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POSSIBILITIES OF INSTALLING CYCLONIC FLOW WIND TURBINES AND WIND COLLECTORS ON BOARD SHIPS

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Abstract. Protecting the environment by reducing greenhouse gas emissions is a goal of all mankind and of the shipping industry implicitly. There are numerous studies and projects in various stages of putting forth the concepts of environmentally friendly ships with zero emissions, yet at the same time the current global maritime fleet is composed of ships that use only fossil fuels. In order to reduce the greenhouse gas emissions generated by the current fleet, it is necessary to find solutions for the implementation of renewable energy sources in the electric power system of the current merchant ships. The wind turbine with cyclonic flow and wind collector represent a solution that brings energy from renewable sources in the ship's electrical system, but at the same time induces a positive effect on the propulsion system by reducing the ship's drag resistance. Given the possibilities of installation on board the ship and very good efficiency, even close to the limit of Betz, the calculations demonstrated the usefulness of installing a set of wind turbines with cyclonic flow and wind collector.

1. Key Words

Renewable energy, cyclonic flow, wind collector, drag resistance, wind energy

2. Introduction

Lately, maritime transport has been the only sector in the EU under no specific obligations to reduce greenhouse gas emissions, despite the fact that the activity of maritime carriers is estimated to generate 2-3% of the total greenhouse gas emissions globally, and according to a study conducted in 2014 by the International Maritime Organization in 2012, the maritime transport sector generated a total amount of 796 million tons of carbon dioxide [1].

In pursuing its goal of reaching "zero carbon emissions", the EU considered it was high time to pursue stricter shipping policies.

Between 2007 and 2012, the world navy consumed between 250 and 325 million tones of fuel. At this current level, emissions could triple by 2050 if left unchecked [2].

The European Parliament Environment Committee voted to include ships with a gross tonnage of at least 5000 t in the European Union Emissions Trading System (ETS) and also to introduce requirements for marine carriers to reduce carbon dioxide emissions. By 2030, in the maritime transport sector, emissions must be reduced by 40%, and even more, starting 2030, in all European Union ports, the operation of ships must be done with "ZERO EMISSIONS" [3]

The requirements listed above show the need to find solutions for the implementation of renewable energy sources in the power systems of merchant ships.

3. Drag Resistance

In the initial design or modernization phase of a ship, the determination of the drag resistance is important, as it needs to be estimated as accurately as possible, and it is well known that the drag resistance determines the power of the propulsion system [4]. Based on W. Froude's hypothesis, the total drag resistance of the bare hull is divided into two components considered to be the two most important ones: the friction component, RF; residual (pressure) component, RR

$$R_T = R_F + R_R \tag{1}$$

The total strength of a ship for test conditions (new hull, freshly painted – when leaving the yard), will be calculated with the relation [5]:

$$R_T = R_F + R_R + R_A + R_{AP} \tag{2}$$

where: R_T – total resistance to drag; R_F – frictional resistance for the ship; R_R – residual resistance; R_A – a correction that takes into account the hull roughness, sometimes the aerodynamic drag for a zero wind speed; R_{AP} –resistance due to the appendages, which depends on the number, shape and size of the appendages.

If the calculation of the drag resistance for service conditions (hull with deposits, rough sea) is to be made, then the total strength of the ship will be increased by a factor between 1,15… 4,3 depending on the condition of the hull and the navigation area [6]:

As can be seen from the design of the ship, the resistance forces generated by the advance through the water are particularly taken into account. The drag resistance of the ship generated by the wind being much lower but not negligible

4. Ship drag generated by wind action on the ship's castle

It is well known that any moving body faces a drag resistance generated by the air masses it encounters on its trajectory. The drag resistance is directly dependent on the speed and angle of incidence of air masses on the surface of the body and the area of the exposed surface [7].

The energy of an airflow moving at a linear velocity v is determined by the expression for the kinetic energy:

$$E = m\frac{v^2}{2} \tag{3}$$

where m is the mass of the moving air, determined by the density of the air ρ and the volume that crosses a certain surface S in the unit of time:

$$m = \rho S v \tag{4}$$

The unit of mass in expression (4) is kg / s and by replacing in (3), the power of the air flow in watts is obtained [8]:

$$P = \frac{\rho}{2} S v^3 \tag{5}$$

Studying the data stored by the ship's anemometer/ anemoscope system, it is noticed that while underway over 95% of its duration the relative wind direction (wind direction towards the ship) is in the 345 ° - 15 ° sector. Under these conditions the ship faces a significant frontal drag resistance generated by the direction and speed of the wind.

