STUDY OF DYNAMICS OF ELASTOMERIC ELEMENTS

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Abstract. By analyzing underwater flexible object motion, new challenges facing mechanical and engineering industry can be seen. For example, the need to address the complex task of elastomers (e.g., rubber or silicone) robotic objects interaction with the water boundary. In this task the water flow resistance forces and deformation of the flexible object must be taken into account. The current work is an attempt to launch an investigation on elastomer dynamics of experimental and theoretical research in two directions. Experimental studies have been conducted with a sample loading on the machine HB Zwick Roell 50th. The theoretical research investigation proposes a new model with internal interactions inside elastomers. The model is based on common lateral and diagonal interaction links between the cross sections of the material. The results of the work are applied for under water robotic systems elastic parts motion modeling. Additionally, a new dynamical material model for muscle dynamics analysis may be used in biomechanics.

Keywords: underwater robot, elastomeric model, rubber experiments, rubber dynamics.

Introduction

The simplest models have shown that the rigid body and local water particle interactions can be divided into two components: normal and tangential (Fig. 1 – 3). The normal component is approximately proportional to the square of the relative speed of the normal components, but the tangential component is linearly dependent on the relative velocity component in tangential direction. In terms of an elastomeric object movement in the water, it is necessary to comply with additional elastomeric deformation.

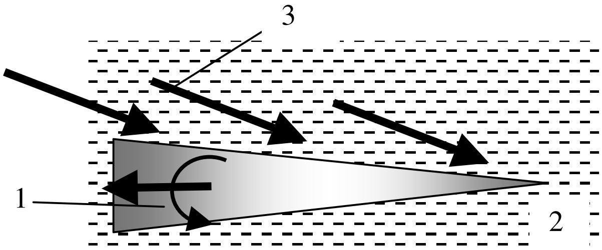

Fig. 1. **Scheme of the rigid object inside water:** 1 – rigid object common plane translation and rotation motion; 2 – water; 3 – water flow velocities

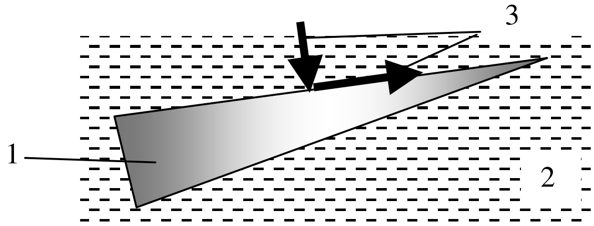

Fig. 2. **Scheme of the rigid object interactions with water:** 1 – rigid object; 2 – water; 3 – rigid object normal and tangential interactions with water

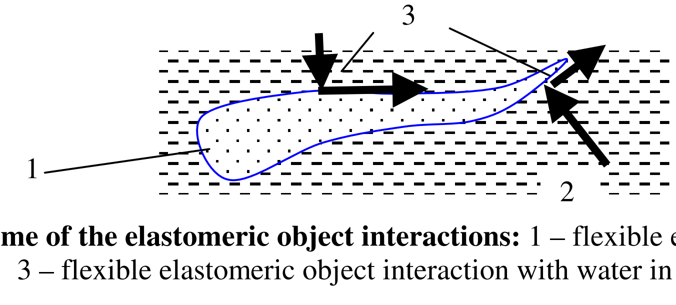

Fig. 3. **Scheme of the elastomeric object interactions:** 1 – flexible elastomeric object; 2 – water; 3 – flexible elastomeric object interaction with water in different points

The studies of elastomeric calculations show that the problem above is not well investigated in a way that mainly static methods are used in determining the static deformation (e.g., rubber shock absorber calculations in mechanical engineering, rubber gaskets calculations underwater and in space missions) [1 – 3]. Some dynamical investigations can be found in [4 – 6].

The current work is an attempt to launch an investigation of elastomeric dynamics of experimental and theoretical research in two directions. Experimental studies have been conducted with a sample of loading on the testing machine HB Zwick Roell 50. Accordingly, the theoretical research proposes a new model with internal interactions, in addition to observing nonlinear diagonal links.

