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INVESTIGATION OF MANIPULATOR WITH VIBRATIONAL DRIVE FOR TRANSPORTATION IN AGRICULTURAL MACHINES

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Abstract

Mechanism for transformation of vibrating motion into translational using the self-stopping device is proposed in the paper. Model of the investigated system is described. Numerical investigations for various parameters of the investigated system are performed and typical graphical relationships are presented. Dynamics of vibrational transportation is investigated, and the obtained results are used in the process of design of mechanisms of the proposed type. Mechanisms of the proposed type can be used in elements of manipulators and robots, including pipe robots and other devices used in agricultural engineering.
Keywords: *vibrational motion, translational motion, self-stopping mechanism, steady state motions.*

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1. Introduction

Mechanism for transformation of vibrating motion into translational using the self-stopping device is proposed in the paper.

Model of the investigated system is described. Numerical investigations for various parameters of the investigated system are performed and typical graphical relationships are presented. Dynamics of vibrational transportation is investigated.

The obtained results are used in the process of design of mechanisms of the proposed type. Mechanisms of the proposed type can be used in elements of manipulators and robots, including pipe robots and other devices used in agricultural engineering.

The investigated element of agricultural machines is shown in Fig. 1.

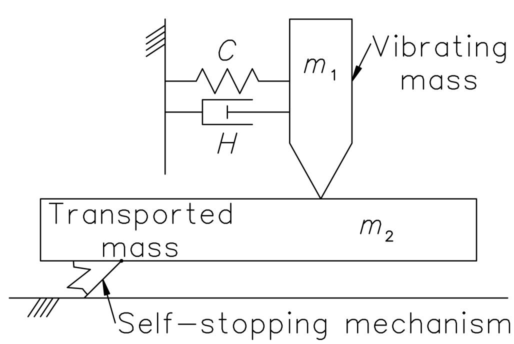


Fig. 1. The investigated element of agricultural machines

Vibrational motions are investigated in (Blekhman, 2018), (Kibirkštis *et al.,* 2018), (Kurila, Ragulskienė, 1986), (Ragulskienė, 1974), (Ragulskis *et al.,* 1965), (Spedicato, Notarstefano, 2017), (Sumbatov, Yunin, 2013).

Dynamics of robots is investigated in (Glazunov, 2018), (Bolotnik *et al.,* 2016), (Ragulskis *et al.,* 2020), (Ragulskis *et al.,* 1987), (Ragulskis, Spruogis, Paškevičius *et al.,* 2021), (Ragulskis, Spruogis, Pauliukas *et al.,* 2021), (Bansevičius *et al.,* 1985), (Spruogis *et al.,* 2002).

First model of the investigated system with two degrees of freedom is described. Then results of numerical investigation of steady state motions for various parameters of the system are presented and conclusions about dynamic behavior of the investigated system are made.

2. Model of the investigated manipulator with vibrational drive

First model in the dimensional form is described. Further x_1 is the displacement of the vibrating mass and x_2 is the displacement of the transported mass and the upper dot denotes differentiation with respect to the time t, that is:

$$\dot{} = \frac{d}{dt}. \tag{1}$$

It is assumed that the vibrating mass is excited by a harmonic force.

When the following condition is satisfied:

$$\dot{x}_1 < \dot{x}_2, \tag{2}$$

then dynamics of the system is described by the equations presented further.

Dynamics of the exciting mass is described by the equation:

$$P_{12} = m_1\ddot{x}_1 + H\dot{x}_1 + Cx_1 - F\sin\omega t - \overline{f}_0 = 0, \tag{3}$$

where m_1 denotes the exciting mass, H denotes the coefficient of viscous friction, C denotes the coefficient of stiffness, F denotes the amplitude of harmonic excitation, ω denotes the frequency of harmonic excitation, $\overline{f}_0$ denotes the coefficient of dry friction.

