Розділ 3.

Автоматизація та управління технологічними процесами

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AUTOMATIC CONTROL OF THE VESSEL IN THE CONDITIONS OF AN IMMINENT COLLISION

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The issues of automatic reset of the ship's kinetic energy in the event of its inevitable collision with the target ship were investigated. Molded controls that provide the fastest kinetic energy reset. The workability and effectiveness of the method was verified by mathematical modeling on the simulation bench.

Formulation of the problem. Over the past 10-20 years, the intensity of navigation and the speed of ships have increased significantly, and the flow of information has also increased with them. It is becoming more and more difficult for shipmasters to find the right management decisions, especially in critical situations, which is the reason for the increase in the number of accidents in maritime transport. Accident statistics in the global maritime industry show that 75% of all accidents are caused by the human factor. Therefore, according to experts, a significant reduction in accidents can be achieved only by reducing human intervention in management, namely by creating automated decision support systems, energy systems and automated systems with automatic control modules. Issues of automatic control are discussed in works [1-5].

List of resolved issues: to develop a method of resetting the kinetic energy of a collision along a gradient; to obtain control that ensures the reset of the kinetic energy of the collision along the gradient; to develop the algorithmic and software of the automatic control module of the vessel in case of an imminent collision; conduct mathematical modeling in the closed scheme "Control system - Control object".

The essence of research. The own ship O_1 moves on a course φ_1 with speed V_1, the target ship O_2 moves on a course φ_2 with speed V_2. Vessels move on courses that intersect at a point O and are at a distance where collision cannot be avoided. It is necessary to develop a method, algorithm and software of the module of automatic control of the movement of the ship O_1, which would allow to minimize the kinetic energy of an inevitable collision. The issue of reducing damages in case of inevitable collision of ships was also considered in the previous works of the authors [6, 7].

The components of the vector of the relative speed of the ship and the target in the projections on the axis of the connected coordinate system $O_1X_1Y_1$ can be determined by the formulas

$$\begin{cases} \Delta V_x = V_1 - V_2 \cos\Delta\varphi, \\ \Delta V_y = -V_2 \sin\Delta\varphi \end{cases} \qquad (1)$$

Taking into account system (1), the relative speed of convergence and the difference in rates can be calculated by the formulas

$$\Delta V = \sqrt{(V_1 - V_2 \cos \Delta\varphi)^2 + (-V_2 \sin \Delta\varphi)^2} = \sqrt{V_1^2 - 2V_1V_2 \cos \Delta\varphi + V_2^2} \tag{2}$$

$$\Delta\varphi = \varphi_1 - \varphi_2 \tag{3}$$

Taking into account (2), (3), the kinetic energy of the collision of ships is equal to

$$K = m\frac{\Delta V^2}{2} = \frac{m}{2}(V_1^2 - 2V_1V_2 \cos(\varphi_1 - \varphi_2) + V_2^2) \tag{4}$$

The idea of the method is to organize the fastest reduction of kinetic energy (4) along the gradient in the direction of the minimum value $K = 0$ by calculating the relevant movement parameters V_1, φ_1 and their subsequent implementation by means of the control system.

As can be seen from formula (4), the minimum value of kinetic energy $K = 0$, for the given example, is reached at $V_1 = 5$ and $\Delta\varphi = 0$.

The gradient of function (4) can be written in the form

$$\frac{dK}{dt} = \frac{\partial K}{\partial V_1}\frac{\partial V_1}{\partial t} + \frac{\partial K}{\partial \varphi_1}\frac{\partial \varphi_1}{\partial t} = < \mathbf{grad}K, \frac{d\mathbf{P}}{dt} >, \tag{5}$$

where

$$\begin{cases} \mathbf{grad}K = (\frac{\partial K}{\partial V_1}, \frac{\partial K}{\partial \varphi_1}) = m[V_1 - V_2 \cos(\varphi_1 - \varphi_2), V_1V_2 \sin(\varphi_1 - \varphi_2)], \\ \frac{d\mathbf{P}}{dt} = (\frac{\partial V_1}{\partial t}, \frac{\partial \varphi_1}{\partial t}) \end{cases} \tag{6}$$

The components $\frac{\partial V_1}{\partial t}, \frac{\partial \varphi_1}{\partial t}$ of the second equation of system (6) are determined by the mathematical model of the own ship

$$\begin{cases} \frac{\partial V_x}{\partial t} = f_1(\mathbf{X}, \Theta, \delta), \\ \frac{\partial V_y}{\partial t} = f_2(\mathbf{X}, \Theta, \delta), \\ \frac{\partial \omega_z}{\partial t} = f_3(\mathbf{X}, \Theta, \delta), \\ \frac{\partial \varphi_1}{\partial t} = \omega_z \end{cases} \tag{7}$$

$$\frac{\partial V_1}{\partial t} = \sqrt{(\frac{\partial V_x}{\partial t})^2 + (\frac{\partial V_y}{\partial t})^2} \tag{8}$$

Mathematical modeling. The workability and effectiveness of the developed methods, algorithmic and software were tested on the simulation bench developed by the authors on the basis of the Navi Trainer 5000 navigation simulator.

Conclusions

Based on the results of research, the following conclusions can be drawn:

1. A method of resetting the kinetic energy of a collision along a gradient has been developed. The kinetic energy gradient of the collision was determined as a function of the parameters of the relative motion of the own vessel and the target.
2. The formula for determining the controls that ensure the reset of the kinetic energy of the collision along the gradient is obtained, it is shown that in the general case of existing control restrictions, this problem can be considered as an optimization problem.
3. Algorithmic and software of the module for automatic control of the ship's movement in cases of imminent collision was developed.
4. The workability and efficiency of the method, algorithm and software are verified by mathematical modeling in a closed circuit with the Navi Trainer 5000 navigation simulator.

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