Assessment of the Possibility of Using ROV in the Mode of Joint Traffic with the Support Vessel

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Abstract. The correspondence of the characteristics of the propulsion and steering complex (PSC) to the values required to compensate for the response of the communication cable determines the efficiency of using tethered underwater vehicles. The report assesses the requirements for the thrust characteristics of the PSC, which ensures the maneuvering of the vehicle relative to the carrier or garage in the mode of movement of the complex along an extended bottom object. The assessment is based on the results of calculating the tension of the communication cable in the stream, due to the joint movement of the tethered system "carrier-garage-vehicle". This tension, together with the hydrodynamic resistance of the apparatus body, determine the requirements for the thrust characteristics of the PSC, as well as for the power supply system of the complex as a whole. An algorithm is proposed for calculating the tension of the communication cable between the vehicle and carrier in a stationary flow, based on the equation of a chain line and numerical integration of the equations of an inextensible flexible thread. An example of using the proposed methodology for calculating the variants of a tethered system is given.

1. Introduction

The purpose of the work is to study the possibility examining extended bottom objects with different variants of tethered systems. The first one is "shallow" and is shown in Fig. 1 single-link system consisting of a support vessel (SV), a remotely operated underwater vehicle (ROV) and a neutral buoyancy communication cable (CC), which provides the power supply of the device and its information exchange with the control station. Figure 2 shows a "deep-sea" version of a two-link tethered system, which includes a SV, a load-carrying cable (LCC) of negative buoyancy, a passive depressor (PD), a fiber-optic lightweight communication cable (LWC) and an autonomous unmanned underwater vehicle (AUV).

In the course of the research, the following tasks were solved:

• determination of the rational ratio between the length of the communication cable and the depth of the vehicle relative to the SV or PD;
• calculation of the tension of the ends of the cable in a single-link tethered system for different values of the speed of its movement and the depth of the vehicle relative to the SV;
• Calculation of the tension of the communication cable in a two-link tethered system, acting on the underwater vehicle and SV.
2. Computation method

To calculate the tension of the cable line of the tethered system and its spatial shape at different values of the speed of movement and the location of the apparatus relative to the vessel, depending on the formulation of the problem, two main tools for calculating the statics of the tethered systems can be used - the numerical integration of the equations of equilibrium of a flexible thread in a stationary stream and the equations chain line.

2.1. The computation of the single-link tethered system

If we accept the assumption that the angle of the attack of the bond cable is quite large, and the tangent component of the hydrodynamic resistance can be neglected, then the cable is located in a plane \( \xi \eta \), the orientation of which is determined by the direction of movement of the system, the buoyancy of the cable and the coordinates of the device relative to the SV (see Fig. 3). At a steady speed of the joint movement of SV and ROV, the formulas for calculating the chain line can be used to determine the tension and configuration of the cable [1]. In Fig. 3, the direction of the associated axis \( \xi \) coincides with the vector of the resultant uniformly distributed load:

\[
\bar{p} = \bar{R}_n + \bar{q}, \quad \bar{R}_n = R_n \bar{n}, \quad R_n = K_n \rho V^2 d / 2; \tag{1}
\]

where \( \bar{R}_n \) is the vector of hydrodynamic resistance, \( \bar{q} \) is the buoyancy of the cable, \( \bar{n} \) - normal to thread, \( K_n \) is the normal coefficient of hydrodynamic resistance, \( \rho \) is the density of water, \( V \) is the speed of the oncoming flow, \( d \) is the diameter of the communication cable.

The tension at any point of the chain line is determined by the ratio:

\[
T_m = p_m / \xi_0, \tag{2}
\]

where \( T_m \) and \( p_m \) are modules of tension and load vectors, respectively; \( \xi_0 \) is the abscissa of the top of the chain line in the flow coordinate system \( \xi \eta \); \( \sin \psi = q / p_m \), \( \cos \psi = \lambda / p_m \), \( \psi \) is the angle of
“trim” of chain line between the axes $\xi_0, \xi$ and $OX_S$. To find the $\xi_0$, the root of the equation $x^*$ is found in the process of iterative search:

$$shx = x\sqrt{L^2 - (OB)^2} / AB$$

(3)

where $L$ – length of cable; $AB$, $OB$ – the span and elevation of the chain line, respectively; $AB = \sqrt{(BC)^2 + z_A^2}$, $BC = x_A \sin \psi - y_A \cos \psi$, $OB = x_A \cos \psi + y_A \sin \psi$; $x_A, y_A, z_A$ are the coordinates of the vehicle in the inertial system $OX_SY_SZ_S$; $\sin \alpha = BC / AB$, $\cos \alpha = z_A / AB$.

