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Investigation of Dynamics of a Pipe Robot Experiencing Impact Interactions

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Abstract

In the process of design of pipe robots, it is important to investigate dynamics of their elements in which impact interactions take place. Soft impacts represent more precise model of impact interactions than ideal impacts. Thus, their investigation is important in engineering. In this paper dynamical behaviour of a vibrating system with soft impacts and zones of single valued motions are investigated.

Keywords: *pipe robot, impact interactions, soft impacts, vibro impact system, dynamic behaviour, region of existence, single valued motions.*

Introduction

In the process of design of pipe robots, it is important to investigate dynamics of their elements in which impact interactions take place. Soft impacts represent more precise model of impact interactions than ideal impacts. Thus, their investigation is important in engineering. In this paper dynamical behaviour of a vibrating system with soft impacts and zones of single valued motions are investigated.

Pipe robots and related vibrational effects were investigated in several earlier papers [1-12]. Dynamics of essentially nonlinear systems with impacts is investigated in [13]. Transmissions and their vibrations are analysed in [14]. Nonlinear effects in robots are investigated in [15]. The investigations presented in this paper are based on the basic results presented in those three research monographs.

Schematic representation of a pipe robot with impact interactions is shown in Fig. 1.

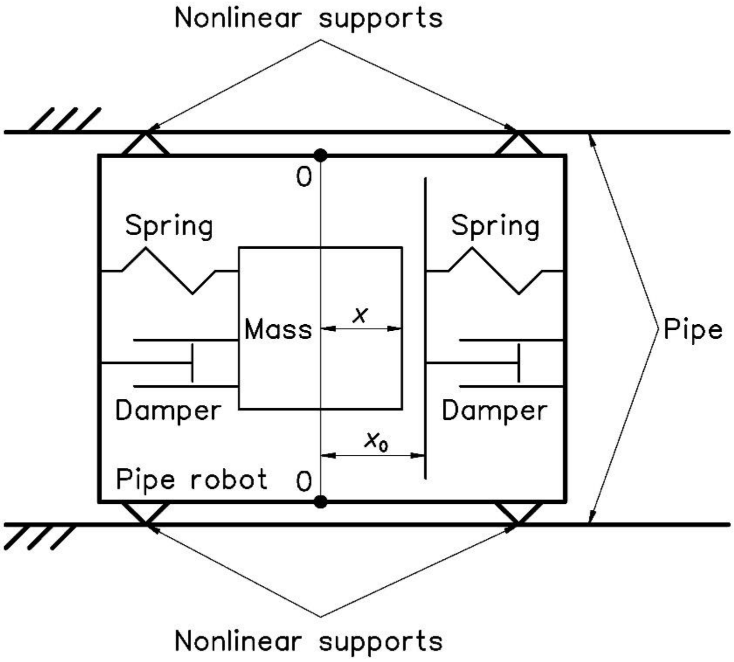


Figure 1: Pipe robot with impact interactions

First, in this paper model of the system with soft impacts performing vibrations is presented. The results for typical regimes of dynamics of the investigated system are presented. Three frequency regions in which single valued regimes of motion take place are analysed.

The presented results are used in the process of design of pipe robots with impact interactions.

Model of the system with soft impacts

The following notation is used:

$$h = \frac{H}{m},\ h_0 = \frac{H_0}{m},\ p^2 = \frac{C}{m},\ p_0^2 = \frac{C_0}{m},\ f = \frac{F}{m}, \tag{1}$$

where H denotes the coefficient of viscous friction, m denotes the mass, H_0 denotes the coefficient of viscous friction of the support, C denotes the coefficient of stiffness, C_0 denotes the coefficient of stiffness of the support and F denotes the amplitude of the harmonic exciting force acting to the mass.

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

$$\ddot{x} + \left(h + h_0\right)\dot{x} + \left(p^2 + p_0^2\right)x = f\sin\omega t,\ \text{when}\ x = x_0, \tag{2}$$

$$\ddot{x} + h\dot{x} + p^2 x = f\sin\omega t, \tag{3}$$

$$h_0\dot{x}_0 + p_0^2 x_0 = 0,\ \text{when}\ x < x_0, \tag{4}$$

where x is the displacement, ω is the frequency of the exciting force, t is the time, x_0 is the displacement of the support. Differentiation with respect to time is denoted by the upper dot.

