Mathematical modeling of the percussion mechanism with a single impact energy increase

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Abstract: The present study aims to develop a mathematical model of the percussion mechanism with a single impact energy increase and determine the influence of the spring stiffness and the ratio of inertial and projectile masses on the main parameters of the destruction process. The method of mathematical modeling of the destruction process was applied. A mathematical model of the percussion mechanism with a single impact energy increase and a diagram for its solution in Matlab-Simulink have been developed; dependences of the main parameters of the destruction process on the spring stiffness and the ratio of inertial and projectile masses have been obtained. The mathematical model of the percussion mechanism makes it possible to increase the energy of a single impact by three-five times in comparison with a freely falling projectile. The reactive component is not transmitted to the base machine.

1. Introduction
Currently, the least energy-consuming method is a mechanical destruction of durable materials. Table 1 compares impact fracture indicators with other technologies [1].

Table 1. Specific energy intensity of various rock destruction technologies

| No | Rock destruction technology                                | Specific energy consumption, J / cm³ |
|----|------------------------------------------------------------|-------------------------------------|
| 1  | Ultrasound destruction                                    | 10104                               |
| 2  | Water jet destruction                                     | 1684                                |
| 3  | Low-power destruction                                     | 253                                 |
| 4  | Rolling cutter destruction                                | 126-253                             |
| 5  | Powerful impact destruction (with an impact speed of up to 10 m/s) | 17-25                               |
| 6  | Explosion destruction (with an impact speed of 700-900 m/s) | 6                                   |
Hydraulic hammers as replaceable working equipment for single-bucket excavators have a wide range of applications and are used for destroying oversized rocks and reinforcing concrete and concrete structures, opening asphalt concrete pavements, and developing frozen soil [2].

The destruction efficiency increases with increasing energy of a single impact [3, 4]. However, its increase is restrained by the reactive component (recoil), which is transmitted to the base machine [5].

2. Materials and methods
The paper uses mathematical modeling methods, the tool-Matlab-Simulink.

3. The study of the structure of the modified lead-tin-base bronze
The aim of the present study is to develop a percussion mechanism with increased energy of a single impact, which is not transmitted to the base machine.

Figure 1 shows a design diagram of the mechanism.

Figure 1. Design diagram of the percussion mechanism

The impact mechanism consists of barrel 1, projectile 2 coaxially placed in the barrel, hydraulic cylinder 3 pivotally connected with barrel 1, grip 4, spring 5 and inertial mass 6 with locks 7. Spring 5 is located between projectile 2 and inertial mass 6.

There are support 8 and safety elements 9.

In the non-working state, barrel 1 is installed vertically, projectile 2 is in a lower position and bumps into the destroyed surface. Inertial mass 6 and locks 7 are located in the upper part of barrel 1 and bumps into spring 5, which is in the unfolded state. The rod of hydraulic cylinder 3 is retracted and grip 4 is not connected with projectile 2.

When the working fluid is supplied to the piston cavity of hydraulic cylinder 3, the rod with grip 4 is mixed down until it contacts projectile 2. Then, the working fluid is directed into the rod cavity of hydraulic cylinder 3, projectile 3 is captured and moves along barrel 1.

As projectile 1 moves, it compresses spring 5, while inertial mass 6 is kept from moving by supports 8. When projectile 2 rests against inertial mass 6, locks 7 are closed, forming a single shock mass.

When the rod cavity of hydraulic cylinder 3 is connected to the drain, grip 4 releases projectile 2, and under gravity, the single impact mass moves downward. Having travelled a certain distance, locks 7 of inertial mass 6 open, and under released energy of compressed spring 5, projectile 2 acquires additional acceleration and strikes against the destroyed surface. Moving in the opposite direction,
inertial mass 6 perceives the reactive component of spring energy, which is not transmitted to the base machine, and the mechanism returns to its original state.

Safety elements 9 protect the structure in case of failures of projectile 3.

The operations of the percussion mechanism can be described by the following system of differential equations:

\[
\begin{align*}
    m_1 \frac{d^2 x_1}{dt^2} &= c_2 (x_2 - x_1) - G_1 \quad (1) \\
    m_2 \frac{d^2 x_2}{dt^2} &= -c_2 (x_2 - x_1) - G_2 \quad (2)
\end{align*}
\]

where \( m_1 \) – inertial mass, kg;
\( x_1 \) – displacement of the inertial mass, m;
\( c_2 \) - spring stiffness, N / m;
\( x_2 \) – projectile movement, m;
\( G_1 \) - weight of the inertial mass, N;
\( m_2 \) – projectile weight, kg;
\( x_2 \)– projectile movement, m;
\( G_2 \) – projectile weight, N.

Equation (1) determines the movement of the inertial mass, while equation (2) is used to determine the movement of the projectile, depending on the main parameters of the percussion mechanism.

When developing a mathematical model of the impact mechanism, the mass movement resistance was not taken into account.

To solve the system of equations in Matlab-Simulink, a diagram shown in Fig. 2 has been developed. Figure 3 shows the simulation results [6].

![Figure 2. The diagram in Matlab-Simulink](image)

The chain of blocks 1-10 simulates the solution of equation (1), blocks 11-19 solve equation (2), the results are output to block 20.
The initial conditions are as follows: projectile mass - 1000 kg; inertial mass - 500 kg; spring rate - 40 kN/m; the projectile, together with the inertial mass, is raised to a height of 2.8 m and dropped down. When the locks open at a height of 1 m, and the inertial mass continues to move down; however, as affected by the spring, it stops and begins to move in the opposite direction 0.025 seconds after (Fig. 2-a).

At a height of 1 m, the projectile acquires an additional impulse and strikes the destructible surface at the zero mark (Fig. 2-b). Moreover, its initial velocity increases from 6 to 16 m/s at the time of impact (Fig. 2-c). The maximum speed of the inertial mass is 13 m/s (Fig. 2-d).

Using the percussion mechanism model, the dependence of the main process parameters on spring stiffness was obtained (Fig. 4).

Figure 3. Simulation results:
a - displacement of the inertial mass (x1); b - movement of the projectile (x2); c - projectile speed; d - inertial mass speed
With an increasing spring stiffness, all the indicators increase. For comparison, the graph shows $T_0$ which is the impact energy during the free fall of a projectile weighing 1500 kg from a height equal to the sum of displacements $x_1$ and $x_2$. A 3-5-fold increase in impact energy can be observed.

Figure 4 shows the dependence of the main process parameters on the ratio of inertial mass and projectile mass.

![Figure 4. Dependence of the main process parameters on spring stiffness](image)

![Figure 5. Dependence of the main process parameters on the ratio of inertial mass and projectile mass.](image)

**Conclusion**

The model developed in the present study makes it possible to increase the energy of a single impact by 3-5 times in comparison with a freely falling projectile, while the reactive component is not transmitted to the base vehicle.
References

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