Figure 3. Calculation of cable tension projections according to the chain line equation.

The resulting solution to the equation (3) will allow us to determine $\xi_0 = 2x^* / AB$ and tension $T_m$.

Further, on a segment $[\eta_A, \eta_S]$ with a selected step $\Delta \eta$, the cable configuration and tension projections are calculated:

$$\eta_{i+1} = \eta_i + \Delta \eta, \quad \xi_{i+1} = \eta_{i+1} / \xi_0 - \xi_S$$

$$\Delta \xi = \xi_{i+1} - \xi_i, \quad \Delta \eta = 2\eta_{1/2}, \quad \Delta \xi$$

$$\sin \theta = \Delta \eta / \Delta \xi, \quad \cos \theta = \Delta \xi / \Delta \eta$$

$$T_x = T_m \cos \theta, \quad T_y = T_m \sin \theta$$

$$T_y = T_m \sin \psi - T_y \sin \alpha \sin \psi$$

$$T_z = -T_m \cos \alpha.$$
The above formulas constitute the content of the ChainLine subroutine used in the calculations of tethered systems under the specified assumptions [2].

2.2. The computation of the two-link tethered system

The TwoSegm subroutine calculates a two-link system at a given tension at the lower end and calculates the target function - the distance between the upper end of the upper segment and a point with the coordinates of the vessel. The algorithm of the subroutine, depending on the formulation of the problem, provides for three implementation options, the structure of which is shown in Figure 4.

![Figure 4. Algorithm options of the TwoSegm program.](image)

Option (a) of the algorithm configuration is selected in the case when the system is towed at a constant speed, or when kept on a constant current at a point known only relative to the vessel. The subroutine Pull uses the ode45 MATLAB procedure and integrates the system of differential equations for the statics of a flexible thread, which in vector form looks like this [1, 3]:

\[
\frac{d\bar{T}}{dt} + \bar{R} + \bar{q} = 0,
\]

where \( \bar{R} = (R_x, R_y, R_z) \) – the force of hydrodynamic pressure acting per unit length of the cable, and its projection; \( \bar{q} \) – weight of a unit of cable length in water; \( \bar{T} = (T_x, T_y, T_z) \) – pulling force at the current point of the cable. Option (b) corresponds to the situation when the coordinates of all three modules are known: the ship, the vehicle and the garage, the vehicle is held at a point with a constant flow. Option (c) is intended for calculating a tethered system on a constant flow in the case when the coordinates of the apparatus are given relative to the garage. The ChainLine subroutine is used here to determine the initial guess. Refinement of the tension vector at the ends of the cable is realized in the course of an iterative search for the minimum of the objective function, which is determined by the calculated coordinates of the root (upper) end of the cable relative to the origin of the coordinate system associated with the depressor.

If the choice of another starting point does not lead to a successful solution, the Func4 subroutine attempts to solve the problem for each segment separately. The input variable for Func4 is the specified position of the garage, the output (objective function) is the sum of two terms – the distance of the upper end of the lower segment to the garage and the upper end of the upper segment to the vessel. The structure of the Func4 subroutine is shown in Figure 5, and the generalized block diagram of the algorithm for calculating the parameters of tethered systems is shown in Figure 6.

3. Choosing a reserve length of the communication cable

During the synchronous movement of the harness system, the tension at the ends of the communication cable depends on its length, as well as on the deepening of the running end relative to the SV or the
depressor. Obviously, with an increase in the cable length, its tension will decrease, due to a decrease in the normal component of the hydrodynamic pressure. However, an excessive increase in length leads to an undesirable increase in electrical losses in copper and complicates the procedure for deploying and mobilizing the tethered system. Therefore, the problem arose of determining the rational reserve of the cable length to the immersion depth of the vehicle.

The graphs in Fig. 7 show the dependence of the resulting tension of the cable running end on the length, calculated according to the method proposed above, obtained for the oncoming flow velocity of 1 m/s, and under the condition that the apparatus moves strictly under the SV.

**Figure 6.** Generalized block diagram of the algorithm for calculating the parameters of the tethered system.
Figure 7. Dependence of the shape of the communication cable on the length at a travel speed of 1 m/s.

Figure 8. Dependence of the tension of the ROV’s communication cable on the length and travel speed.

An analysis of the graphs in Fig. 8 shows that at $L_{lk}>2H_a$ there is a slight decrease in the cable tension, which is about 0.2 N/m. This allows us to consider the ratio $L_{lk}/H_a=2$ rational when deploying tethered systems.

