Nafta-Gaz 2025, no. 8, pp. 524–529, DOI: 10.18668/NG.2025.08.04

Modern tools for rock destruction used in oil and gas wells drilling

Nowoczesne narzędzia do przewiercania formacji skalnych stosowane przy wierceniu otworów ropnych i gazowych

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ABSTRACT: The main problem in the construction of wells for various purposes is the need to drill them with high mechanical speed and durability under various mining and geological conditions. The issue of increasing the durability and versatility of drilling tools is extremely relevant, especially when operating deep wells with long boreholes and horizontal intervals. Modern technologies in the production of very hard artificial and composite materials have made it possible to develop modern drilling tools with outstanding characteristics. The use of PDC rotary cutters increases bit life by means of constant renewal of the part of the cutting surface in contact with the rock. Reducing the force on the cutter to achieve the same drilling speed results in a more stable and lower torque and provides better control over axis orientation during directional drilling. This advantage allows an increase in the angle of curvature at a higher mechanical drilling speed. Drilling with the bits discussed in this article, compared to wells drilled with standard bits, provides a significant increase in rock-breaking tool life and average mechanical drilling speed. In addition, conventional drill bits in these conditions are susceptible to impact damage, which often results in lower mechanical drilling speeds and downhole tool failures, leading to additional costs. This article provides a brief overview of modern drilling bits used in oil and gas wells drilling.

Key words: rock-breaking tools, PDC type bit cutters, comb-shaped teeth for cutting, hybrid drill bits.

STRESZCZENIE: Głównym problemem przy realizacji odwiertów o różnym przeznaczeniu jest konieczność ich wiercenia z wysoką prędkością mechaniczną i przy zachowaniu wysokiej trwałości w różnych warunkach górniczo-geologicznych. Kwestia zwiększenia trwałości i wszechstronności narzędzi wiertniczych jest niezwykle istotna, szczególnie w przypadku wykonywania odwiertów na większych głębokościach, z długimi odcinkami pionowymi lub poziomymi. Nowoczesne technologie produkcji bardzo twardych materiałów sztucznych i kompozytowych umożliwiły opracowanie nowoczesnych narzędzi wiertniczych o wyjątkowych właściwościach. Zastosowanie frezów obrotowych PDC wydłuża żywotność świdra dzięki stałemu odnawianiu części powierzchni tnącej mającej kontakt ze skałą. Zmniejszenie siły działającej na frez przy zachowaniu tej samej prędkości wiercenia skutkuje bardziej stabilnym i niższym momentem obrotowym oraz zapewnia lepszą kontrolę orientacji osi podczas wiercenia kierunkowego. Pozwala to na zwiększenie kąta krzywizny przy wyższej mechanicznej prędkości wiercenia. Wiercenie za pomocą świdrów omawianych w artykule, w porównaniu do otworów wierconych za pomocą standardowych narzędzi, pozwala wydłużyć żywotność narzędzia do zwiercania skał oraz zwiększyć średnią mechaniczną prędkość wiercenia. Ponadto, konwencjonalne świdry są w takich warunkach podatne na uszkodzenia udarowe, co często prowadzi do obniżenia prędkości wiercenia mechanicznego i awarii narzędzi wiertniczych w otworze, powodując dodatkowe koszty. Niniejszy artykuł zawiera krótki przegląd nowoczesnych świdrów stosowanych do wiercenia odwiertów ropnych i gazowych.

Słowa kluczowe: narzędzia do przewiercania formacji skalnych, frezy PDC, zęby grzebieniowe do zwiercania, świdry hybrydowe.

Introduction

When developing a tool for drilling wells for various purposes, the main optimization criteria are an increase in mechanical speed and service life. This is especially true for rock-breaking tools designed for drilling in changing mining and geological conditions of deep and inclined wells. Recently, the issue of increasing the versatility and penetration of drilling tools has been increasingly raised.

When designing a drill bit, important circumstances such as the rock type and the planned rotational speed mode for which the bit is designed should be taken into account. As an important parameter characterizing the drillability of rocks, it is necessary to determine the resistance of a rock to cutting and chipping at different values of the rate of its destruction process. In order to assess the increase in the resistance of a rock to cutting and chipping, the method of evaluating the dynamic hardness of formations, as proposed, can be used (Borisov, 2011).

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Article contributed to the Editor: 23.08.2024. Approved for publication: 22.05.2025.

For soft rocks and rocks of medium hardness, the increase in this parameter can be very significant. The influence of the linear velocity of movement of the cutter of a drilling tool on the process of rock destruction at a constant depth of penetration was studied (Borisov, 2012). Other interesting results of experimental studies on the characteristics of the dynamic process of rock destruction are also presented in the literature. For example, Rozhkov conducted an experiment on pressing a cone (point angle 120°) into rocks with different loading intensities from 15 to 60 N/s (Rozhkov, 1999).

