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Serhii Minieiev

Doctor of Technical Sciences, Professor
M.S. Polyakov Institute of Geotechnical Mechanics of the NAS of Ukraine
49005, 2a Simferopolska Str., Dnipro, Ukraine
<https://orcid.org/0000-0002-4594-0915>

Oleksandr Pashchenko

PhD in Technical Sciences, Associate Professor
Dnipro University of Technology
49005, 19 Dmytro Yavornytskyi Ave., Dnipro, Ukraine
<https://orcid.org/0000-0003-3296-996X>

Volodymyr Antonchyk

Chief Designer
M.S. Polyakov Institute of Geotechnical Mechanics of the NAS of Ukraine
49005, 2a Simferopolska Str., Dnipro, Ukraine
<https://orcid.org/0000-0002-4161-9112>

Valentyn Hankevych

PhD in Technical Sciences, Associate Professor
M.S. Polyakov Institute of Geotechnical Mechanics of the NAS of Ukraine
49005, 2a Simferopolska Str., Dnipro, Ukraine
<https://orcid.org/0000-0002-8535-6318>

Viacheslav Kiba*

Master, Senior Lecturer
Dnipro University of Technology
49005, 19 Dmytro Yavornytskyi Ave., Dnipro, Ukraine
<https://orcid.org/0000-0003-3033-6106>

Development of a six-cone drill bit for efficient drilling of hard and ultra-hard rocks through optimised borehole bottom configuration

Abstract. This study addressed the challenge of efficient drilling of hard and ultra-hard rock formations, characterised by high energy consumption, significant wear of drilling tools, and low penetration rates. The objective was to develop a drilling technology aimed at optimising rock destruction by creating a specialised borehole bottom configuration to facilitate effective rock shearing through tangential stresses. The methodology involved analysing rock failure mechanisms, mathematical modelling of the rock's stress-strain state using ANSYS software, and experimental testing on granite and basalt samples with compressive strengths of 150-200 MPa. A six-cone drill bit was designed, incorporating separate cone wheels for creating a leading annular cut in the

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*Corresponding author



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borehole's peripheral zone, main cones for staged rock shearing, and core cones for breaking the central part of the borehole bottom, preventing core formation and tool damage. Experimental results demonstrated that the proposed technology enables the destruction of approximately 80% of the borehole bottom surface through tangential stresses, reducing energy consumption by 1.4-1.7 times compared to conventional roller-cone drilling methods, as confirmed by energy consumption measurements. The drilling rate increased by 1.2-1.5 times, as validated by field tests. Laboratory measurements indicated that the bearing rollers withstand an average load of 1,000 kg per centimetre of bit diameter, with peak loads from bottom reaction, recorded by dynamometric equipment, exceeding operational loads by 3-4 times. The bearing cooling system, utilising water emulsion and compressed air, reduced bearing temperatures from 200-300°C in conventional designs to 80-100°C, as evidenced by thermal imaging, extending bit lifespan by 1.7-2 times. Statistical analysis with a 95% confidence interval confirmed consistent performance, with an average error of ± 0.2 m/h for drilling rate and ± 0.5 kW-h/m for energy consumption. The technology reduces wear on teeth and bearings, extending tool life by 2.7-3 times. These findings enable broad application in the mining industry, particularly in challenging geological conditions, enhancing drilling efficiency and reducing costs

● **Keywords:** drill bit; roller cone; borehole bottom; shear stress; kerf cutting

● Introduction

Drilling hard and ultra-hard rocks poses a significant challenge due to the high strength of the materials, which leads to rapid wear of the drilling tool, increased energy consumption, and low drilling rates. Conventional drilling methods with cutters are ineffective and economically unprofitable due to the need to apply significant effort, which leads to rapid wear of the tool. Percussive-rotary drilling, which uses the impact energy of the bit teeth to create stresses in the rock, partially improves the process, but does not completely solve the problem. Alternative methods, such as thermomechanical drilling or cryogenic liquid cooling, also have disadvantages, in particular, the deterioration of the quality of carbide teeth due to thermal exposure and high cost.

To analyse the literature, a number of studies on drilling hard rocks published after 2020 were considered. According to H.D. Mi *et al.* (2022), the mechanisms of crack formation in hard rocks depend on the type of rock and drilling modes, but no solutions have been proposed to reduce tool wear or energy consumption. Insufficient attention was paid to the impact of the face configuration on drilling efficiency. P.E. Pastusek *et al.* (2024) found that axial-torsional percussive drilling increases the sinking speed due to vibration, but the issue of tool wear was ignored. O. Pashchenko *et al.* (2024) developed a method for optimising drill bits by selecting materials that reduce wear, but the impact of the face configuration was not considered. According to L. Zhang *et al.* (2023), ultrasonic vibration increases the efficiency of rock destruction, but requires complex equipment, which limits practical applications. Q. Wang *et al.* (2025) emphasised the importance of stress management when drilling ultra-deep wells, but did not propose specific design solutions for drills.

