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INVESTIGATION OF DYNAMICS OF A PIPE ROBOT WITH VIBRATIONAL DRIVE AND UNSYMMETRIC WITH RESPECT TO THE DIRECTION OF VELOCITY OF MOTION DISSIPATIVE FORCES

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Abstract

In all fields of human activities intensification of use of robots and their systems takes place. In agriculture this process takes place too slowly if compared with some domains of machine building industry. Here the problem of creation of robots of various structures and for performance of different tasks is solved by using one coordinate mechanical blocks with vibrational mechanical drives used for this purpose. This block in a separate case is a robot moving in a pipe. Dynamics of such a block is represented as a nonlinear system and because of the nonlinearity of a block it is possible to obtain different laws of motions and their parameters. The investigation is performed by analytical – graphical method. This enables to choose most suitable parameters of the investigated system.

Keywords: pipe robot, vibrations, numerical model, nonlinear phenomenon, numerical results.

1. Introduction

Intensive contemporary development of mechanical structures of robots in general and their applications in various domains are represented in detail in the handbook of V. A. Glazunov (Glazunov V., 2018) and in a number of research papers of his scientific school. Specific precise especially micro manipulators and robots with vibrational drives undergo extensive development ((Bolotnik N. N. *et al.,* 2016), (Ragulskis K. *et al.,* 1987), (Ragulskis K. *et al.,* 1965), (Bansevičius R. *et al.,* 1985) and in a number of other research papers and books) by applying them in various domains of industry and science. A great contribution to those developments is made by the achievements of I. I. Blekhman and his scientific school, which are represented in an excellent research monograph (Blekhman I. I., 2018).

In the middle of the twentieth century new results were obtained as well as new principles of operation of robots were created. In the field of dynamic synchronization methods and means of introduction of autonomous structures into non autonomous systems were created. New methods of synchronization of the processes and vibrations of mechanical systems with pneumatic, hydraulic and other types of vibrators were created ((Ragulskis K. *et al.,* 1967), (Ragulskis K. *et al.,* 1969) and elsewhere). By using known investigations (Bolotnik N. N. *et al.,* 2016), (Kurila R., Ragulskienė V., 1986), (Spedicato S., Notarstefano G., 2017), (Sumbatov A. S., Yunin Ye. K., 2013), (Kibirkštis E. *et al.,* 2018) and other research papers, a number of new type vibrators were created. New results were obtained by creating pneumo vibrators and their dynamic synchronization (Ragulskis K. *et al.,* 1969), (Spruogis B. *et al.,* 2002), (Ragulskis K. *et al.,* 2008) and elsewhere.

Investigations enabled to substantially increase the precision of precise manipulators and robots performing desirable motions and trajectories, to perform positioning of bodies in space with higher precision, to increase dynamicity and compatibility of mechanical systems with control systems.

In this paper a model with unsymmetric with respect to the direction of motion of the robot viscous friction is proposed and investigated. For large values of viscous friction in one direction it can serve as a model of self stopping device used in pipe robots.

2. Model of a pipe robot

The investigated system is described by the following equation:

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

where x denotes the displacement of the analysed dynamical system, dot over the variable is used for indication of differentiation with respect to the time t, f is the amplitude of excitation, ω is the frequency of excitation. Unsymmetric viscous friction is assumed:

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

where h_1 and h_2 denote the coefficients of viscous friction.

3. Results of investigation of a pipe robot dynamics

The following values of the parameters of the investigated dynamical system were assumed:

$$\omega = 1, f = 1, h_2 = 0.1. \tag{3}$$

Four typical values of h_1 were investigated:

$$h_1 = 0.2, h_1 = 0.4, h_1 = 0.8, h_1 = 1.6. \tag{4}$$

Calculations from zero initial conditions were performed. Two periods of steady state motions were investigated.

