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Justification for the Body Construction Selection of the Unmanned Uninhabited Underwater Apparatus

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ABSTRACT: The paper explores the possibility of creating an underwater apparatus in the form of a body of rotation. The form of the device will allow to effectively examine the found underwater objects, the bottom topography, measurement of other parameters of the underwater environment or objects. The devices of a different streamlined body form are considered. The apparatus in the form of a rotation body is proposed. The geometric shape of the proposed apparatus, the system of motion and control are investigated. Methods for calculating the motion parameters, methods for the vehicle positioning in the flow and the underwater vehicle movement in the vertical plane are proposed. The study confirms the ability of the underwater vehicle to move under water in a horizontal and vertical directions. The study confirms that the device possess stability at rectilinear motion, good turning ability and at the same time it is able to position itself during the flow.

1 INTRODUCTION

The theme of the development of remote-controlled underwater vehicles has long been popular throughout the world. Over the past decade, a large number of devices of various shapes and sizes, capable of performing work both in the water column and on the seabed have appeared. Underwater apparatus can be habitable and uninhabitable. In the framework of this paper, uninhabited underwater apparatus, or underwater robots, are considered.

In accordance with the classification proposed in [1], the number of uninhabited underwater apparatus includes: remote-controlled, autonomous, towed, bottom, drifting, etc., which differ in purpose, shape of contours, movement parameters. The shape of the contours, as a rule, is determined by the purpose of the apparatus. Most studies on UUV (Unmanned Underwater Vehicles) reveal practical operating experience or hydrodynamic research results [2-4].

The purpose of this paper is a mathematical description of the movement options of the selected structure of an underwater uninhabited apparatus.

The tasks of the work are the analysis of the existing forms of the hulls of underwater devices, the study of the geometric shape of the proposed apparatus, its movement and control systems with methods for the motion parameters calculation of an alternative design, methods of the apparatus positioning on the flow, the apparatus movement in a vertical plane.

2 THE HULL SHAPE OF THE EXISTING UNDERWATER VEHICLES

The existing types of devices can be divided into devices of a well streamlined shape and devices of a poorly streamlined shape.

The devices of well streamlined shape. The most common form of the body of such a device is an oblong torpedo-shaped form [5-6], sometimes with ballast [7] or flattened in a vertical or horizontal plane, with underwater wings [8-9]. Devices with bodies of similar shape provide a sufficiently high speed of longitudinal movement at a sufficiently low turning ability. These devices are mainly designed for prospecting, hydrographic work, as well as for monitoring of extended bottom structures, for example, oil pipelines. The works on the study of motion during deformation of the hull at high pressure of dense sea water are known [10].The devices of well streamlined shape, as a rule, are autonomous.

The devices of poorly streamlined shape. The devices of poorly streamlined shape are a frame structure with a buoyancy compartment. The attached implements of a wide nomenclature is on the frame structure. The main advantage of the apparatus of this design is the versatility of equipment, since there is no need to fit into the body contours pre-installed by the designer. The main types of body structures, attached implements and the main achievements of underwater vehicles of poorly streamlined shape for the last 20 years are described in the article [11]. The disadvantage is the great resistance of the apparatus shape and, as a result, the increased energy consumption for moving and positioning. The devices of such a composition are used for detailed local studies or works, for example, surveys of a flooded object [1]. The devices of poorly streamlined shape, as a rule, are tethered.

Traditional control system of the underwater apparatus. The control system of the devices, both well-streamlined shape and poorly-streamlined shape, is a helical complex comprising from one to 8 propellers. Propellers can be equipped with guide nozzles, can be placed in tunnels, and can be made stationary or rotary.

The composition scheme of the control complex and the location of the equipment for each device is individual. The increase in the number of propellers leads not only to increased energy consumption, but also to the complexity of the composition of the underwater apparatus.

Underwater apparatus of alternative design. Among the alternative the designs with flapping wing are known [12-13], where the authors note improved hydrodynamic characteristics in comparison with the torpedo shape.

Among the underwater devices of unconventional form, it is necessary to single out the work of [14-15]; they developed a robotic fish of sliding by combining the mechanisms of sliding and reduction.