The following parameters of the investigated system were assumed:

$$f = 1,\ h = 0.1,\ h_0 = 0.1,\ p^2 = 1,\ p_0^2 = 128. \tag{5}$$

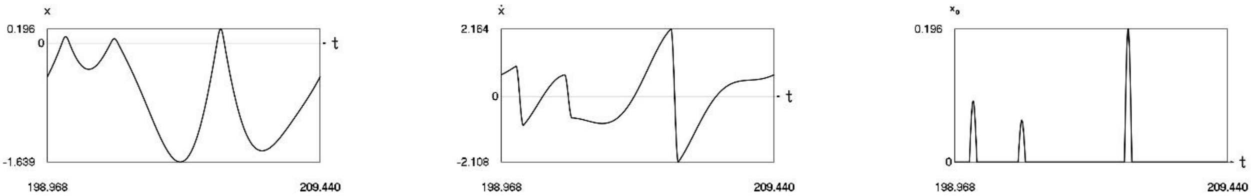
Periodic regimes of motion are investigated.

Investigation of dynamics of the vibro impact system with soft impacts in the first zone of single valued motions

Dynamics of the system for five typical values of frequency of excitation are represented. The first value of frequency of excitation is near to the region of the first zone of single valued motions from the external side of this zone. The second value of frequency of excitation is near to the region of the first zone of single valued motions from the internal side of this zone. Those two values determine the location of the lower boundary of this zone.

The third value of frequency of excitation represents motion at the typical for the first zone of single valued motions frequency of excitation. The fourth value of frequency of excitation is near to the region of the first zone of single valued motions from the internal side of this zone. The fifth value of frequency of excitation is near to the region of the first zone of single valued motions from the external side of this zone. Those two values determine the location of the upper boundary of this zone.

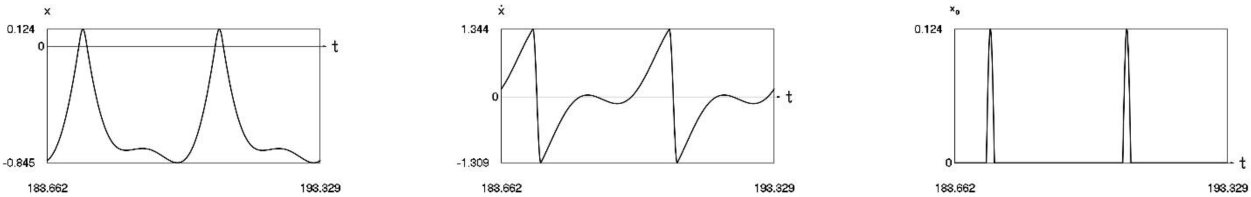
Two periods of the exciting force are investigated. Graphical results are presented in the (Figures 2, 3, 4, 5, 6).



a) Displacement of the system as function of time | b) Velocity of the system as function of time | c) Displacement of the support as function of time

Figure 2: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=1.2$

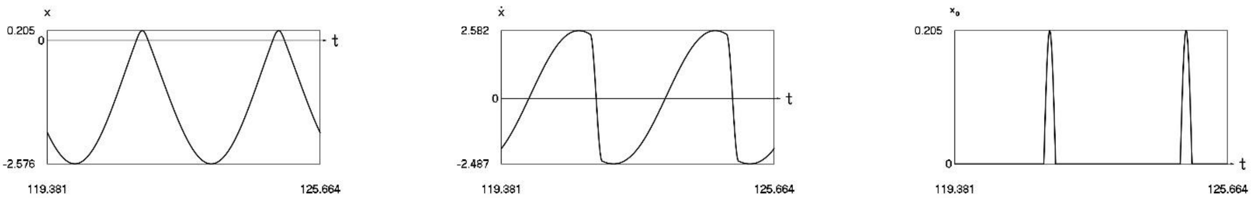
Fig. 2 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=1.2$.



a) Displacement of the system as function of time | b) Velocity of the system as function of time | c) Displacement of the support as function of time

Figure 3: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=1.3$

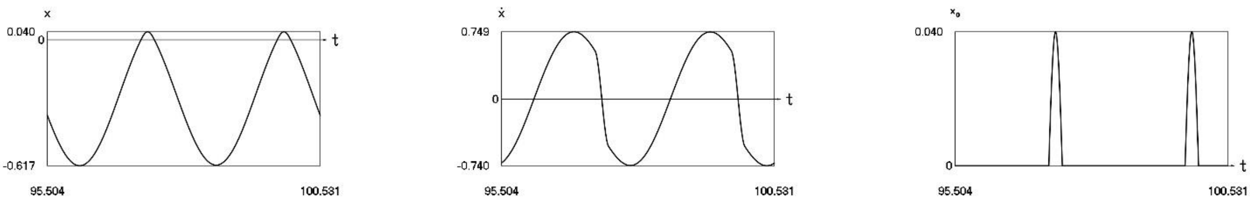
Fig. 3 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=1.3$.