Insufficient attention was paid to comprehensive optimisation of energy consumption and tool wear. The study by O. Pashchenko *et al.* (2025) was dedicated to the development and optimisation of carbide materials designed for rock destruction. The researchers focused on the selection and improvement of hard alloy compositions to increase their efficiency, wear resistance and durability when used in difficult drilling and mining conditions. The paper presents the results of experimental studies of the properties of various alloy compositions, and their practical significance for improving the productivity of technological equipment.

B. Ratov *et al.* (2021) investigated the impact of structural modernisation of Polycrystalline Diamond Compact (PDC) bits on solid rock drilling performance. It is established that the improved geometry of the cutters reduces wear and stability of the tool. However, there is no analysis of the impact of new solutions on the energy efficiency of the process, which is critical when drilling at deep intervals. S. Dewangan *et al.* (2023) investigated thermal load as the main wear factor for carbide bits. It was found that exceeding critical temperatures leads to loss of hardness and microcracks. However, no effective solutions for reducing the temperature in the contact area have been proposed. L. Chen *et al.* (2023) investigated the efficiency of hybrid drills that combines different types of cutting elements. Improvement of the destruction of heterogeneous rocks was proved, but insufficient attention was paid to optimising the shape and structure of the face. J.-S. Park *et al.* (2024) analysed drilling using a water jet under foundation conditions. High drilling accuracy and speed were obtained, but the high cost due to the use of cryogenic fluids was left without a feasibility study.

The studies considered in this section indicate insufficient attention to a comprehensive solution to the problems of drilling hard rocks, in particular, simultaneous optimisation of the face configuration, reduction of energy consumption and tool wear. The aim of the study was to develop a technology for drilling hard and ultra-hard rocks by creating a special face configuration for efficient rock chipping due to tangential stresses. The objectives of the study included the analysis of rock destruction patterns, the development of a six-cone drill bit design, and experimental verification of the effectiveness of the proposed technology.

Materials and Methods

To develop the technology of drilling hard and ultra-hard rocks, a number of materials and regulatory documents were used, which ensured the validity and accuracy of the study. Standard DSTU 4260:2003 (2003) defined the requirements for the design and materials of roller cone drills used for drilling hard rocks, and served as the basis for the development of a six-cone drill, in particular, regarding the choice of materials for bit teeth and bearings. The bit teeth are made of VK8 tungsten carbide with a hardness of 88-90 HRA, and alloy steel of 20KHN3A grade with heat treatment to a hardness of 58-62 HRC was used for bearing units. GOST 17013-71 (1973) set standards for tapered rollers with a diameter of 12-18 mm, made of SHH15 steel with a hardness of 60-65 HRC, which increased the strength of bearing units. To assess the strength of rocks, the authors used data from laboratory tests of granite and basalt samples with a compressive strength of 150-200 MPa, obtained from the geological archives of the M.S. Polyakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine. The water emulsion for cooling bearings met the requirements of DSTU 4489:2005 (2005) with a viscosity of 10-15 MPa·s and a lubricant content of 5-7%, which ensured the stability of its properties during experiments.

The study was conducted in several stages using different methods. The analytical method was used to investigate the patterns of rock destruction. Based on the literature sources, the mechanisms of rock deformation under the action of normal and tangential stresses are analysed, which made it possible to determine the optimal face configuration for effective chipping. For comparative analysis, the drilling technologies described by C. Kong *et al.* (2021), Y. Liu *et al.* (2023), B. Ratov *et al.* (2021) were considered, in particular, conventional roller-cone drill bits (Smith Bits, USA), PDC bits (Halliburton, USA), hybrid bits (Baker Hughes, USA), and laser-assisted methods (Foro Energy, USA) and high-pressure water methods (Jet Drilling Systems,