Dynamics of the transported mass is described by the equation:

$$P_{21} = m_2\ddot{x}_2 + B\dot{x}_2 - A + \overline{f}_0 = 0, \tag{4}$$

where m_2 denotes the transported mass, B denotes the coefficient of viscous friction, A denotes the constant external force acting to the transported mass.

When the following condition is satisfied:

$$\dot{x}_1 = \dot{x}_2, \tag{5}$$

then dynamics of the investigated system is described by the equation:

$$P_{12} + P_{21} = m_1\ddot{x}_1 + m_2\ddot{x}_2 + H\dot{x}_1 + B\dot{x}_2 + Cx_1 - F\sin\omega t - A = 0. \tag{6}$$

The equations are transformed to non-dimensional form by introducing the following notations:

$$p^2 = \frac{C}{m_1},\ \tau = pt,\ ' = \frac{d}{d\tau},\ f = \frac{F}{C},\ f_0 = \frac{\overline{f}_0}{C},\ a = \frac{A}{C},\ h = \frac{H}{\sqrt{Cm_1}},\ b = \frac{B}{\sqrt{Cm_1}},\ \mu = \frac{m_2}{m_1},\ \nu = \frac{\omega}{p}. \tag{7}$$

Thus, in non-dimensional parameters dynamics of the investigated system is described by the equations presented further.

When the following condition is satisfied:

$$x_1' < x_2', \tag{8}$$

then dynamics of the system is described by the equations:

$$\frac{P_{12}}{C} = x_1'' + hx_1' + x_1 - f\sin\nu\tau - f_0 = 0, \tag{9}$$

$$\frac{P_{21}}{C} = \mu x_2'' + bx_2' - a + f_0 = 0. \tag{10}$$

When the following condition is satisfied:

$$x_1' = x_2', \tag{11}$$

then dynamics of the investigated system is described by the equation:

$$\frac{P_{12}}{C} + \frac{P_{21}}{C} = x_1'' + \mu x_2'' + hx_1' + bx_2' + x_1 - f\sin\nu\tau - a = 0. \tag{12}$$

Numerical integration of the equations of motion is performed by using the Newmark constant average acceleration procedure.

3. Investigation of steady state dynamics of the manipulator with vibrational drive

The following parameters of the investigated dynamical system are assumed:

$$\nu = 1,\, f = 1,\; h = 0.1,\, f_0 = 0.5,\; \mu = 1,\; b = 0.1. \tag{13}$$

Zero initial conditions are assumed:

$$x_1(0) = 0,\; x_1'(0) = 0,\; x_2(0) = 0,\; x_2'(0) = 0. \tag{14}$$

Results for three values of the constant force are presented:

$$a = 0, \tag{15}$$

$$a = -0.2, \tag{16}$$

$$a = 0.2, \tag{17}$$

thus, investigations are performed for the case when there is no constant force, when the value of the constant force is negative and when the value of the constant force is positive.

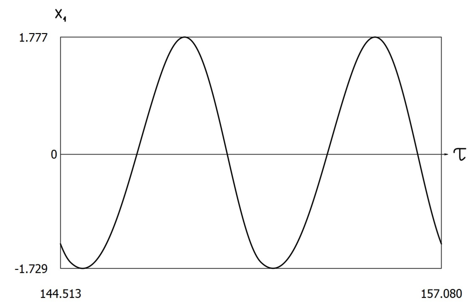
3.1. Results of investigations when there is no constant force

Non-dimensional displacement of the first degree of freedom, non-dimensional velocity of the first degree of freedom, non-dimensional displacement of the second degree of freedom, non-dimensional velocity of the second degree of freedom as functions of non-dimensional time are presented in Fig. 2.

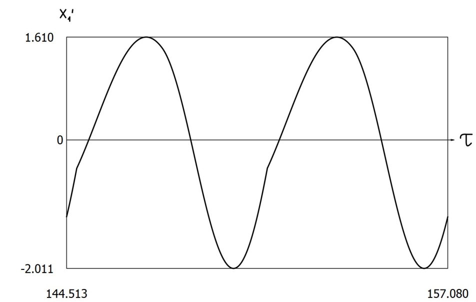
Non-dimensional relative displacement and non-dimensional relative velocity as functions of non-dimensional time are presented in Fig. 3.

