Climbing Robot for Underwater Inspection of Constructions

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Abstract

The paper describes an underwater climbing robot for inspection of underwater constructions. It contains an overview of the design and technical parameters of the robot. The technological module for inspection is considered. Peculiarities of underwater application and different transport modes of robot's motion to initial working position are presented. Experimental characteristics of the transport and technological modules are given. Control and diagnostic systems are discussed.

1 Introduction

The objective of the work is to develop advanced Underwater Inspection Climbing Robot (UICR) that responds to the needs of automation in underwater construction. It contributes to the safety and profitability of inspection operations, especially for accident management.

Climbing robots are promising for automation of different underwater technological tasks, for example cleaning and cutting [1-3]. Another important application of climbing robots is underwater inspection of constructions [4]. They can be used for inspection of channels and dams walls, underwater parts of petroleum platforms, underwater pipelines and so on. Advantages of these types of robots are abilities to move along the surfaces of various materials and reliable fastening on the motion surface to achieve high technological accuracy in spite of a strong current of water which have a direct influence on robots motion along the given trajectory. The underwater climbing robots are applied from ships or stationary objects.

They can be used as a part of an underwater robot complex which consists of an unmanned underwater vehicle bearing climbing robot with power supply unit.

The new design combines the possibilities of climbing robots and sonars underwater sensory system.

2 Design of the UICR

The robot contains transport, technological, and control modules. Application diagram of the UICR is shown in Fig.1a,b. The transport module has a platform with vacuum pedipulators [5]. The technological module is mounted on the platform and contains two groups of sonars. The first group consists of a horizontal sonar and is intended for inspection of motion surface. The second group consists of two vertical sonars and is used for the orientation of the robot and for an avoidance of obstacles.

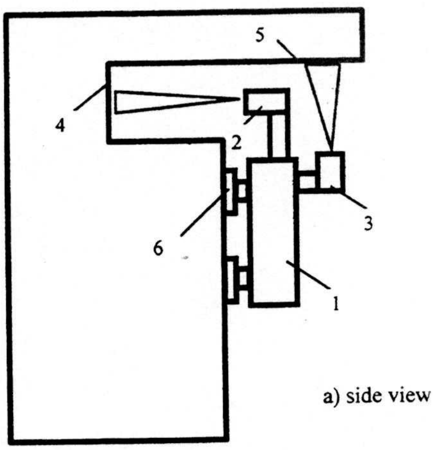
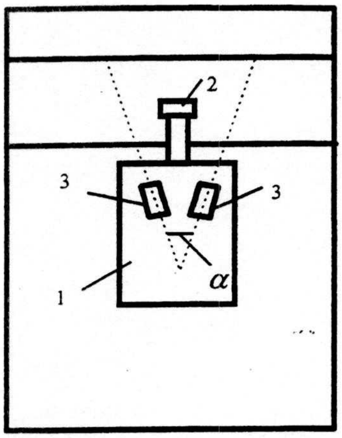


Figure 1a: Application diagram of the UICR
1 - UICR, 2 - horizontal sonar, 3 - vertical sonar, 4 - inspection surface, 5 - orientation surface, 6 - vacuum gripper



b) front view

Figure 1b: Application diagram of the UICR
1 - UICR, 2 - horizontal sonar, 3 - vertical sonar,
α - angle between the horizontal sonars

The design of the UICR was completed in order to apply it under water in different environments and to provide necessary transport and technological motions for inspection (Fig. 2).

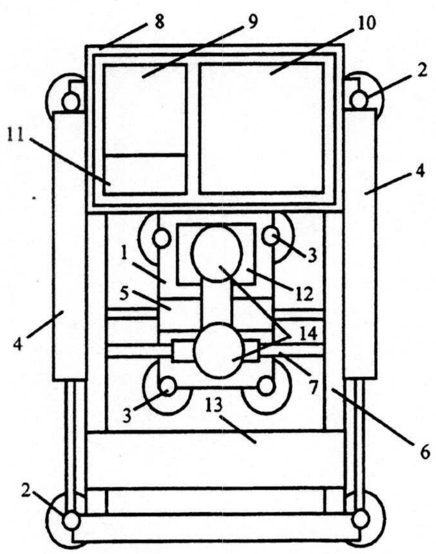


Figure 2: Design of the UICR
1 - platform, 2 - external pedipulators, 3 - internal pedipulators, 4 - vertical transport drive, 5 - horizontal transport drive, 6 - external force frame, 7 - force guide, 8 - on-board control system body, 9 - valves, 10 - on-board computer, 11 - vacuum sensor block, 12 - ejector block, 13 - supply tube block, 14 - external transport grippers.

