The Analysis of Different Methods to Stabilize the Location of Descent Underwater Vehicles

Sergey Anatolevich Gayvoronskiy, Tatiana Ezangina, and Ivan Khozhaev

***Abstract* –The article deals with the position stabilization mode of a descent underwater vehicle under the conditions of sea disturbance. This descent underwater vehicle is connected with a carrier – ship by an elastic rope. A shock-absorbing hoist installed on the descent underwater vehicle is used to damp its oscillation. The analysis of the automatic positioning of the descent underwater vehicle at a selected depth using various stabilization systems is carried out. The systems difference is in the use of various sensors (measuring converter of the rope length, tension deviation sensor and their combination), measuring external disturbance from sea disturbance. The considered systems were simulated and the conclusions were made.**

***Index Terms* – descent underwater vehicles, measuring converter of the rope length, tension deviation sensor, sea disturbance, shock-absorbing hoist, stabilization systems, robust control.**

I. INTRODUCTION

AT present different practical tasks of the World ocean exploration are solved using tethered underwater vehicle tied up with a carrier-ship by means of a cable-rope [1 – 10]. The activities of the World ocean exploration include geological prospecting, oceanographic and other kinds of works. The use of tethered underwater vehicle is very promising since they can increase the operation life of autonomous underwater vehicle. For instance, the descent battery-charging stations are able to charge the storage batteries of autonomous underwater vehicle without taking them aboard. Using descent containers autonomous underwater vehicle can be submerged to the predetermined depth and taken again aboard.

The main problem by using different descent underwater vehicle is to ensure the precise stabilization to the predetermined depth in the sea dusting environment. This problem is associated with vertical oscillations of the tethered descent underwater vehicle affected by sea disturbance. These oscillations can transform into resonance ones and cause the rope break and the tethered descent underwater vehicle hitting the ground. Therefore, the damping of the descent underwater vehicle should be ensured by the stabilization system. To design such systems their mathematical models are required. These models take into consideration the abilities of the elastic "rope-descent underwater vehicle" link (the interval uncertainty of their parameters, its friction on water, etc.). A range of various control modes based on the measurement of their defined coordinates can be used.

The purpose of this work is to analyze the position stabilization systems of a descent underwater vehicle with different control methods

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II. BLOCK DIAGRAMS OF POSITION STABILIZATION SYSTEMS OF A DESCENT UNDERWATER VEHICLE

To analyze the stabilization system its block diagram (Fig. 1) was constructed allowing to realize three control modes. This system can work both with the sensor of rope tension deviation and the measuring converter of rope length as well as with the measuring converter of rope length and the sensor of rope tension deviation simultaneously.

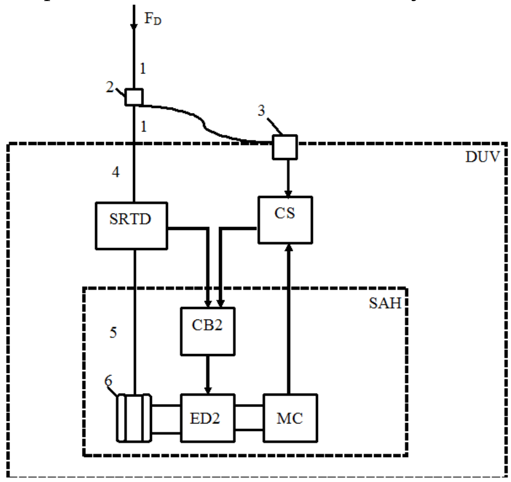

Fig. 1. Stabilization system of a descent submersible vehicle location

The following symbols are introduced in Fig.1: SAH – is shock-absorbing hoist; MC – is the measuring converter of rope length using the reducer on the shaft of the SAH; SRTD – is the sensor of rope tension deviation; ED2 – is electric drive 2, CS – is comparison-summator; CB2 – the second control block (CON- a shock-absorbing hoist regulator); 1– rope–rope, 2 – a lock joint, 3 – fastening, 4 – metal rod, 5 – rope, 6 – the drum of a SAH, F_D – is force of disturbing.