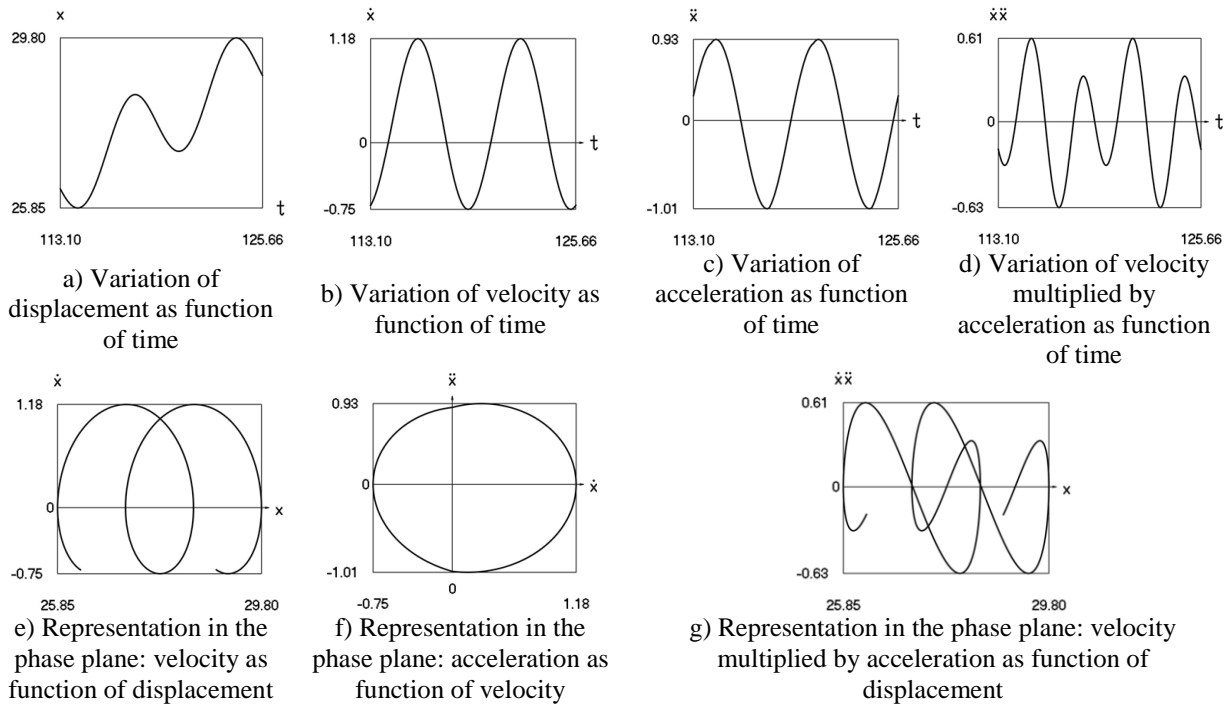Results for the first value of h_1 are represented in Fig. 1.

a) Variation of displacement as function of time

b) Variation of velocity as function of time

c) Variation of acceleration as function of time

d) Variation of velocity multiplied by acceleration as function of time

e) Representation in the phase plane: velocity as function of displacement

f) Representation in the phase plane: acceleration as function of velocity

g) Representation in the phase plane: velocity multiplied by acceleration as function of displacement

Fig. 1. Dynamics of the system for the first set of parameters

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Results for the second value of h_1 are represented in Fig. 2.