Phase trajectories of the first degree of freedom and of the second degree of freedom are presented in Fig. 4.

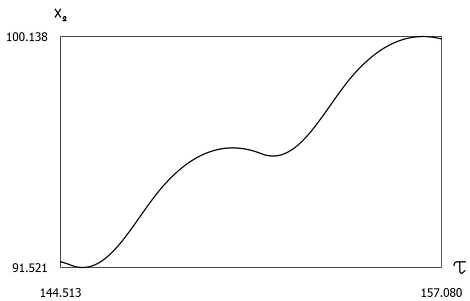
Phase trajectory of relative motion is presented in Fig. 5.



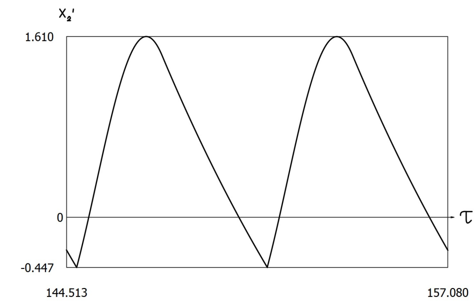
a) Non-dimensional displacement of the first degree of freedom as function of non-dimensional time



b) Non-dimensional velocity of the first degree of freedom as function of non-dimensional time

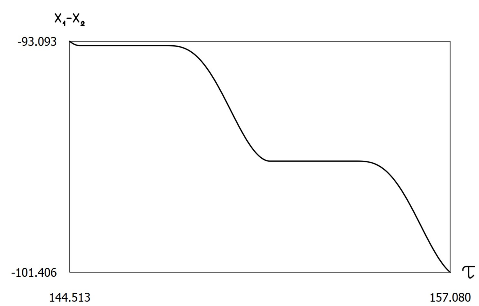


c) Non-dimensional displacement of the second degree of freedom as function of non-dimensional time

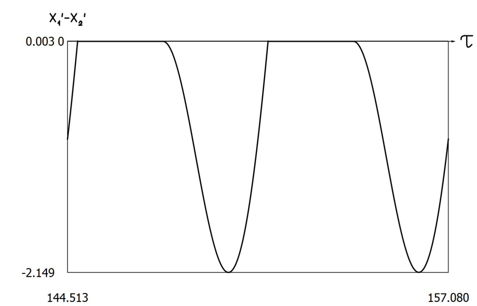


d) Non-dimensional velocity of the second degree of freedom as function of non-dimensional time

Fig. 2. Dynamics of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0$



a) Non-dimensional relative displacement as function of non-dimensional time



b) Non-dimensional relative velocity as function of non-dimensional time

Fig. 3. Relative motions of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0$

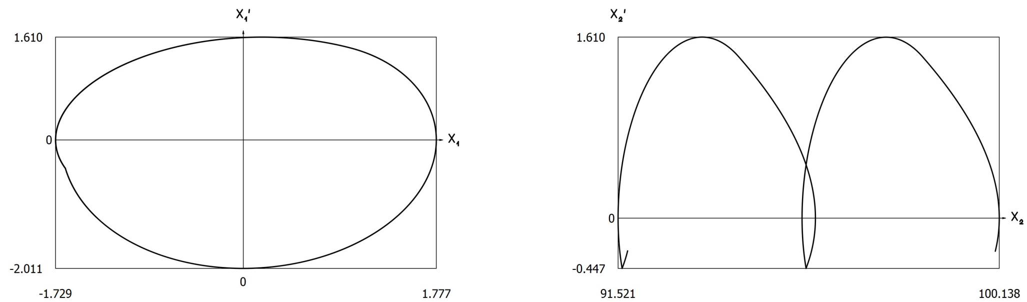
3.2. Results of investigations when the constant force is negative

Non-dimensional displacement of the first degree of freedom, non-dimensional velocity of the first degree of freedom, non-dimensional displacement of the second degree of freedom, non-dimensional velocity of the second degree of freedom as functions of non-dimensional time are presented in Fig. 6.