To develop the block diagram of the stability system of a descent submersible vehicles one should write the equation for some certain system components. The equation of

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vertical motion has the following form: $m\frac{dV_{DUV}}{dt}=F_{tf}$, where V_{DUV} – speed of DUV, F_{tf} – tension force in the rope, $m=\left(m_{DUV}+\mu\right)$ - is the mass of a DUV consideration associated water mass, μ is associated water mass, m_{DUV} is the mass of a DUV in water . The electric drive of shock-absorbing hoist is described by the following equation $J_2\frac{d\omega_{sah}}{dt}=M_d+M_{tf}$, where ω_{sah} is angular velocity of the drum rotation of SAH J_2 – is moment of inertia of SAH, $M_{tf}=F_{tf}R_2$ is torque produced on SAH by rope tension force, M_d is controlling torque of the drive of SAH. Thus, $M_{tf}=F_{tf}R_2$, where R_2 is drum radius of SAH, $M_d=k_{m2}(U_c-U_e)$ where U_c is output voltage of the SAH controller, k_{m2} is the transfer constant of SAH drive on torque, $U_e=k_{e2}\omega$ is back EMF voltage of the motor of SAH, k_{e2} is back EMF coefficient of the motor of SAH.

On the basis of the Hooke's law we will get the equation connecting the rope tension force and displacement force of its end

$$F_{tf}=\frac{C}{l_R}(x_{dis})-(x_{SAH}+x_{DUV}))+\frac{\chi}{l_R}\frac{d(x_{dis})-(x_{SAH}+x_{DUV}))}{dt},$$

where l_R is the lengthening of the rope, x_{SAH} is the movement of the rope on the dram of SAH, $C=C_{ssR}/l_R$ is stiffness coefficient of a rope, C_{ssC} is specific stiffness of a rope, $\chi=\chi_{idR}/l_R$ is the damping coefficient of a rope x_{tR} is the displacement of the rope top end , χ_{idR} is internal damping of a rope, l_R is the lengthening of the rope.

Let us assume that only the measuring converter of rope length is used in the system illustrated in Fig. 1. In this case the shock-absorbing hoist is controlled on the base of comparison of the dusting ordinate $_\Delta l_{dus}$ and the rope length change $_\Delta l_R$ between the lock joint and descent submersible vehicles. The difference signal ($_\Delta l_{dus}$– $_\Delta l_R$) is the control error. The signal is transmitted via the control block 2 to the shock-absorbing hoist, which damps the oscillation of the descent submersible vehicles.

It is to be noticed, that the reduction unit on which the measuring converter is based is an integral element which increases the system astaticism. Therefore, we suggest using P-controller instead of PI- controller. Its mathematical model is illustrated in Fig 2.

Let us assume that only the sensor of rope tension deviation is used in the system illustrated in Fig. 1. In this case the shock-absorbing hoist is controlled on the base of the rope tension deflection $_\Delta F_{tf}=C_{st}(_\Delta l_{dus}-{}_\Delta l_R)$, where $_\Delta l_{dus}$ corresponds to the movement of the upper end of the rope-rope, and $_\Delta l_R$ corresponds to the lower end of the rope. This expression shows that the sensor of rope tension deviation is able to measure the same control error as in the system with the measuring converter of rope length. To increase the rate of astaticism and minimize the errors in the control system we suggest using a PI- controller as a controller. Its mathematical model is illustrated in Fig 3.

Let us assume that the signals from the sensor of rope tension deviation and comparison unit are transmitted to the control block illustrated in Fig. 1. The control is carried out on the base of the observed coordinates of the rope length change and its tension deflection. It should be noticed that the simultaneous use of the reduction unit for the measuring converter and PI- controller for the sensor of rope tension deviation can result in system instability. Thus, we can use the sensor of the rope tension deviation simultaneously with the measuring converter but with a P-controller. Block diagram of this system is presented in Fig. 4.

III. THE PARAMETRIC SYNTHESIS OF THE ROBUST CONTROLLERS

Since there are interval parameters in systems it is necessary to provide them with robust characteristics ensuring the permissible performance quality at any possible variations of unstable parameters [11] – [12]. It is suggested using a robust approach in the control loop of a shock absorbing hoist by the parametric synthesis of a PI–controller. The interval expansion of the mathematical programming technique can be used as the basis of such approach [13]. To apply this approach we suggest combining the procedures of the system analysis and synthesis by affine and interval types of coefficients uncertainty of the polynomial. The work [4] presents the algorithm of such synthesis. In accordance with the developed algorithm the controller synthesis ensuring quasi maximal degree of stability [4] is carried out at the first stage. At the second stage the found parameterizations of the controller are substituted into the polynomial with affine uncertainty $D(s)=\sum_{i=1}^{m}[T_i]A_i(s)+B(s)$, where $[T_i]=[\underline{T_i};\overline{T_i}]$). Then on its basis the boundary vertex-edge route [14] is constructed for the polyhedron of interval system parameters.

