INVESTIGATION OF UNDERWATER ROBOTIC SYSTEM FOR OBJECT MOTION PROPULSION AND ENERGY GENERATION

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Abstract. The main objective of the report is to develop a new non-traditional (propeller free) mobile floating and diving robot. It is intended to investigate new elastomeric materials (e.g., silicone, rubber) properties and to perform structural studies with the intention of using them in underwater robot body, fin and tail constructions synthesis. The robot motion control system is analyzed, adaptive management principles are used. New approaches to gain energy and recharge power pack sources from surrounding medium are investigated in order to create a robot which will be able to operate autonomously. The importance of the proposed system is in further advancement of science of robotics and development of new drives. In particular, potential impact on the report can be characterized by application of innovative materials and technology research, implementation of renewable energy and as a result development of a new robot with unconventional drive and energy restoration possibility. For theory validation the wind tunnel is used. Possibility of energy extraction by vibration motions in water flow is checked experimentally.

Keywords: underwater robot, elastomeric materials, adaptive control, energy extraction.

Introduction

The robot fish motion control synthesis shows that efficiency inverse method algorithm may be used for invention of new underwater robots [1-5]. From that algorithm and analysis of real fish swimming patterns, it is found that as a minimum, three actuators can be implemented into the robot hull (Fig. 1, 2.). As an example, a non-traditional (propeller free) mobile floating and diving underwater robot fish prototype made at the Riga Technical University is shown in Fig. 2. The synthesis of that prototype shows that many important problems can be solved, such as the use of new elastomeric materials for synthesis suspension system of flexible tail or side blades [6]; the use of adaptive control of actuators; finding of new approaches to gain energy and charge power pack sources from surrounding water [7]. These problems are examined in this paper.

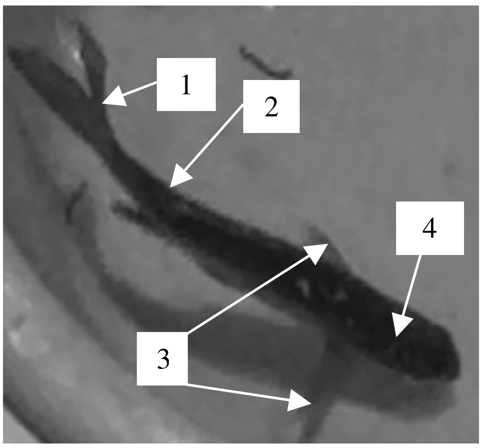


Fig. 1. **Real fish swimming:** 1 – caudal fin; 2 – tail; 3 – side (pectoral) fins; 4 – body

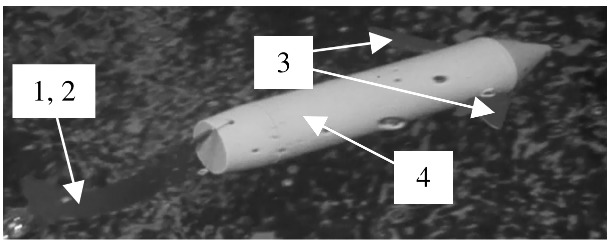


Fig. 2. **Underwater robot fish prototype:** 1, 2 – flexible plane tail; 3 – side level control blades, 4 – hull (with power pack, radio receiver and three actuators)

Elastomeric material models

Some experimental investigations of elastomers materials were made and described in the report [6]. Here additionally to diagonal interactions and penalty functions, gaps between moving mass and elastomers elements are taken into account (Fig. 3-6). For example, one central and two diagonal elements together with the left side gap give the following suspension system elastic force (1) (Fig. 6., 7.):

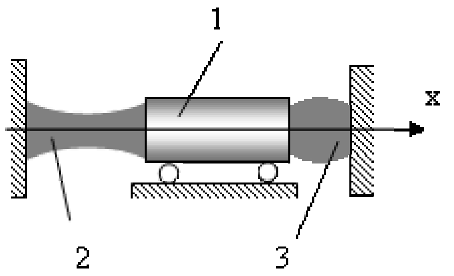


Fig. 3. **Elastomeric material model without gaps:** 1 – moving mass; 2, 3 – tensile and compression deformation elements

