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PECULIARITIES OF DRILLING HARD ROCKS USING HYDRAULIC SHOCK TECHNOLOGY

Purpose. To test the theoretical provisions for calculating the geometric and gas-dynamic parameters of a hydropulse apparatus for strikers using core pipes.

Methodology. The research methodology is based on the tests carried out. The tests were conducted between January 6, 2021, and April 28, 2021. The type of test is laboratory bench trials. In the course of the study, methods of synthesis and analysis of information were applied.

Finding. The basic design parameters of a hydro-pulse generator capable of operating efficiently with impact machines were obtained during the bench research. The optimal scheme of air flow distribution at the exhaust of the hydraulic hammer has been established. The optimal value of the pressure drop in the operating and blocking modes of operation of the generator is determined. In addition, the optimal value of the ejection coefficient in these two modes of operation of the generator was determined.

Originality. The article investigated the technologies of drilling hard rocks in order to optimise the basic geometric parameters of the hydraulic pulse generator, to distribute the working flow in front of the jet blower, to measure the value of the ejection coefficient and pressure drop to clarify the composition and methodology of experiments in borehole conditions.

Practical value. The presented study can be used to optimise the drilling technology as well as a basis for training specialists in the field of hard rock drilling using hydraulic percussion technology.

Keywords: *rock destruction, hydrodynamic methods, of rock destruction, rock-breaking tool, strong rocks*

Introduction. Groundwater is crucial for providing the population with high-quality drinking water. Groundwater is water located in the upper part of the earth's crust (up to a depth of 12–16 km) in a liquid, solid, and vaporous state. Most of it is generated by rain, melting, and seepage of river water from the surface. Groundwater is constantly moving both vertically and horizontally [1]. Its depth, course, and movement intensity depend on the water permeability of rocks. Permeable rocks include pebbles, sand, and gravel. The rock layer containing water is called an aquifer [2].

According to the conditions of occurrence, groundwater is divided into three types: groundwater located in the uppermost layer of soil; soil lying on the first permanent waterproof layer from the surface; interstratal type, located between two waterproof layers. They are widely used for the needs of industry and housing and communal services and irrigation of pastures [3]. One of the most effective drilling technologies in soft and medium-hard rocks is drilling with hydropneumatic transport of destroyed material along a double concentric column and in rocks of high hardness, the technology of percussive-rotary drilling using hydro and pneumatic hammers, and pneumatic installations [4].

However, serial technical means ensure efficient drilling with hydraulic core transfer in soft and medium-hard formations with a diameter of only 200 mm, and serial hydraulic hammers have the insufficient downhole capacity for effective drilling in solid formations with a diameter of more than 200 mm, which is not enough for the construction of large-diameter wells [5]. In addition, both technologies provide high productivity when using water as a cleaning agent, which is far from always possible in the construction of hydrogeological wells due to well instability when drilling in soft rocks [6].

Hydraulic shock technologies should be understood as any technology in which the source of driving force and energy is a water hammer, regardless of whether a water hammer occurs in moving or standing water. The range of such technologies is very wide. The military uses a hydraulic hammer to destroy enemy submarines. Buggers catch fish with a hydraulic shock. Hydraulic shock is used to clean water and heating pipes [7]. Water and oil wells are drilled with the help of hydraulic shock installations, where water is supplied to a height and water or other liquids are heated [8, 9]. Since water is one of the most common substances on Earth, notably, the number of hydraulic shock technologies will continue to grow [10, 11]. One of the first devices in which people started using hydraulic shock technology was a hydraulic cylinder [12, 13].

Bench trials were carried out to optimise the basic geometric parameters of the hydraulic pulse generator, the distribution of the working flow in front of the jet blower, measuring the value of the ejection coefficient and pressure drop to clarify the composition and methodology of experiments in bore-

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hole conditions. Bench studies were carried out in order to test the theoretical provisions for calculating the geometric and gas-dynamic parameters of a hydropulse apparatus for strikers using core pipes.

