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VIBROTECHNOLOGICAL UNDERWATER CLEANING OF SHIP HULLS

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Abstract: *The paper gives information on research results into the efficiency of ship’s hulls cleaning with the help of an underwater robot which is equipped with the vibrating bulldozer blade. The robot can move along a steel ship’s hull with the help of rubber-magnetic caterpillar transport drive, which develops a constant traction force. The paper elaborates and shows the system of descriptive equations. The analysis of the work of the equipment has been carried out by simulating it with MATLAB Simulink software. The results of the simulation allow to implement engineering (CAE) of such equipment, and evaluate its possibilities by designers.*

Key words: *Ship’s hull, grown layer, vibration cleaning, computer simulation.*

1. INTRODUCTION

The fact, that ship’s hulls become overgrown with algae, shells and other biological marine creatives, causes serious economical losses during a ship’s exploitation. The grown layers considerably increase a ship’s mass, and the value of liquid resistance coefficient of the hull. The above mentioned facts in the aggregate demand significant excess consumption of fuel.
Different cleaning equipment in dry docks is well-known, such as systems using rotating brushes, high pressure jets and others.
Recently there have been created also underwater cleaning devices – robots, which allow the user to shorten the cleaning time considerably, because the cleaning process can be carried out simultaneously with loading the ship. The paper analyses the work of one such equipment.

2. MODEL OF CLEANING EQUIPMENT

The diagram of the cleaning equipment is shown in Fig. 1. The device can move along the ship’s hull in all directions due to its rubber - magnetic caterpillar drive. The work of the device is similar to that of a miniature bulldozer, with the difference that, when the blade meets considerable environmental resistance, an adaptive vibrator is put in motion which results in a more effective destruction of the overgrown media.
The rubber-magnetic caterpillar transport drive constitutes an essential part of the model. The caterpillar drive has the form of a continuous band with built-in permanent rear-earth magnets. A layout of the band is shown in Fig. 2.

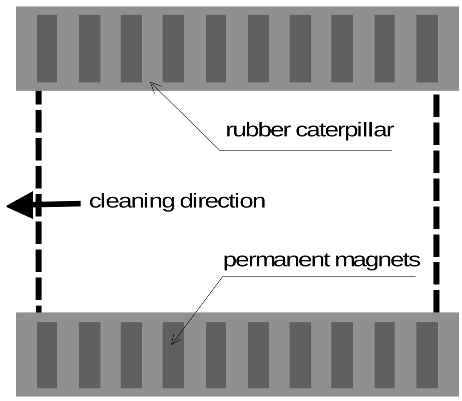

Fig. 2. Layout of the rubber - magnetic caterpillar

We shall determine the maximal traction force F_d (Fig. 1.) which the robot can develop moving along a ship’s metallic surface to destroy the overgrown media, by

$$F_d = \mu_k n k_m A \tag{1}$$

where A – surface area of one permanent magnet,
n – number of magnets,
k_m – the specific coefficient of the attraction force,
μ_k – coefficient of kinetic friction.

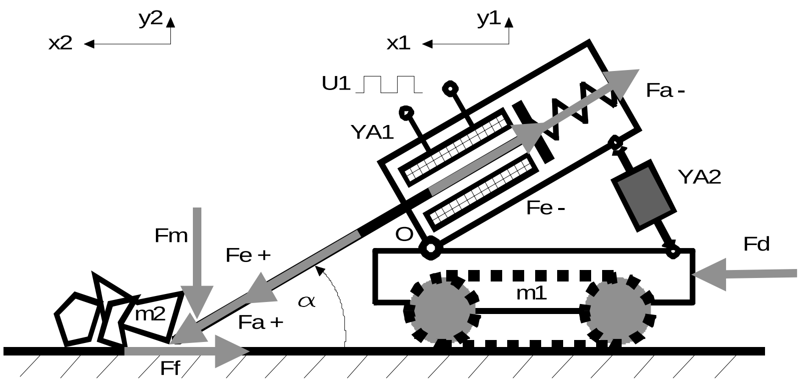

Fig. 1. Physical model of the cleaning equipment

The cleaning robot moving along the ship's hull surface, the traction force is limited, consequently, if the blade encounters the resistance of the overgrown media F_f larger than F_d, the movement of the robot stops as the caterpillar slips out. At the same time the YA1 spring is compressed. The translation of the armature is measured with a sensor (not shown in Fig. 1.) and the coil of the electro-magnet is supplied with current impulses of variable frequency and amplitude. The armature of the electro-magnet YA1 has been made of small mass and, as a result, when the robot meets resistance of the media to be destroyed, the blade exerts force consisting of the sum of two forces – the constant traction force F_d and a variable impulse force of the electro-magnet F_e. The latter, by its amplitude, can considerably surpass the values of F_d. If the resistance force of the media is not large, the robot moves without actuating the electromagnet in the work regime of an ordinary bulldozer.

