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Particularities of Wall Climbing Robot Motion on Underwater Environments[1]

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The paper presents peculiarities of some components of wall climbing robots intended for motion along underwater surfaces and performs underwater technologies. Recommendations for design of vacuum contact devices equipped with "gas-water" ejector are analysed. The information data preparation for modelling and simulation the vacuum contact devices are needed to find required parameters. The obtained hydromechanical characteristics permit to prepare wall climbing robot for realization some underwater technologies.

Vacuum contact devices are intended for produce gripping functions with underwater horizontal or sloping surfaces over which underwater wall climbing robots are moving.

In motion process one platform can move when other platform is connected with surfaces by means vacuum contact devices. Another words, when external group of vacuum contact devices is fixed to the surface, internal one can move with the platform, and so on.

Underwater wall climbing robots consists of internal and external platforms equipped with vacuum contact devices placed on the end of every leg. Sensory system includes a video camera that is used for robot navigation and orientation, proximity sensors for fixation final positions of pneumatic drives and pressure-vacuum sensors intended for measure forces inside of vacuum contact devices.

Technological equipment is installed on the upper platform. Suggested experimental robot prototype has control system that permit to organize automatic or supervision control with participation of man-operator.

The drive design provides both the continuous low velocity mode to fulfill technological operations by the robot, and the discrete high velocity mode. The discrete high velocity mode is convenient for the transportation of technological equipment to working area.

This paper includes following sections: prescribed tasks for underwater wall climbing robot technologies, main peculiarities of the robot, vacuum contact devices study and conclusion.

Keywords: *underwater environment, wall climbing robot, vacuum contact devices, gas water ejector, recommendations for design*

1. Introduction

Climbing machines for underwater applications have a lot of innovations in design, construction, materials and components for mechanical, sensory, control and tool systems. In common case climbing underwater machine is a mobile underwater robot intended for realization technological prescribed tasks. The robot's mechanical system, including vacuum contact devices, drives, sensors are the mechatronic types with special design that permitted to work in underwater conditions up to 20 meters depth. Vacuum contact devices are one of the main components required special attention.

The paper presents discussion related with prescribed tasks, experimental characteristics, demands for basic schemes, recommendations for vacuum contact device design, information data for simulation and modeling.

2. Prescribed tasks for wall climbing robot technologies

Prescribed tasks for underwater climbing robots may be as follows:

— inspection and repair of the surfaces of the pools in nuclear power stations;

— technological processes producing such as cleaning, cutting, welding, along surfaces in such pools;

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— survey and cleaning of ships surfaces, during parking in ports;

— survey and cleaning of channels and dams walls;

— survey and repair of underwater parts of petroleum platforms;

— inspection and repair of underwater pipelines;

— inspection and underwater cutting of sink ships;

— help for divers.

For execution of such work it is necessary to fix the robot on the surface and then to perform the robot's movement along the surface. For these cases it is recommended to take into attention the experience of use the underwater special design climbing robots (UCR) [1]. UCR are capable to move along vertical and slope surfaces, located under water with the help of vacuum grippers [2—4]. Advantages of such robots are ability to move along the surfaces of various materials (metal, concrete, etc.) and reliable fastening on the surface.