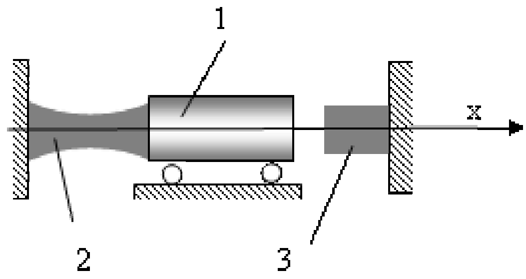


Fig. 4. **Elastomeric material model with one right side gap:** 1 – moving mass; 2 – tensile and compression deformation element; 3 – compression deformation element

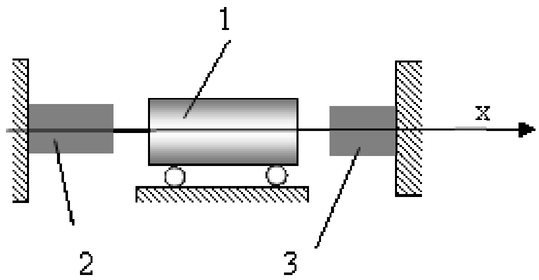


Fig. 5. **Elastomeric material model with two gaps:** 1 – moving mass; 2, 3 – compression deformation elements

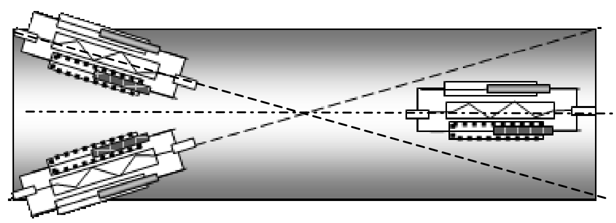


Fig. 6. **Complex elastomeric material model with longitudinal and diagonal interactions**

$$F(x) = -\left[[c1 \cdot x + \frac{2 \cdot c1 \cdot \left[\sqrt{\left(\frac{H}{2}\right)^2 + (L+x)^2} - \sqrt{\left(\frac{H}{2}\right)^2 + L^2} \right] \cdot (L+x)}{\sqrt{\left(\frac{H}{2}\right)^2 + (L+x)^2}}] \cdot \left(0.5 + 0.5 \cdot \mathrm{sign}(x)\right) \right] + \tag{1}$$

$$-\frac{c2 \cdot (x + \Delta 1)}{(x + \Delta 2) \cdot \Delta 2} \cdot \left(0.5 - 0.5 \cdot \mathrm{sign}(x + \Delta 1)\right),$$

where x – displacement;
$c1$ – stiffness of longitudinal or diagonal element;
c2 – coefficient of stiffness of compressing element;
H, L – parameters of cross section of tensile elastomer element;
$\Delta 1$ – left side gap;
$\Delta 2$ – penalty distance.

Example of free damping motion of that model is shown in Fig. 8.

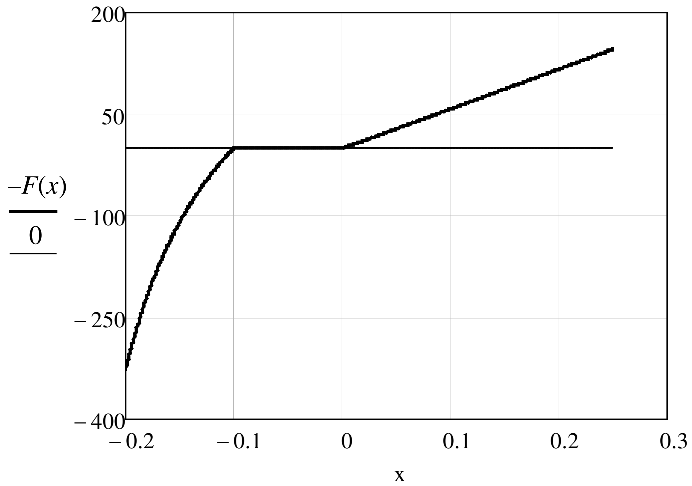


Fig. 7. **Complex elastomeric material model with longitudinal and diagonal interactions in SI units**