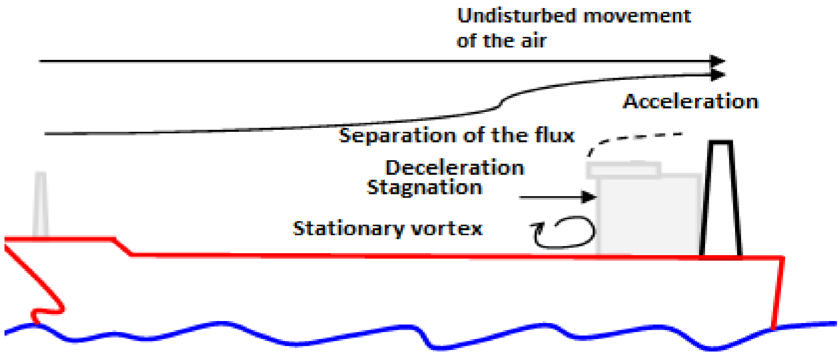

Figure. 1 circulation of air masses at the ship level

Figure 1 shows the airflow diagram, a diagram based on the graphs and information presented by the manufacturer of the anemometer installed on board the ship in its installation and operation manual [9].

It can be seen that in front of the ship's castle there is a stagnation of air masses as well as the formation of stationary vortices. These increase the ship's drag in proportion to the wind speed to the third power [10].

$$P_{op} = \frac{1}{2}\rho A_c v^3 \quad (6)$$

where is the front surface of the ship's castle, is the density of the air and is the speed of the wind.

The daily values of the wind speed recorded by the anemometer while underway are in the range of 6 -14 m / s predominant being the values in its upper half.

In order to calculate the value of air resistance due to air masses we will take into account a wind speed $v = 10\ m/s$.

The drag resistance generated by the wind force will be equal to the total available wind power on the front surface of the ship's hull.

$$P_{op} = \frac{1}{2}\rho A_c v^3 \quad (7)$$

The total exposed surface of the castle is composed of the exposed surface of the accommodation and work space and the front surface of the navigation control.

Exposed area:

$$A_c = 24\ m \cdot 10\ m + 10\ m \cdot 3\ m = 240\ m^2 + 30\ m^2 = 270\ m^2 \quad (8)$$

Drag:

$$P_{op} = \frac{1}{2}\rho A_c v^3 = \frac{1}{2} \cdot 1{,}25 \cdot 270 \cdot 10^3 = \frac{337{,}5}{2} \cdot 1000 = 168750 \quad (9)$$

$$\boldsymbol{P_{op} \cong 168,75\ kW}$$

5. Cyclonic flow wind turbine

The novelty of this type of turbine is a new type of stator and is called "cyclonic flow turbine" because the rotor is driven to a sustained self-movement of the fluid (air) in the form of a vortex, developed inside the stator and continuing in space of the rotor delimited by it [11]

The stator consists of two identical cone trunks figure 2 a, or circular surfaces, which have a ramp (upward slope) to the inside.

The trunks of the cone have an outer radius ***2R*** and the inner ***r***. The two cone trunks are arranged at a certain distance (in this case Dx4 D being the scalar factor) each of them thus constituting the bases at the bottom and at the top of the structure. They are rigidly connected by a set of vertical walls, figure 2 **b**.

On the outer circumference with radius **2R** and along the circle with radius **R** (drawn by the outer edge of the vertical walls) on the surface of the two bases of the stator are fixed sets of guide rails that have the role of supporting and guiding at the bottom and at the top a movable element called a COLLECTOR, figure 2 c, so that it can rotate freely around the central part of the stator.

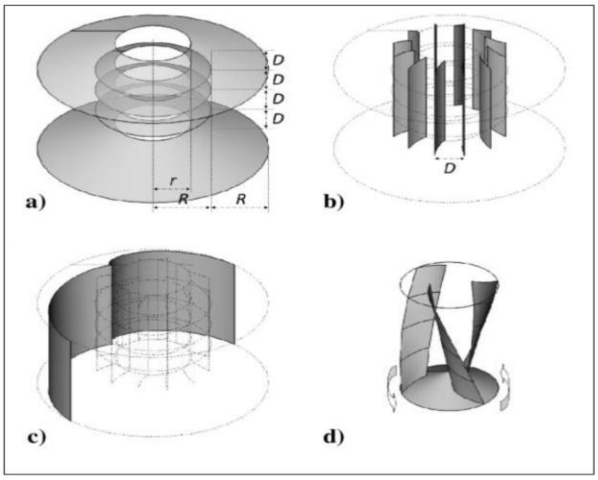

Figure 2. Cyclonic flow wind turbine components.
a) the horizontal elements of the stator, b) the vertical walls of the stator,
c) wind collector, d) rotor [12]