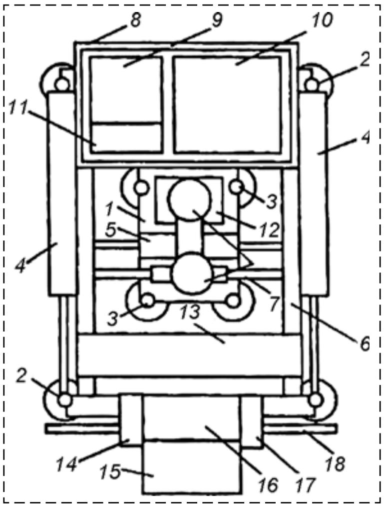

Fig. 1. Scheme of Underwater Climbing Robot

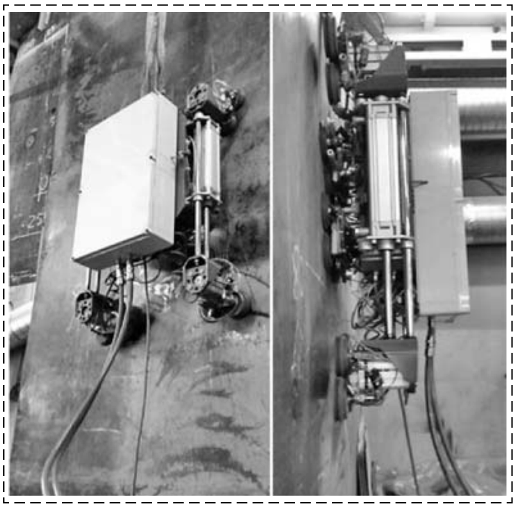

Fig. 2. View of Underwater Climbing Robot

Investigation of UCR motion under water were conducted and some results were received in [5, 6]. In this article the requirements for UCR are formulated and new opportunities of their application are considered.

In spite of obtained previous results, new problems are developed, such as nuclear power station service that required additional investigation to design more reliable vacuum contact devices [7].

3. Main of UCR's peculiarities

Besides general features for all type underwater vehicles (such as increased pressure, fluidity environment, etc.), a surface quality is important of a UCR reliable motion. As a rule, the surfaces, located under water are covered by different kinds of sea-weeds and deposits. Therefore for motion along such surfaces it is necessary special vacuum contact devices or combined with mechanical grippers. Application of jet gauges is possible for control vacuum grippers. Also, it is possible to clean a surface of motion. One of important quantity is that, the influence of water currents on UCR motion is less then on floating underwater vehicles.

Certainly, the main type of underwater vehicles (UV) are various floating apparatuses, however UCR has its own place in general hierarchy and it is difficult to find substitution for them.

The designed UCR consists of two platforms (Fig. 1). Here *1* is internal platform with leg group *3* and vacuum contact devices (VCD) on every leg; *2* — leg group with VCD of external platform; *4* — transport pneumatic drive; *5* — rotating unit; *6* — external platform; *7* — piston-drive; *8* — technological platform; *9* — technological equipment; *10—11* — germatic units of control system; *12—15* — platforms for sensory equipment.

A technological module is installed on the platform. A video camera is used for navigation and orientation of the robot. A control unit organizes automatic control of the whole system.

The URC moves as follows. When the internal group of the VCD is connected to motion surface by means of the grippers, the external one has possibility to move easily with a piston-rod relative to the platform or the platform can rotate to change the direction of motion by rotation unit. When the external group of the VCD is fixed on the surface, the internal one can move with the platform, and so on.

The view of one prototype version is shown in Fig. 2. The following forces are acting on UCR in underwater position (Fig. 3):

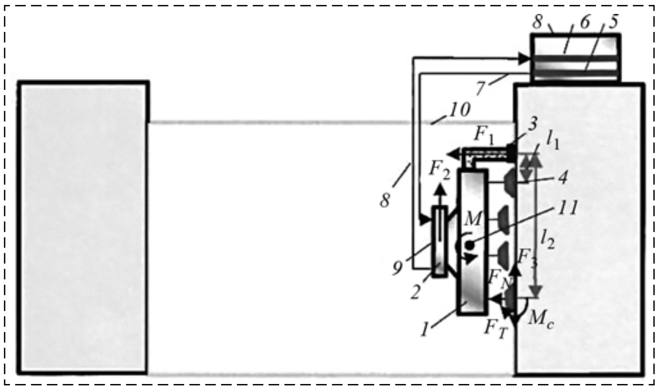

Fig. 3. Underwater robot place and acting forces on Underwater Climbing Robot

F_1 — technological force, F_2 — acting force of water column, F_3, F_N and F_T — friction, normal and tangential forces, acting on every vacuum contact device, M_c — moment acting on every vacuum contact device, M_1 — overturn moment applied at center of mass of UCR.

Acting vibrations on UCR as result of technological processes may be harmonic type, $F_1 = A\sin\omega t$.

Motion equation of the pneumatic drive piston of UCR with technological equipment mass m may be written as follows:

$$\Sigma F_i = 0 \text{ or } \ddot{x} = \frac{1}{m}(F_0 + F_1 + F_2 + F_3 - F_4),$$

where F_1 — technological force, F_2 — acting force of water column, F_3 — dry friction force, $F_4 = D\dot{x}$ — viscous friction in pneumodrive, $D = 2{,}5 \cdot 10^{-2}$ H·(c/M) — coefficient of viscous friction; F_0 — additional payload of UCR, $P_0 = m_0 g \cdot \sin\alpha$, m_0 — total UCR mass, g — acceleration due to gravity, α — angle of surface.

