

The influence of the propeller emergence on the torque during sailing of a ship on a regular wave

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Abstract

While the ship is sailing on waves the relative motions occur which result in propeller emergence, and as a consequence – propeller thrust reduction which results in a decrease in the ship's speed. Propeller emergence is also accompanied by the decrease in torque values, with which the propeller affects the propelling engine. The article presents both calculation results and the algorithm for calculating the decrease in torque of the propeller during ship motion on a regular wave.

Introduction

As direct result of a ship sailing on waves, ship motions can be observed, occurring in continuous way, like the wave inducing them. Other dangerous phenomena associated with ship motions are also present, such as e.g. accelerations or relative motions, which also occur in a continuous way, as well as other phenomena occurring sporadically, for example: deck wetness, slamming or emergence of a propeller. The latter phenomena result among other from the ship's relative motions, and in this case frequency of their occurrence within one hour or per 100 waves is investigated.

Emergence of a propeller is a dangerous phenomenon for the whole propulsion system: it is responsible for the propeller thrust reduction which results in effect in the reduction of the ship's speed on waves (the reduction of the ship's speed on waves is caused by other factors as well) [1]. When determining the value of the torque value it is not enough to know the frequency of propeller emergence e.g. per hour but it is also necessary to establish the value and duration of propeller emergence on a given navigation route.

Propeller thrust reduction while sailing on waves has been presented in numerous papers, e.g. [2], where the wave action on the stream wake has

been considered as it affects the propeller thrust, however, without accounting for propeller emergence, [3] – thrust reduction with propeller emergence present, [4] – thrust reduction with emergence of the tunnel bow thruster. Papers [5, 6] discuss also the approximate effect of the propeller emergence on the decrease of a ship's speed. None of these works, however, provides information on the changes in torque value with a ship sailing on waves.

The article presents an algorithm for calculating propeller emergence and torque reduction together with its duration in case of a ship motions on a regular wave.

Relative ship motion and propeller emergence on regular wave

Using the commonly applied linear theory of ship motions [7], within the scope of which, on regular waves described by equation in moving axis system $O_1x_1y_1z_1$ (Fig. 1):

$$\zeta(t) = \zeta_A \cos[k(x_1 \cos \beta_w - y_1 \sin \beta_w) - \omega_E t] \quad (1)$$

the ship motions take the form of:

$$u_{(l)}(t) = u_{A(l)} \cos[\omega_E t - \varepsilon_{u(l)}(\omega_E)] \quad (2)$$

where:

- $\zeta(t)$ – ordinate of a regular wave;
- ζ_A – amplitude of a regular wave;
- ω_E – encounter frequency of regular wave in moving axis system $O_1x_1y_1z_1$ (Fig. 1):

$$\omega_E = \omega - kV \cos \beta_w \quad (3)$$

- ω – frequency of regular wave in earth axis system $O_1x_1y_1z_1$ (Fig. 1);
- k – wave number:

$$k = \frac{\omega^2}{g} \quad (4)$$

- V – ship speed;
- β_w – angle of wave direction relative to the ship (Fig. 1), $\beta_w = 0^\circ$ – following waves (from the aft), $\beta_w = 90^\circ$, beam wave (on the left side):

$$\beta_w = \mu - \psi + 180^\circ \quad (5)$$

- μ – wave geographical direction ($\mu = 0^\circ$ – northern wave, $\mu = 90^\circ$ – eastern wave);
- ψ – ship course in geographic coordinates ($\psi = 0^\circ$ – northern course, $\psi = 90^\circ$ – eastern course);
- t – time;
- g – gravitation;
- x_1, y_1 – coordinates of a ship-bound point in a moving axis system $O_1x_1y_1z_1$ for which the wave ordinate is calculated;
- $u_{(l)}(t)$ – ship “l” motion ordinate;
- $u_{A(l)}$ – ship “l” motion amplitude;
- $\varepsilon_{u(l)}$ – angle phase of a ship motion “l”.

