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SHIPS THAT USE WEATHER TO FIGHT THE WEATHER

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Abstract. *To cap greenhouse gas emissions, the International Maritime Organization (IMO) has introduced the Energy Efficiency Design Index (EEDI). This index is a measurement of the amount of carbon dioxide that a ship emits in relation to its cargo capacity and speed. The weather conditions affect the emissions. The effect is quantified with a factor (fw) that could affect EEDI by up to around 40%. For seagoing vessels, a significant portion of the weather factor is due to added resistance in waves. This paper includes a unique new technology aiming to reverse the adverse weather effect by converting the wave-induced ship motions directly into a forward ship motion. The technology relies on reaction forces that normally exist when water flows through a pipe bend. An open to the sea ship compartment can be designed to function as a pipe bend. The seawater oscillates inside a specially shaped moon pool due to the relative ship motions in waves. The curved profile of the moon pool deflects the water backward from its natural vertical flow, and the water inertia pushes the vessel forward, according to the momentum conservation law. The new wave-energy drive (WE-Drive) does not have any moving or protruding outside the hull parts. It can efficiently counteract the added resistance in waves. The WE-Drive can reduce the carbon footprint of marine vessels and increase the operability range of battery-powered ships.*

Key words: *Energy-saving devices, renewable propulsion, wave-energy drive.*

1. Introduction

EU has introduced stiff targets for carbon emissions released by waterborne transport. The immediate plan is to cut carbon emissions by 55% by 2030. Recently, a Zero-Emission Partnership aiming to eliminate the emissions by the year 2050 has been initiated. The main propulsion of the current designs, however, still relies mostly on conventional fuels. Therefore, energy-saving solutions and non-fuel secondary propulsion concepts (e.g. based on wind and waves) attract greater attention nowadays.

Wind-propelled technologies are relatively better developed based on historical data and some recent advances. Wind propulsion, however, would not be sufficient to achieve the EU targets even if it gets widely implemented. For example, it would not be practical for every ship type and it can cover only for a portion of the targeted year 2030 emission cuts [1].

Wave-powered ship concepts are more exotic and usually rely on protruding outside the hull moving parts [2]. This paper proposes a unique alternative that may be more attractive from a design, fabrication and maintenance standpoint. It is entirely passive and converts wave energy directly into horizontal thrust without any protruding or moving parts. The wave-generated thrust and the added resistance in waves are both mostly driven by the relative ship motions. Therefore, the secondary thrust would counteract the added resistance and thus would be able to boost the weather factor and the energy efficiency index.

The following sections present the new concept.

2. The pipe bend effect

It is textbook knowledge [3] that water flowing through a pipe bend creates a reaction force F_{R}. The F_R direction does not depend on the flow direction. The F_R direction depends on the pipe bend shape. While the F_R magnitude is a function of the pipe-bend angle θ, velocities V_i, pressures p_i and cross-section areas A_i at both ends of the pipe bend (Fig.1). The reaction force components can be estimated in the following way:

(1) $$F_x = p_2 A_2 \cos\theta - p_1 A_1 - \dot{m}(V_2 \cos\theta - V_1)$$

(2) $$F_y = -p_2 A_2 \sin\theta + \dot{m} V_2 \sin\theta$$

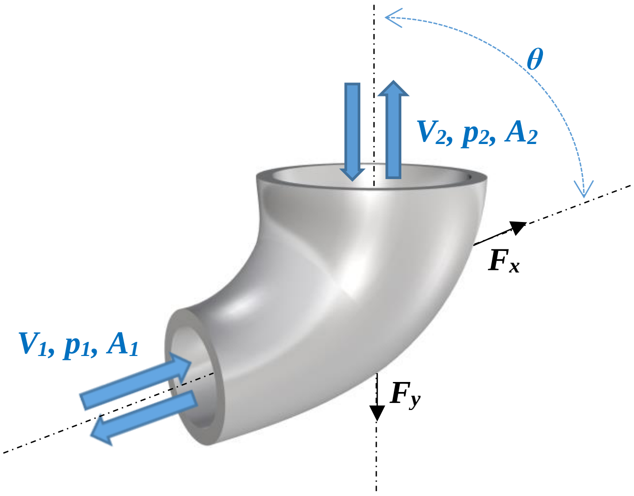

Fig. 1. Water flowing in a pipe bend creates a reaction force

For $\theta=90°$, for example, an oscillating in time water flow would create a horizontal force component F_x that can be decomposed into pressure and inertia components like this:

$$F_x(t) = F_x^{(p)}(t) + F_x^{(i)}(t) = -A_1 p_1(t) - \rho A_1 V_x(t)|V_x(t)| \qquad (3)$$

where ρ is the water density.