These works indirectly confirm that research to search for the optimal shape of an unmanned underwater apparatus is necessary and relevant, and descriptions of the ways of movement of alternative structures require study.

The authors of the article propose an alternative solution for the underwater apparatus, combining the advantages of the types of devices described above.

The body of the apparatus in the form of a disk is equipped with two stationary propellers placed diametrically relative to each other. A general view of the apparatus is shown in Figure 1.

The managing of device with respect to the vertical axis of symmetry is carried out by measuring the stops of the propellers. The change of roll and trim is carried out by the deviation of the center of gravity of the apparatus from the neutral position. The latter is achieved by the displacement of cargoes located inside the body.

The shape of the body can be described analytically, which greatly simplifies the mathematical description of the parameters of its movement. An analysis of the literature [16] confirms that this design is of interest to researchers.

In this article, the authors provide a brief description of the geometry and laws of machine control with the analytical form of the contours, made on the basis of the Cassini oval.

3 GEOMETRY OF THE APPARATUS OF ALTERNATIVE DESIGN

The device has contours of an analytical form and it is a body of rotation, the cross section of which is the Cassini oval. Generally speaking, it is possible to use any form of contours. Using the contours of the analytical form will significantly simplify the study of hydrodynamics at the initial design stage.

The waterlines of the apparatus are concentric circles (Figure 1).

The body of the apparatus and all the quantities necessary for calculation of the motion parameters (displacement, moments of inertia, added masses, etc.) are easy to calculate with minimal involvement of the model experiment. The shape and size of the device body can be determined on the basis of the known total weight and overall dimensions of the carried equipment.

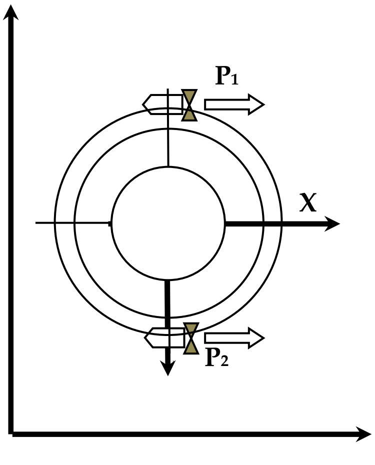

Figure 1. Scheme of the underwater apparatus

If you install the equipment on a special round frame mounted on the scales, it is easy to ensure the center of gravity position in the center of the volume. Calculated specifically for the selected composition of the equipment, the body will allow to simplify the procedure of device trimming.

4 MOVEMENT AND CONTROL SYSTEM FOR APPARATUS OF ALTERNATIVE DESIGN

The propulsion system of the apparatus should include two permanently fixed propellers located symmetrically relative to the longitudinal axis (Fig. 1) in the place of the greatest width. The selection of the propeller diameter and the evaluation of engine power will be determined by calculation using known methods.

The calculation of the required thrust of the propellers can be performed by the formula [2]

$$-C_x + 2\cdot\frac{k_1(J_p)\cdot D_p^{\,2}}{0.5\cdot J_{p0}^2\cdot\bar{V}^2\cdot D^2} = 0$$

where $\tilde{N}_x$ – the dimensionless resistance force of the apparatus body, $k_1(J_p)$ – coefficient of propeller thrust, J_p – instant advance of propeller, J_{p0} – initial advance of propeller, D_p – propeller diameter.

When moving in a horizontal plane in the absence of flow, the device can be controlled by propellers by changing the thrust of one of them.

The calculation of the needful moment of the propellers can be performed by the formula

$$-\tilde{N}_{mz} + \frac{\left[k_1(J_{p1}) - k_1(J_{p2})\right]\cdot D_p^{\,2}}{0.5\cdot J_{p0}^2\cdot\bar{V}^2\cdot D_a^{\,2}} = 0$$

where J_{p1} and J_{p2} – pitch ratio, D_a – machine diameter.

For maneuvering in the vertical plane it is supposed to use the movement of the center of gravity of the apparatus by changing the position of the cargoes inside the apparatus.

