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REVIEW OF OPERATION AND PERFORMANCE OF MARINE VERTICAL AXIS PROPELLERS

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Abstract - Vertical axis propellers are normally fitted to ships that require high degree of maneuverability such as tugs and supply boats. They are also advantageous in case of sailing in narrow channels and shallow waters. Nevertheless, the hydrodynamic performance of this type of propellers is relatively low compared to other types of propellers, such as the screw type. In this paper, the merits of the vertical axis propeller are reviewed and its performance investigated and compared to that of the screw propeller. Moreover, some techniques are used to enhance the performance, such as the vortex lattice theory, the momentum theory and CFD."
A review on the different methods used to design and/or assess the performance of this type of propellers varying from simple to sophisticated approaches.

Keywords - Vertical axis propellers, CFD, hydrodynamic performance.

I. INTRODUCTION

Marine propellers are devices that transmit power from the main engine to thrust force through rotational motion of blades which move the blades in ahead or astern direction [1]. There are different types of propellers depending on its function and environmental conditions such as, fixed pitch propellers, ducted propellers, contra rotating propellers, controllable pitch propellers, water jet proposers and vertical axis propellers [2]. Market globalization caused an increase in commercial exchange between several countries and regions and consequently an intensification of the maritime traffic in rivers and seas and oceans has been observed [3].
The more intense commercial exchanges ask for cheaper transport shipments and this requires connecting places that usually are served by ground transport with the more economic water shipments [4]. Unfortunately not all the waterways are suited for the navigation with traditional propeller propulsion [5].

Shallow waters, rivers and seas, the presence of obstacles, the complexity of water routes and the territorial orography require the availability of power characteristics and manoeuvrability difficult to get in a traditional rudder-propeller system [6]. In this context a new propulsion system can be a real and valid alternative to the rudder-propeller system [7], allowing to the ships to navigate in an effective way also in the difficult routing and in shallow water conditions [8].

Vertical axis propellers is drawn its name from its blade motion vertically see figure 1 [9]. However, it is supported with horizontal shaft axis with two servomotors [10]. The first servomotor is designed for the motion of blades inside propeller casing. Besides, the second motor is built in the blades to control rotation motion of blades through its origin [11]. The motion is transmitted from the main engine through horizontal shafts and then by means of special gears to vertical motion which rotates a disc on which several blades are mounted. The several blades also rotate about its own axis to generate the needed thrust to propel the ship.

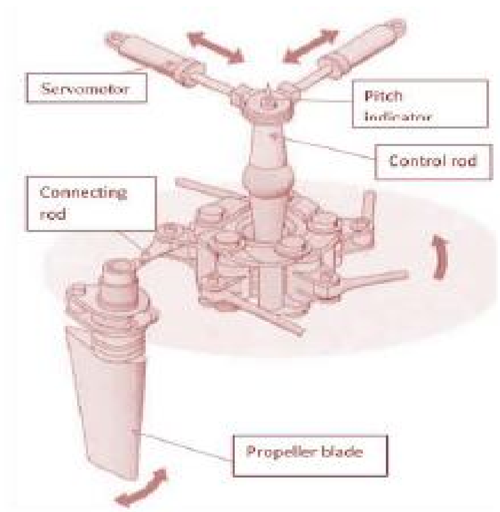

Figure 1 vertical axis propeller [9]

Therefore, the vertical axis propellers have advantages results from its blade operation and design while generates a direction and magnitude for thrust [12]. Therefore, the propeller blades have its privilege to play the role of ship rudder like ise [13].
Vertical axis propeller is used for ships that require high maneuverability or crafts, which are sailing in shallow water, crowded waters and canals such as (tugs) [14].The solution Voith-Schneider has been the one with the highest number of applications [15], especially in those areas demanding a high manoeuvrability of the vehicles [16]. In fact, the main advantage of vertical-axis propellers lies in the fact

that the propeller thrust can be used for steering and stopping the ships without stopping or changing the direction of rotation of the engines [17]. This makes this propeller extremely reliable when the ships have to operate in shallow, crowded and restricted waters, requiring large steering powers at low speeds [18].
In normal navigation, the efficiency of a vertical axis propeller is significantly lower than that of a conventional screw propeller [19]. The propeller, being a rotary machine with a particular law of motion of the blades [20], develops the forces which are not centred compared to the position of the axis on the impeller and this involves the generation of a "parasite" moment [21]. To avoid having a ship that turns around in circles, a pair of contra-rotating propellers must be fitted [22], so that the two opposite moments cancel each other [23]. Usually on the tugboats a couple of propellers is installed at bow, whereas in the ferries is preferred to apply one propeller fore and one aft [24]. The main disadvantage of these propellers is its low efficiency and performance [25]. So, many researches and developments are made to improve the performance of propellers [26]. In addition to experimental testing, there are additional methods such as analytical fluid dynamics (AFD) and Computational Fluid Dynamics (CFD) [27].