a) Displacement of the system as function of time | b) Velocity of the system as function of time | c) Displacement of the support as function of time

Figure 4: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=2$

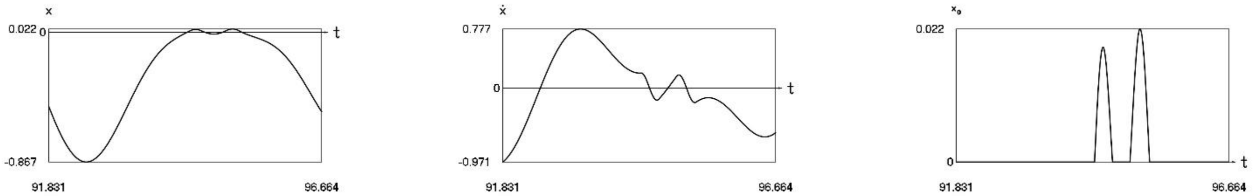
Fig. 4 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=2$.



a) Displacement of the system as function of time | b) Velocity of the system as function of time | c) Displacement of the support as function of time

Figure 5: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=2.5$

Fig. 5 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=2.5$.



a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 6: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=2.6$

Fig. 6 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=2.6$.

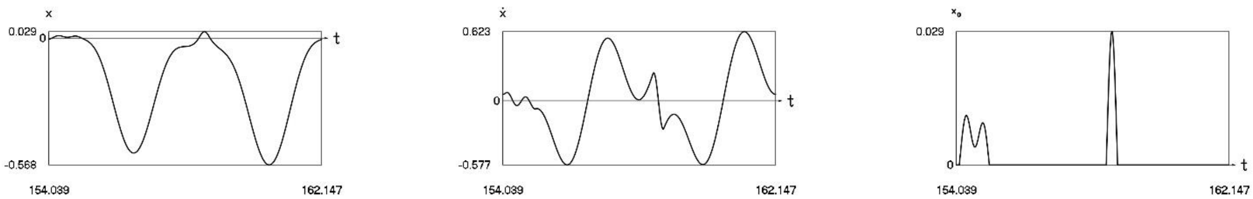
The presented graphical results determine the location of the first zone of single valued motions and show typical behavior of the investigated vibro impact system with soft impacts in it.

Investigation of dynamics of the vibro impact system with soft impacts in the second zone of single valued motions

Dynamics of the system for five typical values of frequency of excitation are represented. The first value of frequency of excitation is near to the region of the second zone of single valued motions from the external side of this zone. The second value of frequency of excitation is near to the region of the second zone of single valued motions from the internal side of this zone. Those two values determine the location of the lower boundary of this zone.

The third value of frequency of excitation represents motion at the typical for the second zone of single valued motions frequency of excitation.

The fourth value of frequency of excitation is near to the region of the second zone of single valued motions from the internal side of this zone. The fifth value of frequency of excitation is near to the region of the second zone of single valued motions from the external side of this zone. Those two values determine the location of the upper boundary of this zone. Four periods of the exciting force are investigated. Graphical results are presented in the Figures 7, 8, 9, 10, 11.



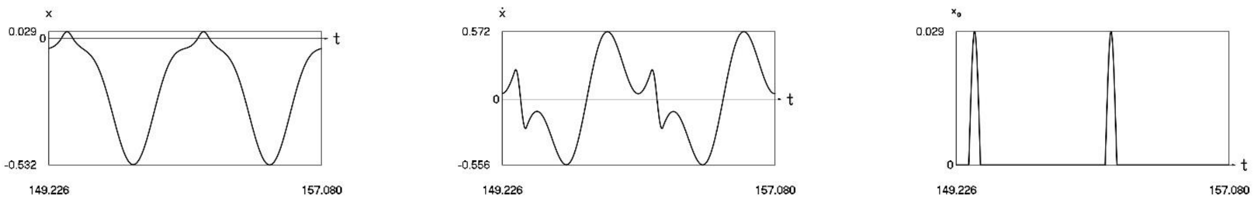
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 7: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=3.1$

Fig. 7 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=3.1$.



