Numerical and Experimental Investigation of Performance of the Asymmetric Pre-Swirl Stator for Container Ship

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ABSTRACT

This paper deals with Numerical and Experimental method for resistance performance of asymmetric pre-swirl stator which has been used an energy saving device by cancelling a propeller rotational energy. Model tests are performed in the towing tank at Pusan National University in Korea to compare and to validate the computed results. In the case of normal merchant ships, the upward flow is generated along the afterbody hull form at the propeller plane. The generated upward flow cancels the rotating flow of the propeller at the starboard part while it increases at port part. The present asymmetric pre-swirl stator propulsion system consists of three blades at the port and one blade at the starboard which can recover the biased rotating flow effectively. This paper provides the design concept to the present asymmetric stator which gives more efficient results than the conventional propeller. The results have been validate by computation numerical as well as by experiment.

Keywords

Asymmetric Stator, Pre-Swirl, Performance

1 INTRODUCTION

In response to the growing concern over global warming, since 2013, the IMO (International Maritime Organization) has ensured that indices related to energy efficiency are applied to new building ships at every stage, from shipbuilding to navigation and management.

In particular, EEDI (Energy Efficiency Design Index for new ships), an energy efficiency index applied during shipbuilding, refers to the CO_2 emissions generated to transport 1 ton of cargo for 1 nautical mile. Starting with a 10% reduction in January 2013, CO_2 emissions should be reduced in stages, for a total reduction of 30% by 2015.

Accordingly, studies are being actively conducted globally to improve hull forms and propulsion systems, with the ultimate goal of decreasing the EEDI.

Efforts to improve the performance of propulsion systems have been made for a long time, including the installation of a composite propulsion system.

A composite propulsion system (Fig. 1) is broadly divided into the pre-device, main device, and post-device .

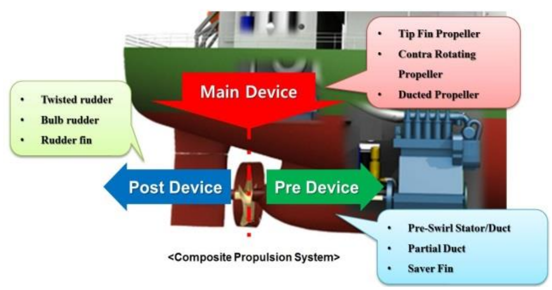

Figure 1: Composite Propulsion System

As pre-devices, a pre-swirl stator (PSS), pre-swirl duct (PSD), duct-type appendage, and fin-type appendage are known to be effective. As main devices, a tip rake propeller (TRP), contra-rotating propeller (CRP), and duct propeller (DP) are known to be effective. In addition, as post-devices, a twisted rudder, propeller-rudder, and rudder bulb & fin are known to be effective.

In particular, when it comes to pre-devices, studies on a PSS from Daewoo Shipbuilding & Marine Engineering Co., Ltd and PSD-Mewis Duct from Becker Marine Systems have been conducted. Although the performance differs depending on the ship type, the energy reduction effect is known to be approximately 3%–8%.

Furthermore, in the case of the main device, a CRP , where two propellers recover energy by rotating in opposite directions, is known to improve the performance by approximately 10%. The Kappel Propeller , which improves the performance by reducing the 3D effect at the wingtip, actually improves the performance by approximately 1%–5%. As for post-devices, there is a trend to move from a semi-spade rudder toward a full-spade rudder, which provides a much better rudder force. In particular, there is an increase in the use of a twisted rudder with asymmetric upper and lower cross-sectional shapes because of the difference in the upper and lower flows when the propeller post-swirl flows into the rudder. In addition, efforts are being made to improve the hydrodynamic performance by installing bulbs to reduce the influence of the propeller hub vortex and resolve the discontinuity of the part connecting the upper and lower sides of a twisted rudder. There actually was a case where the performance increased by approximately 2% when the interconnectivity between the propeller and rudder was improved.

This study dealt with an asymmetric stator installed in a pre- device, and the difference in the resistance performance in relation to its installation was verified through a model test and the computational fluid dynamics (CFD).

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2 Design of Asymmetric Pre-Swirl Stator

Ultimately, a ship propeller should be able to show the best performance in the slip stream of a full-scale ship. Stators, like propellers, are also placed in a non-uniform slip stream composed of three velocity components in the axial, radial, and tangential directions.

Because the stator is located in front of the propeller, the wake distribution on the stator plane is slightly different from that on the propeller plane, but the nonuniformity is similar.

This study aimed at designing the most appropriate stator for this wake distribution using the results of a harmonic analysis of the nonuniform wake measured in model testing on a stator plane.

