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ANNIVERSARIES OF INNOVATIVE DRILLING TECHNOLOGIES
Reference Review

The design and creation of diamond rock cutting tools, namely the big diamond drill bit; the small diamond drill bit; the bit equipped with synthetic diamonds; and the bit reinforced with composite materials using diamonds have been considered. The benchmarks of innovative development of drilling technologies have been presented.

Keywords: diamond drilling crown, artificial borehole deviation, and screw downhole motor.

In 2012, we marked a series of anniversaries of drilling technologies: 150 years of diamond drilling (dia-mond drill bit); 100 years of artificially deviated wells; and 50 years of downhole drilling motors.

Let's consider each benchmark of innovative development of drilling technologies separately.

150 YEARS OF DIAMOND DRILL BIT

Rock drilling is a complex and time-consuming process, the effectiveness of which depends on the opera-tional capabilities of drilling tool used. There are *four stages* of diamond drilling tool evolution.

Stage I: the invention of big diamond drill bit. The diamond core drill was proposed by George Leschot, a Swiss watchmaker. This is the story as narrat-ed by Russian mineralogist Beskorovanov [1]:

In 1862, while supervising the blasting operations during the construction of a railway tunnel in the Swiss Alps, Leschot was challenged with drilling of solid granite rocks as drill bits made of high-strength tem-pered steel were worn our very quickly. The deadlines were disrupted. Leschot's experience as a watch-maker led him to consider diamonds for a drill bit end. He was sitting and despairingly gazing through the window at a huge pile of waste steel bits. In a fit of anger he crossed the window glass with his diamond ring with two scratches appearing on the glass surface... Leschot suddenly understood that only the dia-mond as the hardest known material was able to crush granite and mountain rocks. He ordered diamonds for manufacturing several dozens of pilot diamond bits. His son, Rodolfe, together with Piguet, a mechanical engineer, improved the drilling rig and came up with a way to mount the diamonds in the bit. These diamond tools were much more expensive than their steel counterparts, but proved themselves to much more efficient in operation. The rate of tunnel drilling increased substantially. Being encouraged with the success achieved, Leschot applied a diamond bit in blasthole mining operations in massive marble rocks. Again, the diamond bit displayed its advantages. So, the era of diamond drilling begun.

Initially, the diamonds were fixed on the drill bit with bit's metal. There are several ways to impregnate dia-monds in drill bits.

The best and most common is the so-called Russian method for diamond impregnation in the drill crown that provides reliable (firm) fixing of diamonds on the body of drill bit and protection of diamonds from damage during operation. This method is characterized by impregnation of diamonds both in lateral sur-face of the crown and in its cutting face. The large gems are placed on the outer surface of the cutting face, while the small ones are fixed on its inner surface. The diamonds placed on the cutting face of the crown should completely cover it.

Stage II: the small diamond drill bits. Firstly, large diamonds were used for manufacturing the drill bits. Till the 1930s, Carbonado commonly known as the black diamonds that had finely crystalline structure and low brittleness were exclusively used for the reinforcement of crowns. Weight of single diamond ranges from 0.5 to 2 carats. It is the most expensive industrial diamond. When drilling hard, especially crumbling rocks, the consumption of diamonds increased, with drilling costs rising sharply.

Then, small diamonds were offered to be used. Depending on the size, the diamond particles are arranged on the crown cutting face a) in one layer (single layer crowns), b) in several layers (multi-layer crowns) or are evenly dispersed within a metal matrix (impregnated crowns).

The single-layer crowns are reinforced with diamonds ranging from 2—5 up to 40—60 pcs/carat. The multi-layer crowns are reinforced with smaller diamond grains, from 60—90 to 90—120 pcs./carat. The impreg-nated diamond bits are reinforced with diamond particles within the range from 120—500 pcs/carat or even more.

Stage III: drill bits with synthetic diamonds. The first attempt to synthesize diamonds was made in 1823, by the founder of Kharkov University Karazin who got superhard solid crystals of unknown substance as a result of wood carbonization at a high temperature.

In 1893, Professor Khrushchev, also received a crystal scratching glass and corundum, as a result of rapid cooling of molten silver saturated with carbon. His experiment was successfully replicated by A. Mois-sone who substituted iron for silver. Later, it was found that the substance synthesized in these experi-ments was silicon carbide (moissonite), not diamond, which had very similar properties.