Vertical, absolute displacement of a ship resulting from its motions, equals:

$$S_{zP}(t) = Z(t) + y_P \Phi(t) - x_P \Theta(t) \quad (6)$$

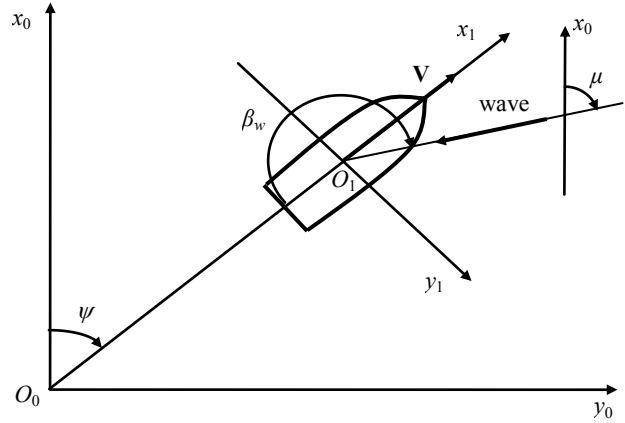


Fig. 1. Wave direction, ship speed and course

while relative:

$$R_{zP}(t) = S_{zP}(t) - \zeta(t) \quad (7)$$

where:

- $Z(t), \Phi(t), \Theta(t)$ – ship motions on a regular wave: heave, rolling, pitching;
- x_P, y_P – coordinates of a ship bound point P , for which the vertical relative movement is calculated, in this case it is a point situated on the top of a propeller blade in its upward position (Fig. 2).

On the basis of relative movement, the equation (7) and the propeller position (to be exact: the position of a top end of a propeller blade – point P , Fig. 2) it is possible to calculate the height and duration of propeller emergence. The height of propeller emergence h_{ws} appears when,

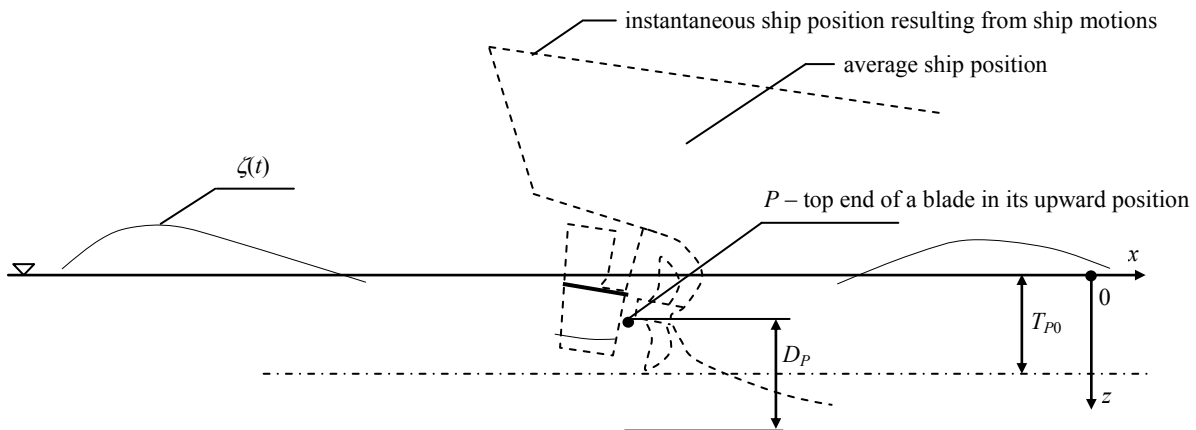
$$h_{ws}(t) = R_{zP}(t) - T_{zS}(t) > 0 \quad (8)$$

where T_{zS} is the draught of the top end of a propeller blade in its upward position:

$$T_{zS} = T_{P0} - 0.5D_P \quad (9)$$

T_{P0} – draught of propeller shaft (Fig. 2),

D_P – diameter of a propeller.