After that the found route mapped onto the root plane and the vertex which is the closest to the imaginary axis is defined V_q (q– vertex number). Finally, previously calculated vertex coordinates are substituted into interval characteristic polynomial $D^q\left(\vec{k},\alpha^*,\beta\right)=\operatorname{Re}D^q\left(\vec{k},\alpha^*,\beta\right)+\operatorname{Im}D^q\left(\vec{k},\alpha^*,\beta\right)$.

The following non-linear equation system is derived, based on the interval characteristic polynomial

$$\begin{cases}\operatorname{Re}D^q\left(\vec{k},\alpha,\beta\right)=0;\\ \operatorname{Im}D^q\left(\vec{k},\alpha,\beta\right)=0;\\ \partial\operatorname{Re}D^q\left(\vec{k},\alpha,\beta\right)/\partial\alpha=0;\\ \partial\operatorname{Im}D^q\left(\vec{k},\alpha,\beta\right)/\partial\alpha=0;\\ \dots\\ \partial^c\operatorname{Re}D^q\left(\vec{k},\alpha,\beta\right)/\partial\alpha^c=0;\\ \partial^c\operatorname{Im}D^q\left(\vec{k},\alpha,\beta\right)/\partial\alpha^c=0.\end{cases}\quad(1)$$

Solving this problem we define the values of maximal degree of stability α and ensure its parameterizations of $\vec{k}$ controller.

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Let us apply this algorithm for the combined synthesis of the second system. Upon the results of the first and second stages [5] the vertex has been found $V_{20}(\underline{T_1};\overline{T_2};\underline{T_3};\overline{T_4};\underline{T_5})$, where $[T_1]=[m]$, $[T_2]=[\chi]$, $[T_3]=[\chi][m]$, $[T_4]=[C][m]$, $[T_5]=[C]$. After that, the coordinates of the obtained vertex are substituted into the set of nonlinear equations (1)

$$\begin{cases} \operatorname{Re} D^{20}\left(k_1,k_2,\alpha,\beta\right)=0; \\ \operatorname{Im} D^{20}\left(k_1,k_2,\alpha,\beta\right)=0; \\ \partial \operatorname{Re} D^{20}\left(k_1,k_2,\alpha,\beta\right)/\partial\alpha=0; \\ \partial \operatorname{Im} D^{20}\left(k_1,k_2,\alpha,\beta\right)/\partial\alpha=0. \end{cases}$$

Solving the set of nonlinear equations, we will find the desired controller parameters $k_3=0.77$, $k_4=2.2$ and maximal robust degree of stability $\alpha=0.35$.

As a results of applying of the combined synthesis algorithm for the first system and the third system controller settings $k_0=10^3$ was found.

As a result of applying of the combined synthesis algorithm the controller parameters for the first system $k_0=10^3$, and the third system is $k_0=5\times10^4$ was found

IV. Comparative Simulation of the Control Processes of the Position Stabilization Systems of the Descent Underwater Vehicle

To compare the stabilization accuracy of the descent underwater vehicle location at different modes with the sensor of rope tension deviation and the measuring converter the simulation of the corresponding systems at a depth of 6000 meters was carried out. The investigations were carried out at different sites of action of the disturbing signal caused by irregular sea disturbance (Fig. 5): on the carrier-ship and lock joint.

The simulation results are shown in Fig. 6 – 8. The system simulation allowed finding the mean square value of the vertical deviation of the descent underwater vehicle from the location stabilization $\sigma_1=2.7\times10^{-3}$ m. As a result of system simulation using the sensor of rope tension deviation we have found the mean square value of the vertical deviation of the descent underwater vehicle from the location stabilization $\sigma_2=0.11$ m.

In the case of simultaneous use of the sensor of rope tension deviation and the measuring converter in the system the mean square value of the vertical deviation of the descent underwater vehicle from the location stabilization makes up $\sigma_3=1.6\times10^{-3}$ m. Upon the simulation results we can conclude that the more accurate stabilization of the descent underwater vehicle is possible when using the sensor of rope tension deviation.

