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DETERMINATION OF THE PIVOT POINT POSITION AND ITS USE FOR MANEUVERING THE VESSEL

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ВИЗНАЧЕННЯ ПОЛОЖЕННЯ ПОЛЮСУ ПОВОРОТА ТА ЙОГО ВИКОРИСТАННЯ ДЛЯ МАНЕВРУВАННЯ СУДНА

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ОПРЕДЕЛЕНИЕ ПОЛОЖЕНИЯ ПОЛЮСА ПОВОРОТА И ЕГО ИСПОЛЬЗОВАНИЕ ДЛЯ МАНЕВРИРОВАНИЯ СУДНА

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In recent years, the number, size and speed of ships has increased significantly, and with them the amount of information that the skipper must process in real time has increased too. Especially difficult conditions are observed in ports, narrowness and channels. Port sizes increase much more slowly than ship sizes, which also creates difficult conditions for piloting vessels. Therefore, in ports, channels, and narrowness, more precise maneuvering controls are required. So, skippers previously suggested that, in the presence of yaw, the ship rotates around the center of gravity. However, in practice it has been observed that in the presence of longitudinal speed the vessel does not rotate around the center of gravity, but around another point.

For a large ratio of port sizes to ship sizes, accurate knowledge of the position of the ship's rotation center in the yaw channel was not so important, however, as this ratio decreased, knowledge of the position of the rotation center became crucial.

To date, extensive practical experience has been accumulated on this issue, requiring explanation. Studying this experience, experts came to the conclusion that the rotation centre of the vessel is determined not only by its mass-inertial characteristics, as in the case of objects operating in the air or airless environment (aircraft or spacecraft), but also by hydrodynamic forces and moments which lead to a displacement of the rotation centre relative to the centre of gravity towards the resulting lateral hydrodynamic resistance. With increasing forward speed, the rotation centre of the vessel moves forward along the diametrical plane and at a maximum forward speed is located at a distance 1/4 of the length of the vessel from the stem. With increasing reverse speed, the rotation centre of the vessel shifts along the diametrical plane to the stern and at the maximum reverse speed is located at a distance 1/3 of the length of the vessel from the stern.

Deflection of the stern rudder causes the simultaneous appearance of both lateral force and control torque, which lead to the simultaneous occurrence of lateral speed and angular rate of the vessel around the rotation centre. A similar situation also occurs with the use of active controls (sails, thrusters, azimuth controlled devices, separate rotary nozzles, etc.). In addition, due to the presence of external influences from wind and currents, as well as waves, the vessel is always subject to the action of lateral forces and moments, which cause lateral speed and angular rate.

It is noted that the complex motion of the vessel, consisting of lateral motion and rotational motion, can be replaced with one rotational motion around a point called the pivot point. A lot of works [1–14] have been devoted to determining the position of the pivot point, as well as their accounting in the handling of the vessel.

In works [3–7, 14] the pivot point was identified with the rotation centre and the rotation centre was calculated as the point of application of the resultant lateral resistance forces.

In article [8–13] the pivot point was considered as a nominal point, the position of which is determined by the lateral speed of the vessel's diametrical plane and the angular rate of the vessel in the yaw channel relative to the centre of gravity.

In accordance with the above review, both the first and second approaches to determining the position of the pivot point are not entirely correct.

The authors of this article consider that the pivot point is indeed a conditional point, but its position must be determined not relative to the centre of vessel gravity, but relative to the rotation centre of the vessel. It was shown also, that the rotation centre of the vessel is located between the centre of gravity of the vessel and the point of application of the resultant lateral resistance forces so that the torque relative to this centre of rotation has the greatest efficiency.

In addition, in all the considered works, it was not shown how to quantitatively form the vessel control for the implementation of movement taking into account the pivot point position. The article proposes a method and algorithms for determining the motion control of a vessel taking into account the pivot point position, including the optimal ones.

Pivot point. The pivot point is a conditional point in the central line of the vessel at which the drift angle (or total lateral speed) is zero. The total lateral speed of any point on the diametrical plane located at a distance R from the center of rotation is determined by the lateral speed of the center of rotation V_y and the tangential speed $\omega_z R$ from the rotation of this point around the center of rotation. For pivot point position the sum of these speeds is zero $V_y + \omega_z R = 0$ and position R of the pivot point can be determined as follows

$$R = -\frac{V_y}{\omega_z}. \tag{1}$$

The pivot point is a consequence of the rotational motion of the vessel relative to another point - the center of rotation and the necessary condition for the existence of the pivot point is rotational motion relative to the center of rotation. A sufficient condition for the existence of a pivot point is lateral movement. Thus, the pivot point and the rotation centre of the vessel are two different points. They can only coincide when $V_y = 0$. From formula (1) it follows that the pivot point position R varies in the range $-\infty \le R \le +\infty$, it is very mobile and can move from $+\infty$ to $-\infty$ and vice versa in a short time, when the angular rate of the vessel fluctuates around zero.

