SIGNATURE OF HYDRODYNAMIC PRESSURE FIELD

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The article presents the results of calculations of the hydrodynamic pressure field around the ship as a space function, calculated by boundary method. Calculated hydrodynamic pressure field is compared with the measured field for a special vessel, the description of the shape of the hull is approximate.. Presented results of the calculations have been obtained using single layer, that is the source of continuously distributed. Constructed using this method, a program called SHiPP will be complemented by the method of calculating the double layer, that is the dipoles of continuously distributed. Calculations for the signature of the ship at a constant speed obtained polynomial dependence of the maximum underpressure at ship, depending on depth. A good conformity of calculated and measured hydrodynamic pressures. The error is less than 1-2 percent for the underpressure. For overpressure is of the order of several percent.

INTRODUCTION

Pressure field around the ship moving at constant speed in calm water is static in the moving coordinate system associated with it (MCS - moving coordinate system). The stationary system associated with the ground (FCS - fixed coordinate system) field is characterized by the dynamics of change at different time period. At the point in a fixed coordinate system, we observe the passage of the ship next to the initial pulse pressure increase with a relatively short duration, usually followed by long-term pressure for ships with an average length (period and amplitude of the phenomenon termed respectively the **p**rimary **p**eriod of **p**ressure **f**ield of the **s**hip - PPPFS and **a**mplitude of the **p**ressure drop **s**hip - APS) and then re-pulse pressure increase when passing the stern. Time passing by a point in the FCS ship is equal to the quotient of the length between perpendiculars Lpp and ship speed Vs as T0 = Lpp/Vs, (PPPFS ≈ T0). For ships longer moving with considerable speed may not occur stern pulse pressure (flow separation occurs at the stern and the base period increases, PPPFS > T0) or may occur an extra boost when passing mid-ship, (when you see the k pulse pressure increase base period may achieve value PPPFS ≈ T0 / (k-1)). While the amplitude of the pressure drop is a fraction of APS stagnation pressure $q = (\rho V_s^2)/2$ and is equal to

$$APS = f(L, B, T, Cb, r)*q.$$

This fraction is a function f(L, B, T, Cb, r) depends on the main dimensions of the ship and their relations or shape of the hull of the ship and the distance r from the viewpoint of the ship.. At a certain shape of the ship such as those arising from the good properties of resistance function $f(L, B, T, Cb, r) = const \approx C_1/r^4$ and $APS = C_2 * V_S^2$, where the constant $C_2 (r) \approx (C_1/r^4)*\rho/2$, i.e., the amplitude of the pressure drop is dependent only on the ship's speed and distance from control point. Limiting the maximum value of APS so limited operating speed of the ship to the speed limit Vs: $V_{limit} = (APS / C_2)^{1/2}$

During the movement of the ship on the wave of the image pressure field in the FCS imposed pressure changes caused by wind waves and changes in the pressure field generated by the systems interacting with each other and the ship of wind waves with periods shorter or much shorter than PPPFS.

At the design stage of the ship, there are wider opportunities for changes in the characteristics of pressure field generated by the ship and relate to such a change in the ratio of width to length with a change in general and the length of the volume distribution at the same time changes the value of the function f(L, B, T, Cb, r) and thus the value of the constant C_2. This allows you to change the size of APS without changing the operating speed V_s. It should be emphasized that this is achieved at the expense of much more than by changes in ship speed, distance, and even cheaper to change PPPFS period.

The volume distribution along the length of the ship and the resulting ratios of the main dimensions and block coefficient are responsible both for the magnitude of the resistance units in particular, the wave resistance and pressure resistance. At the design stage one of the main criteria and constraints for designers is the task of minimizing the power of resistance to operating speed. It is one of the main criteria but not the only one. Ship design is of finding the global minimum in the multiparameter space with the appropriate weights for specific parameters. Determination of maximum and impassable for a ship already designed the APS limited operating speed of the ship to the speed limit V_{limit} as above.

As you can see from the above analysis in the absence of restrictions on changes of parameters such as V_s and r is possible (though with limitations) change the characteristics of pressure field of the ship at the checkpoint. In terms of actual operation limits for the ship speed V_s and the distance r there, preventing the change of parameters of any range. It is possible only in principle, the speed limit to a safe speed, even though such it is never because of the wide range of parameter settings change the amplitude and period PPPFS and APS.