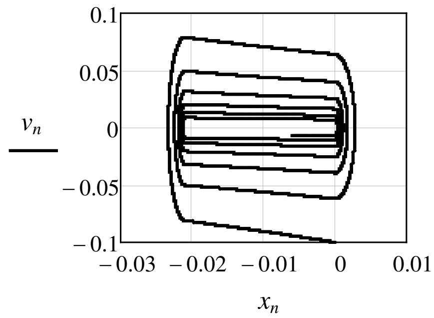
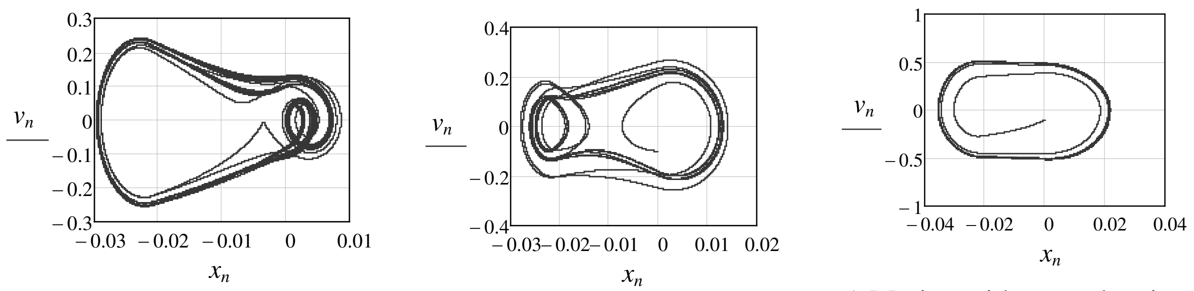


Fig. 8. **Free dumping motion in phase plane for one degree of freedom system**

Modelling of one degree of freedom system motion with time and adaptive control

Some results of the modelling system with elastomeric material stiffness characteristics are shown in the phase plane in Fig.9. It is shown that the harmonic excitation force produces two-types of motion in the phase plane and cannot be used for real robot drives. Existence of the adaptive force like negative dry friction gives strongly one motion in the phase plane.



a) Harmonic excitation with positive velocity. Motion is not stable, because may transform to the form "b")

b) Harmonic excitation with negative velocity. Motion is not stable, because may transform to the form "a")

c) Motion with control action like adaptive force (as negative dry friction). Motion is stable because only one periodic cycle exists

Fig. 9. **Examples of induced motion in the phase plane**

New approaches to gain energy control from water flow

Investigations show that for energy accumulation from water flow without special excitation control actions two degree of freedom system can be used (Fig. 10.). The system includes first – translation motion mass m1 and second – flat shape plate mass m2, rotating around the internal axis which is fixed in the first mass (Fig. 10.). Differential equations of motion can be obtained from the following two equations of kineto – statics (2) and (3):

$$\begin{aligned} &-c1\cdot x-b1\cdot \dot{x}^2\cdot sign(\dot{x})-(m1+m2)\cdot a-m2\cdot\frac{L}{2}\cdot[\varepsilon\cdot\cos(\varphi)-\omega^2\cdot\sin(\varphi)]+ \\ &+R\tau\cdot\cos(\varphi)+Rn\cdot\sin(\varphi)=0; \end{aligned} \quad (2)$$