Canada). Mathematical modelling was performed using ANSYS 2023 R1 software suite, where numerical models of the stress-strain state of the rock with an elastic modulus of 50-70 GPa and a Poisson's ratio of 0.25-0.3 were created, reproducing the behaviour of the rock under the action of chisel teeth to estimate the stress distribution and determine the zones of maximum destruction. The experimental method involved laboratory tests of rock samples with a strength of 150-200 MPa on a hydraulically driven stand (manufacturer: MTS Systems, USA) with a capacity of 50 kW and a maximum axial load of 100 kN. Drilling was modelled using a prototype of a six-cone drill with a diameter of 215.9 mm, equipped with six conical rollers (two for an angular cutting, two main, two core rollers) with an angle of inclination of the rotation axis of 35° and a rotation speed of 60-120 rpm. The efficiency of creating a circumferential groove and step chipping was evaluated using an HBM U10M dynamometer (HBM, Germany) with a measurement range of 0-200 kN and an error of ±0.2%. The temperature regime of the bearings was recorded by a FLIR T540 thermal imager (FLIR Systems, USA) with a resolution of 464×348 pixels and an error of ±2°C in the range of 0-650°C during the operation of the bit with cooling with water emulsion and compressed air with a flow rate of 0.5-1.0 m³/min. The statistical method was used to process test results that included 5-10 repetitions for each drilling mode with a duration of 30-60 minutes for each test under conditions of axial pressure of 50-100 kN, medium temperature of 20-25°C, and relative humidity of 40-60%. Data processing was performed using Statistica 13.3 software (TIBCO Software, USA) to determine the average drilling speed, energy consumption, and drill bit life with a confidence interval of 95%. The average values and standard deviations were calculated and the statistical significance of differences between groups was checked according to the Student's t-test.

Results and Discussion

Several methods described in the literature are considered to analyse the efficiency of drilling hard and ultra-hard rocks. According to Z. Guo *et al.* (2023) and Y. Xi *et al.* (2025), the drilling method using roller-cone drill bits involves creating a face surface perpendicular to the central axis of symmetry of the well, with a rounded transition from the walls to the face surface and a core protrusion in the centre. The main disadvantage of this method is the high energy intensity, since most of the face surface, from the corner zone to the core protrusion, is destroyed due to the creation of a compression zone under the chisel tooth in the form of a hemisphere, as shown in Figure 1. When the tooth is

buried in the rock, compressive stresses and rock resistance increase. Since the free surface of the bit face, with the exception of the area under the tooth, is not exposed to external action, the stressed areas of the rock deform upwards, breaking molecular bonds in the zones of maximum stresses under the tooth. This leads to the destruction of the rock in the form of small fragments or sand thrown out on a free surface. However, the fracture zone remains limited, and energy costs are significant due to the overwhelming effect of normal stresses, which require maximum energy to break most rocks.

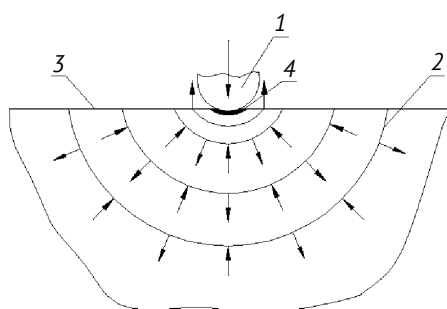


Figure 1. The tooth of the roller-cone drill bit and the volume of rock that is in a stressed state under the influence of tooth pressure

Notes: 1 – tooth; 2 – volume of stressed rock; 3 – free face surface; 4 – zone of destroyed rock under the tooth

Source: compiled by the authors

According to C. Kong *et al.* (2021), the drilling method with the formation of a hemispherical face surface deep into the rock mass is characterised by high energy intensity due to the need for significant compression of the rock to carve it onto a spherical surface, which depends on normal stresses that exceed the tensile strength or tangential stresses. Insufficient attention was paid to reducing energy consumption by using tangential stresses. Y. Liu *et al.* (2023) proposed a method that consists in creating a leading groove in the form of a hollow cylinder in the centre of the face along the axis of symmetry of the well with a perpendicular surface and a rounded transition from the walls. This method is complicated and energy-intensive due to the need for a specialised tool for forming a groove, which increases the cost compared to standard roller cone drilling. The destruction of most of the face occurred due to the creation of a hemispherical compression zone under the tooth, as shown in Figure 2. As the tooth was driven deeper, compressive stresses increased and rock deformation was directed towards the free surface of the face and the groove. Since the resistance of the rock to tangential stresses is less (tangential) than normal (perpendicular), the breaking of molecular bonds

occurred along the groove, which required less energy. However, the angle of the chipped hole was less than 180° , which led to incomplete overlap of the holes and the need for additional rolling of the roller cone to destroy the residual rock, as shown in Figure 2, which increased energy consumption. Insufficient attention is paid to creating a continuous strip of destroyed rock.