Experimental investigations

The experimental pressing process of rubber elements and the result are shown in Fig. 4. The main qualitative conclusion about the function of the compression force F and displacement Δ is that when $\Delta \to 0$, the $F \to \infty$. In this report it will be taken into account by the penalty function $F \sim 1/\Delta$. Additionally, the force F close small deformations are approximately linear depending on deformation.

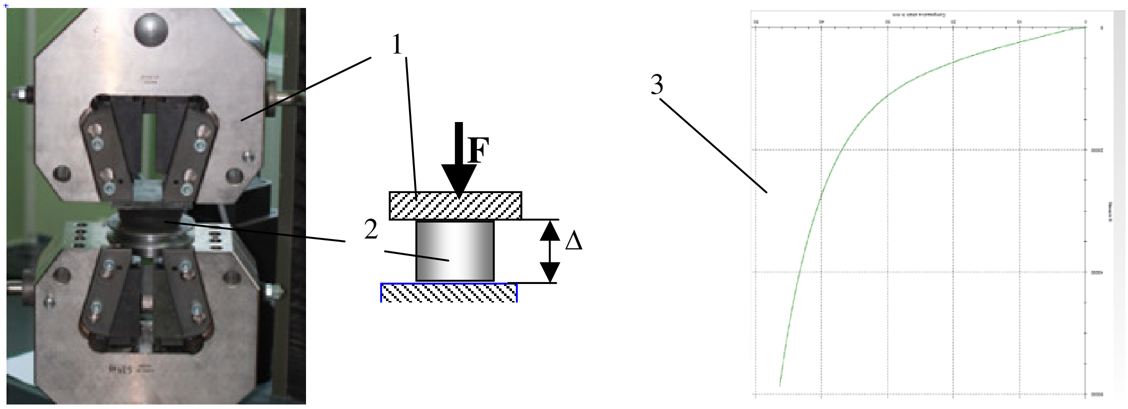

Fig. 4. **Compression process:** 1 – movable jaw; 2 – sample; 3 – compression force

Elements of the tensile process and the obtained results are shown in Fig. 5. The experimental device includes two parallel samples and two rollers, fixed into the testing machine. Some results of testing of small six similar samples and one middle sample are shown in Fig. 5. The tensile process was done till breaking points for all samples.

The tensile testing process allows formulating the next important conclusions:

- before the breaking point the force is approximately a linear function of displacement or stiffness is constant;
- close small deformation, the force F is nonlinear with smaller stiffness than in the breaking point.

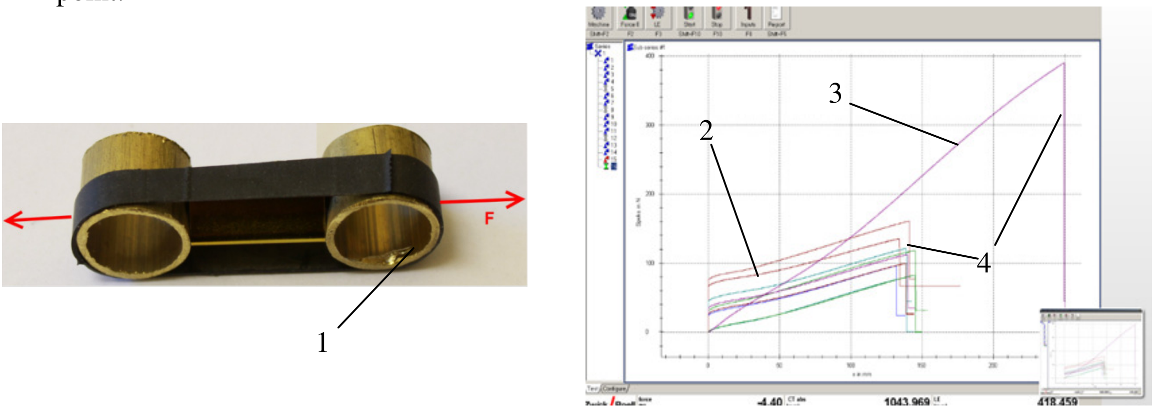

Fig. 5. **Tensile process:** 1 – experimental device with two parallel samples; 2 – graphic of tensile forces as deformation function for small six similar samples; 3 – force for middle sample; 4 – breaking points for all samples

