© K. Ragulskis, A. Pauliukas, A. Bubulis, P. Paškevičius, R. Maskeliūnas, L. Ragulskis 2022

УДК 621.317
UDC 621.317

K. Ragulskis[1], A. Pauliukas[2], A. Bubulis[3], P. Paškevičius[4], R. Maskeliūnas[5], L. Ragulskis[6]
[1]*Kaunas University of Technology, K. Donelaičio Str. 73, LT-44249, Kaunas, Lithuania*
[2]*Vytautas Magnus University, Studentų Str. 11, LT-53361, Akademija, Kaunas District, Lithuania*
[3]*Kaunas University of Technology, Mechatronics Institute, Studentų Str. 56, LT-51424, Kaunas, Lithuania*
[4]*Company "Vaivora", Palemono Str. 2a, LT-52191, Kaunas, Lithuania*
[5]*Vilnius Gediminas Technical University, Saulėtekio Ave. 11, LT-10223, Vilnius, Lithuania*
[6]*Vytautas Magnus University, Vileikos Str. 8, LT-44404, Kaunas, Lithuania*

INVESTIGATION OF DYNAMICS OF A SYSTEM WITH TWO SIDED IMPACTS

В елементах маніпуляторів та роботів мають місце різні види ударних взаємодій. У тому числі часто спостерігаються двосторонні удари. Для їхнього дослідження пропонується спеціальна чисельна процедура. Подано чисельні результати для типових параметрів досліджуваної системи з одним ступенем свободи. Представлені та взаємно порівняні результати без застосування цієї процедури та з нею.

Були отримані результати різних значень коефіцієнта в'язкого демпфування і коефіцієнта відновлення. Вони представлені трьох типових наборів цих параметрів. Перший набір типових значень параметрів описує рух досліджуваної системи із двосторонніми ударами, що відповідають нагоді консервативних ударів. Другий набір типових значень параметрів описує рух досліджуваної системи з двосторонніми ударами, що відповідають випадку консервативних міжударних рухів. Третій набір типових значень параметрів описує рух досліджуваної системи з двосторонніми ударами, що відповідають випадку повністю дисипативної динаміки.

Подано тимчасову діаграму зсуву, тимчасову діаграму швидкості та динаміку системи при двосторонніх ударах у фазовій площині. Отримані графічні уявлення показують переваги вдосконаленого розрахунку ударних взаємодій.

Результати застосовуються при проектуванні елементів маніпуляторів та роботів з двосторонніми ударами.

Ключові слова: нелінійність ударного типу, гармонічне порушення, двосторонні удари, нелінійні перехідні процеси, графічні зображення.

INTRODUCTION

In the elements of manipulators and robots, various types of impact interactions take place.

Among the most typical impact interactions two sided impacts are often observed. For their investigation a special numerical procedure is proposed.

Numerical results for typical parameters of the investigated system having one degree of freedom are presented. Results without application of this procedure and with it are presented and mutually compared.

Dynamics of essentially nonlinear system is investigated in [1]. Impact motions are analyzed in [2]. Theoretical basis of vibrating systems with impacts is described in [3]. Vibrations and impacts in transmissions are presented in [4]. Systems with impacts are investigated in [5]. Applications in the field of manipulators and robots are presented in [6]. Industrial robots are investigated in [7]. New types of mechanisms are presented in [8]. Essentially nonlinear problems of dynamics are analyzed in [9]. Robot with impact interactions is described in [10].

First the model of the system having one degree of freedom with two sided impacts is described. Then the procedure for calculation of impact interactions is presented. Graphical results for typical parameters of the system without application of this procedure and with application of it are compared.

MODEL OF THE SYSTEM WITH TWO SIDED IMPACTS

The investigated system having one degree of freedom with two sided impacts is described by the differential equation:

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

where x is the displacement of the system, h is the coefficient of viscous damping, f is the amplitude of harmonic excitation, ω is the frequency of harmonic excitation, t is the time, and the upper dot denotes differentiation with respect to it.