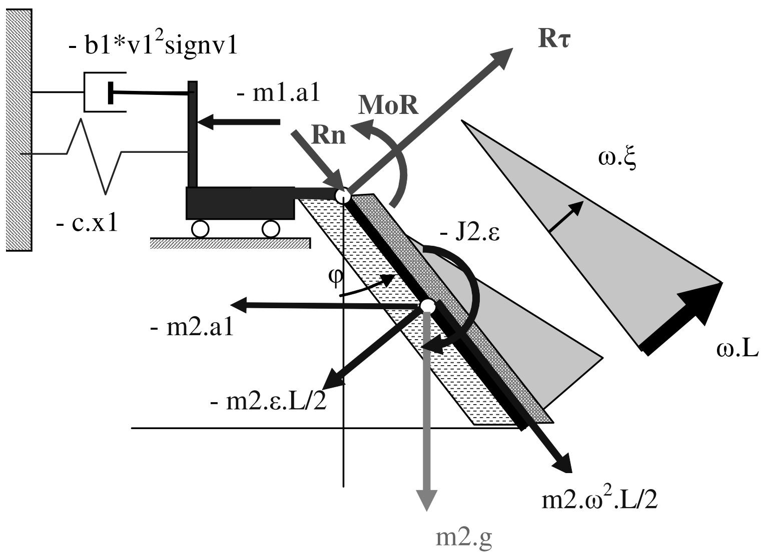


Fig. 10. **Two degree of freedom model for energy extraction**

$$MoR - m2 \cdot a \cdot \frac{L}{2} \cdot \cos(\varphi) - m2 \cdot \varepsilon \cdot (\frac{L}{2})^2 - J2 \cdot \varepsilon - m2 \cdot g \cdot \frac{L}{2} \cdot \sin(\varphi) - c2 \cdot \varphi - b2 \cdot \dot{\varphi} = 0. \quad (3)$$

Here

$$R\tau = kt \cdot B\left[(\dot{\varphi})^2 \cdot \frac{L^3}{3}\right] - 2 \cdot \dot{\varphi} \cdot (V0 - \dot{x}) \cdot \cos(\varphi) \cdot \frac{L^2}{2} + [(V0 - \dot{x}) \cdot \cos(\varphi)]^2 \cdot L;$$

$$Rn = kn \cdot B \cdot (V0 - \dot{x}) \cdot \sin(\varphi) \cdot L;$$

$$MoR = kt \cdot B \cdot \left[\dot{\varphi}^2 \cdot \frac{L^4}{4} - 2 \cdot \dot{\varphi} \cdot (V0 - \dot{x}) \cdot \cos(\varphi) \cdot \frac{L^3}{3} + [(V0 - \dot{x}) \cdot \cos(\varphi)]^2 \cdot \frac{L^2}{2}\right],$$

where a, ε – acceleration of mass m1 and angular acceleration of plate;
φ, ω – angle and angular velocity of a plate;
$R\tau$,Rn – components of flow forces along perpendicular an radial directions of plate;
c1, b1, kt, kn – parameter constants;
B, L – width and length of plate;
$V0$ – velocity of a flow.

Some results of equation modelling are shown in Fig. 11-14. Explanations of the motion quality are given under all pictures. The main conclusion is that it is possible to produce energy from constant flow by vibrations of a system with two degrees of freedom.

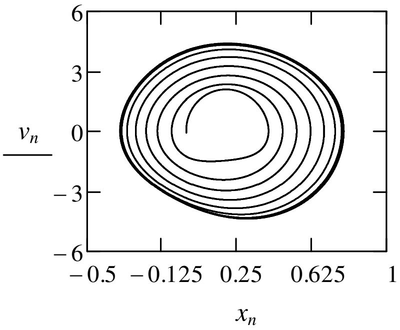


Fig. 11. **Motion in phase plane of mass *m*1**

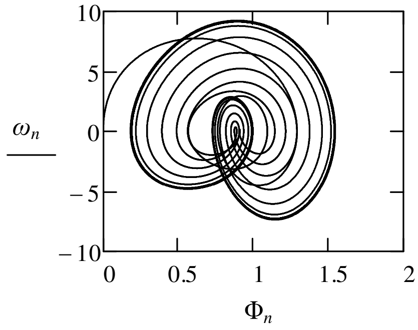


Fig. 12. **Angular rotation motion in phase plane of plate**

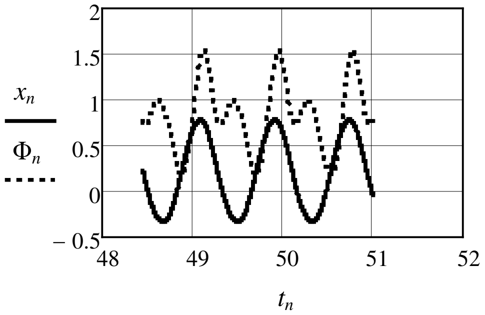


Fig.13. **Translation motion *x* of mass *m*1 and rotation motion Φ of plate (mass m2) in time domain**

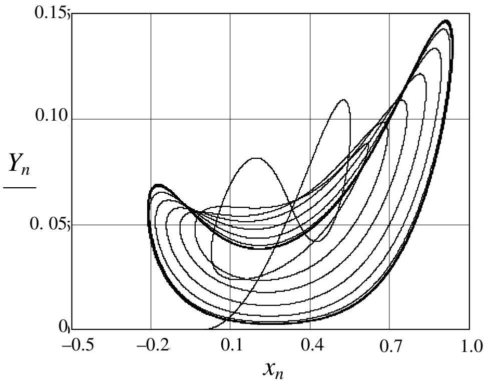


Fig. 14. **Motion of mass center of plate in vertical plane:** stationary trajectory is like a loop that allows to generate energy from constant velocity flow

Experimental investigations

For theory validation the wind tunnel was used (Fig. 15.). The possibility of energy extraction by vibration motions is checked experimentally. Use of a model is shown in Fig. 16 and 17.

