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INVESTIGATION OF DYNAMICS OF A PIPE ROBOT WITH SELF-STOPPING MECHANISM

Pipe robots are used in agricultural engineering for transportation of various materials inside the pipe as well as for cleaning of internal surfaces of the pipes.

In this paper a model of a pipe robot with self-stopping mechanism is proposed and described in detail. Numerical investigations are performed, and the obtained results are presented in the form of graphical relationships. Variations of displacements as well as variations of velocities of the exciting mass and of the case of the pipe robot as functions of time are investigated. Results for steady state regime of motion are presented.

Displacement of the first degree of freedom, velocity of the first degree of freedom, displacement of the second degree of freedom, velocity of the second degree of freedom as functions of time in the steady state regime of motion are investigated. Also, difference of displacements as well as difference of velocities as functions of time in the steady state regime of motion are represented.

Results for three typical values of the constant force are described in the paper: first the results when the constant force is assumed equal to zero are presented and then the results for the two typical nonzero values of the constant force are presented. From the obtained graphical representations, the influence of the value of the constant force to the dynamic behavior of the pipe robot can be seen.

The obtained graphical representations enable to understand the behavior of the investigated pipe robot with self-stopping mechanism.

Keywords: pipe robot, self-stopping mechanism, harmonic excitation, steady state motions, parameters of the system.

INTRODUCTION

Pipe robots are used for transportation of various materials inside the pipe as well as for cleaning of the internal surfaces of the pipes.

In this paper a model of a pipe robot with self-stopping mechanism is proposed and described in detail. Numerical investigations are performed, and the obtained results are presented in the form of graphical relationships.

Variations of displacements as well as variations of velocities of the exciting mass and of the case of the pipe robot as functions of time are investigated.

The obtained results are used in the process of design of pipe robots.

Implementation of a pipe robot is presented in [1]. Pipe robot with impact interactions is analyzed in [2]. Pneumatic exciters of vibrations are investigated in [3]. Dynamics of a pipe robot is analyzed in [4]. Vibrations of elements of manipulators and robots are investigated in [5]. Dynamic effects of essentially nonlinear system are analyzed in [6]. Nonlinearity of specific type is described in [7]. Impact motions in elements of manipulators and robots are investigated in [8]. Essentially nonlinear systems are analyzed in [9]. Dynamics of transmissions is investigated in [10]. Synchronization is analyzed in [11]. Robots of high precision are investigated in [12]. Industrial robots are described in [13]. New mechanisms in robotics are described in [14]. Specific nonlinear systems are investigated in [15]. Nonlinear effects of vibrations are analyzed in [16]. Robot of a special type is investigated in [17]. Periodic orbits of nonlinear mechanical systems are analyzed in [18].

First, a model of the investigated pipe robot with self-stopping mechanism is presented. Then results of performed numerical investigations for typical parameters of the system are described. Influence of the constant force on the dynamic behavior of the pipe robot is investigated.

MODEL OF THE PIPE ROBOT WITH SELF-STOPPING MECHANISM

The exciter of vibrations is located inside the case of a pipe robot, and they are mutually interconnected by a spring and a damper. The case of a pipe robot interacts with the walls of the pipe by a self-stopping mechanism, which allows the motion of the case of the pipe robot in one direction and does not allow the motion of the pipe robot in the opposite direction.

Dynamics of the pipe robot with self-stopping mechanism takes place according to two regimes of motion: self-stopping mechanism allows the motion of the pipe robot; self-stopping mechanism does not allow the motion of the pipe robot.

DYNAMICS OF THE SYSTEM WHEN THE SELF-STOPPING MECHANISM ALLOWS THE MOTION OF THE PIPE ROBOT

Dynamics of the investigated system is described by the following equations:

$$m_1\ddot{x}_1 + H\left(\dot{x}_1 - \dot{x}_2\right) + C\left(x_1 - x_2\right) = F_1, \quad (1)$$

$$m_2\ddot{x}_2 + H\left(\dot{x}_2 - \dot{x}_1\right) + C\left(x_2 - x_1\right) = F_2, \quad (2)$$

where x_1 is the displacement of the pipe robot, x_2 is the displacement of the exciter of vibrations, m_1 is the mass of the case of the pipe robot, H is the coefficient of viscous friction between the exciter of vibrations and the case of the pipe robot, C is the coefficient of stiffness between the exciter of vibrations and the case of the pipe robot, F_1 is the force of resistance to the motion of the pipe robot, m_2 is the mass of the exciter of vibrations, F_2 is the exciting force of the exciter of vibrations and the upper dot denotes differentiation with respect to the time.