If the pitch angle of the stator is the same for each blade for a nonuniform wake, both the nonuniformities of the axial direction component and the velocities in the tangential direction appear in opposite directions on the starboard and port sides from the stator, resulting in a significant change in the load on each blade. Therefore, it is difficult to obtain the maximum efficiency if the pitch angle of each blade of the stator is improperly adjusted.

This study substituted α equi. (Equivalent angle-of-attack) for the loading amount of the stator to create a more visual presentation. In other words, the loading amount was replaced by the corresponding 2-D local angle-of-attack as shown below for the radius of each blade (Fig. 2).

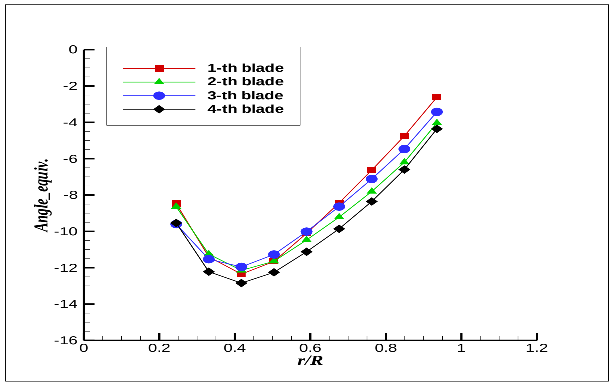


Figure 2: Radial circulation distribution on the Stator blade

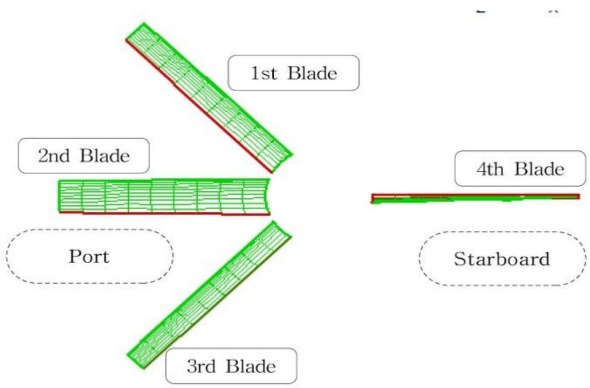
The ship's specifications should be changed according to the radial direction to match the inflow speed of the blade radius.

However, when designing completely different specifications based on the radial direction, the loss caused by production difficulty and excessive production cost should be calculated in comparison with the benefit of the propulsion efficiency improvement.

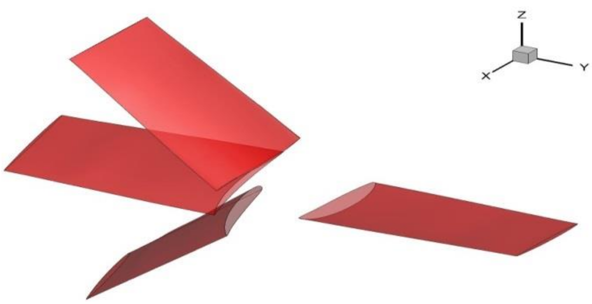
A compromise at an adequate level should be reached because an excessive change in the pitch angle not only causes production problems but also is hydro-dynamically unsound. Considering this situation, Table1 shows the optimal pitch angle of a PSS to be applied in the future, whereas Fig.3 shows the design of the model to be implemented in this study.

Table 1. Designed radial angle distribution along radii(Degree)

Stator	Position(°)	Angle (°)
1st Blade	45	14
2nd Blade	90	19
3rd Blade	135	12
4th Blade	270	2



. (a) Distribution of Stator Blade



(b) 3D Modeling

Figure 3: Distribution and 3D Modeling of Stator Blade

3 Experimental Setup

3.1 Towing Tank

A model test was conducted in the towing tank of Pusan National University (PNU). The PNU towing tank has dimensions of 100 m in length, 8 m in width, and 3.5 m in depth.

Figure 4: The Facilities of PNU Towing Tank

3.2 Model Ship

The target vessel is a 3600 TEU Container Ship, and the model ship is shown in Fig.5, with the specifications listed in Table 2. This study conducted resistance tests for ships with and without a stator.

(a) 3600 TEU Container Body Plan

(b) KCS Stern Profile without /with stator

Figure 5: 3600 TEU Container Model Ship

Table. 2 Principal Particulars of Ship (KCS)

	Real ship	Model ship
Length PP [m]	230.00	5.82
Length WL [m]	232.50	5.89
Breadth [m]	32.20	0.82
Depth [m]	19.0	0.48
Design Draught [m]	10.8	0.27
CB	0.651	0.651
Design speed [knots]	24.00	3.82
Scale ratio	39.5	

3.3 Model Test

Resistance tests were carried out in the PNU towing tank targeting a KCS ship. The resistance performance was assessed at 16 knots -27 knots, depending on the installation of the stator in the design load.

