# Automatic vessel control in stormy conditions

Vadym Mateichuk, Serhii Zinchenko, Oleh Tovstokoryi, Pavlo Nosov and Yaroslav Nahrybelnyi
Navigation faculty
Kherson State Maritime Academy
Kherson, Ukraine

Ihor Popovych
Department of Psychology,
Kherson State University
Kherson, Ukraine

Vitaliy Kobets
Chair of Informatics, Software Engineering and Economic Cybernetics
Kherson State University
Kherson, Ukraine

*Abstract* — **Vessel control in a storm is the most difficult stage in the vessel voyage, as it requires quick decisions to be made in difficult conditions. Practical experience shows that the deterioration of the working conditions of the crew is usually associated with increase in the number of control mistakes [1]. The article examines the possibility of automatic control of a vessel in a stormy conditions by automatic calculation in the on-board controller of the vessel optimal safe speed and course during a storm. This allowed to significantly increase the accuracy of calculations, to exclude the human factor, to reduce the depletion of the crew, to increase the reliability of the vessel control in a storm. The efficiency and effectiveness of the method, algorithmic and software were tested on Imitation Modeling Stand in a closed loop with mathematical vessel models of the navigation simulator Navi Trainer 5000.**

*Keywords* — **Automatic control; Closed loop systems; Control system synthesis; Motion control; Steering systems.**

## I. INTRODUCTION

In ancient times and the Middle Ages, vessel control in a storm was performed in such a way as to coordinate their actions with the actions of the element and not to contradict it. With the advent of the sail, active vessel control methods emerged.

The seaworthiness of modern ships, their speed and size have changed a lot. The range of their possible applications has also expanded. For example, in articles [2–9], recommendations for control a modern ship in a storm are considered.

To facilitate the task of a vessel control in storm, a number of scientists have proposed special diagrams for choosing the course and speed in storm conditions.

The most widespread is the universal diagram of the Yu.V. Remez, which allows to determine unfavorable combinations of velocity and course angles of waves (resonant zones) for any vessel and any wavelength $\lambda$ and choose a safe speed and course of the vessel outside the resonance zone.

The use of automatic control systems of the vessel allows to significantly reduce the impact of the human factor and increase the safety of navigation [19–35], especially in difficult sailing conditions.

This paper proposes an automatic storm system, which does not have disadvantages of manual control, namely: the automatic storm system uses specialized equipment to measure the parameters of the wave; measurement of vessel motion parameters and excitation parameters, as well as their processing and formation of controls is automatic and constant, which allows to constantly monitor any changes in vessel motion and wave parameters; software always calculates the correct result and can work in any stormy conditions; moreover, unlike manual storming, the problem can be solved optimally. Therefore, the development of the vessel automatic storm system is an urgent scientific and technical task.

It is required to develop an automatic control system that would ensure safe sailing in stormy conditions without operator intervention [36–48].

## II. RESEARCH RESULTS

Pitching and rolling of the vessel are excited by forced oscillations of waves. Conditional period of waves $\tau(n)$ depends on the wave length $\lambda$, vessel speed $V(n)$ and the course angle of the wave $q(n)$ – the angle between the waves direction and the vessel diametrical plane

$$\tau(n) = \frac{\lambda}{1.25\sqrt{\lambda} + 0.514V(n)\cos q(n)}. \quad (1)$$

Particularly dangerous is the case of resonant oscillation, in which the period of free oscillations of the vessel coincides with the period of forced oscillations or close to it.

$$0{,}7 \le \frac{T_B}{\tau(n)} \le 1{,}3, \quad (2)$$

$$0{,}7 \leq \frac{T_L}{\tau(n)} \leq 1{,}3 \ . \qquad (3)$$

Inequalities (2), (3) determine the resonance zone $\mathbf{\Omega}$ for the rolling and pitching respectively. The task control in the storm is to create such conditions for the movement of the vessel, under which inequalities (2)–(3) are not fulfilled.

