Development of the Underwater Robotics Complex for Laser Cleaning of Ships from Biofouling: Experimental Results

A Yu Bykanova¹, V V Kostenko¹, A Yu Tolstonogov¹

¹Institute for Marine Technology Problems FEB RAS, 5a Sukhanova Street, Vladivostok 690091, Russia

E-mail: kostenko@marine.febras.ru

Abstract. Periodic cleaning of a hull from biofouling provides high efficiency motion of a vessel. Inspection and cleaning of the underwater part of the vessel afloat is usually carried out by divers aimed with an underwater video system, non-destructive devices for hull structures monitoring, as well as tools for cleaning surfaces from biological fouling and corrosion products. The aim of the study was to develop a new technical tool for remote survey and cleaning of vessels based on the remotely operated uninhabited underwater vehicle (ROV) with build-in underwater laser cleaning equipment. As a result of the research, the prototype of an underwater robotic inspection and laser cleaning system for vessels afloat was designed and developed. The experimental results of the motion control system of the ROV with a hybrid propulsion system both in air and under water are presented. The efficiency of the laser cleaning equipment in stand-alone mode and as part of the vehicle was confirmed. The technical solutions obtained during the development of presented cleaning system allow efficiently and safely inspecting and cleaning the hull without docking of the vessel to be conducted.

1. Introduction

The importance of hull biofouling reduction derives from the economic indicators of the operation of the vessel, which is directly related to the cost of cargo delivery, as well as the duration of the operation of offshore hydraulic structures and structures. Hulls biofouling negatively affects the hydrodynamic parameters of the vessel, which leads to a deterioration the motion properties of one. This leads to decreased vessels speed and increased operating costs. Fuel costs for approximately 80% of the operating costs of any vessel, thus, the “smooth” hull is the main factor in the economical operation of the vessel.

Among the existing methods for underwater cleaning of the hull [1-7], laser cleaning has several advantages [8-11]:

- the possibility of selective handling of the hull;
- removal of contaminants with minimal risk of hull metal damage;
- non-contact and local impact;
- the process is controlled by software adjustment of radiation parameters;
- no consumables;
- the ability to obtain a high speed treatment of contaminated surfaces.
The article deals with a number of issues related to the development of a remote-controlled underwater vehicle (ROV), which provides laser cleaning of the hull surface from biofouling, as well as the inspection of the underwater part of the vessel afloat.

The design solutions of the ROV obtained during the development are following:
- general design of the ROV with integrated laser cleaning equipment;
- control system of the ROV;
- technical solutions for sealing laser cleaning equipment;
- the results of experimental studies of the laser cleaning system and its components.

2. The main results of the ROV development

In accordance with technical requirements of the cleaning system, the ROV should provide:
- maneuvering in the water in the wide range of longitudinal and transverse velocities with depth roll and pitch control;
- maneuvering by wheels underwater and in the air along the steel surface at a speed of 0.01–0.32 m/s with the possibility of reversing and turning in place;
- compensation of the reaction of the air flow from “nozzle” of the laser cleaning module by force of vertical thrusters;
- visual control by front and back view cameras;
- broadcast and accumulation data from cameras and vehicle parameters to the control post in real time.

The functional diagram of the cleaning system obtained as result of requirements analysis mentioned above is shown in Figure 1.

![Figure 1. Functional diagram of the hull cleaning system of a ship afloat.](image)

The support frame design of the ROV provides the placement of the laser cleaning module (LCM), elements of the propulsion system, the control unit, video cameras and LED lamps. The common view of the vehicle is shown in Figure 2, and its parameters are summarized in Table 1.
Figure 2. Common view of the ROV:
1 - vertical thrusters, 2 – buoyancy, 3 – the laser cleaning module, 4 - horizontal thrusters, 5 - wheels with built-in magnets, 6 – the rear video camera, 7 – the LED, 8 – the front video camera, 9 – thruster control units, 10 – the main control unit, 11 - the nozzle of the laser cleaning module

Table 1. Main parameters of the ROV.

