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Теоретические исследования и практическое использование вибрационных процессов в технике и технологиях являются актуальной сферой деятельности и научных интересов многих ученых в России и за рубежом.

Результаты этих работ нашли свое отражение в программе XI Международной научно-технической конференции «Вибрация-2014. Вибрационные технологии, мехатроника и управляемые машины».

Проведение конференции в Юго-Западном государственном университете стало уже хорошей традицией и закономерностью, подтверждающей успешное развитие научной школы по вибрационной механике, заложенной заслуженным деятелем науки и техники России, профессором П.М. Алабужевым. В сборнике, публикуемом по итогам ее работы, представлены результаты исследований ведущих ученых России, Германии, Франции, Непала, Латвии, Украины, Белоруссии.

Тематика представленных на конференции научных работ весьма широка и многогранна: история развития механики, динамика конструкций и машин, моделирование динамических процессов, виброзащита, волновые процессы и случайная вибрация, мехатроника, робототехника и биомеханика. Особое внимание уделено системам, имеющим автоматическое управление и регулирование.

Сборник будет полезен научным работникам, инженерно-техническим специалистам, аспирантам и студентам, занимающимся проблемами исследований в области динамики машин и разработкой современной вибрационной техники и вибрационных технологий.

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NEW DEVICES FOR PRODUCING OF DRIVING FORCE IN ROBOTIC FISH

This paper considers fish-like designs of underwater vehicles with oscillating tails and fins. To produce driving force, the original method based on the cyclic variation of the effective working area of the fin is proposed. Realization of this method makes it possible to minimize energy losses within operation cycles, when fin's motion is affected by water resistance forces. Thanks to that useful driving forces are increased, and operation of fin propulsive device becomes more effective. Examples on synthesis of propulsive devices with varying working area of vibrating tail are given.

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 bio-mimetic fish-like robots with oscillating tails and fins have been proposed as well [1, 2]. This paper considers the possibilities to increase the efficiency of vibration propulsive devices of robotic fish by special variation of working area of the fin interacting with external liquid medium.

On the basis of Pontryagin's maximum principle [3] the optimal control law for variation of additional area $S(t)$ of vibrating tail is found. It was shown [4] that the optimal control action corresponds to the case of bound values of area limits: $S(t) = S_{\min}$ – for the motion cycles, when propulsion of the fin is affected by the water resistance forces; $S(t) = S_{\max}$ – for the motion cycles, when useful driving force is formed. Due to such variation of additional area $S(t)$ of vibrating tail, energy losses are reduced, and operation of the device becomes more effective. Main ideas on variation of additional area of vibrating tail are realized in the patented method [5] for driving force forming in propulsive devices. To realize this method, one-tail vibration propulsive device was developed [4]. This paper considers some new designs of two-tail propulsive devices with varying working area of vibrating fin.

Two-tail propulsive devices with swinging fins. In this case, the propulsive device is equipped with two identical fins, which can execute synchronic rotations in opposite directions about the fulcrums placed in the back part of a floating vehicle.

A schematic diagram of the proposed two-tail vibration propulsive device (top view) is shown in Fig. 1, while the design of a fin with varying working area is presented in Fig. 2 [6]. Two identical fins are hinged to the back part of the floating vehicle 1 and can rotate in synchronism about the axes O_1 and O_2. Each fin is made of the thin-walled plate 2, which can rotate about the axle 3, located in the lower part of fin's working plane. Additionally, the inner end of the axle 3 through a prestressed torsion spring 4 (e.g. torsion bar) is connected with the plate 2, but the outside end of the axle 3 through a hinge 5 is linked with drive of the propulsive device. The outside end of the axle 3 is equipped with the stop 6, which limits relative rotation of the plate 2 about the axis x_1 directed in outside from the fore-and-aft axis y, but does not limit relative rotation of the plate 2 in opposite direction.