If the following conditions are satisfied:

$$x \le a, \tag{2}$$

where *a* denotes the lower limiting value at which impacts take place, and

$$\dot{x} < 0, \tag{3}$$

then it is assumed that:

$$x = a \tag{4}$$

and

$$\dot{x}^{+} = -R\dot{x}^{-}, \tag{5}$$

where *R* denotes the coefficient of restitution, the superscript minus denotes the value of velocity before the impact and the superscript plus denotes the value of velocity after the impact.

If the following conditions are satisfied:

$$x \geq b, \tag{6}$$

where *b* denotes the upper limiting value at which impacts take place, and

$$\dot{x} > 0, \tag{7}$$

then it is assumed that:

$$x = b \tag{8}$$

and

$$\dot{x}^{+} = -R\dot{x}^{-}. \tag{9}$$

IMPROVED DETERMINATION OF IMPACT INTERACTIONS IN THE SYSTEM WITH TWO SIDED IMPACTS

The following notation is introduced: *T* is the time step, the subscript 0 denotes the value at the initial moment of a time step and the subscript *T* denotes the value at the final moment of a time step.

If the following condition is satisfied:

$$x_T < a, \tag{10}$$

then the reduced time step is calculated in the following way:

$$T_r = T\frac{a - x_0}{x_T - x_0}, \tag{11}$$

and it is assumed that:

$$x_{T_r} = a, \tag{12}$$

$$\dot{x}_{T_r} = \dot{x}_0 + \left(\dot{x}_T - \dot{x}_0\right)\frac{T_r}{T}, \tag{13}$$

$$\ddot{x}_{T_r} = \ddot{x}_0 + \left(\ddot{x}_T - \ddot{x}_0\right)\frac{T_r}{T}. \tag{14}$$

If the following condition is satisfied:

$$x_T > b, \tag{15}$$

then the reduced time step is calculated in the following way:

$$T_r = T\frac{b - x_0}{x_T - x_0}, \tag{16}$$

and it is assumed that:

$$x_{T_r} = b, \tag{17}$$

$$\dot{x}_{T_r} = \dot{x}_0 + \left(\dot{x}_T - \dot{x}_0\right)\frac{T_r}{T}, \tag{18}$$

$$\ddot{x}_{T_r} = \ddot{x}_0 + \left(\ddot{x}_T - \ddot{x}_0\right)\frac{T_r}{T}. \tag{19}$$

INVESTIGATION OF BEHAVIOUR OF THE SYSTEM WITH TWO SIDED IMPACTS

Typical parameters of the investigated system with two sided impacts were assumed:

$$\omega = 1,\ f = 1,\ a = -0.8,\ b = 0.8. \tag{20}$$

Calculations from zero initial conditions are performed:

$$x(0) = 0,\ \dot{x}(0) = 0. \tag{21}$$

Results for the following time step are presented:

$$T = \frac{\frac{2\pi}{\omega}}{100}. \tag{22}$$

Results for various values of coefficient of viscous damping and of coefficient of restitution were obtained. Further they are presented for three typical sets of those parameters.

INVESTIGATION OF THE SYSTEM WITH TWO SIDED IMPACTS FOR THE TYPICAL VALUES OF PARAMETERS $h = 0.5,\ R = 1$

Those typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative impacts.

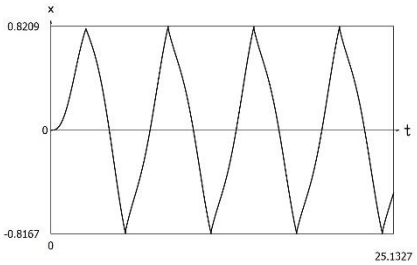
Results of graphical investigations of dynamics of the system with two sided impacts without improved calculation of impact interactions are shown in Fig. 1.

In Fig. 1, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.