Reduction gear sets the desired value of the output drive velocity. The microprocessor connected with regulator and rack carries out a control of the PC working longitudinal motion.

This drive design provides both the continuous low speed mode to fulfil technological operations by the robot, and the discrete high speed mode. The discrete high speed mode is convenient for the fast transportation of the technological equipment by the UCR to working zone. The discrete high speed mode is switched on by a control muff disconnection. In the continuous low speed mode a control muff connects the engine block with PC. In this case, the drive output velocity depends on the engine velocity.

4. Vacuum contact devices study

Vacuum contact device (VCD) is intended for realize gripping function of UCR with a surface in underwater position. The standard friction gripper (FG) have a normal gripping force of over 1000 N, but they need an initial press force about 150 N to seal the possible roughness and cracks of a motion surface. There are standard sealing grippers (SG), which can seal the roughness up to 4 mm and more by an elastic edge, but they have no sufficient gripping force. The combination of these two kinds of grippers gives a possibility of having a high gripping force with a sealing effect on the rough surfaces.

This two-staged VCD is shown in Fig. 4, where *1* — elastic sealing, *2* — pad is realize function of force sealing and is connected with piston drive *5*, *4* — ejector, *6* — position sensor, P_{S1}, P_{S2} — supply

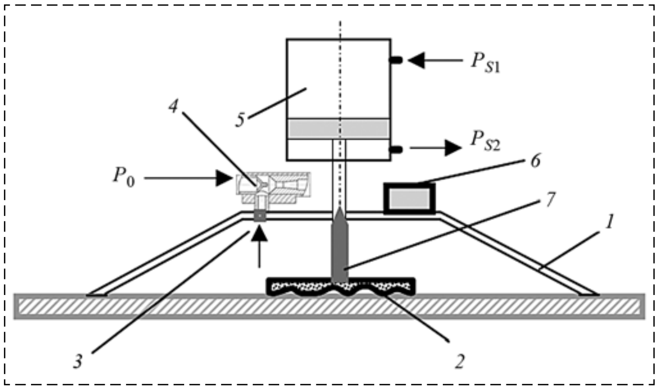

Fig. 4. Scheme of vacuum contact device with a piston drive

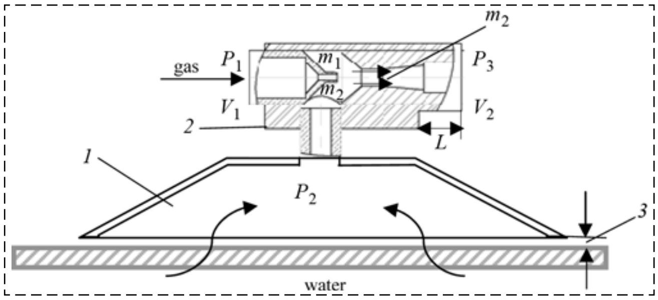

Fig. 5. Scheme of vacuum contact device with ejector

pressure for piston drive. At the initial moment only the SGs are actuated. They produce an attaching force enough to seal the roughness for the FGs. This is the first "sealing" stage. After the sealing response time is finished in about 1,7 sec the power ejector is switched on. As result the FGs carry out a force fixation of the UCR by means VCD on the motion surface in about 2 sec response time. Time is the second "force" stage of the gripping. The used FGs with diameter 160 mm provide an attaching force up to 1100 N. The two-staged gripping takes approximately 4 sec and then it is possible to begin a working stage to fulfil a stride by moving one group of the VCD relative to another one, which is fixed to a motion surface.

The gas ejector 4 (Fig. 4) of VCD is intended for produce vacuum P_2 in the chamber 3. Air and water mass flow through the every of channels 1, 2, 3 of the ejector 4 (Fig. 4, 5) can calculated as

$$m_i = \rho_i V_i S_i,$$

where ρ_i — density, V_i — velocity, S_i — space of cross section of *i*-flow. For gas stream $S_1 = \frac{\pi d_1^2}{4}$, for water stream $S_2 = \frac{\pi d_2^2}{4}$, for mixture flow $S_3 = \frac{\pi D^2}{4}$.

