APPLICATION OF THE PHASE POINT MOVEMENT METHOD IN THE PROBLEM OF VESSEL STORMY SAILING

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Introduction. Navigating a ship during a storm presents one of the most challenging and hazardous situations for maritime operations. The combination of high winds, large waves, and unpredictable sea conditions can expose vessels to a variety of dangers, including capsizing, loss of stability, and structural damage.

Phenomena such as harmonic and parametric resonance, loss of stability in following seas, broaching, and wave impact on the ship's stern can further complicate navigation and increase the risks of ship's capsizing. Inadequate control during these conditions may result in severe accidents or even the loss of the vessel.

In stormy weather conditions, the ship's navigator must carefully select the vessel's speed and course to ensure safe navigation and minimize the risks of dangerous phenomena.

Also very important of optimization of way to change parameters from dangerous zone to safe zone. This study will describe the method of optimally movement the phase point to a safe storming area.

Research relevance. This research is relevant due to the increasing challenges faced in maritime navigation under severe weather conditions. The global economy depends on the safety of international maritime navigation [1-3]. As global shipping traffic intensifies [4-6] and extreme weather events become more frequent, ensuring the safety and efficiency of vessels during storms is paramount [7-9]. The Phase Point Movement Method provides a novel approach to optimizing vessel control by dynamically adjusting navigation parameters to avoid hazardous conditions.

Problem statement. The Phase Point Movement Method presents a promising approach for optimizing vessel control by dynamically adjusting navigation parameters based on real-time conditions. However, its application in stormy sailing scenarios remains underexplored. There is a need to assess how this method can be implemented to enhance the safety and performance of vessels during adverse weather conditions.

Research results. After calculating the safe speed and course, the ship's navigator adjusts the telegraph and the helm to new positions to change the current navigation parameters to safe ones [10]. During this process, the trajectory of the phase point movement from its current position $A\{e_1 \cos q_1, e_1 \sin q_1\}$ to the final position $D\{\mathbf{e}_2 \cos q_2, \mathbf{e}_2 \sin q_2\}$ is not controlled and may takes a considerable time.

Fig. 1 shows the experiment where the trajectory of movement of the phase point AD from the dangerous zone of harmonic resonance takes 90 seconds and the possible shortest way, which may be significantly shorter (red color).

To determine the shortest way, it is necessary to solve the optimization problem of moving the phase point out of the resonance zone with a fixed left end and a free right end. The optimization of the trajectory is achieved by correctly selecting the control law $f(e(t), q(t))$ for the movement of the phase point.

$$\begin{aligned} &S^*\big(\{e_1 \cos q_1, e_1 \sin q_1\}, \{e_2 \cos q_2, e_2 \sin q_2\}\big) = \\ &= \min_{f(e(t), q(t))} S\big(\{e_1 \cos q_1, e_1 \sin q_1\}, \{e \cos q, e \sin q\}\big), \end{aligned} \tag{1}$$

where S - trajectory of movement of the phase point, e_1, q_1 – parameters of ship movement in resonance area, e_2, q_2 – parameters of ship movement in safe area.

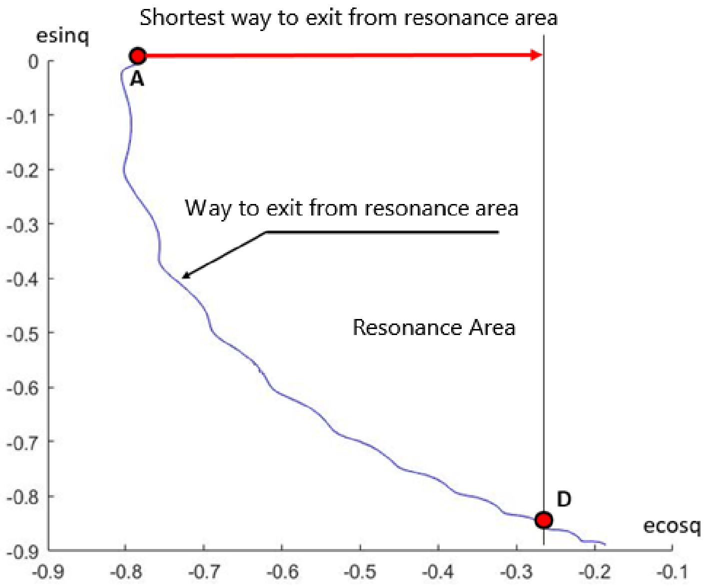

Figure 1 - The actual and shortest way to exit from resonance zone

As shown in Fig. 2, in case of performing a combined maneuver (Course and Speed), the phase transition 1-3 is the shortest in distance but not the shortest in terms of the time the phase point stays in the harmonic resonance zone. The transition 1-2-3 to the safe zone $\overline{\Omega}_{sa}$ is longer in distance, but the time spent in the harmonic resonance zone is three times shorter. Obviously, the transition 1-2-3 will be optimal from a safety perspective, as it ensures the shortest time for the phase point to remain in the dangerous zone. The transition 1-2 proceeds along a horizontal line.

