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DEVELOPMENT OF THE ELECTROMECHANIC BUOYANCY VARIATION SYSTEM OF UNDERWATER GLIDER

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Underwater gliders are a class of autonomous underwater vehicles (AUV). Gliders have many practical applications, especially in oceanography and data collection. A special place here is occupied by underwater monitoring, which today can be carried out either with research vessels or underwater gliders. Under this task gliders are better suited than research vessels, because they have a much lower noise level, which affects the final results of scanning the water column with a hydrophone. However, gliders can differ in the level of generated noise, primarily dependent on the buoyancy variation system. Nowadays five schemes of buoyancy variation systems are known. This paper briefly describes their design, advantages and disadvantages. After an overview comparison of all systems, an underwater glider with electromechanical buoyancy variation system was designed. A bench of the electromechanical buoyancy variation system with similar units was designed for vibroacoustics investigation. The continuation of the work is aimed at acoustics characteristics studying of the AUV in open and closed water.

Keywords: underwater glider, buoyancy variation system, vibroacoustics, underwater monitoring

1. Introduction

Over the past decade the revolutionary in all industries have been changed, primarily due to the wide spreading of the robotic solutions. Industries associated with the development of the ocean were not an exception. The new classes of underwater robots – underwater robots with a hydrostatic principle of motion, providing long-term monitoring of the water area, which gained recognition and developed great scientific and technical potential. Such robots move in the water along inclined trajectories due to a change in their residual buoyancy.

The main distinguishing features of underwater gliders:

- Extremely long range (> 1.5 thousand km.);
- High autonomy (up to a year);
- Convenient mass-dimensions characteristics (weight 50 - 120 kg, length - 2 m, wingspan - up to 1 m);
- Low cost of production and operation;
- Group application;
- The simplicity of procedures for collecting measurement information and adjusting the program task.

One of the practical applications of underwater gliders is acoustic monitoring of water areas for ecology and seismology problems. For this purpose, hydrophones, echo sounders and other measuring equipment are mounted on underwater gliders. Recording of whale songs, the echoes of underwater earthquakes that indicate the approach of a tsunami, the sounds of a collision of icebergs, the rustling of growing corals is far from a complete list of where underwater gliders are able to be implemented.

Since underwater gliders have a high-power reserve (from 3 months to 6 months of continuous operation in an autonomous mode), acoustic measurements become economically advantageous when solving problems with underwater robots, rather than scientific research vessels (the power reserve is limited to 2-3 months of operation). Also, one of the problems of using science vessels for underwater acoustic monitoring is the noise produced by the ship during the passage of the route, which often exceeds 1/3-octave frequency bands above the recommended levels of water exploration by 20-22 dB in the frequency range below 200 Hz and 10 dB at frequencies above 500 Hz [1]. However, problems with the arrangement of hydrophones on the AUV body are pulsations and vibrations arising in the systems of the robot itself, as well as pulsations of the ambient pressure resulting from the movement of the robot in the aquatic environment.

The pressure pulsations during immersion and emersion can be reduced by optimizing the shape of the robot's body. Underwater robots operate in a wide range of Reynolds numbers, which causes different modes of flow around it. This fact is the reason for the impossibility of optimal shaping of the hull shape for the whole variety of flow modes. The main focus of this work is aimed at determining the vibro-acoustic characteristics of the buoyancy variation systems and developing the most rational from the point of view of generated noise.

For example, in [2], the development of a buoyancy variation mechanism (BVM) is presented in the form of a cylinder in which the piston stretches the bellows-diaphragm. The diaphragm provides accurate control of the change in volume, which is important when there is a feedback control of the piston position. Here, to maintain the density of the diaphragm fit to the piston and to the cylinder inside the system, a 70% vacuum is maintained.

