Energy Saving Device for Ship
— IHIMU Semicircular Duct —

INUKAI Yasuhiko : Ship & Offshore Basic Design Department, IHI Marine United Inc.
ITABASHI Masahiro : Ship & Offshore Basic Design Department, IHI Marine United Inc.
SUDO Yasuhiro : Ship & Offshore Basic Design Department, IHI Marine United Inc.
TAKEDA Takeshi : Ship & Offshore Basic Design Department, IHI Marine United Inc.
OCHI Fumitoshi : Ship & Marine Technology Department, Products Development Center, Corporate Research & Development

To meet the increasing energy saving demand due to the rapid rise in fuel oil costs, a semicircular duct type energy saving device was developed. Compared with the present energy saving devices of the circular duct type, the lower part of the duct was removed to maximize its performance when located in the complex flow field around the stern, considering the hydrodynamic factors which govern the energy saving effect. A number of model tests were carried out and the results indicated that the energy saving for IHIMU semicircular duct was around 5%. This paper describes the principle and procedure for the development of the new type semicircular duct.

1. Introduction

Because of a recent surge in crude oil prices and a great demand for CO_2 reduction related to environmental issues, a demand to reduce the fuel oil consumption of ships is greater than ever before. On the other hand, full ships including very large crude carriers and bulk carriers tend to increase their fullness continuously, and the improvement of propulsive performance by the improvement of hull form is almost reaching its limit. Therefore, it is desired that energy saving equipment with high cost performance be commercialized so that horsepower can be steadily reduced by means other than hull forms.

IHI Marine United Inc. has developed energy saving devices such as the A. T. Fin [(1)] (Additional Thrusting Fin) and L. V. Fin [(2)] (Low Viscous resistance Fin). This time, it has newly succeeded in developing a duct type energy saving device and added it to lineup of energy saving devices. Instead of a conventional circular duct, this duct is a semicircular type produced by removing the lower half part of a circular duct. It was found that the energy saving effect of this device is greater than that of circular ducts, where horsepower was reduced by approximately 5% based on the model tests. This paper describes the development process of this new semicircular duct.

2. Duct design

Based on the examination for various types of energy saving devices that were already commercially available, the development was started with a focus on a duct type energy saving device (hereinafter called “duct”), which showed a relatively greater energy saving effect among them.

2.1 Basic principles of energy saving

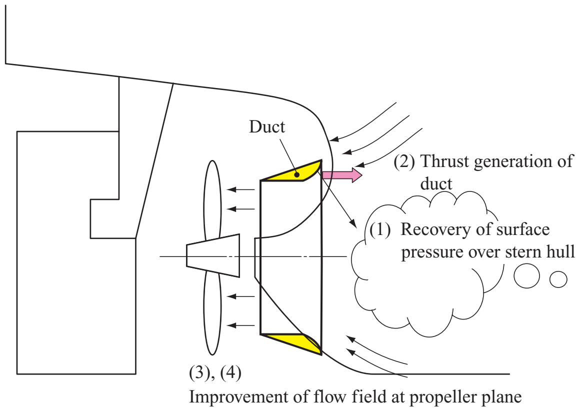
The duct is typically located just in front of a propeller, and has a circular shape or the like. The duct has the following effects in general. **Figure 1** shows the basic principles of energy saving.

(1) Reduction of hull resistance by straightening effect of stern flow field

Figure 2 shows an example of wake pattern at the propeller plane of a full ship. Around a stern hull, there is typically a complicated flow with bilge vortices (separation flow around a stern hull) (see **Figs. 1** and **2**). The duct controls the separation flow on the hull surface by straightening this flow into the axial direction, and consequently contributes to a reduction in hull resistance.

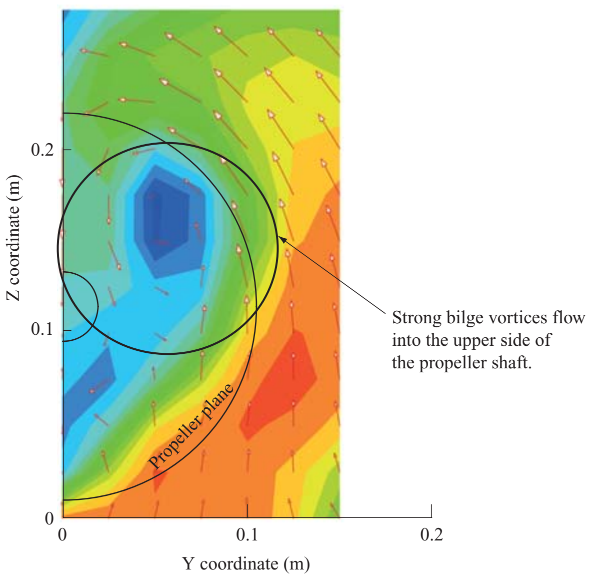
(2) Thrust generation of duct

As shown in **Fig. 1**, the flow around the stern hull is a conjugated flow consisting of bilge vortices



(Note) The numbers (1) to (4) correspond to the numbers of principles of energy saving described in **Section 2.1**.