Rys. 2. The influence of a relative motion on the propeller emergence

Calculating the propeller emergence on regular wave – an example

Calculations have been performed for a bulk carrier of the characteristics given in the table 1.

Table 1. Technical parameters and ship dimensions

Ship length between perpendiculars	$L_{PP} = 138.0$ m
Width	$B = 23.0$ m
Draught	$T = 8.5$ m
Displacement	$\nabla = 21,411$ m ³
Speed	$V = 14.24$ kn
Propeller diameter	$D_P = 5.0$ m
Rotational speed of the propeller	$n_P = 110$ rpm
Draught of the propeller shaft	$T_{P0} = 5.9$ m
Distance between the propeller and midship section \mathcal{Q}	$x_P = -68.16$ m

For the ship (Table 1) frequency characteristics of ship motions on a regular wave have been calculated at different speed values V and wave directions β_w relative to the ship (Fig. 1).

Relative motion of the top end of the propeller blade (point P – Fig. 2) has been calculated according to (7), while propeller emergence – equation (8), has been presented in figure 3.

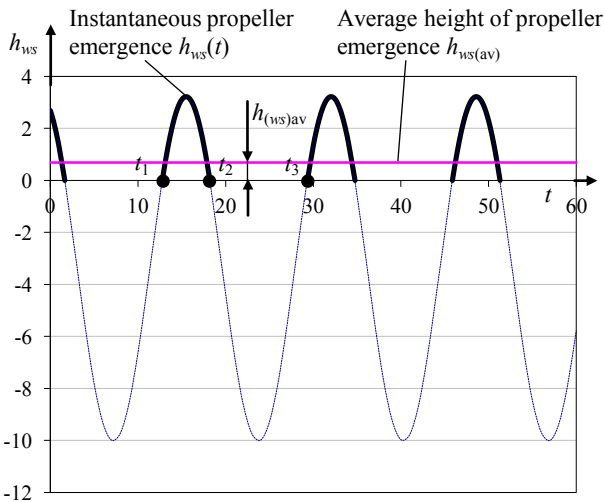


Fig. 3. The height of emergence of the top end of a propeller blade: $\omega = 0.6$ 1/s, $V = 6$ m/s, $\beta_w = 0^\circ$, $\zeta_A = 6$ m, $t_1 = 12.77$ s, $t_2 = 18.20$ s, $t_3 = 29.31$ s

On the basis of the distribution in time of the propeller blade emergence ordinate $h_{ws}(t)$ the average value of propeller blade emergence $h_{(ws)av}$ has been calculated (Fig. 3):

$$h_{(ws)av} = \frac{1}{T_{ws}} \int_{t_1}^{t_3} h_{ws}(t) dt \quad (10)$$

where:

$$h_{ws}(t) = \begin{cases} R_{zP}(t) & \text{where } \in (t_1, t_2) \\ 0 & \text{where } \in (t_2, t_3) \end{cases} \quad (11)$$

t_1, t_2 – start and finish of the propeller blade emergence (Fig. 3),

t_3 – finish of the relative motion $R_{zP}(t)$ (Fig. 3).

Average height of propeller emergence for different amplitudes ζ_A and different regular wave frequency ω and direction relative to the ship has been presented in figure 4.