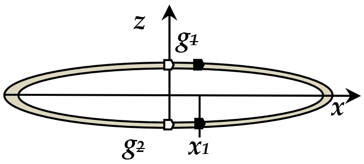

Figure 2. Trim angle change system.

It is known that the cargo movement within the system [2], leads to the occurrence of the moment causing the trim or roll of the apparatus, depending on the direction of the cargo movement and the accepted system of designations. The mechanism of the system operation will be the same.

The relationship between the cargoes movement and the angle value of trim is determined by a simple formula [17]

$$-\tilde{N}_{my}(\psi) + \frac{g_1\cdot x_1}{\rho W} = 0,$$

where $\tilde{N}_{my}$ – dimensionless hydrodynamic moment on the device body, g_1 – total weight of displaced cargoes, x_1 – the distance over which cargoes are moved, ψ – trim angle.

When the trim angle changes, the vertical component of the force will exist for a short evolutionary period of motion. At steady motion, the apparatus will move in a straight line, experiencing only the action of the longitudinal component of the force (resistance force).

The immersion speed at a constant mode of the propeller operation will be determined by the projection of the speed of the apparatus movement in the diametrical plane on the vertical axis, that is, the value of the trim angle.

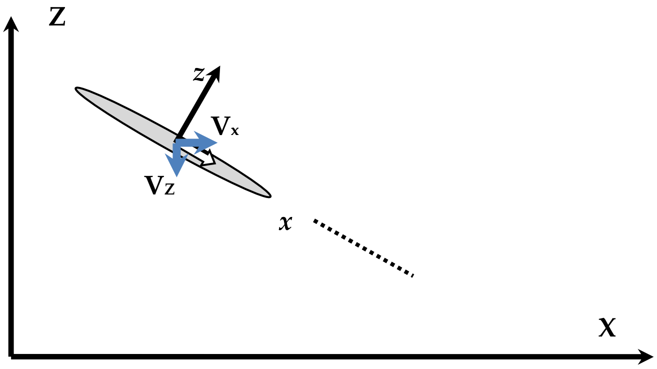

Figure 3. The controlled movement of the device in the vertical plane.

It is possible to change the direction of movement of the apparatus in the same way as controlling it in a horizontal plane, that is, using the propellers operation.

To prevent a strike about the bottom during the apparatus descent, it is necessary to control the distance to the obstacle and level the apparatus as it approaches, that is, to be controlled in the same way as aircraft controlling during landing.

5 METHODS FOR CALCULATION OF MOTION PARAMETERS

The system of six differential equations of motion can be used to calculate the parameters of the apparatus motion, as it is usually done when calculating the parameters of ships movement [2]. Due to the symmetry of the body, the equations of motion and the expressions for hydrodynamic characteristics used in them will be significantly simplified.

The values of hydrodynamic forces and moments acting on the apparatus in an arbitrary motion will be written in the following form:

- longitudinal force $X = C_x\cdot 0.5\rho V_0^2\cdot\bar{V}_x^2\cdot\frac{\pi D^2}{4};$

- lateral force $Y = C_y \cdot 0.5 \rho V_0^2 \cdot \overline{V}_y^2 \frac{\pi D^2}{4}$;

- vertical force $Z = C_z \cdot 0.5 \rho V_0^2 \cdot \overline{V}_z^2 \cdot \frac{\pi D^2}{4}$;

- moment relative to the longitudinal axis (roll moment) $M_x = C_{mx} \cdot 0.5 \rho V_0^2 \cdot \overline{V}_x^2 \cdot \frac{\pi D^3}{4}$;

- moment relative to the lateral axis (trim moment) $M_y = C_{my} \cdot 0.5 \rho V_0^2 \cdot \overline{V}_y^2 \cdot \frac{\pi D^3}{4}$;

- moment relative to the vertical axis z (moment of yaw) $M_z = C_{mz} \cdot 0.5 \rho V_0^2 \cdot \overline{V}_z^2 \cdot \frac{\pi D^3}{4}$;

where C_x, C_y, C_z, C_{mx}, C_{my}, C_{mz} - dimensionless hydrodynamic characteristics of the apparatus depending on the shape of the contours, V_0 – speed at the beginning of the maneuver, $\overline{V}_x$, $\overline{V}_y, \overline{V}_z$ - change of speed in the process of maneuver in projections on the coordinate axes, D – machine diameter.