During the experiments on the stand, the following tasks were solved:

1. Establishment of the optimal scheme for distributing the flow of air or aerated solution at the exhaust of the hydraulic hammer.
2. Study on the influence of the main geometrical dimensions of the hydropulse generator on the energy parameters of the impact machine.
3. Determination of the optimal values of pressure drop in two modes of operation of the generator: a) operating; b) blocking.
4. Determination of the optimal value of the ejection coefficient in two modes of operation of the generator: operating and blocking.
5. Optimization of all main parameters and creation of a model of a hydropulse generator for well research.

Literature review. For a more extensive consideration of the subject matter, it is necessary to consider the studies by other researchers in a similar area [14, 15]. In the course of the study, papers by many researchers were considered. The aim of the work by Kovalev, et al. was to identify the most promising method for drilling wells in the intervals of hard rocks and promising areas for further research [16]. The research methods used by Kovalev, et al. are the analysis and generalisation of the results of previous theoretical and experimental studies. The authors showed the prospects of hydrodynamic methods of rock destruction [16]. The classification of hydrodynamic methods of rock fracturing according to the nature of the force impact on the face has been developed. According to this classification, all hydrodynamic methods are divided into three groups: erosive, abrasive, and combined. The analysis of hydrodynamic methods showed that, in relation to drilling wells in hard rocks, the most promising hydroabrasive method is jet drilling, which is implemented using a special injection device that continuously circulates in the balls at the bottom of the well until they are completely worn out. The principle of operation of the ball device is analysed along with the main results of theoretical and experimental studies on the ball method of drilling wells. The advantages of the method are formulated, including the disadvantages that prevent its introduction into production.

The paper by Gorodilov offers a comprehensive investigation of hydraulic shock systems for mining and other industries [17]. Despite the wide variety and diversity of research, theories and design methods face certain problems, and there are prospects for creating and improving effective designs of hydraulic shock systems. In recent years, the Pulse Systems Modelling Laboratory of the Institute of Mining SB RAS has been conducting comprehensive theoretical and experimental studies on hydraulic shock systems, the results of which are summarised by Gorodilov [17]. Based on the analytical model of an independent system with a constant flow source, mathematical models for the main classes of self-oscillating hydraulic shock systems were constructed, the researcher carried out a dimensional analysis and selected criteria for dynamic similarity. The systems are examined for their dynamics, the output characteristics are analysed and the ranges of effective operating modes are determined. Formulas for integral characteristics of systems are obtained. General formulas for the dynamics of self-oscillating bilateral hydraulic shock systems are found. HPS Java with a graphical environment is designed for the early selection of combinations of key parameters for two-sided hydraulic shock systems. The principles of the programme of modelling of hydraulic shock systems are formulated and a programme of practically real dynamics is developed. The C++ programme is based on a separate description of the simulated system as a set of structures-classes corresponding to physical objects, the researcher proposes a procedure for modelling the operation of the system in time. Several original designs of hydraulic shock action and fluid distribution have been developed and patented, including systems with adjustable frequency and impact energy, including adaptive devices with variable characteristics depending on the properties of the processed material. The availability and operability of systems and equipment were confirmed experimentally [17].

The relevance of the study by Saruev and Shadrina is conditioned by the need to improve the technique and technology of geological exploration, energy and well efficiency [18]. The main purpose of the research was to analyse and summarise the obtained findings for the possible development and application of resource-saving drilling technology using a deformation wave generator. A literature review of theoretical and experimental studies on impact drilling of small wells in rocks of medium and high hardness is carried out. Shock mechanisms have been developed to increase the penetration rate. However, the increase in the energy of the deformation wave is reduced due to the strength of the drilling tool. With a constant bore diameter, the increased impact load must be transmitted through the drill string and its connections, which have the original size. It is these elements of the drill string that slow down the introduction of new technologies. The methodology of the study consisted in theoretical analysis, an extensive review of the scientific literature on all issues of generating energy pulses, the passage of deformation waves through the drill string, the decomposition of rocks, suitable operating modes of impact drilling, optimisation of drilling before the engineering process, design methods of selected impact drilling systems, workflow modelling, determination of the energy parameters of drilling rigs, and comparison of the results of independent studies. The paper presents modern ideas and successes in the field of impact drilling of small holes. The researchers identified the reasons for the discrepancy between the study results. The authors proved the effectiveness of research on improving technological processes and drilling technologies. The main lines of research on drilling technology and technological process were identified and recommendations were formulated for improving drilling efficiency by increasing the destruction of rocks during drilling [18].