3.4 Model Test Result

The results of the resistance tests with and without the stator installed were as follows. Rtm and EHP increased by approximately 6.9% and 11% with the stator, compared to the bare hull condition. The resistance seemed to increase as a result of the excessive cord length of the stator and the pitch angle.

4 Numerical Analysis

The CFD software used for this study was Star CCM+ of CD-adapco, which was used globally since 2004. This analysis software is used for product development in approximately 95% of the research centers of businesses.

In this study, the analysis was conducted under the same conditions as the model testing.

4.1 Analysis Condition

The analysis conditions used in this study are listed in Table 3, and the boundary conditions and grid system are summarized in Figs.6 and 7, respectively.

Table. 3 Analysis Conditions (KCS)

	KCS
Program	STAR CCM+ (Ver 9.04)
Governing Equation	Incompressible RANS Equation
Discretization	Cell Centered FVM
Turbulence model	Realizable κ-ε model
Wall function	Non-Equilibrium
Velocity-Pressure Coupling	SIMPLE Algorithm
Rotation Method	Moving Reference Frame
Yp	0.0003(Hull), 0.0001(Propeller)
Cell Number	5,000,000
Physical Time	30s

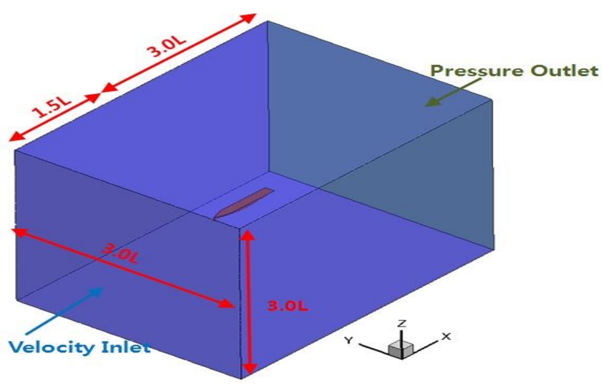


Figure 6: Boundary Condition

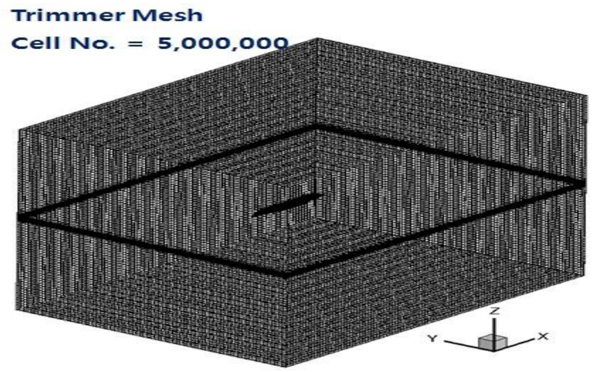


Figure 7: Grid System

4.2 Numerical Analysis Results

The results of the resistance tests using CFD with and without the stator installed are shown in Figs. 8 and 9, respectively. Because the calculated values showed a low reliability in the initial time period, the average value for a 10–20-s period with a consistent tendency was used. Under the with-stator condition, the resistance was approximately 6.65% greater than that of the Rtm(N) bare hull at the design speed (24 knots).