Due to the fact that the apparatus is a rotation body, the body shape remains unchanged in the direction of the axes x and y. Due to this, the hydrodynamic and inertial forces will lie on one straight line passing through the center of gravity.

At the same time, the condition of equality of the dimensionless components of the longitudinal and lateral hydrodynamic forces is satisfied, that is $\tilde{N}_x \equiv \tilde{N}_y$, and the moment of these forces relative to the center of gravity will be zero, that is $\tilde{N}_{Mz} = 0$.

The vertical force will be determined by the body shape in the plan, and will depend on the angle of rotation relative to the direction of rotation, i.e. $\tilde{N}_z = \tilde{N}_z(\psi)$.

Dimensionless hydrodynamic moments with respect to the axes x and y will change with changing of roll θ and trim ψ angles. However, it is noted that for the corresponding values θ and ψ the moments values are equal, that is, $\tilde{N}_{mx} = \tilde{N}_{my}$.

When moving near the bottom at a distance of less than two widths of the body, the device will experience a repulsive force due to the screen effect.

At low speeds, this will allow it to move at a constant distance from the plane.

6 THE DEVICE POSITIONING ON THE FLOW

In the presence of a flow, the apparatus completely immersed in it can be positioned at a point provided that it is able to take a position along the incident flow and its propellers can provide the necessary thrust.

The device is not able to extinguish the lateral component of speed. However, a controlled lag movement on the flow is possible if we allow a small angle between the line of the propellers thrust and the direction of the flow. At the same time, the lateral component of the hydrodynamic force will appear on the apparatus body, under the action of which the apparatus can move in the desired direction, and then turn around towards the flow.

7 THE DECLINE OF THE APPARATUS IN THE VERTICAL PLANE

Ensuring the controlled movement of the device in a vertical plane, when the device is immersed with a minimum deviation from the vertical axis, is possible using a maneuver (fig. 4).

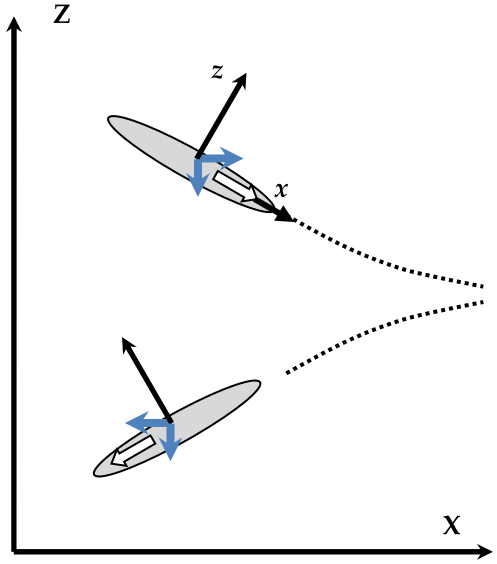

Figure 4. The scheme of the apparatus movement in a vertical plane using the maneuver

The maneuver is performed while simultaneous changing the speed magnitude and movement direction of the apparatus and the trim angle.

8 CONCLUSION

The device, made in the form of a body of rotation and equipped with two stationary propellers, is capable to move inside the water column, both in the horizontal and in the vertical directions. The device has the stability of straight motion, good maneuverability and at the same time is able to position itself on the flow.

Due to the listed properties, it can be used for a survey, implementing the additional surveys, television and sonar surveys of detected objects, also for surveying the bottom topography, the nature of the soil, or other measurements of environmental or objects parameters, and research, monitoring the parameters of the aquatic environment, shooting the bottom topography, the study of soil, underwater flora and fauna using the scientific and research equipment. When monitoring parameters of the aquatic environment or when shooting the bottom topography, the proposed device shape will allow to double the width of survey band by placing the equipment on different borts. Further model experimental studies are planned to be carried out using an aerodynamic tube and an experimental tank.

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