The Constructive Optimization of the Mechanically Loaded Elements in a Launch and Recovery System for a Remote-Controlled Underwater Complex

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Abstract. The article analyzes various design solutions for the implementation of the tasks of launching and lifting underwater vehicles from the vessel. The urgency and importance of the optimal design development of the most loaded elements in the launch and recovery device is shown. The selection of constructing the extension frame is substantiated considering the operating conditions of launch and recovery device. The authors propose a method of constructive optimization of the outrigger frame, which can be used for any structures made of shaped pipes. Three-dimensional and numerical modeling was carried out, as well as a comparative analysis of the strength characteristics of mechanically loaded elements when changing their design parameters, due to the optimization criteria. The optimal design of the U-shaped outrigger frame of the launch and recovery device has been determined, considering the given conditions.

Keywords: launch and recovery system (LARS), unmanned underwater vehicle, extension U-shaped frame, three-dimensional simulation, static strength calculation, design optimization, internal strain, strength factor.

1. Introduction

An increase in demand of modern industry for mineral resources leads to the intensification of the development of the world's oceans and dictates the need for intensive underwater work using various technical devices. The number of such devices includes the remote controlled unmanned underwater vehicles (UUV), which are widely used in oceanological studies and evaluating the margins of the mineral and biological resources of the ocean [1].

The review shows much attention of the design and control of the UUV [2-4], however, launch and recovery systems (LARSs), as auxiliary equipment, are unreasonably given less importance. While the operations of launching and recovering the UUV are associated with great risks and are the most responsible and determining the safety of the UUV and its performance [5]. Therefore, the effective and safe use of UUV is possible only if there are special devices on the carrier vessel that ensure the removal of the UUV overboard, launching and recovering.
For the launch and recovery procedures of UUV, the most common LARS is located directly on board the vessel. A typical example of the LARS is shown in [6]. With the significant weight of the UUV its descent under the water is accomplished through the special mine to avoid of the dangerous values of the bank of vessel, which appear in the process of lowering-raising operations from the stern and the boards of vessel. In certain cases for guaranteeing of additional mobility and controllability of underwater apparatus descent and the lift of underwater apparatus is achieved from that carried out outside the special platform as this shown in [7]. There is increasing recognition the unmanned surface vehicle for launching and recovering the UUV, usually in the form of a catamaran [8], that it makes it possible to free the ensuring vessel from the need for having cargo cranes, arrows, winches, hoists and other similar devices. Along with traditional LARS, original technical solutions also appear. Thus, in 9 is proposed the unique method of launching and recovering large UUV means in the special cocoon, and in [10] it is proposed to accomplish descent under the water by means of the pneumatic arched construction.

As the review has shown, at present, design work is moving towards ensuring the full autonomy of the UUV and, as a consequence, most of the existing LARS are designed specifically for autonomous vehicles, which, after launching under water, become independent of the carrier vessel and are not mechanically connected to it. However, in Russian practice of launching and recovering operations, the most widespread are remote-controlled UUV [11, 12]. For the functioning of such devices, it is necessary to have a coil with a cable, through which the device is powered and controlled. Thus, the cable - wire rope connection of the lowered nonautonomous object with the vessel-carrier sets additional conditions and limitations on the construction LARS.

The survey design the special features and the conditions the operation LARS for the UUV gives to us the foundation for assuming that the task the optimization of the construction LARS for the remote controlled UUV is very relevant.

2. Informal statement of the problem
It is necessary to develop optimum construction of LARS for launching and recovering the multifunctional remote controlled UUV, intended for fulfilling the geological survey works. Launching and recovering operations are carried out by means of a cable-wire rope connection on a stationary vessel. With the selection of construction of LARS the determining value has a presence of the cable-wire rope connection of the lowered nonautonomous object with the carrier vessel, sizes, the form and mass UUV and the depth of its sinking, and also the need for operational provisions with the fixed or moving carrier vessel. The developed LARS is designed for launching and recovering of the UUV with a mass of 1200 kg. Launching and recovering operations are carried out by means of a cable-wire rope connection on a stationary vessel. Considering the factors given above, for the conducting launching and recovering operations can be used only vessel LARS (Figure 1), since the use of the extension floating platforms or catamarans limited by the recovering of autonomous apparatuses. 