Opportunities in the field of artificial materials have allowed the development of modern drilling tools with outstanding characteristics. The scientific research on the patterns of operation of drilling tools has shown that the design parameters of the tool have an impact on its performance. The development of a new drilling tool is carried out taking into account the production capabilities and the latest findings in this area. Currently, the most popular tool is reinforced with PDC cutters.

The latest Axe cutter shape improves cutting force efficiency and heat transfer with higher resistance to frontal cutter loads, which is achieved by increasing the diamond layer thickness, combining different sizes of polycrystalline diamond grains and optimizing the materials used. Abnormal wear of the cutting edge of the PDC cutters is the cause of premature tool failure. The ability to rotate the PDC cutters around its axis creates conditions for their uniform wear and, as a result, leads to an increase in the life of the drilling tool.

An increase in the resource of the rock-breaking tool is possible by ensuring the rotation of the PDC cutters. The possibility of placing the maximum number of rotating cutters is achieved by the angle of inclination of the ending surface of the drill bit at 45°. At the same time, the maximum value of the clamping force and the optimal alignment of the plane of action of the drill bit in the well are achieved.

To ensure active rotation of the cutters during drilling, the friction characteristics of their lateral surface should be increased.

Drill bits equipped with diamond carbide plates (DCP)

With the modernization of the currently widely used roller bits and drilling technology, the necessary growth of the main technical and economic indicators of drilling operations is no longer provided. Therefore, new types of bits began to be used in the construction of oil and gas wells – bits and teeth equipped with diamond-carbide plates. Such tools are used for drilling almost all types of rocks under various conditions. The new cutting-type bits provide a higher drilling speed and bit stroke compared to diamond and three-cone bits, with lower energy consumption during drilling.

This is due to the fact that the destruction of rocks, which is carried out by cutting, is more efficient than crushing–compression (bits with a cone) and crushing–friction (diamond bits). The use of drill bits with turbine and screw downhole engines is currently very effective.

The geometric shape and parameters of the crushing elements (the height and length of the teeth, the angle of sharpening of their vertices, tooth spacing on the cone) vary depending on the physical properties of rocks for different bits. The teeth on the cone are typically wedge-shaped or hemispherical (Figure 1). Long-tooth, non-conical designs are intended for the rotary method of drilling rocks of medium-hard. Short-cone roller bits are mainly used for drilling with downhole motors, as well as for rotary drilling of soft and medium hardness rocks (Tretyak et al., 2017). Depending on the shape and arrangement of the teeth in the bits, the mechanical drilling speed can be increased when destroying the rocks. Given the variety of physical and mechanical properties of rocks with depth, the location of teeth in these types of rock-breaking tools also plays a significant role.

Figure 1. Drill bit with teeth of different shapes on a cone (Salavatov et al., 2017)

Rysunek 1. Świder z zębami o różnych kształtach na stożku (Salavatov i in., 2017)

Drill bits with a new generation of AxeBlade comb-shaped cutters

The SLB (Schlumberger) Company is currently developing a wide range of high-tech dynamic drilling bits designed to work with the most complex formations, drilling trajectories and difficult well conditions (Russian Federation Patent, No. 2638220; US Patent, No. 20180320449A1).

Specially designed cutting structures provide capabilities not available with standard PDC cutting teeth:

- drilling at long intervals in rocks containing silica and pyrite;
- 360° rotation for uniform distribution of erosion and heat;
- simultaneous rock destruction and borehole processing.

The Smith Bits division of Schlumberger has developed unique AxeBlade tungsten carbide comb-shaped diamond cutters that are positioned throughout the profile to significantly improve the impact force and mechanical drilling speed (Figure 2).

Before the advent of StingBlade bits with unique conical diamond inserts, the productivity of PDC drill bits was achieved by improving materials and changing the way they were processed. The newest shape of the Axe cutter increases the efficiency of cutting force and heat transfer with higher resistance to frontal loads on the cutter, which is ensured by increasing the thickness of the diamond layer and combining different sizes of polycrystalline diamond granules.

The Axe cutters have a unique shape that fractures the rock in a unique way, combining both shearing and crushing mechanisms. At the same time, the penetration depth of the incisor into the rock increases by at least 22%. As a result, more rock is removed, leading to an increase in the instantaneous mechanical penetration rate compared to standard PDC bits, at the same load and rotation speed.