| Parameter                                | Value       |
|------------------------------------------|-------------|
| Maximum depth, m                         | 10          |
| Dry weight, kg                           | 78          |
| Dimensions (length/width/height), m      | 0.730/0.720/0.450 |
| Maximum forward speed in water, m/s      | 0.60        |
| Maximum depth speed, m/s                 | 0.25        |
| Maximum yaw speed in water/air, grad/s   | ±50/40      |
| Max./min. velocity on the ground m/s     | ±0.40/0.01  |
| Roll control range, grad                 | ±45         |
| Pitch control range, grad                | ±45         |
| Maximum power consumption, W             | 920         |
| Traction force of magnetic wheels with steel surface, kg | 12 |
| Tether diameter, mm                      | 8           |
| Tether length, m                         | 20          |
| Data exchange type                       | PLC adapter |
| Data exchange between ROV – control board | Ethernet   |

The layout of the propulsion system is shown in Figure 3-a, it provides maneuvering in the water with given horizontal and vertical velocities, control of depth, yaw, pitch and roll and compensation of the reaction of the air flow from “nozzle” of the laser cleaning module during motion along steel surface. In addition, a pair of wheels allows the motion of the vehicle on the surface to be implemented for hull cleaning at the required speed not only under water, but also in air. Functional diagram of the propulsion system is shown in Figure 3-b.
The network organization of the onboard control system (OCS) of the ROV is flexible and open for additional devices integration for hull inspection (thickness gauge, measuring the cathode potential and hull deformations, etc.) [12-19]. The high-speed Ethernet communication channel via PLC modems allows real-time information exchange between the vehicle and control station to be done without additional signal wires and increasing cable diameter [20]. The functional diagram of the OCS is shown in Figure 4.

The laser cleaning module includes a 2D Mid Power Scanner IPG laser scanner, AC-DC modules for onboard power conversion, the durable container with the porthole for laser radiation, fiber optic connector and the slotted nozzle with fittings for the airline to drain the surface to be cleaned. The functional diagram of the LCM is shown in Figure 5.
3. The results of experimental studies of the cleaning system

In May-June 2019, pool tests of the cleaning system and its main systems - underwater laser cleaning equipment, as well as the ROV motion control system was conducted. Tests of laser cleaning module were carried out in the handmade pool of the IAPU FEB RAS laser technology center by the KUKA industrial manipulator for module moving.

![Figure 5. Functional diagram of the laser cleaning module.](image)

**Figure 5.** Functional diagram of the laser cleaning module.

**Figure 6.** Fragments of payload tests of underwater laser cleaning system (the plate before and after underwater cleaning is shown on the right).

Optimal parameters of the underwater cleaning process were determined during these tests: wavelength, power and scanning speed of laser radiation, air pressure at the entrance to the slotted nozzle, and also the speed of movement relative to the surface being cleaned.

The tests of the ROV and its systems were carried out in two stages. At the first stage, the operability of the vehicle during moving in air on a horizontal surface was tested. Fragments of these tests are shown in Figure 7.
Applied technical solutions during development and meet the motion parameters with specification of underwater laser cleaning technology were confirmed during the tests. At the second stage, the motion control system of the ROV was tuned. The tests were carried out in the experimental water pool of IMTP FEB RAS.

At the final stage, laser cleaning equipment was tested as a part of the ROV. The vehicle provided translational movement of the laser cleaning equipment over the metal plate being cleaned in the experimental pool.

**4. Conclusions**
During the study technical solutions for hull cleaning by laser radiation were received. The following main results were obtained:

- the hybrid propulsion system was developed and tested at IMTP FEB RAS. It provides vehicle motion in the water column and along the metal surface to be cleaned. At the same time, the magnets integrated into wheels reliably hold the vehicle during moving on a steel surface not only under water, but also in air;
- the network organization of the ROV onboard control system makes it easy to integrate additional equipment into the vehicle for hull inspection (thickness gauges, measuring the cathode potential and hull deformations, etc.);
• technical solutions formed during the development of the cleaning system was confirmed by the positive results of pool tests.

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