3. MODEL OF DESCRIPTION

To analyze the activity of the robot and evaluate its efficiency , we shall use the d'Alambert principle for determining the system of kinostatic equations (Sautas-Little & Inman, 1999), according to which we can write

$$\sum_i F_{1X_i} = 0$$
$$\sum_i F_{1Y_i} = 0$$
$$\sum_j F_{2X_j} = 0 \qquad (2)$$
$$\sum_j F_{2Y_j} = 0$$
$$\sum_k M_{A_k} = 0$$

where F_1, F_2 and M_A – forces acting on the bodies with masses m1 and m2 and the moment acting on the body of robot about the fixed point (Fig. 1.),
x,y – the axis of the coordinate frame.

If the determination of values of the robot's physical parameters and the forces acting upon it creates no difficulties, analytical description of the destroyable medium (encrustation) constitutes a disputable issue. In accordance with the description given by researchers (Armada & Gonzalez de Santos, 2002), it can be considered that the layer of incrustations is divided into three parts:
- the primary layer consists of silt, mud or plants with low density,
- secondary layer is composed of algae with stronger density,
- tertiary layer is constituted by molluscs.

The mollusc shells on the tertiary layer with their irregularity and rigidity contributes the main layer which increases the resistance to ships hull cleaning. Thus, in order to describe the properties of the medium, we choose a mathematical model where the first and second layers of the incrustation form a viscous resistance force to the bulldozer blade, proportionally to the velocity in the first power, but the third layer forms resistance force which can be overcome by applying shearing force, which forms in the layer shear stress larger than that permitted, i.e.. (Pisarenko et al., 1975)

$$F_f = R\frac{dx}{dt} + \lambda(D,\tau,t) + F_{df} \qquad (3)$$

where R – coefficient of viscous resistance of the media,
λ (D, τ, t) – the resistance force in the shearing process which depends on the properties of the material τ, the blade dimensions D, time t,
F_{df} – force of dry friction, expressed by the attraction force F_m acting on the blade and coefficient of kinetic friction,
x – displacement of the blade.

In the expression (3) the main force of resistance is created by the continuous resistance of the destruction of encrustation. To achieve the maximum of the encrustation destruction force, it is useful to adjust the slope angle of the blade approximately equal to zero. In such a way the equation system (2) can be greatly simplified and the efficiency of the ship's hull cleaning can be evaluated by one characteristic – the speed of the robot's translation determined by the speed of destroying the encrustation.

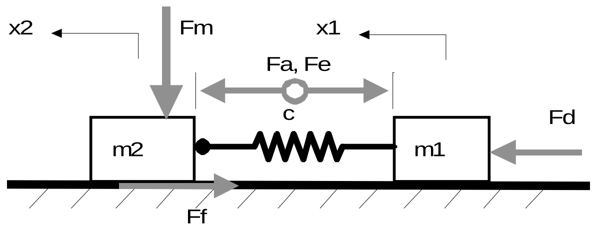

Fig. 3. Simplified model of ship hull cleaning equipment

We shall determine the possibilities of the movement of the ship hull cleaning robot by simulating its activity with the MATLAB Simulink software using the equations

$$m1\frac{d^2x1}{dt^2} = F_d - F_a - F_e - F_f$$
$$m2\frac{d^2x2}{dt^2} = F_a + F_e - F_{ff} \qquad (4)$$

where F_d – traction force,
$F_a = F_0 + cx1$ – spring force,
F_0 – pre-tension force of the spring,
$F_e = f(t)$ – force of the electro-magnet,
F_f – resistance force of the layers according to (3),
Fff – resistance force of media acting on mass m2 during its translation,
m1 – mass of the robot,
m2 – the mass of the destroyed material,
c – spring stiffness,
x1 – displacement of the robot,
x2 – displacement of destroyed mass,
t – current time.

The simulation block diagram of the robot translation is shown in Fig. 4.

One of the characteristic features of the activity is that during its movement the working tool – the blade can come upon the rise of a welding joint.

If the robot's built-in camera states the former fact, the electro-magnet YA2 is activated and the blade is lifted over the joint rise (Fig. 1).

When analyzing the simulation results, we may say that in general the operation of a ship's hull cleaning equipment should be analyzed applying an equation system of variable structure. It is connected with the fact that the placement of a ship hull's encrustment is of random character.