Paper [3] presents the development of a BVM based on an electrical linear actuator connected at the end to a piston displacing the diaphragm. However, the main disadvantage of this design is the lack of modularity of the mechanism, since all components of the drive are located in a monolithic body, which greatly complicates access to the units after assembly.

In [4] glider with two piston mechanisms for changing buoyancy, at the nose and at the stern, was used. This greatly simplified the design of the device, since there was no need to use a mechanism for moving the battery to adjust the trim angle. Also discussed is the effect of rectangular wings on the dynamics of the movement of the device, depending on different locations relative to the center of mass of the body.

In [5] a hydraulic BVM is used in the glider, which is a cylinder on one side of which there is an open circuit that allows seawater to fill the cylinder, and on the other hand a vacuum chamber with a piston from the high-pressure oil chamber. The hydraulic pump transfers oil, thereby driving the piston pushing water out of the cylinder.

Less common are BVMs, based on the thermal effect of changing the working fluid aggregate state. The principle of change in buoyancy here is analogous to the work of classical hydraulic BVM with the difference that here a heat exchanger is mounted on the body of the apparatus for generating energy. The obvious advantage of a thermo-glider is the power consumption only for the power supply of the sensors, as well as the trim and roll adjustment. The main drawback of such a scheme is the low efficiency and the need for a drop in the temperatures of the water area of at least 10 ° C.

2. Describing of the buoyancy variation mechanisms

Nowadays, 5 systems of change in buoyancy are widely spread [6]. They can work on the principle of changing the integral volume of the device or its mass. There are varieties with both a hydraulic circuit and an electromechanical one. In general, hydraulic circuits operate on the principle of changing the integral volume, since they include an internal cavity having a fixed volume from which the working medium is pumped by the pump into an external cavity with a variable volume. The outer cavity, being in an open environment, can increase or decrease in size, thus directly influencing the buoyancy of the glider, leading it to a mode of emersion or immersion. There are varieties of systems with both an irreversible pump (Fig. 1a) and with a non-reversible pump (Fig. 1b). Another type of hydraulic BVM with a piston driving a flexible membrane is shown in Fig. 1c. A classical BVM consisting of a pump and a ballast tank, used today in many varieties of AUV, is shown in Fig. 1d. BVM with hydraulic drive, filling and emptying the ballast outer tank with a piston is shown in Fig. 1e.