Non-dimensional relative displacement and non-dimensional relative velocity as functions of non-dimensional time are presented in Fig. 7.

Phase trajectories of the first degree of freedom and of the second degree of freedom are presented in Fig. 8.

Phase trajectory of relative motion is presented in Fig. 9.



a) Phase trajectory of the first degree of freedom b) Phase trajectory of the second degree of freedom

Fig. 4. Phase trajectories of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0$

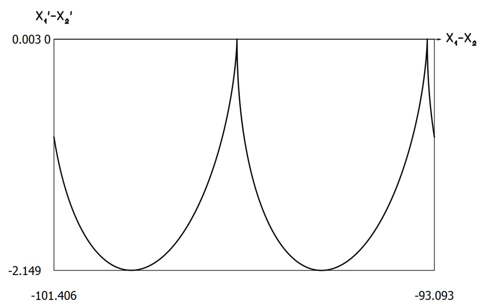
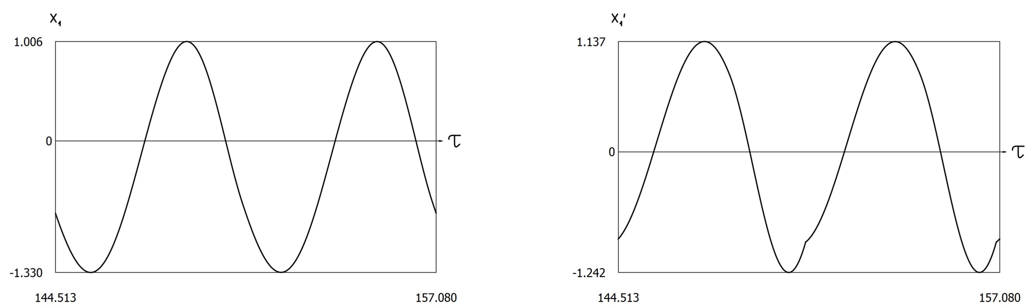
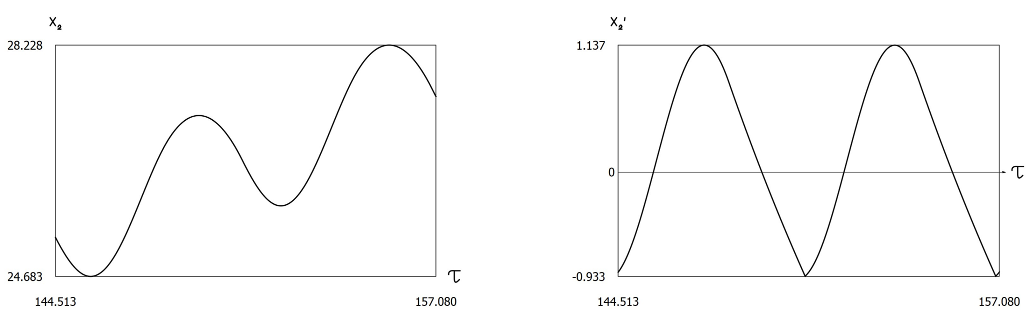


Fig. 5. Phase trajectory of relative motion of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0$



a) Non-dimensional displacement of the first degree of freedom as function of non-dimensional time

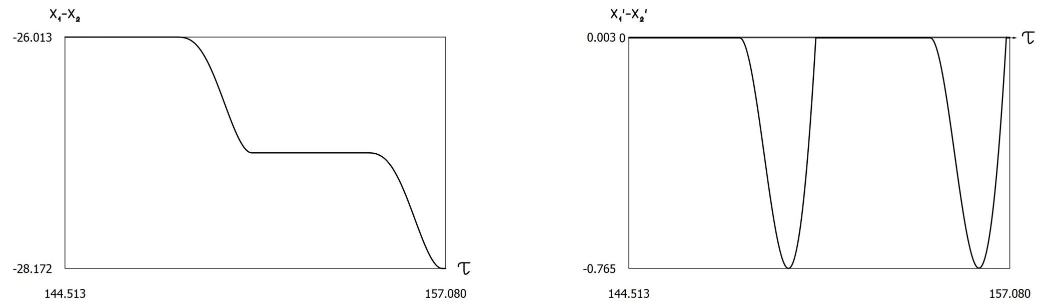
b) Non-dimensional velocity of the first degree of freedom as function of non-dimensional time



