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CONSTRUCTION OF A SIMULATION MODEL OF THE SYSTEM "STRIKER-TOOL-PROCESSED MEDIUM"

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This study investigates the process of impulse interaction between the elements of an impact device and the processed medium (PM). The task addressed is to combine simulation and mathematical modeling of the process.

A simulation model of the striker has been constructed using the Ansys programming system. The basic elements of the striker were built in a geometric shape close to cylindrical; a PM simulator was developed in the Design Modeler module. The degrees of freedom of the elements, their physical properties and external factors were adopted in accordance with the structural scheme and operating modes of the striker.

Adequacy of the simulation model was assessed by comparison with discrete and discrete-continuous models. The finite difference method was used to solve the system of differential equations under given initial and boundary conditions. The comparison was carried out by the parameters of impact interaction: co-impact time, vibrations of the contact and impact ends of the tool. Strikers and tools of different sizes with flat contact ends were considered. The impact time was determined by the difference in speeds and displacements of the contact ends of the striker and the tool; it is 0.1–0.5 ms. In this case, the striker speed varied in the range of 3–20 m/s. High-frequency oscillations of the tool ends amounted to 3000–6000 Hz and were determined by the dimensions of the striker and the tool. The discrepancy of the parameters relative to the Ansys system did not exceed 10%.

The simulation model has made it possible to evaluate the energy transformation in the "striker-tool-processed medium" system. The coefficient of energy transfer to PM from the tool is 0.55–0.65; from the striker to the tool – 0.75–0.8.

The results lay the foundation for applying the simulation model to conduct numerical experiments involving elements of a striking device of complex geometric shape. The simulation model and discrete-continuous models could be used to select rational parameters when designing striking devices

Keywords: Ansys Mechanical, impact device, co-impact time, model identification, energy characteristics

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1. Introduction

Modern systems for modeling physical processes based on numerical methods using software systems such as Ansys, SolidWorks (USA), etc. are widely used in the design of technical devices. When experimentally studying fast-moving processes, for example, high-frequency oscillations, there is an issue related to the fact that it is quite difficult to ensure accurate measurement of the parameters of impulse processes during physical tests. Given this, much attention is paid to mathematical modeling.

Any mathematical models assume the presence of simplifications and assumptions; this also applies to the geometric shape of the elements of impact devices. Construction of complex models that describe impulse processes in a system consisting of a certain set of interacting elements is also relevant. When modeling impulse processes in an impact device, it is advisable to distinguish three main interacting elements: the striker, the tool, and the processed medium. It should be noted that when synthesizing mathematical models, the problem of their identification always arises; in other words, substantiating the correctness of the assumptions introduced. Comparing the results obtained for a simplified model with the results for more complex models could serve as a method for identifying and verifying simple mathematical models. At the same time, the correct choice of parameters for setting up complex software systems (such as Ansys, SolidWorks, etc.) is checked.

Only combined modeling using models of different complexity with implementation algorithms in complex programs, along with original developments, may enable high research efficiency.

Therefore, it is a relevant task to conduct studies aimed at estimating parameters of oscillatory processes using system methods of mathematical modeling.

2. Literature review and problem statement

When modeling the processes of impulse collision between the elements of a striker structure, discrete and continuous models are used [1–9]. The process of interaction during the impact of discrete elements was considered in [1]. The impact force was determined according to the Hertz model, i.e., in a power dependence on the difference in displacements of the centers of mass. In this model, an approximate solution to the differential equation was derived, from which the dependence of the impact time on the main dynamic parameters was determined. Such a simplified model does not make it possible to take into account the influence on the determination of the geometric parameters of the striker and the tool of the reaction from the side of the processed medium. In [2], the striker and the tool in the discrete model of the drill bit are connected by elastic and dissipative elements. The resulting system of ordinary differential equations and its solution do not take into account the wave processes of percussion-rotational drilling, which is important for assessing the energy parameters of the dynamic process. In [3], the translational and rotational motion of the tool is considered on the basis of the discrete model. Discrete models make it possible to reveal the evolution of the oscillation process and the movement of elements but, in principle, it is impossible to distinguish high-frequency oscillations arising from the elastic characteristics of the materials of the striker and the tool. In [4], a method for increasing the efficiency of the impact device by holding the striker in the presence of an electromagnetic drive is investigated. The model consists only of discrete elements, which limits its effectiveness in determining the force factors in the cross-sections of the striker and the tool. A number of works consider the issue of optimizing the elements of the impact device to improve energy efficiency. In [5], the Adams (Automatic Dynamic Analysis of Mechanical Systems) program and the energy approach are used. The application of specialized programs can be considered rational but, at the same time, questions arise about the verification of the mathematical models used.

The problem of deriving the values of internal force factors and high-frequency oscillations is partially solved in discrete-continuous models only for the tool [6]. A model of the tool in the form of a rod with a variable cross-sectional area made it possible to estimate the normal stresses in different sections of the tool and at different times. In addition, estimates of the influence of the pre-impact velocity of the striker, the resistance of the processed medium on the tool oscillations, and the time of impact interaction were obtained. In work [7], the interaction time was increased by installing a two-element striker. Objective difficulties are associated with the spatial one-dimensionality of the models. The adopted simplification does not make it possible to calculate the tangential and radial stresses in the sections of the tool and striker, to assess the influence of the shape of the striker and tool on the effectiveness of the impact device. These issues were partially solved [8], in which the influence of the shape of the striker on the energy parameters of the impact device was studied. A simplified model of the striker and tool and a geometric solution of the system of equations based on the method of characteristics were considered. When studying the oscillation process using the given models, the issue of their identification and verification in the case of three or two dimensions remains unresolved.