Theoretical model

The idea is to invent a new theoretical model of the elastomer flexible element for object dynamics modeling in which the experimental results are taken into account. In this model, the simple basic element includes elastics and damping parts without internal mass (Fig. 6). If necessary, control action may be added, too (Fig. 6). Then from the basic elements and many complex elements (Fig. 6) a joint elastomer flexible element that can be built-in the vibrating mechanical system with mass m (Fig. 7) may be formed.

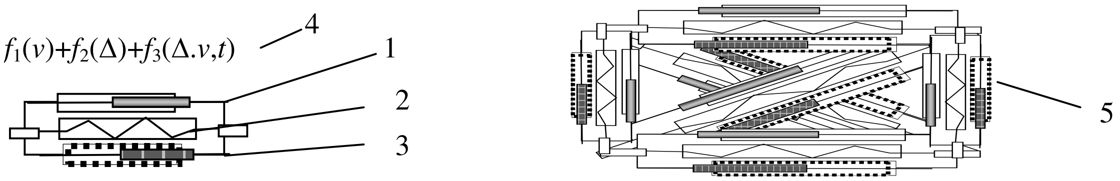

Fig. 6. **Theoretical model:** 1 – damping interaction; 2 –elastic interaction; 3 – control action; 4 – interaction forces as velocity (v); displacement (Δ) and time (t) functions; 5 – one complex element with longitudinal; transversal and diagonal interactions

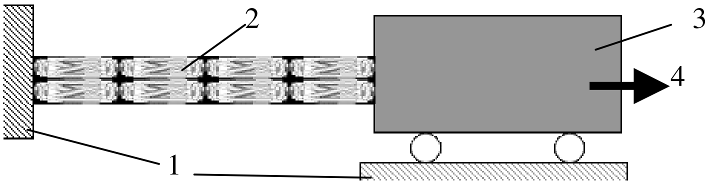

Fig. 7. **Vibrating mechanical system:** 1 – fundament; 2 – joint element; 3 – vibrating mass; 4 – exciting force

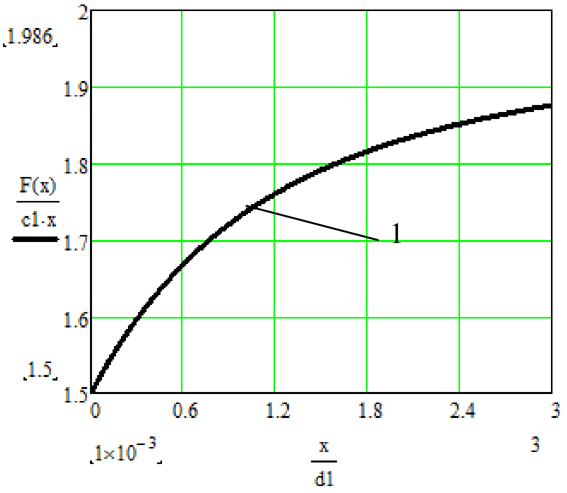

Fig. 8. **Graphic:** 1 – relationship between nonlinear elastomer elastic force and linear force (with coefficient c1) as displacement x and initial length d1 function

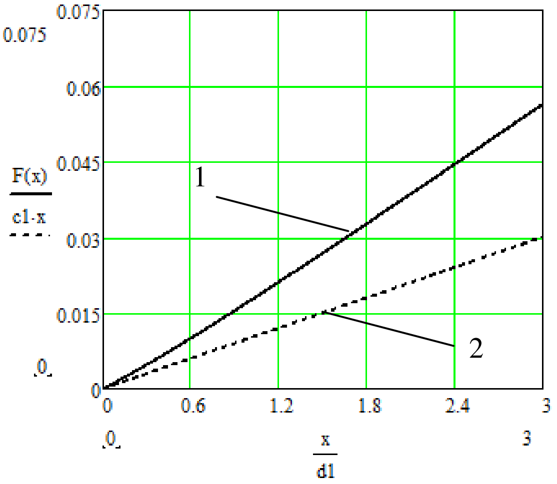

Fig. 9. **Graphic:** 1 – nonlinear elastomer elastic force $F(x)$; 2 – linear force c1x as displacement x and initial length d1 function.