The next section will show that the horizontal reaction force component F_x can have a practical value for propulsion purposes.

2. A pipe bend in a ship

An open to the sea ship compartment can be designed to mimic the pipe bend effect. Floaters with moon pools, for example, experience an oscillating water column (OWC) when exposed to wave environments [4]. The OWC is used to compress air that drives a turbine converting the wave energy to electricity. The objective here is to utilize an OWC to propel a ship without intermediate conversion to electricity. To convert the mechanical energy directly, the moon pool needs to be curved, so it can benefit from the pipe bend effect described in the previous section. The forward ship compartment, in front of the collision bulkhead may be the optimal location for such a moon pool (Fig.2). First, the ship bow usually experiences the highest vertical accelerations; second, this compartment is normally almost empty of equipment; and third, the ship bow already has a curved in the right direction shape. Another potential location for the moon pool may be between twin propellers at the stern.

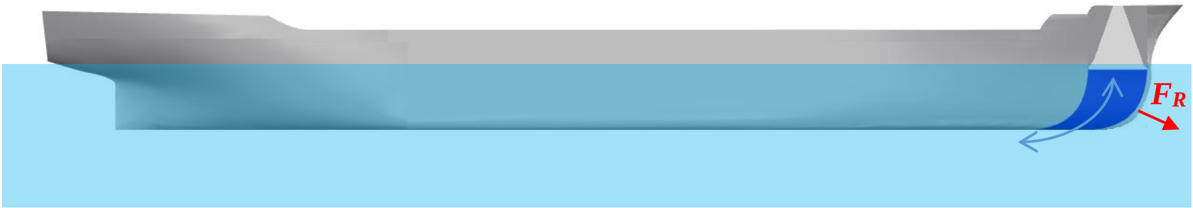

Fig. 2. Water oscillating in a curved moon pool creates a propulsive reaction

The water inside a pipe (Fig. 1) moves due to the pressure differential at both ends. The water in a moon pool, on the other hand, would oscillate in waves due to inertia and hydrodynamic pressures. Therefore, both force components (3) would be in play. When the ship pitches bow down, the pressure increase at the keel and the water inertia in the moon pool would be both moving the water up relative to the hull. When the ship pitches bow up, the water inertia and the gravity will be pulling the water down relative to the ship.

Standard water jet propulsion relies on high flow speed, while the presented here wave-energy drive (WE-Drive) relies on the large volume of water moving through the bend. The ship inertia in Pitch, Heave and Roll directions is significant and should create a sufficient flow rate through the 'pipe bend' to generate thrust. Taking into account that the added resistance is insignificant compared to the ship inertial forces, the WE-Drive would counteract the added resistance while using a small portion of the ship underwater volume. Preliminary CFD simulations and model tests of a vertically oscillating horn shape (Fig. 1) seem to confirm that [5]. The WE-Drive would resemble a double bow wall compartment that is open to the sea at the keel level.

3. WE-Drive advantages

Ships use more power in bad weather, which affects their carbon emissions. The intent behind the WE-Drive concept is to supplement green power exactly when it is most needed. In this sense, ships equipped with WE-Drive will use weather to fight the weather.

The Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI. EEDI is inversely proportional to the weather factor f_W.

$$EEDI = \frac{CO_2\ Emissions}{Cargo\ Capacity\ \boldsymbol{f_W}\ V_{ref}} \tag{4}$$

where the reference ship speed (V_{ref}) is normally the ship speed at 75% of the maximum continuous rated power under EEDI Condition (ship's loading condition corresponding to the maximum summer load draught), while f_W reflects the ship speed reduction in bad weather:

$$f_W = \frac{V_w}{V_{ref}} \tag{5}$$

where V_W is the achieved speed in Beaufort 6 weather conditions.