a) Variation of displacement as function of time

b) Variation of velocity as function of time

c) Variation of acceleration as function of time

d) Variation of velocity multiplied by acceleration as function of time

e) Representation in the phase plane: velocity as function of displacement

f) Representation in the phase plane: acceleration as function of velocity

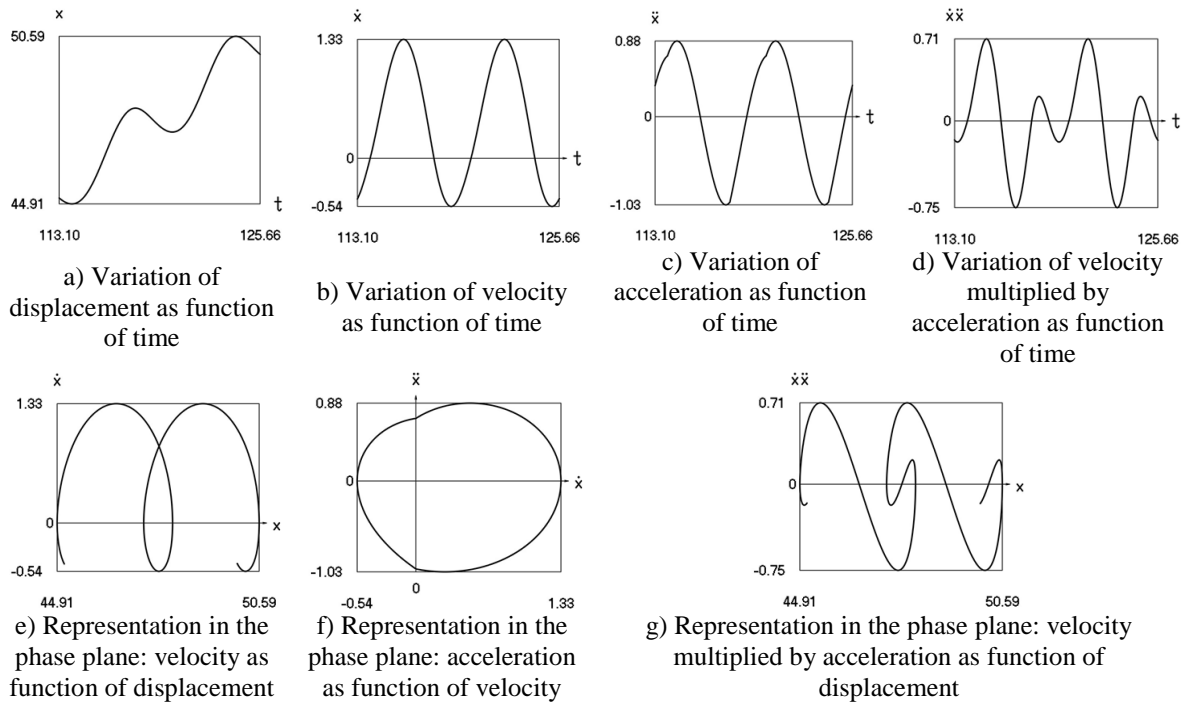g) Representation in the phase plane: velocity multiplied by acceleration as function of displacement

Fig. 2. Dynamics of the system for the second set of parameters

Results for the third value of h_1 are represented in Fig. 3.