The graphics in Fig. 9 shows that stiffness of elastomer is not constant and corresponds to experimental results (Fig. 5).

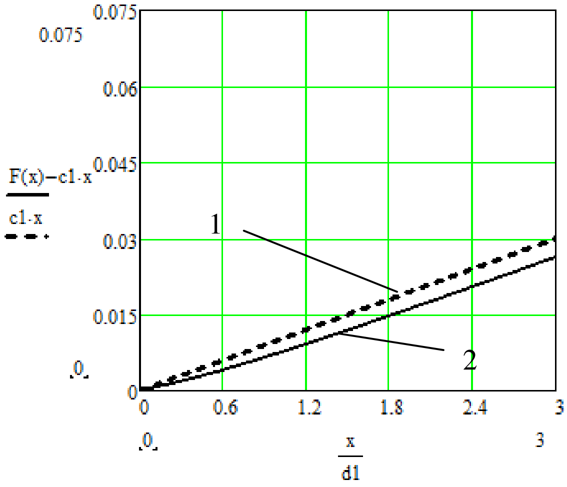

Fig. 10. **Graphic:** 1 – difference of nonlinear elastomer elastic force and linear force (with coefficient c1) as displacement x and initial length d1 function; 2 – linear force

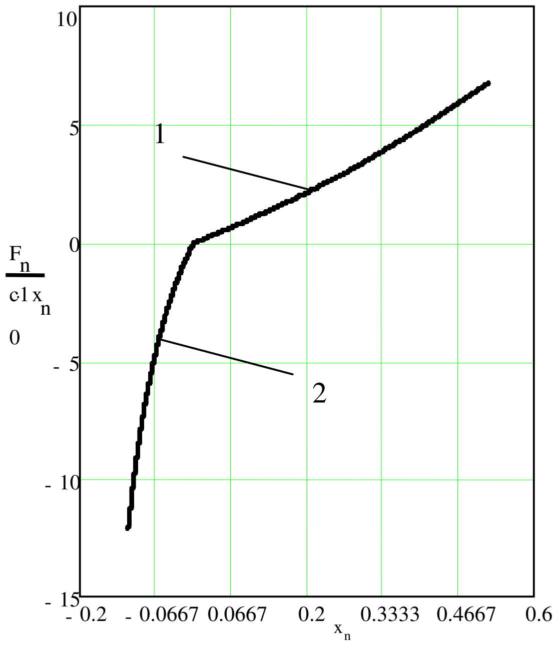

Fig. 11. **Graphic:** 1 – theoretical elastomer model force as displacement function in tensile region, 2 – theoretical elastomer model force as displacement function using penalty function in the compressing region (see Fig. 4.)

Example of motion modelling using the new elastomer model

To check up the new elastomer element application for dynamics task a system with one degree of freedom was investigated (Fig. 7.):

$$m \cdot \ddot{x} = -b \cdot \dot{x} - f(x) + P0 \cdot \sin(\omega \cdot t),$$

where m – mass;
$\ddot{x}$ – acceleration;
$\dot{x}$ – velocity;
$f(x)$ – elastomer elastic force;
t – time;
$b, \omega, P0$ – constants.

The results of modelling are shown in Fig. 12 – 14.