To determine the resonance zone $\mathbf{\Omega}$ , from inequalities (2), (3), taking into account (1), we find

$$e(n)\cos q(n) \geq \frac{1}{V \max}(1{,}42\frac{\lambda}{T_B} - 2{,}31\sqrt{\lambda}) , \qquad (4)$$

$$e(n)\cos q(n) \leq \frac{1}{V_{\max}}(2{,}64\frac{\lambda}{T_B} - 2{,}31\sqrt{\lambda}) , \qquad (5)$$

$$e(n)\cos q(n) \geq \frac{1}{V_{\max}}(1{,}42\frac{\lambda}{T_L} - 2{,}31\sqrt{\lambda}) , \qquad (6)$$

$$e(n)\cos q(n) \leq \frac{1}{V_{\max}}(2{,}64\frac{\lambda}{T_L} - 2{,}31\sqrt{\lambda}) . \qquad (7)$$

Fig. 1 shows the range of the vessel reduced speed $\mathbf{e} = \dfrac{\mathbf{V}}{V_{\max}} \leq 1$ , the resonant zone (shaded) and non-resonant zones $\mathbf{\Omega}_1, \mathbf{\Omega}_2$ for wave length $\lambda = 230\,m$ .

Define the control quality function as follows

$$Q = (e(n)\cos q(n) - e(n-1)\cos q(n-1))^2 + $$
$$+ (e(n)\sin q(n) - e(n-1)\sin q(n-1))^2 , \qquad (8)$$

where $e(n) = \dfrac{V(n)}{V_{\max}}$ is the safe reduce speed in a storm

(p.4), $e(n-1) = \dfrac{V(n-1)}{V_{\max}}$ is the actual reduce speed in a storm (p.1), $q(n), q(n-1)$ is the safe wave angle and actual wave angle, respectively.

Thus, the safe speed and course calculation unit determines the optimal pair of parameters $\{e(n), q(n)\}$ by minimizing the control quality function (4), in the presence of constraints (1)–(3) and $e(n)_{\min} \leq e(n) \leq e(n)^{st}_{\max}$. Since the quality function (4) is smooth, to solve this optimization problem with linear and nonlinear constraints, we used the standard gradient optimization procedure fmincon of the MATLAB Optimization Toolbox library
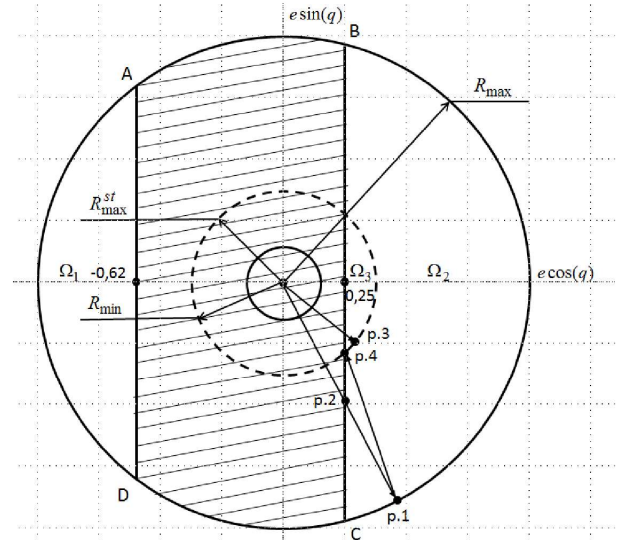
y=fmincon(@myfun,**y0,A,b,Aeq,beq,lb,ub**,@mycon)



Figure. 2. The range of the vessel reduced speed, resonant (shaded) and non-resonant $\mathbf{\Omega}_1, \mathbf{\Omega}_2$ zones

The operability and efficiency of the method, algorithmic and software are tested at the Imitation Modeling Stand [49, 50].