In 1879, James Ballantyne Hannay, a Scottish chemist, discovered that alkali metals reacted with organic compounds with carbon released in the form of graphite flakes, and suggested that, under high pressure this carbon can crystallize as diamond. Having carried out a series of experiments in which a mixture of paraffin, bone oil, and lithium was kept for a long time in a sealed red hot steel pipe, he managed to ob-tain a few crystals that later were identified as diamonds. The scientific world did not recognized his dis-covery, as at that time, the diamond was believed not to be obtained at low pressure and temperature. The repeated study of Hannay's samples in 1943 with the use of X-ray analysis confirmed that the obtained crystals were diamonds, but Prof. Kathleen Lonsdale, who carried out the analysis, reiterated that the Hannay experiments were a scientific hoax [2].

In 1939, *Uspekhi Khimii* (a famous Soviet scientific and research journal) published an article by Prof. Ovsei Leipunsky with detailed calculations, graphs, and sheets and accurate and reliable parameters of diamond synthesis. He was an outstanding chemist and physicist widely regarded as the author of the technique for diamond synthesis (1939) used now in industrialized countries. To mark him together with his brother, Acad. Alexander Leipunskii, and sister, Prof. Dora Leipunska, B. Horobets published a book *Three of the Atomic Project: the Secret Leipunski Physics* (2008). In 2009, he published the 2nd edition titled *The Secret Physics of USSR Atomic Project: the Leipunski Family*. This book tells the story of invention by O. Leipunski and implementation of advanced method for diamond synthesis in Sweden, the USA, and the USSR.

Fifteen years later, Leipunski's theory was verified by experiment in many laboratories by specialists of *Allmanna Svenska Elektriska Aktiebolaget* (ASEA, Sweden) and *General Electric* (USA).

In 1960, in the Soviet Union, at the laboratory of ultrahigh pressures, Leonid Vereshchagin managed to get the first artificial diamonds. Later, the laboratory was transformed into the Institute of

High Pressure Physics (IHPP) of USSR, with Vereshchagin being its first director. At the same time, in Kyiv, the Insti-tute of Superhard Materials (director V. Bakul) was established to develop technologies and tools for the diamond application in the industry (grinding and polishing wheels, diamond saws, chisels, drill bits, etc.). In the USSR, the problems related to the synthesis of diamonds were studied at the Institute of High Pressure Physics, the Academy of Sciences of USSR; at the Institute of Superhard Materials of the Acad-emy of Sciences of the UkSSR and at many specialized factories and research institutes.

Stage IV: Diamond drill bits reinforced with composite materials. There are two types: a) reinforced with superhard material *Slavutich*; and b) reinforced with diamond-carbide inserts.

Works of State Mining Institute (SMI) — National Mining University (NMU) Related to Diamond Drilling

The Dnepropetrovsk Mining Institute (nowadays, the National Mining University, NMU) was founded in 1899. The Department for Exploration of Mineral Deposits was established in 1929, by Prof. A. Gimmel-farb. However, diamond drilling works started before the creation of the department. In the 1920s, the Professor published a series of articles related to diamonds and their application in the industry, as well as to diamond drilling for extracting coal in Donbass and iron ore in the Kursk magnetic anomaly area [3].

The diamond drilling researches were performed in two directions: the design and the engineering (tech-niques for drilling with the use of diamond bits).

The design direction include the following R&Ds: diamond drill vibration bits [4]; diamond drill bit with asymmetric hydraulic system [5]; detachable diamond drill bits [6]; and rock cutting disc [7].

In 1984, the SMI and the Tula branch of TsNIGRI designed vibro-absorbing diamond drill bits 01A3-ZhM with the natural diamonds and 01A3sv-ZhM with the synthetic ones [4]. The shanks are made of an-ti-vibration (damping) composite material D30-MP. The crown diameters crowns are 46; 59; 76; and 93 mm. The crowns are designed for rotary drilling of exploration wells with coring in the low abrasive, sol-id, and low-fractured rocks referred to the 4th —9th categories of drillability. The application of 01A3-ZhM and 01A3sv-ZhM drill bits instead of 01A3 and 01A3sv bits with steel shanks enables to increase average operating life (durability) by 25—30 % and penetration rates by 10—15 %. Diamond drill bits 01A3-ZhM and 01A3sv-ZhM were manufactured at the Kabardino-Balkarian diamond tools factory.