Mine LARS are mainly used when launching and lifting equipment of a large mass, since lifting operations carried out from the stern and sides of the vessel can lead to significant list of the vessel.
LARS with the **trapping parallelogram-lever device** have fairly complicated construction and are used with the stringent requirements for the stability of the lowered object and the retention of its horizontal position. Since such strict requirements are not imposed on the LARS for this UUV, the use of this type of LARS is not justified.

The widest use obtained LARS, executed in the form **catheads and the hinged frame**. In some cases, the articulated beams can be telescopic. The advantages of the crane beam are: versatility (can be used for various types of work); large coverage area; compactness. The disadvantages include: relatively low carrying capacity; large bends of the load-carrying cable; the relative complexity of the design (in comparison with the RVC with a hinged frame).

Compared to a crane-beam, LARS with an articulated frame have a higher lifting capacity and, in combination with a simpler design, provide higher reliability.

Thus, in order to carry out tripping operations under specified operating conditions, the most reasonable type of LARS will be a structure with a hinged frame. The scheme of the proposed LARS and its elemental composition are shown in Figure 2, where the LARS is shown in the operating position when the UUV is outside the vessel.

Since the outboard frame is the most mechanically loaded structural element of the LARS during its operation, the reliability and safety of the entire LARS, as well as the safety of the submerged vehicle, will depend to a greater extent on its safety margin. Therefore, optimization of the shape and size of the supporting frame becomes a priority in the design of any SPU of this type. At the same time, the outrigger frame must ensure the rigidity and strength of the LARS structure for retraction of the descent equipment to a safe distance from the vessel hull in order to avoid the apparatus hitting the side of the vessel. The reach of the boom must be such that the equipment is not damaged during the launching and recovering operations. The outrigger frame must be rigidly attached to the foundation on the open deck. Taking into account all of the above, the task of constructive optimization of the supporting frame will be to minimize its weight while ensuring the required margin of safety and free movement of the underwater vehicle under it.

### 3. Constructive optimization of the outrigger frame of the launch and recovery system (LARS)

In LARS with a hinged frame, A-shaped and U-shaped frames are mostly used. An example of using an A-shaped frame in a LARS is considered in [13]. On the one hand, this shape of the frame makes it possible to reduce its total weight, however, it deprives a certain degree of freedom of the apparatus suspended on the frame, which can lead to collisions during a rolling or a wind. The use of the A-shaped form is justified only for small in weight and dimensions UUV. In our case, it would be more expedient to design a U-shaped frame, directly on which the rosipas block is fixed, as shown in Figure

![Diagram of Types of LARS Vessel](image)
2. This design of the LARS allows you to dock the UUV with the submersion position 5 without the use of a stern launching device.

![Diagram of LARS design](image)

Figure 2. The proposed design of the LARS in the operation position.
1 - platform; 2 - drum; 3 - control panel; 4 - electrical box; 5 - UUV; 6 - U-shaped outrigger frame (boom); 7 - hydraulic cylinders; 8 - cable layer; 9 - motor reducer; 10 - rosipas block; 11 - s bearing frame; 12 - hydroelectric station.

The developed LARS should ensure the retention of the cable-wire rope at a safe distance from the side of the vessel during the tripping operations. In the proposed layout of the LARS, this requirement is ensured by the dimensions of the U-shaped boom and the angle of its inclination in relation to the deck when the UUV is taken overboard before the actual descent begins.