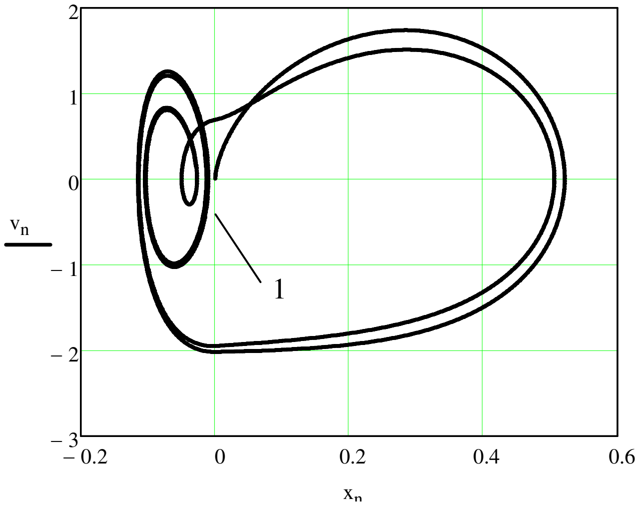

Fig. 12. **Graphic:** 1 – motion velocity *v* as displacement *x* function in phase plane

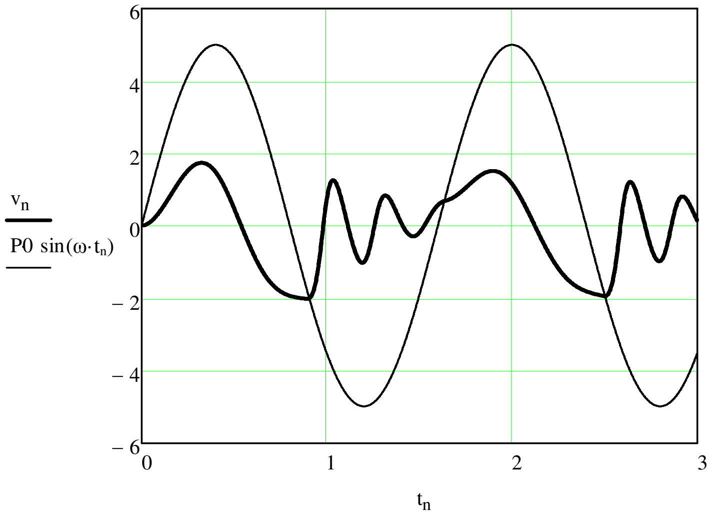

Fig. 13. **Graphic:** 1 – motion velocity v in time *t* domain, 2 – harmonica force in time domain

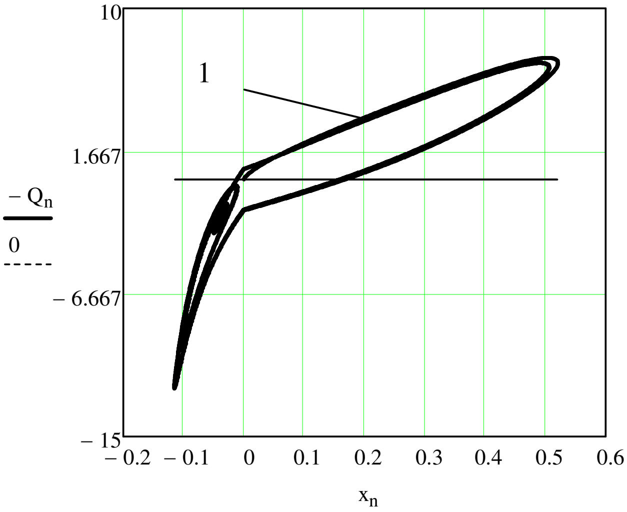

Fig. 14. **Graphic:** 1 – hysteresis of common force Q as displacement x function

Results and discussion

A new model of rubber interaction model with a moving body has been obtained. The model includes a joint element in which many complex elements with diagonal interactions are combined. The model can be implemented in mechanical systems for elastic constraints synthesis. The model can be used for transition and stationary motion investigations, including one or two side collisions. Additionally, the new dynamical model may be used in biomechanics for muscle dynamics analysis, taking into account the possibility to control internal forces inside the joint element.

Conclusions

From the experimental investigations it has been found that rubber tensile and compressing deformation are strongly non symmetric. Taking that into account, for tensile deformations super joint with diagonal interaction is recommended. Respectively, for compressing deformations the penalty function can be used. The proposed model allows investigating dynamics of mechanical systems with new nonlinear elastic constraints like elastomer elements.

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