EEDI REDUCTION BY INVESTIGATING METHODS OF REDUCING SHIP RESISTANCE

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Abstract: The article systematizes methods of reducing ship resistance, including: optimizing the hull form in order to have smaller form resistance and wave resistance; turning the turbulent flow into laminar flow at the boundary layer and using air cavity via injection of air under or around the hull, to reduce the ship frictional resistance. The paper also indicates the obtained reduction of resistance, difficulties, drawback as well as their effect on other features of ship by applying the above methods in practical. Based on that, designers can choose the most appropriate solution, to have EEDI index satisfaction as well as to improve the ship's safety and economic efficiency, depending on the specific condition.

Keywords: EEDI, resistance, hull form, air cavity, boundary layer.

1. Introduction

Recently, many efforts have put on environment protection, especially about global warming and reduction of CO2 emission. The majority of the international society has recognized the necessity of limiting our use of natural resources in order to prevent environmental hazards. Besides, there are considerable development in marine transportation and activities: from offshore installation supply to the exploitation of marine resources. According to Third IMO GHG Study 2014, during the period 2007–2012, maritime transport emits around 1000 million tons of CO_2 annually and is responsible for about 2.5% of global greenhouse gas emissions. Shipping emissions are predicted to increase between 50% and 250% by 2050 – depending on future economic and energy developments. This is not compatible with the internationally agreed goal of keeping the increase of global temperature

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by below 2°C compared to pre-industrial levels. This requires worldwide emissions to be reduced at least by a half by 2050. Thus, in 2010, International Maritime Organization introduced Energy Efficiency Design Index (EEDI) as a technical measure to limit pollution of the environment to newest ships. The EEDI is an index that indicates the energy efficiency of a ship in terms of CO_2 (generated)/ton mile (cargo carried). Therefore, smaller EEDI means smaller CO_2 exhausting to the environment. According to the regulation of MARPOL 2011 (Chapter 4 Annex VI Res. MEPC_203_62) it requires new ships to be 10% more efficient since beginning in 2015, 20% more efficient by 2020 and 30% more efficient from 2025. With that reason, many efforts have been made to reduce EEDI. From the EEDI equations, according to Bazari & Longva and IMO MEPC 63 (Zabibazari, Tore longva, 2011), there are 15 methods of EEDI reduction. One of those methods is reducing ship resistance, and it is main topic of this paper.

It is known that, for displacement ship, the ship resistance in calm water consists of following main components: wave, form and frictional resistance.

$$R_T = R_F + R_W + R_{VP} \qquad (1)$$

Where: R_T – the total resistance, R_F - the frictional resistance; R_W – the wave resistance; R_{VP} – the viscous form resistance.

Thus, it is necessary to study the dependence of its components on the main characteristics of ship as well as the fluid properties in order to propose the method of reducing these components to reduce the ship resistance.

2. Methods of reducing ship frictional resistance

According to ITTC standards, the frictional resistance is determined as:

$$R_F = 1/2 \cdot \rho \cdot C_F \cdot V^2 \cdot S \qquad (2)$$

As can be seen in formula (2), the water density (ρ) is constant, therefore, the frictional resistance only reduces in the case of decrease the wetted surface of the ship and/or the frictional resistance coefficient (C_F).

Refer to wetted surface. In practical, there are two ways of reducing the wetted surface area of a ship:

The first way is choosing: the reasonable main dimensions of the ship while remain the same displacement. However, reducing wetted surface area by using this way may increase the remaining resistance components. As can be seen in Figure 1, reducing the ship length (the parameter has greatest influence on wetted surface area) makes the wetted surface area significantly decrease. However, the two remaining resistance components (wave resistance

and form resistance) increases simultaneously. Therefore, the deduction of wetted surface area obtained by applying this method made ineffective in reducing the ship resistance.