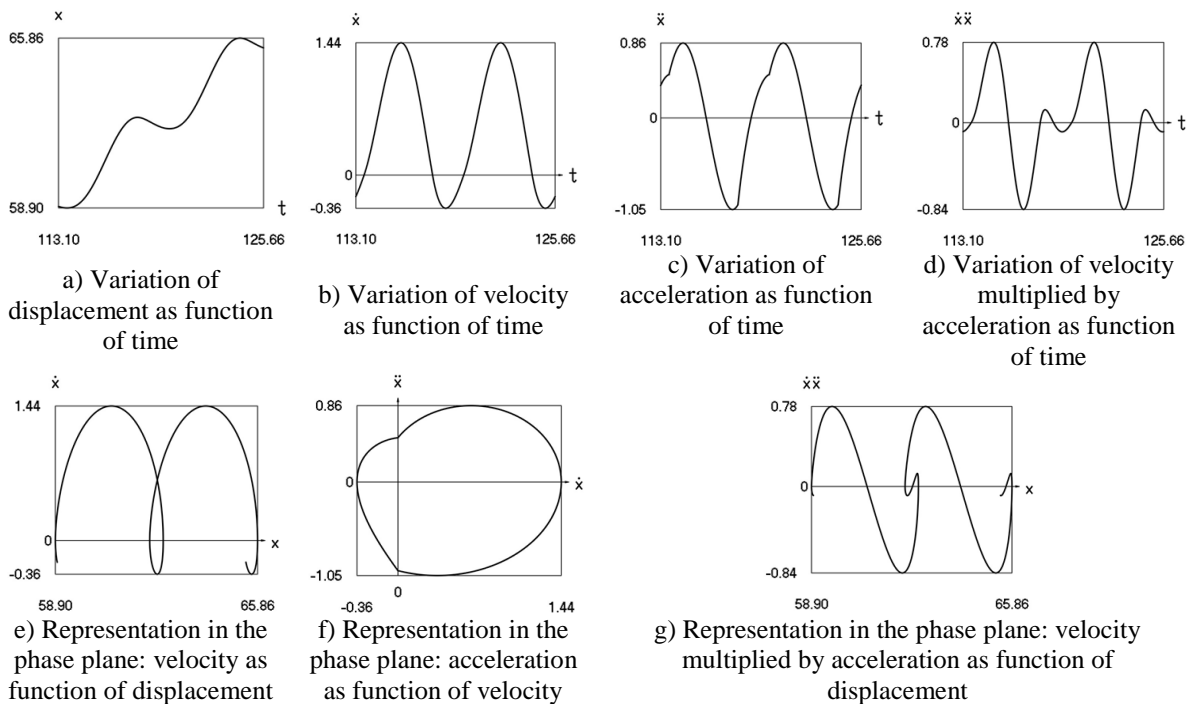a) Variation of displacement as function of time

b) Variation of velocity as function of time

c) Variation of acceleration as function of time

d) Variation of velocity multiplied by acceleration as function of time

e) Representation in the phase plane: velocity as function of displacement

f) Representation in the phase plane: acceleration as function of velocity

g) Representation in the phase plane: velocity multiplied by acceleration as function of displacement

Fig. 3. Dynamics of the system for the third set of parameters

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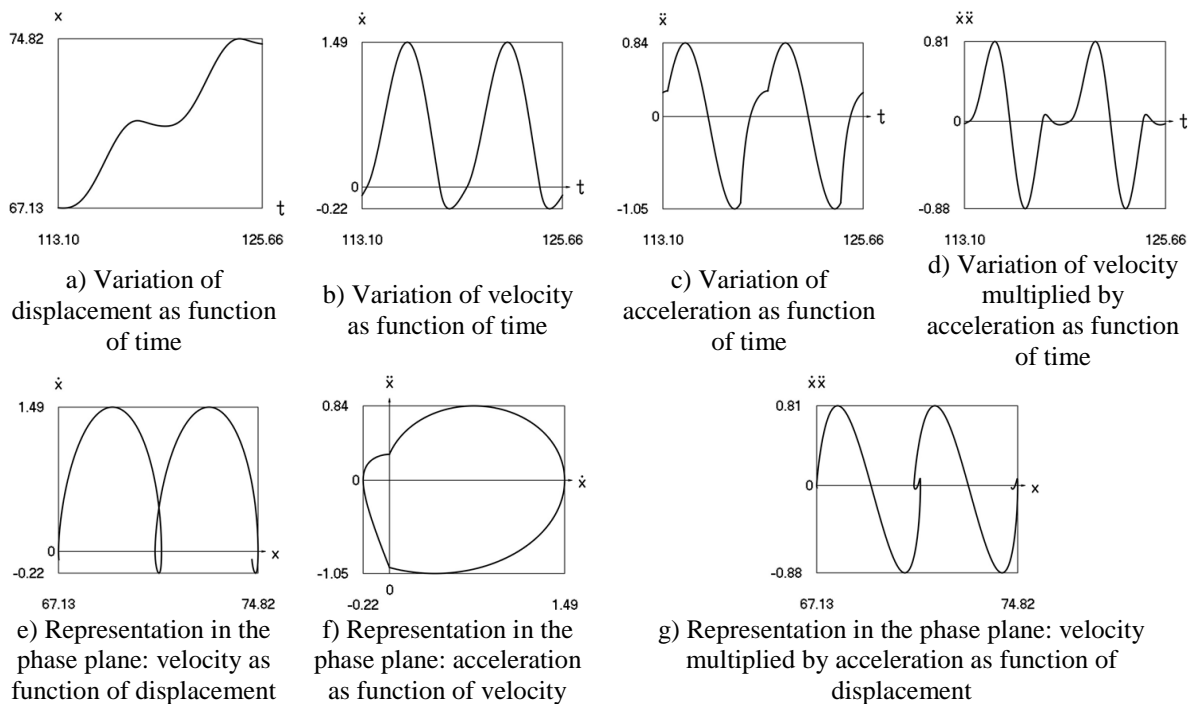Results for the fourth value of h_1 are represented in Fig. 4.

