Simulation of ship handling in reverse

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Abstract. One of the main problems of seamanship is steering the boat in reverse modes. This skill can be achieved using simulators or simulators that work based on a mathematical model. This model should adequately describe all ship maneuvers, including simulation in reverse modes. The article deals with the mathematical modeling of maneuvering from a ship in reverse. The authors performed model calculations, basic test maneuvers, such as "Circulation", "Exit Circulation" and "Zigzag". The analysis of trajectories testifies to the qualitative correspondence of the calculation results according to the mathematical model to the practice of navigation, and this model can be used for automatic control of the vessel, for assessing the movement of the vessel in reverse, and teaching navigation skills on simulators and simulators. The vessel when moving in reverse, at low speeds obeys the steering organ, but at speeds greater than the average stroke on the backward shift, it leaves the circulation very slowly and sometimes becomes uncontrollable. The withdrawal of a reverse circulation vessel is extremely difficult and requires additional skills and abilities from the navigator.

1. Introduction
During operation, navigators must perform various maneuvers, including steering the vessel when reversing, for example, when maneuvering in the roadstead, in the port. The practice of navigation shows that the ship's controllability in reverse imposes additional requirements on the boatmaster due to the extremely low reaction of the ship to the steering organ. In conditions of limited dimensions of the fairway, it is important to have information about the behavior of the vessel when the vessel is operating in reverse. To ensure the safety of navigation, it is important to be able to determine the trajectory of the vessel's movement, including in reverse conditions. This is possible when using a mathematical model of the movement of the vessel in predicting the behavior of the vessel and in the automatic control of the vessel.

2. Reverse vessel control
When reversing from a "stop" when shifting the steering element, the vessel turns easily, but in the case of reverse shifting of the rudder it becomes practically uncontrollable, and in some cases practically falls into circulation. This effect arises since the rudders are not in the jet of the propeller, which sharply reduces the efficiency of the steering complex. This applies to ships equipped with exposed propellers. In addition, the jet generated by the propeller, when reversing, is directed towards the body, creating a lateral force. This effect is called "throwing a jet onto the sink". The
hydrodynamic moment on the hull and the moment on the steering element are directed in different directions, which reduces the turnability of the vessel. The total moment acting on the ship's hull becomes less than when moving "forward". The angles of attack of the rudders, when reversing, at which the flow stall occurs, become smaller, which reduces the lateral force. Vessels equipped with swivel attachments, when reversing, generally retain satisfactory controllability.

The distribution of the forces acting on the vessel during all periods of circulation in the forward and reverse gear is practically the same. But during the “zigzag” maneuver during the reverse shift, the vessel equipped with open rudders loses controllability due to the lower efficiency of the steering element.

Figure 1. Trajectory of movement of a dry cargo ship at full reverse

Based on the above, the deterioration of controllability in reverse should be considered in the complex of ensuring the safety of the vessel's movement and when used in training in the skills of controlling the vessel in reverse [3-5]. This can be achieved using simulators and simulators that work because of a mathematical model of the ship's movement. Let us consider several maneuvers calculated according to the mathematical model presented in [2]. Figure 1 shows the circulation of a dry-cargo vessel at full reverse speed with various rudder shifts. It can be seen from the figure that the vessel easily enters the circulation, despite the ratio of the hydrodynamic and steering moments directed in different directions, which is typical for the unsteady period of circulation when reversing.

Figure 2 shows the result of calculating the maneuver of the vessel entering the circulation and exiting it to the reverse running mode.

Figure 2. Circulation and exit from circulation, when shifting the steering body 35x35 during the reverse
The figure shows that the vessel, when moving in a rectilinear manner in reverse, when shifting the steering element, is relatively easy to turn towards the shifting. This happens because the pivot point is forward of the center of gravity.

When performing the out-of-circulation maneuver in reverse. The results of the study (Figure 2) showed that on a steady reverse circulation, the center of rotation moves to the aft perpendicular of the vessel, which reduces the shoulder of the lateral force arising on the DRC. Thus, it is obvious that it is very difficult to get the vessel out of circulation when reversing, and sometimes it is impossible to do this without changing the speed or reverse of the main engines.

One of the characteristics of the ship's handling is the steering diagram, which depicts the dependence of curvature, drift angle and ship speed of steady circulation as a function of rudder shift. Figure 3 shows a diagram of the handling of a dry cargo vessel when the vessel is moving in reverse. It can be seen from the figure that the vessel is theoretically unstable on the heading, which is typical for almost all vessels.

![Diagram of ship handling in reverse](image)

**Figure 3**. Diagram of ship handling in reverse. 1- \( \nu \); 2- \( \beta \); 3 - \( \omega \)

According to the above calculations, the vessel is in reverse, the vessel is more agile and less stable on the course than in the forward course, which is confirmed by the practice of navigation.

The reaction of the vessel to the shifting of the DRC can be demonstrated using a zigzag maneuver. Such maneuvers are performed with various steering gear shifts. For example, a ship moving at full speed shifts the rudders by 350 and makes a turn until the heading angle becomes equal to 350. The DRC is shifted to the same angle of the opposite side. The boat is circling until the heading angle is -350. The process is repeated 3-4 times. "Zigzag" is also performed from the ship's rest position (from the stop). Figure 4-6 shows the trajectories of a dry cargo vessel when performing Zigzag maneuvers.
The analysis of the vessel's behavior indicates a poor-quality reaction of the vessel in reverse as compared to forward. This is confirmed by the assessment of navigators about the practical
uncontrollability of vessels in reverse and explains the physics of this phenomenon. An accidentally buried vessel quickly enters circulation but leaves for a very long time and during this time passes 6-7 lengths of the ship's hull. A characteristic in this respect is the maneuver reproduced in Fig. 6 at \( t = 350 \). When reversing from a stop, the vessel at low speed obeys the steering organ, but with an increase in speed, the vessel performing the “zigzag” maneuver still obeys the first backward shift but later becomes uncontrollable.

3. Conclusion

The analysis of trajectories testifies to the qualitative correspondence of the calculation results according to the mathematical model to the practice of navigation and can be used in the automatic control of the vessel, training of navigators on simulators, and for the quantitative and qualitative assessment of the movement of the vessel in reverse.

References

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