The Technology of Geophysical Vessel Control for the Study of the World Ocean

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Abstract. The article performs the issues of positioning and ensuring the movement of a geophysical vessel along a routing line, applied aspects of marine geophysical technologies according to the technical characteristics of a vessel, allowing to carry out the operation complex on the shelf zone of the World Ocean. The points of balancing modes and stability region of the controlled object without stalling vessel in the circulation of the vertical plane relative to center-line plane are calculated for the realization of the parameters of the vessel motion. We determine a linearized model of a controlled device and a table of the numerical values of the coefficients determined in the vicinity of various balancing modes. In addition, the roots of a characteristic equation for the pair of towed objects directly from an underground garage and a vehicle have been established.

Keywords: geophysical vessel, the towed geophysical complex, marine equipment, stabilization of the vessel motion, marine mobile object, depth controller, submarine, parent vessel, routing line.

1. Introduction

One of the priority directions for the economic development in the third millennium is the further development of the spaces and resources of the World Ocean. In the Russian Federation, the state policy in the field of maritime activities is regulated by the Maritime Doctrine, approved by the President of the Russian Federation on July 27, 2001. Marine activities are defined as the study, development and use of the World Ocean in the interests of security, sustainable economic and social development of our state, ensuring the sovereign rights and jurisdiction of the Russian Federation exercised on its continental shelf for the purpose of exploration, development, conservation and management of natural resources [3].

The most important practical aspect is the equipment of special geological (geophysical) vessels with multipurpose towed complexes, capable in the line of vessels traffic to solve the wide spectrum of research tasks.

The implementation of systems of towed geophysical complexes (TGC) requires combining into a common several specific scientific and technical problems, such as: the problem of stabilizing the movement of the vessel along the routing line; movement of the TGC with the desired quality parameters (a given angle of attack, distance from the bottom, etc.); the required parameters for the safe operation of the TGC.

The organization of such works in the lane of the parent vessel for the study of the shelf, such as leveling the bottom surface, photo-television recording of local objects, taking soil and water samples, determining the radioactivity of water and soil, requires a systematic approach to the study of techniques and
technologies for the use of geophysical equipment placed on a carrier of neutral buoyancy (CNB). CNB together with the depth controller garage (DCG) constitutes the geophysical complex of the outboard equipment.

The tasks, solved by geophysical vessels are wide, and with the most characteristic technological operations, them they most frequently assign on the rescue operations, the lift of the sunken objects, the search for different objects and others. The whole list of tasks solved by these vessels requires special navigation technologies with the use of adapted control interfaces. Frequently this is accompanied by the special states of motion of the vessels, which in majority their correspond to the regimes of slow speed.

The aim of the current study is improvement the applied aspects of marine geophysical technologies in terms of the technical characteristics of the vessel, allowing for the entire range of works on the shelf zone of the World Ocean.

2. Materials and Methods
Taking into account the special features of the operation of geophysical vessels, let us speak about realization in the flow charts of the methods of positioning and guaranteeing the motion along the line of the assigned profile.

A fairly complete model of the vessel movement is given by the authors [1] in the form:

\[
E = 0.5 [V^T \Omega^T] (D + \Lambda) \begin{bmatrix} V \end{bmatrix},
\]

(1)

where \( E \) is the generalized kinetic energy of vessel, \( V^T \) is velocity vector in three planes, \( \Omega^T \) is angular velocity vector, \( D \) is the matrix of the inertia of hull of the ship (in the general case, this ellipsoid of revolution), \( \Lambda \) is the matrix of apparent additional masses.

The parameters of the vessel movement are determined by three components of linear velocities \( V^T = [v_x, v_y, v_z] \) and three components of angular velocities \( \Omega^T = [\omega_x, \omega_y, \omega_z] \). A prerequisite for calculating the kinematic parameters is to determine the position of the vessel center of mass \( [x(t), y(t), z(t)] \), as well as the angles \( \theta(t), \phi(t), \psi(t) \). These parameters are used to calculate the vessel kinematics, taking into account the influence of wind-wave disturbances.

When compiling differential equations, we will use a linked coordinate system. The coordinate system links the vessel center of mass to the axes of longitudinal motion \( x \), lateral motion \( y \), and vertical motion \( z \). When using such a coordinate system, turns, projections of the angular and linear velocities of the ship - towed object system are considered.

The angles are distinguished:
- \( \phi \) is yaw, rotation in the vertical plane and movement in the longitudinal - transverse;
- \( \psi \) is trim difference (pitch), rotation in the transverse and displacement in the vertical – longitudinal planes;
- \( \theta \) is roll, rotation in the longitudinal, movement in the vertical - transverse planes.

All rotations are related quantities, therefore displacements and rotations taken as positive when moving counterclockwise are called Euler angles.

Most applied problems investigate the dynamics of real objects or their prototypes. If there is a need to synthesize a control system for advanced technology, then modeling methods are applied on models using similarity methods for real objects.

3. Results and Discussion
Considering the expansion of the range of tasks to be solved by the use of a towed system - a depth controller garage and an underwater vehicle equipped with a complex of bathymetric equipment, as shown in Figure 1, let us consider a model of the towed system "Vessel - Unmanned Submarine Vehicle" (V-USV).
When using hydroacoustic geophysical research stations, it is necessary to ensure the movement of the carrier vessel along the line of a given profile, while achieving stabilization parameters:
- track angle within ±1°;
- side drift ±1.5°.

