UDK 656.61.052:681.51

EXPERIMENTAL DETERMINATION OF THE VESSEL'S ROTATION CENTER DISPLACEMENT

S. Zinchenko, O. Tovstokoryi, A. Ben, Ya. Nahrybelnyi, P. Nosov
Kherson State Maritime Academy

Abstract. *The purpose of the work is to experimentally determine the displacement of the rotation center relative to the center of gravity/middle frame at the maximum speed of the ship's circulation. This aim is achieved by comparing the position of the pivot point on a stationary vessel, determined theoretically, and the position of the pivot point on a vessel circulating at maximum speed, determined during an experiment on a navigation simulator. Since the position of the pivot point is calculated from the center of rotation and depends on the arm of the applied lateral force (the distance between the steering wheel and the center of gravity / middle frame), which is assumed to be the same in both cases, the detected difference will be the displacement of the center of rotation.*
Keywords: *rotation center displacement, pivot point position, vessel circulation, maneuvering in compressed waters.*

ЕКСПЕРИМЕНТАЛЬНЕ ВИЗНАЧЕННЯ ЗМІЩЕННЯ ЦЕНТРУ ОБЕРТАННЯ СУДНА

С. Зінченко, О. Товстокорий, А. Бень, Я. Нагрибельний, П. Носов
Херсонська державна морська академія

Анотація. *Метою роботи є експериментальне визначення зміщення центру обертання відносно центру тяжіння / мідель шпангоуту на максимальній швидкості судна. Поставлена мета досягається шляхом порівняння положення полюсу повороту на нерухомому судні, визначеного теоретично, і положенням полюсу повороту на судні, що рухається з максимальною швидкістю, визначеного під час експерименту на навігаційному тренажері. Оскільки положення полюсу повороту відраховується від центру обертання і залежить від плеча прикладеної бокової сили (відстані між кермом і центром ваги / мідель шпангоутом), яка прийнята однаковою в обох випадках, виявленою різницею буде зміщення центру обертання.*
Ключові слова: *зміщення центру обертання, положення полюсу повороту, циркуляція судна, маневрування у стиснених водах.*

The center of rotation and the pivot point are two special points that are important when maneuvering a ship. Relative to the rotation center, the ship has the smallest inertia moment and therefore rotates around it. In the presence of lateral speed, the ship moves with lag and rotates around the rotation center at the same time. This complex movement can be replaced by a "pure" rotation around another point – the pivot point. The pivot point is calculated from the rotation center, which, in turn, can shift relative to the center of gravity / midframe, depending on the speed of the vessel. Knowing the position of the rotation center and the pivot point will allow to reduce the maneuvering area of the vessel, which is especially important when maneuvering in compressed waters. Therefore, the research to which this article is devoted solves an actual scientific and technical problem. Many authors' works are devoted to the study of the position of the rotation center and the pivot point. So, in the book [1] the authors obtained analytical dependences of the pivot point position, as an imaginary point of vessel rotation, on the arm of the lateral force application and constructed graphs. In the obtained results, the arm of the lateral force application and the corresponding position of the pivot point were calculated from the middle frame, and not from the rotation center. In the work [2], the author gives interesting considerations regarding the rotation center, which should be located between the gravity center and the lateral hydrodynamic resistance , and shifts in the direction of vessel’s movement. The author notes that the maximum displacement of the lateral hydrodynamic resistance center is up to 10 % of the vessel's length. Fundamental studies on ship management are given in the book [3], in particular, in section 7.2.4. “Pivot Point” shows the state of the imagery about the pivot point and its use in steering a ship. In articles [4, 5], the author lists the main propositions of the traditional pivot point theory and cites the works of the authors, starting from 2008, in which these propositions are denied. The author notes that, according to the mentioned scientists, the center of the ship's physical rotation is the center of lateral hydrodynamic resistance, which can shift in the direction of the ship's movement. In the article [6] the author notes that understanding the basics of the pivot point behavior is extremely important for a correct understanding of the ship's behavior. Knowing the pivot point position in a maneuvering situation provides the vessel operator with information about the geometry of the movement. To determine the pivot point position, the author conducted a full-scale experiment on a Panamax vessel with a right-handed propeller and a fixed pitch. The experiment showed that the pivot point position was at a distance of approximately 17 % of the ship's length from the bow. In the article [7] the author notes that the pivot point is used to describe the maneuverability and controllability of the vessel. This is not the real center of rotation, but the apparent one. The position of the pivot point is used by vessel operators as an auxiliary tool for determining the external forces acting on the vessel. Also, the position of the pivot point can be estimated by the size of the maneuvering area. For a ship moving forward, the pivot point is also shifted forward and at maximum speed is shifted 25 % of the ship's length. For a vessel moving astern, the pivot point is shifted aft and at maximum astern speed is shifted 25 % of the vessel's length.

