Dynamics of the accessible solid body’s movement controlled by two drives with rectreline movement of it’s mass center

V N Platonov, E S Briskin and N G Sharonov
Department of Theoretical Mechanics, Volgograd State Technical University, 28 Lenin Avenue, Volgograd 400005, Russia
E-mail: dtm@vstu.ru

Abstract. Based on experimentally obtained step response, an analytical relationship between the input and output parameters of the anchor-rope propulsion’s control system, reflecting it’s dynamic properties, is obtained. The features of motor control, DC and stepper in the structure of the actuators of the anchor-rope propulsion have been set.

1. Introduction
One of actual important science problem today is the studying of the translational motion of a robot with walking propellers [1, 2, 3], in particular, an underwater pantone platform using an anchor-rope propulsion [4, 5]. A feature of such robotic systems is the use of an excess, from the point of view of ensuring the given movement of the robot platform, of the number of propulsions, which is explained by the need for reliable interaction of anchors with a difficult to predict bottom topography and its physical and mechanical properties.

In the process of the moving such platform with anchor-cable propulsions, the need arises for a controlled load distribution between them. In this case, the most important factor directly determining the dynamics of the platform’s movement is the form of transients that occur in the propulsions. Such dynamics indicators of the walking robotic systems movement as gaitiness, controllability and maneuverability directly depend on such transients.

2. Formulation of the problem
The task of distributing dynamic load between several actuators according to one or another criterion is quite well known. The simplest example is working of the automobile differential. Cable robot control systems are also known [6]. The load distribution between several actuators is implemented in control systems of an interconnected electric drive [7].

In [8] modeling of translational rectilinear motion of the platform with the help of two anchor-rope propulsions is presented. Equations of cargo movement and solutions were obtained that allow one to determine control actions (voltages supplied to electric drives) for realizing the set force ratio in propulsion ropes $\lambda = T_2/T_1 = \text{const}$. However, in the process of platform movement, it becomes necessary to change the value of $\lambda$ (when turning, changing gait, when moving along the bottom with a complex geometric relief, etc.). Therefore, the force ratio $\lambda$ has the character of time dependence $\lambda(t)$. For $\lambda \neq \text{const}$, the problem of determining the transition process laws and the problem of assessing the quality indicators of the control process are arising.

For the analysis of transients in anchor-rope propulsions, their identification is necessary.
3. Solution method
As one of the methods to describe the dynamic properties of the considered anchor-rope propulsion control system, the apparatus of transfer functions can be used. In this case, the platform’s mover is considered as a model of the "black box" type. The problem under consideration is reduced to finding an analytical relationship between the control object input and output based on experimentally measured input data and corresponding output data. An anchor-rope propulsion in this case can be considered as a control object, shown in Figure 1.

![Figure 1](image)

**Figure 1.** Representation of the model stand as a control object.

For the control object under consideration, the transfer function can be determined for a variety of input-output ratios, the most significant of which are:
- a) input supply voltage to the motors - output translational speed of the armature;
- b) input supply voltage to the motors – the flywheels torque difference;
- c) the flywheels angular velocities difference - the flywheels torque difference.

To determine the transfer function of the control system using the model stand shown in Figure 2, the experimental step response was shot for the value of the forces ratio $T_2/T_1$ in the ropes as the output channel during the transition process from one given setting of this ratio to another.

![Figure 2](image)

**Figure 2.** Model stand of anchor-rope propulsion: 1 – anchor imitator (load); 2 – step motors; 3 – flywheels; 4 - strain gauges mounted into a ropes; 5 – control board.
The model stand is the electro-mechanical system with the load lifted by two flywheels using ropes. The rotation of the flywheels is carried out by stepper motors. Strain gauges are installed in the cables to provide torque measurements.

The set values in the experiment are: the law of the load movement \( y = y(t) \) and the rotation angles of the stepper motors rotors \( \Delta \phi_1, \Delta \phi_2 \). During the experiment, the relationship between the forces in the ropes \( T_1 \) and \( T_2 \) was fixed. The experimental step response is shown in Figure 3.

![Figure 3](image_url)

**Figure 3.** The experimental step response of anchor-rope propulsion with setting the flywheel angular velocity difference as input channel.