V. Conclusion

Upon the comparison of the mean square deviation of the vertical movement of the descent underwater vehicle for different systems it was determined, that $\sigma_2<\sigma_3<\sigma_1$. The inequality $\sigma_3<\sigma_1$ is correct, since a correcting element in the form of the sensor of rope tension deviation is introduced in the system with the measuring converter. This inequality, where $\sigma_2<\sigma_3$, is explained by the use of the sensor of rope tension deviation with a PI-controller in the system. Unlike the integrator, PI-controller allows increasing the overall transfer coefficient of the system and improving the location stabilization accuracy of the descent underwater vehicle. From the results of mathematical modeling, we can conclude that precise stabilization of the descent submersible vehicle is possible using the sensor of rope tension deviation.

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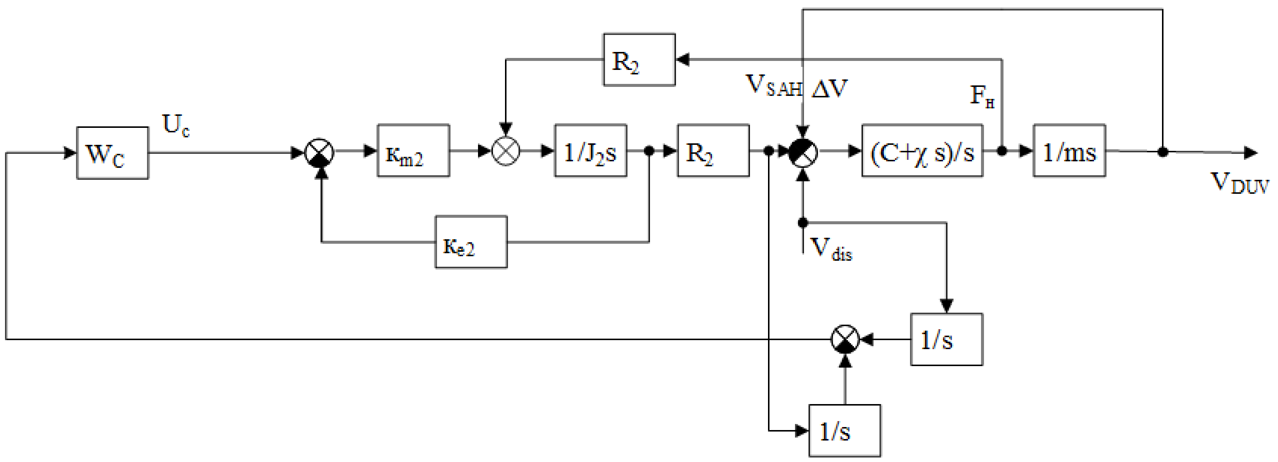


Fig. 2. Blok diagram of position stabilization systems of a descent underwater vehicle with the measuring converter

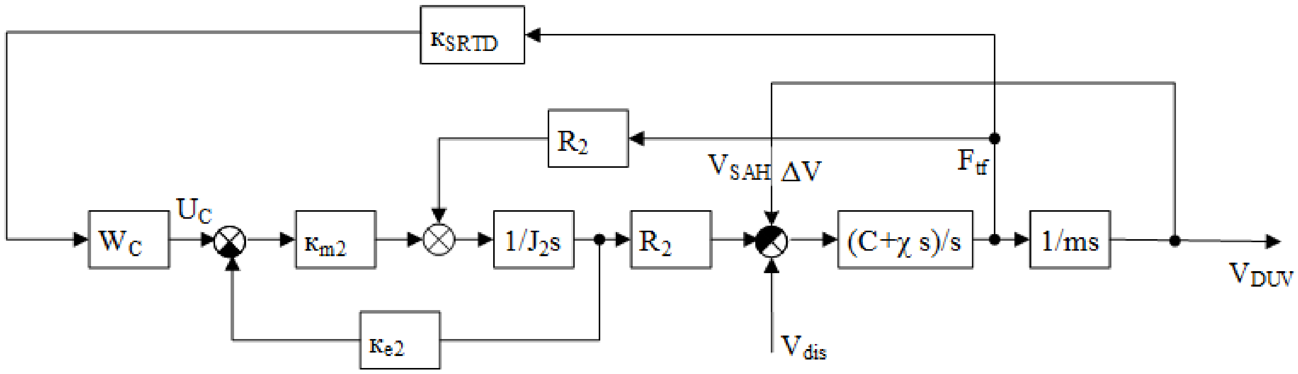


Fig.3. Blok diagram of position stabilization systems of a descent underwater vehicle with the sensor of rope tension deviation