c) Non-dimensional displacement of the second degree of freedom as function of non-dimensional time

d) Non-dimensional velocity of the second degree of freedom as function of non-dimensional time

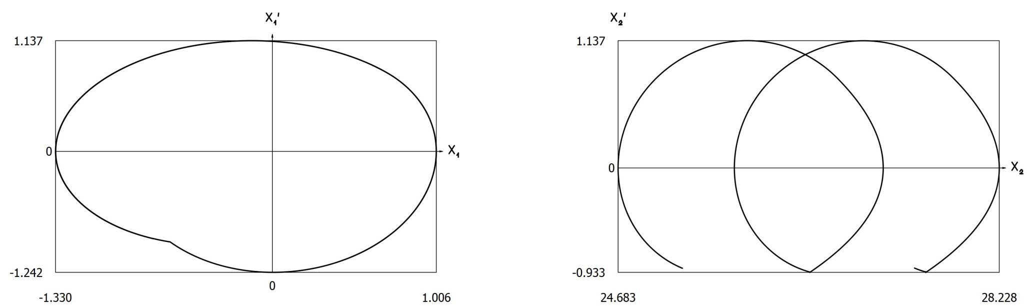
Fig. 6. Dynamics of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = -0.2$



a) Non-dimensional relative displacement as function of non-dimensional time

b) Non-dimensional relative velocity as function of non-dimensional time

Fig. 7. Relative motions of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = -0.2$



a) Phase trajectory of the first degree of freedom

b) Phase trajectory of the second degree of freedom

Fig. 8. Phase trajectories of the investigated system for
$\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = -0.2$

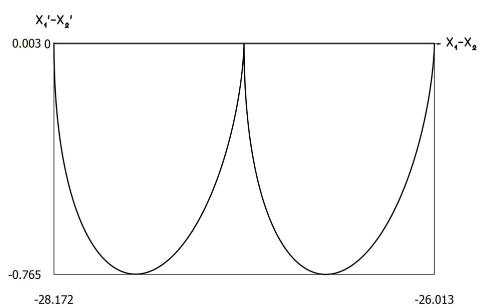


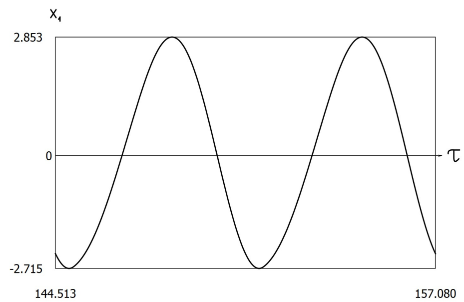
Fig. 9. Phase trajectory of relative motion of the investigated system for
$\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = -0.2$

3.3. Results of investigations when the constant force is positive

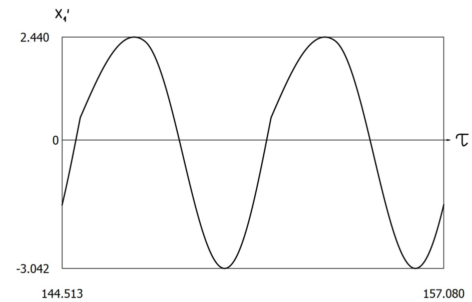
Non-dimensional displacement of the first degree of freedom, non-dimensional velocity of the first degree of freedom, non-dimensional displacement of the second degree of freedom, non-dimensional velocity of the second degree of freedom as functions of non-dimensional time are presented in Fig. 10.