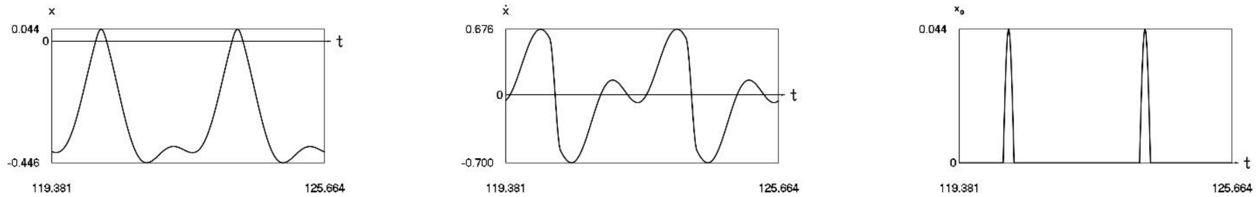
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 8: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=3.2$

Fig. 8 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=3.2$.



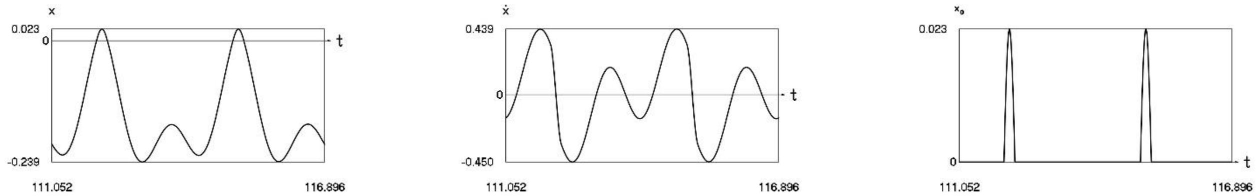
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 9: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=4$

Fig. 9 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=4$.



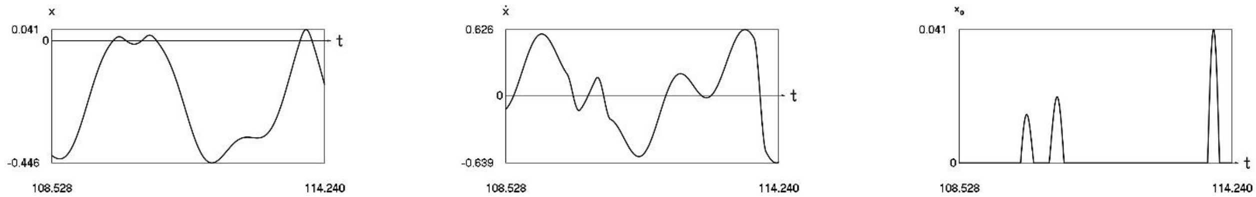
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 10: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=4.3$

Fig. 10 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=4.3$.



a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 11: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=4.4$

Fig. 11 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=4.4$.

The presented graphical results determine the location of the second zone of single valued motions and show typical behavior of the investigated vibro impact system with soft impacts in it.

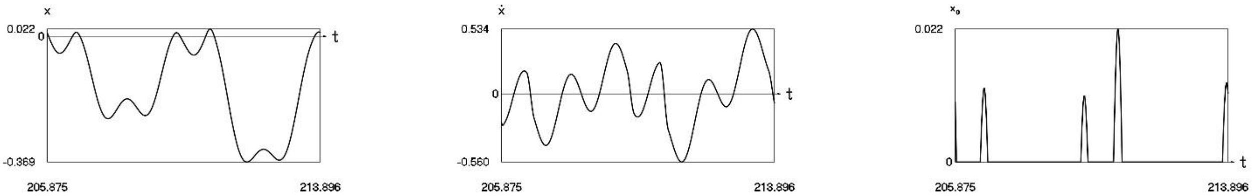
Investigation of dynamics of the vibro impact system with soft impacts in the third zone of single valued motions

Dynamics of the system for four typical values of frequency of excitation are represented. The first value of frequency of excitation is near to the region of the third zone of single valued motions from the external side of this zone. The second value of frequency of excitation is near to the region of the third zone of single valued motions from the internal side of this zone. Those two values determine the location of the lower boundary of this zone.

The third value of frequency of excitation represents motion at the typical for the third zone of single valued motions frequency of excitation.

Also, the third value of frequency of excitation is near to the region of the third zone of single valued motions from the internal side of this zone. The fourth value of frequency of excitation is near to the region of the third zone of single valued motions from the external side of this zone. Those two values determine the location of the upper boundary of this zone.