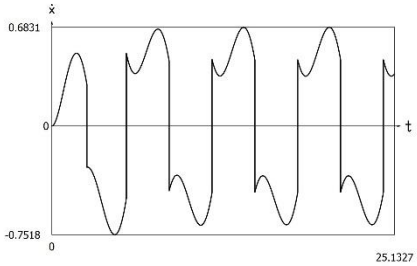
Results of graphical investigations of dynamics of the system with two sided impacts with improved calculation of impact interactions are shown in Fig. 2.

In Fig. 2, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.

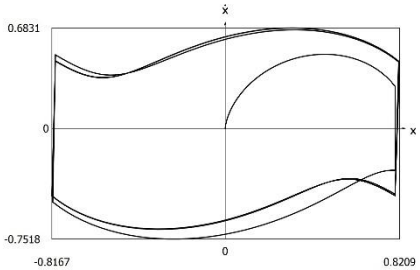
It can be observed that the improved calculation of impact interactions has advantages, which are clearly seen in the comparison of representations a) and c) from both previous figures.



a) Time history of displacement

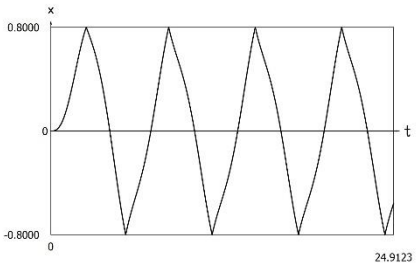


b) Time history of velocity

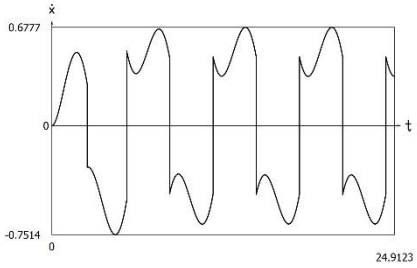


c) Dynamics in the phase plane

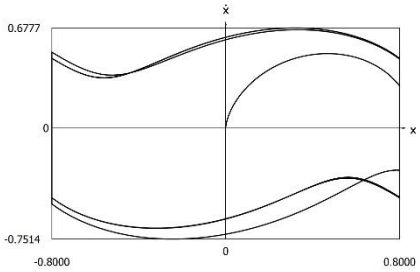
Figure 1. Dynamics of the system with two sided impacts without application of the improved calculation of impact interactions



a) Time history of displacement



b) Time history of velocity



c) Dynamics in the phase plane

Figure 2. Dynamics of the system with two sided impacts with application of the improved calculation of impact interactions

INVESTIGATION OF THE SYSTEM WITH TWO SIDED IMPACTS FOR THE TYPICAL VALUES OF PARAMETERS $h = 0,\ R = 0.5$

Those typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative inter impact motions.

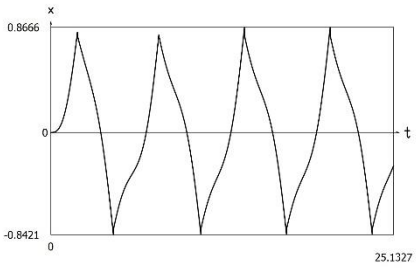
Results of graphical investigations of dynamics of the system with two sided impacts without improved calculation of impact interactions are shown in Fig. 3.

In Fig. 3, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.

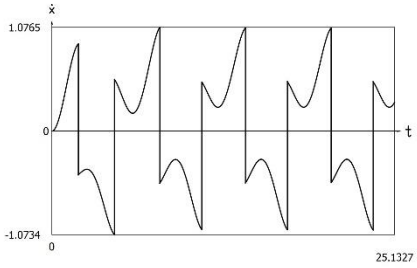
Results of graphical investigations of dynamics of the system with two sided impacts with improved calculation of impact interactions are shown in Fig. 4.

In Fig. 4, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.