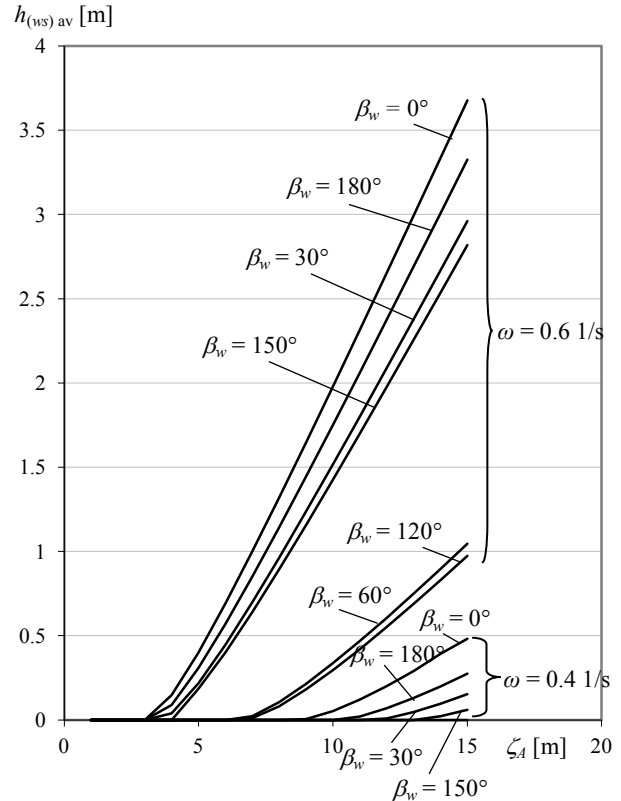


Fig. 4. Average height of propeller emergence on regular wave for different wave amplitudes ζ_A and wave directions β_w relative to the ship ($V = 6$ m/s)

Emerging surface of propeller blades

While the propeller is emerging from water, some parts of its blades will rotate in the air – hence the lift force of such blades, and consequently their thrust force and torque will reach almost zero values in comparison to the blades still in water.

Rotational speed of a propeller 110 [rpm] is shown in table 1. The movement of the top end of a propeller blade has been presented in figure 5.

On the basis of figure 5, a propeller can be expected to fully rotate a dozen or even up to twenty times while emerging from water. Hence, it has been assumed that the surface of the propeller blades emerging from water will be proportional to the height of propeller emergence $h_{ws}(t)$. For longer periods of time the average surface of propeller blades emerging from water can also be adequately proportional to the average height of propeller emergence $h_{(ws)av}$ (10) (Fig. 3).

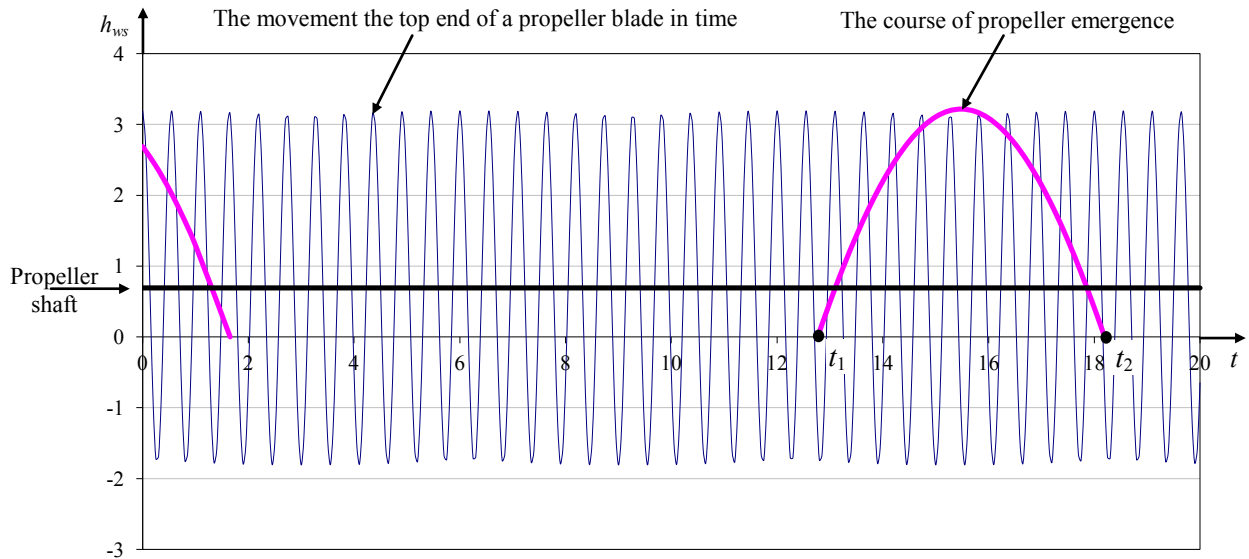


Fig. 5. The movement of the top end of propeller blade during propeller emergence in the course of time (all parameters the same as in figure 3)