Figure 2. PDC type bits with cutting edges in a comb-like shape (Ishbaev et al., 2024)

Rysunek 2. Świdry typu PDC z krawędziami zwiercającymi o kształcie grzebieniowym (Ishbaev i in., 2024)

StingBlade drill bits with conical diamond-shaped elements

Due to the high resistance of Stinger inserts to impact loads and wear, StingBlade bits provide an increase in bit penetration due to an increase in mechanical drilling speed, while maintaining improved directional alignment and minimizing impact loads in complex drilling conditions that cause dynamic damage to standard bits (Figure 3). When drilling with StingBlade bits, compared with wells drilled with standard bits, the service life of the rock-breaking tool is increased by an average of 55%, and the average mechanical drilling speed by 30% (US Patent, No. 20180291691A1).

Figure 3. StingBlade bits with diamond conical inserts (Pak, 2015)

Rysunek 3. Świdry StingBlade ze stożkowymi wkładkami diamentowymi (Pak, 2015)

Abnormal wear of the cutting edge of the PDC cutters is the cause of premature tool failure. StingBlade diamond inserts have numerous advantages over traditional PDC bits. The unique three-dimensional characteristics of the diamond insert of the conical diamond teeth of the Stinger ensure an increase in the productivity of the bits across a wide range of rocks and operating parameters. The placement of Stinger diamond inserts on the surface of the bit provides a qualitative change in the drilling efficiency and rock destruction. Stinger diamond inserts apply a more concentrated load on the rock, and their thicker diamond layer increases impact strength and wear resistance. This combination makes it possible to significantly increase the penetration and mechanical drilling speed when using StingBlade bits in difficult drilling conditions, including drilling of hard, interbedded, conglomerate rocks and rocks containing silicon and pyrite. Conventional drill bits in these conditions are prone to damage under shock loads. Shock and vibration loads can lead to reduced mechanical drilling speeds and downhole tool failures, resulting in additional costs. Due to a more balanced cutting structure of Stinger diamond inserts, StingBlade bits reduce the aforementioned loads.

This feature allows improved drilling efficiency, increased penetration at higher mechanical drilling speeds, as well as an extended operational life of bits and other components of the bottom hole assembly. Most of the diamond surface of the fixed cutters remains unused. Although widely used, PDC fixed cutters have a unique limitation: the majority of the cutting edge is attached to the bit blade, limiting contact with the rock.

Accordingly, more than 60% of the cutting edge circumference of the cutter remains unused and only 10% to 40% of the cutting edge (red area) is involved in rock breaking (Figures 4, 5).

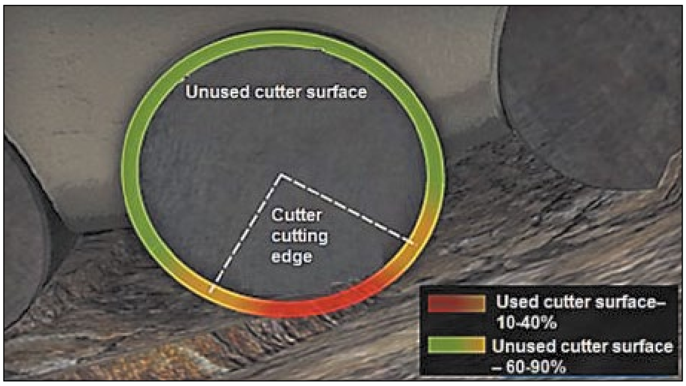

Figure 4. Rotating drilling bits with ONYX 360 cutters (Kabdushev and Korgasbekov, 2022)

Rysunek 4. Obrotowe świdry z frezami ONYX 360 (Kabdushev i Korgasbekov, 2022)

The portion of the cutting edge of fixed cutters that comes into contact with the surface is subjected to mechanical or thermal stresses that cause wear and chipping. This concentrated wear on a small portion of the cutting surface results in a loss of penetration efficiency, slowing down the mechanical rate of penetration.

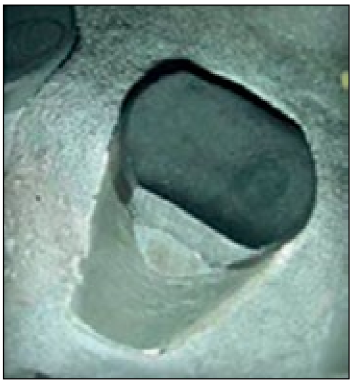

Figure 5. Structure of fixed cutters, zone of wear degree and its concentration on the fixed cutter (Neskoromnykh et al., 2020)

Rysunek 5. Struktura frezów stałych, strefa stopnia zużycia i jego koncentracja na frezie stałym (Neskoromnykh i in., 2020)

