About features of management of mobile robots with stepping movers of a rope type in a water environment

E S Briskin\textsuperscript{1,2}, V V Gulevsky\textsuperscript{1}, I S Penshin\textsuperscript{1}, N G Sharonov\textsuperscript{1,2}

\textsuperscript{1}Department of Theoretical Mechanics, Volgograd State Technical University, 28 Lenin Avenue, Volgograd 400005, Russia
\textsuperscript{2}Center for Technology Components of Robotics and Mechatronics, Innopolis University, Innopolis, Russia
dtm@vstu.ru

Abstract. The methods of moving robotic platforms having in their arsenal either an anchor-rope or an anchor-rope-tracked mover are analyzed. The algorithms of operation of caterpillar-anchor-cable movers of various designs and gait algorithms for a platform with an anchor-cable mover are determined.

1. Introduction
The current level of development of the oil and gas industry, the need to study and develop the wealth of the bottom of the oceans forces the industry to develop various kinds of devices for moving in the water column and along the seabed \cite{1,2,3}. For the most part, vehicles moving along the bottom are analogues of land machines modified for work under water, which imposes a number of restrictions on them, such as: a limited radius of action from the base station or shore, a small depth available for work, the ability to move exclusively along the prepared bottom, high risk of linking tracks, wheels in a muddy bottom \cite{4,5}. Mobile devices moving in the water column have greater mobility and are able to work at a wider range of depths, but at the same time they have a number of serious drawbacks that prevent their widespread use for industrial purposes, namely: limited carrying capacity, the inability to work in areas with strong undercurrents.

2. Cable propulsor

2.1. Anchor-rope propulsor
Most of the above disadvantages of existing mobile submarine systems are deprived of mobile platforms with an anchor-rope propulsion \cite{4,5,6,7}. Unlike other walking movers \cite{8,9,10,11,12}, used on land and in the aquatic environment, is the use of cables in conjunction with cargo-anchors, adapting to different topography of the bottom. The movement of a robot with an anchor-rope propulsion is carried out due to the cyclical action of the executing mechanism, in this case flywheels with cables, on the anchor, which is the organ of the robot to engage the surface. The movement scheme of a robot with an anchor-cable mover is shown in Figure 1.
The movement is as follows: the anchor 1 is meshed with the ground 7 and in conjunction with the pulling cable 2 and the carrying cable 3, which are connected with the flywheels 4. At the beginning of the movement, the pulling cable 2 pulls the entire robot to the armature 1, until the cable 2 takes a vertical position. After this, the cable 2 begins to raise the anchor 1 and at a certain point in time, the flywheel with the cable 3 is turned on, which transfer the anchor 1 to the initial position, thus describing the trajectory 6. Thus, the cyclic movement of the anchor-rope propulsion occurs.

2.2. Track-anchor-cable propulsor
Another example of a platform with a small positive buoyancy for moving under water in the near-bottom zone is a model with track-anchor-cable propulsor, a schematic diagram of the first of them is presented in Figure 2. Examples of the use of tracks as a mover for the robot support structure are known in the art. For example, the robot is attached to the surface by pumping air from a sealed bowl connected to the track, due to the difference in atmospheric pressure and pressure inside the bowl, a force appears that presses the bowl to the surface and holds the robot on the surface [12]. In the with track-anchor-cable propulsor, the track serves to transfer the anchor-cable system with which the mobile platform moves along the bottom of the reservoir. Mobile robots with anchor-rope propulsors, which use the principle of movement similar to anchor dredgers, are close in the possibilities of movement and use as a platform for basing various equipment [13], but unlike them, they have great mobility and capabilities.
Figure 2. Schematic diagram of a mobile platform with a track-anchor-cable propulsor.

Schematic diagram of the track-anchor-cable propulsor shown in Figure 1, close to the rotor-orthogonal propulsion [14] and consists of the following elements: platform 1 with variable buoyancy; conveyor 2 - which rotates in the direction of platform movement, with 3 winches located on its links having a control system; anchor - 5 connected to the winch with a cable - 4.

A device with a similar displacement system is capable of moving along a complex topography of the bottom, along low-density soil while maintaining a low roll of platform 1 carrying a payload. The movement is as follows: In “position 1”, the anchor connected by a cable to the conveyor link directed towards the platform V travels, lowers to the bottom of the reservoir; rotating around its axis, the conveyor 1 by tensioning the cable moves to a distance X, passing into "position 2"; when the conveyor link reaches an angle of rotation of 120 degrees, the anchor located on the bottom begins to rise from the bottom with the help of a winch, and the anchor located at that moment on the link directed towards the platform, lowers to the bottom.

There is also a second circuit diagram of an track-anchor-cable propulsor excluding winches and a control system from the diagram in Figure 2, which will make it possible to cheapen the development and production of such an apparatus, but will limit its scope to areas with a relatively flat bottom. The schematic diagram of the second mobile platform is presented in Figure 3.
Figure 3. schematic diagram of a mobile platform with a track-anchor-cable propulsor.

Schematic diagram of the track-anchor-cable propulsor shown in Figure 3 consists of the following elements: platform 4 with an adjustable variable buoyancy; caterpillars (conveyor) 5 - rotating in the direction of movement of the platform; anchor 2 connected to the winch by a cable 3, the mechanism of the skew track 1.

The principal difference of this scheme of the track-anchor-cable propulsor is the absence of winches for each anchor cable, a fixed length of the anchor cable, and also the presence of a skew mechanism of the track relative to the horizontal plane of the platform 4. The movement of the mobile platform is as follows: the track 5 rotates, the anchors located in the lower branch of the track are lowered to the bottom, the cable length is fixed, while the track is running. At the moment of approach of the point of attachment of the cable on the caterpillar to the platform aft, the anchor breaks off the bottom, due to the existing skew of the caterpillar, until this caterpillar crosses to the bow of the platform.