While destroying solid and hard rocks, a significant part of energy is spent on the friction of the drill bit on the rock. This energy is converted into heat. The thermal energy of friction can be used to intensify the rock destruction. For this, the temperature in the zone of contact between the cutting elements and the rock should be high enough to heat the face layer of the rock and to weaken it. In order to utilize the heat energy of friction, the National Mining Academy of Ukraine together with Institute of Superhard Materi-als of the NAS of Ukraine has designed thermomechanical drill bits with the use of superhard composite materials and diamonds. The bench tests have been conducted for various designs of drill bits made of different superhard materials: polycrystalline diamond, boron carbide, silicon nitride, «geothermal» mate-rial, relit, and tungsten carbide powder.

For pilot tests, thermomechanical drill bits based on artificial diamonds were used. They differed from the serial bits BS-33 by the presence of one or two wide flushing ports [8]. The bench studies have showed that the specific wear of pilot bits was 1.6—2.4 times lower, as compared with the serial diamond bits, while drilling granite from Kudashevsky deposit having a density of 2.7 kg/m^3, porosity 0.98—1.6, tensile strength for axial compression of 140—192 MPa and abrasion of 0.48—0.45 g/cm (Table 1).

The results of drilling wells with the use of thermomechanical drill bits under operating conditions are given in Table 2. Due to the utilization of heat energy of friction, the penetration rate increases 1.20—1.25 times and the footage per run increases 1.21—1.26 times.

The engineering directions includes the following R&Ds:

- Techniques for pulsed drilling with variable axial load, *F* = *var* [9]; with variable flow rate of washing liquid, Q = *va*r [10—13]; with variable rotation rate of cutting tool, *n* = *var* [14, 15];
- Technique for diamond drilling at a minimum flow rate of washing liquid, which ensures thermome-chanical destruction of rocks [16, 17];
- Technique for diamond drilling with the use of drilling fluids containing surfactants.

The team of engaged researchers consists of E.F. Epstein, V.F. Syryk, N.A. Dudlia, N.M. Gavrilenko, A.N. Davidenko, A.V. Varenik. In the course of drilling fluids research, the mechanisms of influence of surfactants on the rocks and on the washing liquid have been understood, with a large amount of materials requiring a separate consideration accumulated.

The SMI together with *Geotechnics* Design Office has developed a technique for hydraulic diamond drill-ing with the use of high-frequency hammers G59V and G76V with combined reflectors OG59 and OG76 located according to SMI recommendations, with intraphase and intracyclic settings [9].

Acceptance tests of reflectors OG59 and OG76 have been made in iron ore deposits of the Kryvyi Rih GRE PGO *Yuzhukrgeologia* and Zyryanovskaya GRE PGO *Vostkazgeologia*. The test results are as fol-lows: increase in penetration rate is 10.3—21.8 %; increase in footage per run is 10.2—42 %; reflector service life is 1150—1400 hours; maximum drilling depth is 2,280 m.

The SMI and OMPNT PGO *Yuzhukrgeologia* have designed and implemented a technique for rotary-percussion drilling with the use of high-frequency hammers G59V and G76V with and without OGV-MP reflectors, which ensures an increase in ROP of 7.8—20.8 % and an increase in footage per run of 34 %. The developed technique for rotary-percussion drilling with the use of high-frequency hydraulic hammers with wave reflectors, intraphase and intracyclic settings increases the efficiency and depth of hydraulic percussive drilling. For the first time in the world of drilling practice, a drilling depth of over 2,000 m (2,280 m) has been reached. The hydropercussive systems GV+OGV have been commercialized at FMZ.

Table 1

Bench tests of Thermomechanical Drill Bits

Type of drill bit	Penetration rate		Specific wear	
	m/hour	%	mm/m	%
BS-33-59	2.53	100	0.026	100
BS-33-59-TM1/1	2.81	112	0.017	63
BS-33-59-TM2/1	3.24	128	0.011	42
BS 33-59-TM2/2	3.00	118	0.096	369

Table 2

Test Drilling of Wells under Operating Conditions by Thermomechanical Drill Bits

Type of drill bit	Depth of drilling, m	Footage per drill bit		Penetration rate	
		m	%	m/hour	%
BS-33-59	14.80	7.40	100	2.99	100
BS-33-59-TM2/1	18.64	9.32	126	3.60	120
BS-33-59-TM1/2	17.90	8.95	121	3.75	125

Supply of cleaning agent with a variable flow rate ensures a deeper heating of rock due to a full manifes-tation of the internal friction between the mineral grains constituting the rock, and between the atoms, ions, and molecules within crystal lattices, on the one hand. On the other hand, the presence of non-stationary temperature field entails an increase in fragility of the rock.