The use of complex programming systems based on the finite element method allows us to take into account the influence of shapes of the striker and tool on the oscillation process. At the same time, problems arise with the correct adjustment of these systems because of the proprietary software and the adopted simplifications of the model [9, 10].

Thus, all this gives grounds to argue that it is advisable to compare the results for simple models, discrete, discrete-continuous, and more general, which play the role of a "black box" for the user. Such a comparison may be considered necessary for the use of simplified models along with simulated three-dimensional models in the design of impact devices.

3. The aim and objectives of the study

The purpose of our study is to construct a simulation model of the oscillation process of an impact device's elements in the Ansys system, which will enable the verification of simplified mathematical models of discrete and discrete-continuous types with the correct setup of the Ansys system.

Achieving the goal requires solving the following tasks:

– to build in Desing Modeler the 3D models of the system "striker-tool-processed environment";

– to select simplified models of discrete and discrete-continuous types for comparing the results, determine their parameters;

– to conduct numerical experiments with simplified models of the striker and the Ansys system, with different geometry of the strike and tool;

– to determine estimates of the stress distribution across the cross-sections of the strike and tool, as well as the coefficients of energy transformation from the strike through the tool into the processed medium.

4. The study materials and methods

The object of our study is the process of impulse interaction between the elements of the impact device and the processed medium.

The hypothesis of the study assumes the following.

The process of interaction between the striker and the tool when resisting the processed medium (PM) has an oscillatory nature and can be described by a system of wave differential equations under boundary and initial conditions. To determine the parameters of the oscillations, the Ansys system can be used, which acts as a "black box" model for the tester. This system can play the role of a tool to devise methods for identifying and verifying simplified discrete and discrete-continuous models (DCMs) of the oscillatory process of the impact device. Comparing the results from numerical experiments using different mathematical models allows for rational tuning of the Ansys system.

The main assumptions adopted in our work:

a) the cross-sections of the rod-tool and rod-striker remain flat during impulse interaction;

b) the contact ends of the strike and the tool are assumed to be flat;

c) the force of the impact interaction between the strike and the tool depends on the difference in their displacements according to a power law;

d) the strike and the tool move only in the direction of the *x*-axis;

e) the action of the strike on the tool is determined by the magnitude of the pre-impact velocity;

g) the properties of PM are determined by the modulus of elasticity and Poisson's ratio of the material.

Discrete models and DCMs are identified as systems of ordinary differential equations and partial differential equations. These systems are linked by contact and boundary conditions. An approximate solution to such a system is found by the finite difference method. Finite difference method algorithms are programmed in simple systems, but there is always a challenge of identifying and verifying mathematical models that have a simplified structure. This is especially relevant to the simplification of the geometric shape of the striker and the tool.

The geometric model of the striker, tool, and processed medium is built in the Desing Modeler module. The shape of the striker and tool is taken close to cylindrical to ensure the ability to compare results relative to the discrete-continuous model. The Ansys Explicit Dynamics module is used for simulation. It should be noted that the use of the explicit method of the dynamic process requires a limitation of the time interval over which the solution to the initial-boundary problem is searched. For fast-moving processes, such a limitation is not critical. Therefore, for considering the impact process, the calculation time was set to 5 ms.

The use of complex professional systems in the design of elements of a shock device of complex geometric shape requires substantiating the correctness of such calculations. Comparison of the results obtained by the systems for models with a simple geometric shape, close to cylindrical, is an evidentiary basis for confirming their correctness. On the other hand, this provides a method for selecting rational parameters for tuning the Ansys system.

Thus, the integrated use of discrete and discrete-continuous models with "black box" models allows for rational research of shock devices taking into account their complex geometric shape.

5. Results of research into the oscillation process of an impact device's elements

5. 1. Construction of a simulation model in Ansys

The diagram of the impact device and the typical dimensions of the striker and tool are shown in Fig. 1.

Data on the basic properties of materials used in the numerical experiments are given in Table 1.

Table 1

Materials properties

System element	Striker	Tool	Processed medium
Material	Steel	Steel	Plastic, steel
Weight, kg	162.86	132.8	130.5
Density, kg/m^3	7850	7850	1200
Modulus of elasticity, E, Pa	2×10^{11}	2×10^{11}	10^8–2×10^{11}
Poisson's ratio	0.3	0.3	0.3

The type of mesh for using the finite element method (FEM) is shown in Fig. 1, *c*. The number of mesh elements is about 100000–300000.

Here are the main settings in Ansys Explicit Dynamics: Fixed Support – rigid fixation in all degrees of freedom (an element that simulates the processed medium); Remote Displacement – fixation in translational degrees of freedom (along the y and z axes). In this case, the adopted motion restrictions allowed us to build a structural diagram of the device (Fig. 1, *d*).

Between the ends of the striker and the tool at the initial moment of time, a gap of $\delta_1 = 1$ mm was set; between the ends of the striker and the processed medium – $\delta_2 = 2$ mm. Such gaps made it possible to clearly determine the moments of collision from the elements of the impact device (Fig. 1, *a*).