Center of rotation. The article [14] shows that starting point of the centre of lateral resistance is a point between the centre of vessel gravity and the centre of underwater surface area, when these two do not coincide. Authors of this article suggest, that center of rotation is located between the gravity center and the point of application of the resulting force of lateral resistance forces. This is because the rotation center is always located at a point relative to which the arbitrary torque has the greatest efficiency. Based on this assumption, taking into account the boundary conditions, the authors obtained an expression that determines the position of the center of vessel rotation depending on its speed.

$$\Delta x = \frac{L}{2}\left(1 - \frac{V_{\max}}{V + V_{\max}}\right). \tag{2}$$

Unlike the pivot point, the displacement of the rotation center relative to the center of gravity occurs slowly, within the hull of the vessel, depends on the longitudinal speed and is determined by the formula (2). Limit displacement of the rotation center relative to the gravity center with unlimited increase in speed is $\Delta x = \frac{L}{2}$. Thus, as follows from the above, the pivot point, the rotation centre and the gravity centre of the vessel are three different points which generally do not match each other.

Turning control. As mentioned above, two ship movements – lateral and rotational – are equivalent to one rotational around the pivot point. In the above review of articles, the authors determined the position of the pivot point. In practice, the solution of the inverse problem is required – the definition of controls that implement a turn around a given pivot point. Examples of such tasks are presented in Fig. 1.

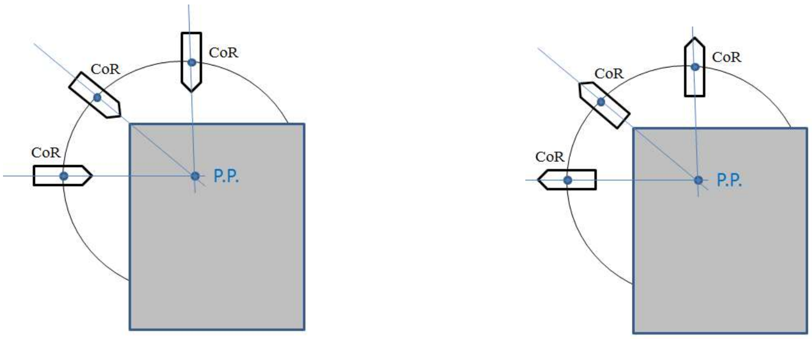


Fig. 1 – Turn around a given pivot point

The system of linear differential equations of lateral and angular motion of the vessel with controls δ_1, δ_2 is

$$m\frac{dV_y}{dt} = \frac{dF_y}{d\delta_1}\delta_1 + \frac{dF_y}{d\delta_2}\delta_2 - \frac{dF_y}{dV_y}V_y,$$

$$I_z\frac{d\omega_z}{dt} = -\frac{dF_y}{d\delta_1}l_1\delta_1 + \frac{dF_y}{d\delta_2}l_2\delta_2 - \frac{dM_z}{d\omega_z}\omega_z, \tag{3}$$

Using the system of equations (3), there were constructed the domains of admissible controls presented in Fig. 2.

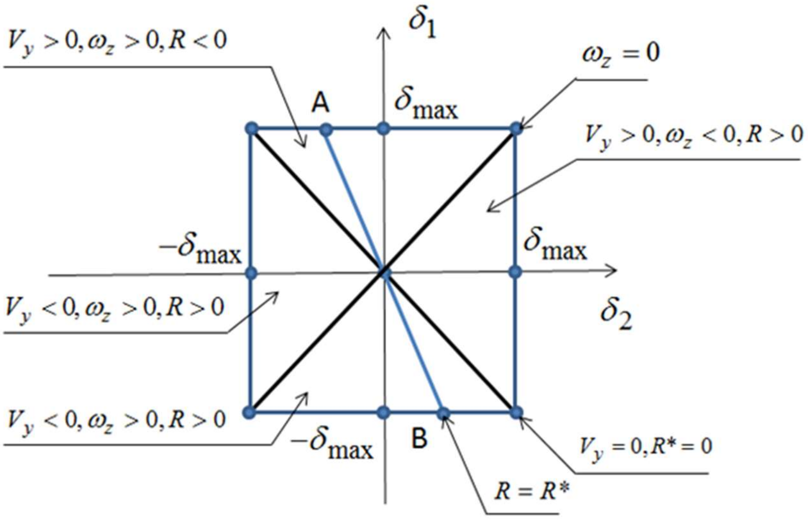


Fig. 2 – Domains of admissible controls

Fig. 3 shows the dependence of the control distribution coefficient k_{ru} on the position of the pivot point for the vessel OSV3. Hydrodynamic coefficients $\frac{dF_y}{dV_y}$, $\frac{dM_z}{d\omega_z}$ obtained experimentally on a simulator.