a) Variation of displacement as function of time

b) Variation of velocity as function of time

c) Variation of acceleration as function of time

d) Variation of velocity multiplied by acceleration as function of time

e) Representation in the phase plane: velocity as function of displacement

f) Representation in the phase plane: acceleration as function of velocity

g) Representation in the phase plane: velocity multiplied by acceleration as function of displacement

Fig. 4. Dynamics of the system for the fourth set of parameters

The influence of the parameters of the investigated system to its dynamic behavior is observed in the presented graphical results.

Variation of displacement as function of time shows the effect of vibrational transportation taking place because of the unsymmetric viscous friction. Variation of velocity as function of time indicates the vibration behavior of the investigated dynamical system. Variation of acceleration as function of time shows more complicated variation than variation of velocity as function of time. Variation of velocity multiplied by acceleration as function of time has an even more complicated pattern of behavior than variation of previously described quantities as functions of time, but it can be noted that all the latter three characteristics in steady state regime of motion have periodic variation.

Representations in the phase plane play an important role in the investigations of dynamics of vibrating systems. Velocity as function of displacement indicates the effect of vibrotransportation of the investigated pipe robot. Acceleration as function of velocity has a closed phase trajectory indicating vibration behavior of the analysed nonlinear dynamical system. Velocity multiplied by acceleration as function of displacement has a phase trajectory which is not closed and thus also indicates the effect of vibrotransportation taking place in the pipe robot.

From the comparison of the corresponding drawings from the previous figures the influence of the parameters of the investigated system to the dynamic behavior of the pipe robot is observed. For example the values of x in the drawings a) of each of the Figures 1, 2, 3 and 4 indicate that with the increase of the coefficient of viscous friction h_1 the distance travelled by the pipe robot increases. Comparisons of similar type can be made between other corresponding drawings of the previous Figures 1, 2, 3 and 4.

4. Investigation of velocity of a pipe robot in steady state regime of motion

Further investigation of velocity of a pipe robot in steady state regime of motion is performed. Average velocity and its first three harmonics are presented in Fig. 5.