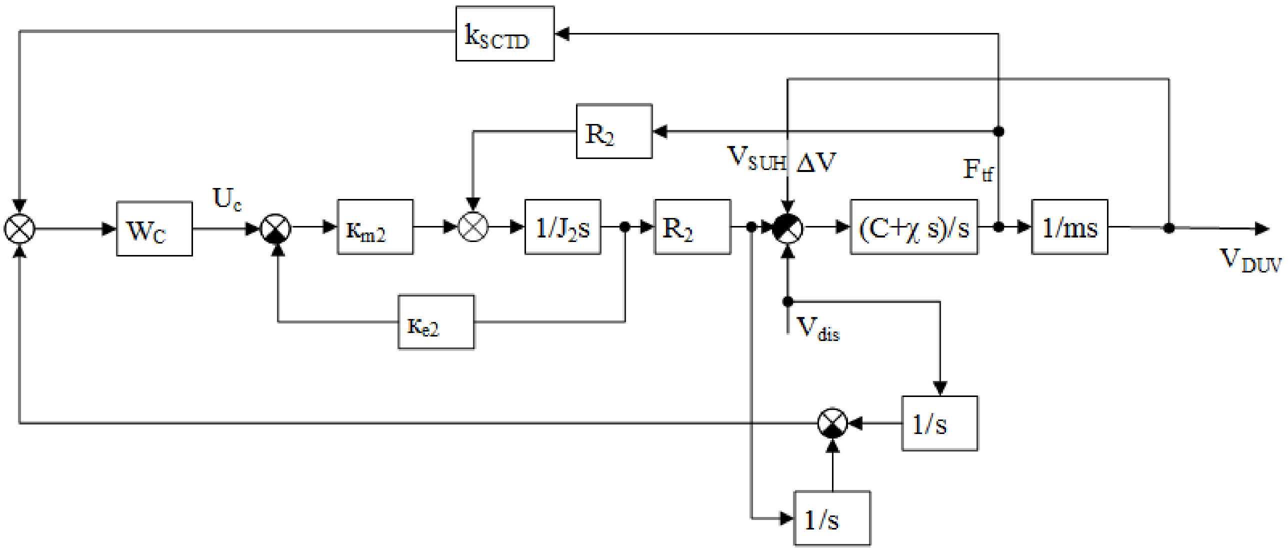
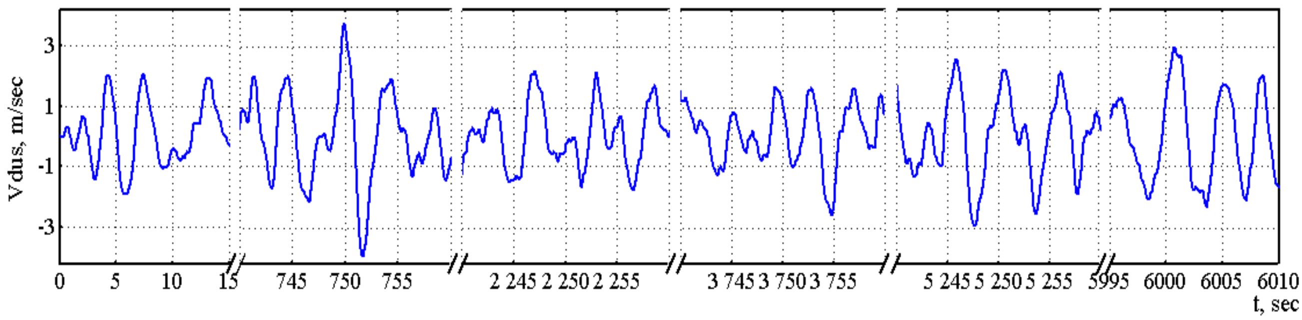


Fig. 4. Blok diagram of position stabilization systems of a descent underwater vehicle with the sensor of rope tension deviation and the measuring