Karpov and Petreev solved the problem of determining effective methods of perforation drilling using pneumatic hammers and proposed criteria for evaluating ranges of their values that ensure drilling with minimal energy consumption and crown wear [19]. The authors presented the calculation formulas of drilling technologies and showed the effectiveness of maximum destruction with minimal impacts per full turn of the drill. The upper limit of the angle of rotation of the crown between impacts at maximum drilling power and minimum energy consumption during the destruction and wear of tungsten carbide plates has been established. Drilling methods using impact drills based on various models of impact tools can be optimised in accordance with the energy criterion of rock destruction and the energy intensity of the crack [19]. In the work by Bondarenko, et al., the classification of pulse drilling technologies is considered, including such drilling methods as monoparametric, two-parameter, and three-parameter [20]. The authors have developed the theoretical foundations of the monoparametric method for drilling long-range wells using high-frequency hydraulic hammers with hydraulic shock reflectors. The authors also proposed criteria for the effectiveness of impact drilling, confirmed by drilling practice [20].

Thus, having analysed the work of various researchers on the problem of peculiarities of drilling hard rocks using hydraulic shock technology, it is important to note the following: water hammer technologies should be understood as any technology in which the source of driving force and energy is water

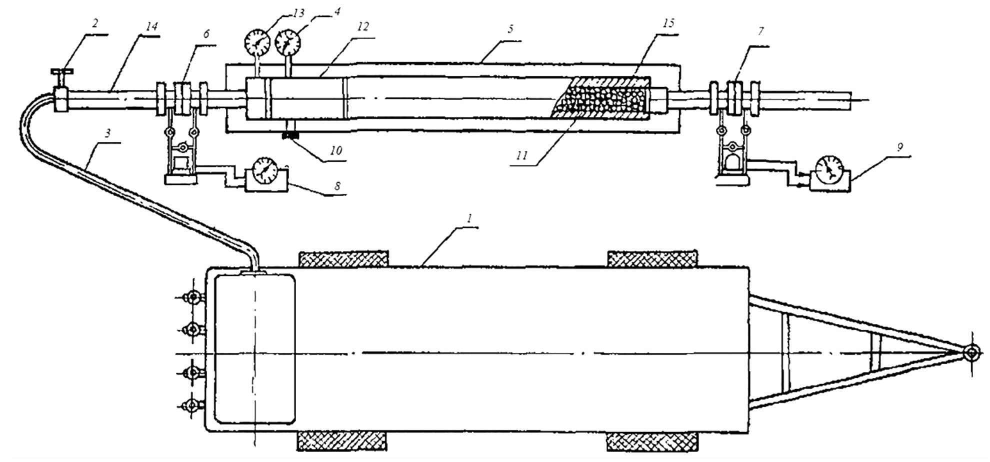

Fig. 1. Test bench for hydraulic pulse generator:

1 – compressor; 2 – pressure regulator; 3 – flexible pipe; 4 – vacuum gauge; 5 – reflective casing; 6, 7 – DM-3537 flowmeter; 8, 9 – DPR-type secondary instrument; 10 – plug for measuring the distance between the diffuser and the nozzle; 11 – core lifter; 12 – test projectile; 13 – pressure gauge; 14 – hammer; 15 – core material

shocks, regardless of whether water shocks occur in a moving or standing water. It was also determined that water and oil wells are drilled with the use of hydraulic shock installations.

Materials and methods. To solve the tasks set in the work, an integrated approach was used, which includes the analysis and generalization of scientific and technical achievements and literary sources, combines theoretical and experimental studies. The study used methods of synthesis and analysis of information. The study also used the scientific literature analysis method. Data calculated using the SPSS Statistics software package. Microsoft Excel was used to calculate standard deviation statistics.

The tests were conducted between January 6, 2021, and April 28, 2021. The type of test is laboratory bench trials. The testing was carried out on the premises of training workshops of the Department of "Technological machines and equipment" of the Mining and Metallurgical Institute of the NAO "KazNTU named after K. I. Satbayev". The purpose of the product is hydraulic pulse generator to improve drilling efficiency. The purpose of the stand: a stand for testing a hydraulic pulse generator.