When the robot meets the tertiary layer, cleaning actions are different when compared to cleaning the primary and secondary layers.

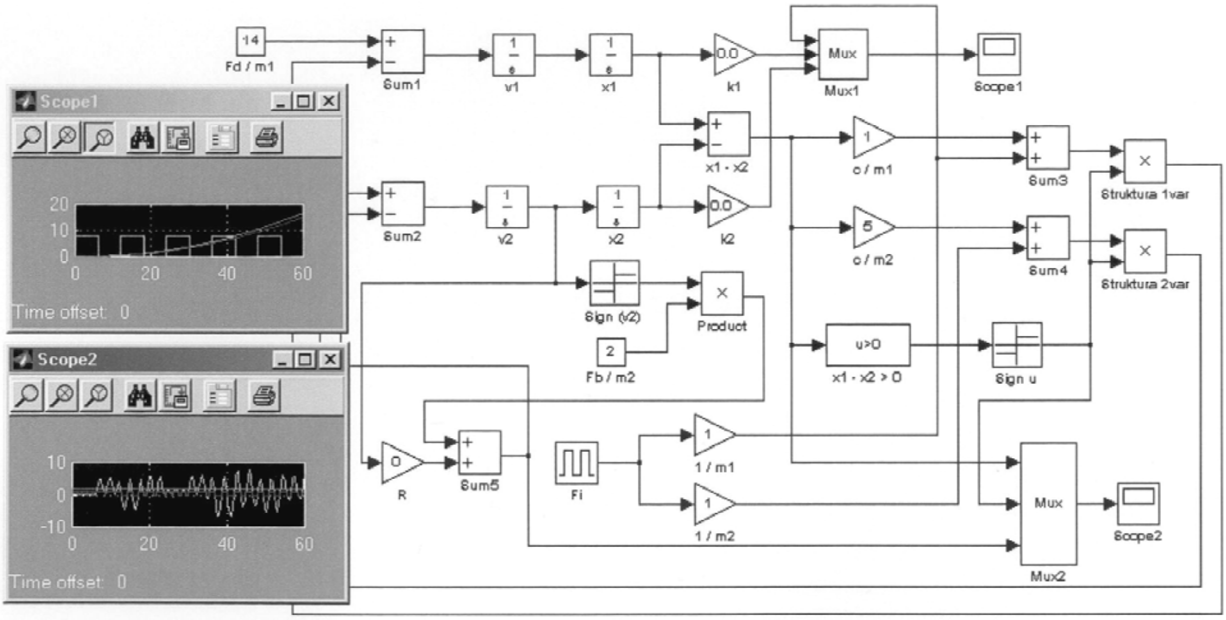

Fig. 4. Simulink bloc … controller (Jimenez et
hull cleaning possibiliti …

… et in the model was
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Fig. 5. SMC controller program flowchart for TTH control

5. CONCLUSIONS

Millions of tons of fuel are wasted each year due to the underwater growth, barnacles, and seagrass on the ship hulls which increases a ship's hydraulic resistance.

A smooth clean hull is the most efficient fuel saving device.

To prevent spending additional money on fuel, a ship's hull should be cleaned twice a year.

There exists different cleaning equipment for hull cleaning, including diver-operated underwater rotary brush cleaning units and others.

Our work is concerned with automated equipment for underwater cleaning of ship hulls. The working tool of the equipment has been made like a vibrating bulldozer blade. This solution has both advantages and disadvantages.

We may refer the following factors to advantages:

- the working tool may be attracted to the metal surfaces of a ship hull by magnetic forces, thus ensuring stable working conditions,
- the blade can be made of practically any dimensions,
- the cleaning work can be performed faster as compared to that of a rotary brush cleaning unit, at the same time consuming less energy,
- the blade can be easily equipped with waste removal equipment,

However, the solution has its disadvantages:

- the cleaning of the surface is not efficient if the radii of ship hull are small,
- as cleaning is done practically during one travel of the blade, the quality of the cleaned surface can be lower than that accomplished by applying a rotary brush cleaning unit,
- it is not possible to carry out the polishing operations of ship surfaces without applying extra equipment.

The efficiency of the equipment has been analyzed by simulating its work with the help of MATLAB Simulink software and can be evaluated by viewing its simplified mathematical model.

The simulation results depend on the assumed hypothesis about the physical properties of the medium to be destroyed.

It is useful to use a videocamera for monitoring the robot equipped with a rubber–magnetic caterpillar drive for underwater cleaning. The camera, in combination with a control computer, allows the system to choose the best adaptive working conditions and evaluate the properties of the area to be cleaned.

The results of the research offer a proposal for the project AURORA of a program within framework 5 of the European Union.

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