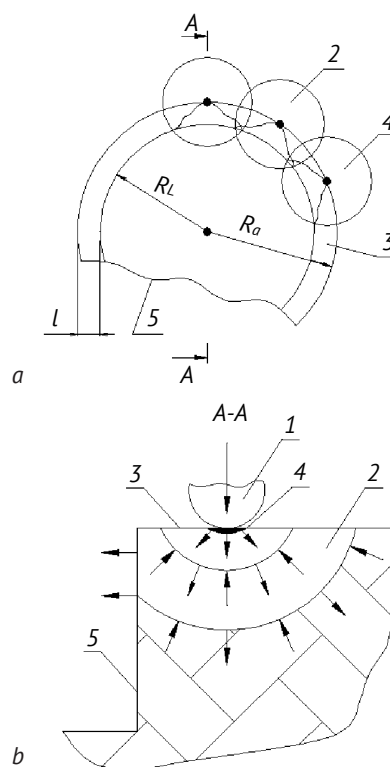


Figure 2. View of the face with a leading groove in the centre of the well

Notes: 1 – tooth; 2 – volume of stressed rock; 3 – free face surface; 4 – zone of compressed rock under the tooth; 5 – leading groove; R_L – radius of the leading groove; R_a – radius of action of the teeth of roller cone; r – radius of the volume of stressed rock

Source: compiled by the authors

Another drilling method involved creating a leading circumferential groove in the middle zone of the face in the form of a half-hole and a face surface in the form of a truncated cone with a vertex on the axis of symmetry. The disadvantage of this method was the lack of a step transition from groove to cone surfaces, which makes it impossible to create a free side surface for effective rock chipping by tangential stresses, as shown in Figure 2. The destruction occurred on an inclined surface, which was more effective than on a flat surface (Fig. 1), but depended on normal stresses that required more energy. Insufficient attention was paid to optimising the face configuration to maximise

tangential stresses. In all the considered methods of roller cone drilling, low efficiency of destruction of the central part of the face was observed due to the almost zero linear speed of the tool, which led to the formation of a core that damaged the roller cones and caused their premature breakage. To improve drilling of hard rocks, a technology has been developed that involves chipping rock on a free side surface to destroy most of the face, which reduces energy consumption, increases drilling speed, and reduces the cost of operation. The proposed method is shown in Figure 3.

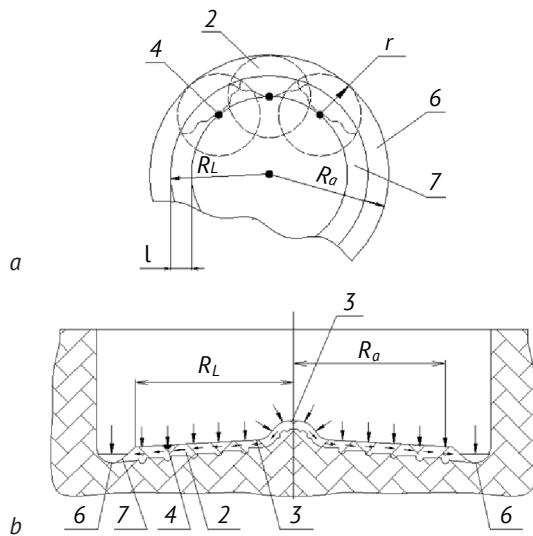


Figure 3. View of the face with a leading circumferential groove in the corner zone of the well

Notes: a – top view; b – side view; 2 – volume of stressed rock; 3 – bit face surface; 4 – zone of compressed rock under the tooth; 6 – leading circumferential groove; 7 – free side surface of the circumferential groove; R_L – radius of the leading groove; R_a – radius of action of the teeth of the roller cone; r – radius of the volume of stressed rock

Source: compiled by the authors

To implement a new method for drilling hard and ultra-hard rocks, the authors proposed a new design of a six-cone drill bit shown in Figures 4, 5.

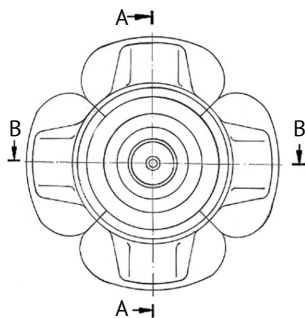


Figure 4. Top view of the six-cone drill bit

Source: compiled by the authors

The chisel assembly process is as follows. Conical rollers 6, filled with thick grease, are installed in the main roller cones 5 and mounted onto the trunnions of the main cones 2. Through the holes in the trunnions 2, locking rollers 7 are inserted while rotating the main roller cones 5; afterward, the hole in the trunnion 2 is sealed with a plug and welded. The roller-cone wheels 10 are assembled similarly: rollers 11 are mounted onto the trunnions of the roller-cone wheels 3, and the wheel locking rollers 12 are inserted. In the core roller cones 14, the core-cone rollers 15 are installed, mounted onto the shafts of the central support 4, and secured with screws 20.