The influence of propeller emergence on regular wave on propeller torque

Propeller screw fully submerged in water, whose basic geometric parameters are given in table 1, with hydrodynamic characteristics in figure 6.

With the aid of a specialist computer programme, based on the algorithm [8], distribution of thrust forces and torque on separate propeller radii at various angular positions of propeller blades have been calculated. For a blade fully submerged in water such distribution is shown in figure 7.

During propeller emergence from water, the basic thrust forces and torque acting upon the propeller blades emerging from water (Fig. 8), equal zero.

With propeller rotation (Fig. 8), the emerging surface of a propeller blade will change at estimated propeller emergence. Such distribution in time of a propeller blade emerging from water has been shown in figure 9. Thrust force and torque values at given height of propeller emergence will change in a similar fashion. Average torque values at different propeller emergence heights have been given in figure 10. The influence of the wave inducing the emergence of a propeller with its regular wave parameters and direction relative to ship, has been given in figures 11–13.

Conclusions

Calculations performed for a propeller emergence on a regular wave in course of time indicate that for one cycle of a propeller emergence, especially in the case of a following wave, such propeller

can rotate fully over a dozen times with parts of the propeller blades emerging from water. A computer programme calculating torque distribution along the propeller radius at various angular positions, allowed us to calculate a total torque of a propeller when some parts of its blades emerge from water. The article presents also a comparison between instantaneous and average decrease in torque values on regular wave. Algorithm created here for propeller emergence will subsequently be used for further calculations of propeller emergence and torque decrease on irregular waves.

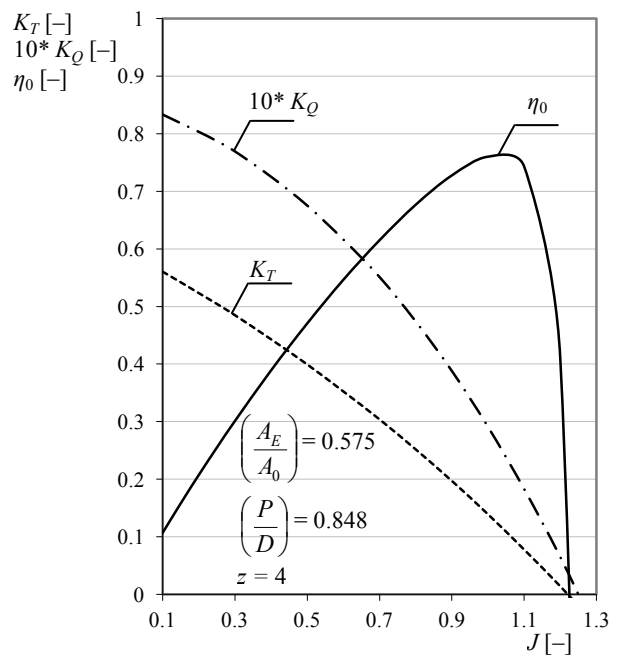


Fig. 6. Hydrodynamic characteristics of an open-water propeller fully submerged in water