The robot has a platform and the external and internal pedipulators with the vacuum grippers. Two horizontal transport drive are mounted on the platform. The external pedipulators are fixed on the moving parts of the vertical transport drives. The internal pedipulators are connected with the platform. The vertical transport drives are fixed on the moving parts of the horizontal transport drives. This design allows to perform any desired two-coordinate motion of the robot. Each vacuum gripper has a connection to an ejector block. Pneumatic cylinders as the transport drives are used to have the same power source for the vacuum system and the drive system. The force guides between vertical transport drives and the platform, and an external force frame are intended to provide the stiffness of the robot. All electrical parts of the robot are placed in a watertight control system body which is attached to the external force frame.

An on-board computer, a vacuum sensor block and the control valves for the transport drives are installed inside the body. All pneumatic tubes of the drive system are concentrated in a supply tube block to provide convenience of their decontamination, if necessary.

The UICR transport motion is performed as follows: when the internal pedipulators are connected to the motion surface by means of the grippers, the external pedipulators has the opportunity to move vertical relative to the platform. When the external pedipulators are fixed to the surface, the internal group can move horizontal with the platform by means of the horizontal transport pneumatic cylinders, and so on.

Simultaneous motions of the vertical and horizontal drives allows to move the frame with the technological tool in any direction according to a velocity relation between the drives. A combination of the transport and technological drive motions provides a possibility to have desirable trajectory of the sonars. The combine drive system is effective in underwater conditions because of its watertight and compact design.

There are two possibilities for the robot to reach a working position depending on the service conditions. The first variant is its own transport motion from an initial position to the place of technological task. This variant does not demand additional transport equipment but time of the transportation is limited by a speed of the robot's transport drive system. The second variant is realized by means of an external manipulator which can transport the UICR to desirable working position. The UICR is attached to the manipulator at the initial position by means of an external transport gripper system. It can be transported to the working zone directly through the water with a respectively high speed and than must be detached to perform autonomous technological motion.

Main technical specifications of the UICR are as follows:

1. Payload	15 kg
2. Weight (without equipment)	9 kg
3. Maximum Stride	80 mm
4. Range of Transport Speed	(0.6 -3.0) m/ min
5. Drive system	combined
6. Maximum Stepover Height	40 mm
7.Gripper System	vacuum
- number of ejectors	4
8.Technological Equipment	sonars
9. Overall Dimensions:	
- length	590 mm
- width	430 mm
- height	220 mm
10. Supply:	
- air pressure	0.6 MPa
- air consumption (max)	80 Nl/ min

A usage of the vacuum grippers with ejectors under water has some peculiarities. First of all, the pressure difference between the pressure in the gripper volume and the pressure of environments depends on a depth of the robot's position under water. The deeper is the robot's position the better is vacuum connection of the gripper to the motion surface because of an increase of the water pressure for 9.8 KPa per metre. At the same time the direct application of the pneumatic ejectors under water demands some measures to maintain their dynamic characteristics, for example an additional air volume in an output line of the ejectors.

A view of the UICR transport module during motion under water is shown in Fig. 3.

A gripper diameters and underwater gripper forces can be found with a help of a diagram in Fig. 4.

The 100 mm diameter gripper is given as a basic variant. This gripper provide the 450 N force by the 60% vacuum inside the gripper volume on the water level. Under water the force changes proportionally up to 900 N for the 10 m depth.

It is easy to find other gripper diameters and attaching forces for different possible vacuum levels from the diagram.

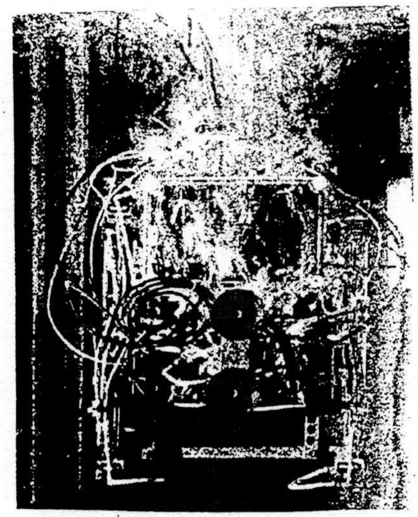


Figure 3: UICR transport module under water

Reliable functioning of the pneumatic system of the robot depends on the proper consumption calculation of the pneumatic actuators. Maximum consumption value demands the ejector block of the system.