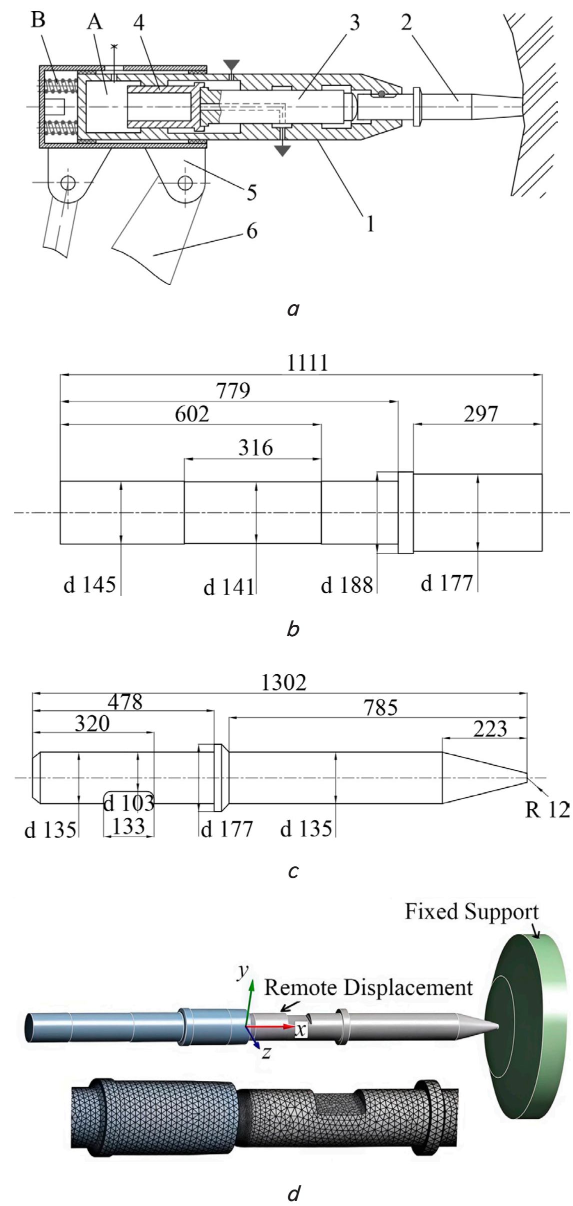


Fig. 1. Elements of the impact device and basic geometric dimensions: *a* – diagram of the impact device, in which: 1 – housing; 2 – tool; 3 – striker; 4 – valve; 5 – adapter; 6 – manipulator; *A* – pneumatic accumulator chamber; *B* – shock absorption unit; *b* – typical dimensions of the striker; *c* – typical dimensions of the tool; *d* – typical simulation model in Ansys

5. 2. Selection of models for comparison

In [1], a model of the contact force of impact interaction was used, which was determined from the following formula

$$P = \begin{cases} k \cdot (u_1 - u_2)^{\alpha}, \text{ if } u_1 \geq u_2, \\ 0, \text{ if } u_1 < u_2. \end{cases} \quad (1)$$

In formula (1) $Du = u_1 - u_2$, u_1, u_2 – displacement of the center of mass of the bodies in contact in the direction of impact, $\alpha \geq$

1. The coefficient k is determined by the geometry of the contact surfaces and the properties of the material of the bodies

$$k=\frac{4}{3\left(1-\mu_1^2\right)/E_1+3\left(1-\mu_2^2\right)/E_2}\sqrt{\frac{R_1R_2}{R_1+R_2}}, \qquad (2)$$

where R_1, R_2 are the radii of curvature of the contact surfaces of the interacting bodies, m_1, m_2 are Poisson's ratios, E_1, E_2 are the elastic moduli of the material of the contacting bodies.

Analytical and numerical studies of the given model were carried out by a number of authors. Let us outline some known results that were used to test numerical algorithms.

Taking into account the difference in displacements

$$y=\Delta u=u_1-u_2,$$

in [1], the initial problem is considered, which, for α = 3/2, takes the following form:

$$\frac{d^2y}{dt^2}=\begin{cases}-\frac{k}{m}y^{3/2}, \text{ if } y\ge 0,\\ 0, \text{ if } y<0,\end{cases} \qquad (3)$$

$$y(0)=0,\ \frac{dy}{dt}(0)=V_0, \qquad (4)$$

here $m=m_1\times m_2/(m_1+m_2)$ is the combined mass of the contacting bodies.

Equation (3) allowed one to determine the maximum value of y

$$y_{\max}=\left(\frac{5}{4}\cdot\frac{m}{k}\cdot V_0^2\right)^{\frac{2}{5}}. \qquad (5)$$

The solution to the initial problem using elliptic functions is given in [1]. The impact time is calculated from the following form

$$T=\frac{2.9432}{V_0^{1/5}}\left(\frac{5m}{4k}\right)^{\frac{2}{5}}. \qquad (6)$$

The given model can be considered the simplest among those considered in this study. The model consists of only two discrete elements, connected by stiffness, which is determined from the Hertz formula.

To compare the time of impact of the striker with the tool at given parameters for two variants of the striker and tool (Fig. 1), calculations were carried out, the results of which are given in Table 2.

