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THE VALUE OF THE ENERGY OF THE PNEUMATIC ACCUMULATOR FOR DIFFERENT POLYTROPIC PROCESSES

Abstract: *The paper presents the results of the analysis of the energy percussion device with a pneumatic accumulator and establishes a correlation between the energy value and the parameters of the accumulator as volume and pressure. Mathematical models are used to determine the efficient charge energy of the pneumatic accumulator during the installation of a striker for polytropic processes (isothermal, isochoric, isobaric and isentropic). The results show that the energy value increases with increasing pressure during the isothermal process more sharply than during the isentropic process, and the energy value decreases with increasing volume in the isobaric process. Studies of the thermodynamic conditions of the pneumatic accumulator can be used to choose the design of a percussion device to optimize the energy performance of devices for the destruction of hard and frozen rocks.*

Keywords: *percussion device, polytropic processes, destruction of rocks, charging energy.*

Анотація: *У роботі наведено результати аналізу функціонування енергетичного ударного пристрою з пневмоакумулятором та встановлено кореляцію між значенням енергії та параметрами акумулятора, а саме - об'ємом та тиском. За допомогою математичних моделей визначено раціональну енергію зарядки пневмоакумулятора для політропних процесів (ізотермічних, ізохорних, ізобарних та ізотропічних). Результати дослідження показують, що енергетична ефективність зростає із збільшенням тиску під час ізотермічного процесу більш швидко, ніж під час ізотропічного процесу, а також енергетична ефективність зменшується зі збільшенням об'єму в ізобарному процесі. Дослідження термодинамічних умов пневмоакумулятора можуть бути використані при виборі конструкції корпусу ударного пристрою для оптимізації енергетичних характеристик при руйнуванні твердих і мерзлих гірських порід.*

Ключові слова: *ударний пристрій, політропні процеси, руйнування гірських порід, енергія зарядки.*

Introduction. The underground building has received much attention in the last years [1-4]. Percussive destruction of hard and frozen rocks destruction has a pivotal role in underground buildings such as metro build and tunnel buildings. A considerable amount of literature [5-9] has been published on this rock destruction. A percussion device with a pneumatic accumulator is among the most widely used types of rock destruction device.

The energy of the pneumatic accumulator is analysed in order to find a way for improving performers of percussion devices. This paper takes a new look at the energy of the pneumatic accumulator for polycrotic processes including isochoric, isobaric, isothermal, and isentropic processes. Also, we study the dependence of charging energy on pressure and volume.

In the literature, there are few examples of studying the thermodynamics of the pneumatic accumulator in different fields. In [10], the authors analysed the impact of the thermal process on the energy storage capacity of the hydro-pneumatic accumulator for the automotive industry and compared isothermal and adiabatic energy storage. Wang. Hu. et al. [11] developed a new isobaric compressed air storage device and concluded that could decrease energy consumption by 18%. Buhagiar, Daniel, and Tonio Sant [12] created a thermodynamic model of the gas compression process for observing temperature and pressure fluctuations. In

[13], the authors analysed the influence of the initial parameters such as volume and pressure on the speed and energy consumption of the pneumatic accumulator. Characteristics of a hydro-pneumatic type accumulator have been widely investigated [14] by creating a simulation model of the physical system. Unfortunately, most research has tended to focus on pneumatic energy storage rather than pneumatic accumulator in a device. Thus, this paper focuses on polycrotic processes in the pneumatic accumulator.

Purpose and objectives of the research.

The objective of the paper is to analyze the influence of thermodynamic conditions on the charging energy of the pneumatic accumulator and examines the dependence of charging energy on pressure and volume for different types of polytropic processes.

Research materials and results.

Calculation of the charging energy of the pneumatic accumulator. The method of creating a mathematical model for calculating necessary parameters was applied. Mathematical models that cover almost any part of engineered objects are commonly used [15][16][17].

In the engineering sciences, the method is frequently used to modelling complex systems that can help to increase the effectiveness of current manufacturing processes.