This washing mode is implemented using standard equipment and tools by incorporating thereto a surface or a submersible device that interrupts the flow of cleaning agent at a constant pumping rate or by chang-ing the design parameters during the pump operation (reduction of number of working pistons or valves).

The bench tests of diamond drilling with pulse washing were carried out while drilling granite blocks with the use of process water [10—13]. Table 4 presents the results of bench tests of drilling for the pulse washing modes listed in Table 3.

As Table 4 shows, all pulse washing modes ensure an increase in ROP. The ROP increase factor varies from 1.18 to 2.2. Pulsing with a pause-to-time-of-supply ratio of 1:1 has a more significant impact on ROP that that of 1:5.

In case of pulse washing, the ROP increase factor depends on power on bottomhole. Table 5 shows de-sign values of power on bottomhole N calculated according to the formula:

Table 3

Pulse Washing Modes

Pause in supply of washing fluid, $t_п$, s	0.315	0.205	0.125	0.105	0.068
Time of supply of washing fluid, $t_{под}$, s	0.315	0.205	0.625	0.525	0.342

Table 4

Washing Mode Effect on ROP of Diamond Drilling

RPM, min^{-1}	Axial load P, daN	Washing mode	Pause, $t_п$, c	Time of supply, $t_{под}$, c	$t_п/t_{под}$	Average consumption of washing fluid, l/min	ROP	
							cm/min	%
Drill bit 01A3-59								
239	700	Pulsing	0.375	0.375	1 : 1	13.3	1.23	211
		Pulsing	0.125	0.635	1 : 5	26.6	1.15	197
		Constant	—	—	—	40	0.58	100
239	700	Pulsing	0.205	0.205	1 : 1	23.3	1.07	220
		Pulsing	0.068	0.342	1 : 5		0.99	203
		Constant	—	—	—		0.48	100
377	900	Pulsing	0.315	0.315	1 : 1	14.4	4.47	146
		Pulsing	0.105	0.525	1 : 5	28.8	3.64	118
		Constant	—	—	—	40	3.06	100
Drill bit AK1-59								
377	900	Pulsing	0.315	0.315	1 : 1	14.4	1.78	144
		Constant	—	—	—	40	1.24	100
699	700	Pulsing	0.315	0.315	1 : 1	14.4	1.31	127
		Constant	—	—	—	40	1.03	100
699	1100	Pulsing	0.315	0.315	1 : 1	14.4	7.16	143
		Constant	—	—	—	40	5.00	100

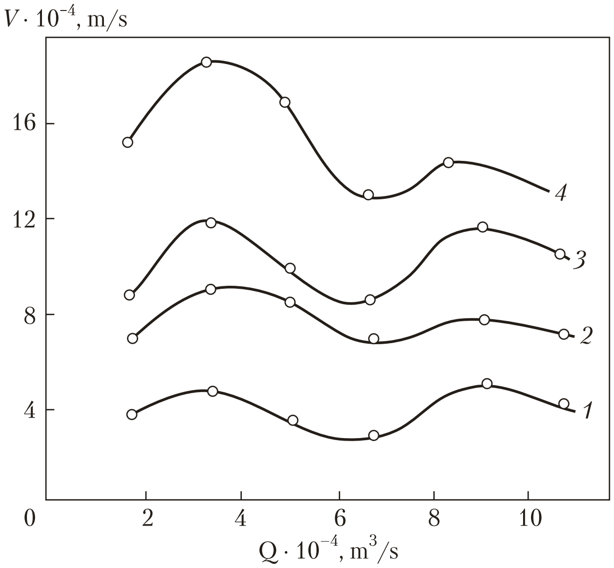

Fig. 1. Dependence of rate of drilling of sandstone using a diamond bit on consumption of cleaning agent (rotation speed n = 377 min^{-1}; bit diameter = 76 mm). Axial weight: *1* — P = 5 kN; *2* — P = 8 kN; *3* — P = 11 kN; *4* — P = 14 kN

$$N = 2 \cdot 10^{-7} Fnd_{av},$$

Where F is axial load, daN; n is rpm, min^{-1}; d_{av} is average diameter of drill bit, mm.

Having compared data of Tables 4 and 5, one can see that at a power on bottomhole of 1.7 kW, the pulse washing leads to doubled ROP.

With increasing power on bottomhole up to 3.4—7.1 kW, ROP increases 1.18—1.46 times.