To solve the set problem of constructive optimization, it is possible to use universal computer-aided design systems, provided that they have a built-in strength calculation module, such as, for example, Compass 3D, SolidWorks, etc. So in works [14,15] we have shown a fairly wide functionality of the Compass 3D system, including in the field of strength calculation. Existing special software systems of finite element analysis, such as ANSYS, can also be used, as was shown in [16], where the structural stability of the LARS winch was assessed. In order to compare these programs in this work, as a means for solving the problem of structural optimization of the outrigger frame, we used the SolidWorks program, in which we performed three-dimensional solid modeling and numerical simulation of the outrigger frame stress-strain state. The problem was solved in a static setting.

The U-shaped frame is a welded structure consisting of three beams, two longitudinal and one transverse. In the center of the cross beam, a rosipas block is attached, through which a cable passes. The UUV is attached to the end of the cable, the mass of which is 1200 kg. All frame parts are made of 40 grade steel. In the original frame design, we will take square pipes as beams in accordance with GOST 8639-82, the cross-sectional dimensions of which are 100x100, and the wall thickness is 6 mm. In this case, the overall dimensions of the outrigger frame are due to the dimensions of the UUV itself and cannot be changed.

We carry out constructive optimization for the mode of lifting the UUV and carrying it overboard, since the weight of the UUV in air is much higher than in water. This mode is of a short-term nature, in connection with which it is sufficient to obtain a safety factor of at least 1.25. In turn, in the process of taking the UUV overboard, from all possible positions of the outrigger frame, the most severe load conditions will be in its extreme lower position when the frame assumes a working position overboard.
From this moment, when the descent of the apparatus begins and until it enters the water, when the buoyancy force begins to act, the greatest loads will act on the frame. Therefore for us and reliability precisely this state of frame will be most significant on the strength. If in this regime the required coefficient of reliability will be achieved, then with the confidence it will be possible to assert that in other positions of frame the coefficient of reliability will be above.

The weight of the UUV acts as an external load for the frame, which, in the simulation, is replaced by a cube of the corresponding mass. The frame is fixed through the holes made in the lower part of the longitudinal beams. The lower holes are used to attach the frame to the deck, and the upper holes are used to connect the hydraulic cylinders currents (see Figure 2). The reaction type is a fixed hinge. Figures 3.4 show the graphs of the stress-strain state of the frame in the lowest position.

For the analysis of the reliability of initial construction were also determined the internal strains of object, also, as the objective function - the distribution of safety factor according to the construction of the object (Figure 5,6).

As can be seen from the above graphs, for the original frame model in the extreme position, the safety factor of the frame is 0.97, which is less than required (1.25). Consequently, it becomes necessary to optimize its design. Their graphs also show that the maximum stresses and internal...
deformation occurs in the longitudinal beams at the points of attachment of the hydraulic cylinder rods (marked in red), where the bending moment is mainly acting. While the stresses in the transverse beam are minimal, which means its design is selected correctly and further changes in its size and configuration are not required.

In order to increase the safety margin of the frame, it is possible to increase the wall thickness of the pipe of the longitudinal beams, leaving the outer dimensions of the pipe section at 100 mm. In the course of our work, we carried out numerical simulations at various wall thicknesses to analyze the effect of this parameter on the strength characteristics of the frame. The results of calculating the stress-strain state for a square pipe with a wall thickness of 7, 8 and 9 mm are presented in Table 1. The table includes the extreme maximum values for the model for stresses, displacements and deformations and the minimum value of the safety factor.

| Indicators                                      | Pipe Wall Thickness, mm |
|------------------------------------------------|-------------------------|
| Von Mises stresses, N / m²x10⁶                  | 267 238 214 197         |
| Total relative displacements, mm                | 5.81 5.81 5.81 5.81     |
| Internal deformation of the object, x10⁻⁴      | 10.86 9.69 8.72 8.01    |
| Factor of safety                                | 0.97 1.10 1.20 1.30     |
| Frame weight, kg                                | 187.6 211.8 235.6 258.8 |