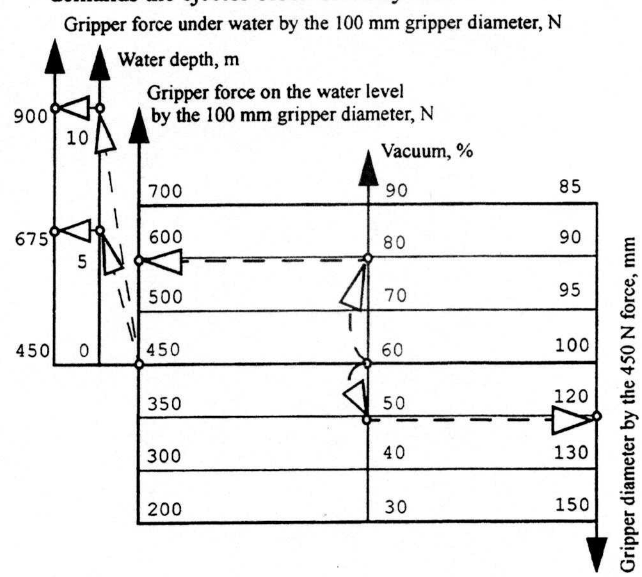


Figure 4: Diagram for design calculations of underwater vacuum grippers

A diagram for underwater consumption calculations of the UCR vacuum ejectors is shown in Fig. 5. The air consumption to evacuate the air volume of 1 Nl by the 75% vacuum level is equal to 3.7 Nl.

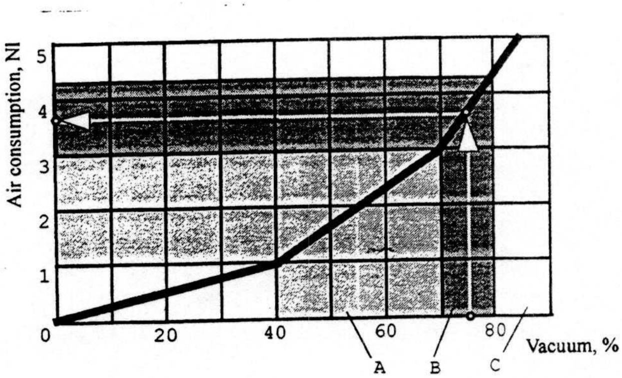


Figure 5: Diagram for underwater consumption calculations of the UCR ejectors to evacuate the air volume of 1 Nl: A - permissable working zone, B - nominal working zone, C - power ejectors working zone.

This consumption must be multiplied by the total gripper volume to find necessary total consumption of the ejector block. Then the corresponding number of the ejectors in the block can be found taking into account a consumption which maintains a nominal vacuum level in the grippers during continues functioning of the ejector block.

A force compensation of the robot's weight and of a technological force is provided by means of a buoyancy force during underwater transport and technological motions. A diagram of the force compensation is presented in Fig. 6.

The buoyancy force is created automatically inside the on-board control system body by means of pressured air from the outputs of the electropneumatic valves in the body. As result, an overpressure and the buoyancy force are formed inside the body.

The overpressure serves as additional safety measure to provide the watertight design of the on-board control system at the same time. A value of the force is controlled by means of a release valve in a vent line of the body. A value of the buoyancy torque is regulated with a help of an adjusting bracket which changed the lever length of the buoyancy force.

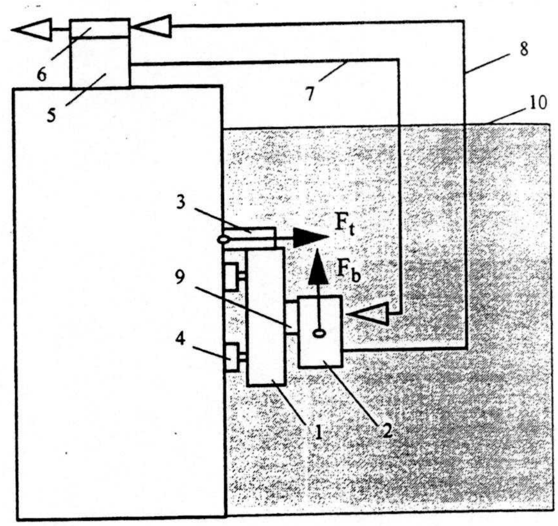


Figure 6: Diagram of the force compensation: 1 - UCR, 2 - on-board control system body, 3 - technological tool, 4 - gripper, 5 - compressor, 6 - release valve, 7 - pressure line, 8 - vent line, 9 - adjusting bracket, 10 - water level, F_t - technological force, F_b- buoyancy force.