Fig,5. The diagram of the ordinate variation of irregular sea disturbance

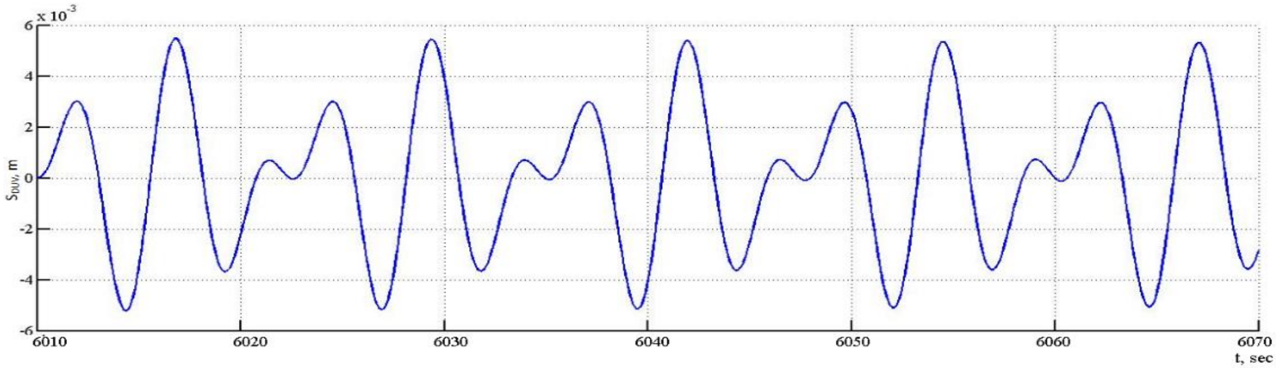


Fig. 6. Vertical movement variation curves of the descent underwater vehicle with the measuring converter

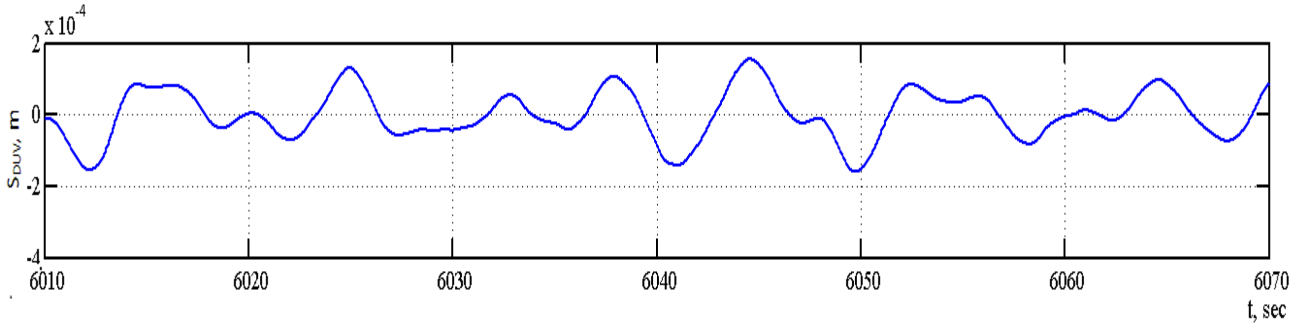


Fig.7. Vertical movement variation curves of the descent underwater vehicle with the sensor of rope tension deviation

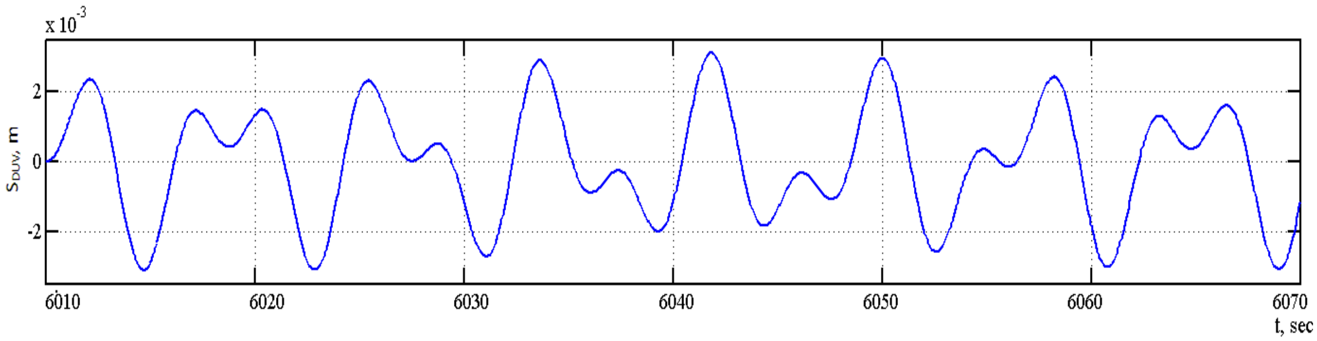


Fig. 8. Variation curves in the vertical movement stabilization mode of the descent underwater vehicle with the sensor of rope tension deviation and the measuring convert