The paper formulates the problem of flow around the ship of inviscid fluid. A resolution for the problem. Using this method allows to construct a computational algorithm and the program performing relatively fast calculation of hydrodynamic fields as a PC, and on this basis, the necessary characteristics of these fields. Due to the speed of calculation seems to be impossible to develop a version for use directly on the craft and / or obtain the necessary characteristics of radio in the occurrence of a special situation.

For the purposes of a preliminary numerical analysis developed on the basis of this method a preliminary program for the calculation of hydrodynamic flow around and fields. Singularities in the form of a single layer are arranged on the surface dampened the simplified shape of the boat and at the bottom. For the same shape and small values of the Froude number hydrodynamic field results are correct. For higher speed is necessary to extend a single layer on the free surface area surrounding the ship.

1. FORMULATION OF THE PROBLEM

The ship is moving at a speed of $V_s = V_0 =$ const. Determination of velocity and pressure fields flow around the hull is made by solving the linearized tasks formulated by the following equations of continuity of flow (Laplace equation for the velocity potential φ) and the boundary conditions at the bottom, free surface and away from the ship's vertical surfaces defining a closed area around the vessel. The equations were formulated in coordinate systems Oxyz, Oξηζ, the first inertial axis x located at the free surface deformation and pointing in the direction of the velocity vector of the ship $\mathbf{v_0}$ and the vertical axis directed downward, coinciding with the second only at the beginning of motion . The second movable coordinate system rigidly connected to the hull of the ship. The mathematical model of fluid motion in the vicinity of the ship describe the equation:

$$\Delta\varphi = 0 \tag{2.1}$$

$$\frac{\partial^2\varphi}{\partial x^2} - \frac{g}{v_0^2}\frac{\partial\varphi}{\partial z} - \frac{\mu}{v_0}\frac{\partial\varphi}{\partial x} = 0 \quad z = 0 \tag{2.2}$$

$$\frac{\partial\varphi}{\partial z}(z = h) = 0 \tag{2.3}$$

$$\frac{\partial\varphi}{\partial y}\left(y = \pm\frac{b}{2}\right) = 0 \tag{2.4}$$

$$\frac{\partial\varphi}{\partial u}(S) = v_0 n \tag{2.5}$$

$$\zeta = -\frac{v_0}{g}\frac{\partial\varphi}{\partial x} \quad z = 0 \tag{2.6}$$

where: h - depth of water, b - a multiple of the width of the ship, S - surface area wetted by the ship moving at forward speed v_0, Ω - is the wetted surface by the ship, **n** - normal vector to the surface, in equation (2.5) to the surface of the hull of the ship , g - gravitational acceleration vector.

The potential φ is determined by the method of Kirchhoff through distribution of sources on the surface S, so. single layer of the first kind. To determine the potential φ must know the potential of the source moving uniformly with velocity v_0 at the free surface of water, called the source function as well as the Havelock Green's function for a source with the following form:

$$\varphi(\vec{r}) = -\frac{Q}{4\pi}G(x, y, z, \xi, \eta, \zeta) \tag{2.7}$$

where: $\vec{r} = x\vec{\imath} + y\vec{\jmath} + z\vec{k}$ - radius vector,

Green's function have the form:

$$G(x, y, z, \xi, \eta, \zeta) = G(M, N) = \frac{1}{r} - \frac{1}{r_1} + G(M, N) \tag{2.8}$$

Where the points M and N are the coordinates, respectively: M(x, y, z), N(ξ, η, ζ). As follows from the above formulas, the distributions of sources $q_s(N)$ and dipole σ(N) are not dependent on one another, and so the question is whether such part of the surface ∂V, such as the waterline of the ship S_{WL}, it can be reset? The answer to this and similar questions can give the test compared with the results of numerical experiments. In the event of confirmation of such a possibility would simplify the above formulas to the form described below:

potential φ:

$$\varphi(M) = -\frac{1}{4\pi}\int_{\Omega=S_s}(q_s G)\, dS \tag{2.9}$$

and the distribution of sources:

$$q_s(M) = 2v_0 n_x(M) + \frac{1}{2\pi}\int_\Omega q_s(N)\frac{\partial G(M,N)}{\partial n_M}dS \tag{2.10}$$

To obtain a numerical solution of this integral equation and find the distribution of singularities on the surface of the hull of the ship S_S and other strongly interacting surfaces in the flow, such as the bottom surface S_d in the flow in shallow water, the surface ∂V is divided into N panels, which will be placed singularities.