The wind intercepted by the two sides of the mobile collector is gradually directed to the central part of the windward cylindrical surface of the stator (the back of the stator which is not directly exposed to the wind). An identical flow is intercepted by the front of the stator exposed to the wind, figure 3.

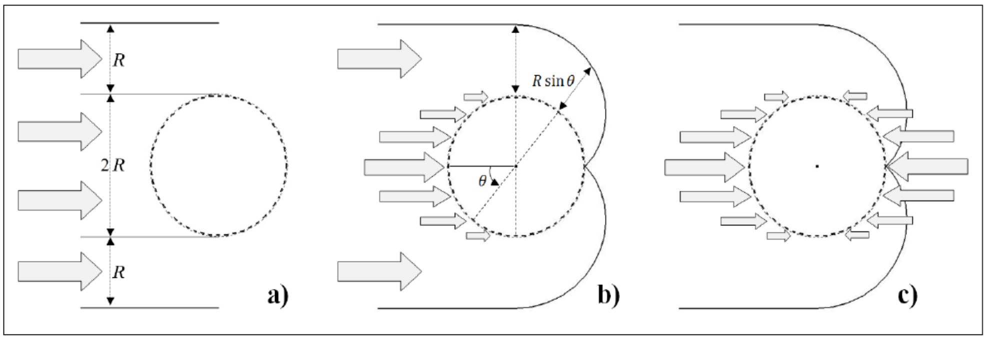

Figure 3.
Direct interception of the flow by the stator upwind and directing an identical flow to the stator downwind [12]

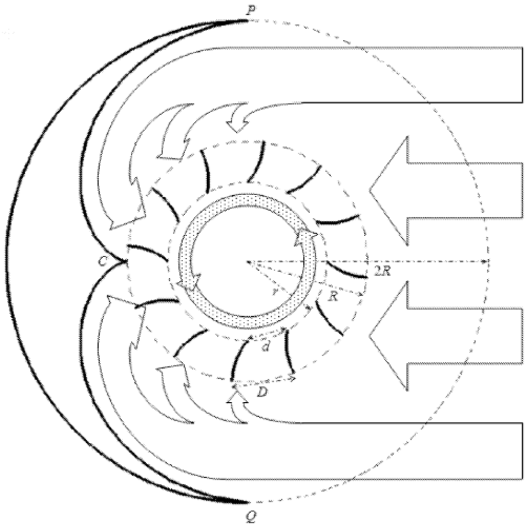

Figure 4. Arrangement of the vertical walls of the stator [11]

According to the calculations, the value of the scalar factor D is:

$$D = R/1{,}932 \tag{10}$$

Given the dimensions of the castle of an oil / chemical tanker of 50000 tdw, the angles of visibility in the navigation command and the stated need for the personnel operating the ship, namely to have visibility on deck during loading or unloading operations, we took into account the possibility of placing two rows of turbines with cyclonic flow, on the surface between the upper limit of the windows on deck A and the lower limit of the navigating bridge, and on the width on the entire front opening of the castle. We have an area with a height of 7 (seven) meters and a width of 24 (twenty-four) meters [3]. From the analysis of the dimensions and angles of visibility we came to the conclusion that the best option is to consider the installation of a number of eight cyclonic wind turbines arranged in two rows, the bottom row being moved to the bow with a distance equal to 3 R to the top row, the latter being arranged near the castle bulkhead, fig. 5.

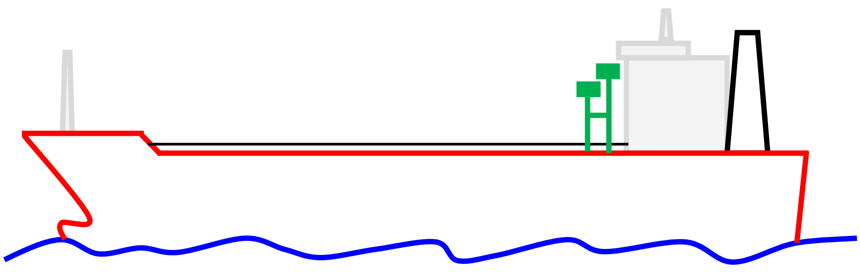

Figure. 5 Installing cyclone flow turbines on board the ship

Starting from the dimensions of the ship's castle and the intention to install two rows of four turbines, we can easily deduce that the space allocated to a turbine is wide $L = 6\ m$ and high $= 3{,}5\ m$.