Automatic adaptation of the buoyancy force to the corresponding technological torque can be achieved by means of force feedback loop in the control system of the robot.

3 Technological system of the UICR

The technological system consists of the sonars with technological drives. The sonars are installed on the UICR according to Fig. 1.

Diagram of the sonar sensitivity is shown in Fig.7.

The sensitivity depends on the angle between sonar axes for different shapes of signal receiver (curve 1 - without cone, curve 2 - cone of 80 grad., curve 3 - cone of 30 grad.).

It is necessary to pick out corresponding sonar signals to identify such peculiarities of the inspected construction, as cracks, grapes, destructions, cavities or deformations.

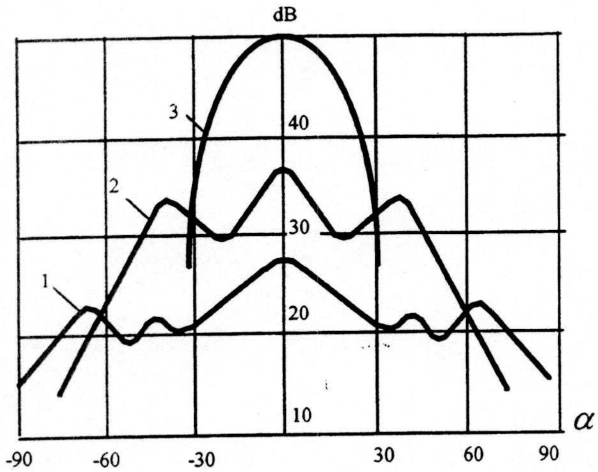


Figure 7: Diagram of the sonar sensitivity

Transformation characteristics of a sonar transducer for such a purpose is shown in Fig. 8.

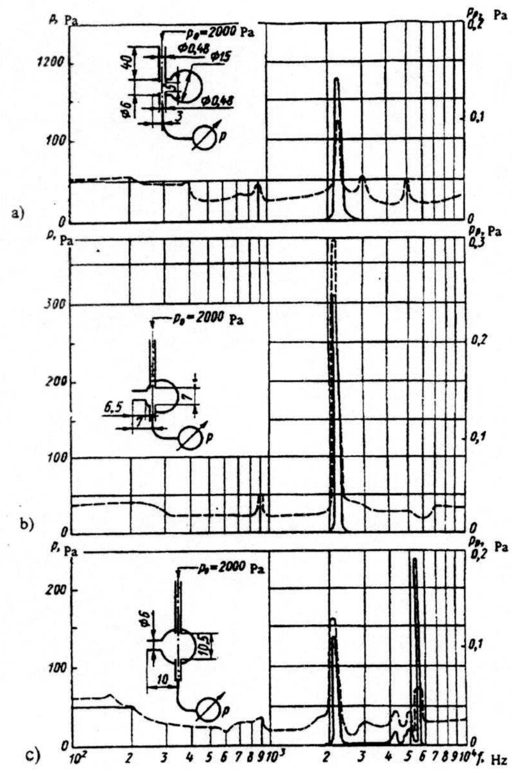


Figure 8: Transformation characteristics of a sonar transducer for different designs

Transformation characteristics depend on a design of the transducer. It is possible to choose desirable characteristic according to technological task.

4 Control and diagnostic systems

Control system of underwater WCR includes two circuits - programming and diagnostic, connected by hardware units together in the general system (Fig. 9).