In the case of single-layer density layer q_j on a particular panel can remain evenly distributed throughout the panel, or can I focus in the middle panel, ie, the control point C. The first method is more accurate, and the other in performing the calculations easier. Similarly for the double layer density σ_j dipole panel j can be just as above fold. As a result, also get the two methods.

Using a single layer and method of distributing the surface ∂V of the panels, the solution of the integral equation (2.9) we obtain from the condition of impermeability of the surface and solution of the problem reduces itself to solve the system of linear equations in the following form:

$$\sum_{j=1}^{N} A_{ij} q_j = \overrightarrow{v_\infty} \cdot \overrightarrow{n_i} = v_{ni} \quad i = 1, \dots, N \tag{2.11}$$

where the coefficient matrix A_{ij} has the effect of the form:

$$A_{ij} = \frac{1}{4\pi} \frac{\overrightarrow{n_i} \cdot \overrightarrow{r_{ji}}}{r_{ji}^3} \Delta S_j \quad for\ i \neq j \tag{2.12}$$

$$A_{ij} = \frac{1}{2} \quad for\ i = j \tag{2.13}$$

where: A_{ij} - projection unit velocity induced by the singularity from the j-th panel on the i-th panel in the direction normal to the i-th panel $\overrightarrow{n_i}$,

$r_{ji} = |\overrightarrow{r_{ji}}|$ – length of the vector of the j-th to the i-th panel ,

ΔS_j - surface area of the j-th panel.

Using a double layer, in turn, the resulting system of equations will have the form:

$$\sum_{j=1}^{N} A_{ij} \sigma_j = \overrightarrow{v_\infty} \cdot \overrightarrow{n_i} = v_{ni} \quad i = 1, \dots, N \tag{2.14}$$

where the coefficient matrix A_{ij} has the form:

$$A_{ij} = \frac{1}{4\pi} [-\overrightarrow{n_i} \cdot \overrightarrow{n_j} + 3(\overrightarrow{n_i} \cdot \overrightarrow{e_{rji}})\overrightarrow{e_{rji}} \cdot \overrightarrow{n_i}] \frac{\Delta S_j}{r_{ji}^3} \quad dla\ i \neq j \tag{2.15}$$

$$A_{ij} = 0 \quad for\ i = j \tag{2.16}$$

where the sign as above, see (2.13).

2. NUMERICAL SOLUTION OF THE PROBLEM

Based on the above solution to theoretical issues has been developed for the preliminary research model number. Single layer was distributed on the surface of the hull of the boat and at the bottom, $\partial V = S_s + \Omega$. The study initially adopted a simplified numerical hull design. Surface of the hull was divided into square panels, in which the center of gravity placed checkpoints C. It is assumed that the total expenditure of singularities on the panel is focused in point C. Was used a single layer.

3. THE RESULTS OF CALCULATIONS

Measurements of hydrodynamic pressure fields (HPF) was performed on the special ship. The information needed to test the function describing the spatial distribution of the amplitude of the pressure drop around the ship (APS) and comparisons with measurements were supplied from the GPS and follow the water itself. Based on the above information and to set up individual volume distribution as a function of the length of the ship computations HPF were performed using the program SHiPP, (**S**ignature **H**ydrodynamic **P**ressure **P**rogram).

Description of the geometry of the hull is in Fig. 1.