4. **Calculation of cable tension in a single-link tethered system**

The calculation of the CC tension was carried out for a communication cable of the КП100ВКП type with the following characteristics: diameter $d_c = 10$ mm, weight in water $q = +0.00066$ kg/m. In all calculations, the cable length reserve $L_{lk}/H_a=2$ was taken. At the same time, the vehicle was positioned strictly under the support vessel at a submersion depth of 100 m. The dependences of the tension of the communication cable ends on the speed of the joint movement of the vessel and the vehicle obtained as a result of calculating are shown in Fig. 10. Fig. 9 demonstrates the change in the shape of the CC in the longitudinal-vertical plane.
The analysis of the results of the calculation shows that the tension of the CC at a working depth of 100 m at a speed of movement of the tethered system relative to the water of 1.0 m / s does not exceed 700 N. The existing load-carrying CC with zero buoyancy due to the use of aramid power elements have a working tension of 2000 - 5000 N. Therefore, the factor limiting the speed of the single-link tethered system will be the traction characteristics of the ROV PSC, which must meet the following requirements

\[
F_x = T_{xy} + R_{ax} \quad F_y = T_{yx} + Q_a, \quad (7)
\]

where: \( F_x, F_y \) – are the longitudinal and vertical thrusts of the DSC, respectively; \( R_{ax} \) – is the frontal hydrodynamic resistance of the ROV; \( Q_a \) – is the residual buoyancy of the vehicle. The use of a ROV as part of a single-link tethered system at a speed of 1 m / s requires the following thrust reserves for the DSC: \( \Delta F_x \geq 700N, \Delta F_y \geq 100N \).

5. Calculation of cable tension in a two-link tethered system

For the calculation, the scheme shown in Fig. 2 was adopted with the following characteristics:
- upper load-carrying cable "SV-PD": \( L_{DP} = 50 \text{ m}, d_D = 0.019 \text{ m}, q_D = -0.285 \text{ kg/m} \);
- bottom floating cable "PD-UV": \( L_{UV} = 100 \text{ m}, d_U = 0.01 \text{ m}, q_D = -0.0007 \text{ kg/m} \);
- passive depressor: \( Q_D = -100 \text{ kg}, C_s=1.2, U=1 \text{ m}^3 \);
- the vehicle is located strictly under the PD at a depth of 100 m.

The force of the hydrodynamic resistance of the depressor was determined by the formula [4]:

\[
R_{gx} = C_s \cdot \frac{D \cdot V^2}{2} \cdot U^{2/3}, \quad (8)
\]

where: \( C_s, U \) – coefficient of hydrodynamic resistance and displacement, respectively.
In fig. 11 the graphs are shown which illustrating the change in the shape of cables in a two-link tethered system at speeds from 0.5 to 1.5 m/s. The results of calculating the tension of communication cables on the device and the supporting vessel are shown in Fig. 12.

![Graphs showing the change in the shape of cables](image)

**Figure 11.** Dependence of the shape of the two-link system on the travel speed.

![Graph showing the tension of the communication cable](image)

**Figure 12.** Dependence of the tension of the communication cable of a two-link system on the travel speed.

The analysis of the results of the calculation shows that the cable tension on the vehicle, which occurs at a maximum oncoming flow velocity of 1.5 m/s, does not exceed 400 N. Thus, the effectiveness of the two-link tethered system has been confirmed when carrying out deep-water operations, which is provided by the power unloading of the lower cable due to the use of a passive depressor. The use of this technical solution it possible to almost halve the disturbing effect of the cable on the apparatus. The most promising seems to be a two-link tethered system using an autonomous unmanned underwater vehicle with an optical carrying micro-cable for communication with a depressor.

6. Conclusion
The carried out modeling of the stationary mode of movement of tethered underwater systems allows us to draw the following main conclusions:

- A rational margin of cable length relative to the towed equipment's depth has been determined, which corresponds to twice the depth of submersion.
- The principal possibility of tracking extended seabed object with both single-link and two-link tethered systems has been confirmed.
- For a single-link tethered system, involving the use of a surveq ROV with power supply through a communication cable, the tension of the running end at a speed of 1 m/s when vehicle is buried 100 m is about 720 N. The cable used in this case has a multiple safety reserve, and the energy resources available for the ROV quite enough to create the required thrust of the PSC.
- The use of a passive depressor connected with support vessel by armored load-carrying communication cable provides a significantly increased working depth of the ROV's applying. In this case, the reaction of the communication cable at the vehicle is reduced to 400 N.
The using in a two-link system an optical micro-cable for AUV's communication with the depressor allows minimizing the tension of the cable running end and obtaining the ability to inspect extended objects at practically any depth with autonomy corresponding to the capacity of vehicle's batteries.

7. References
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