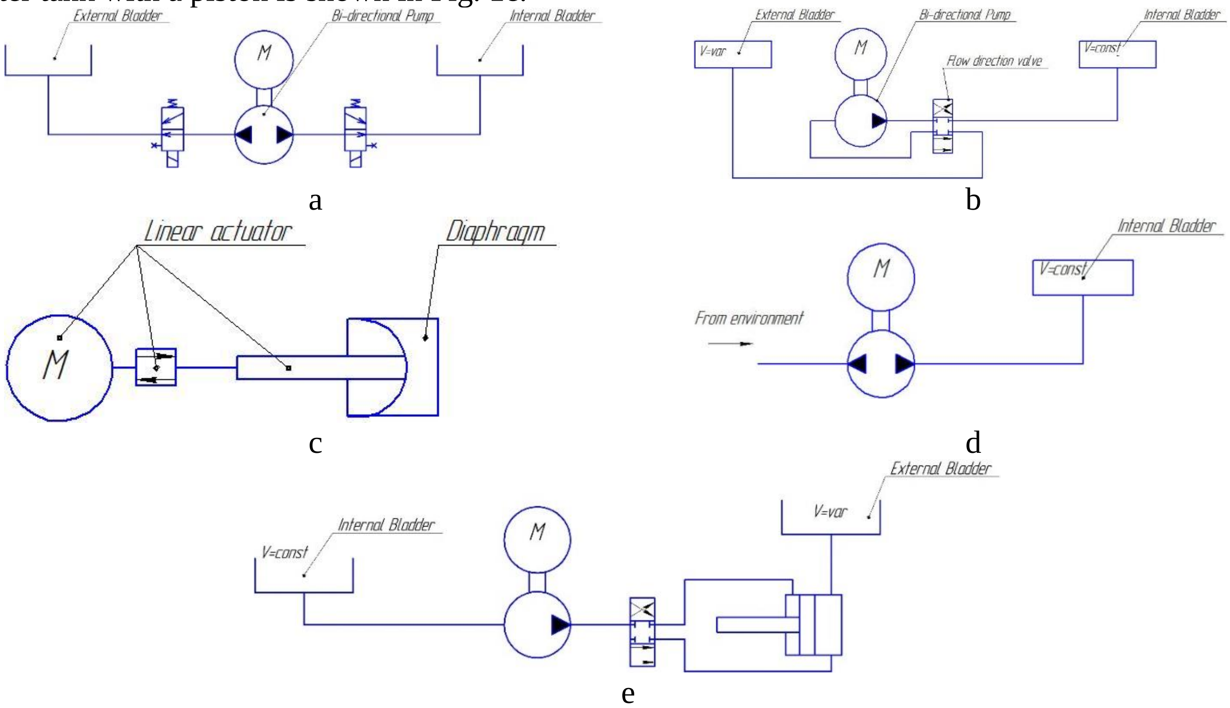

Figure 1: Hydraulic buoyancy variation mechanisms schemes

However, despite the wide variety of design schemes for hydraulic BVMs, their significant drawback in the form of a general noise system consisting of acoustic construction noise and vibrations of working fluid in pipelines, does not allow the installation of hydrophones for underwater acoustic studies on the AUV. In work [7] experimental vibroacoustic characteristics of hydraulic BVM were determined with the help of a semi-natural bench for testing the buoyancy variation systems. They showed that under different operating conditions of the AUV (emersion, immersion, drift on the surface), the main sources of vibration are pumps, electric motors, and hydraulic distributors. Also, system vibrations are generated due to pulsations of oil pressure at the pump inlet caused by the hydrostatic effect during the first 2 seconds after a cold start.

An analogue of hydraulic BVMs, lacking their main drawbacks in noise and vibration, are electromechanical buoyancy variation systems, allowing the glider to change its mass, filling the volumes of ballast tanks with seawater for immersion regimes or emptying them for regimes of ascent. A significant difference here is the use of a linear actuator with a servo drive instead of a hydraulic cylinder. Another advantage of such a system is a significant reduction in the mass-size characteristics of the AUV.

3. Development of the electromechanical buoyancy variation system

For the study, an electromechanical buoyancy variation system with a linear actuator was developed, which was placed in the aft part of the underwater glider (Fig. 2). It is a cylinder, the rod of which is connected to the shaft of the stepping motor (Fig. 2).