In addition, the bit run time is significantly reduced, leading to a reduction in penetration per drilling (Russian Federation Patent, No. 2421589). To address the above, the use of rotating PDC cutters is proposed, which increases bit operational life by constantly renewing the part of the cutting surface in contact with the rock, allowing the cutting edge to maintain sharpness longer. In addition, rotation improves heat dissipation by preventing thermal energy build-up. The ability to rotate PDC cutters around their axis creates conditions for uniform wear, which in turn increases the life of the drilling tool. Compared to PDC bits with fixed Axe Blade-type cutters, ONYX 360 rotating cutter PDC bits (Figure 6) significantly increase the service life of PDC bits due to 360° rotations. Optimal positioning in the most worn areas of the bit cutting structure allows the full length of the cutting edge to be used when penetrating the rock. Cutter rotation helps maintain edge sharpness, thus increasing the life of the ONYX 360 bits by approximately 57%.

Compared to bits with only fixed cutters, PDC bits with ONYX 360 rotary cutters showed a 57% increase in penetration length, resulting in fewer tripping operations and lower drilling costs (US Patent, No. 20180320449A1, Neskoromnykh, 2023).

Bits with ONYX 360 cutters have the following advantages:

- Increased bit life;
- Increased penetration;
- Increased average mechanical penetration rate;
- Improved heat dissipation for longer cutter life;
- Ability of cutters to rotate 360°;
- Number and positioning of cutters can be varied to increase their life in the areas of the bit's cutting structure that are subject to the most wear;
- Cutters can be integrated into the cutting structure of any PDC bit without changing the cutter diameter.

Hybrid (“Kummer”) drill bit system

The concept of developing a hybrid drill bit system was made in the 1930s and was fully realized after the development of semi-crystalline diamond PDC bits. This problem was successfully solved by Hughes Christensen employees for drilling heterogeneous and hard rocks, leading to the development of a unique hybrid drilling technology. Figure 7 shows one type of hybrid bit. This new hybrid drill bit is based on the proven technology of the PDS-type bit and the use of cutting conical cone bits located on the drill bit body (Salavatov et al., 2017).

The hybrid drill bit system drills shale, clays and rocks with high plasticity 2.4 times faster and more efficiently than roller cone bits. While drilling wells from an offshore fixed drilling rig using a “Kummer” system – which combines a PDC-type bit for drilling soft rock and a conical roller cone bit for drilling hard rock – a higher mechanical drilling rate was achieved than when these bits were used separately (Neskoromnykh et al., 2020). For example, while in the past it took 170 to 180 working days to drill a well, recently, after improvements in hybrid bits, it takes 40 to 50 working days to drill a similar well.

Figure 6. Drill bits with rotary cutters ONYX 360: a) the ONYX 360 cutter shaft is fully integrated into the housing to ensure the retention and rotation of the cutters during drilling; b) ONYX 360 cutters before installation in the drill bit: assembled (left) and disassembled (right) (Neskoromnykh et al., 2020)

Rysunek 6. Świdry z obrotowymi frezami ONYX 360: a) wałek frezu ONYX 360 jest w pełni zintegrowany z korpusem, aby zapewnić utrzymanie i obrót frezów podczas wiercenia; b) przed montażem w świdrze: zamontowane (po lewej) i rozmontowane (po prawej) (Neskoromnykh i in., 2020)

Figure 7. A type of hybrid drill bit (Salavatov et al., 2017)

Rysunek 7. Przykład świdra hybrydowego (Salavatov i in., 2017)

Conclusion

1. The possibility of rotation of PDC cutters around the longitudinal axis during drilling allows an increase in the service life of the rock cutting tool and the average mechanical speed of drilling, since the cutting surface of the cutter is installed in the most loaded part, allowing more rational use of the drilling tool's surface, which is subject to heavy wear.
2. The most rational angle of inclination of the bit surface with rotary cutters, providing the maximum value of downforce in the borehole and maximum overlapping of the bit depth impact plane, is an angle of 45°, where the maximum number of rotary cutters can be placed in the bit.
3. To reduce cutter sliding, it is necessary to increase the frictional properties of the cutter side surface, which will enable more active rotation of the cutter during drilling, especially when placed on the front and side surface of the bit.
4. Concentrated wear of a small part of the cutting surface leads to a loss of the efficiency of penetration into the rock, slowing down the mechanical rate of penetration.

The use of rotating PDC cutters, which increase the drill bit's service life by constantly renewing the part of the cutting surface in contact with the rock, allows the cutting edge to remain sharp longer. In addition, rotation improves heat dissipation by preventing the accumulation of thermal energy.

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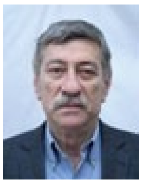

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