According to the authors of this study, the most effective is the automatic determination of the pivot point position, center of rotation and the use of this information for the automatic formation of ship controls, which will significantly increase the accuracy of ship control, reduce delays in operator decision-making, reduce the influence of the human factor on control processes, reduce the maneuvering area. In the authors' works [8–22], the authors' developments for solving automatic control problems are given.

Determining the pivot point position on a stationary vessel. It is known that the pivot point abscissa is determined by the formula:

$$X_{nn} = -\frac{V_y}{\omega_z}. \quad (1)$$

To determine the lateral speed V_y and angular rate ω_z of the vessel, we write down the linearized system of lateral and angular motion of the vessel, to which a lateral force F_y is applied at a distance X_p from the rotation center

$$\begin{cases} (m+\lambda_{22})\dot{V}_y = F_y - \dfrac{\partial R_y}{\partial V_y} V_y, \\ (I_z+\lambda_{66})\dot{\omega}_z = F_y X_p - \dfrac{\partial M_z}{\partial \omega_z}\omega_z \end{cases}. \tag{2}$$

For steady motion $\left(\dot{V}_y = 0, \dot{\omega}_z = 0\right)$, from system (2) we find:

$$V_y = \frac{F_y}{\left(\dfrac{\partial R_y}{\partial V_y}\right)}, \quad \omega_z = \frac{F_y X_p}{\left(\dfrac{\partial M_z}{\partial \omega_z}\right)}. \tag{3}$$

After substituting the constant values of lateral and angular velocity from equations (3) into equation (1), we obtain the formula for determining the pivot point position relative to the gravity center when applying a lateral force F_y at a distance X_p from the center of rotation

$$X_{nn} = -\frac{\left(\dfrac{\partial M_z}{\partial \omega_z}\right)}{\left(\dfrac{\partial R_y}{\partial V_y}\right)}\frac{1}{X_p}. \tag{4}$$

In relative values, equation (4) will have the form

$$\bar{X}_{nn} = -\frac{1}{L^2}\frac{\left(\dfrac{\partial M_z}{\partial \omega_z}\right)}{\left(\dfrac{\partial R_y}{\partial V_y}\right)}\frac{1}{\bar{X}_p}. \tag{5}$$

From formula (5), we find the relative position of the pivot point $\bar{X}_{PP} = 0{,}232$ for the relative arm $\bar{X}_p = 0{,}5$ of the lateral force application. To determine the position of the pivot point on a moving vessel, experiments were carried out on the Navi Trainer 5000 navigation simulator for vessels OSV3-AH and Ro-Ro passenger ferry 13.

Ship model OSV3-AH. Both engines are telegraphed in the “Full Forward” position. Both rudders are placed on the starboard side. The speed of the ship at the beginning of the experiment is $V_x(0) = 15{,}51$kn. For a stable circulation, readings are taken from the CONNING display: vessel speed is $V_x = 9{,}49$ kn., tangential bow speed is $V_n = 1{,}32$ kn., tangential stern speed is $V_s = -8{,}9$ kn. The relative value of the abscissa of the rotation pole can be found using the formula

$$\overline{X}_{PP} = \frac{-V_n}{V_s - V_n}(\overline{X}_B - \overline{X}_A) + \overline{X}_A, \qquad (6)$$

$$\overline{X}_{PP} = \frac{-1{,}32}{-8{,}9 - 1{,}32}(-\frac{1}{2} - \frac{1}{2}) + \frac{1}{2} = 0{,}37.$$