The simplest model reflects only the process of interaction between the striker and the tool without taking into account their geometric shape. In [6], a DCM of impact interaction in the system "striker-tool-PM" has been proposed. For greater clarity, we give the basic system of equations:

$$\frac{\partial^2u(t,x)}{\partial t^2}=a^2\left[\frac{1}{S(x)}\cdot\frac{dS(x)}{dx}\frac{\partial u(t,x)}{\partial x}+\frac{\partial^2u(t,x)}{\partial x^2}\right], \qquad (7)$$

$$0<t\le T,\ 0\le x\le L,$$

$$m_1\frac{d^2y}{dt^2}=R(t)+G(\Delta u)\cdot\left(u(t,0)-y\right)+ +b_1\frac{d}{dt}\left(u(t,0)-y\right). \qquad (8)$$

Here $u(t,x)$ – longitudinal displacements of the cross section x at time t, $y(t)$ – displacement of the discrete element, $G(\Delta u)$ – elasticity in the Hertz model.

The boundary conditions for the tool reflect the nature of the interaction between the ends with the discrete element and PM:

$$S(0)E\frac{\partial u}{\partial x}(t,0)=-G(\Delta u)\left(y(t)-u(t,0)\right)- -b_1\left(\frac{dy}{dt}-\frac{\partial u(t,0)}{\partial t}\right), \qquad (9)$$

$$S(L)E\frac{\partial u}{\partial x}(t,L)=-c_2u(t,L)-b_2\frac{\partial u(t,L)}{\partial t}. \qquad (10)$$

The initial conditions for the tool and the discrete element reflect the initial impulse effect of the discrete element on the tool end:

$$u(0,x)=0,\ \frac{\partial u}{\partial t}(0,x)=0, \qquad (11)$$

$$y(0)=0,\ \frac{dy}{dt}(0)=V_1. \qquad (12)$$

The solution to system (7) to (12) was derived by the finite difference method (FDM) [6, 11].

Table 2

Computation results

System element	Striker	Tool
Elastic modulus E, Pa	2×10^{11}	2×10^{11}
Poisson's ratio, μ	0.3	0.3
Contact radii, m	0.5	0.5
Weight, kg (Variant 1)	4.27	11.86
Weight, kg (Variant 2)	162.86	132.8
Initial speed, m/s	20	0
Design stiffness coefficient, N/m$^{3/2}$	7.326×10^{10}	
Estimated time of impact, ms, (variant 1)	0.1259	
Estimated time of co-impact, ms, (variant 2)	0.4437	

5. 3. Results of numerical experiments

Calculations with reduced sizes of the striker and the tool were carried out for the purpose of comparison with the discrete-continuous mathematical model (variant 1, Table 1). The results of calculations at the initial speed of the striker V = 20 m/s are shown in Fig. 2, 3, which allowed us to compare the characteristics of high-frequency oscillations of the tool ends for the simulation model and DCM (8) to (13). The oscillation frequency is 6000 Hz; the phase shift is ~0.1 ms. For comparison, the value of the phase shift of the tool ends was determined from the following formula

$$\Delta T=L\sqrt{\frac{\rho}{E}},$$

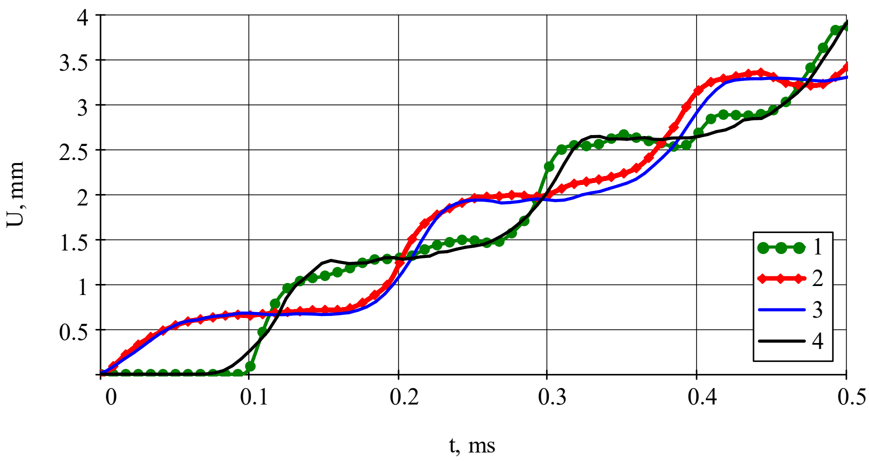
where $L = 0.5$ m is the length of the tool. With the values $r = 7{,}850$ kg/m^3, $E = 2\times 10^{11}$ Pa, $DT = 0.099\times 10^{-3}$ s is obtained.

The basic parameters are: $b_1 = b_2 = 0$, $m_1 = 4.3$ kg, $V_1 = 20$ m/s, $h = 5$ mm, $T = 0.5$ ms, $\tau = 6.25\times 10^{-8}$ s.