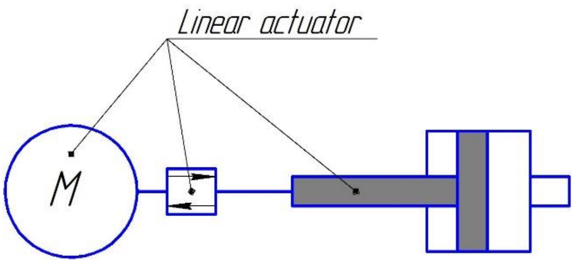

Figure 2: Buoyancy variation system's schematic diagram

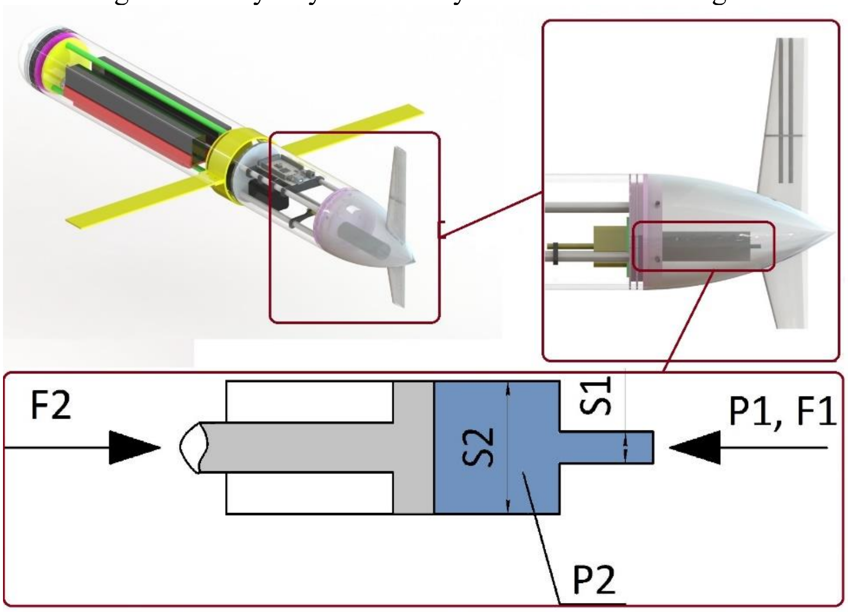

Figure 3: Linear drive of the buoyancy change

The calculation of the suction capacity of the buoyancy variation system is based on the basic equations of hydrostatics. For the selection of the optimal size the data for the suction capacity are shown in Table 1.

Table 1: Data for calculating the suction capacity

Parameter	Meaning
Ambient pressure, P_1	3 atm.
Suction hole radius, r_1	3 mm.
The force with which the stepping motor pushes the piston, F_2	10 H

First, calculate the force with which the environment presses on the suction hole at the maximum depth of immersion:

$$F_1 = P_1 \cdot S_1 = 300\ 000\ H / м^2 \cdot 0,000028\ м^2 = 8,4\ H \quad (1)$$

Since the force on the shaft of the stepper motor is greater than the design pressure of the water column on the suction hole, we can leave the originally selected version of the stepper motor.

The selection of the cylinder diameter, the volume of which will subsequently constitute the residual buoyancy of the apparatus, is shown in Table 2. The calculation data varied depending on the diameter of the suction port and the ambient pressure. Based on their results, it was decided to choose the option of calculation No. 1, since it satisfies the dimensional conditions of accommodation in the aft compartment.

Table 2: Cylinder parameters

No. 1	No. 2	No. 3
$S_1 = 0.000028 м^2$	$S_1 = 0.000079 м^2$	$P_1 = P_2 = 450 кН$
$F_1 = P_1 \cdot S_1 = 8.4 Н$	$F_1 = P_1 \cdot S_1 = 23,7 Н$	$F_2 = 10 Н$
$\frac{F_1}{S_1} = \frac{F_2}{S_2}; \Rightarrow S_2 \approx 30 мм^2$	$\frac{F_1}{S_1} = \frac{F_2}{S_2}; \Rightarrow S_2 \approx 40 мм^2$	$S_2 = \frac{F_2}{P_2} = 0,00002 м^2 \approx 20 мм^2$
$D_2 = \sqrt{\frac{S_2 \cdot 4}{\pi}} = 6.2 мм$	$D_2 = \sqrt{\frac{S_2 \cdot 4}{\pi}} = 7.1 мм$	$D_2 = \sqrt{\frac{S_2 \cdot 4}{\pi}} \approx 5 мм$

Next, it is necessary to conduct semi-natural tests of the electromechanical buoyancy change system to evaluate noise and vibration. For this purpose, a bench system was designed with an imitation of a linear actuator as a drive and a hydraulic simulation the load on the cylinders at different depths of immersion (Fig. 4).