The modelling object was a percussion device with a pneumatic accumulator

$$L(x)=\frac{p_0\cdot V_0}{n-1}\left[e(x)^{\frac{n-1}{n}}-1\right] \tag{1}$$

Mathematical models from Eqs. (1) used for the calculation of the charging energy of the pneumatic accumulator during the putting up of the striker in general. [18]

The input values were:

–volume $V_0=6.74\cdot10^{-4}m^3, V_1=5.49\cdot10^{-4}\ldots5.54\cdot10^{-4}\ldots6.74\cdot10^{-4}m^3,$,

–pressure $P_0=5\cdot10^5 Pa, P_1=5\cdot10^5\ldots5.0510^5\ldots6.25\cdot10^5 Pa,$,

–value of striker position x,

–measure of gas compression in the pneumatic accumulator $e(x)$, and

–polytropic index $n=1.3$ (for the adiabatic process).

The output value was the charging energy and graphs of the dependence of charging energy on pressure and volume.

The polytropic index n and the value of gas compression $e(x)$ are variable and depend on the type of polytropic process.

The polytropic index can be calculated using the value of heat capacity of gas:

$$n=\frac{C-C_p}{C-C_v}, \tag{2}$$

where C — the heat capacity of gas in this process,

C_p і C_v — the heat capacity of the same gas, respectively, at constant pressure and volume. These indicate the quantity of heat that can increase the temperature of unit mass by 1°C. [19].

The measure of gas compression is given by

$$e(x)=\frac{P(x)}{P_0}, \tag{3}$$

where *P(x)* – the current value of the pressure during the putting up of the striker.

Isochoric process

For the isochoric process, the volume of the closed system remains constant ($V = const$) - polytropic index is equal to infinity $n_v = \infty$, as $C_v = const$ and respectively $C = C_v$. In this case, the impact energy, which corresponds to the charging energy of the pneumatic accumulator, is independent of the pressure and equals zero.

Isobaric process

Pressure of the system for isobaric process remains constant ($P = const$) polytropic index is equal to zero $n_p = 0$, as $C_p = const$ respectively $C = C_p$. The measure of gas compression equals $e_p(x) = 1$, because $P = P_0$.

Then the charging energy determines [20]:

$$L_p(x) = P \cdot (V(x) - V_0), \tag{4}$$

Isothermal process (constant-temperature)

For the isothermal process temperature of the system is constant ($T = const$) polytropic index is equal to one $n_t = 1$ [6], and the charging energy determines:

$$L_t(x) = P_0 \cdot V_0 \cdot \ln \frac{P_0}{P(x)}, \tag{5}$$

Isentropic process (constant - entropy)

For the isentropic process (type of an adiabatic process where the transfer of heat not matter), polytropic index n is equal to adiabatic index γ, which is calculated as the ratio of heat:

$$n = \gamma = \frac{C_p}{C_v}, \tag{6}$$

In this case measure of gas, compression is determined by Eqs. (3) and the energy is calculated by Eqs. (1).

The Matlab software program is used to provide the calculation and built graph dependence of the impact energy of compression index.

The dependence of charging energy on pressure and volume for different types of polytropic processes

The dependence of charging energy on pressure.

The value of the charging pressure of the pneumatic accumulator is set in the specified range. As a result of calculations in Mathcad, a graph of the dependence of charging energy on pressure for isochoric L_v, isothermal L_t, and isentropic L_{pv} processes was obtained (Fig. 1).

As is shown by the graph:

- or the isochoric process, the energy was fixed, equal to zero, and was not dependent on pressure,
- for the isothermal process, the value of energy grew together with pressure, and
- for the isentropic process, the energy value is less climbed than during the isothermal process.

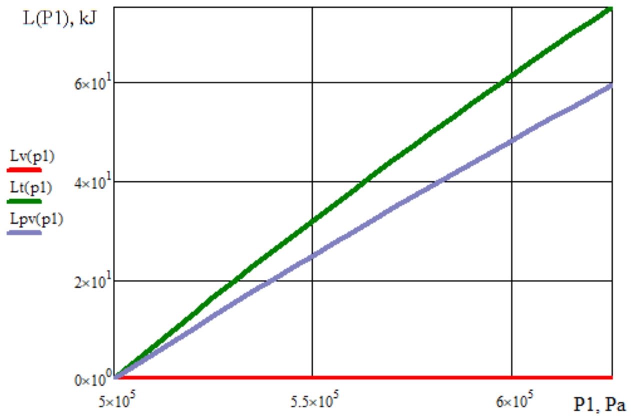

Fig. 1 – *Graphs of the dependence of charging energy on pressure.*

The dependence of charging energy on volume.