Operation principle of the proposed propulsive device is as follows. In working regime both fins execute synchronic slews in opposite directions about cylindrical hinges O_1 and O_2, receiving motion from driving mechanism. In Figs. 1 and 2 drive mechanism is not shown because it can be realized using well-known facilities - electric motor, electromagnetic device, hydraulic actuation, etc.

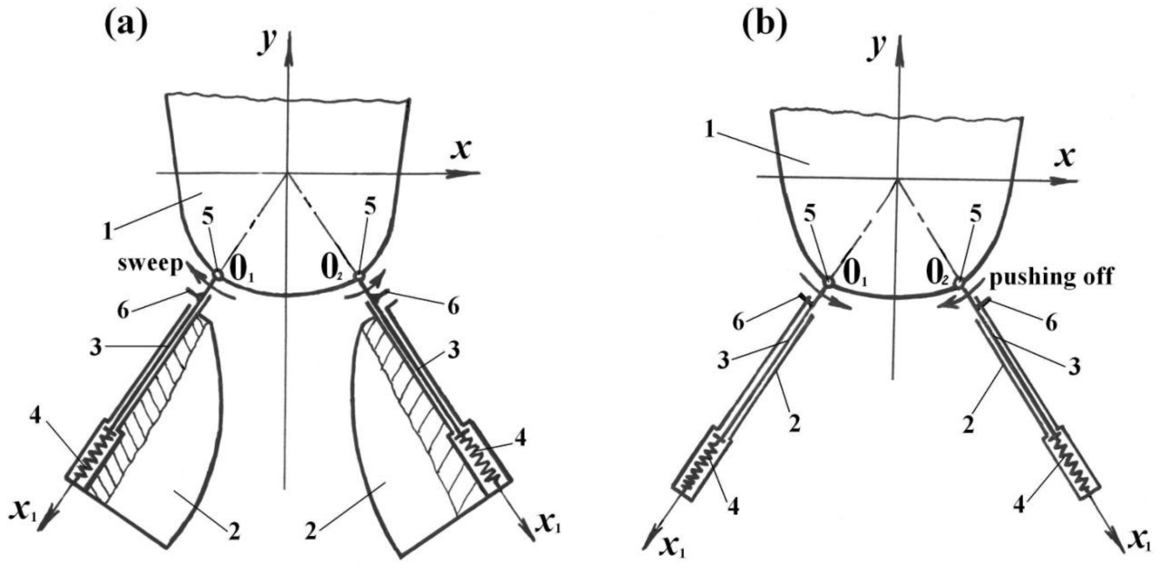

Fig. 1. Schematic diagram of the two-tail vibration propulsive device:

(a) motion stage "sweep"; (b) motion stage "pushing off"

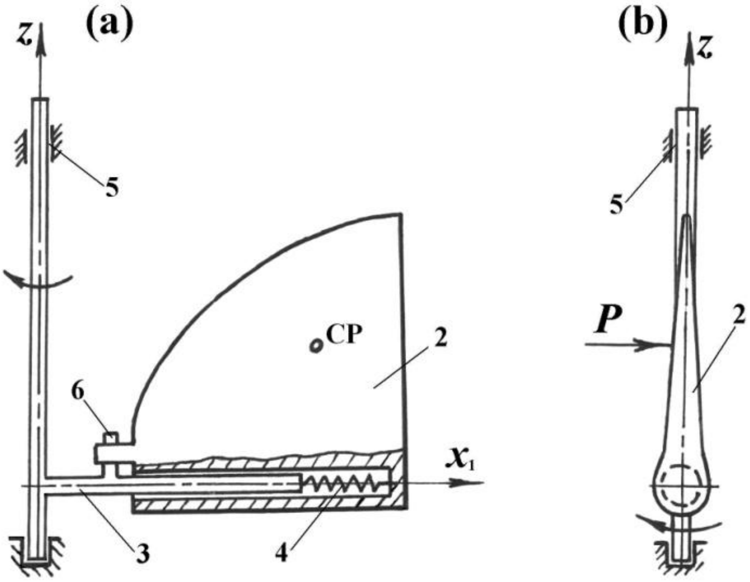

Fig. 2. Design of the fin with varying working area: (a) front view; (b) right side view