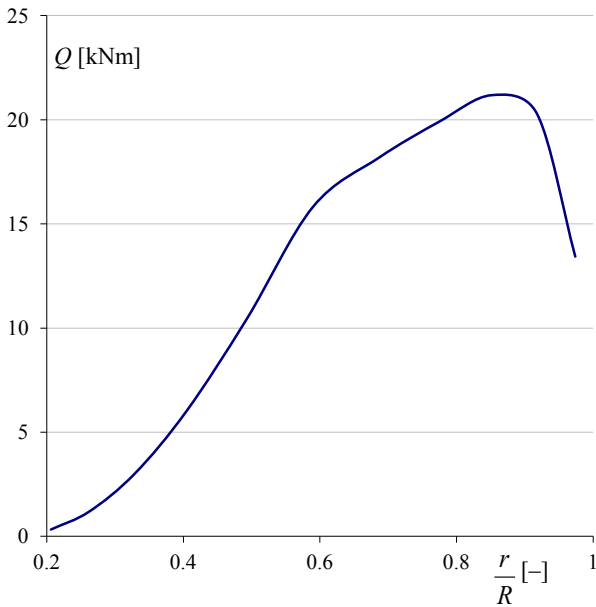


Fig. 7. Torque distribution on a blade of a propeller fully submerged in water in the relative radius function r/R ; $Q = 519.14$ kNm – torque of a propeller fully submerged in water at ship speed $V = 7.32$ m/s

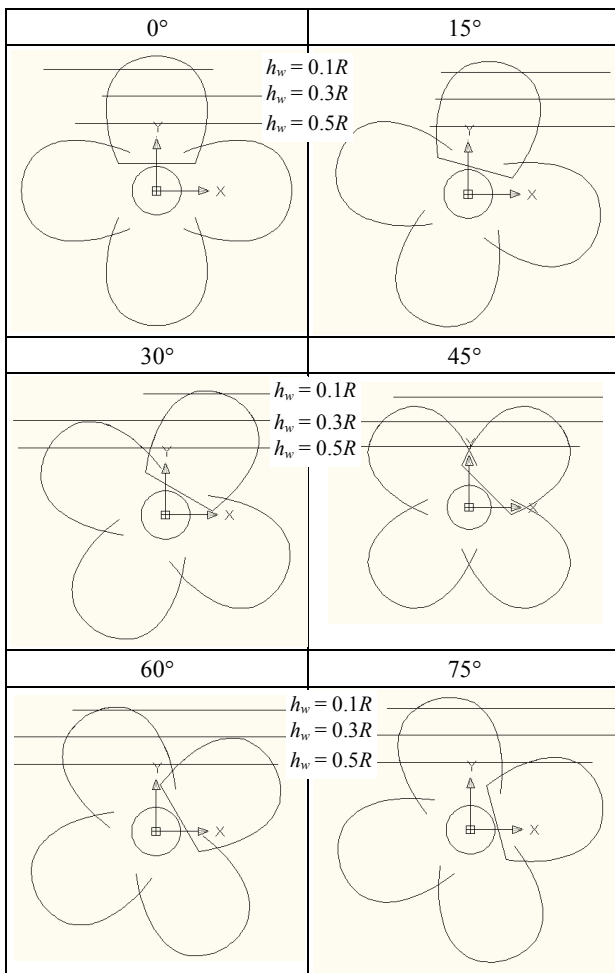


Fig. 8. Changes in the surface of a propeller emerging from water during rotation

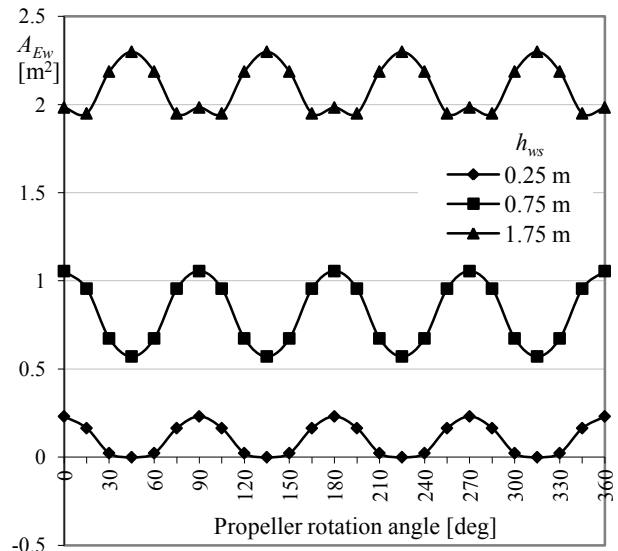


Fig. 9. Changes in the surface of propeller emerging from water at different angular positions at three heights of propeller emergence (one full propeller rotation)