The SMI developed a ZRMA device with rubber metallic elastic element that ensured not only vibration damping, but also the operation of drill bit with a variable rotation speed. The use of this device while drilling rocks in the Donbass region significantly reduced the number of accidents and breakdowns of drilling tools and enabled increasing:

1) ROP: by 25 % (with the use of carbide drill bits); by 30 % (with the use of diamond drill bits).

2) footage per run: by 15 % (with the use of carbide drill bits); by 12% (with the use of diamond drill bits) [14—15].

Table 5

Design Values of Power on Bottomhole

n, min^{-1}	P, daN	N, kW
239	700	1.7
377	900	3.4
699	700	4.9
699	1100	7.1

The studies of the effect of washing liquid flow on ROP have showed that this relationship is quite com-plex (Fig. 1) [16, 17].

One can see on the diagram that there are two peaks on the ROP curve at various flow rates of cleaning agent, with the highest one corresponding to the lesser consumption rate of washing fluid. Similar de-pendence of ROP on the flow rate of cleaning agent was received for impregnated drill bits by SMI re-searchers S.A. Volkov and N.V. Soloviev.

Thus, R&Ds of the SMI Department of Mineral Exploration have been successfully implemented, passed acceptance tests and commercialized. Among them, there are anti-vibration diamond drill bits 01A3-ZhM, 01A3sv-ZhM-KB3AI and hydro-percussive systems, including high-frequency hydraulic hammer and reflector of hydraulic waves.

Some R&Ds have passed in-process tests: the technology of diamond drilling with minimum consumption rate of washing fluid; diamond drill bit with asymmetric hydraulic system; drilling technology with n = var with application of ZRMA. Several developments are being tested in laboratories.

100 YEARS OF ARTIFICIALLY DEFLECTED WELLS

The technique for mechanical rotary drilling with the use of steam engines was created in 1842. For many years, it was used only for drilling vertical wells. Only 70 years later, people have learned to artificially change the position of the well axis underground [18, 19, and 23]. There are *six stages* of evolution of the technology for artificial deflection of borehole axis.

Stage I: the birth of artificially deflected wells in 1912. In Southern Africa, in the course