Fig. 2 shows graphs of changes in roll angle, trim angle, speed and course of the vessel with automatic control of the vessel Ro-Ro passenger ferry 13 in a storm. Initial course of the vessel is $K(0) = 75°$, initial speed is $V(0) = 18{,}5\,kn.$ , initial sea disturbance is 2 points. The vessel, moving the course $K(n) = 75°$ , accelerates to speed $V(n) = 19\,kn.$ , after which the simulator is set to sea disturbance 11 points. As can be seen from the graphs, during the storm the speed of the vessel begins to decrease to $V(n) = 7\,kn.$ At the same time, the automatic storm system begins to change course from $K(n-1) = 75°$ to safe b to exit the resonance zone. In Fig. 1 this corresponds to the movement from p. 1 to p. 4.

### III. CONCLUSIONS

The scientific novelty of the obtained results is that for the first time theoretically substantiated design features of the original system of automatic control of the vessel in a storm, which consist in constant, with the onboard controller cycle, automatic measurement of vessel and wave motion parameters, automatic calculation outside resonant zones, taking into account resonant zone boundaries, minimum vessel speed and maximum vessel speed in a storm, automatic selection of safe optimal motion parameters from outside resonant zones according to the specified criterion of optimality, automatic maintenance of safe optimum parameters of movement in a storm, and provide fundamentally new technical characteristics: the ability to automatically control the vessel in a storm, reduce depletion of the vessel's crew when sailing in difficult conditions, increase the accuracy and reliability of the vessel control in a storm, which determine its advantages over known solutions.
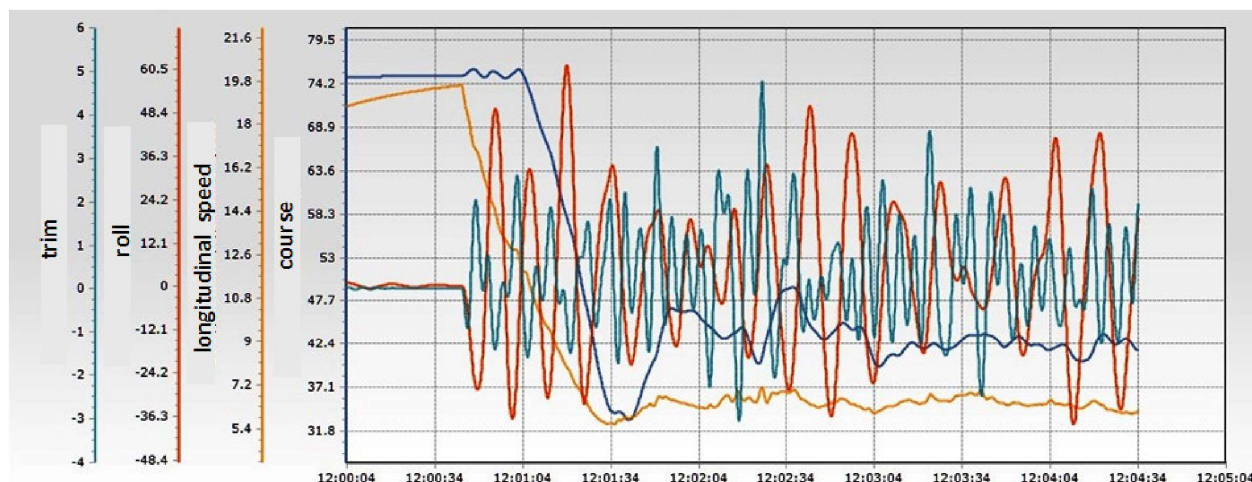
Figure. 2. Automatic control of the vessel Ro-Ro passenger ferry 13 in a storm

The practical value of the obtained results is that the developed method and algorithms are implemented in the software of the vessel automatic storm system and investigated by mathematical modeling on the imitation modeling stand in a closed loop with vessel mathematical models for different types of vessel, sailing areas and meteorological conditions.

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