II. PRINCIPLES OF VERTICAL AXIS PROPELLER PERFORMANCE

2.1 Theory of Operation

The theory of operation of the cycloidal propeller is based upon the effect of a blade or foil moving in a circle about a fixed center, which at the same time is translating along a straight path. Hence, the motion so described is precisely that of a point on a circle rolling on a flat surface.
Mathematically we could define the locus of such a moving point as a cycloidal curve [28].

III. VERTICAL AXIS PROPELLER PERFORMANCE CHARACTERISTICS

The curtate cycloidal (below Pi or low-pitch type) is the one commonly used and will be briefly discussed. The character of the curtate cycloid, that is the size of the loop and the distance between loops, is a function of the propeller pitch and propeller slip [29]. As pitch increases the loop decreases from a complete circle at zero pitch to a cusp at Pi pitch. As slip increases, the loop for a given pitch will increase [30].. When the propeller is at rest, the four blades will assume the positions indicated on the propeller diagram [31]. As the propeller rotates the blades will oscillate with a variable velocity, the linkage is such that each blade will assume the same attitude at a given point in the circle as the preceding blade did when it had reached that same point in the circle [32]. If one blade "A" is followed around the circle, it will occupy successively the positions of the other three blades B, C, D. If the path of "A" is traced as the propeller rotates and translates with velocity V, it will be found that the blade successively occupies the position and attitude shown as A1, A2, A3, and A4.
For given angles of propeller rotation 6 these attitudes describe each blade of the unit as a whole or the attitude of one blade as it moves along the cycloid path. In the below Pi or low-pitch propeller, the blade oscillates about the tangent to the orbit circle [33].
As pitch increases from zero to Pi, the curve becomes progressively larger and is characterized by the sharp peak and steep gradient in the region of 6 = 180* [34]. As indicated by this gradient, a practical limit is reached due to the high accelerations experienced near Pi pitch [35]. The flow associated with an oscillating blade system such as the cycloidal propeller is very complex and has not been completely analysed to date [36]. In order to gain a general understanding of the operation of the propeller, a grossly simplified model will be used ignoring induced velocity effects and vortex generation [37]. The resultant *velocity* having an angle of *attack* to the blade develops a lift force Fn normal to the chord which can then be resolved into a thrust component Ft and a side force component Fs [38]. By symmetry, the side forces in the forward half of the propeller are equal and opposite to the side forces in the after half of the propeller, thus cancel out [39]. The thrust forces vary in magnitude for each blade position but all have the same sign, therefore the total thrust is a summation of all the blade thrust forces. As the pitch changes, the blade attitude (U angle) changes, thus changing the angle of attack and therefore the lift force [40]. At zero pitch, all blade chords are tangent to the circle and no resultant thrust is generated. For constant RPM, thrust varies directly with pitch, thus giving ship speed control without change in RPM [41]. Steering is accomplished by moving point N in around the centre **0,** ON remaining constant [42]. This rotates each blade an amount sufficient to maintain a right angle between the blade chord and steering centre ray [43]. The angular displacement of the whole blade system causes an equivalent angular displacement of the thrust forces, this gives steering capability through a full 3600**.** The below Pi or low-pitch propeller described above is the most prevalent one in actual use. The Voith Schneider propeller is based on this concept as well as the majority of American designs [44]. It should be pointed out, however, that most of the propellers built depart slightly from the true cycloid motion for various practical reasons.

3.1.Hydrodynamic Characteristic of Vertical axis propellers performance:

The performance characteristics of a propeller can conveniently be divided into two parts [45]:
1. Open water characteristics.
2. Behind-hull properties.

In the case of open water characteristics, these relate to the description of the forces and moments acting on the propeller when operating in a uniform fluid stream. The behind-hull characteristics are those generated by the propeller when operating in a mixed wake field behind a body [46]. Clearly these latter characteristics have both a steady and unsteady component by the very nature of the environment in which the propeller operates.

3.1.1 General Open Water Characteristics

The forces and moments produced by the propeller are expressed in their most fundamental form in terms of a series of non-dimensional characteristics: these are completely general for a specific geometric configuration [47].

The non-dimensional terms used to express the general performance characteristics are as follows:

Thrust coefficient KS = T/ρn2D4

Torque coefficient KD = Q/ρn2D5

Advance coefficient λ = Va /nD

To establish the non-dimensional groups involved in the above expressions, the principle of dimensional similarity can be applied to geometrically similar propellers [48]. The thrust of a marine propeller when working sufficiently far away from the free surface so as not to cause surface waves may be expected to depend upon the following parameters [49]:

(a) The diameter (D).
(b) The speed of advance (Va).
(c) The rotational speed (n).
(d) The density of the fluid (ρ).
(e) The viscosity of the fluid (μ).
(f) The static pressure of the fluid at the propeller station (P0 −e).