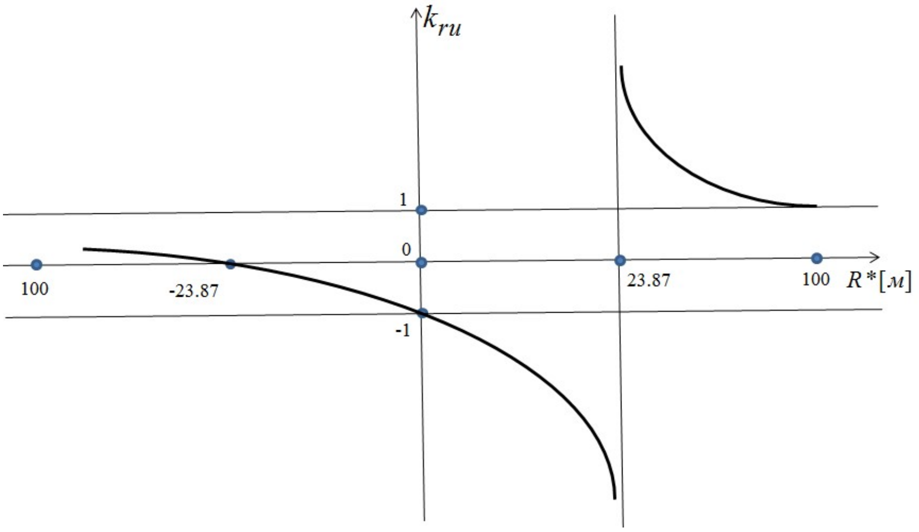


Fig. 3 – Dependence of the coefficient of distribution of controls on the position of the pivot point for OSV3

Optimal controls. As follows from Fig. 2 a turn around a given pivot point $R = R^*$ can be realized by many different sets of controls, which means that among them there is an optimal control according to a given criterion. Choose as a criterion the minimum turn-around time. Then, in accordance with the Pontryagin maximum principle, for the linear control objects to which our object belongs, the optimal controls are realized at the boundary of the control area (p. A and p. B) in Fig. 2.

Experiment

Verification of the results obtained on the simulator Navi Trainer 5000. The point for which a maneuver was calculated is located at the extremity of one of the breakwaters in the Bosphorus Strait (Fig. 4).

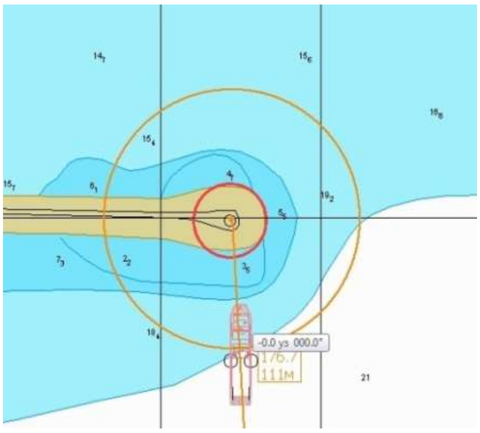
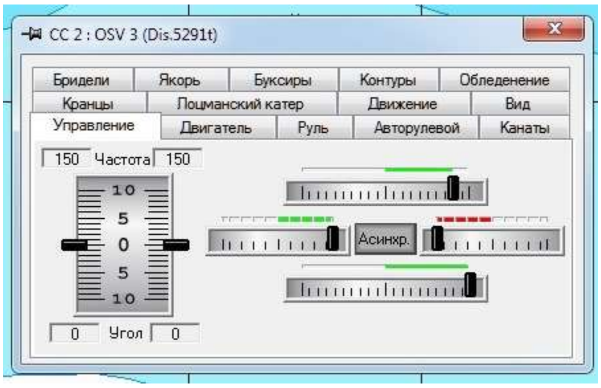


Fig. 4 – Pivot point at the tip of one of the breakwaters in the Bosphorus

There were calculated the positions of the thrusters for a speed-optimal turn around a given pivot point and the thrusters were set to a pre-calculated position (Fig. 5).



150 Частота 150

0 Угол 0

Fig. 5 – The pre-calculated position of the thrusters

Fig. 6 shows the ship's movement trends around the pivot point according to the pre-calculated positions of the thrusters.

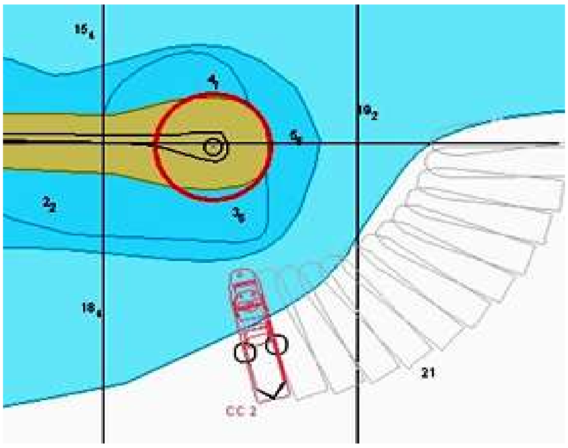


Fig. 6 – Ship's movement trends around the pivot point

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