Results and discussion. For the study, a layout consisting of a hydraulic shock and a core pipe was adopted. The bench model of the generator is made of aluminium alloy D16T GOST 2685-75, in which the nozzle and diffuser are removable, for experimental selection of the basic geometric size. Fig. 1 shows a test bench for a hydro-pulse generator.

The stand has a compressor *1* of the PR-10M brand, a pressure regulator *2*, a flexible pipe *3*, a receiving chamber with a vacuum gauge *4* (of the SM-10 brand), a reflective casing *5* (matched by the diameter of the well) and flowmeters *6, 7* (of the DM-3537-type with a secondary instrument DPR-8.9). To measure the distances between the diffuser and the nozzle, a special plug *10* is provided, the test projectile *12* is connected from the ejector side to the pipe *3*, an exemplary pressure gauge *12*, and in the lower part of the core intake pipe with a flowmeter *7*.

The main operating mode of the generator is the time it takes for the water flow to compress and increase the pressure in the nozzle. In addition, the calculated characteristics of the generator show that the largest value of the coefficient is obtained at a working flow pressure $P_p = 0.2–0.35$ MPa. Therefore, to simulate the working and blocking modes of the hydraulic shock on the stand, the pressure and flow rate through the nozzle are changed using pressure regulator *2*; as a result, the following pressure values were obtained: in the operating mode, $P = 0.14–0.20$ MPa; in the blocking mode, $P_p = 0.20–0.38$ MPa.

Air and water were supplied to the layout from the compressor (Fig. 1). To determine the nature of changes in pressure and airflow, a flowmeter 6 and a pressure gauge *10* are built into the feed line. The pressure in the feed line was changed using regulator *2*, and the airflow was maintained within 4.0–8.0 m^3/min, since losses at the junctions of drill pipes and adapters were taken into account.

Considering the limited range of the gas-dynamic values of the airflow in front of the device, primarily the pressure (which should not exceed 0.2 MPa) is associated with the presence of a hammer in front of the ejector. As a result, a model of an ejector projectile was created, in the nozzle of which discharge channels were made, providing free exhaust of the working agent from the hammer, and the exit of the diffuser channels into the annulus space contributed to the creation of a stable reverse flow circulation.

Three main factors affect the operation of the hydraulic pulse generator (Fig. 2):

1. The main geometric parameter is the ratio of the area of the diffuser F, to the area of the critical section of the nozzle F (F_d/F_{cr}).
2. The total area of the discharge channels F_K.
3. The optimal cross-sectional area of the holes in the outer pipe F_0.

By changing the main geometric parameter, the mode of the working flow passing through the discharge channels, holes in the outer pipe and the inter-pipe gap is regulated [13]. Therefore, to find the area of effective operation of the hydraulic pulse generator that does not affect the energy parameters of the hammer, a set of experimental and design studies was carried out (Fig. 2).

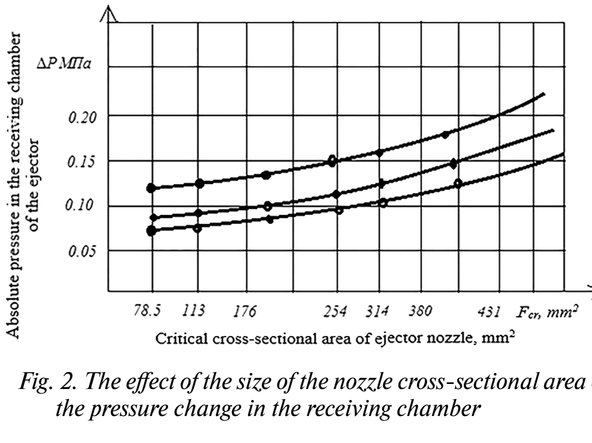

Fig. 2. The effect of the size of the nozzle cross-sectional area on the pressure change in the receiving chamber