During the slewing of plate 2 from the fore-and-aft axis y up to the end positions ("sweep", see Fig. 1a) their relative rotation about the axis x_1 is simultaneously realized due to the action of hydrodynamic forces (because plate's 2 centre of pressure CP is placed over the rotation axis 3). Relative rotation of plates 2 is finished, when their working area become parallel to the co-ordinate plane xy. Fluid flows around fins 2 also become parallel to their working area, as the result, fluid flow practically does not press on working areas of fins. Therefore, summary braking loads on both fins (plates 2) in sweep are sufficiently reduced.

At the end of sweep stage, both plates 2 self-reset their initial position in plane x_1z, swinging about the axis x_1 due to the action of prestressed torsion spring 4. During the next stage ("pushing off") both fins are moved in a vertical position (see Fig. 1b), as further swing of plate 2 about the axis x_1 is limited by stops 6. As the result, the working area of plate 2 becomes perpendicular to the fluid flow (see Fig. 2), and therefore the action on plate 2 of hydrodynamic pressure force P is sufficiently increased. In the stage of pushing off, such position of a fin (perpendicular to flow) is more effective, because it favours the increase of useful driving force.

Thanks to cyclic rotation of both fins about the axis x_1, it has become possible to sufficiently reduce the summary braking loads on both fins in sweep and wherewith increase operation efficiency of vibration propulsive device.

Two-tail propulsive device equipped with fins made in the form of thin-walled semi-cylinder chute. Variation of working area of tail during operation of propulsive device can be achieved by making of fin in the form of thin-walled semi-cylinder chute. Type design of such fin is shown in Fig. 3. Fin can rotate about vertical axis *z*, making angle φ between fore-and-aft axis *y* of floating vehicle and longitudinal axis *x* of chute (in initial position angle φ is equal to zero).

Vibration propulsive device is equipped with two identical thin-walled semi-cylinder fins (in Fig. 3 only one fin is shown). Besides, both fins are jointed to propulsive device in such manner that convex part of the chute is directed outside from the fore-and-aft axis *y* of floating vehicle (in the direction of “sweep”). In accordance with the classification of mechanical objects [7], chute may be considered as thin-walled, if its geometrical parameters comply with conditions $\delta << l$ and $\delta << R$, where δ is fin’s thickness, *l* is fin’s length, *R* is a radius of fin’s medium surface. In this case variation of fin’s working surface can be achieved using effect of the loss of stability of rectilinear equilibrium form of both chutes during their motion [8].

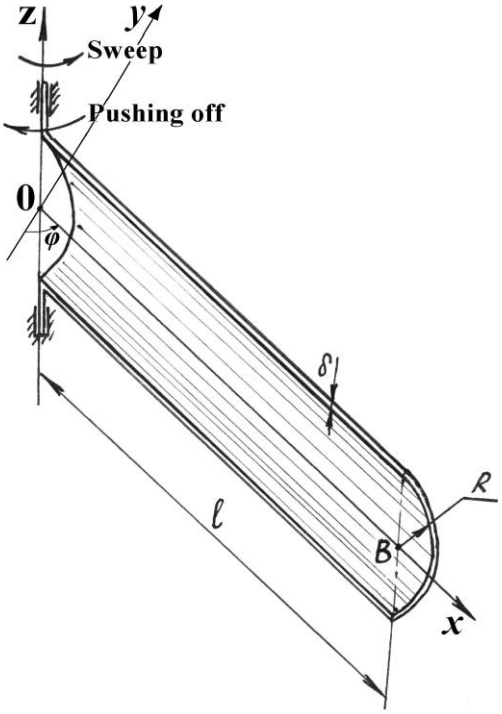

Fig. 3. Design variant of fin in the form thin-walled semi-cylinder chute
(*x* is longitudinal axis of a fin; *y* is fore-and-aft axis of floating vehicle; *z* is vertical rotation axis)

Sequential positions of both fins during adjustment of this specific motion regime are shown in Fig. 4.