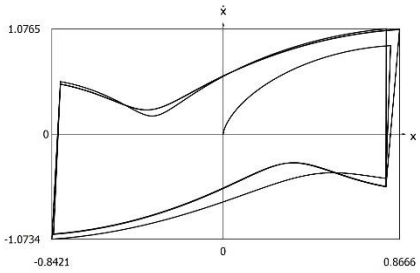
It can be observed that the improved calculation of impact interactions has advantages, which are clearly seen in the comparison of representations a) and c) from both previous figures.



a) Time history of displacement

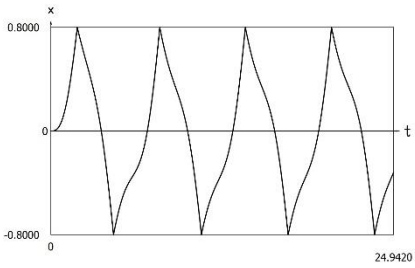


b) Time history of velocity

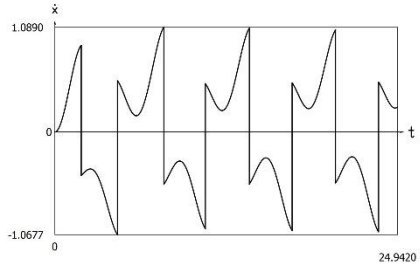


c) Dynamics in the phase plane

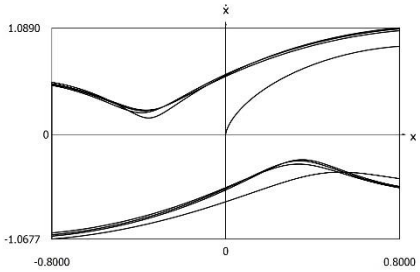
Figure 3. Dynamics of the system with two sided impacts without application of the improved calculation of impact interactions



a) Time history of displacement



b) Time history of velocity



c) Dynamics in the phase plane

Figure 4. Dynamics of the system with two sided impacts with application of the improved calculation of impact interactions

INVESTIGATION OF THE SYSTEM WITH TWO SIDED IMPACTS FOR THE TYPICAL VALUES OF PARAMETERS $h = 0.5,\ R = 0.5$

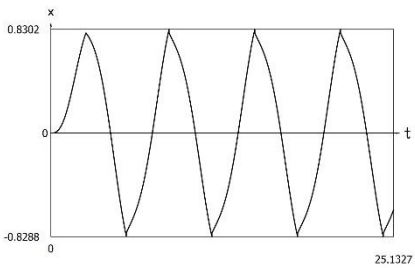
Those typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of fully dissipative dynamics.

Results of graphical investigations of dynamics of the system with two sided impacts without improved calculation of impact interactions are shown in Fig. 5.

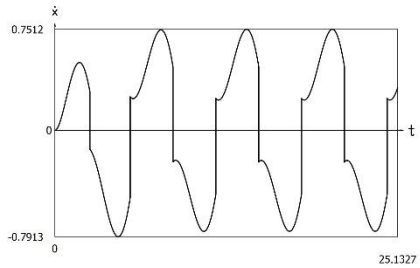
In Fig. 5, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.

Results of graphical investigations of dynamics of the system with two sided impacts with improved calculation of impact interactions are shown in Fig. 6.

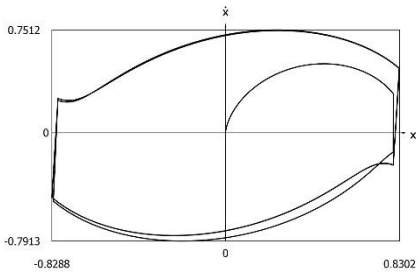
In Fig. 6, time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are shown.