Fig. 1 Basic principle ducted energy saving device



(Note) 1. The blue area indicates low velocity region.
2. The vectors indicate velocity vectors in the Y-Z plane.

Fig. 2 Example of wake pattern at propeller plane

and a flow along the main hull. Therefore, a thrust force of the duct itself can be generated by properly adjusting the blade shape and the angle of attack.

(3) Increase in wake gain

A wake gain can be obtained by inducing a low velocity wake flow in the bilge vortex zone toward the propeller plane.

(4) Improvement in propeller efficiency

The radial component of a stern flow is transformed into an axial flow by the duct and the distribution of axial velocity in the propeller plane is made uniform. This generates a favorable flow field to improve the propeller cavitation performance. In other words, this allows a beneficial propeller design (e.g. reduction of propeller disk area) which results in the improvement of propeller efficiency.

2.2 Design concept of duct

Based on the above basic principle of energy saving, design concepts for the duct shape and location were decided as follows.

- The straightening effect is enhanced by placing the duct at a position where stern bilge vortices are strong (Principles (1) and (4)).
- A forward thrust force of the duct is increased by placing the duct at a position where the angle of a diagonal flow is large (Principle (2)).
- The duct diameter is set at approximately 0.7 times the propeller diameter to induce a low velocity wake flow into this area where the propeller generates the maximum force (Principle (3)).
- Because bilge vortices are typically strong on the upper side of the propeller shaft, a semicircular duct by removing the lower half of a circular duct is desirable.

Prior to the design, a stern flow field was measured at the mounting position of the duct to collect information required for the duct design. The measurement was carried out by means of an L-shaped pitot tube when the propeller was working during a self-propulsion test. **Figure 3** shows the circumferential distribution of the flow velocity and the inflow angle of the hull wake into the duct, that was measured at 0.7 times the radius of the propeller. From this figure, it is found that the inflow angle and the inflow velocity is large on the upper side of the propeller shaft (θ = 0 to 50 degrees). Therefore, it is found to be important to properly design the upper part of the duct in order to ensure that the duct effectively generates a thrust force and improves the straightening effect.

Based on this flow field data, both a semicircular duct and a circular duct were designed for comparison purpose. **Figure 4-(a)** shows the semicircular duct, and **Figure 4-(b)** shows the circular duct.

3. Verification of energy saving effect

In order to verify the energy saving effect of the designed semicircular duct, a tank test was carried out at the IHI towing tank. Model ship applied for the tank test is the latest 300 000 ton crude oil tanker.

3.1 Propulsive performance test

A propulsive performance test consists of a resistance test and a self propulsion test. The resistance test measures hull resistance when the propeller is not installed, and the self propulsion test measures a self propulsion factor (interference factor of the propeller, the hull, and the rudder) when the propeller is working. The above propulsive performance test was carried out with and without the designed duct. The test results were used to calculate required horsepower, and both cases were compared to determine the energy saving effect.

In order to verify the difference between the circular form and the semicircular form, a circular duct model was prepared to carry out an identical test.