The main characteristics of the ship hydrostatic:

Design length	:	76.001 [m],	Length over all	:	82.897 [m]
Design beam	:	12.600 [m],	Beam over all	:	12.600 [m]
Design draft	:	4.800 [m]			

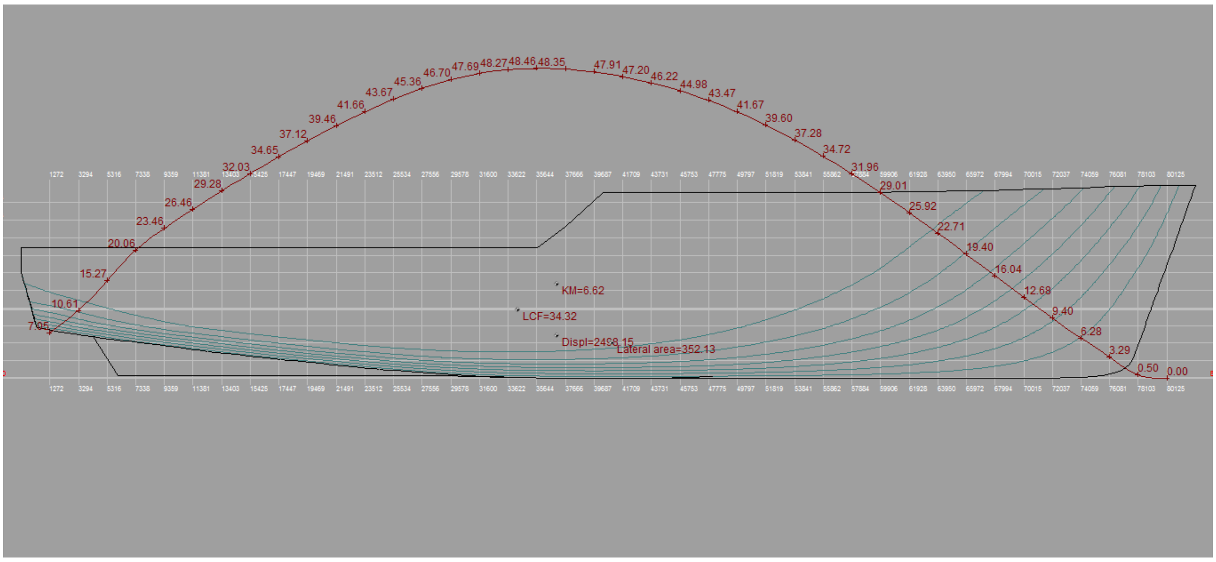

Fig.1. The special ship hull geometry.

Presented results of measurements of hydrodynamic pressure fields (HPF) were taken in the waters of the Baltic Sea with a depth H = 23m. These results are illustrated in the following figures with averaged 15 points.

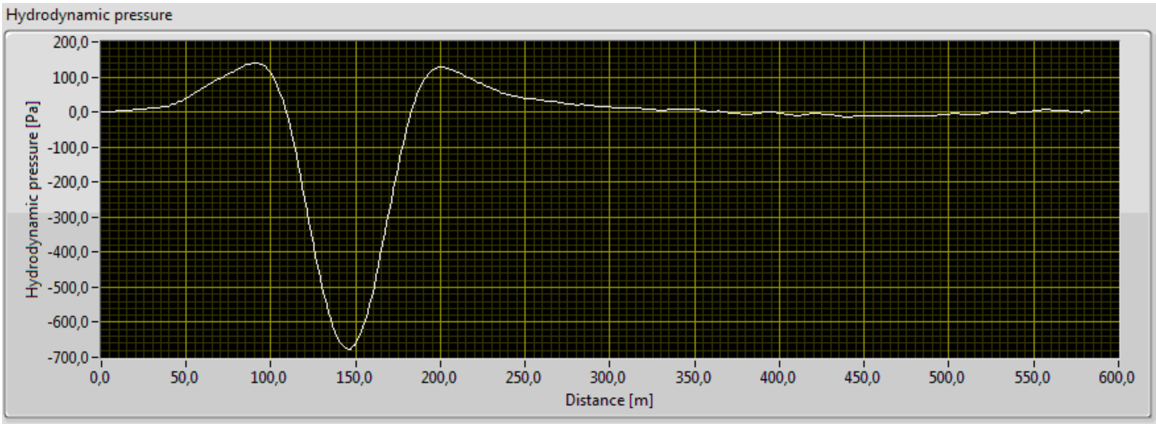

Fig.2. The measurement results of HPF at the bottom of the depth H = 23m in the PS of ship, the moving average speed of v = 12.4 knots.

