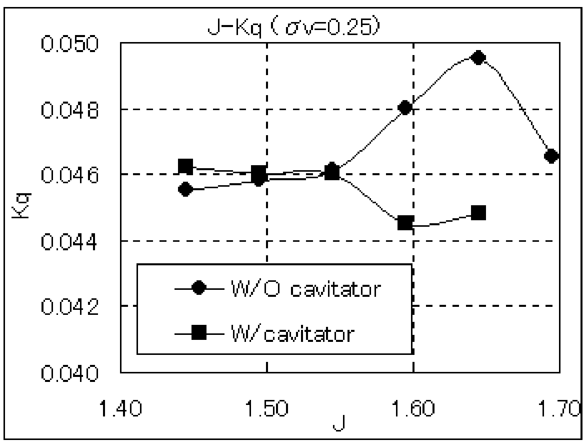

Figure 5: Comparison of torque coefficient against propeller advance ratio between with and without cavitator

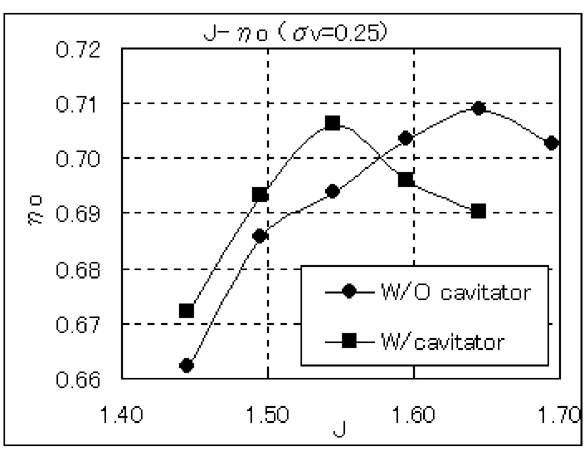

Figure 6: Comparison of efficiency against propeller advance ratio between with and without cavitator

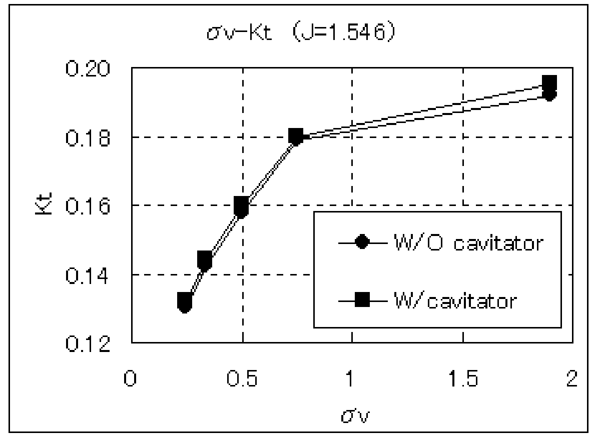

Figure 7: Comparison of thrust coefficient against cavitation number between with and without cavitator

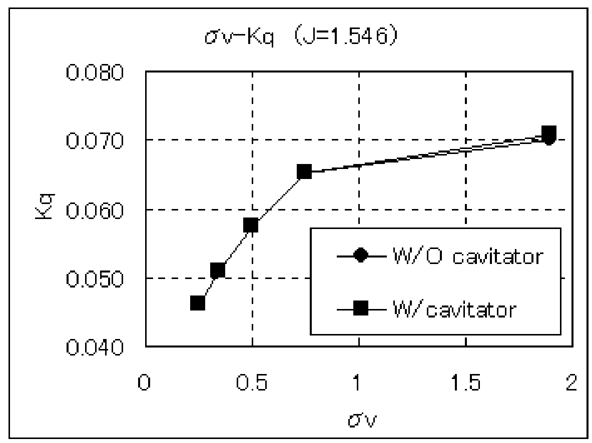

Figure 8: Comparison of torque coefficient against cavitation number between with and without cavitator

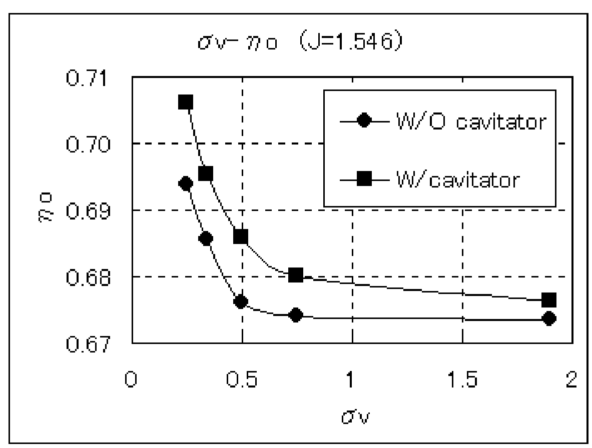

Figure 9: Comparison of efficiency against cavitation number between with and without cavitator