Initially, the issues of maintaining the existing working pressure on the exhaust of the hydraulic pulse generator during the operation of the downhole machine during drilling were solved. To do this, by selecting the cross-sectional areas of the discharge channels F_K and the nozzle of the hydraulic pulse generator F_{cr}, the necessary optimal parameters of the device were found. The generalised results of experimental data on the absolute pressure on the exhaust of the hammer, depending on the cross-sectional area of the holes in the nozzle F_{cr} and the discharge channels F_K are shown in Table 1. Notably, to obtain more accurate and reliable experimental data, the dimensions of each nozzle and diffuser were checked repeatedly

Table 1 and Fig. 3 provide generalised experimental data on the optimal cross-sectional areas of the holes F_{kr}, F_d, F_K, depending on the size of the column set.

Fig. 4 shows the dependence of the pressure drop ΔP_c on the critical section of the packing nozzle F_{cr}, obtained by us during the experiments.

With an increase in the number of discharge channels, the value of ΔP_c drops, which is associated with a decrease in the degree of compression of the air stream jet. However, the presence of the discharge channels with a total area of $F_K = 307.72$ mm^2 at $F_{cr} = 18.0$ mm allows maintaining the value of the differential pressure ΔP_c within 0.04–0.042 MPa at blocking, $\Delta P_c = 0.018–0.021$ MPa at operating modes, with the absolute pressure before generator $P_p = 0.115$ MPa with water hammer (Table 2).

The diameter of the diffuser $d_d = 35$ mm was chosen based on the research, but its value may be 30 or 40 mm (Table 1). Additional dimensions in the design of the model of the hydraulic pulse generator were selected based on the analysis of the calculated data. From the analysis of the results above, it follows that the optimal length of the mixing chamber is $(6–8)d_d$. However, to reduce the total length of the hydraulic pulse generator, the length of the mixing chamber can be taken within $l_d = 70–100$ mm.

Table 1

The results of measurements of the absolute pressure on the exhaust of the hammer, depending on the diametrical dimensions of the hydraulic pulse generator

Critical diameter of nozzle d_p, mm	Diffuser diameter d_g, mm	Distance of nozzle from diffuser 1n, mm	Area of discharge channels F_K, mm^2	Total area of holes in nozzle mm^2	Absolute pressure in front of hydraulic hammer, MPa, *Pp*
18.5	40	30.0	153.86	422.527	0.232
18.5	35	20.0	307.72	576.387	0.111
18.5	30	35.0	307.72	576.387	0.113
18.0	40	30.0	307.72	562.06	0.111
18.0	35	25.2	307.72	562.06	0.112
17.5	40	35.4	153.86	394.47	0.236
17.5	35	30.0	307.72	548.33	0.112
17.5	30	25.2	307.72	548.33	0.115
14.5	40	28.5	307.72	472.77	0.166
14.5	35	30.0	307.72	472.77	0.165
10.0	40	29.6	307.72	386.22	0.263
10.0	45	35.0	307.72	386.22	0.267
10.0	40	28.4	153.86	232.36	0.394
10.0	30	35.1	153.86	232.36	0.396
6.0	40	30.3	307.72	335.98	0.361
6.0	40	34.1	307.72	335.98	0.380
6.0	35	28.2	307.72	335.98	0.344
6.0	30	25.1	307.72	335.98	0.379

Note: Operating airflow $Q = 0.086$ kg/s

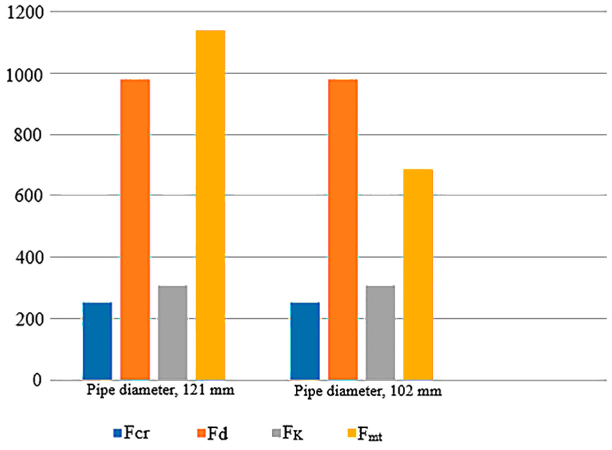

Fig. 3. Characteristics of the diametrical dimensions of the hydraulic pulse generator depending on the pipe diameter