The chisel is rigidly attached with a bushing 1 to the drill rod 22. The cavity between the drill rod 22 and distribution bushing 23 is filled with coolant 26 (water emulsion with a viscosity of 10-15 MPa·s and a lubricant content of 5-7%). The drilling bit is placed on the surface of the rock, and then through the drill rod 22 and axial channel 16 in the distribution bushing 23 compressed air is supplied. Compressed air enters the mixing chamber 25, where the pressure is slightly lower than on the surface of the coolant 26. Due to the pressure difference, the coolant 26 moves through capillary channels 24 to the mixing chamber 25. Coolant drops in the chamber 27 are picked up by compressed air flows and, passing through the cooling channels of the roller cone 9, core roller cooling channels 18 and wheel cooling channels 21, provide cooling and lubrication of bit bearings. Through channels for purging the well 17 the face surface is blown and rock destruction products are removed.

Next, an axial force and torque are applied to the drilling rig. The first teeth of the wheel roll over the face surface 13 located on the wheels of roller cone wheels 10 which create a peripheral circumferential groove on the bit face surface. Next, the larger teeth of the roller cone begin to go deeper into the rock on the bit face surface 8 on the largest diameter of the main roller cone 5, and then smaller teeth and so gradually to the tops of the roller cone 5. As the rolling cone wheels are buried (drilled) 10 and the main roller cones 5 in the rock, in the central part of the bit face, a protrusion begins to appear in the form of a core into which the teeth of the core roller cones are buried 19 which are found in core roller bits 14 and completely destroy this protrusion (core) as it grows.

The bearing assembly, consisting of load-bearing rollers and locking rollers, turned out to be the most vulnerable element of roller-cone drill bits. The load-bearing rollers take the main load, which, according to the results of laboratory measurements, is an average of 1,000 kg for each centimetre of bit diam-

eter. Locking roller-cone drill bits fix the roller on the trunnion, partially taking the load. During the operation of the drilling bit, the torque equipment recorded peak loads from the face reaction, which exceeded the working load by 3-4 times, which required a significant margin of safety of rolling elements. The temperature regime of the bearings was complicated due to insufficient cooling. The use of water for cooling was considered impractical due to the need for additional equipment such as pipelines, pumps and filters, and due to

flooding of wells, mine workings and quarries, which created the need for settling tanks and pumps for removing water, in particular for laying explosives, significantly increasing drilling costs. Compressed air was used to remove rock degradation products and cool the bearings, but it had an increased temperature and low heat capacity. This led to heating of the bearing units to 200-300°C, as established by thermal imaging measurements, which reduced their service life and caused the bit to fail to wear the teeth.