The identification of the control object was carried out by approximating the presented experimental step response with a second-order transfer function of the form:

\[
W(s) = \frac{k}{s^2 + C_1s + C_2},
\]

where \( k, C_1 \) and \( C_2 \) - parameters for determining; \( s \) - the Laplace variable. The search for these parameters was carried out using the least squares method by minimizing the total summed error between the experimental step response and the step response approximated by the transfer function (1). As a result, for the presented transient process from one given setting of the \( T_2/T_1 \) ratio to another, the following values of the sought parameters were determined: \( k = 1, C_1 = 1, C_2 = 1.5 \). A comparison of the experimental step response and approximated by the transfer function (1) step response is presented in Figure 4.

![Figure 4](image_url)

**Figure 4.** Approximation of the experimental step response by the step response of the second-order transfer function: 1 – set value; 2 - experimental step response; 3 - step response of the second-order transfer function.
In accordance with the obtained values of the coefficients, the transfer function (1) can be represented in the following form:

\[ W(s) = \frac{1}{s^2 + 1.6s + 2.57} \]  

(2)

where \( C = 1.267 \), \( \xi = 1.014 \).

Then the differential equation describing the connection can be written in the following form:

\[
\frac{16}{\xi^2} \frac{d^2 y(t)}{dt^2} + 1.6 \frac{dy(t)}{dt} + 2.57 y(t) = \frac{d^2 x(t)}{dt^2}
\]  

(3)

where \( x(t) \) - is the input signal to the control system (in this case, this is the flywheels angular velocities difference \( \omega_2/\omega_1 \)); \( y(t) \) - is the output signal (in this case, this is the adjustable ratio \( T_2/T_1 \)).

The obtained transfer function (2) corresponds to the second-order vibrational link. The differential equation (3) describe transient processes in an elastic system with a damping element. The damping element in the system under consideration is a strain gauge sensor with a steel plate as a sensitive element. Due to the fact that steel has a significant modulus of elasticity, the transition process is stable and there are no oscillations in the system under consideration.

Based on the obtained transfer function (2), the Bode-diagrams of the control object shown in Figure 5 can be obtained and analyzed.

![Bode-diagrams of the control object](image)

**Figure 5.** Bode-diagrams of the control object.

### 4. Results

During the researching the step response of the stand anchor-rope propulsion control system was experimentally obtained. Based on the obtained experimental step response, the control object is identified and it’s transfer function is obtained. Based on the identified math model, the analysis of the control object frequency characteristics is done. The results obtained are used in the development of a real model of an underwater pantone platform with an anchor-cable propulsion.

**Acknowledgments**

The research was supported by Russian Science Foundation (project No. 19-38-90265).

**References**

[1] Serov V A, Kovshov I V, Ustinov S A 2017 Tasks of technological robotic walking platforms in the development of underwater (ice) mineral deposits Izvestiya YUFU. Tekhnicheskie nauki. 9 (194) pp 181-191

[2] Jin-Ho Kim, Tae-Kyoeong You, Suk-Min Yoon, Hyung-Woo Kim, Jong-Su Choi, Cheon-Hong Min and Sup Hong 2013 Electric-Electronic System of Pilot Mining Robot, MineRo-II Proceedings of the Tenth ISOPE Ocean Mining and Gas Hydrates Symposium Szczecin pp 269-273
[3] Chernyshev V V and Arykancev V V 2015 MAK-1-underwater walking robot *Robototekhniika i tekhnicheskaya kibernetika* 2 pp 45-50

[4] Briskin E S, Sharonov N G, Serov A V and Penshin I S 2018 Motion control of underwater mobile robot with anchor-rope propulsion devices *Robototekhniika i tekhnicheskaya kibernetika* 2 (19) pp 39-45

[5] Briskin E S, Penshin I S, Smirnaya L D and Sharonov N G 2017 Determination of forces in the engines of the anchor-cable type *Izvestiya VolgGTU. Aktual'nye problemy upravleniya, vychislitel'noj tekhniki i informatiki v tekhnicheskikh sistemah* 14 (209) pp 87-90

[6] Fadeev M Yu and Maloletov A V 2019 Controlling a parallel four-wire robot using the inverse kinematic model *Proc. Int. Conf. MIKMUS* pp 696-699

[7] Egorov E K 2010 Load distribution in multi-motor drives *Vestnik KuzGTU* 2 (78) pp 96-99

[8] Briskin E S and Platonov V N 2019 On math modeling of solid body’s motion control with an excess number of rope propulsion devices 7 pp 422-427