- *The second way*: Create an air layer embraced the ship wetted surface. This method is not only to considerably reduce the amount of the wetted surface area but also having no effect on the other resistance components. `Therefore, the authors will present this method.
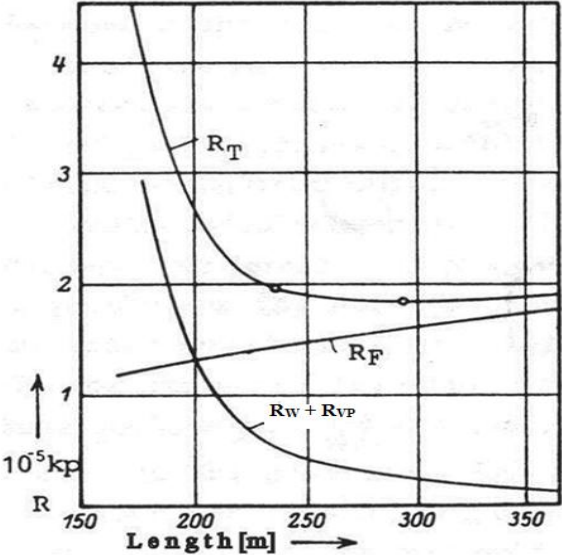

Fig.1. Effect of length on the resistance of a ship with constant displacement $\Delta = 30,000$ t and speed $V = 29$ kn (Apostolos Papanikolaou 2014, p.82)

Refer to frictional resistance coefficient (C_F*).* This coefficient depends on Reynolds. In case of laminar flow (when Reynolds is less than the critical value $Re < Re_{cr} = 2,5.10^5$), frictional resistance coefficient can be defined by formula (3). In case of turbulent flow (when Reynolds is higher than the critical value) frictional resistance coefficient can be defined by formula (4) (Jinkin V.B. 2010, p.102)

$$C_F = 1,328 / \sqrt{Re} \tag{3}$$

$$C_F = \frac{0,075}{(\log 10 (Re) - 2)^2} \tag{4}$$

As can be seen in formula (3) and (4), in case of laminar flow, frictional resistance coefficient is much smaller than in case of turbulent flow. Actually, the usual value of Reynolds number of displacement ship is $Re = 10^8 \div 10^9$ which is much higher than the critical value. Thus, to decrease the ship frictional resistance coefficient (synonymous with reducing ship frictional resistance) turning the turbulent flow into laminar flow at the boundary layer should be made.

2.1. Using air bubble lubrication for decreasing friction resistance

The idea of "air bubble lubrication" – creating the separated thin membrane of air between ship wetted surface and the surrounding liquid in order to reduce the wetted surface area and thereby reducing ship frictional resistance was proposed in the 19th century by the famous scientists Froude and Laval.

The systematic study of the above idea has been made by many authors in different countries around the world, such as Butuzov A.A., Gorbachev Y. N., in Russia (A. A. Butuzov 1990)., Fukada, K., Yasuhiro M., in Japan (Fukada, K. 2010), in MARIN's research projects (Maritime Research Institute of the Netherlands), PELS (Project Energy-saving air-Lubricated Ships) and SMOOTH (Sustainable Methods for Optimal design and Operation of ships with air lubrical Hulls) (EU project) (E.J. Foeth 2008) Numerous of tests in scale of model and full scale have been made to evaluate the effect of air lubrication by bubble injection on resistance and propulsion, seakeeping and maneuverability. In the time of Soviet, 10 ships using air cavity had been put in operated, which has displacement of 15 tons, speed of 70 km/h. The complete design of domestic passenger ship with capacity 70 and 100 seats and 300 tons displacement, using air cavity had been made.

Experiments carried out on model and full scale ship confirmed the effectiveness of using air cavity in ship's bottom as follows (Fukada K. 2010), (Kato H. 2003), (E.J. Foeth . 2008), (Jinkin V.B. 2010), (Butuzov A.A. 1990):

- Consider to the low speed cargo ship, the necessity power reduction of the main engine at the calculating speed ranged from 10 to 20 %;
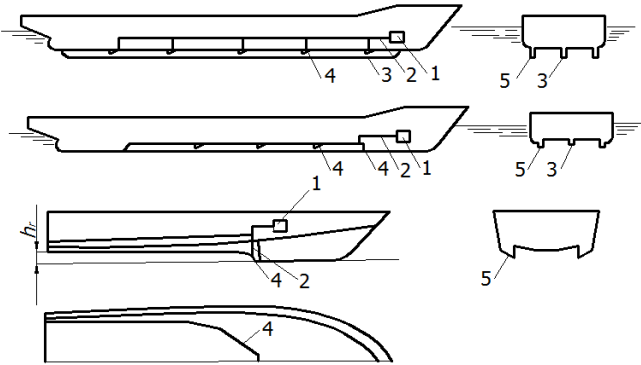