Two identical thin-walled semi-cylinder fins 2 and 3 are hinged to the back part of floating vehicle 1 (see Fig. 4,a, b). Both fins can rotate in synchronism in opposite directions about fulcrum O. Hydrodynamic resistance force $q_1(r,\omega)$, which acts on convex surfaces of both fins during their motion from fore-and-aft axis y up to end positions (“sweep”), is as follows (see Fig. 4,a):

$$q_1(r,\omega) = k_1 \cdot r^2 \cdot \omega^2, \tag{1}$$

where k_1 is a resistance coefficient of fluid flow going from fin’s convex side (“sweep”); r is a fin’s cross-section coordinate measured from point O.

In fins’ opposite motion (“pushing off”) hydrodynamic resistance forces $q_2(r,\omega)$ change their direction and act on concave surfaces of both chutes (see Fig. 4,b):

$$q_2(r,\omega) = k_2 \cdot r^2 \cdot \omega^2, \tag{2}$$

where k_2 is a resistance coefficient of fluid flow going from fin’s concave side (“pushing off”).

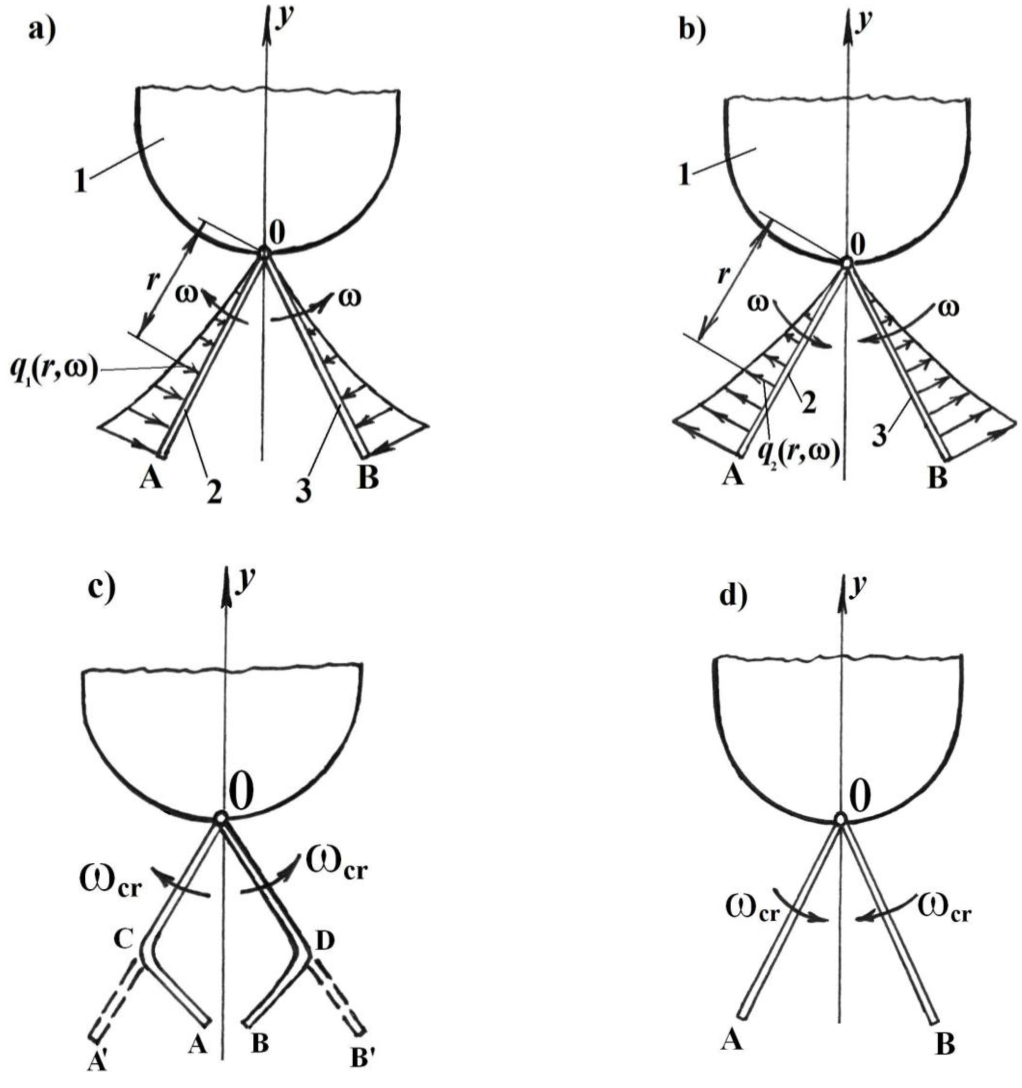

Fig.4. Sequential positions of fins during adjustment of the motion regime, which corresponds to the loss of stability of rectilinear equilibrium form of both chutes

Due to geometry of thin-walled semi-cylinder fin, coefficient k_1 is always less than coefficient k_2 [8]. Therefore braking force q_1 in sweep is also always less than useful load q_2 in pushing off.

In accordance with the equations (1) and (2), it is possible to change values of loads q_1 and q_2 by the variation of frequency ω of fin's angular oscillations. Besides, as it is known [8], thin-walled semi-cylinder chute can lose a stability of its initial rectilinear equilibrium form, if load $q(r,\omega)$ exceeds certain critical value q_{cr} dependent on chute material and dimensions. As load q_1 is always less than load q_2, then also $q_{cr1} < q_{cr2}$. Therefore by smooth variation of frequency ω it is possible to realize a working regime with frequency $\omega = \omega_{cr}$, when load q_1 is equal to its critical value q_{cr1} ($q_1 = q_{cr1}$), but at the same time $q_2 < q_{cr2}$.