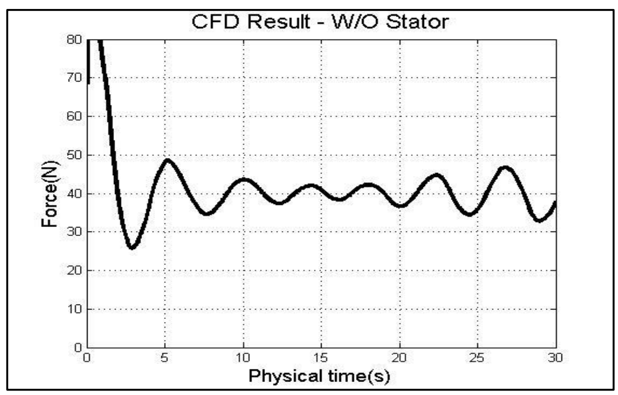


Figure 8: time history of **Bare Hull**

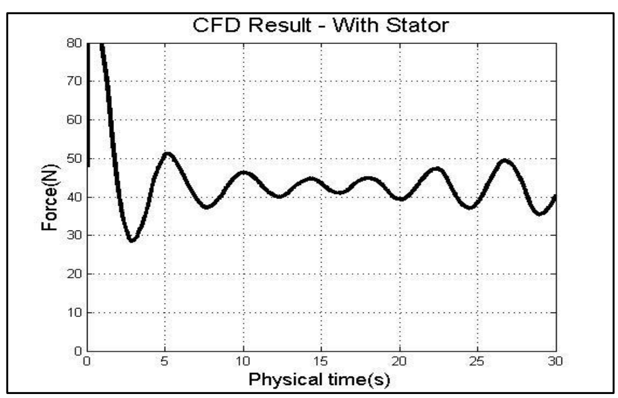


Figure 9: time history of **with Stator**

5 Compared with Experimental and Numerical Results

The resistance values of the KCS ship with and without the stator were compared in model tests and numerical analyses. Based on Rtm(N), the model test and numerical analysis results showed a difference of approximately 2.5% between the bare hull and hull with the stator. The results are listed in Table 4.

Table. 4 Comparison of Result

	Bare_Rtm(N)	With_Rtm(N)	Diff(%)
EFD	39.07	41.77	6.9
CFD	40.11	42.78	6.6
Diff(%)	2.6	2.4	

6 New Design of Asymmetric Pre-Swirl Stator

The aforementioned stator was called Design 1. In addition, as a result of validating the performance through model tests and CFD analyses for Design 1, the hull with the stator was assumed to have no propulsion efficiency due to an excessive resistance increase compared to the bare hull. As a result, the stator was redesigned, and was called Design 2.

The design process was the same as the previously mentioned process. α equi.(Equivalent angle-of-attack) (Fig. 10) and the optimal pitch angle (Table 5) were obtained by modifying the geometry.

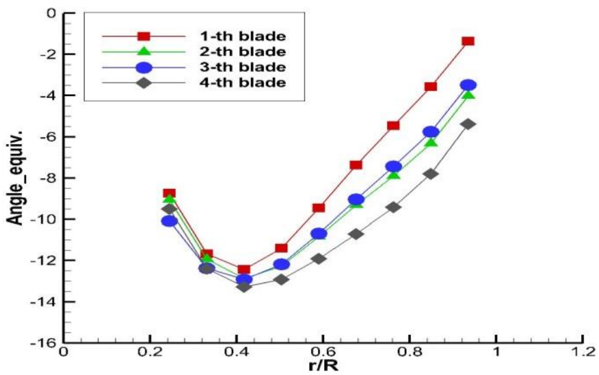


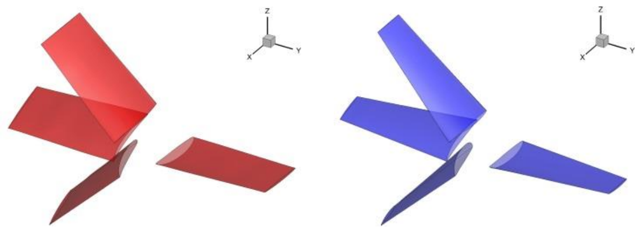
Figure 10: Radial circulation distribution on the Design2 Stator blade

Table. 5 Designed radial angle distribution along radii(Degree)

Design 2 Stator	Position(°)	Angle (°)
1st Blade	45	8
2nd Blade	90	14
3rd Blade	135	9
4th Blade	270	1.5

Fig. 11 shows the difference between the Design 1 and 2 stators. Design 2 was designed by shortening the overall cord length and adjusting the proportion of the hub and tip sides.

A performance validation was conducted for Design 2 using a CFD analysis, and a further performance validation is scheduled with a model test.



(a) Design 1 (b) Design 2

Figure 11: Comparison of Design 1 and Design 2

7 Numerical Analysis Result of Design 2 Stator

The analysis conditions for Design 2 were the same as those previously mentioned. The results are listed in Table 6.

Table. 6 CFD Result of Design 2

	Bare_Rtm(N)	With_Rtm(N)	Diff(%)
CFD	40.11	41.07	2.4

8 CONCLUSIONS AND FUTURE WORK

This study validated the resistance performance after the installation of an asymmetric stator in a pre-device through model tests and numerical analyses.

An asymmetric stator was designed utilizing the potential base PASTA program after checking the wake distribution of KCS.

The examination of the performance of the Design 1 stator through model tests and numerical analyses showed that Rtm and EHP increased by approximately 6.9% and 11% with the stator compared to bare hull condition, respectively.

Thus, the resistance was assumed to have increased as a result of the excessive cord length and pitch angle. Therefore, numerical analyses were conducted for the redesigned Design 2 Stator.

The performance will be verified through resistance tests in the future, and the propulsion efficiency will be examined by checking the self-propulsion performance.

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REFERENCES

Kwon, J. I. "A Study on the Biased Asymmetric Pre-swirl Stator For a Container Ship", M.S Dissertation, Pusan National University, Busan, Korea (2013)