Otherwise, the obtained data will be heavily noisy by the yaw of the sonar antennas relative to the line of motion, it is also desirable to maintain a certain angle of attack of the movement of the apparatus, thus providing a "perspective" projection of the survey.

Movement along the line of a given profile is shown in Figure 2.
If we consider the dynamics of the vessel and towed object controlled from the board of the vessel, by changing the length of the towing cable, then the dynamics of the V-USV system will be described by three coordinate systems:

- fixed Cartesian axes $O_g X_g Y_g Z_g$;
- coordinate system describing the fluid flow, including the one attached to the vessel hull $O'_g X'_g Y'_g Z'_g$.

The system of equations describing the dynamics of motion of the V-USV system [2]:

$$
\begin{align*}
& \left\{ \begin{array}{l}
(1 + k_{11}) \dot{v} \cos \beta - m(1 + k_{11}) \dot{v} \sin \beta + m(1 + k_{22}) \dot{v} \omega \sin \beta = T_E - X_K - X_p - T_X, \\
-m(1 + k_{22}) \dot{v} \sin \beta - m(1 + k_{22}) \dot{v} \beta \sin \beta + m(1 + k_{11}) \dot{v} \omega \sin \beta = Y_K + Y_p - Y_A + T_Y, \\
J_2 (1 + k_{66}) \dot{v} - m(k_{22} - k_{11}) \dot{v} \sin \beta \cos \beta = M_K + M_p - M_B - M_T - M_A. \\
\end{array} \right.
\end{align*}
$$

where:

$(X_g, Y_g)$ is coordinates of the vessel center of gravity in a fixed coordinate system; $\dot{v}$ is speed of the vessel center of gravity; $\omega$ is angular speed of rotation of the vessel; $\beta, \varphi, \gamma$ are angles of drift, course and speed; $R$ is instantaneous radius of curvature of the center of gravity trajectory; $k_{11}, k_{22}, k_{66}$ are coefficients of added masses along the longitudinal and transverse axes of the vessel and the added moment of inertia; $m$ is mass of the vessel; $J_2$ is moment of inertia of the vessel about the vertical axis; $X_K, Y_K, M_K$ are longitudinal and transverse rudder force and the moment created by the transverse rudder force relative to the ship's center of gravity; $Y_A, M_A$ is transverse aerodynamic force and moment created by the vessel center of mass; $Y_p, M_p$ is transverse force from the propeller and the moment created relative to the center of mass of the vessel; $T_E$ is useful propeller thrust; $T_X, T_Y$ are projections of the horizontal force on the $X, Y$ axis; $M_T$ is moment from $T_X$.

Towed vehicle is characterized by parameters:
- size - 2400 x 3600 x 2000 mm;
- weight - about 4000 kg;
- negative buoyancy - from 0 to 40 kN.

The towed vehicle, according to calculations and field measurements, has the following dynamics parameters at various towing speeds given in tables 1, 2, 3.

Table 1. The results of calculations of the forces required to retrace the CNB away from the direction of towing

| Towing speed            | V   | m/s | 1.0 |
|-------------------------|-----|-----|-----|
| CNB horizontal strafe   | Z   | m   | 0.0 | 10.0 | 15.0 | 20.0 |
| Demolition of CNB       | X   | m   | 72.2| 71.5 | 70.6 | 69.2 |
| Deepening force         | $T_y$| N   | 49.0| 55.0 | 63.0 | 73.0 |
| Diverting force         | $T_z$| N   | 0.0 | 52.5 | 86.0 | 126.0 |

Table 2. The results of calculations of the efforts required to divert the CNB away from the direction of towing

| Towing speed            | V   | m/s | 1.5 |
|-------------------------|-----|-----|-----|
| CNB horizontal strafe   | Z   | m   | 0.0 | 10.0 | 15.0 | 20.0 |
| Demolition of CNB       | X   | m   | 72.3| 71.5 | 70.5 | 69.1 |
Deepening force

| T_y | H   |
|-----|-----|
| 178,0 | 194,0 | 211,00 | 234,0 |

Diverting force

| T_z | H   |
|-----|-----|
| 0,0 | 123,0 | 198,0 | 288,0 |

Table 3 - The results of calculations of the efforts required to divert the CNB away from the direction of towing

| Towing speed   | V   | m/s | 3,0 |
|----------------|-----|-----|-----|
| CNB horizontal strafe | Z   | m   | 0,0 | 10,0 | 15,0 | 20,0 |
| Demolition of CNB downstream | X   | m   | 72,2 | 71,4 | 70,4 | 69,0 |
| Deepening force | T_y | H   | 890,0 | 950,0 | 1020,00 | 1110,0 |
| Diverting force | T_z | H   | 0,0 | 500,0 | 805,0 | 1163,0 |

The graph below (Figure 3) shows the values of the required lateral forces depending on the lateral displacement of the towed vehicle.

![Figure 3. Transverse depending on displacement USV](image)

4. Conclusion

It should be noted that for this diagram with the speeds of towing to 3 the units the required efforts demonstrate practically realizable values. In this case, the total force of the necessary stops at a speed of 3 knots is 522 N, which requires approximately 5.5 kW of electricity supplied to the thrusters. On 6 units the composite force of supports composes 2273 N, that will require approximately 23 kW of electric power.

The obtained results give an idea about the necessary values of the required electrical power by engine-steering complex TGC for the motion with those required motion of quality along the routing line with the use of the towed system V-USV.

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