a) Time history of displacement

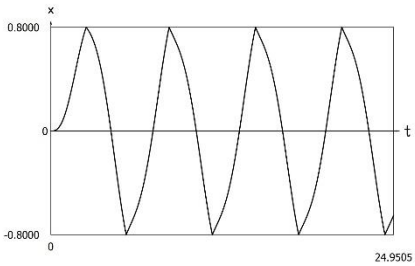


b) Time history of velocity

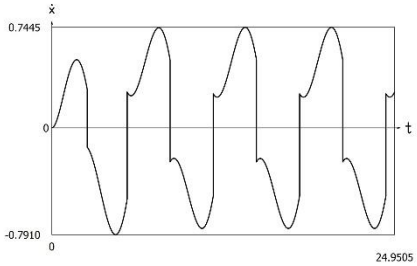


c) Dynamics in the phase plane

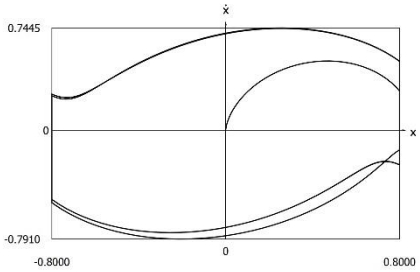
Figure 5. Dynamics of the system with two sided impacts without application of the improved calculation of impact interactions



a) Time history of displacement



b) Time history of velocity



c) Dynamics in the phase plane

Figure 6. Dynamics of the system with two sided impacts with application of the improved calculation of impact interactions

It can be observed that the improved calculation of impact interactions has advantages, which are clearly seen in the comparison of representations a) and c) from both previous figures.

The obtained graphical representations show the advantages of the improved calculation of impact interactions.

CONCLUSIONS

In the elements of manipulators and robots, various types of impact interactions take place, among the most typical impact interactions two sided impacts are often observed.

First the model of the system having one degree of freedom with two sided impacts is described. Then the procedure for calculation of impact interactions is presented. Graphical results for typical parameters of the system without application of this procedure and with application of it are compared.

Results for various values of coefficient of viscous damping and of coefficient of restitution were obtained. They are presented for three typical sets of those parameters. The first set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative impacts. The second set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative inter impact motions. The third set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of fully dissipative dynamics.

Time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are represented. The obtained graphical representations show the advantages of the improved calculation of impact interactions.

The results are applied in the design of elements of manipulators and robots with two sided impacts.

REFERENCES

1. Ragulskis K., Bubulis A., Pauliukas A., Paškevičius P., Maskeliūnas R., & Ragulskis L. (2020). Unsymmetric dry friction for models of surface cleaning. Сучасні технології в машинобудуванні та транспорті, 1(14), 26-34, DOI: 10.36910/automash.v1i14.343.
2. Ragulskis K., Spruogis B., Matuliauskas A., Mištinas V., & Ragulskis L. (2021). Investigation of impact motions in elements of manipulators and robots. Mathematical Models in Engineering, 7(3), 54-62, DOI: https://doi.org/10.21595/mme.2021.22240.
3. Ragulskienė V. (1974). Виброударные системы (Теория и применение). 320, – Vilnius: Mintis.
4. Kurila R., & Ragulskienė V. (1986). Двумерные вибрационные приводы. 137, – Vilnius: Mokslas.
5. Ragulskis K., Vitkus J., & Ragulskienė V. (1965). Самосинхронизация механических систем (1. Самосинхронные и виброударные системы). 186, – Vilnius: Mintis.
6. Ragulskis K., Bansevičius R., Barauskas R., & Kulvietis G. (1987). Vibromotors for Precision Microrobots. 326, – New York: Hemisphere.

7. Bansevičius R., Ivanov A., Kamyshnyj N., Kostin A., Lobikov L., Michieiev V., Nikolskaja T., Ragulskis K., & Shangin V. (1985). Промышленные роботы для миниатюрных изделий. 264, – Moscow: Mashinostroyenye.
8. Glazunov V. (2018). Новые механизмы в современной робототехнике. 316, – Moscow: Tehnosphere.
9. Sumbatov A. S., & Yunin Ye. K. (2013). Избранные задачи механики систем с сухим трением. 200, – Moscow: Physmathlit.
10. Ragulskis K., Spruogis B., Paškevičius P., Matuliauskas A., Mištinas V., Pauliukas A., & Ragulskis L. (2021). Investigation of dynamics of a pipe robot experiencing impact interactions. Advances in Robotics & Automation Technology, 1(2), 1-8, DOI: 10.39127/2021/ARAT:1000103.