Figure 2. Scheme of devices creating air cavity in ship's bottom (A. A. Butuzov 1990)

a-air cavity system in displacement ships, b – unique air cavity in displacement ship, c – air cavities in high speed craft. air compressor, 2 – air supply line, 3- longitudinal keel, 4 – redan, 5 – side girder

- Consider to the high-speed ship, the reduction in necessity power at calculating speed ranged from 15 to 30 %, or if the engine power remained constant, the ship speed will increase from 10 to 30%;

- The consuming energy of air fan in all cases did not exceed 3% of the main engine power;

- The application of the creating air bubbles device does not deteriorate the other performance of the ship (stability, maneuverability, sea keeping) and does not hinder the use of other innovative solutions, the method of increasing the efficiency of propulsion system.

- The use of air cavity also reduces the cost of cleaning and painting the wet surface of ship hull during operation.

However, besides the advantage that the air cavity system exist drawback such as:

- The empirical study indicates that the realization of this idea in reality just successful in the flat bottom of the ship. And recently, this solution is to be applied only on river ships. The current shipping vessels have not used this method. This can be explained by the fact that, firstly, the wet surface part at the flat bottom of the ship is much smaller than that of the river, and secondly it affects the ship's rolling (Jinkin V.B. 2010, p 303).

- Using air cavity under the ship bottom may reduce the efficiency of the propulsion system and according to some studies, the overall reduction in propulsive efficiency due to creating an air cavity is about 2-3 %.

- The effectiveness on reducing ship frictional resistance by applied air cavity depends on speed of ship, environment condition (wave height) and the operation of air compressor. The test results on the model of 300.000 DWT tanker indicates that (A. A. Butuzov 1990):

+ Efficiency of ship using air cavity system will be declined by reducing the ship speed;

+ When the ship is running in full load regime on wave level 5, the effect of waves on the efficiency of ship is very small. When increasing the wave level, the unique air cavity was destroyed and effectiveness of the device is dramatically declined: if the ship were running on wave level 6, the benefit in resistance is 7-8 %, while on wave level 7, the ship resistance is not reduced but increased by 10-11 %;

+ The resistance of ship using air cavity system will increase by about 20% compared to ship not using air cavity when the air compressor does not operate.

- In case of using air cavity system on existing ships, it creates protruded part under the based plane, reducing the cargo capacity of ship when operating in shallow waters.

2.2. Turning the turbulent flow into laminar flow at the boundary layer

The application of laminar at the boundary layer to decline the ship frictional resistance can be made by the boundary layer suction or creating a pliable coating (Coating softened) on the ship surface (Jinkin V.B. 2010).

In case of using pliable coating: The creation of pliable coating on the ship surface in some circumstances can be reduce the frictional resistance 1,5÷ 2,0 times until Re = 2.10^7 (Jinkin V.B. 2010). Nevertheless, due to the complexity of creating the above coating and the unstable of its elastic parameters … which is not currently use in practical.

The boundary layer suction can be executed along the surface of ship hull or focused on the specialized gaps arranged along the ship hull. In principle, the suction of boundary layer may ensure that the laminar flow occurs in the boundary layer at any value of Reynold number. Therefore, in this case, the significant efficiency can be obtained after deducting the power consumption of liquid suction. Theoretical assessment indicates that when the ship's Reynold number Re = 10^8÷10^9 the optimal the arrangement of suction points of the boundary layer suction can reduce the ship frictional resistance 6-7 times (Jinkin V.B. 2010, p 303). Recently, however, this idea has been realized in practical because it encounters a structural irreparable obstacle (the complexity of creating an effective boundary layer suction system) and technology (there are very strict requirements for surface conditions that require very smooth).

The changing of physical properties of liquid at the boundary layer (the layer between ship hull and liquid) can be obtained by other mean which is – inserting the high polymer layer. The addition of small amount of polymer in the water can reduce the ship hull frictional resistance by 2-3 times. The concentration of polymer is very small (10^{-4} – 10^{-6}), which explain that it is impossible to obtain the efficiency by changing the density and viscosity of liquid. The remained problem is that the polymer alters the water physical properties and turning it into non –Newtonian liquid. However, the effect of added polymer is only effective in the turbulent flow of the drainage shape objects.