3.1.2 Behind Hull Characteristics

The behind-hull propeller characteristics, so far as powering is concerned, have been traditionally accounted for by use of the term relative rotational efficiency ηr. This term, which was introduced by Froude, accounted for the difference in power absorbed by the propeller when working in a uniform flow field at a given speed and that absorbed when working in a mixed wake field having the same mean velocity [50]:

3.2. Computational fluid dynamics (CFD):

VOITH has adopted a numerical technique to investigate the hydrodynamic characteristics of the vertical axis Propeller (VAP) system that based on experimental measurements [51]. The system has four vertical blades connected to the horizontal disk. Each blade has two speeds, one around a disk and second local rational along its axis. The method is finite volume CFD code (Fluent v16) with RNG k-ε turbulence model. For the purposes of this paper, a VAP with 4 blades is analyzed at various operating conditions [52]. Hydrodynamic characteristic parameters including thrust, torque and open water efficiency are presented as shown in figure (6-9).

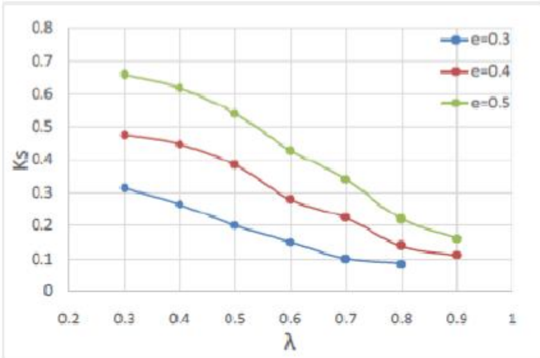

Figure 6 Thrust coefficient at different pitch ratios

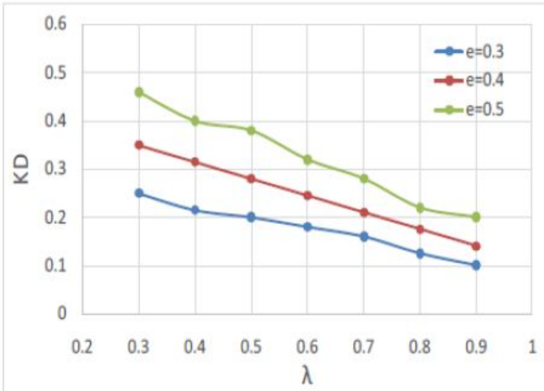

Figure 7 Torque coefficient at different pitch ratios

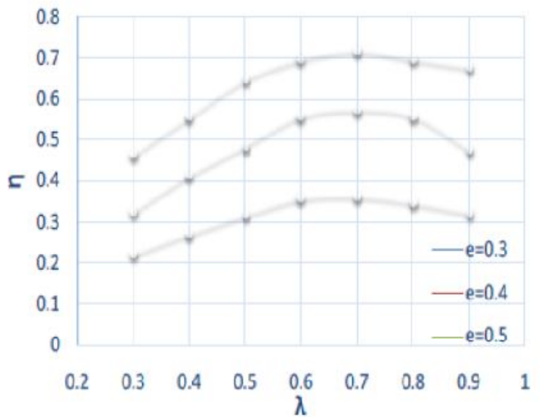

Figure 8 Efficiency at different pitch ratios

IV. CASE STUDY (A NEW METHOD FOR ESTIMATING BP-Δ CHART FOR ANY VAP)

Referring to the numerical method that calculated by voith . Kotb has presented a novel idea to predict a BP-e chart with different advance coefficient (λ) that that acquired through using analytical techniques as following:

- KD=4M/ ρ u2D2L

Where u= π Dn eqn (3)

- KD =4M/ ρ π 2D2n2L

Assuming that L=D

- $M=0.25KD\ \rho\ \pi^{2}D^{5}n^{2}$
- $PD=M*\omega$
- $PD=0.5KD\ \rho\ \pi^{2}n^{3}D^{5}$

Where $\lambda = Va / \pi nD$

- $D= Va/\pi n \lambda$

Then $PD=0.5\ KD\ \rho\ \pi^{2}n^{3}(Va/\lambda^{5}\pi^{5}n^{5})$

- $BP= (\rho /2\ \pi^{3})\ KD/\lambda^{5}$

The results are represented on figure (9).

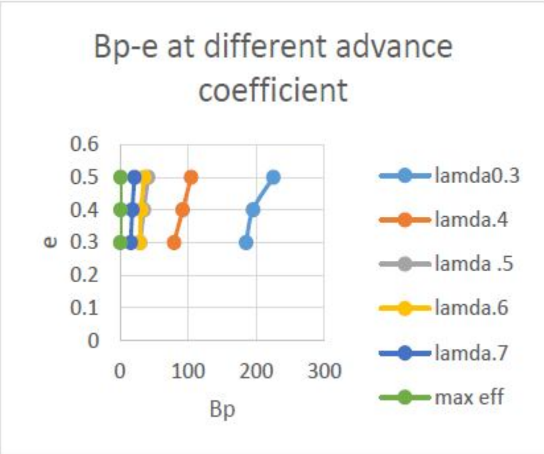

Figure 9 Bp-e chart at different advance coefficient

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