The value of the volume of the pneumatic accumulator chamber is set in the specified range. As a result, graphs of energy dependence on the volume of the pneumatic accumulator chamber for isochoric L_v and isobaric L_p processes were obtained (Fig. 2).

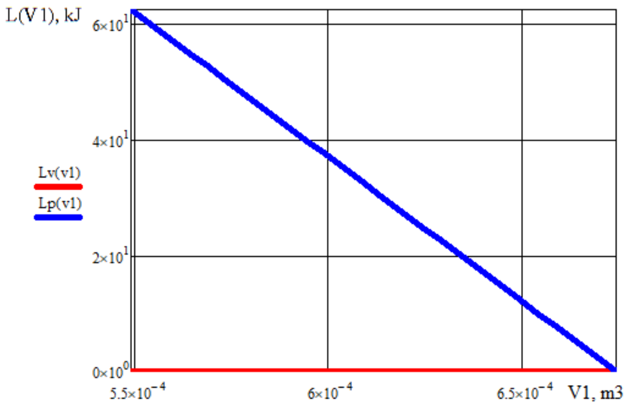

Fig. 2 – *Graphs of energy dependence on the volume of the pneumatic accumulator chamber.*

From the graph it is shown:

- for the isochoric process, the energy was fixed, equal to zero, and was not dependent on volume, and
- for the isobaric process, the energy decreases when the value of volume rose.

Influence of thermodynamic conditions on the charging energy of the pneumatic accumulator. While not all of the results were significant, the overall direction of results showed the trends that could be helpful in learning the influence of polytropic processes (isochoric, isobaric isothermal, and isentropic) on the value of energy parameters. And how to increase the performance of rock destruction by percussion instruments with a pneumatic accumulator.

Our experiments confirm previous experimental results [21] which show that the maximum pressure in the pneumatic accumulator, the higher the growth of energy value.

Other research [22] proposes the method to detect impact energy of pneumatic drill with stress wave technology, which is used widely. However, their system referred to this system that could only collect the stress wave efficiently and calculate the values of impact energy, and our method can also be used for the prediction of energy value, which would thus seem to be acceptable, too.

As expected, the result of our research demonstrates the impact of volume and pressure value on the energy of the percussion accumulator for isochoric, isobaric, isothermal, and adiabatic processes.

Given that our findings are based on a calculation process for an ideal gas, the results from such analyses should thus be treated with the utmost caution.

Our study was useless in the study of the energy for the isochoric process because during this process the value of energy equals zero and was not dependent on pressure and volume.

Since the focus of the study was on pneumatic accumulators which can contain a not large gas volume, there is a possibility that dissimilar evaluations would have arisen if the focus had been on the accumulator which had a bigger volume.

We believe this method could be also used in the engineering of internal combustion engines where polytropic processes are very important for their thermodynamic cycles such as the Otto and the Diesel cycle. Also, there is a good probability that studies of polytropic processes could help to find a way to increase the impact of energy.

Conclusion. The paper has investigated the energy of the pneumatic accumulator and the dependence of this energy on parameters pressure and volume for polycrotic processes such as isothermal, isochoric, isobaric, and adiabatic processes:

- In the course of an isochoric process, the energy is zero regardless of the pressure and volume values,
- In the course of an isobaric process, as the volume increases, the value of energy decreases,
- In the course of an isothermal process, with increasing pressure, the value of energy increases, and
- In the course of an isentropic process, with increasing pressure, the energy increases less rapidly than in the isothermal process.

This study has gone some way towards enhancing our understanding of the thermodynamics process in a pneumatic accumulator. Future work will focus on finding a probabilistic approach to determine the dependencies of different types of polytropic processes. We hope that our research can serve as a basis for future studies on the increasing working energy of the pneumatic accumulator.

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