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Study on Performance of Combined Energy Saving Devices For Container Ship by Experiments*

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ABSTRACT

Recently, research of Energy Saving Device (ESD) has been developed due to the regulation of the Energy Efficiency Design Index (EEDI). This study deals with performance of combined ESD based on experiments in model scale. Model tests are performed in the towing tank at Pusan National University in Korea to validate its performance. The ESD at three regional area (before, on and behind of propeller) has been developed in the previous research. In the present study, the effect of the combined ESD is investigated compared to that of each devises respectively. The results are expected to be compared with computations and validated by sea trial results in near future.

Keywords

EEDI, Combined ESD, Model Test

1 INTRODUCTION

Recently, with the growing concern about global warming and depletion of fossil fuels, IMO (International Maritime Organization) has ensured that indices related to energy efficiency are applied to new building ships at every step, from shipbuilding to navigation and management. In particular, EEDI (Energy Efficiency Design Index), 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 2013, EEDI should be reduced in 30% by 2025(Zabi Barazi et al., 2011). In response to the regulation, studies are being conducted actively to improve hull forms and propulsion system with the ultimate goal of decreasing the EEDI.

The ESD (Energy Saving Device) is the device to reduce the EEDI and also increases the energy efficiency by improving propulsion performance. According to location of ESD, it can be classified into the Pre Device, Main Device and Post Device. As a pre device, PSS (Pre-Swirl Stator), Mewis duct, wake equalizing duct and saver fin are well known to be effective. Furthermore, as a main device, CRP (Contra Rotating Propeller), Kappel propeller, TR (Tip Rake) propeller and as a post device, twisted rudder, rudder bulb & fin are well known to be effective.

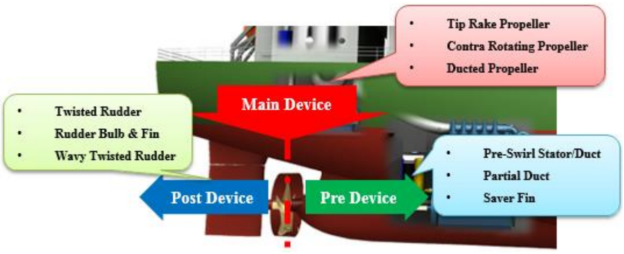


Figure 1 Energy Saving Device

The purpose of the present study is to find out the synergy effect of the combined system of the promising devices. Especially the selected each devices has a function of saving rotational energy by each mechanism. The effect is shown by experimental result. The more detail phenomena, such as the saving mechanism, and overlapping amount of tangential energy are also expected to be investigated in near future.

This study deals with Combined ESD and its performance is verified through model tests. The PSS, TR propeller, and WTR (Wavy Twisted Rudder) are adopted as Pre Device, Main Device, and Post Device, respectively.

2 Design of Combined Energy Saving Device

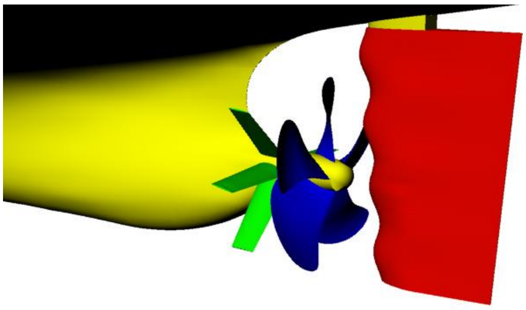
The target vessel is a 3600 TEU KCS (Kriso container ship) and the model ship is shown in Figure 2, with the principal particulars listed in Table 1. In order to constitute the combined ESD, this study refers to previous studies which have been developed and conducted (Kim et al., 2004; Kang et al., 2004; Kwon et al., 2013; Kang et al., 2016; Lee et al., 2016; Shin et al., 2016; Kim et al., 2017; Lee et al., 2017; Kim et al., 2009; Heo et al., 2017; Tae et al., 2017). The combined ESD adopted this study is shown Figure 3.