Non-dimensional relative displacement and non-dimensional relative velocity as functions of non-dimensional time are presented in Fig. 11.

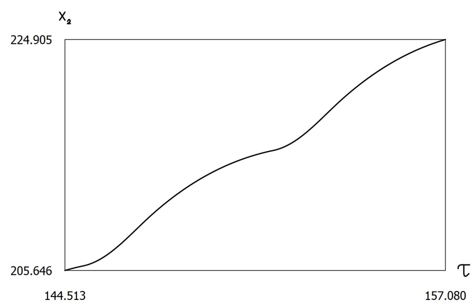
Phase trajectories of the first degree of freedom and of the second degree of freedom are presented in Fig. 12.



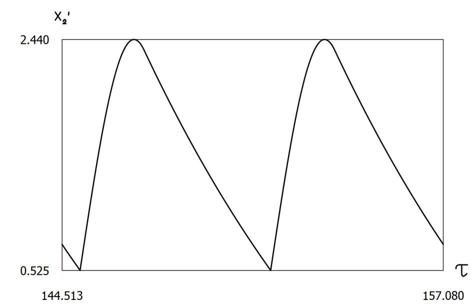
a) Non-dimensional displacement of the first degree of freedom as function of non-dimensional time



b) Non-dimensional velocity of the first degree of freedom as function of non-dimensional time

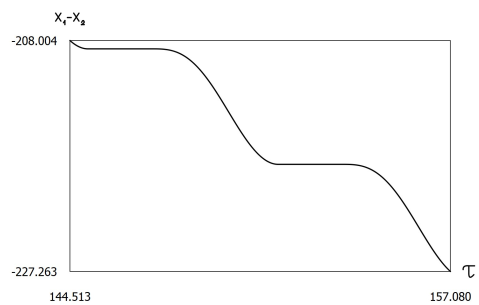


c) Non-dimensional displacement of the second degree of freedom as function of non-dimensional time

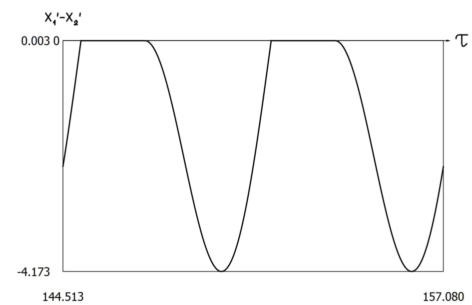


d) Non-dimensional velocity of the second degree of freedom as function of non-dimensional time

Fig. 10. Dynamics of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0.2$



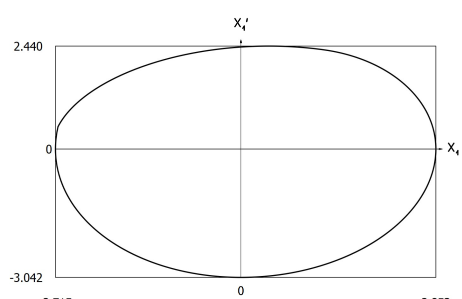
a) Non-dimensional relative displacement as function of non-dimensional time



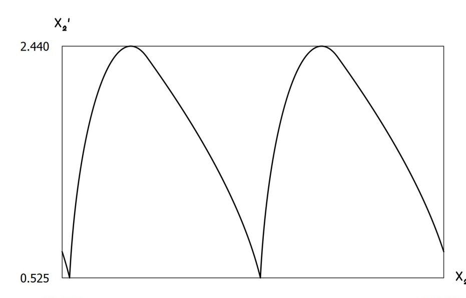
b) Non-dimensional relative velocity as function of non-dimensional time

Fig. 11. Relative motions of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0.2$

Phase trajectory of relative motion is presented in Fig. 13.



a) Phase trajectory of the first degree of freedom



b) Phase trajectory of the second degree of freedom

Fig. 12. Phase trajectories of the investigated system for $\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0.2$

From the presented graphical results, it can be observed that the zones where the velocities of both degrees of freedom are approximately equal depend on the value of the constant force. Substantial dependence of the distance travelled by the second degree of freedom from the value of the constant force is also seen.