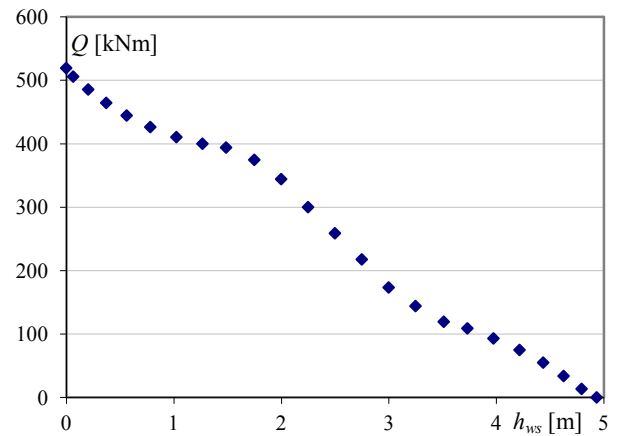


Fig. 10. Torque on the propeller in relation to the propeller emergence height

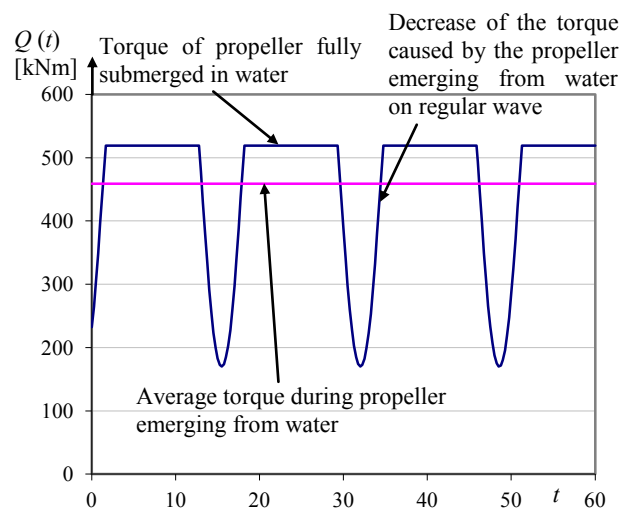


Fig. 11. Instantaneous torque change during propeller emergence from water on regular wave (frequency $\omega = 0.6$ 1/s, amplitude $\zeta_A = 6$ m, wave direction $\beta_w = 0^\circ$ relative to ship ($V = 6$ m/s))