Figure 2 3600TEU KRISO Container Ship (KCS)

Table 1 Principal particulars of 3600 TEU 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	

(a) Experiment Model



(b) 3-D Modeling

Figure 3 Combined Energy Saving Device

2.1 Pre Device

The selected Pre Device is Asymmetric PSS (Pre-Swirl Stator) which improves the propulsion efficiency through the recovery of rotational energy by making a counter-swirl flow against the tangential velocity lost by the propeller. Shown in Kang et al., 2016 and Shin et al., 2017, the purpose is that PSS improves the self-propulsion performance through minimizing the resistance increase caused by PSS, reflecting the characteristic of the container ship with rather high speed. The optimized design of PSS is based on potential and CFD program and validated by model test. The efficiency gain of the present PSS is 3.9% in comparison with conventional ship. The configuration of the adopted PSS is shown in Figure 5 with designed pitch angle listed in Table 2. The rotational energy is normally saved by PSS as 50% of total rotational energy which has been researched by Lee et al. 1992.

Table 2 Designed pitch angle of Stator

Blade No.	Position(˚)	Pitch Angle(˚)
1st	45	5
2nd	90	10
3nd	135	2
4th	270	1.5

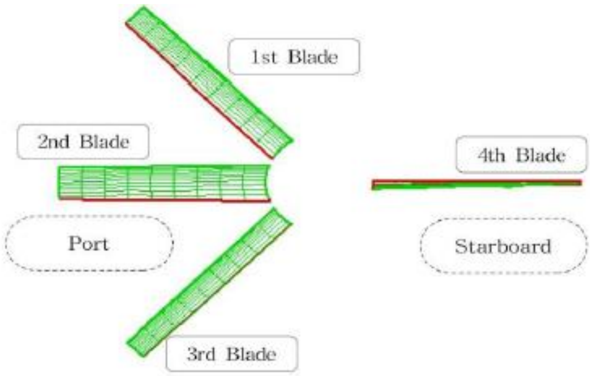


Figure 4 Distribution of Stator Blade

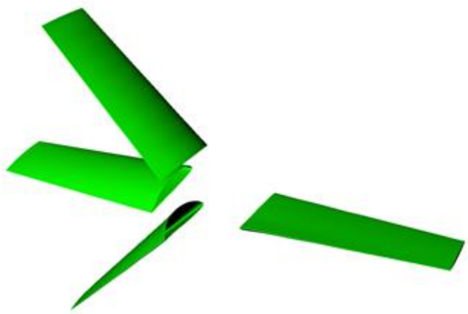


Figure 5 Asymmetric Pre-Swirl Stator

2.2 Main Device

The selected Main Device is TR (Tip Rake) propeller which reduces tip vortex through preventing the cross flow around propeller tip.

The TR propeller concept came from CLT (Condensed Loaded Tip) propeller which is the extreme case of preventing tip vortex. The CLT propeller, however, has sometimes a cavitation problem around the corner of tip region. Recently the smoothly curved TR propeller is more popularly used. There are two types of TR propeller according to direction of rake distribution; Forward type, Backward type. In this study, the backward type is adopted because it is better performance than forward type shown in the Lee et al. 2017.

The efficiency gain of the present TR propeller is 1.5% in comparison with conventional ship. The rake distribution and configuration of the TR propeller are shown in Figure 6~7, respectively.