The following balance equations are valid for gas-water ejector [6, 7]:

motion balance:

$$m_1V_1 + P_1S_1 + m_2V_2 + P_2S_2 = = (m_1 + m_2)V_3 + P_3S_3; \quad (1)$$

energy balance:

$$m_1\frac{V_1^2}{2} + m_2\frac{V_2^2}{2} = (m_1 + m_2)\frac{V_3^2}{2}. \quad (2)$$

Using those equation, it is possible to find vacuum P_2, if other parameters are known [7]:

$$P_2 = \left[\frac{1}{S_2}m_1V_1 + P_1S_1 + m_2V_2 - P_3S_3 - (m_1 + m_2)\left(\frac{m_1V_1^2 + m_2V_2^2}{m_1 + m_2}\right)^{1/2} - \frac{1}{2D}(\lambda P_3(L - L_T)\Phi^2)\frac{m_1V_1^2 + m_2V_2^2}{m_1 + m_2}\right], \quad (3)$$

where P_1, P_2, P_3 — pressure in the cross section 1, 2, 3, coefficient $\lambda = \frac{0,3164}{(Re)^{1/4}}$, Re — Reynolds number, Φ^2 — Martinelly parameter [9].

We supposed that pressure P_2 is in chamber 1 (Fig. 5), x — variable pneumatic restriction where pressure change from atmospheric P_a up to vacuum P_2, 3 — constant pneumatic restriction, and $P_a - P_2 = k \cdot P$ — linear approximation.

The force characteristics depends on the depth are presented in Fig. 6.

The number of the VCD for such a purpose is calculated beforehand depending on a total weight of the UCR with technological equipment. A diameter of one VCD is got from the next formula:

$$d = \sqrt{\frac{4F_n}{\pi\Delta\rho}},$$

where F_n — normal detaching force, $\Delta\rho$ — pressure difference between VCD vacuum volume and environment.

The normal detaching force is calculated as

$$Fn \geqslant \frac{F_t}{\mu} + F_e,$$

where F_t — tangential detaching force; F_e — normal detaching force from technological equipment; μ — friction coefficient.

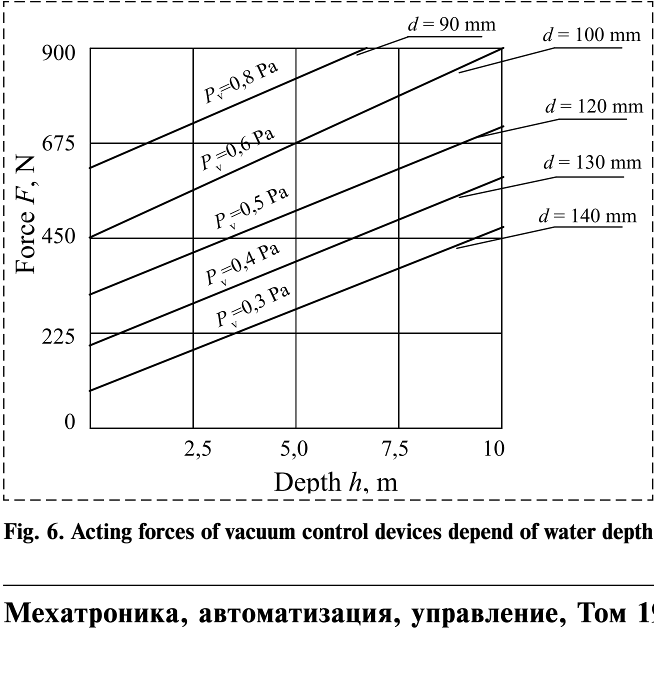

Fig. 6. Acting forces of vacuum control devices depend of water depth

Conclusion

Main particularities of technological wall climbing robot motion on underwater conditions are under consideration. Recommendations for vacuum contact devices design permit to choose needed force parameters of underwater climbing robots. It is supposed that every robots is equipped with "gas-water" ejector that generate necessary vacuum for satisfy reliable force contact robot with surface in underwater conditions.

The experimental characteristics of vacuum contact devices are illustrate the possibilities of robot motion in underwater environments.

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