It is assumed that the force of resistance to the motion of the pipe robot has the following form:

$$F_1 = A - B\dot{x}_1, \quad (3)$$

where A and B are constants.

It is assumed that the exciting force of the exciter of vibrations has the following form:

$$F_2 = f \sin \omega t, \quad (4)$$

where f is the amplitude of excitation, ω is the frequency of excitation and t is the time variable.

Thus, the equations of motion of the investigated system have the following form:

$$m_1\ddot{x}_1 + B\dot{x}_1 + H\left(\dot{x}_1 - \dot{x}_2\right) + C\left(x_1 - x_2\right) = A, \quad (5)$$

$$m_2\ddot{x}_2 + H\left(\dot{x}_2 - \dot{x}_1\right) + C\left(x_2 - x_1\right) = f \sin \omega t. \quad (6)$$

This regime of motion takes place until the following condition is satisfied:

$$\dot{x}_1 = 0. \quad (7)$$

DYNAMICS OF THE SYSTEM WHEN THE SELF-STOPPING MECHANISM DOES NOT ALLOW THE MOTION OF THE PIPE ROBOT

In this case it is assumed that:

$$\dot{x}_1 = 0. \quad (8)$$

Dynamics of the exciter of vibrations is described by the following equation:

$$m_2\ddot{x}_2 + H\dot{x}_2 + Cx_2 = f \sin \omega t + Cx_1. \quad (9)$$

Also, the following force is calculated:

$$P = A + H\dot{x}_2 - C\left(x_1 - x_2\right). \quad (10)$$

This regime of motion takes place until the following condition is satisfied:

$$P = 0. \quad (11)$$

INVESTIGATION OF DYNAMICS OF THE PIPE ROBOT WITH SELF-STOPPING MECHANISM

The following parameters of the investigated pipe robot with self-stopping mechanism were assumed:

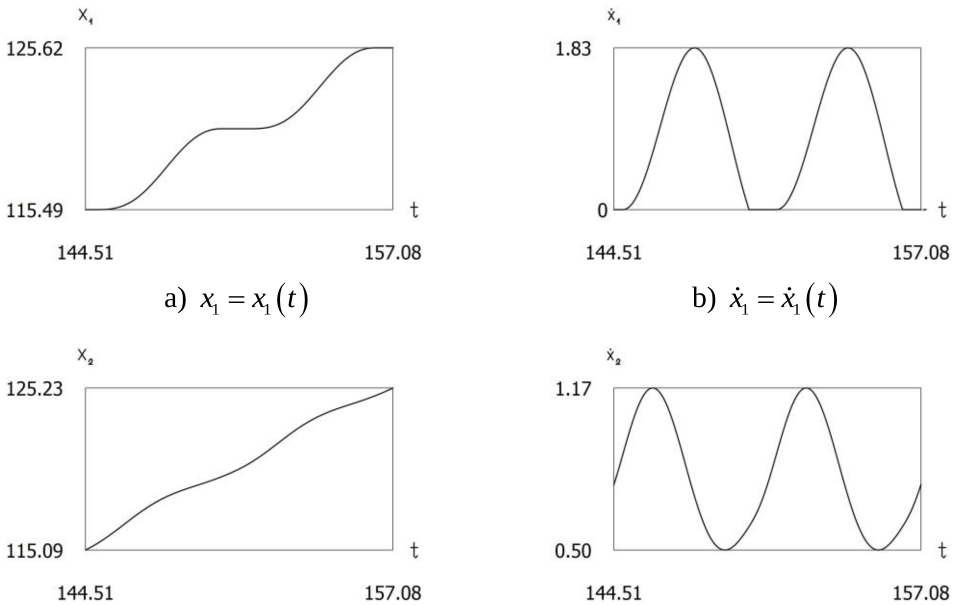
$$\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1. \tag{12}$$

Investigations for the three values of the constant force of resistance to the motion of the pipe robot were performed:

$$A = 0, \tag{13}$$
$$A = -0.2, \tag{14}$$
$$A = -0.4. \tag{15}$$

INVESTIGATIONS FOR THE VALUE OF $A = 0$

Variations of displacements as functions of time and of velocities as functions of time are presented in Fig. 1.



a) $x_1 = x_1(t)$ b) $\dot{x}_1 = \dot{x}_1(t)$

c) $x_2 = x_2(t)$ d) $\dot{x}_2 = \dot{x}_2(t)$

Figure 1. Results of investigation of dynamics for $\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = 0$

Variations of difference of displacements as functions of time and of difference of velocities as functions of time are presented in Fig. 2.