K. Ragulskis, A. Pauliukas, A. Bubulis, P. Paškevičius, R. Maskeliūnas, L. Ragulskis. *Investigation of dynamics of a system with two sided impacts.*

In the elements of manipulators and robots, various types of impact interactions take place. Among them two sided impacts are often observed. For their investigation a special numerical procedure is proposed. Numerical results for typical parameters of the investigated system having one degree of freedom are presented. Results without application of this procedure and with it are presented and mutually compared.

Results for various values of coefficient of viscous damping and of coefficient of restitution were obtained. They are presented for three typical sets of those parameters. The first set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative impacts. The second set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of conservative inter impact motions. The third set of typical values of parameters describe the motion of the investigated system with two sided impacts corresponding to the case of fully dissipative dynamics.

Time history of displacement, time history of velocity and dynamics of the system with two sided impacts in the phase plane are represented. The obtained graphical representations show the advantages of the improved calculation of impact interactions.

The results are applied in the design of elements of manipulators and robots with two sided impacts.

Keywords: nonlinearity of impact type, harmonic excitation, two sided impacts, nonlinear transient processes, graphical representations.

Казім'єрас РАГУЛЬСКІС, член академій наук СРСР (згодом Російської академії наук) та Литви, професор, габілітований доктор, Каунаський технологічний університет, Каунас, Литва, e-mail: kazimieras3@hotmail.com.

Арвідас ПАУЛЮКАС, доктор, Університет Вітовта Магнуса, Академія, Каунаський район, Литва, e-mail: arvydas.pauliukas@vdu.lt.

Альгімантас БУБУЛІС, професор, габілітований доктор, Каунаський технологічний університет, Інститут мехатроніки, Каунас, Литва, e-mail: algimantas.bubulis@ktu.lt.

Петрас ПАШКЕВІЧУС, доктор, компанія «Вайвора», Каунас, Литва, e-mail: info@vaivorairko.lt.

Римас МАСКЕЛЮНАС, професор, габілітований доктор, Вільнюський технічний університет імені Гедімінаса, Вільнюс, Литва, e-mail: rimas.maskeliunas@vgtu.lt.

Люторас РАГУЛЬСКІС, доктор, Університет Вітовта Магнуса, Каунас, Литва, e-mail: l.ragulskis@if.vdu.lt.

Kazimieras RAGULSKIS, Member of Academies of Sciences of the USSR (later of the Russian Academy of Sciences) and Lithuania, Professor, Habilitated Doctor, Kaunas University of Technology, Kaunas, Lithuania, e-mail: kazimieras3@hotmail.com.

Arvydas PAULIUKAS, Doctor, Vytautas Magnus University, Akademija, Kaunas District, Lithuania, e-mail: arvydas.pauliukas@vdu.lt.

Algimantas BUBULIS, Professor, Habilitated Doctor, Kaunas University of Technology, Mechatronics Institute, Kaunas, Lithuania, e-mail: algimantas.bubulis@ktu.lt.

Petras PAŠKEVIČIUS, Doctor, Company "Vaivora", Kaunas, Lithuania, e-mail: info@vaivorairko.lt.

Rimas MASKELIŪNAS, Professor, Habilitated Doctor, Vilnius Gediminas Technical University, Vilnius, Lithuania, e-mail: rimas.maskeliunas@vgtu.lt.

Liutauras RAGULSKIS, Doctor, Vytautas Magnus University, Kaunas, Lithuania, e-mail: l.ragulskis@if.vdu.lt.

DOI 10.36910/automash.v1i18.757