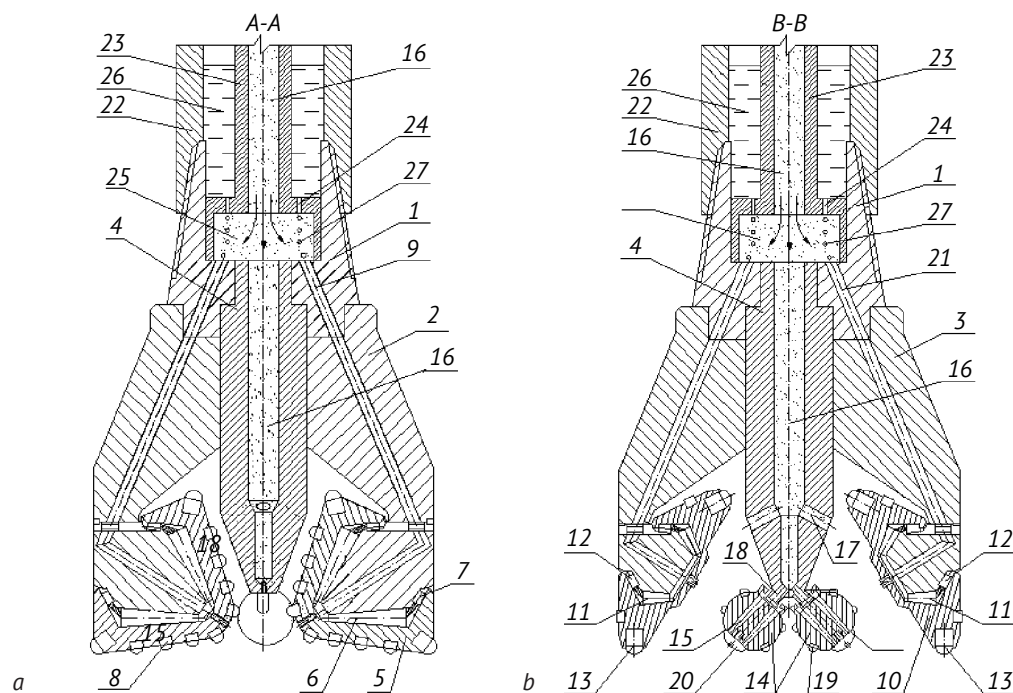


Figure 5. Longitudinal section of a six-cone drill bit

Notes: 1 – bushing; 2 – trunnion of the main roller cone; 3 – trunnion of the roller cone wheel; 4 – central support; 5 – main roller cone; 6 – conical roller; 7 – locking roller; 8 – roller cone teeth; 9 – roller cone cooling channel; 10 – roller cone wheel; 11 – wheel roller; 12 – wheel locking roller; 13 – wheel teeth; 14 – core roller cone; 15 – core cone roller; 16 – axial channel; 17 – well-flushing channels; 18 – cooling channels of core roller cones; 19 – teeth of core roller cones; 20 – screw; 21 – wheel cooling channel; 22 – drill rod; 23 – distribution sleeve; 24 – capillary channels; 25 – mixing chamber; 26 – coolant; 27 – coolant droplets

Source: compiled by the authors

Drilling of the corner zone is the most energy-intensive process, causing rapid wear of the outer teeth of the bits, especially when creating a groove. The proposed design of the six-cone drill extended the service life of the tool, by reducing the load on the main cones, which worked in the mode of chipping rock on a free side surface. Through capillary holes in the end wall of the bushing, the emulsion entered the cooling channels, evaporated in a stream of compressed air, removing heat. The lubricant in the emulsion reduced friction, contributing to additional cooling, which reduced the bearing temperature to 80-100°C, as confirmed by thermal imaging measurements.

The developed technology for drilling hard and ultra-hard rocks provided for the creation of an advanced circumferential groove in the corner face zone, followed by step chipping of the rock to a free side surface. Experimental tests carried out on rock samples with a compressive strength of 150-200 MPa showed that the design of the six-cone drill ensured the destruction of approximately 80% of the face surface due to tangential stresses. Due to this, energy consumption decreased by 1.4-1.7 times compared to conventional roller cone drilling methods, which is confirmed by energy consumption measurements. The drilling speed increased by 1.2-1.5 times, as established according to field tests.

The use of tangential stresses to destroy 80% of the bit face surface reduced the load on the tool, which extended its service life by 2.7-3 times. The use of a bearing cooling system with water emulsion and compressed air ensured that a stable temperature was maintained in the range of 80-100°C, preventing overheating.

Statistical analysis of the results with a confidence interval of 95% confirmed a stable increase in drilling productivity and a decrease in wear of the teeth and

bearings of the bit. The average measurement error of drilling speed was ± 0.2 m/h, and energy consumption was ± 0.5 kWh/m. The proposed cooling system reduced the temperature of the bearing assembly to 80-100°C, which extended the drill bit life by 1.7-2 times compared to traditional methods, as shown by thermal imaging measurements. Table 1 shows a comparison of the main performance indicators of the proposed technology with conventional roller cone drilling.

Table 1. Comparison of drilling efficiency

Indicator	Conventional drilling	Proposed technology
Drilling speed, m/h	1.5-2.0	1.8-3.0
Energy consumption, kWh/m	12-15	16.8-25.5
Bit resource, m	150-200	255-400

Source: compiled by the authors

V. Hankevich *et al.* (2019) explored the challenges of drilling in high-temperature geothermal solid rock reservoirs, focusing on adapting oil and gas technologies such as thermostable PDC and hybrid chisels, and laser-assisted and high-pressure water methods. They concluded that innovative bits increase durability and efficiency in harsh environments, while auxiliary techniques such as laser drilling improve speed and reduce wear by cooling and removing debris. However, the researchers paid insufficient attention to optimising the face configuration to maximise the use of tangential stresses, and to integrating bearing cooling systems for mechanical chisels; compared to the study, their approach did not consider step-by-step rock chipping, which could further reduce energy consumption, as shown in the results of the study.