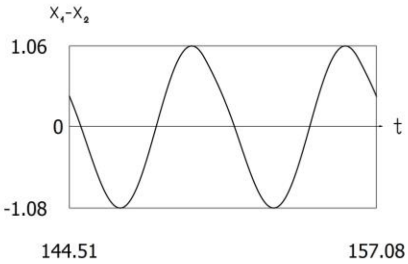
INVESTIGATIONS FOR THE VALUE OF $A = -0.2$

Variations of displacements as functions of time and of velocities as functions of time are presented in Fig. 3.

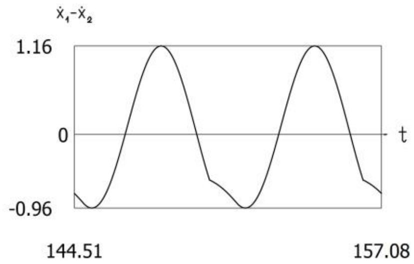
Variations of difference of displacements as functions of time and of difference of velocities as functions of time are presented in Fig. 4.

INVESTIGATIONS FOR THE VALUE OF $A = -0.4$

Variations of displacements as functions of time and of velocities as functions of time are presented in Fig. 5.

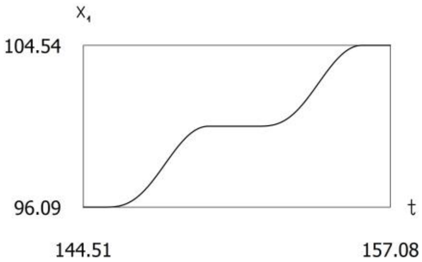


a) Difference of displacements as function of time

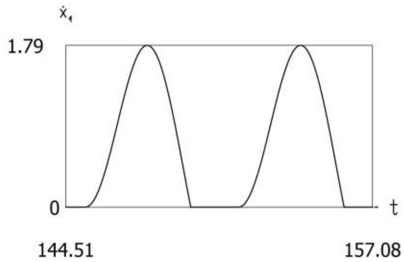


b) Difference of velocities as function of time

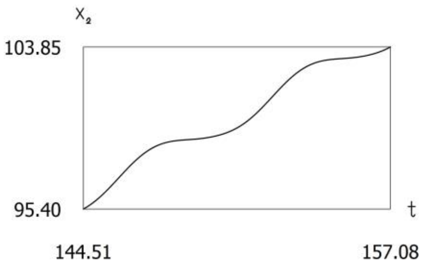
Figure 2. Relative motions for $\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = 0$



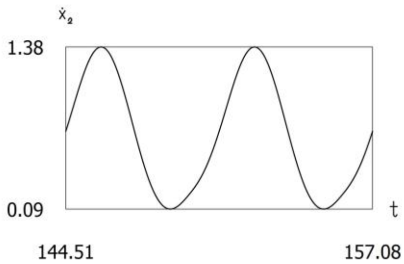
a) $x_1 = x_1(t)$



b) $\dot{x}_1 = \dot{x}_1(t)$

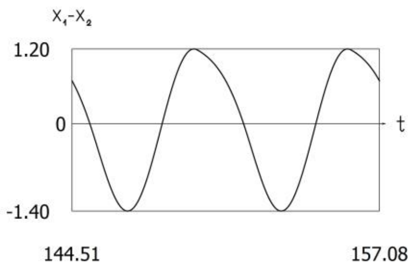


c) $x_2 = x_2(t)$

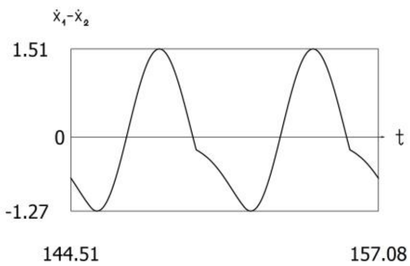


d) $\dot{x}_2 = \dot{x}_2(t)$

Figure 3. Results of investigation of dynamics for
$\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = -0.2$



a) Difference of displacements as function of time

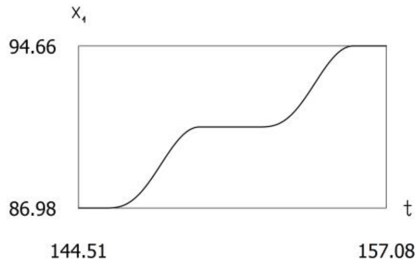


b) Difference of velocities as function of time

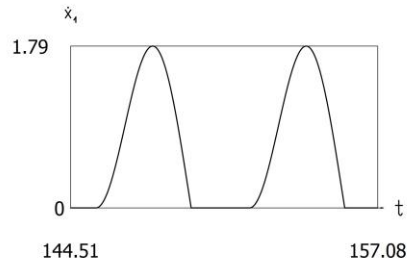
Figure 4. Relative motions for $\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = -0.2$

Variations of difference of displacements as functions of time and of difference of velocities as functions of time are presented in Fig. 6.