In order to install the turbines, it is necessary that 10% of the space allocated to the turbine be left free for their spacing, resulting in the values:

$$R\ =\ 1{,}35\ m \text{ și } D\ =\ 0{,}7\ m \tag{11}$$

$$Total\ diameter\ of\ the\ turbine = 5{,}4\ m$$

$$Height\ of\ the\ stator = 4D = 2{,}8\ m$$

Maximum available power of a turbine at a wind speed $v = 10m/s$

Noting with v_e wind speed (outside speed, or inlet speed) and with $\rho = 1{,}25\ Kg/m^3$ air density, the total available power is expressed by the relation [1]:

$$P_e^{max} = \frac{1}{2}\rho A_e v_e^3 = 4(\sqrt{6}+\sqrt{2})\rho D^2 v_e^3 \tag{12}$$

We also enter the data $D = 0{,}7m$ and $v = 10m/s$ in equation 12 and the maximum available power results

$$P_e^{max} = \frac{1}{2}\rho A_e v_e^3 = 4(\sqrt{6}+\sqrt{2})\rho D^2 v_e^3 = 4(\sqrt{6}+\sqrt{2}) \cdot 1{,}25 \cdot 0{,}7^2 \cdot 10^3 = 9466\ W \tag{13}$$

The power coefficient determined from the CFD simulation for wind speed $v = 8m/3$ was $C_p = 0{,}54$

For $v = 10m/3$ we will take into account a decreasing power coefficient $C_p = 0{,}53$

The power of a turbocharged wind turbine with an opening of the air duct $D = 0{,}7\ m$ at a wind speed $v = 10\ m/s$ will be:

$$P_{TVN} = C_p \cdot P_e^{max} \tag{14}$$

$$P_{TVN} = 0{,}53 \cdot 9466 = 5017\ W$$

Future calculations will take into account:

$$\boldsymbol{P_{TVN} = 5\ kW}$$

The distinction between the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) usually consists of "anthropogenic" references to the Earth because the wind blows parallel to the Earth surface, more correctly, it must refer to the main direction of flow lines [13]. In this turbine, the air flow passes through the rotor in the axial direction like horizontal-axis turbines because we are practically witnessing a change in the outflow plane of the air flow from the inlet to the turbine stator.

The construction and operation of the cyclonic wind turbine make it suitable for installation and operation in front of the ship's castle. The fact that the air masses enter the turbine horizontally and evacuate them vertically is an advantageous way for the air masses in front of the castle, which become stationary and increase the resistance to advance, to be directed over the castle towards the acceleration component. air flow fig. 6.

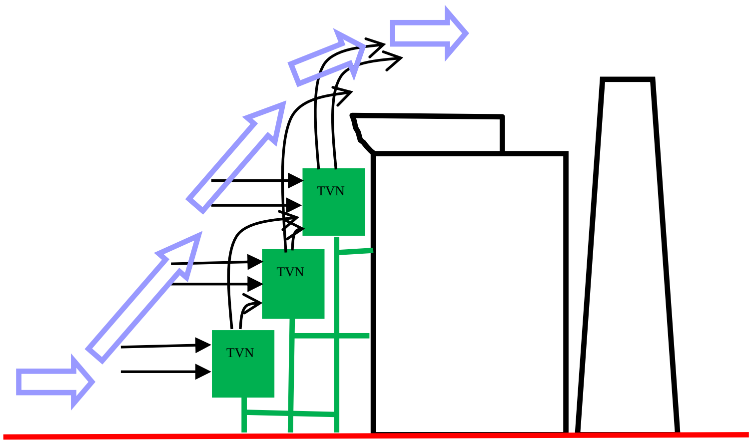

Figure. 6 Directing air masses over the ship's castle

At the same time as directing the air masses over the ship's castle, the main function of this turbine is fulfilled, namely the extraction of wind energy and the transformation into electricity.