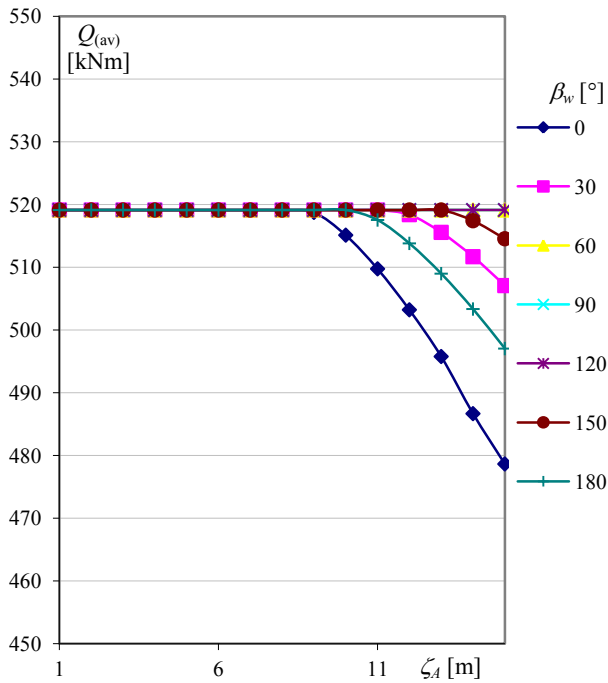


Fig. 12. Torque change during propeller emergence from water on regular wave $\omega = 0.4$ 1/s at various wave amplitudes ζ_A and wave β_w direction relative to ship ($V = 6$ m/s)

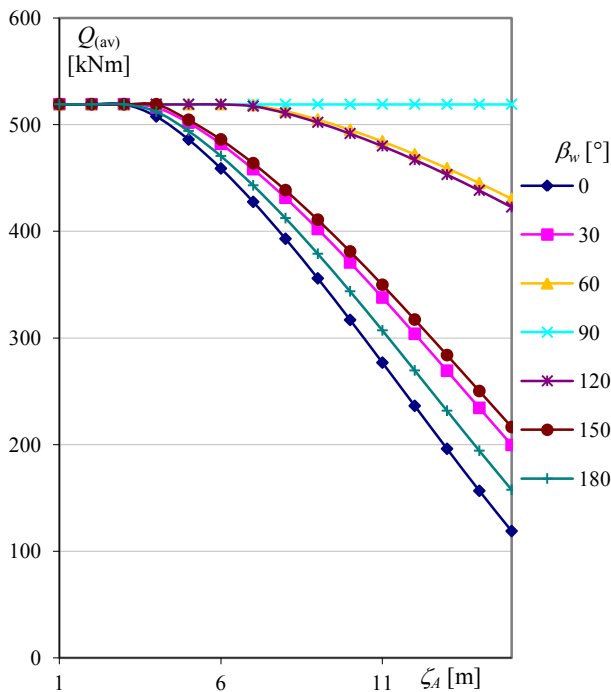


Fig. 13. Torque change during propeller emergence from water on regular wave $\omega = 0.6^\circ$ 1/s at various wave amplitudes ζ_A and wave β_w direction relative to ship ($V = 6$ m/s)

References

1. SZELANGIEWICZ T.: Seakeeping in cargo vessels design. 14th International Conference on Hydrodynamics in Ship Design, Szczecin-Międzyzdroje, Poland, September 27–29, 2001, 324–334.
2. LUBIENIECKI M.: Wyznaczanie sił hydrodynamicznych generowanych na śrubie w wyniku ruchu na fali. Praca doktorska, Instytut Maszyn Przepływowych PAN, Gdańsk 1996.
3. FALTINSEN O.M.: Sea Loads on Ships and Offshore Structures. Cambridge University Press, Cambridge 1990.
4. MINSAAKS K.J., THON H.J., KAUCZYŃSKI W.: Influence of Ocean Environment on Thruster Performance. Proc. Int. Symp. Propeller and Cavitation, 1986, 124–142.
5. SZELANGIEWICZ T., ŻELAZNY K.: Prediction of the influence of emergence of propeller on the propeller thrust reduction during ship navigation on waves. Scientific Journals Maritime University of Szczecin, 2010, 21(93), 10–13.
6. SZELANGIEWICZ T., ŻELAZNY K.: The propeller thrust and speed reduction as a result of the propeller emergence on a given ocean route. Scientific Journals Maritime University of Szczecin, 2010, 22(94), 63–66.
7. DUDZIAK J.: Teoria okrętu. Fundacja Promocji Przemysłu Okrętowego i Gospodarki Morskiej, Gdańsk 2008.
8. SZANTYR J.A.: Method for Analysis of Cavitating Marine Propellers in Non-uniform Flow. Intern. Shipbuilding Progress, Vol. 41, No. 427, 1994.