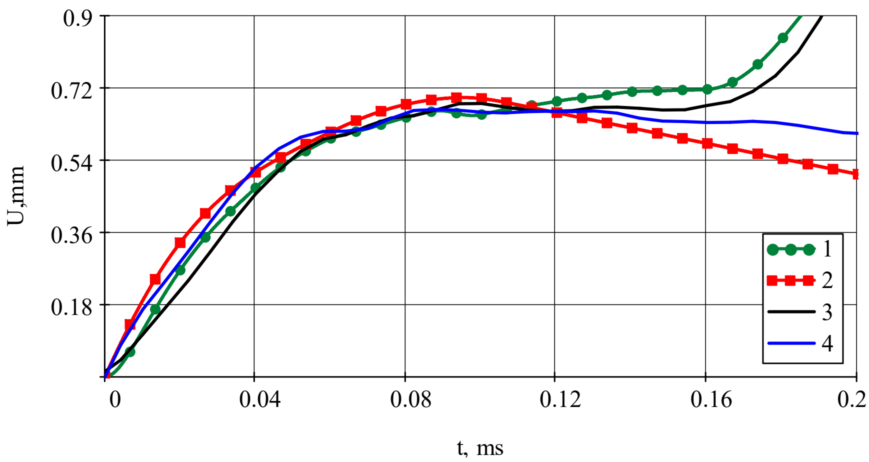
The time of collision of the striker with the tool can be determined from the plots shown in Fig. 2, *b*. The time is 0.12 ms (for the simplified model 0.1259 ms, the discrepancy is about 5%). A larger discrepancy was obtained for the discrete-continuous model when comparing speeds (Fig. 3).

5. 4. Estimating the stresses and energy transformation in the system

Fig. 1 shows a diagram, the main dimensions of the striker, the tool, as well as the shape of the working environment simulator.



a



b

Fig. 2. Comparing the solution derived by a finite difference method (discrete-continuous model, 1, 2) to the one derived by a finite element method (*Ansys*, 3, 4): *a* – movement of the tool ends; *b* – movement of the contact ends of the tool (1, 3) and the striker (2, 4)

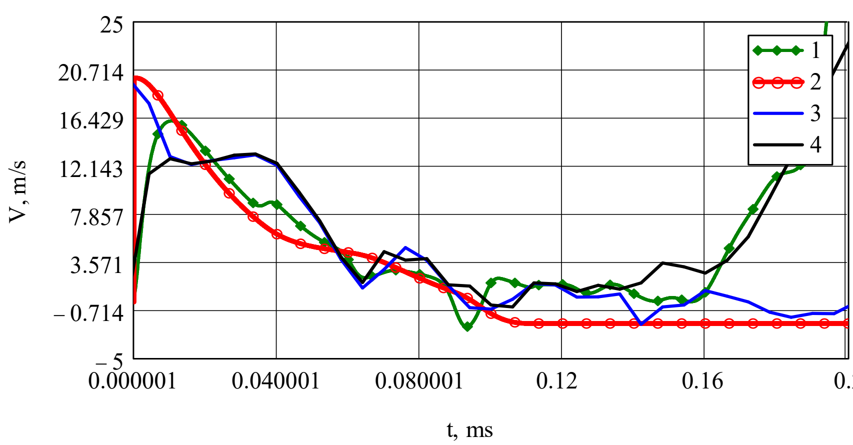


Fig. 3. Comparing the speeds of contact ends of the tool (1, 4) and the striker (2, 3): 1, 2 – Mathcad, finite difference method; 3, 4 – Ansys, finite element method

The plots (Fig. 5) show the change in stresses of the contact end of the tool and the processed medium. The process was considered with high rigidity of the processed medium (material – steel, $E = 2 \times 10^{11}$ Pa). The purpose of such a calculation is to compare the efficiency of energy transformation in the system "striker-tool-processed medium".

The displacements of contact ends of the striker and the tool are shown in Fig. 4.

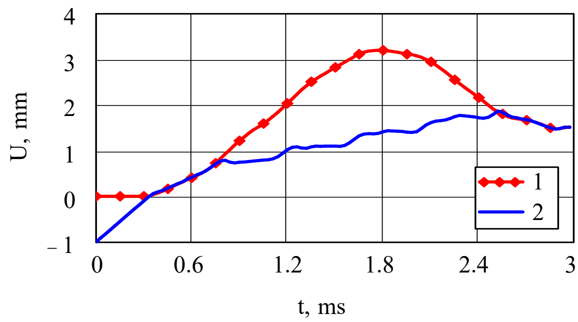


Fig. 4. Displacements: 1 — right end of the striker; 2 — left end of the tool

The plots in Fig. 4 show the duration of contact between the ends of the striker and the tool (co-impact time). Approximate calculations of the co-impact time

$T_1 = 0.84 - 0.33 = 0.1$ ms.

The change in stresses over time is shown in Fig. 5.

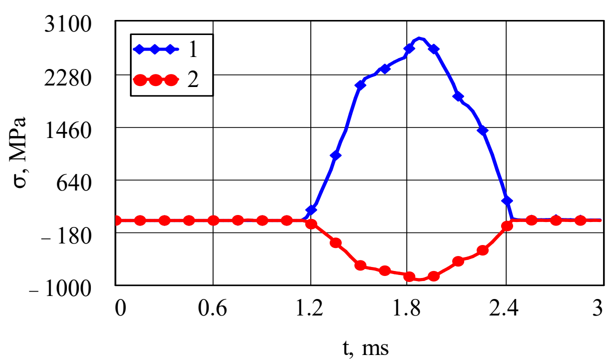


Fig. 5. Change in stresses over time: 1 — equivalent stresses in the contact zone of the tool with the processed medium; 2 — normal stresses in the tool cross-sections for the right end of the tool

The following is a change in the energy characteristics of the striker, tool, and PM over time. Fig. 6 shows the change in the striker energy over time.

The change in the energy of the tool and PM over time is shown in Fig. 7.