3.2 Energy saving effect of duct

Figure 5 shows the improvement ratios of EHP (Effective

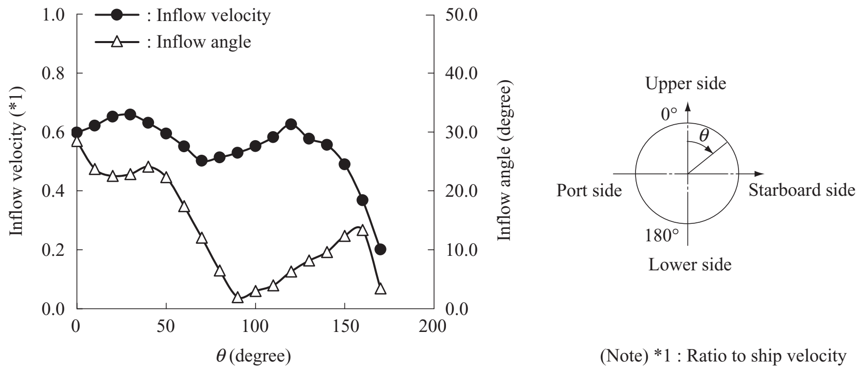


Fig. 3 Inflow velocity and angle of attack at duct position

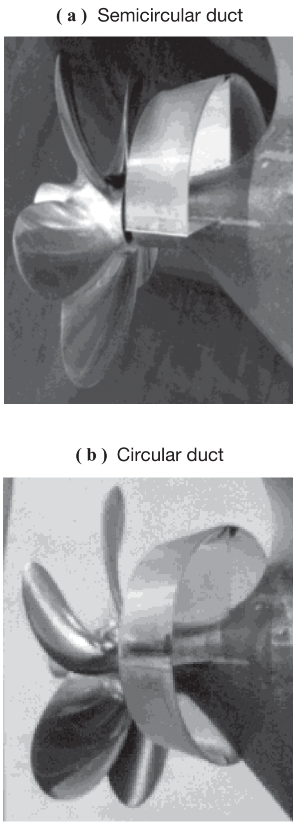
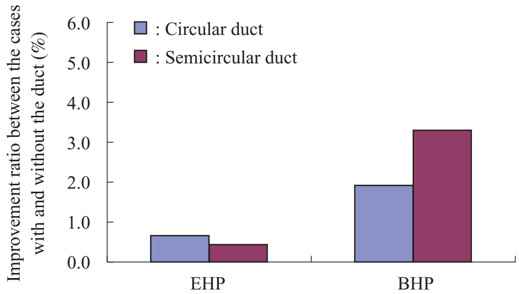


Fig. 4 General arrangement of designed duct



(Note) $EHP = R \times V_s$

$$BHP = EHP \times \frac{1 - w}{1 - t \cdot \eta_R \cdot \eta_o \cdot \eta_t}$$

EHP	: Effective horse power,	R	: Hull resistance
V_s	: Ship velocity,	BHP	: Brake horse power
η_o	: Propeller efficiency,	η_t	: Shaft transmission efficiency
t	: Thrust deduction fraction,	w	: Wake fraction
η_R	: Relative rotative efficiency		

Fig. 5 Energy saving by ducted device

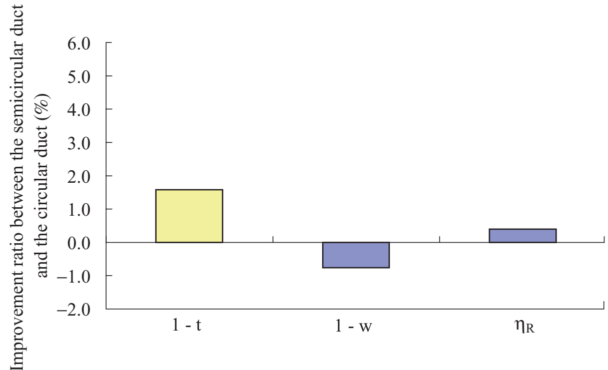


Fig. 6 Comparison of self propulsion factors between circular and semicircular ducted devices

Horse Power) and BHP (Brake Horse Power) between the cases with and without the duct. As shown in this figure, EHP and BHP were improved when the duct was installed. An energy saving effect of approximately 3% was achieved by the reduction of the hull resistance and the improvement of the self propulsion factor.

It was found that the energy saving effect of the semicircular duct was greater than that of the circular duct. **Figure 6** shows the comparison of self propulsion factors between the circular duct and the semicircular duct. When both self propulsion factors are compared, the improvement of 1-t, which is related to a thrust force generated by the duct, is notable. From this result, it can be considered that the upper half of the duct plays a significant role in improving the energy saving effect (generating a thrust force).

3.3 Improvement of semicircular duct form

In order to establish a method for designing the semicircular duct, the effect of the following parameters (related to the duct shape and location) on the energy saving performance was verified by a tank test to accumulate design data.

· Mounting location of duct
· Angle of aperture of duct
· Length of duct

The results obtained from the parametric study show that the energy saving effect is greater as the duct is longer, particularly as the upper part is longer. Based on this result, an improved semicircular duct with a longer chord length of the upper part was designed, and the energy saving effect was verified by a tank test (**Fig. 7**).

Figure 8 shows the improvement ratios of EHP and BHP between the cases with and without the above mentioned duct. As shown in this figure, the improvement ratios of EHP and BHP of the improved semicircular duct were greater than those of the original semicircular duct, and an energy saving effect of approximately 5% was achieved.

When the self propulsion factors of the circular duct and the improved semicircular duct are compared, the significant improvement of 1-t is found, which mainly brings the improvement of BHP (**Fig. 9**).