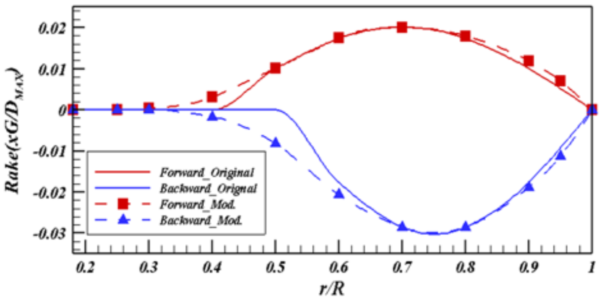


Figure 6 Rake Distribution depending on radius

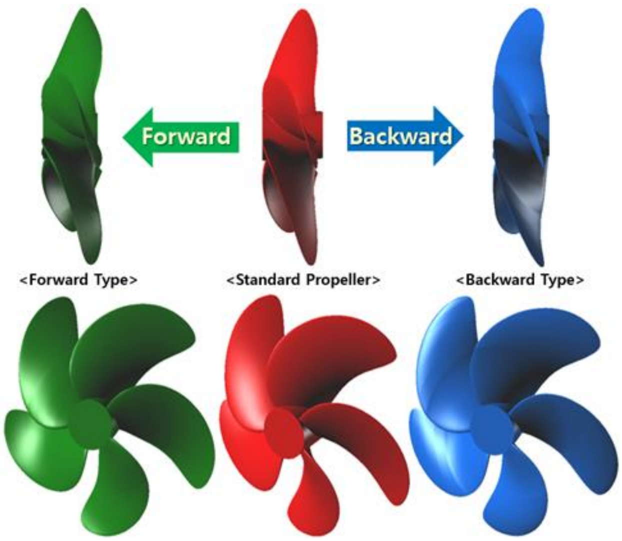


Figure 7 Tip Rake Propeller

2.3 Post Device

The selected Post Device is WTR (Wavy Twisted Rudder) which has been developed for delaying the stall problem in a conventional twisted rudder. The hydrodynamic performance in a little angle of attack condition is almost same as a conventional twisted rudder which has been also shown in Tae et al., 2017.

The efficiency gain of the present WTR is 1.9% in comparison with semi-spade rudder case which is similar to the reported efficiency gain of a normal twisted rudder. The configuration of the adopted WTR is shown in Figure 9.

Table 3 Self-Propulsion Results of Post Device

	Experiments	
	2πnQ	Diff. (%)
Full Spade Rudder	80.40	-
Twisted Rudder	79.16	-1.54
Wavy Twisted Rudder	78.92	-1.85

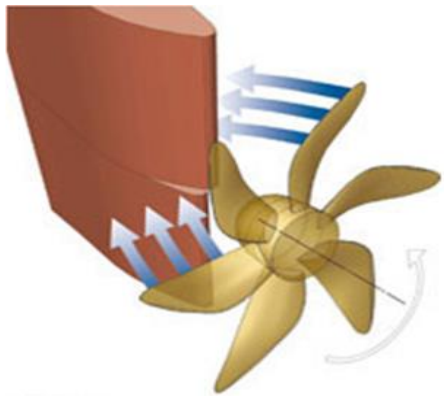


Figure 8 Concept of Twisted Rudder

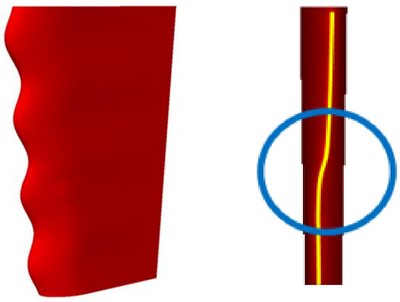


Figure 9 Wavy Twisted Rudder

3. Model Test

Model tests have been conducted in PNU (Pusan National University) towing tank. The dimensions of PNU towing tank are 100 m in length, 8 m in width and 3.5 m in depth.

The model test results of the resistance and self-propulsion test are shown in Table 3~5. The increase of R_{TM} is 2.9% in comparison with that of bare hull. The 2πnQ, which means delivered power in model scale, is decreased by 5.4% in the combined ESD.

Figure 10 Towing Tank in Pusan National University

Table 4 Resistance Results

	Bare Hull	w/ Combined ESD	Diff.(%)
R_{TM} (N)	45.45	46.77	2.90

Table 5 Self-Propulsion Results

	Bare Hull	w/ Combined ESD	Diff.(%)
rps	10.90	10.53	-3.39
Torque (N-m)	1.17	1.15	-2.04
2πnQ	80.40	76.09	-5.37

4. Comparison of performance between Combined ESD and single ESD

Each model test of powering performance for the bare hull (without ESD), with PSS, with TR propeller and WTR has been conducted. The combined system has also been executed to compare with the others.

As shown in Table 6, the resistance of combined ESD is bigger than the hull case of 2.9% in model scale which is bigger than the other ESD cases. It is reasonable that the resistance summation of each device is almost same as the combined system.

In self-propulsion test, the comparisons of rps(rotation per second) and torque are shown in Table 7 and 8, respectively. As shown in Table 9, the required power of the combined ESD is less than the bare hull case of 5.4% in model scale which is less than the sum of each gain of other ESDs. The difference is around 1.8% which might be due to the overlapping of tangential energy saving. Overlapping portion of rotational energy is rather less than expectation because diameter caused by the effect of stator downstream is less than that of propeller. The portion of overlapping amount is expected to be validated by other method such as the investigation of CFD.

