Influence evaluation of the tow ship oscillation on the towed system motion

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Abstract. Influence of the tow ship oscillation on the value of hydrodynamic force, acting on the towed system at different tow speeds is considered. Influence of tow speed on running depth is shown. Based on computational studies, an estimation of the effect of the ship-towing pitch on the movement of the towed system was carried out.

1. Introduction
Due to the fact that the towed system weight is negligible (less than 1% of tow ship weight), than the displacement of a ship stern - a brace of a tow ship (point of the inboard end of the cable) can be considered as the disturbing influence on the towed system movement. Amplitude and frequency are assumed to be known. It is shown in some papers [1], [2], [3] that change of cable tension value doesn’t lead to the significant change of tow line shape. This lets us consider that cable point displacement towards tow line tangent is constant and equal to tangent displacements of its inboard end.

Moreover, because of viscosity of the medium, cable point displacements normal to the towed line are damped on the limited distance (usually tens of meters) from the source. Taking into account that tow line camber can make hundreds and thousands of meters, the cable near vibration source is considered linear and tension in cable is constant. So, the equation of thread in viscous fluid under the constant tension is used to describe the movement of cable points at this segment.

2. Estimation of the hydrodynamic force acting on the blunt body oscillating in fluid stream
In this case, a blunt body is the body that is influenced by the hydrodynamic force, and the main component of hydrodynamic force is directed along the instantaneous relative viscosity vector of the body. Example of such body is a reciprocating sphere.

Although a depth controller and a photomodule aren’t sphere bodies, they can be considered as parallelepipeds with small aspect ratio (close to cube) that allows us to make a suggestion that only drag force will effect on them from the flow:

\[ X = C_x \frac{\rho v^2}{2} S \]  

where: \( C_x \) – non-dimensional force coefficient; \( \rho \) – medium density; \( v \) – value of instantaneous relative velocity vector; \( S \) – reference area.
It is assumed that coefficient $C_X$ weakly depends on body orientation in fluent stream and therefore $C_X$ is accepted constant [4].

Taking into account that the submerged weight of the depth controller and the photomodule considerably exceeds drag force value i.e. the towed line in the attachment point of the depth controller and the photomodule is practically plumb [5], we can assume that:

$$\begin{cases}
v_x = v_0 \\
v_y = y_0 \omega_0 \cos \omega_0 t
\end{cases}$$

(2)

where: $v_x$ – horizontal component of body velocity; $v_y$ – vertical component of body velocity; $v_0$ – ship speed; $y_0$ – amplitude of vertical displacement of tow ship stern; $\omega_0$ – frequency of vertical displacement of tow ship stern.

Since $v^2 = v_x^2 + v_y^2$, then, considering equations 1 and 2, drag force value acting on the body can be introduced as:

$$X = C_X \frac{\rho v_0^2}{2} S \left[ 1 + \left( \frac{y_0 \omega_0}{v_0} \right)^2 \cos^2 \omega_0 t \right]$$

(3)

Drag force horizontal component is given below:

$$X_X = X_0 \left[ 1 + \left( \frac{y_0 \omega_0}{v_0} \right)^2 \cos^2 \omega_0 t \right]^{1/2}$$

(4)

Drag force vertical component is given below:

$$X_Y = -X_0 \left( \frac{y_0 \omega_0}{v_0} \cos \omega_0 t \left[ 1 + \left( \frac{y_0 \omega_0}{v_0} \right)^2 \cos^2 \omega_0 t \right]^{1/2} \right)$$

(5)

Equations 4 and 5 can be represented as Fourier series transformation:

$$X_X = X_0 \left( B_0 + B_2 \cos 2\omega_0 t + B_4 \cos 4\omega_0 t + \ldots \right)$$

(6)

$$X_Y = -X_0 \left( C_1 \cos \omega_0 t + C_3 \cos 3\omega_0 t + \ldots \right)$$

(7)

where coefficients $B_i$ and $C_i$ depend on $\frac{y_0 \omega_0}{v_0}$ parameter [6].

![Figure 1](image-url). Dependence of the coefficients $B_0$, $B_2$ on $\frac{y_0 \omega_0}{v_0}$ parameter.
Figure 2. Dependence of the coefficients $C_1$, $C_3$ on $\frac{y_0\varphi_0}{v_0}$ parameter.

Assuming that the amplitude and the frequency of vertical displacement of the tow ship stern, the slope angle of the towed line depth controller-ship on the inboard end and the slope angle of the tow line photomodule – depth controller on the inboard end are known, it is possible to calculate $\frac{y_0\varphi_0}{v_0}$ parameter value for depth controller and photomodule for considered tow speeds range 0.5 m/s, 1.0 m/s, 1.5 m/s [7],[8].

\[
\left( \frac{y_0\varphi_0}{v_0} \right)_{DP} = \left( \frac{y_0\varphi_0}{v_0} \right)_{SHIP} \sin A_{\varphi_01} \quad (8)
\]

\[
\left( \frac{y_0\varphi_0}{v_0} \right)_{FM} = \left( \frac{y_0\varphi_0}{v_0} \right)_{DP} \sin A_{\varphi_02} \quad (9)
\]

In equations 8, 9: $A_{\varphi_01}$ – the towed line slope angle at the attachment point to the tow ship; $A_{\varphi_02}$ – the towed line photomodule-depth controller slope angle at the attachment point to the depth controller.

Results of $\frac{y_0\varphi_0}{v_0}$ parameter calculation are given in table 1, here $y_0 = 2$ m, $\varphi_0 = 1$ s$^{-1}$.

| Towing speed | 0.5 m/s | 1.0 m/s | 1.5 m/s |
|--------------|---------|---------|---------|
| \(\frac{y_0\varphi_0}{v_0}\)_{DP} | 3.8     | 1.5     | 0.7     |
| \(\frac{y_0\varphi_0}{v_0}\)_{FM} | 3.7     | 1.2     | 0.4     |

3. Conclusion
Comparing the table 1 data and graphs presented on Figures 1 and 2, we can assume that the maximum effect of tow ship oscillation on system movement is supposed to be at towing speeds 0.5 m/s – 1.0 m/s.

It should be noted that there is an increase of constant component of depth controller and photomodule drag by 2.7 times at towing speed 0.5 m/s and by 1.4 times at towing speed 1.0 m/s as compared to calculated values. This leads to the decrease of running depth of towed vehicles.
Change of running depth can be estimated by integrating the equilibrium equation with the changed initial conditions.

Horizontal swinging of the towed vehicle with a frequency multiple to a double frequency of tow ship stern will also take place.

References

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