From the presented results it is seen that with the increase of nonlinearity the amplitude of the first harmonic decreases, while the average velocity and the amplitudes of the second and third harmonics increase. Thus for sufficiently strong nonlinearity this model can be used as an approximation of the behavior of the self stopping device used in pipe robots.
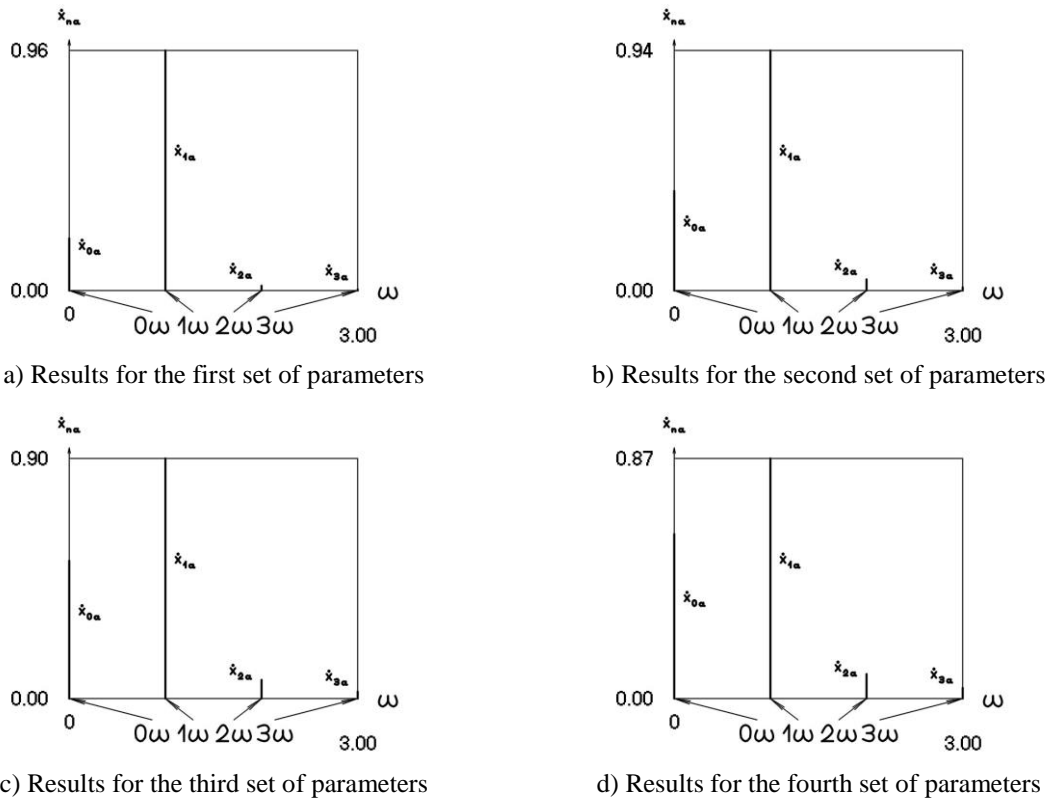
a) Results for the first set of parameters

b) Results for the second set of parameters

c) Results for the third set of parameters

d) Results for the fourth set of parameters

Fig. 5. Average velocity and its first three harmonics

Average velocity in steady state regime of motion as function of h_1 is presented in Fig. 6.
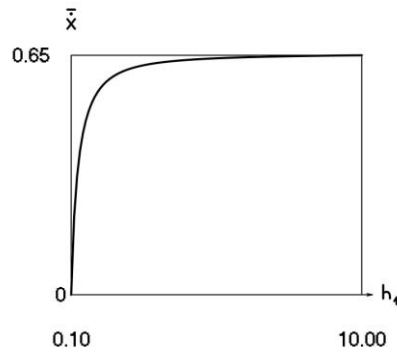

Fig. 6. Variation of average velocity in steady state regime of motion with increasing nonlinearity

From the presented graphical relationship shown in Figure 6 it is possible to choose the value of viscous friction h_1 which is used in the process of numerical investigation of dynamic behavior of a pipe robot.

5. Conclusions

Robot of one coordinate motion is presented, in which the line of the exciting force of the vibration drive coincides with the line of motion of the robot itself. Motion of the robot is obtained because of the nonlinearity, which takes place because of the dissipative forces which are unsymmetric with respect to the direction of motion of the robot. From definite value of those dissipative forces the system becomes as an ideal self stopping device. Presented graphical relationships enable to choose the desirable steady state motion. Sequentially connected chain of such

robots may be easily synchronized and the choice of their phases can be performed in order to ensure reliable operation.

On the basis of such elementary robots it is possible to create complicated robots easily, which perform complicated motions and trajectories in space.

Investigation of velocity of a pipe robot in steady state regime of motion is performed. Average velocity and its first three harmonics are analysed. From the presented results it is seen that with the increase of nonlinearity the amplitude of the first harmonic decreases, while the average velocity and the amplitudes of the second and third harmonics increase. Thus for sufficiently strong nonlinearity this model can be used as an approximation of the behavior of the self stopping device used in pipe robots.

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