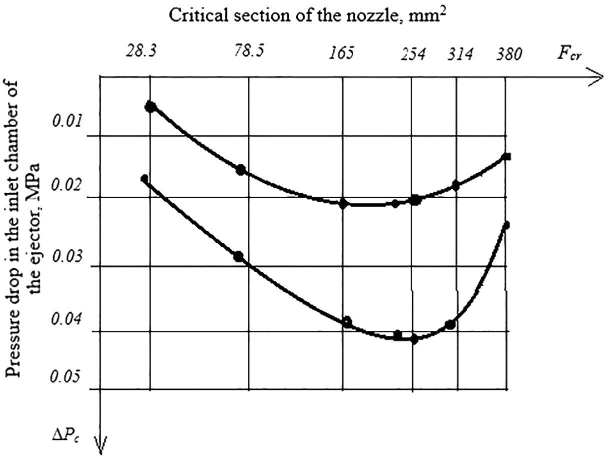

Fig. 4. The dependence of the pressure drop (P_c) on the area of the critical section of the nozzle of the hydraulic pulse generator nozzle (F_{cr})

Distance from the nozzle to the beginning of the cylindrical part of the mixing chamber is of great importance for the jet performance. Based on the theory of the spread of a flooded jet, it is possible to provide equations for determining the optimal position of the nozzle [15]. It is recommended to take $1n = (1–1.5)d_d$, where $1n = 35$ mm is the distance from the nozzle to the cylindrical part of the mixing chamber.

The full length of the nozzle should be within $(6–10)l_s$; however, in a hydraulic pulse generator, the initial diameter of the nozzle is limited by the size of the core projectile in diameter. Therefore, it is recommended to take the taper and the total length of the nozzle for design reasons. The entrance area to the mixing chamber (confuser) should have a shape in the form of a cone with a length of 0.8 of the mixing chamber diameter, the cone angle of the confuser being within 60°. The edges of the confuser should be rounded, have a smooth interface with the walls of the mixing chamber and the receiving chamber. The cylindrical part of the mixing chamber must be of such a length that the ejection and working flows are completely mixed and their velocities are equalised. According to these recommendations, in the course of experimental work, additional design parameters were established, the length of the nozzle is 24–30 mm with a nozzle opening angle of 1–1°30'.

Table 2

Pressure differential produced by the hydraulic pulse generator at different nozzle diameters and the number of discharge channels

No.	Critical diameter of nozzle. Rcr, mm	Area of discharge channels, *Rcr*, mm^2	Number of discharge channels, pcs.	Maximum pressure drop in the receiving chamber of the ejector, MPa	
				operating mode	blocking mode
1	6.0	0.00	0	0.011	0.030
		158.86	1	0.008	0.026
		307.72	2	0.007	0.024
		461.58	3	0.004	0.020
2	10.0	0.00	0	0.018	0.036
		153.86	1	0.015	0.031
		307.72	2	0.014	0.026
		461.58	3	0.010	0.020
3	14.5	0.00	0	0.026	0041
		153.86	1	0.022	0.037
		307.72	2	0.020	0.036
		461.58	3	0.012	0.029
4	17.5	0.00	0	0.028	0.044
		153.86	1	0.024	0040
		307.72	2	0.020	0.036
		461.58	3	0016	0030
5	18.0	0.00	0	0.029	0.046
		153.86	1	0.024	0.043
		307.72	2	0.021	0.042
		461.58	3	0.016	0.036
6.	18.5	0.00	0	0.028	0044
		153.86	1	0.025	0.042
		307.72	2	0.019	0.039
		461.58	3	0.015	0.035
7	200	0.00	0	0.026	0042
		153.86	1	0.021	0.038
		307.72	2	0.017	0.036
		461.58	3	0.013	0.030
8	22 0	0.00	0	0.021	0.036
		153.86	1	0.017	0.028
		307.72	2	0.014	0.023
		461.58	3	0.009	0.021

Note: diffuser diameter is $d_d = 35$ mm

Table 2 shows the data obtained during experiments with the model of the tested hydraulic pulse generator in two modes of operation of the hydraulic hammer. It can be seen from Table 2 that the largest value of the pressure drop ΔP_c and the air ejection coefficient U_r is provided at $P = 0.25–0.38$ MPa, which indicates a high degree of compression of the working jet. However, with a further increase in the pressure in the nozzle to $P_p = 0.5$ MPa, the value of the ejection coefficient decreases due to the difference in the speeds of the working ejected flows and the swirl of the jet in the diffuser part of the hydraulic hammer.