Ro-Ro passenger ferry model 13. Telegraphs of both engines in the "Full Ahead" position. Both rudders are placed on the starboard side. Vessel speed at the beginning of the experiment is $V_x(0) = 20{,}18$ kn. For steady circulation, readings are taken from the CONNING display: vessel speed is $V_x = 9{,}41$ kn., tangential speed of the bow is $V_n = 0{,}97$ kn., tangential speed of the stern is $V_s = -8{,}63$ kn. The relative value of the pivot point abscissa according to formula (6) is equal to

$$\overline{X}_{PP} = \frac{-0{,}97}{-8{,}63 - 0{,}97}(-\frac{1}{2} - \frac{1}{2}) + \frac{1}{2} = 0{,}399.$$

It can be seen from the obtained results that the average relative value of the pivot point position is $\overline{X}_{PP} \approx 0{,}385$. The difference between the relative position of the pivot point determined on a stationary vessel and the relative position of the pivot point determined on a circulating vessel at maximum speed is $\Delta\overline{X} = 0{,}385 - 0{,}232 = 0{,}153$.

Conclusion. The results of the conducted experiments and performed calculations show that the position of the pivot point, calculated for a stationary vessel, differs from the position of the pivot point of a vessel circulating at maximum speed by an amount of $\Delta\overline{X} = 0{,}153$. According to the authors, the detected difference is explained by the displacement of the ship's rotation center relative to the gravity/middle frame center in the presence of longitudinal speed.

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Zinchenko Serhii *Doctor of Technical Sciences, Associate Professor, Professor of the Ship Handling Department, Kherson State Maritime Academy. srz56@ukr.net; ORCID: 0000-0001-5012-5029.*

Tovstokoryi Oleh *Candidate of Technical Sciences, Head of the Ship Handling Department, Kherson State Maritime Academy. otovstokory@gmail.com; ORCID: 0000-0003-3048-0028.*

Ben Andrii *Candidate of Technical Sciences, Professor, Vice-Rector for Research, Kherson State Maritime Academy. a_ben@i.ua; ORCID: 0000-0002-9029-3489.*

Nahrybelnyi Yaroslav *Doctor of Pedagogical Sciences, Professor, Dean of Navigation Faculty, Kherson State Maritime Academy. yar1507@ukr.net; ORCID: 0000-0003-3266-5798.*

Nosov Pavlo *Candidate of Technical Sciences, Associate Professor, Head of Innovative Technologies and Technical Devices of Navigation Department. pason@ukr.net; ORCID: 0000-0002-5067-9766.*

UDK 656.61.052:621.43

SHIP HANDLING AS AN INFLUENTIAL FACTOR IN PROCESSES WITHIN FUNCTIONAL SHIP TECHNICAL SYSTEMS

P. Nosov, S. Zinchenko, A. Ben, I. Gritsuk
Kherson State Maritime Academy

Abstract. *The thesis examines the impact of ship handling methods on the operation of its technical systems, especially in complex maneuvering conditions. It highlights the human factor in decision-making processes, particularly during complex maneuvers in unpredictable situations, and their influence on ship energy systems, specifically engines. The research emphasizes the need for the development and implementation of automated and intelligent control systems to enhance efficiency and safety in navigation, as well as to reduce the impact of human factors on the risks of accidents.*

Keywords: *ship handling, technical systems of ships, human factor, energy systems, automated control systems, intelligent systems, maritime safety.*

УПРАВЛІННЯ СУДНОМ ЯК ФАКТОР ВПЛИВУ НА ПРОЦЕСИ У ФУНКЦІОНАЛЬНИХ СУДНОВИХ ТЕХНІЧНИХ СИСТЕМАХ

П. Носов, С. Зінченко, А. Бень, І. Грицук
Херсонська державна морська академія

Анотація. *Теза розглядає вплив методів управління судном на роботу його технічних систем, особливо у складних умовах маневрування. Вона акцентує увагу на людському факторі в процесі прийняття рішень, особливо під час виконання складних маневрів у непередбачуваних ситуаціях, та їх вплив на суднові енергетичні системи, зокрема двигуни. Дослідження підкреслює необхідність розробки та впровадження автоматизованих та інтелектуальних систем керування для підвищення ефективності та безпеки мореплавства, а також для зменшення впливу людського фактора на ризики аварійності.*

Ключові слова: *управління судном, технічні системи суден, людський фактор, енергетичні системи, автоматизовані системи керування, інтелектуальні системи, безпека мореплавства.*