A numerical experiment was conducted under a "normal" mode, in which PM is a plastic material, the modulus of elasticity is $E = 100$ MPa. The speed of the striker $V = 10$ m/s, the duration of the process $T = 1$ ms. The results are shown in Fig. 8–11.

High-frequency oscillations have a reduced amplitude when compared with a short striker (Fig. 2, *a*). In this case, the amplitude of high-frequency oscillations for the striker ends has increased (Fig. 8, *a*).

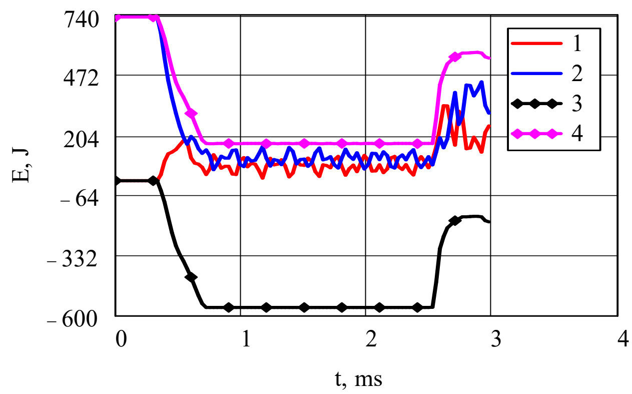


Fig. 6. Change in the energy of the striker over time: 1 — internal energy; 2 — kinetic energy; 3 — contact energy; 4 — total energy

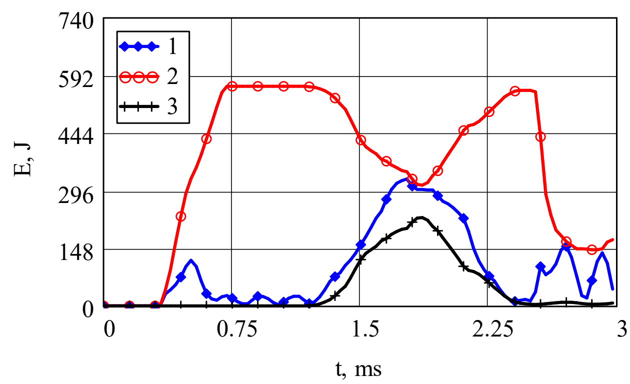


Fig. 7. Energy change over time: 1 — internal energy of the tool; 2 — kinetic energy of the tool; 3 — kinetic energy of the processed medium

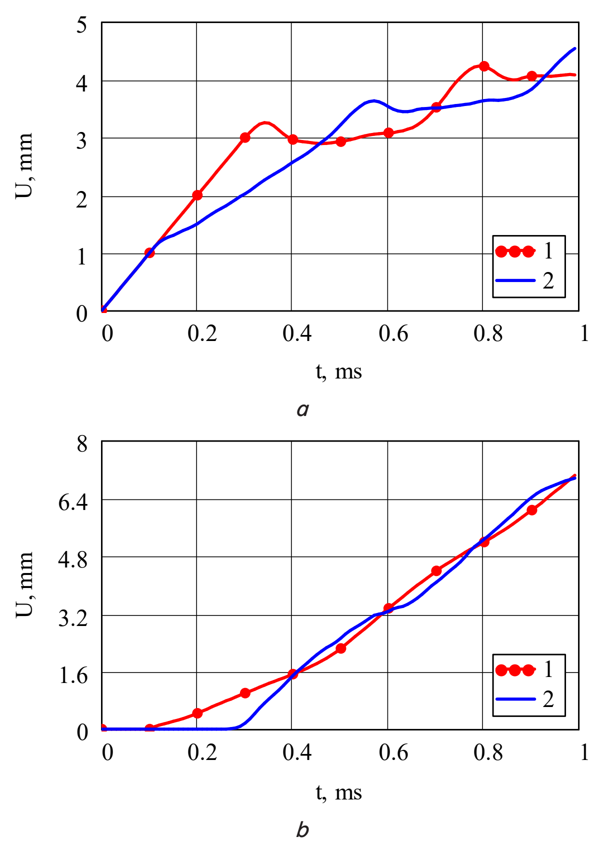


Fig. 8. Displacements of the ends: *a* — striker; *b* — tool; 1 — left end; 2 — right end

It is worth noting that the period before the tool end contacts PM is $t = 3/10000 = 0.3$ ms. The first peak is the contact of the striker and tool ends, the second is the contact of the tool and PM (Fig. 9). The maximum value of stress (compression) in terms of modulus is 390 MPa, and the moment of contact with PM is 150 MPa, which does not exceed the strength limit of steel.

Fig. 10 shows the movement of contact ends of the striker and the tool. The contact occurs at time 0.1 ms and ends at time 0.55 ms.