4. Study on structural strength

A study on structural strength, which was essential for commercializing the semicircular duct, was carried out.

As an example, **Fig. 10** shows the result of strength calculation for the duct support plate obtained by means of the finite element analysis method (FEM). From this study, it was found that a support structure have sufficient strength to endure impact loads caused by pitching in rough weather and/or lateral forces during turning motion. Further, it was also confirmed that resonance could be adequately avoided.

As a result of various studies on structural strength, it was verified that the designed duct structure have a sufficient strength and thus applicable from safety point of view.

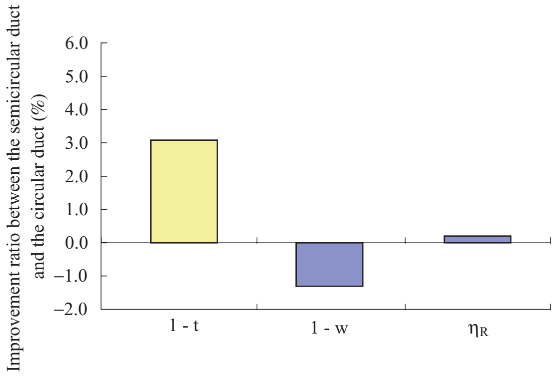
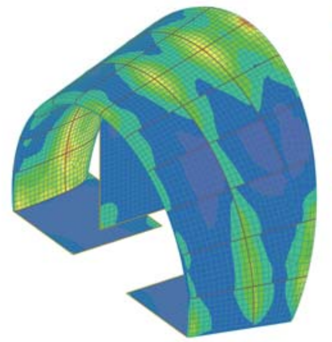


Fig. 9 Comparison of self propulsion factors between circular and improved semicircular ducted device

(a) Stress contour



(b) Vibration mode

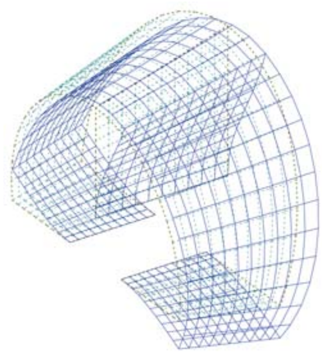


Fig. 10 Example of FEM analysis

(a) Original form (b) Improved form

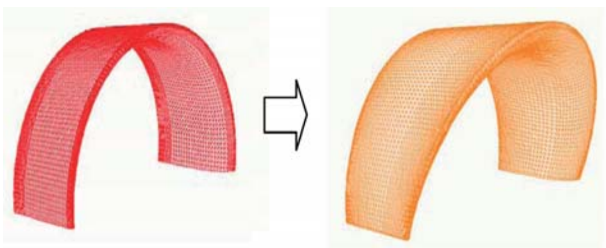


Fig. 7 Improvement in semicircular ducted device

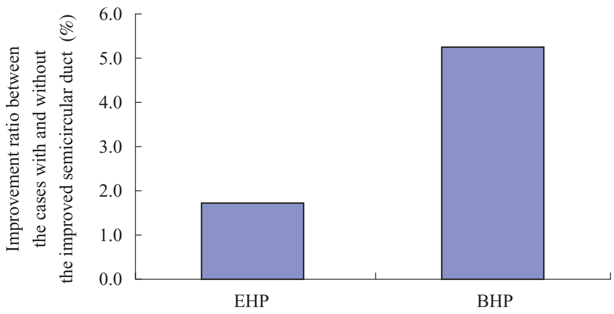


Fig. 8 Energy saving by improved semicircular ducted device

5. Conclusion

In response to the strong social demand for reduction of fuel oil consumption, a semicircular duct type energy saving device for a full ship has been developed. It is found that the energy saving effect of this device was greater than that of conventional circular ducts, and horsepower was reduced by approximately 5% based on a model test. In addition, structural strength was also verified, and the prospect of commercialization was confirmed.

Since crude oil prices have continued to surge during the development term of this device, expectations for lower fuel consumption of ships are increasingly growing. The authors will promote the early adoption of this device and further improvement.

REFERENCES

(1) M. Mori, T. Yamasaki, R. Fujino and Y. Ohtagaki : IHI A. T. Fin - 1st Report Its Principle and Development - , Ishikawajima-Harima Engineering Review Vol. 23 No. 3 May (1983) pp. 266 - 273

(2) A. Masuko, Y. Koshiba and T. Ishiguro : Energy Saving Device for Ships IHI-L. V. Fin, Ishikawajima-Harima Engineering Review Vol. 38 No. 6 Nov. (1998) pp. 392 - 397