The device of mobile platforms, both the first and second types for the track-anchor-cable propulsor, will allow to move the payload and mechanisms for the development of the shelf of the seabed, as well as the study of sea depths, laying of underwater pipelines, etc. A mobile platform with track-anchor-cable propulsor will be able to work at a wide range of depths, under the influence of sea currents, a type 1 platform is suitable for moving along an unprepared seabed.

3. Formulation of the problem

3.1. Theoretical background
Moving the platform with the anchor-rope propulsion requires solving the problem of determining the number of anchors sufficient for a stable position of the mobile platform. One of the features is the required number of anchors that are meshed $N$. Thus, all loads that perform the function of anchors can be divided into anchors interacting with the ground and anchors in transport $K$. The total number of anchors is then represented in the expression:
The value of N is important, since with an insufficient number of anchors in the mesh, either drift by the course of the platform itself or imbalance can occur. Figure 4 shows the design diagram of the platform pontoon for anchors in gear and anchors in transport.

\[ M = N + K \]  

(1)

The task is to determine the cable tension forces \( T_{k1}, T_{k2}, T_{j1}, T_{j2} \) depending on the installation location of the blocks on the platform \( b_k, b_j \); stride length \( L \), weight \( G \), buoyancy \( \Phi \), forces of resistance to movement \( Q \), gait, as well as conditions of slipping of anchors on the ground.

3.2. Synthesis of Equations

The solution method is based on the consideration of the model problem of uniform motion of all bodies included in the considered mechanical system of translational motion of the underwater platform. Since the number of unknown tension forces \( T_{k1}, T_{k2}, T_{j1}, T_{j2} \) and reactions \( N_j, F_j \) exceeds the number of obtained equations of motion, it becomes necessary to draw up additional equations that simultaneously determine the possibility of controlling individual tension forces [16].
Mandatory conditions are the conditions of the state of tension of all cables, the absence of separation and slipping of the anchor in the support:

\[ T_{j1} > 0; T_{j2} > 0; T_{k1} > 0; T_{k2} > 0; N_j > 0; F_{cuj} \leq fN_j \]  

(3)

For anchors in transport, the equations:

\[
\begin{aligned}
\sum_{j=1}^{N} T_{j1} \cos \alpha_{j_1} + \sum_{j=1}^{N} T_{j2} \cos \alpha_{j_2} + \sum_{k=1}^{K} T_{k1} \cos \alpha_{k_1} + \sum_{k=1}^{K} T_{k2} \cos \alpha_{k_2} - Q &= 0 \\
\sum_{j=1}^{N} T_{j1} \sin \alpha_{j_1} + \sum_{j=1}^{N} T_{j2} \sin \alpha_{j_2} + \sum_{k=1}^{K} T_{k1} \sin \alpha_{k_1} + \sum_{k=1}^{K} T_{k2} \sin \alpha_{k_2} - G + \Phi &= 0 \\
\sum_{j=1}^{N} b_j T_{j1} \sin \alpha_{j_1} + \sum_{j=1}^{N} T_{j2} (b_j + L) \sin \alpha_{j_2} + \sum_{k=1}^{K} b_k T_{k1} \sin \alpha_{k_1} + \sum_{k=1}^{K} T_{k2} (b_k + L) \sin \alpha_{k_2} + \Phi &= 0
\end{aligned}
\]  

(2)

Equations for support anchors:

\[
\begin{aligned}
\sum_{i=1}^{N} \left( F_j - T_{j1} \cos \alpha_{j1} + T_{j2} \cos \alpha_{j2} \right) &= 0 \\
T_{j1} \sin \alpha_{j1} + T_{j2} \sin \alpha_{j2} + N_j - mg &= 0
\end{aligned}
\]  

(5)

The resulting equations (2), (4) and (5) complemented by \((2N+2K-3)\) cable tension control equations [7]:

\[
\sum_{i=1}^{M} \left( a_{j_1 i} T_{j1} + a_{j_2 i} T_{j2} \right) + \sum_{k=1}^{K} \left( b_{k_1 i} T_{k1} + b_{k_2 i} T_{k2} \right) = C_i
\]  

(6)

\(a_{j_1 i}, a_{j_2 i}, b_{k_1 i}, b_{k_2 i}, C_i\) – power management matrix elements.

When calculating dependencies (2), (4) and (5) with considering (3), platform movement is set. When one of the forces \(T_{j1}, T_{j2}\) becomes less than or equal to zero (which corresponds to the maximum movement of the object with the position of the supports on the ground unchanged), transfer is required. The calculation for the new combination of supports is carried out using the equations (2) and (5), and for support in the transference the system of equations becomes fair (4). Thus, this method allows to obtain the values of the cable tension forces for each support at each stage of movement.
The ratio of the phases of support and transfer for various propulsors forms a gait. One possible gait option is the movement diagram of five movers over time \( \tau \), when moving from a state of rest and further cyclic transfer of supports.

![Anchor movement diagram](image)

**Figure 5.** Anchor movement diagram.

In the motion algorithm constructed by Figure 5, at any moment in time there are three anchors in the support, and two are in the carry.

4. Conclusions

Studies conducted for the platform, which includes an anchor-ropepropulsor in its equipment, allow us to analyze the design features of the anchor-ropepropulsor for various gait.

Schematic diagrams of platforms with track-anchor-cable, anchor-rope propulsors allow you to develop devices with different load capacities, for a specific type of transported cargo. The development of such devices is a promising direction in the development of the mobile robot industry. Currently, it is planned to develop algorithms for the movement of platforms with the indicated types of propulsors on a prototype.

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