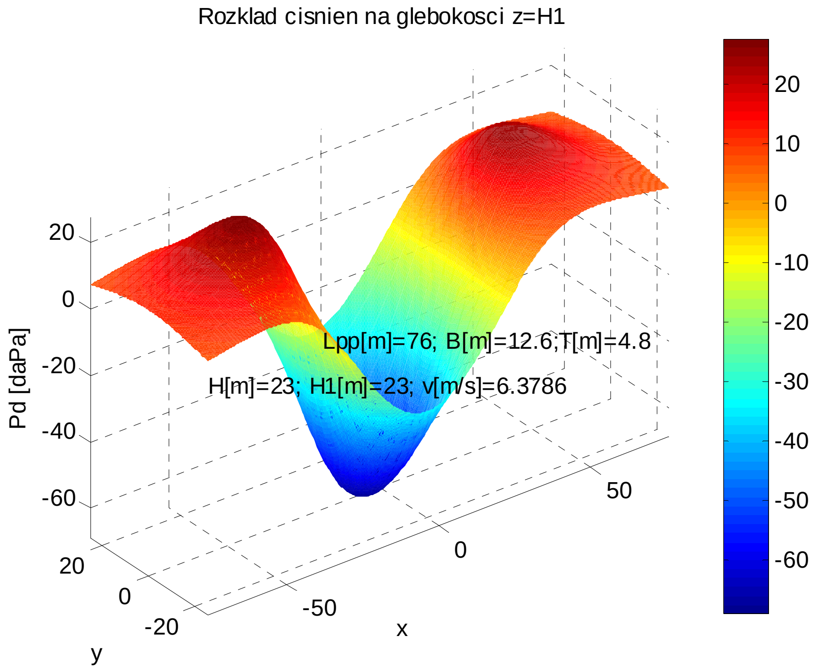

Fig.3. The calculated HPF of the ship at the bottom of the depth H = 23m and the velocity v = 12.4kn.

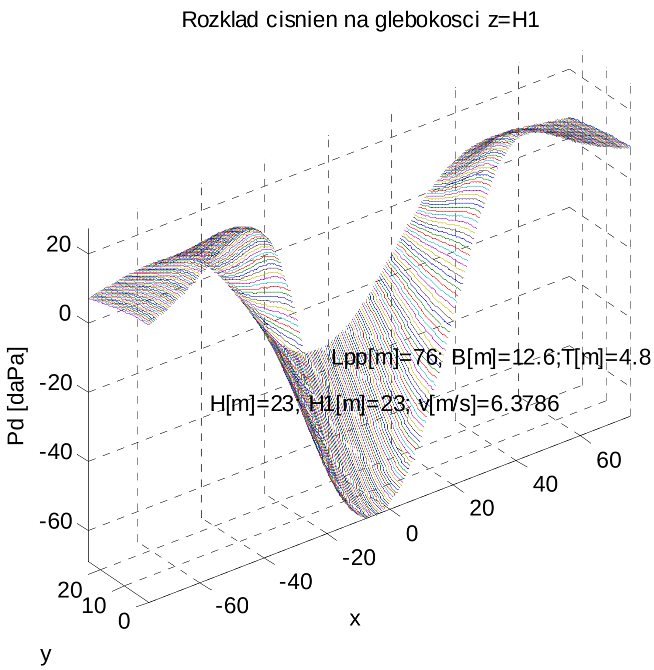

Fig.4. The calculated cross sections of HPF at the bottom of the depth H = 23m and the velocity v = 12.4kn.

3. CONCLUSIONS

By comparing the measured values with the calculated pressure at a depth of 23m can be observed:

- in Fig.2 and 3 for the ship speed v = 12.4kn measured hydrodynamic pressure field HPF respectively +140Pa -680Pa and a computed +220P and -690Pa;

- comparing the calculated HPF for the different speed of the ship with the measured values were similar good compliance of the minimum pressure and a little less of the maximum pressure of conformity.

Dependence min. APS - amplitude of the pressure drop ship function values of the depth of H1 for the ship speed equal to v = 12.4kn expressed by the following relationship:

$$p_{dmin} = ax^3 + bx^2 + cx + d \tag{4.1}$$

where: p_{dmin} in [hPa], x=H1 – depth in [m], while the coefficients are equal: a=9.5999e-3, b=-0.5514285, c=10.3628571 and d=-71.099999.

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