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IMPROVED CALCULATION OF VISCOUS FRICTION IN THE MODEL OF A PIPE ROBOT

***K.Ragulskis*[1], *B.Spruogis*[2], *A.Pauliukas*[3]*, *P.Paškevičius*[4], *A.Korpach*[5], *A.Matuliauskas*[2], *V.Mištinas*[2], *L.Ragulskis*[3]**

[1]Kaunas University of Technology, Lithuania
[2]Vilnius Gediminas Technical University, Lithuania
[3]Vytautas Magnus University, Lithuania
[4]Company "Vaivora", Lithuania
[5]National Transport University, Ukraine

Abstract. Pipe robots are used in agricultural engineering for transportation of materials. Also, they are used for cleaning of internal surfaces of the pipes. In the process of numerical investigation of dynamics of a pipe robot, a specific model for viscous friction is used. This influences the results of numerical calculations of dynamics of a pipe robot. A numerical procedure for more precise calculation of viscous friction is proposed in the paper. Results of investigations for two values of time steps are obtained: without the proposed procedure and with it. Advantages of the improved calculation of viscous friction are indicated.

Keywords. viscous friction, pipe robot, vibrational transportation, dynamic processes.

1. INTRODUCTION

Pipe robots are used in agricultural engineering for transportation of materials. Also, they are used for cleaning of internal surfaces of the pipes.

In the process of numerical investigation of dynamics of a pipe robot, a specific model for viscous friction is used. This influences the results of numerical calculations of dynamics of a pipe robot.

A numerical procedure for more precise calculation of viscous friction is proposed in the paper. Results of investigations for two values of time steps are obtained: without the proposed procedure and with it. Advantages of the improved calculation of viscous friction are indicated.

Pipe robots are investigated in (Ragulskis *et al.*, 2020). Related problems of dynamics are investigated in (Glazunov, 2018), (Blekhman, 2018), (Bolotnik *et al.,* 2016), (Bansevičius *et al.,* 1985), (Kibirkštis *et al.,* 2018), (Ragulskis *et al.,* 1965), (Ragulskis *et al.,* 2021), (Spruogis *et al.,* 2002), (Spedicato, Notarstefano, 2017), (Sumbatov, Yunin, 2013) and in other research papers. Dynamics of essentially nonlinear vibrating systems is investigated in (Ragulskienė, 1974). Dynamics of transmissions is investigated in (Kurila, Ragulskienė, 1986). Robots and their dynamics are investigated in (Ragulskis *et al.,* 1987).

First the model of a pipe robot having one degree of freedom with forced harmonic excitation is presented. Then the procedure for improved calculation of viscous friction is described. Graphical results without improved calculation of viscous friction and with it are obtained.

2. MODEL OF THE PIPE ROBOT

It is assumed that the pipe robot is described by the differential equation:

$$\ddot{x} + 2h\dot{x} = f \sin \omega t, \qquad (1)$$

* Author for contacts: dr. Arvydas Pauliukas
E–mail: arvydas.pauliukas@vdu.lt

where x denotes the displacement of the pipe robot, h denotes the coefficient of viscous friction, f denotes the amplitude of harmonic excitation, ω denotes the frequency of harmonic excitation, t denotes the time variable, and the upper dot denotes differentiation with respect to the time.

The nonlinear viscous friction has the form:

$$2h = \begin{cases} 2h_2, \text{when } \dot{x} > 0, \\ 2h_1, \text{elsewhere}, \end{cases} \tag{2}$$

where h_1 and h_2 are assumed to be constant values.

The force of viscous friction is denoted as:

$$P = 2h\dot{x}. \tag{3}$$

3. IMPROVED CALCULATION OF VISCOUS FRICTION IN THE MODEL OF A PIPE ROBOT

It is assumed that T denotes the time step, the subscript 0 represents the beginning of a time step and the subscript T represents the end of a time step.

Viscous friction is assumed as:

$$2h = \begin{cases} 2h_2, \text{when } (\dot{x} > 0) \vee \big((\dot{x} = 0) \& (\ddot{x} > 0)\big), \\ \qquad 2h_1, \text{elsewhere}. \end{cases} \tag{4}$$

If:

$$\dot{x}_T > 0, \tag{5}$$

and:

$$\dot{x}_0 < 0, \tag{6}$$

or if:

$$\dot{x}_T < 0, \tag{7}$$

and:

$$\dot{x}_0 > 0, \tag{8}$$

then the concept of reduced time step is introduced:

$$T_r = -\frac{\dot{x}_0}{\dot{x}_T - \dot{x}_0} T. \tag{9}$$

Then:

$$x_{T_r} = x_0 + (x_T - x_0)\frac{T_r}{T}, \tag{10}$$

$$\dot{x}_{T_r} = 0, \tag{11}$$

$$\ddot{x}_{T_r} = \ddot{x}_0 + (\ddot{x}_T - \ddot{x}_0)\frac{T_r}{T}. \tag{12}$$

4. RESULTS OF INVESTIGATION OF DYNAMICS OF A PIPE ROBOT

The following parameters of the pipe robot are assumed:

$$\omega = 1, f = 1, h_1 = 1, h_2 = 0.1. \tag{13}$$

Calculations from zero initial conditions are performed:

$$x(0) = 0, \dot{x}(0) = 0. \tag{14}$$

Results for two values of the time step are investigated:

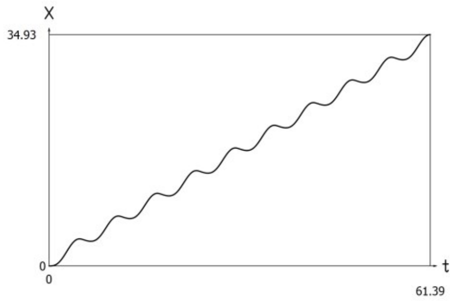
$$T = \frac{\frac{2\pi}{\omega}}{40}, \tag{15}$$

and:

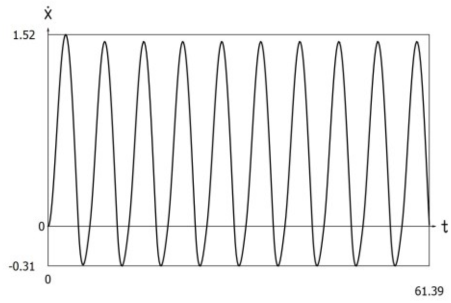
$$T = \frac{\frac{2\pi}{\omega}}{80}. \tag{16}$$

Results of calculations for the first value of the time step with improved calculation of viscous friction are presented.

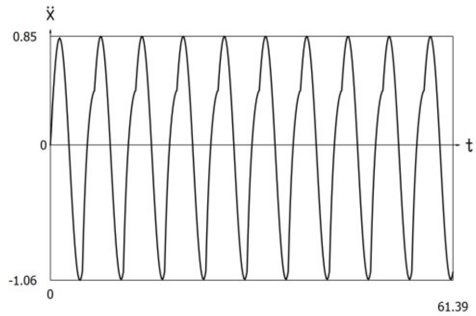
Variation of displacement, velocity, acceleration, and velocity multiplied by acceleration is presented in Fig. 1.



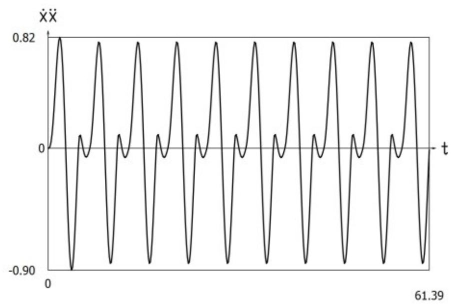
a) Displacement as function of time.



b) Velocity as function of time.



c) Acceleration as function of time.



d) Velocity multiplied by acceleration as function of time.

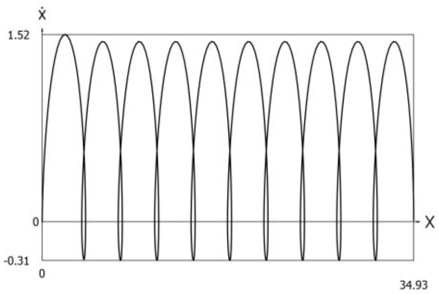
Figure 1. Dynamics of the pipe robot.

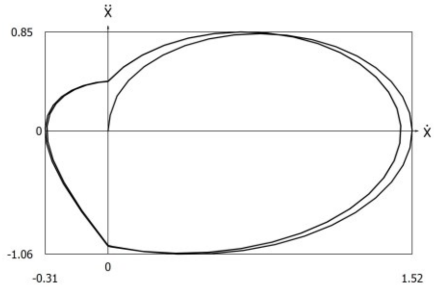
Phase trajectories of the pipe robot are presented in Fig. 2. Force of viscous friction as function of velocity is presented in Fig. 3.

From the presented investigation advantages of the improved calculation of the force of viscous friction are observed.

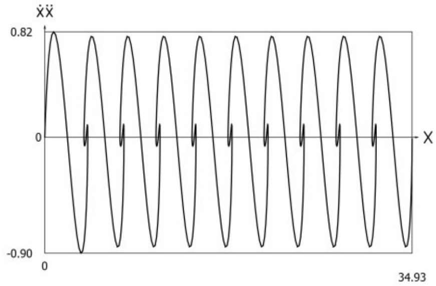
5. CONCLUSIONS

In the process of numerical investigation of dynamics of a pipe robot, a specific model for viscous friction is used. This influences the results of numerical calculations of dynamics of a pipe robot. A numerical procedure for more precise calculation of viscous friction is proposed in the paper. Results of investigations for two values of time steps are obtained: without the proposed procedure and with it.





a) Velocity as function of displacement. b) Acceleration as function of velocity.



c) Velocity multiplied by acceleration as function of displacement.

Figure 2. Phase trajectories of the pipe robot.

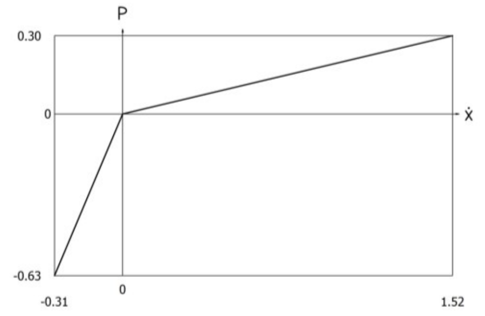


Figure 3. Force of viscous friction as function of velocity.

Variations of displacement, velocity, acceleration, and velocity multiplied by acceleration are investigated. Phase trajectories of the pipe robot are obtained. Force of viscous friction as function of velocity is represented.

From the presented investigation advantages of the improved calculation of the force of viscous friction are observed.

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