To realize this method, the only way is to put the polymer in the boundary layer between ship hull and liquid through the gaps or through the surface bore or also by applying on the ship hull paint coatings. In all cases, although, the reduction of resistance is quite large from 15 to 50%,. Researching the effect of this additive on the environment has not been fully studied due to its the high cost, this can explain the reason of no appliance of this method in practical recently (Jinkin V.B. 2010, p.304).

3. **The methods to reduce wave and form resistance**

3.1. **The methods to reduce form resistance**

The viscous form resistance coefficient of the ship is the function of Reynolds number and hull form as in formula (Jinkin V.B. 2010), (Moland, A. F.,2011)

$$C_{VP} = C_F k \qquad (5)$$

Where: C_F – frictional resistance coefficient, k – form factor correction, depending on the hull form (C_B, L/B, B/T,…).

The formula (5) shows that there are two ways to reduce viscous form resistance

- Reduce frictional resistance coefficient

- Hull form optimization to reduce form factor correction k. This method is discussed below together with the methods to reduce wave resistance of the ship

3.2. The methods to reduce wave resistance

The wave resistance of the ship is a function of

- Hull form, especially bow and stern shapes

- The relative position between hull and water surface

So, for a specific speed of the ship, there are two ways to reduce wave resistance

- Hull form optimization;

- Fully immerse the ship under the water surface (Jinkin V.B. 2010).

In case of hull form optimization method, both the wave resistance and viscous form resistance can be reduced. To optimize hull form, the main interest is trying to reduce wave-making resistance, and it becomes main objective of hull form optimization. Ideally, when the bow and stern wave systems cancel each other, the wave-making resistance is minimum. Thus, bow and stern are two interested areas for hull form optimization. Among them, bulbous bow might be the part that has been optimized mostly with many results presented by many authors. Optimized bulbous bow can reduce bow pressure wave and consequently, reduce wave -making resistance. Recently, with the development of computational resources together with the development of Computer-aided-design (CAD) and Computational Fluid Dynamic (CFD), designers have a powerful tool to improve the hull form efficiency, or in other words, to reduce hull resistance.

According to some recent studied, the reduction of wave resistance after hull form optimization step mainly depends on the starting hull form. If the initial hull is designed by some high experienced designers, the amount of reduction is not much. Some study show that the wave resistance can decrease by 4.32% (Weilin Luo 2016), or 13.2 % (Jin-Won Yu, 2017, or 9% (Mathew Renaud 2013) or 12% (Jong-Heon Park 2015).

Besides, hull form optimization using CFD approach also shows some limitation, particularly computational time, software's cost and high skills man power. The increase of constraints also takes more time for preparation, computation and analysis. The uncertainty of

the result can be a problem, for example, the resistance reduction does not meet the expectation or requirement of the customers. Typically, there are thousands variations of hull form during optimization process. It requires large amount of investment on computational resources such as a very big cluster. The increase of constraints, for example: the stability, ship motion requirements makes the problem more complex and requiring more time for preparation, computation and analysis. All of the drawback above show that the hull form optimization is rather costly.

For the method of fully immersing the hull form under water surface, the wave resistance can be reduced significantly because in this case the effect of free surface is almost neglected. Besides, when the submarine moves under water, there is very less wave-making resistance, motion effect and the increase of resistance in case of rough weather. Some authors showed that with same displacement and engine power, the speed of tanker moving under water with the depth of about 1/3 ship's length, is higher about 20-30% than moving on water surface (Jinkin V.B. 2010). In 1989, Malakhit company in Russia built an underwater tanker to carry oil product in North Pole. The basic dimension of that ship is length (L) = 215 m; breadth (B) = 40 m; depth (D) = 40 m, capacity 60.000 m^3, velocity 16 knots, working depth at 100 m. However, many underwater cargo ship designs have not been produced due to bad influence to living condition of crew and building cost

4. Conclusion

Based on the study of the methods to reduce ship resistance, the paper has presented some result as follows:

- Summary systematically the methods to reduce frictional resistance, viscous form resistance and wave resistance.

- The paper shows the amount of resistance reduction obtained and the drawback of each methods.

- Within the resistance reduction methods, the hull form optimization, selecting optimized the ship dimension with objective of minimum resistance is the most popular one at the moment. It is possible that it might not be used for near future because all new-built hull form has been optimized and the method reaches its limitation.

- The resistance reduction by using air bubble lubrication and by turning the turbulent flow into laminar flow at the boundary layer is a potential method in the future, due to the development of material technology, leading to the decrease of material price.

5. Acknowledgments

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