K. Fan (2025) researched digital drilling techniques for *in-situ* measurement of rock properties in energy conservation and resource extraction projects, including models of rock penetration, cutting, and destruction based on mechanical interactions. The researcher concluded that a better understanding of machine-breed interaction helps to identify structural distributions, obtain rock parameters, improve efficiency, and reduce costs, with the prediction of integrating intelligence, automation, and big data. Insufficient attention was paid to the mechanisms of destruction under tangential stresses in hard rocks and design solutions for cooling the tool; in contrast, the study integrates such mechanisms into the drill design, which led to a noticeable reduction in energy consumption, which was not achieved in digital models.

Y. Koroviaka *et al.* (2023) covered the historical development of percussive drilling, experimental methods, and factors influencing the mechanical response of bit-rock interactions, with a focus on energy and

fragmentation in deep solid rocks. The researchers concluded that percussive drilling is 5-15 times more efficient than rotary drilling, but there are gaps in understanding destruction at high temperatures and pressures, offering improved models and experiments. The combination of percussive drilling with bit configurations for tangential stresses and bearing cooling systems has not been sufficiently explored; this study complements this by demonstrating reduced wear through innovative design that surpasses the focus on the energy efficiency of the percussive method. V. Whitem *et al.* (2024) reviewed methods, challenges, and paths for drilling super-hot geothermal systems, evaluating conventional, hybrid, and energy methods with technology readiness levels. The researchers concluded that PDC bits reach TRL 8-9, but further tests are needed at temperatures above 400°C, with an emphasis on cooling and corrosion. Chisel designs for maximising tangential stresses and integrating emulsion systems have not been sufficiently considered; the study eliminated this by showing a 2.7-3-fold increase in tool life, which was not achieved in their hybrid approaches.

A. Alsaihati *et al.* (2024) studied the efficiency phases of drilling with PDC bits in solid rocks at various pressures and parameters, using machine learning to analyse ROP and torque. The researchers concluded that there are three phases of efficiency, with correlations of parameters that allow real-time optimisation of drilling. Insufficient attention was paid to mechanical structures for tangential stresses and cooling of bearings; compared to the conducted study, their ML approach did not integrate step chipping, which in the results of the study reduced energy consumption by 2.4-2.7 times. X.-H. Wang *et al.* (2023) analysed the mechanisms of rock drilling and destruction using Abaqus simulations and experiments on three types of rocks.

Drilling speed, rotation, and rock strength were found to be negatively correlated, with positive correlations for pressure and torque. Insufficient attention was paid to the design of chisels for step chipping and cooling systems; compared to the study, their simulations did not consider the reduction of wear due to emulsion, as in the tests of the study.

D. Nelms (2023) tested polygonal cutting elements in PDC chisels for hard interbedated rocks. The researcher concluded that such elements increase impact resistance by 60-70%, extending the interval by 27-30% with a higher ROP. Insufficient attention was paid to bearing cooling systems and face configurations; compared to the current study, their bits do not integrate core rollers, which in the results of the study extended the service life by 2.7 times. Comparison with these studies showed that the proposed technology combines tangential stresses and cooling more efficiently, surpassing the focus on PDC or percussive methods in reducing energy consumption and wear.

● Conclusions

The proposed technology for drilling hard and ultra-hard rocks involves sequential chipping of rock in stepped layers on a free side surface. This approach provides a gradual movement of the free surface in the form of a wavy circle from the circumferential groove in the corner face zone to the central part of the well. Thus, most of the bit face surface, with the exception of the circumferential groove area, is destroyed by chipping using tangential stresses. Such stresses require significantly lower energy costs compared to the normal stresses typical of conventional drilling methods, which lead to the grinding of rock to sand and dust. This reduces the load on the drill bit, reduces wear on the teeth and parts of the tool, and also helps to save energy.

The developed design of the six-cone drill bit reduces the energy intensity of drilling due to the destruction of most of the face by sequentially chipping

rock to a free surface. The tangential stresses that dominate this process have a lower tensile strength compared to the normal stresses created by conventional roller cone chisels. This allows destroying the rock more efficiently, reducing energy consumption. The use of core cones in the bit design ensures effective destruction of the central part of the bit face, preventing the formation of core, which in conventional bits often causes damage to the cones. The chisel teeth experience less wear, as chipping rock onto a free surface requires less effort compared to conventional cutting. Bearing units equipped with tapered rollers have a greater load-bearing capacity due to the increased contact area. Constant cooling and lubrication with a water emulsion ensures a stable temperature regime, reducing the temperature of bearings to 80-100°C, which significantly extends their service life by 1.7-2 times, as the test results showed.

