

# “New Fish-like Designs of Underwater Vehicles”

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**Keywords** – robotic fish, underwater vehicle, vibrating tail, propulsive device, optimal control, internal gyrodrive.

## I. INTRODUCTION

Autonomous underwater vehicles are widely used in engineering for different practical purposes (research, exploring, transportation of freights, etc.). The majority of existing underwater vehicles have traditional propulsion mechanisms with screw propellers. However, various biomimetic fish-like robots with oscillating tails and fins have been proposed as well [1]. This paper considers the essence of two new methods for the producing of driving force [2, 3] which make it possible to increase the efficiency of vibration propulsive devices of underwater vehicles.

## II. SPECIAL VARIATION OF WORKING AREA OF VIBRATING TAIL

A simple robotic fish model consists of two rigid bodies – a hull and a tail that are mutually connected with a pivot. In our case, the mass of the hull is sufficiently higher than the mass of the tail. Therefore it is possible to find optimal control law for variation of an additional area of a vibrating tail (in order to produce the driving force) on the basis of simplified model with one degree of freedom (Fig. 1). In this case, the tail is fastened to the stationary base with the pivot A, and the motion of the tail is described with one co-ordinate - angle  $\varphi$ .

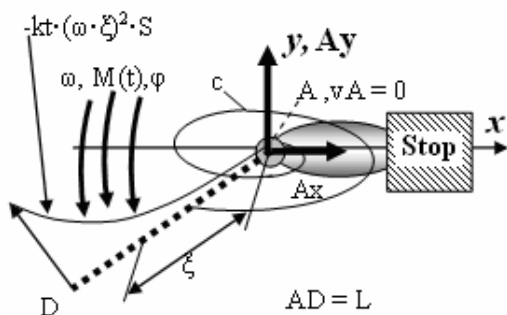


Fig. 1. Simplified dynamic model of robotic fish

Tail interaction with water is described by hydrodynamic resistance force proportional to the square of velocity in local fin's point. Elastic properties of the system are taken into account with torsion spring  $c$ . The external excitation is simulated with turning moment  $M(t)$ .

In order to realize the onward motion of the robotic fish (the motion in the direction of  $x$  axis, see Fig. 1), it is necessary to maintain a negative mean value of the reaction component  $A_x$  during the stationary vibrations of the fin. The search for an optimal control law for variation of area  $S$  of the vibrating tail, which ensures maximal positive impulse of driving forces acting on the tail, has been made using the maximum principle of Pontryagin with the aid of program MathCAD. It was shown that the optimal control action is the following:  $S(t) = S_{\min}$  – for the case of the fin's motion from the neutral position ( $\varphi = 0$ ) till its momentary stop ( $\varphi_{\max}$  or  $\varphi_{\min}$ );  $S(t) = S_{\max}$  – for the case of the fin's motion from its momentary stop ( $\varphi_{\max}$  or  $\varphi_{\min}$ ) till the neutral position ( $\varphi = 0$ ). The proposed method for producing of driving force [2] is realized in different designs of one-tail and two-tail vibration propulsive devices.

## III. GYROSCOPIC METHOD FOR PRODUCING OF DRIVING FORCE

Up to now gyroscopic effect has been mainly used for damping unfavorable oscillations of a body of a water vehicle or for stabilization of position of a vehicle due to external force loading. Here the opposite concept is proposed: not to stabilize, but to swing gyroscope and vehicle on which it is located. Essence of the proposed method can be explained through the schematic diagram shown in Fig. 2.

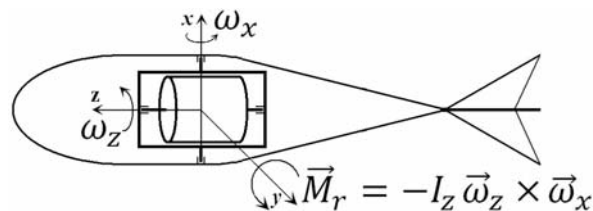


Fig. 2. Principle model of the gyroscopic propulsive device

To create translation movement of the vehicle in the direction of the axis  $z$ , a high speed rotation of the nutation axis  $z$  with frequency  $\omega_z$  is excited. Simultaneously, oscillation of external frame about the precession axis  $x$  with the sufficiently smaller frequency  $\omega_x$  is generated. In this case, in accordance with the gyroscope theory, reaction driving torque  $M_r = I_z \omega_z \omega_x$  acting on vehicle body is generated. Torque  $M_r$  causes swinging of the body of the vehicle about the vertical axis  $y$ . As the result of vehicle interaction with surrounding water medium, a driving force in the direction of the axis  $z$  is formed [3]. The operation capacity of the proposed method is validated by simulation with software MSC ADAMS MD R3 as well by experiments with physical prototype.

## IV. CONCLUSIONS

Two new methods for producing of driving force in underwater vehicles are proposed. The first method is based on the variation of working area of a vibrating fin during operation, while the other one lies in the equipping of vehicle with an internal gyroscopic device. The efficiency of the methods proposed is confirmed by mathematical simulation and experiments on physical models of floating vehicles.

This work was supported by the European 7<sup>th</sup> Framework Programme Project ID 231495 „Robotic Fish Locomotion and Sensing” (FILOSE).

## V. REFERENCES

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