For most seagoing ships, at least half of the weather factor is due to waves and the rest is caused by wind. This is valid even for containerships with significant windage area; e.g. see [6] for S175 containership. The weather factor depends on the ship type and deadweight DWT (Fig. 3). IMO estimates, for example, fw<0.8 for tankers and containerships [7]. Besides, smaller ships are more affected than ships with larger deadweight. Our preliminary studies suggest that WE-Drive can efficiently counteract the added resistance in waves because both, the proposed here auxiliary thrust and the added resistance, are driven mostly by the ship relative motions in waves. Therefore, we expect that the WE-Drive can increase the weather factor from 0.8 to 0.9, which translates into a minimum of 11% increase in the efficiency

(EEDI), i.e. energy savings, on top of any other best available technologies for stand-alone solutions.

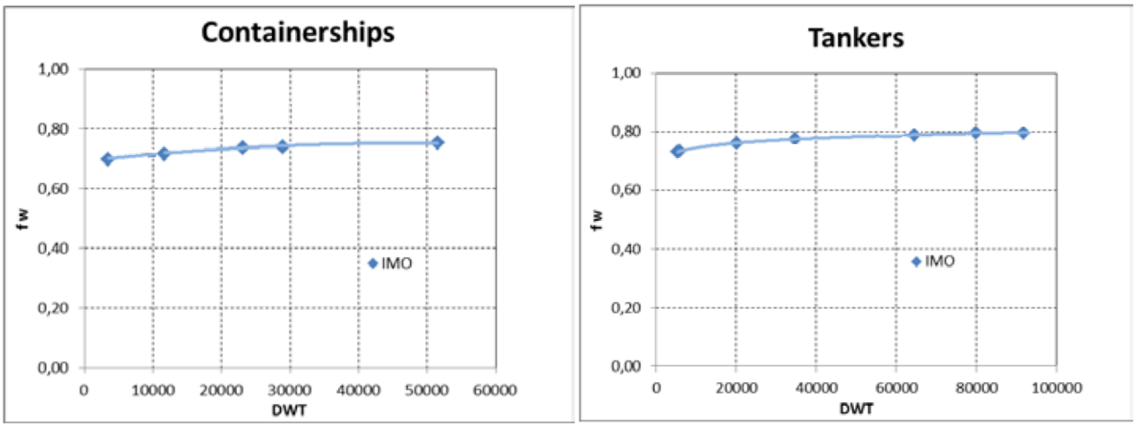

Fig. 3. Weather factor estimates by the International Maritime Organization

(6) $$\mathbf{11\%} = \left(\frac{1}{0.8} - \frac{1}{0.9}\right) / \left(\frac{1}{0.8}\right)$$

Many ships have smaller windage area than containerships, their weather factor is dominated by the wave component, where the WE-Drive is expected to perform better, e.g.

(7) $$\mathbf{16\%} = \left(\frac{1}{0.8} - \frac{1}{0.95}\right) / \left(\frac{1}{0.8}\right).$$

For smaller ships, the energy savings should be even higher e.g.

(8) $$\mathbf{18\%} = \left(\frac{1}{0.7} - \frac{1}{0.85}\right) / \left(\frac{1}{0.7}\right);$$

see Fig. 3.

Based on the estimated percentages, the ambition is to develop a technology that can suppress the added resistance in waves at least as efficiently as bulbous bows reduce the wave resistance in calm water.

3. Future work

A proposal for Horizon Europe funding has been submitted by the Bulgarian Ship Hydrodynamics Centre with partners from Portugal, Spain, Italy and Greece. The consortium includes researchers, experimental facilities, designers, operators, classification society, high-performance computing centre and experts in general design optimization. The proposed scope of work includes numerical and experimental proof of feasibility, and also numerical and experimental proof of scalability. The integrated into a hull WE-Drive will be first evaluated and optimized for a single ship. Then, it will be incorporated into three different ship types and displacements to prove scalability. The funding should be decided in the first quarter of 2022.

3. Conclusion

A new energy-saving concept is presented. The new WE-Drive is expected to increase EEDI by 11% - 18% depending on the ship type and displacement. It supplements ships with green energy in adverse weather conditions when it is most needed. The WE-Drive aims to improve the weather factor. It would significantly reduce emissions and increase the range of battery-powered ships in a simple and efficient way.

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