In this case, it was not possible to obtain certain flow rate readings due to the compressor operating at maximum speeds (intermittent operation) and the gradual transition (unequal in time) of the ejector operation to the "swirl" mode. Therefore, the average values of the obtained ejection coefficient range from $U_r = 0.21–0.36$.

Conclusions. Thus, a new scheme of air distribution in a hydropulse generator has been developed by calculation and experimental methods, which does not affect the energy parameters of the pneumatic hammer and is capable of creating conditions for the formation of a stable reverse circulation.

In order to determine the optimal values of the pressure drop and the ejection coefficient, removable samples of nozzles and diffusers of various design dimensions were tested and rejected on the stand.

The authors of the study selected the value of the main geometric parameter to be constant and equal for all types of percussion reconnaissance vehicles.

As a result of bench studies, the main design parameters of a hydropulse generator capable of working effectively with impact machines were obtained.

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References.

1. Ghosh, R., Schunnesson, H., & Gustafson, A. (2017). Monitoring of drill system behavior for water-powered in-the-hole (ith) drilling. *Minerals*, *7*(7), 121. https://doi.org/10.3390/min7070121.

2. Yang, S., Ou, Y., Guo, Y., & Wu, X. (2017). Analysis and optimization of the working parameters of the impact mechanism of hydraulic rock drill based on a numerical simulation. *International Journal of Precision Engineering and Manufacturing, 18*(7), 971-977. https://doi.org/10.1007/s12541-017-0114-4.

3. Song, X., Aamo, O. M., Kane, P.-A., & Detournay, E. (2020). Influence of weight-on-bit on percussive drilling performance. *Rock Mechanics and Rock Engineering, 54*, 3491-3505. https://doi.org/10.1007/s00603-020-02232-x.

4. Zhabin, A. B., Lavit, I. M., Polyakov, A. V., & Kerimov, Z. E. (2020). Mathematical model of piston/bit interaction in percussive destruction of rocks. *Mining Informational and Analytical Bulletin*, *11*, 140-150. https://doi.org/10.25018/0236-1493-2020-11-0-140-150.

5. Xu, Z., Yang, G., Wei, H., & Ni, S. (2015). Dynamic performance analysis of gas-liquid united hydraulic hammer. *Engineering*, *7*(8), 499-505. https://doi.org/10.4236/eng.2015.78046.

6. Mitusov, A. A., Reshetnikova, O. S., & Lagunova, Y. A. (2017). Study of the disclosure two-line valve in the gradation of the working stroke of the striker hammer. *Gornoe Oborudovanie I Elektromekhanika*, *2*(129), 34-39.

7. Gorodilov, L. V. (2018). Analysis of dynamics and characteristics of main classes of self-oscillating volume-type hydraulic impact systems. *Journal of Machinery Manufacture and Reliability, 47*(1), 19-27. https://doi.org/10.3103/S1052618818010077.

8. Zhang, X., Luo, Y., Gan, X., & Yin, K. (2019). Design and numerical analysis of a large-diameter air reverse circulation drill bit for reverse circulation down-the-hole air hammer drilling. *Energy Science & Engineering, 7*(3), 921-929. https://doi.org/10.1002/ese3.321.

9. Abu Bakar, M. Z., Butt, I. A., & Majeed, Y. (2018). Penetration rate and specific energy prediction of rotary–percussive drills using drill cuttings and engineering properties of selected rock units. *Journal of Mining Science, 54*(2), 270-284. https://doi.org/10.1134/S106273911802363X.

10. Eremyants, V. E. (2018). Variation in energy and production data of pneumatic percussive machines in the uplands. *Journal of Mining Science, 53*(4), 694-701. https://doi.org/10.1134/S1062739117042680.

