Analysis of the Striker Stroke Impact on the Hydropneumatic Impact Devices Energy Performance

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Abstract. The study results of the hydropneumatic impact devices striker movement impact on the energy performance during the operating stroke are presented. The energy parameters of the hydropneumatic impact units include power and single impact energy. The mathematical model of the hydropneumatic impact unit operating process is briefly described. The idle stroke, deceleration, operating stroke of the hydropneumatic impact unit striker are characterized. The software for conducting the hydropneumatic impact unit study is developed. The impact devices energy performance depends on the striker velocity at the time of impact, as well as on the striker mass and stroke. Gas pressure in the pneumatic accumulator also influences the energy performance. The striker velocity and single impact energy graphic dependences on the striker stroke and mass, gas pressure in the pneumatic accumulator are represented. The analysis of the obtained dependences is provided. The velocity at the time of the hydropneumatic impact device tool impact on the ground can vary in a wide range from 4.5 to 8 m/s at the stroke of the striker from 50 to 100 mm. It makes possible to use a hydropneumatic impact device as various replacing equipment of road building machines such as excavators.

Keywords: the hydropneumatic impact device, the stroke of the striker, the impact energy

1. Introduction
Hydropneumatic impact device (HID) is the main element of the hydraulic impact equipment. Hydropneumatic impact device consists of the body, the striker, the control unit of the device and tool operating cycle. Power impulses of certain intensity and frequency are generated by the hydropneumatic impact device, the impulses to affect the excavated ground or object [1]. Active operation equipment and hydraulic pulse equipment are designed for the firm soil excavation, making the holes in the ground, rocks excavation, soil compaction, pile elements driving and extraction [1]. At the initial stage of designing the hydraulic impact device, one should know its main elements design parameters considered in paper [2]. According to the paper [2], methods, algorithms and selecting programs of the main parameters are promising for hydraulic impact devices designing. However, the energy parameters of the hydraulic impact devices are not considered in the paper [2]. In papers [3, 4, 5, 6] the issues of the hydraulic impact devices dynamic processes modelling are studied. Energy performance of the hydraulic impact devices are also not mentioned in the following papers [3, 4, 5, 6]. A significant factor affecting the hydropneumatic impact device efficiency is the impact energy, depending on the striker velocity at the time of impact, as well as on the striker mass and stroke.
2. Problem statement
The most common hydraulic impact devices are HID. Easy impact energy regulation is their distinctive feature. The impact energy regulation is achieved by changing the impact velocity when gas charging pressure of the pneumatic accumulator varies [1].
Hydropneumatic impact device is characterized by the cyclical operation: by the striker idle stroke resulting in the deceleration phase, and striker operating stroke. The operating stroke of the striker results in impacting the medium. HIU design scheme is shown in figure 1 [1].

![HIU design scheme](image)

**Figure 1.** HIU design scheme:

1 is the tool; 2 is the body; 3 is the striker; 4 is the overflow chamber; 5 is the pressure chamber; 6 is the pneumatic accumulator; 7 is the control valve; 8 is the delivery line

HIU main parameters are the following:
- the striker mass,
- the stroke of the striker,
- the gas charging pressure of the pneumatic accumulator;
- the pistons diameters of the pneumatic accumulator, pressure and overflow chambers;
- the tool shank diameter;
- the efficiency;
- the hydraulic hammer weight.

The striker stroke values, pneumatic accumulator gas pressure, striker mass affect the impact speed as well as the single impact energy and power. The striker stroke is one of the main parameters having a significant influence on the hydropneumatic impact device operation.

3. Theory
The hydropneumatic impact device operating processes were calculated by using the fundamental laws of mechanics and hydraulics. The hydropneumatic impact device mathematical model is based on the striker motion and fluid flow continuity differential equations system. The mathematical model takes into consideration the hydropneumatic impact device main design parameters as well as the basic
vehicle parameters. The idle stroke, deceleration and operating stroke are characterized [1]. The system of the basic equations describing the operating processes has the following form:

\[ m \frac{d^2 x}{dt^2} = F_d - F_s \]  

(1)

\[ Q_B = S_P \cdot \dot{x} + \frac{V_P + S_P (\ell_B + x)}{E_P} \cdot \dot{p}_B \]  

(2)

\[ Q_C = S_O \cdot \dot{x} + \frac{V_O + S_O (\ell_C - x)}{E_O} \cdot \dot{p}_C \]  

(3)

\[ W_a = \frac{P_{go} (\frac{\ell_o}{\ell_o - \ell})^n S_A (\ell_o - \ell)}{n - 1} \left( \frac{\frac{\ell_o}{\ell_o - \ell}}{\frac{\ell_o}{\ell_o - \ell}} \right) \]  

(4)

where \( x \) is the striker displacement, \( m \) is the striker mass, \( F_d \) is the driving force, \( F_s \) is the resistance force, \( V_P, V_O \) are the fluid volumes of the pressure and overflow lines, correspondingly, \( E_{pp}, E_{wc} \) are the presented elasticity modules of the pressure and overflow lines, \( P_P, P_O \) are the pressures of the pressure and overflow chambers, \( S_P, S_O \) are the pressure and overflow chambers areas, \( S_B = \pi(D_b^2 - d_{um}^2)/4 \), \( S_C = \pi(D_C^2 - d_{um}^2)/4 \), \( W_a \) is the energy generated by the pneumatic accumulator, \( P_g \) is the gas charging pressure of the pneumatic accumulator, \( S_A \) is the active area of the pneumatic accumulator chamber, \( S_A = \pi D_A^2/4 \), \( \ell_o \) is the length of the pneumatic accumulator chamber, \( \ell \) is the stroke of the striker, \( n \) is the polytropic process index. The hydropneumatic impact device design parameters values used during the analysis are given in [1].

4. Experimental results

The developed software is for conducting the HIU study. The software makes it possible to determine the HIU main parameters, speed, impact energy as a function of the striker stroke, pneumatic accumulator gas pressure, striker mass (figures 2, 3).
The graphs (figure 2) show the velocity to reach the values of ~ 8 m/s during the striker stroke. The graphs \( p_g(t) \) (figure 3) present the gas pressure change in the pneumatic accumulator chamber when operating the HIU.

The calculations special cases of the pneumatic accumulator energy, impact velocity, single impact energy are shown in figures 4-6 in the form of three dimensional graphs.
Figure 4. The pneumatic accumulator energy dependence on the gas charging pressure and striker stroke (the diameter is $D_A=0.14$ m, the length $l_0$ is $0.175$ m)

Figure 5. The velocity variation at the time of impact depending on the pneumatic accumulator gas charging pressure and striker stroke (the striker mass is $m=150$ kg)
5. Conclusions
The mathematical model of the hydropneumatic impact device made it possible to obtain the impact energy and velocity dependences on the striker stroke and mass, and pneumatic accumulator gas charging pressure at the time of impact.

The impact velocity of the hydropneumatic impact device tool depends on the striker mass and stroke, as well as on the pneumatic accumulator gas pressure. By increasing the stroke and pneumatic accumulator gas charging pressure, impact velocity increases. The striker mass increase results in the tool impact velocity decreases.

The tool impact velocity can vary in a wide range from 4.5 to 8 m/s (figures 2, 4-6) at the striker operating stroke from 50 to 100 mm. It makes possible to apply the hydropneumatic impact device as various replacing equipment of road building machines such as excavators.

6. References
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