In Fig. 4 (a, b) fins are shown before critical condition (in the case of $\omega < \omega_{cr}$), when both chutes remain stable of rectilinear equilibrium form. Under the critical frequency $\omega = \omega_{cr}$ both fins lose a stability of its initial rectilinear equilibrium form during motion from fore-and-aft axis y of floating vehicle up to end positions (see Fig. 4,c). As the result, longitudinal axes of fins are bended and take up positions ACO and BDO. Fluid flows around fins become almost parallel to their parts AC and BD, therefore summary braking loads on both fins in sweep are sufficiently reduced.

At the end of sweep stage both fins are straightened due to the action of internal elastic moment. During next stage ("pushing off") both fins are moved in straight form (see Fig. 4, d), because under $\omega = \omega_{cr}$ load q_2 is always less than its critical value q_{cr2}. In this case straight fins favour the forming of useful driving forces, and that is why such fin's position is more effective.

As the result of theoretical study, method for adjustment of operation condition of fin-type vibration propulsive device is proposed [9]. This method lies in equipping of vibration propulsive device with two identical fins and making of each fin in the form of thin-walled semi-cylinder chute. Fins are jointed to propulsive device in such manner that convex part of the chute is directed outside from the fore-and-aft axis of floating vehicle. Then floating vehicle is immersed into a liquid. The adjustment of operation condition of the propulsive device is carried out by gradual increasing of frequency of fin's angular oscillations and by further observing of equilibrium form of each fin under adjusted frequency values. Operation frequency of fins' oscillations is taken for the motion regime, which corresponds to the loss of stability of rectilinear equilibrium form of both fins during their motion from fore-and-aft axis of floating vehicle up to end positions. The method proposed ensures more effective operation of vibration propulsive device. Further increase of efficiency can be achieved by making in both fins of stress concentrators equally distanced from their free ends [10].

Some other designs of two-tail vibration propulsive devices with varying working area of fin are developed [11, 12]. Their practical application gives the possibility to increase driving characteristics, velocity of motion and efficiency of operation of robotic fish.

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