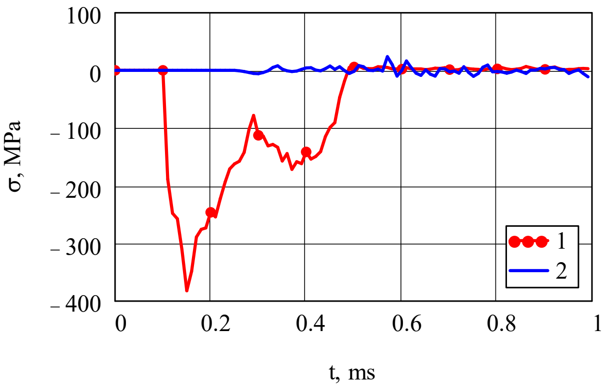


Fig. 9. Normal stresses in the tool cross-sections: 1 – maximum stresses (in modulus); 2 – minimum stresses

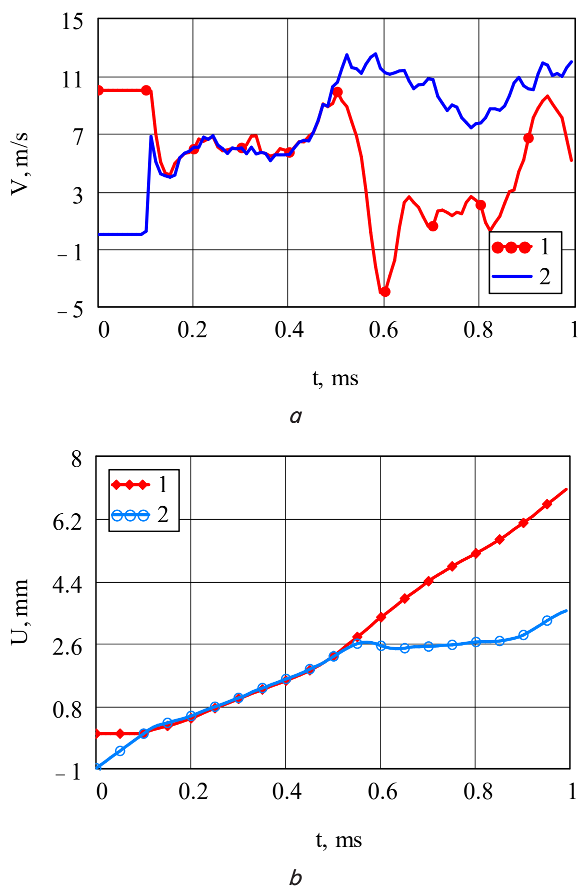


Fig. 10. Change of parameters over time: *a* – speed of contact ends; *b* – displacement of contact ends; 1 – striker end; 2 – tool end

Comparison of energies for the regime at small values of the elastic modulus of PM showed similar results (Fig. 11).

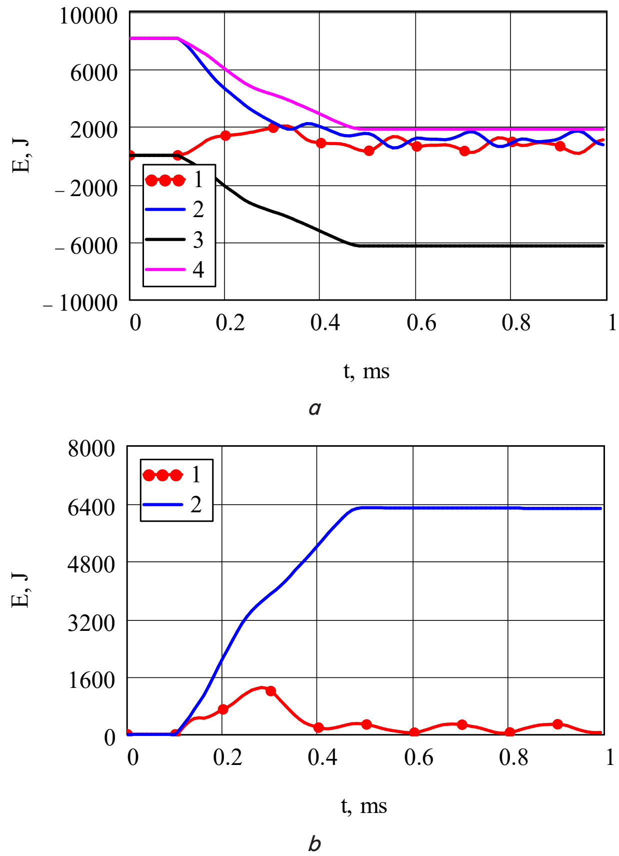


Fig. 11. Change in energy over time: *a* – striker energy; *b* – tool energy; 1 – internal; 2 – kinetic; 3 – contact; 4 – total

The obtained identical energy characteristics with different properties of the processed medium serve as the basis for the correctness of numerical experiments. Such experiments made it possible to estimate the energy transformation coefficients in the "striker-tool-processed medium" system.

6. Results of investigating the effectiveness of a simulation model: discussion

When using mathematical models, it is important to check their correctness and ranges of permissible parameters. The use of Ansys system programs requires correct parameter settings; therefore, it is important to compare the results with the discrete and discrete-continuous models studied in [6, 7]. To compare the results, a simplified form of the striker and the tool with simplified properties of the processed medium was chosen (Fig. 1). This approach allowed us to determine the possibility of using the Ansys/Mechanical (Explicit Dynamics) system when designing impact devices with rational dimensions of the striker and the tool.

The time of impact of the striker with the tool was determined in the range of 0.1–0.5 ms, which is consistent with the obtained theoretical data for discrete elements [1, 6]. The time of impact was determined by the difference in displacements and the difference in velocities of the contact ends of the striker and the tool (Fig. 3). The displacements were reduced to a common coordinate system (Fig. 2), and fairly close values of the contact duration between the ends of the striker and the tool were obtained. The results are consistent with the discrete model considered in [1] (Table 2).