11. Gorodilov, L. V., & Vagin, D. V. (2016). Software architecture for simulation the executive bodies hydraulic drives of mining and construction machinery. *Problemy Nedropolzovaniya*, *3*, 48-52.

12. Neskoromnykh, V. V., & Golovchenko, A. E. (2020). Experimental study of rock destruction by eccentric impact pulses during rotary-percussion drilling. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, 331*(1), 135-147. https://doi.org/10.18799/24131830/2020/1/2455.

13. Li, Y., Luo, Y., & Wu, X. (2018). Fault diagnosis research on impact system of hydraulic rock drill based on internal mechanism testing method. *Shock and Vibration, 2018*, 1-9. https://doi.org/10.1155/2018/4928438.

14. Bovin, K. A., Gilev, A. V., Shigin, A. O., Kurchin, G. S., & Kirsanov, A. K. (2019). Analysis of blast hole drilling at siberian open pit mines. *International Journal of Mechanical and Production Engineering Research and Development*, *9*(6), 779-790. https://doi.org/10.24247/ijmperddec201966.

15. Lazutkin, S. L., & Lazutkina, N. A. (2019). Determination of rational parameters actuators adaptive shock system shock device. *Sovremennye Naukoemkie Tekhnologii*, *5*, 58-63.

16. Kovalev, A. V., Ryabchikov, S. Ya., Aliev, F. R., Yakushev, D. A., & Gorbenko, V. M. (2015). Problems of hydrodynamic methods of drilling wells and the main directions of their solution. *Bulletin of the Tomsk Polytechnic University*, *326*(3), 6-12.

17. Gorodilov, L. V. (2019). Design Theory, methods, programs and development for hydraulic percussion systems. *Gornyi Zhurnal, 10*, 55-60. https://doi.org/10.1177/1687814019841486.

18. Shadrina, A. V., & Saruev, L. A. (2015). Analysis and science-based compilation of the results of studying percussion-rotary underground slimhole digging. *Bulletin of the Tomsk Polytechnic University, Geo Assets Engineering, 326*(8), 120-136.

19. Karpov, V. N., & Petreev, A. M. (2021). Determination of efficient rotary percussive drilling techniques for strong rocks. *Journal of Mining Science, 57*(3), 447-458. https://doi.org/10.1134/S1062739121030108.

20. Bondarenko, V., Kovalevs'ka, I., & Ganushevych, K. (2014). *Progressive technologies of coal, coalbed methane, and ores mining*. London: CRC Press. ISBN: 9780367576097.

Особливості буріння твердих порід із застосуванням гідроударної технології

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Мета. Перевірка теоретичних положень розрахунку геометричних і газодинамічних параметрів гідроімпульсного апарату для ударників з використанням колонкових труб.

Методика. Методологія дослідження базується на проведених випробуваннях. Випробування були проведені в період із 6 січня 2021 року до 28 квітня 2021 року. Видом випробувань є стендові лабораторні експерименти. У процесі дослідження були використані методи синтезу та аналізу інформації.

Результати. У ході стендових досліджень отримані основні конструктивні параметри гідроімпульсного генератора, здатного ефективно працювати з ударними машинами. Установлена оптимальна схема розподілу потоку повітря на вихлопі гідроударника. Визначене оптимальне значення перепаду тиску в робочому й блокувальному режимах роботи генератора. Крім того, визначені оптимальні значення коефіцієнта ежекції у цих двох режимах роботи генератора.

Наукова новизна. У роботі була досліджена технологія буріння твердих порід для того, щоб оптимізувати основні геометричні параметри гідроімпульсного генератора, розподілити робочий потік перед струменевим апаратом, встановити величини коефіцієнта ежекції й перепад тиску для уточнення складу та методики експериментів у свердловинних умовах.

Практична значимість. Представлене дослідження може бути використане для оптимізації технології буріння та як база для підготовки фахівців у сфері буріння твердих порід із застосуванням гідроударної технології.

Ключові слова: *руйнування гірських порід, гідродинамічні технології, породоруйнівний інструмент, міцні гірські породи*

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