Table 6 Comparison of Resistances in Model Scale

	Experiments	
	R_{TM}(N)	Diff. (%)
Bare Hull	45.45	-
Asymmetric Pre-Swirl Stator	46.30	1.87
Wavy Twisted Rudder	45.83	0.84
Combined ESD	46.77	2.90

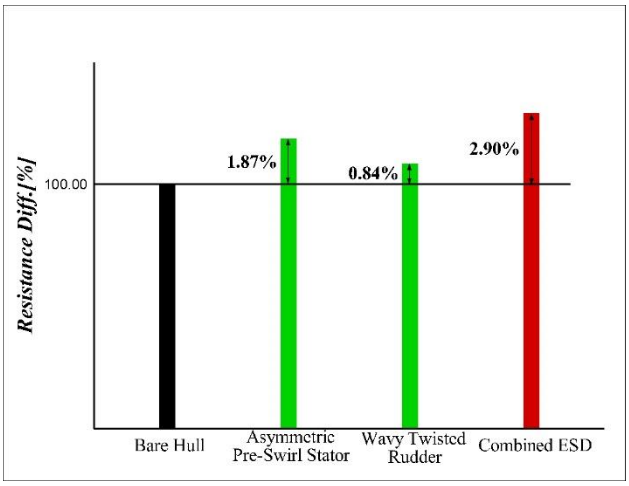


Figure 11 Comparison of Resistance in Model Scale

Table 7 Comparison of rps in Model Scale

	Experiments	
	rps	Diff. (%)
Bare Hull	10.90	-
Asymmetric Pre-Swirl Stator	10.65	-2.29
Tip Rake Propeller	10.90	-0.04
Wavy Twisted Rudder	10.87	-0.28
Combined ESD	10.53	-3.39

Table 8 Comparison of Torque in Model Scale

	Experiments	
	Torque (N-m)	Diff. (%)
Bare Hull	1.174	-
Asymmetric Pre-Swirl Stator	1.155	-1.62
Tip Rake Propeller	1.157	-1.42
Wavy Twisted Rudder	1.156	-1.58
Combined ESD	1.150	-2.04

Table 9 Comparison of 2πnQ in Model Scale

	Experiments	
	2πnQ	Diff. (%)
Bare Hull	80.40	-
Asymmetric Pre-Swirl Stator	77.29	-3.87
Tip Rake Propeller	79.23	-1.46
Wavy Twisted Rudder	78.92	-1.85
Combined ESD	76.09	-5.37

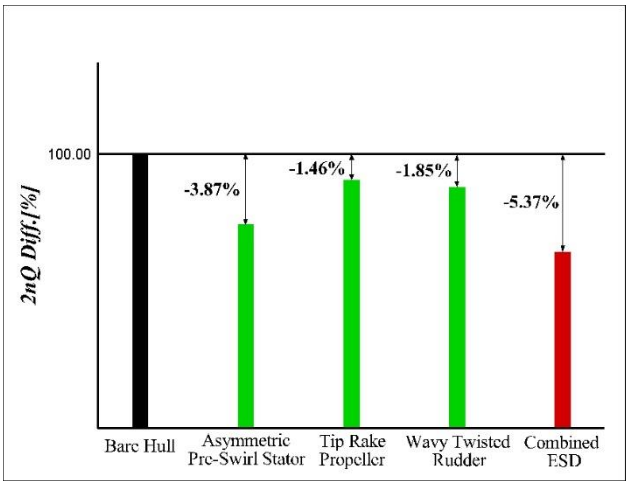


Figure 12 Comparison of 2πnQ in Model Scale

5. Conclusion and Future Works

The combined ESD has been investigated with experimental validation in efficiency point of view. The most efficiently and popularly used devices have been adopted in each zone which are PSS in pre-zone, TR propeller as main device and WTR in post-zone.

The added resistance due to the combined system is increased and almost the same of the summation of added resistance of each device. Self-propulsion test has also been conducted for each case. The efficiency gain with the combined ESD is less than the summation of efficiency gain with each case. The rotational energy saving might be somewhat overlapped each other, the gain is however not so small which is propably due to the non-overlapping of the effect of PSS and TR propeller. The more detail investigation of the effect of each device is expected to be conducted in near future.

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