The safety factor of 1.3 obtained as a result of the successive increase in the pipe walls with a thickness of 9 mm is quite acceptable, however, this frame design will significantly increase its weight, which is undesirable taking into account the specified optimality criteria. Therefore, we consider the method of increasing the thickness of the pipe unacceptable, and for the purpose of further optimization, we analyzed another constructive solution: as longitudinal beams, use rectangular pipes in accordance with GOST 8645-68, the profile of which is 120x40 mm in size. As a result of the calculation of the stress-strain state of the frame for a rectangular pipe with a wall thickness of 8 mm, we obtained the following indicators:

- Von Mises stresses, N / m² 2 x10 6: 296
- Total relative displacements, mm: 5.81
- Internal deformation of the object, x10⁻⁴: 12.04
- Factor of safety: 0.89
- Weight, kg: 194.7

The results obtained show that changing the design by changing the profile of the longitudinal beams of the frame does not have a positive effect, since the calculated safety factor of such a frame is lower (0.89) than for a square pipe of the same wall thickness (1.2). And therefore, such a path of constructive optimization, in our opinion, is also unpromising.

In connection with the inconsistency of the above methods of constructive optimization, we proposed another constructive solution: to increase the stiffness of the longitudinal beams in the transverse direction, stiffeners of a rectangular cross section were added to their upper and lower planes. In this case, the initial parameters of the pipe profile with a wall thickness of 6 mm were taken.

As a result of the calculation of the stress-strain state of the frame for a rectangular pipe with a wall thickness of 8 mm, we obtained the following indicators:

- Von Mises stresses, N / m² 2 x10 6: 137
- Total relative displacements, mm: 4.57
- Internal deformation of the object, x10⁻⁴: 4.89
- Factor of safety: 1.50
Weight, kg: 232.6

After analyzing the new results of force calculations, we can conclude that this U-frame design is optimal from the point of view of the safety factor (1.5) and the weight of the structure (232.6 kg). Indeed, for the same weight of a square frame with a wall thickness of 8 mm at 235.6 kg, it gives a safety factor of only 1.2, while a frame with stiffeners provides a 25% increase in safety factor. It is possible to further increase the safety margin due to an increase in the overall dimensions of the stiffener, but this will lead to a heavier structure, an increase in metal consumption for its manufacture, etc., that is, it is impractical.

Thus, we have proposed a methodology for performing constructive optimization, during which the following stages can be distinguished:

1. Statement of the problem of constructive optimization.
2. Changes to the design:
   - increasing the wall thickness of the hollow pipe;
   - changing the shape of the pipe profile;
   - adding additional structural stiffeners.
3. Checking the optimization conditions for the strength factor and the mass of the structure.

At the second stage, various methods of changing the design are sequentially implemented in the indicated priority, i.e. increase the thickness of the pipe wall to a significant increase in the weight of the structure. If in this case the required optimization conditions are not satisfied, then proceed to the next method. The proposed method of constructive optimization can be used for any metal structures made of shaped pipes, for which there is a standard range of different wall thickness and shape of the pipe profile. At the same time, the procedure for constructive optimization described by us can be implemented in any program that has the function of static strength analysis, such as the above systems, such as Compass 3D, SolidWorks, Inventor, ANSYS, etc.

4. Conclusion
As a result of this work, the authors reviewed the main design solutions used in modern practice of launching and recovering operations for UUV. A comparative analysis of the applicability of various LARS to the task of launching and recovering a remote-controlled UUV weighing 1200 kg from a vessel was carried out. The choice of a vessel LARS with a hinged frame was substantiated and its design was proposed, containing a U-shaped outrigger frame. For the outrigger frame, as the most loaded structural element of the LARS, the task of constructive optimization was formulated and a methodology for its implementation was proposed. In the course of solving the optimization problem, we performed numerical modeling of the stress-strain state of the outrigger frame for various design parameters. As a result, an optimal frame design has been achieved, providing the maximum strength factor with the minimum structure weight.

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