Six periods of the exciting force are investigated. Graphical results are presented in the Figures 12, 13, 14, 15.



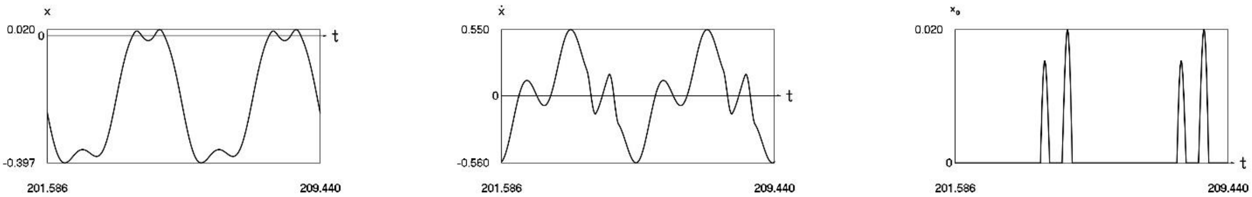
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 12: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=4.7$

Fig. 12 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=4.7$.



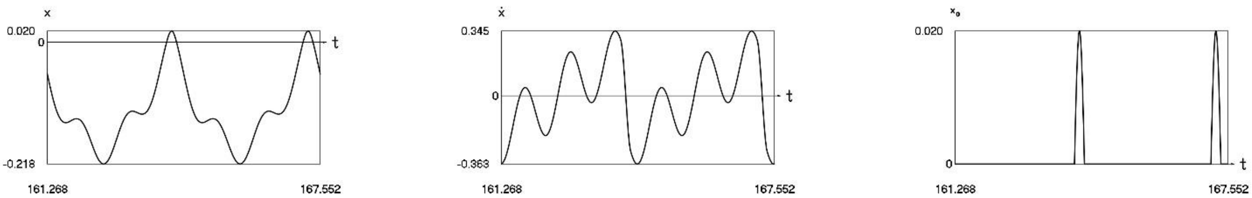
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 13: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=4.8$

Fig. 13 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=4.8$.



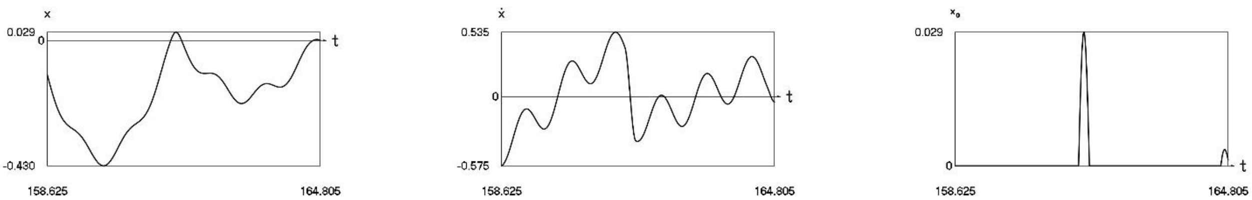
a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

Figure 14: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=6$

Fig. 14 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=6$.



a) Displacement of the system as function of time

b) Velocity of the system as function of time

c) Displacement of the support as function of time

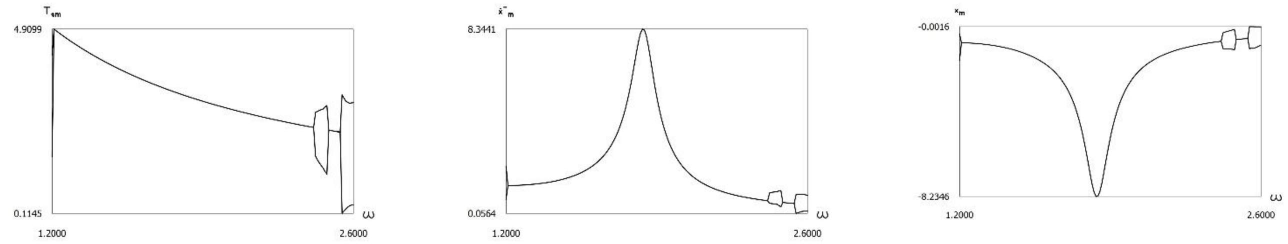
Figure 15: Motion of the system at $f=1,\ h=0.1,\ h_0=0.1,\ p^2=1,\ p_0^2=128,\ \omega=6.1$

Fig. 15 shows variation of displacement of the system in time, variation of velocity of the system in time, variation of displacement of the support in time for $\omega=6.1$.