$$e(t)\sin q(t) = const = e_1 \sin q_1, \tag{2}$$

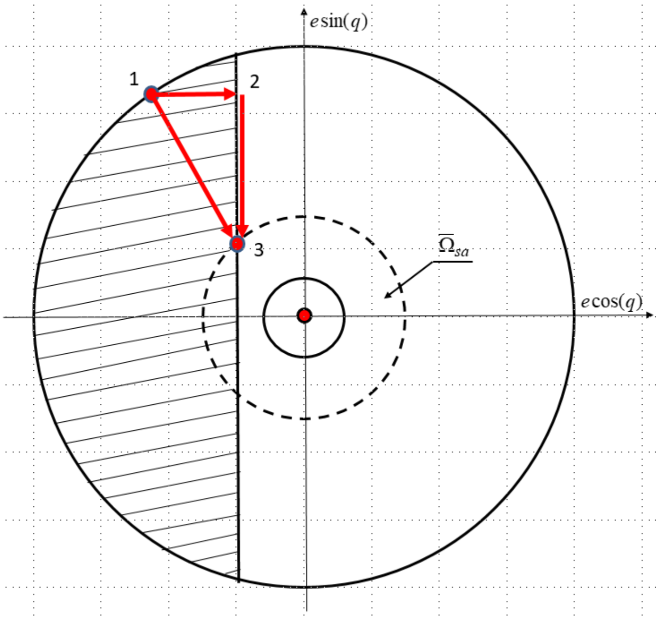

Figure 2 - Possible phase transitions to the safe zone

The process of moving the phase point out of the dangerous area was simulated in the MATLAB environment. As seen from Fig. 3, the phase point, disregarding resonant oscillations, moves parallel to the ecosq axis and crosses the boundary of the resonance zone ecosq = -0.2 along the shortest path. It is also evident from Fig. 3 that as the phase point approaches the boundary of the resonance zone ecosq = -0.2, the amplitude of the resonant oscillations diminishes.

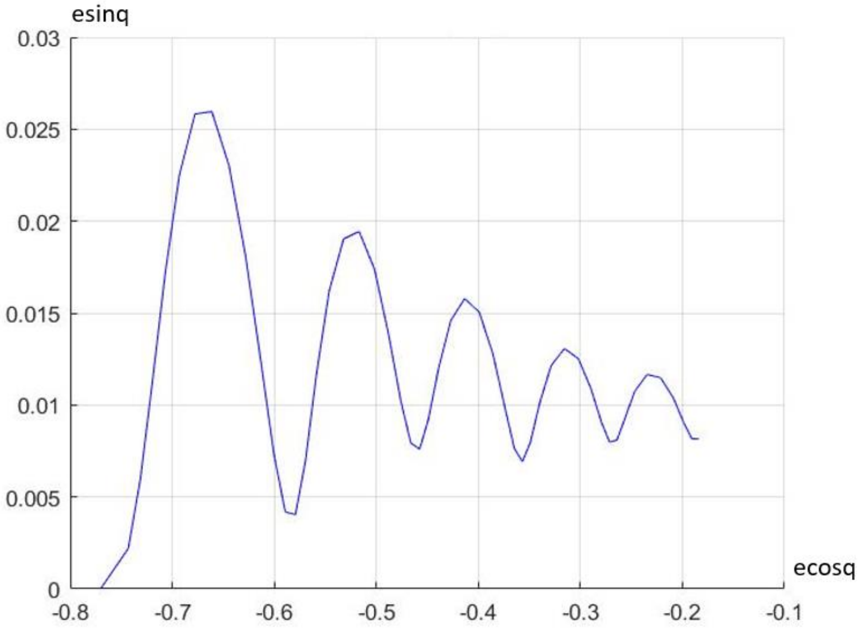

Figure 3 - Simulation results in the MATLAB environment

Conclusions. A method for optimally moving the phase point to a safe area has been presented. This method involves coordinated changes in the vessel's course and speed. Unlike existing solutions, it allows for better control of the phase point's movement into a safe area, reducing the time the phase point spends in the dangerous zone. This minimizes the risks of phenomena that could lead to vessel capsizing, automates the storming processes, reduces the impact of human factors on storming procedures, and enhances the safety of stormy navigation.

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