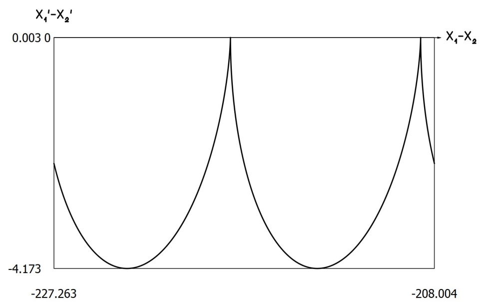
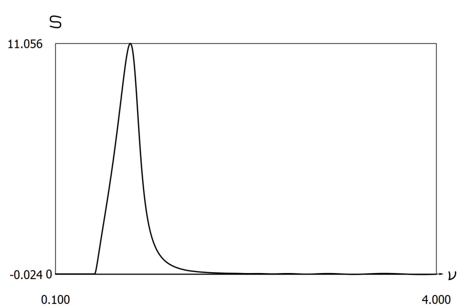


Fig. 13. Phase trajectory of relative motion of the investigated system for
$\nu = 1,\ f = 1,\ h = 0.1,\ f_0 = 0.5,\ \mu = 1,\ b = 0.1,\ a = 0.2$

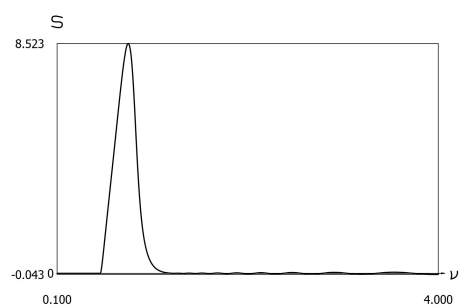
4. Investigation of travelled distance in steady state regime of motion as function of frequency of excitation

The travelled distance of the second degree of freedom during a period of excitation in steady state regime of motion as function of frequency of excitation for the three values of the constant external force is presented in Fig. 14.

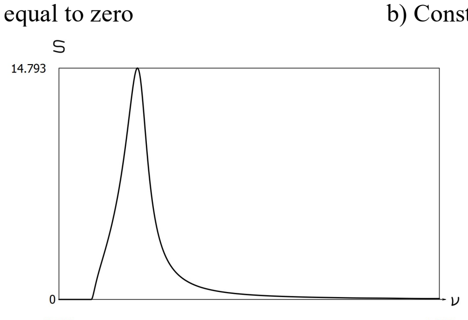
From the presented results optimal frequency of excitation corresponding to maximum value of the travelled distance is determined.



a) Constant force is equal to zero



b) Constant force is negative



c) Constant force is positive

Fig. 14. Travelled distance during a period of excitation in steady state regime of motion as function of frequency of excitation

5. Conclusions

Mechanism for transformation of vibrating motion into translational using the self-stopping device is proposed. Model of the investigated system is presented as well as numerical investigations for various parameters of the system are performed and graphical relationships for typical parameters of the investigated system are presented. Dynamics of precise vibrational transportation is investigated.

Non-dimensional displacement of the first degree of freedom, non-dimensional velocity of the first degree of freedom, non-dimensional displacement of the second degree of freedom, non-dimensional velocity of the second degree of freedom as functions of non-dimensional time are presented. Non-dimensional relative displacement and non-dimensional relative velocity as functions of non-dimensional time are also investigated. Phase trajectories of the first degree of freedom and of the second degree of freedom are presented. Phase trajectory of relative motion is also investigated. Investigations are performed for the case when there is no constant force, when the constant force is negative and when the constant force is positive.

From the presented graphical results, it can be observed that the zones where the velocities of both degrees of freedom are approximately equal depend on the value of the constant force. Substantial dependence of the travelled distance from the value of the constant force is also seen.

The obtained results are used in the process of design of mechanisms of the proposed type. Mechanisms of the proposed type can be used in elements of manipulators and robots, including pipe robots and other devices used in agricultural engineering.

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