The presented graphical results determine the location of the third zone of single valued motions and show typical behavior of the investigated vibro impact system with soft impacts in it.

Main characteristics of dynamic behaviour in the three zones of single valued motions

Results for the first zone of single valued motions are presented in Fig. 16.



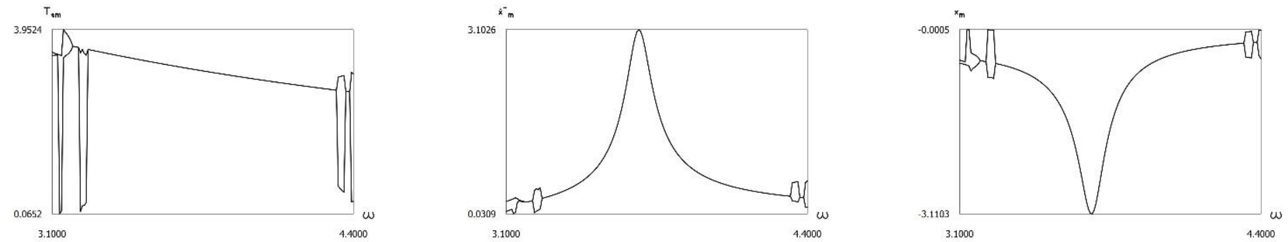
a) Minimum and maximum inter impact intervals

b) Minimum and maximum velocities before impact

c) Minimum and maximum minimum displacements in inter impact intervals

Figure 16: Characteristics of steady state motion for the first zone of single valued motions as functions of frequency of excitation in periodic regime for $f = 1,\ h = 0.1,\ h_0 = 0.1,\ p^2 = 1,\ p_0^2 = 128$

Results for the second zone of single valued motions are presented in Fig. 17.



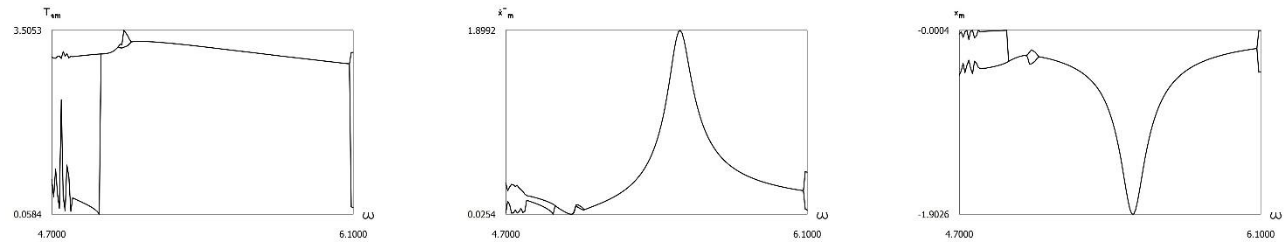
a) Minimum and maximum inter impact intervals

b) Minimum and maximum velocities before impact

c) Minimum and maximum minimum displacements in inter impact intervals

Figure 17: Characteristics of steady state motion for the second zone of single valued motions as functions of frequency of excitation in periodic regime for $f = 1,\ h = 0.1,\ h_0 = 0.1,\ p^2 = 1,\ p_0^2 = 128$

Results for the third zone of single valued motions are presented in Fig. 18.



a) Minimum and maximum inter impact intervals

b) Minimum and maximum velocities before impact

c) Minimum and maximum minimum displacements in inter impact intervals

Figure 18: Characteristics of steady state motion for the third zone of single valued motions as functions of frequency of excitation in periodic regime for $f = 1,\ h = 0.1,\ h_0 = 0.1,\ p^2 = 1,\ p_0^2 = 128$

Three resonant zones of single valued motions are investigated. They represent optimal regions of operation of the pipe robot with soft impacts.

Conclusions

In engineering applications, it is important to investigate dynamics of vibrating systems in which impact interactions take place. Soft impacts represent more precise model of impact interactions than ideal impacts. Thus, their investigation is important in engineering practice. In this paper dynamical behaviour of a vibrating system with soft impacts and the first three zones of single valued motions are investigated.

Graphical results for typical regimes of dynamics of the investigated system are presented. The first three frequency regions in which single valued regimes of motion take place are analysed in detail.

The presented results are used in the process of design of pipe robots with impact interactions taking place in their elements.

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