The positive impact on the ship's power system is twofold, namely:

1. electricity is produced

We will take into account a wind speed $v = 10\, m/s$, $D = 0{,}7m$, a power factor $C_p = 0{,}53$ and a number of 8 (eight) turbines installed.

$$P_{TVN} = C_p \cdot P_e^{max} \quad (15)$$

$$P_{TVN} = 0{,}53 \cdot 9466 = 5017\, W \quad (16)$$

$$P_{SEN} = P_{tvn} \cdot 8 = 5017W \cdot 8 = 40136W \quad (17)$$

The power of the naval wind system will be:

$$\boldsymbol{P_{SEN} \cong 40\, kW}$$

2. a significant part of the airflow that initially produced the effect of drags is taken to the turbines and directed over the castle reducing the resistance to advance.

Turbine surface (turbine manifold) A_{tt}:

$$D = 0{,}7\, m$$

$$R = 1{,}932\, D = 1{,}932 \cdot 0{,}7 = 1{,}3524$$

$$Total\ diameter\ of\ the\ turbine = 5{,}4\, m$$

$$Height\ of\ the\ stator = 4D = 2{,}8\, m$$

$$A_{tt} = 5{,}4\, m \cdot 2{,}8\, m \cdot 8 \approx 121\, m^2$$

The air flow whose lines of incidence go to the surface of the collectors of the eight turbines will be directed over the castle reducing the resistance to advance in proportion to this surface.

$$P_{red} = \frac{1}{2}\rho A_{tt} v^3 = \frac{1}{2} \cdot 1{,}25 \cdot 121 \cdot 10^3 = \frac{151{,}25}{2} \cdot 1000 = 75625\, W \quad (18)$$

$$\boldsymbol{P_{red} = 75{,}63\, kW}$$

Consequently, the total power input from the wind energy P_{EV} brought into the ship's power system and as assistance to the propulsion system is:

$$P_{EV} = P_{SEN} + P_{red} = 40{,}13\, kW + 75{,}63\, kW = 115{,}86\, kW \quad (19)$$

The actual input from wind energy by a system with eight navalized cyclonic flow wind turbines is:

$$\boldsymbol{P_{EV8} = 115{,}88\, kW}$$

The optimal installation variant of this type of turbine is the one with a number of 12 (twelve) turbines, including at the level of the "A" deck, the inconvenience regarding the lack of visibility between the control room of the loading / unloading operation and the main deck can be eliminated. by using video-electronic means.

For a system with 12 (twelve) turbines the values are as follows:

$$P_{SEN12} = P_{TVN} \cdot 12 = 5{,}017\, kW \cdot 12 = 60{,}2\, kW \quad (20)$$

$$A_{tt12} = 5{,}4\, m \cdot 2{,}8\, m \cdot 12 = 181{,}44\, m^2 \quad (21)$$

$$P_{red12} = \frac{1}{2}\rho A_{tt} v^3 = \frac{1}{2} \cdot 1{,}25 \cdot 181{,}44 \cdot 10^3 = \frac{227{,}22}{2} \cdot 1000 = 113610\, W = 113{,}61\, kW \quad (22)$$

$$P_{EV12} = P_{SEN12} + P_{red12} = 60{,}2\, kW + 113{,}61\, kW = 173{,}81\, kW \quad (23)$$

$$\boldsymbol{P_{EV812} = 173{,}81\, kW}$$

We notice that for a system with 12 (twelve) turbines the compensation of the forward resistance effect is total, there is even an extra 5 kW.

5. Conclusion

The search for solutions to bring a 'clean / green' energy input produced by wind or photovoltaic systems into the ship's power system is proper to reduce greenhouse gas emissions. The wind turbine with cyclonic flow can be a solution by installing it on board commercial vessels.

The numerical modeling confirms the theoretical result for both of the wind's speed and big Reynolds numbers. This geometry sustains a constant air flow through air ducts.

The power available in the inner space of the rotor is equal to that intercepted by the stator in the case of a laminar flow. Losses due to air viscosity are largely offset by increased air density in the duct.

We have proved that by positioning a set of naval cyclones with cyclonic flow in front of the ship's castle, a significant percentage of wind energy can be extracted, which acts as a resistance to the ship's advance. Due to its special construction and mode of operation this turbine changes wind direction, the air flow being intercepted horizontally and discharged vertically, so that the air masses acting on the castle are directed to pass over it reducing the ship's resistance to advance and producing electricity at the same time.

We presented mathematical models of the wind turbine as a component part of an energy system based on wind sources with applicability to naval vessels.

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