The proposed drilling technology and the design of a six-cone drill bit provide a comprehensive solution to the problem of drilling hard and ultra-hard rocks. Due to a reduction in energy intensity by 1.4-1.7 times and a reduction in tool wear by 1.2-2 times, confirmed by laboratory and field tests on rock samples with a compressive strength of 150-200 MPa, a significant reduction in the cost of drilling operations was achieved. Prospects for further research include optimising the parameters of the circumferential groove, improving the cooling system for operation in ultra-high temperatures, and adapting the technology for drilling larger-diameter wells.

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● Conflict of Interest

None.

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Сергій Мінєєв

Доктор технічних наук, професор
 Інститут геотехнічної механіки імені М.С. Полякова НАН України
 49005, вул. Сімферопольська, 2а, м.Дніпро, Україна
<https://orcid.org/0000-0002-4594-0915>

Олександр Пащенко

Кандидат технічних наук, доцент
 Національний технічний університет «Дніпровська політехніка»
 49005, просп.Дмитра Яворницького, 19, м.Дніпро, Україна
<https://orcid.org/0000-0003-3296-996X>

Володимир Антончик

Головний конструктор
 Інститут геотехнічної механіки імені М.С. Полякова НАН України
 49005, вул. Сімферопольська, 2а, м.Дніпро, Україна
<https://orcid.org/0000-0002-4161-9112>

Валентин Ганкевич

Кандидат технічних наук, доцент
 Інститут геотехнічної механіки імені М.С. Полякова НАН України
 49005, вул. Сімферопольська, 2а, м.Дніпро, Україна
<https://orcid.org/0000-0002-8535-6318>

В'ячеслав Кіба

Магістр, старший викладач
 Національний технічний університет «Дніпровська політехніка»
 49005, просп.Дмитра Яворницького, 19, м.Дніпро, Україна
<https://orcid.org/0000-0003-3033-6106>

Розроблення шестишарошкового долота для ефективного буріння міцних та надміцних порід шляхом оптимізації конфігурації забою

Анотація. Дослідження присвячено вирішенню проблеми ефективного буріння міцних та надміцних гірських порід, яка характеризується високими енерговитратами, значним зносом бурового інструменту та низькою швидкістю проходки. Метою роботи було розроблення технології буріння, спрямованої на оптимізацію процесу руйнування порід шляхом створення спеціальної конфігурації забою свердловини для забезпечення ефективного сколювання матеріалу за рахунок дотикових напружень. Методологія дослідження базувалася на аналізі закономірностей руйнування порід, математичному моделюванні напружено-деформованого стану породи з використанням програмного забезпечення ANSYS, а також експериментальних випробуваннях на зразках гранітів і базальтів із міцністю на стиск 150-200 МПа. Було розроблено конструкцію шестишарошкового бурового долота, яка включає окремі шарошкові колеса для створення випереджаючого кільцевого врубу в кутовій зоні забою, головні шарошки для ступінчастого сколювання породи та кернові шарошки для руйнування центральної частини забою, що запобігає утворенню керну та пошкодженню інструменту. Результати експериментальних випробувань показали, що запропонована технологія забезпечує руйнування приблизно 80 % поверхні забою за рахунок дотикових напружень, що дозволило знизити енерговитрати в 1,4-1,7 рази порівняно з традиційними методами шарошкового буріння, як встановлено вимірюваннями енергоспоживання. Швидкість буріння зросла в 1,2-1,5 рази, що підтверджено даними польових випробувань. Лабораторні вимірювання засвідчили, що несучі ролики підшипникового вузла сприймають навантаження в середньому 1 000 кг на кожен сантиметр діаметра долота, а пікові навантаження від реакції забою, зафіксовані динамометричним обладнанням, перевищують робоче навантаження в 3-4 рази. Система охолодження підшипників із використанням водяної емульсії та стиснутого повітря знизила температуру підшипникових вузлів із 200-300 °С у традиційних конструкціях до 80-100 °С, як показали тепловізійні вимірювання, що подовжило ресурс долота в 1,7-2 рази. Статистичний аналіз результатів із довірчим інтервалом 95 % підтвердив стабільність показників продуктивності, із середньою похибкою вимірювань швидкості буріння $\pm 0,2$ м/год і енерговитрат $\pm 0,5$ кВт·год/м. Запропонована технологія сприяє зниженню зносу зубків і підшипників, подовжуючи термін служби інструменту в 2,7-3 рази. Отримані результати відкривають можливості для широкого застосування технології в гірничодобувній промисловості, зокрема в складних геологічних умовах із міцними породами, забезпечуючи зниження витрат і підвищення продуктивності буріння

Ключові слова: бурове долото; шарошка; забій; дотичні напруження; кільцевий вруб