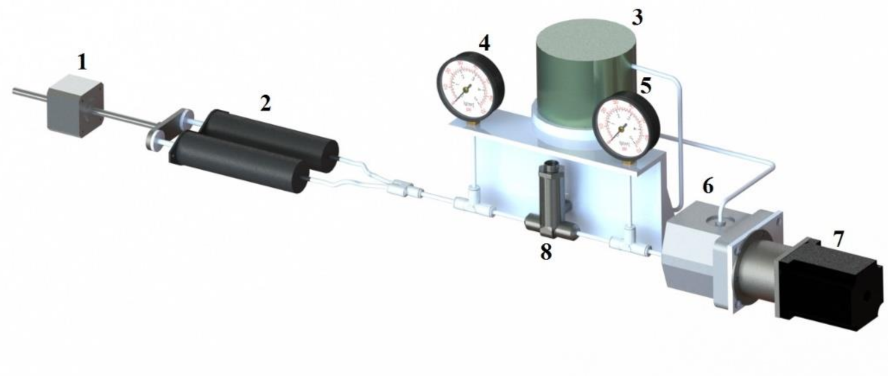

Figure 4: Bench system for testing of BVM electromechanical drive. 1 - electric drive of cylinders; 2 - two cylinders with the same volume (60 cm^3); 3 - a tank with oil; 4 - manometer for setting the safety valve; 5 - a manometer in a pressure pipeline of the pump; 6 - the pump; 7 – electric motor; 8 - safety valve

To study vibroacoustic indicators of BVM on the electric drive, vibration acceleration sensors and pressure pulsation sensors will be installed in the water pressure simulation system. After sensor measurements, an experimental noise study will be conducted with an Norsonic Nor848A acoustic camera. For further work, it is necessary to compare the data obtained experimentally from an acoustic camera and sensors to determine the frequencies that could potentially affect the operation of the hydrophone, and, accordingly, the accuracy of acoustic monitoring of the water area.

4. Conclusion

Since the solution of tasks of acoustic monitoring of water areas implies the use of devices with minimal noise and vibration characteristics, after comparing existing AUV variants with various systems of buoyancy change, the authors concluded that it is necessary to create an underwater glider with electromechanical BVM. This mechanism is much quieter than its hydraulic counterparts, since it does not have pipelines with hydraulics that create pulsations of oil in the system, and pumping units that propagate vibrations during operation throughout the apparatus. The selection of the electric motor of the drive, as well as the overall dimensions of the external cavities, was carried out. A bench system with a similar BVM was also designed to evaluate the vibro-acoustic parameters during operation.

5. Further work

Subsequent work is an assembly of the AUV and testing of its main units and systems in conditions of closed and open water. It is also necessary to conduct acoustic tests of the apparatus to determine the average noise frequencies, the results of which will affect the selection of the hydrophone and the overall tuning of the noise filters during its operation.

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REFERENCES

1 Kuznetsov M.Y., Shevtsov V.I., Poljanichko V.I. Inderwater noise characteristics of TINRO-Center’s reseach vessels // Izv. TINRO. — 2014. — Vol. 177. — P. 235–256

2 S. F. Hoerner and Henry V. Borst. Fluid Dynamic Lift. Published by Mrs. Liselotte A. Hoerner, Midland Park, NJ, 1985.

3 N. G. Hogg and R. X. Huang (eds). Collected Works of Henry Stommel. American Meteorological Society, Boston, 1996.

4 P. Holmes, J. Jenkins, and N. E. Leonard. Dynamics of the Kirchhoff equations I: Coincident centers of gravity and buoyancy. Physica D, 118:311–342, 1998.

5 A. Gelb and W. E. Van der Velde. Multiple-input Describing Functions and Nonlinear System Design. McGraw Hill Book Company, New York, 1968.

6 Janes N, Design of a Buoyancy Engine for an Underwater Glider, NRC Publications Archive, 2004, pp.136

7 Salimzhan A. Gafurov, et al, Semi-Natural Test Bench for Buoyancy Variation System of Underwater Robot’s Investigation, *24th International Congress on Sound and Vibration*, London, 2017