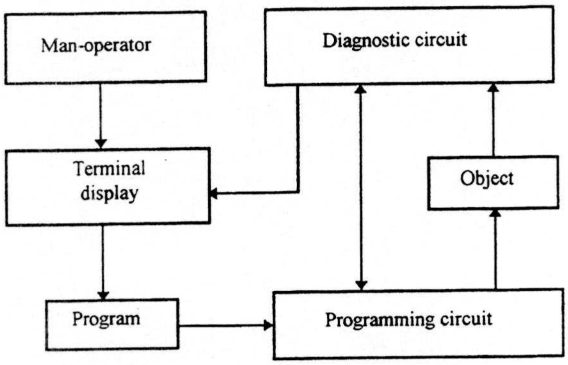


Figure 9: Programming and diagnostic circuit

The system includes the lower programming testing control loop and the upper decision control loop intended for help the main-operator (if supervision mode is used) to make a decision about testing processes and parameters which have to be measured. The microprocessor is connected with this programming system by means of a special interface unit. The detecting signal is generated on the basis of an off-line decision making procedure in the case of the interaction of the modelling or simulation processes with testing. Measuring robot systems can be used for solving of many problems in the technical diagnostics and testing procedure.

As an example of this testing and verification procedure which depends on the testing task and the parameters for a man-operator, the specification concept is illustrated for our underwater UICR and Japanese experience for water swimming robot JSR [6]. The concept and verification systems are typical and may be used for the testing of mobile robots for automation systems and for robots in construction.

The testing procedure, which connected very closely with design and development processes, depends on environment specifications. The procedure is correlated with technology in the testing.

The robot performs sophisticated work activities supported by remote operator, as maintenance, inspection and repairing equipment and facilities, including offshore oil installations.

For motion additional mobility, underwater robot has a control unit on the platform for offshore oil equipment, 3-dimensional moving and for position and velocity control, avoidance of the obstacles.The robot have to use visual inspection, non-destructive testing and cleaning by wire or fluid brushes.

Static and dynamic forces are acting on the on-board manipulator and transport system of UICR. Static force is a buoyancy force $F = \rho V_o$, where ρ - liquid density, V_o - UICR volume. If the on-board manipulator is under motion, the dynamic inertia resistance forces and viscous resistance forces are acting also. The inertia resistance forces arise in the case of the motion with acceleration or slowing down and characterise by linear and an angular joint moment of momentum vectors.

Viscous resistance forces depend on link robot velocity, liquid front angles, surface roughness and link forms. In general case, each robot link produces rotation-translation complex motion when liquid circulation and round flows have various directions. There are two kinds of viscous resistance forces - normal and tangential. Normal force acting to the link can be presented in the form:

$$F_{hi} = \frac{1}{2} K_n \rho \cdot l_i (V_{ni})^2 di, \; i = 1, ..., n,$$

where K_n - coefficient of normal force resistance of link, ρ - liquid density, V_{ni} - normal direction velocity of the flow to the i-th link, d_i - conventional diameter of the i-th link.

Tangential force acting on the link can be presented in the form:

$$F_{ti} = \frac{1}{2} K_T \rho (V_{ti})^2 di, \; i = 1, ..., n,$$

where K_T - coefficient of axis force resistance of a link, V_{ti} - tangential direction velocity of the flow to the i-th link.

The dynamic equations of the robot were used for computer simulation of motion study for such a system:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_k}\right) - \frac{\partial L}{\partial q_k} = F_{k,},$$

here $F_k=F_d+F_v+F_b$; F_d - generalised force which is equal to a sum of moments of driving forces, F_v - generalised viscous resistance force of the motion of k-th link, F_b - other external disturbances, q_k and $\dot{q}_k$ - generalised co-ordinates and velocities of the k-th link, $L=T-\Pi$ - difference between potential and kinetic energies, where the buoyancy and inertial resistance forces are taking into account.

The motion equations were represented for simulation in the form

$$\sum_{i=1}^{n} a_{0k}^{i}\ddot{q}_i + \sum_{j=1}^{n}\sum_{i=j}^{n} a_{1k}^{ji}\dot{q}_j\dot{q}_i + a_{2k} = F_k, \quad k=1...n$$

To solve the equations it is required to calculate the coefficients $a_{ok}^{i}, a_{1k}^{ji}, a_{2k}, i, j, k = 1...n,$ depending on configuration, geometry, masses and inertia parameters of the robot. Calculation of these coefficients is complex algorithmic problem and its solution requires a long computer time.

Besides, it was necessary to determine the generalised forces F_k and the sum of moments of driving forces F_d were considered depending on input control signals of robot's drives.

Conclusion

The designed robot provides automation of underwater inspection and economic efficiency in its application.

Acknowlegement

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