However, it should be noted that the duration of the collision depends significantly on the geometric and mass characteristics of the striker and the tool (6). The dependence of this parameter on the main properties of the processed medium (modulus of elasticity and Poisson's ratio) was not revealed as a result of numerical experiments.

Numerical experiments (Fig. 2, *a*) showed the presence of longitudinal high-frequency oscillations of the tool cross-sections, which are observed in a number of works using discrete-continuous models [6, 7]. The discrepancy with the solution in Ansys by the finite element method is about 5% (Fig. 2, *a*). Calculations showed an increase in the amplitude of these oscillations with a decrease in the striker length and an increase in the diameter (the ratio of the striker length to its diameter was about 1.4). For the striker, on the contrary, the amplitude of high-frequency oscillations increased with an increase in its length (Fig. 8); the ratio of the striker length to its diameter was about 6.1. It should be noted that, as with any numerical method (the finite difference and finite element methods were used in the programs), fast-moving processes require a fine time grid, therefore, the simulation was carried out on a small time interval of 0.5–3 ms.

It can be concluded that the discrete-continuous model is effective for impact devices with long instruments and short strikers.

Thus, the obtained parameter values for the discrete and discrete-continuous models differ quite little from the parameter values in the simulation model. This result can be considered sufficient to substantiate the correctness of the considered DCMs.

To assess the energy transformation in the system "striker-tool-processed medium", calculations were performed at a large value of the elastic modulus of the processed medium ($E = 2\times10^{11}$ Pa). Fig. 4 shows plots that characterize the process of impact of the working end of the tool with the processed medium at high rigidity of the latter. The initial speed of the strike is 3 m/s. By the moment of contact, the time period is $t = 3/3000 = 10^{-3}$ s = 1 ms. The stresses reach values of 1000–3000 MPa (Fig. 5), which means that the material is fractured. When the rigidity of the processed material decreases, the magnitude of the stresses decreases significantly.

With reduced rigidity of the processed medium, the change in stresses in different sections of the tool (Fig. 9) has a peak character at the moment of impact and stresses reach a value of 475 MPa (at a pre-impact velocity of 10 m/s), which approaches the strength limit of the material (500 MPa).

Using the Ansys system made it possible to analyze energy flows in the "striker-tool-processed medium" scheme. For comparison, two variants of PM were considered: steel and plastic material. The steel PM variant made it possible to determine the energy transfer coefficient to the PM from the tool, this value is 0.55–0.65. The energy transfer coefficient from the striker to the tool is 0.75–0.8. Thus, a comprehensive analysis of the effectiveness of simulation models (based on Ansys/Mechanical (Explicit Dynamics) and mathematical discrete-continuous models opens up the possibility of determining the ranges of modeling fast-moving pulse processes in the "striker-tool-processed medium" system.

The list of limitations regarding our study on the effectiveness of the simulation model:

– the use of a model for the striker and the tool, the shape of which is close to the cylindrical with a conical contact part of the tool;

– time intervals for modeling the process of interaction between the device elements are 1–5 ms, which is due to the rapidity of the process and the requirement to use a small time step in the numerical method;

– when using the model, it is necessary to take into account the specific properties of the processed medium.

Disadvantages of the study on the connection between a simulation model and mathematical models:

1) the interaction between the tool and the striker with the body of the impact device is not taken into account. The Ansys system allows one to take this interaction into account, but this requires more detailed development of the geometry and boundary constraints;

2) the model simulates the processed medium only by the linear properties of elasticity and plasticity. When modeling, it is necessary to take into account the nonlinear properties of the material;

3) the study was not sufficiently complete to determine the range of parameters of discrete and continuous models;

4) in the impact process there are high-frequency oscillations of the contact ends of the striker and the tool. Determining the energy characteristics of these oscillations is an urgent task.

Possible areas for further research:

– construction of a simulation model based on the geometry of the impact device close to the real structure;

– consideration of nonlinear properties of the processed medium, limiting parameters of fluidity and strength of the material;

– identification of the simulation model relative to experimental data;

– determining the influence of the geometric shape of the striker and the tool on the parameters of oscillations;

– comparison of the simulation model with mathematical continuum models;

– construction of a simulation model with two strikers.

7. Conclusions

1. A 3D geometric model of the striker has been built in the Desing modeler module of Explicit Dynamics (Ansys), which includes the striker, impact device, and processed environment. The boundary conditions were simulated by limiting the degrees of freedom of the tool. The shape of the tool and striker was chosen close to existing structural analogues. The initial conditions were determined by the initial velocity of the striker and tool.

2. Our simulation results (based on a finite element method) were compared with the simplified theory of collision of two discrete elements (Hertz model). The results coincided with an acceptable error (5–10%). This discrepancy is not a criterion for the accuracy of the model. Comparison with the results for the discrete-continuous model "striker-tool-processed environment" can be considered a partial identification of the model. The discrepancy in the displacements of the contact ends was no more than 10%; in the velocities of the contact ends of the striker and tool – no more than 12%.

3. The influence of the ratio of the length to the diameter of the striker on the nature of the oscillations of the tool and striker sections has been shown; with a decrease in this ratio, the amplitude of high-frequency oscillations increases.

4. The use of a simulation model allowed us to estimate the energy transfer coefficients from the striker to the tool (0.75–0.8), and from the tool to the processed medium (0.55–0.65). Estimates of equivalent stresses in the tool sections were found, which at certain points in time reached values in the range of 380–1500 MPa.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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