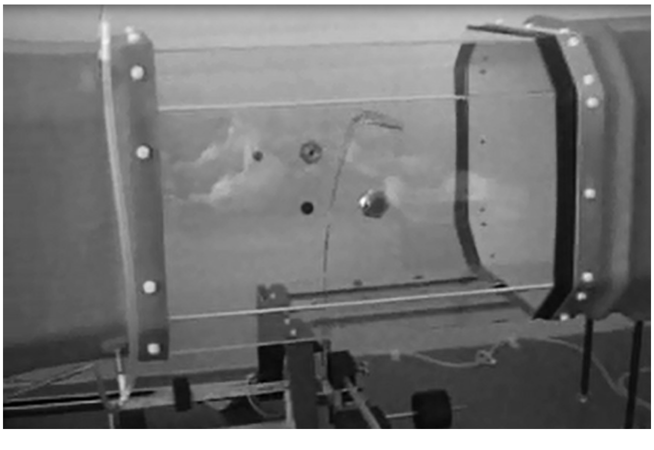


Fig. 15. **Model inside flow of wind tunnel**

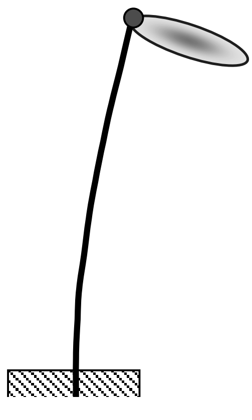


Fig. 16. **Two degrees of freedom console beam and leaflet**

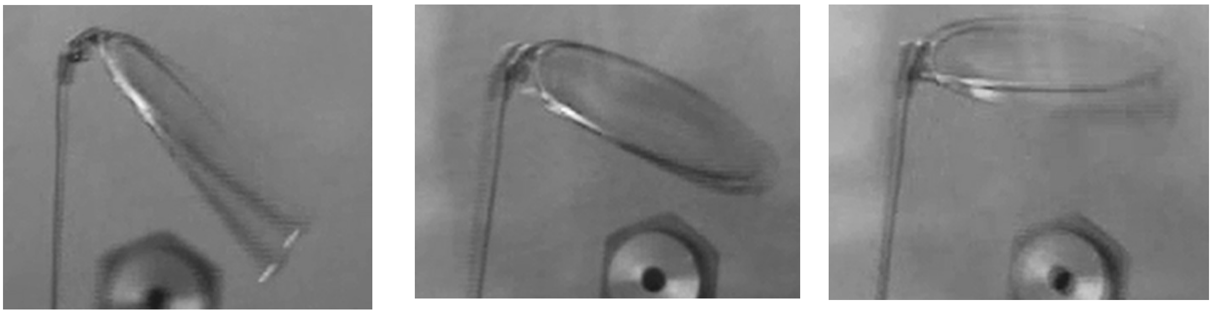


Fig. 17. **Examples of different leaflet positions inside wind tunnel:** experimentally trajectory of leaflet center mass motion (like a loop) corresponds to the results of modeling (see Fig. 14)

Results and discussion

Elastomer material elasticity diagrams are strongly nonlinear that give vide applications for vibration generation by adaptive control forces. Investigations show that from constant fluid flow in a system with one degree of freedom it is not possible to initiate the energy extraction process. It means that after the transition process the system stops in equilibrium position. Only two degrees of freedom system provide loop trajectory motion of the plate that allows us to get stable stationary vibrations in the fluid flow for energy production.

Conclusion

New approaches to gain energy and recharge power pack sources from surrounding fluid medium are investigated. For that purpose two degrees of freedom system with elastomer material suspension and adaptive control are offered. The importance of the proposed system is in further advancement of science of robotics and development of new underwater robot drives.

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