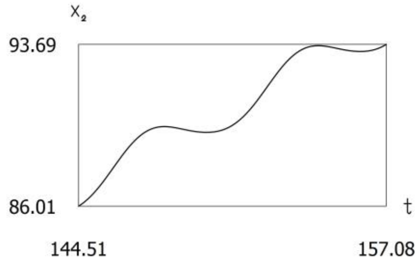
The obtained graphical representations enable to understand the behavior of the investigated pipe robot with self-stopping mechanism.



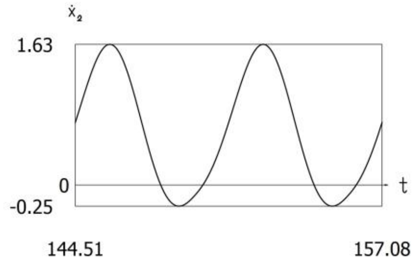
a) $x_1 = x_1(t)$



b) $\dot{x}_1 = \dot{x}_1(t)$

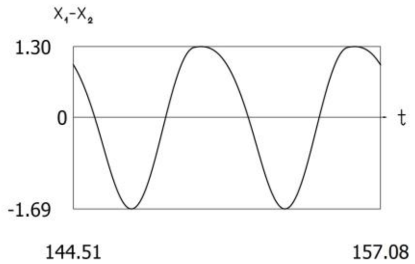


c) $x_2 = x_2(t)$

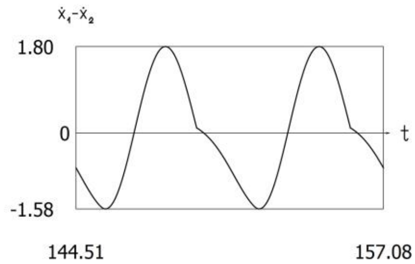


d) $\dot{x}_2 = \dot{x}_2(t)$

Figure 5. Results of investigation of dynamics for
$\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = -0.4$



a) Difference of displacements as function of time



b) Difference of velocities as function of time

Figure 6. Relative motions for $\omega = 1,\ m_1 = 1,\ B = 0.1,\ H = 0.1,\ C = 1,\ m_2 = 1,\ f = 1,\ A = -0.4$

CONCLUSIONS

Pipe robots are used in agricultural engineering for transportation of various materials inside the pipe as well as for cleaning of internal surfaces of the pipes. In this paper a model of a pipe robot with self-stopping mechanism is proposed and described in detail. Numerical investigations are performed, and the obtained results are presented in the form of graphical relationships. Variations of displacements as well as variations of velocities of the exciting mass and of the case of the pipe robot as functions of time are investigated. Results for steady state regime of motion are presented.

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K. Ragulskis, A. Pauliukas, M. Maiak*, *P. Paškevičius, R. Maskeliūnas, L. Ragulskis. **Investigation of dynamics of a pipe robot with self-stopping mechanism.**

Трубні роботи використовуються у сільськогосподарському машинобудуванні для транспортування різних матеріалів усередині труби, а також для очищення внутрішніх поверхонь труб.

У цій статті запропоновано і докладно описано модель трубного робота з механізмом, що самозупиняється. Проведено чисельні дослідження, а отримані результати подано у вигляді графічних залежностей. Досліджуються зміни переміщень, а також зміни швидкостей збудливої маси та корпусу трубопровідного робота як функції часу. Представлені результати для режиму руху, що встановився.

Досліджуються переміщення першого ступеня свободи, швидкість першого ступеня свободи, переміщення другого ступеня свободи, швидкість другого ступеня свободи як функції часу у стаціонарному режимі руху. Також представлено різницю переміщень, а також різницю швидкостей як функції часу в стаціонарному режимі руху.

У статті описані результати трьох типових значень постійної сили: спочатку представлені результати, коли постійна сила прийнята рівної нулю, а потім представлені результати для двох типових ненульових значень постійної сили. З отриманих графічних уявлень видно вплив величини постійної сили динамічне поведінка робота.

Отримані графічні зображення дозволяють зрозуміти поведінку досліджуваного трубопровідного робота з механізмом самозупинення.

Ключові слова: трубопровідний робот, самотормозний механізм, гармонічне порушення, встановлені руху, параметри системи.

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