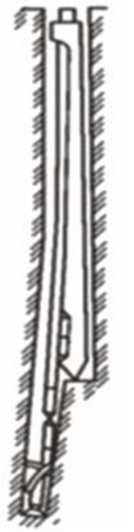

Fig. 2. Artificially deflected well

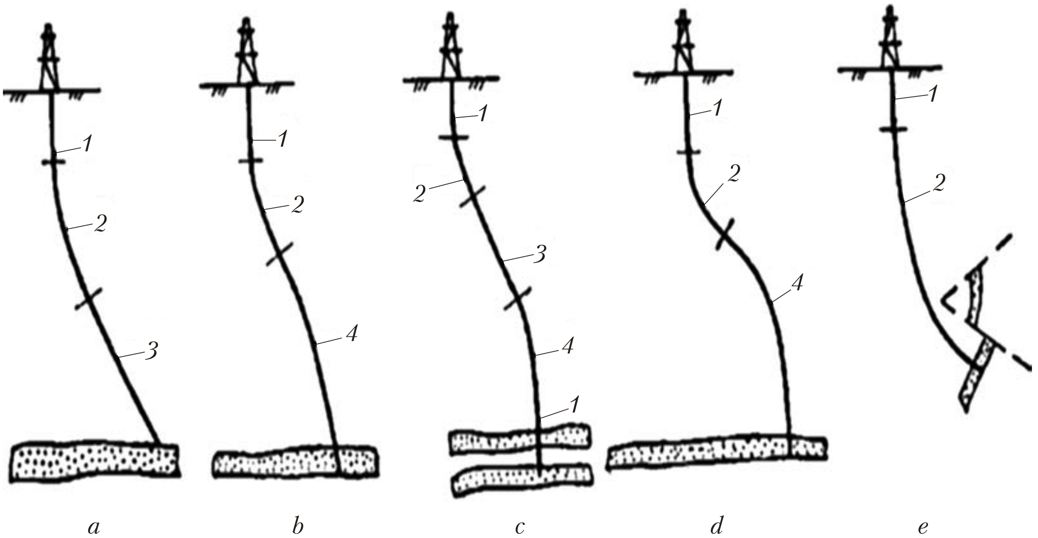

Fig. 3. Directed/controlled angle drilling

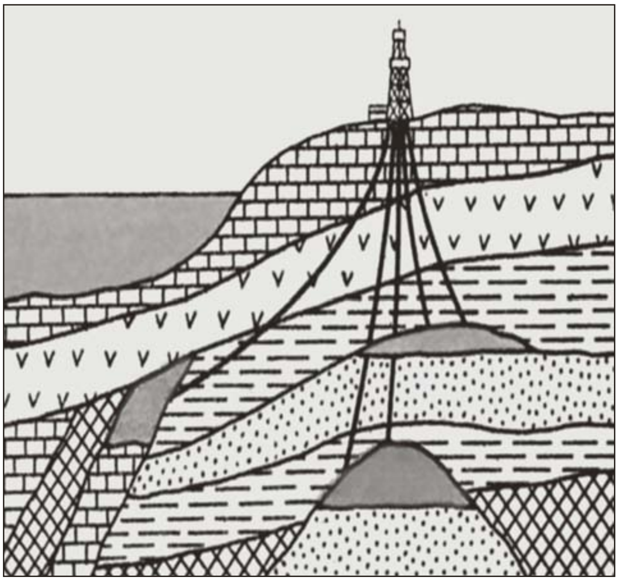

Fig. 4. Cluster of wells

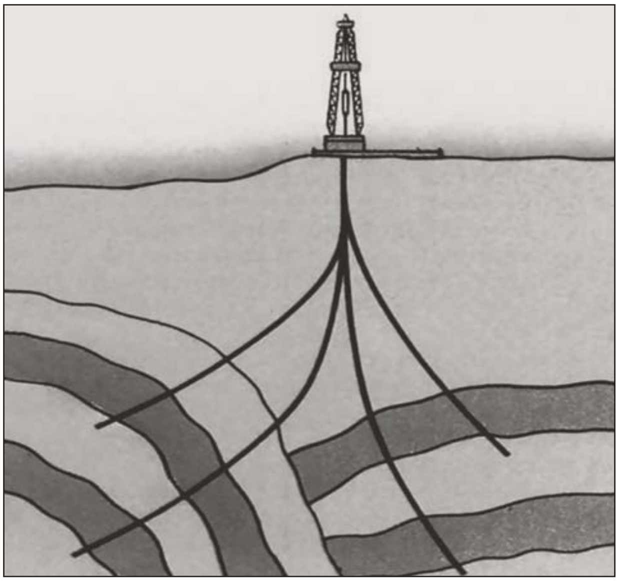

Fig. 5. Multihole drilling

of diamond drilling of wells it was necessary to change the position of well axis. This was realized using a drill wedge (Fig. 2). The operation was called «artificial deflection of the well» (ADW).

Stage II: directed/controlled angle drilling. Further, the technology of artificial deflection of wells improved. Well profiles got very sophisticated profiles (Fig. 3). This method of drilling was called directed/controlled angle drilling (DD/CAD).

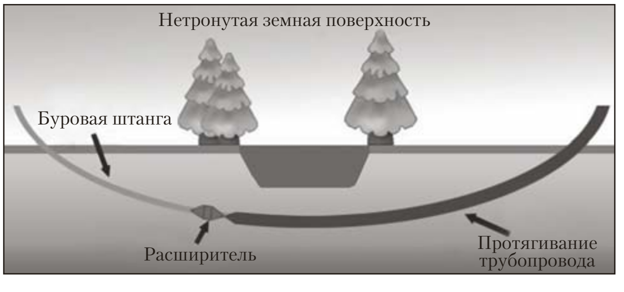

Fig. 6. Horizontal directed drilling

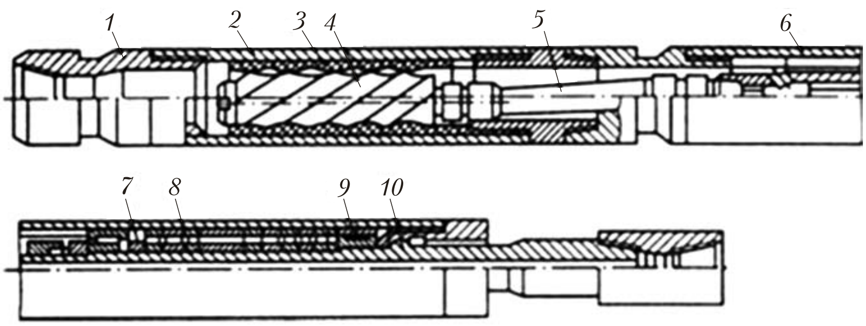

Fig. 7. Single-lobe, single-section motor: *1* — adapter; *2* — housing of the motor section; *3* —stator; *4* — rotor; *5* — driveshaft; *6* — spindle case; *7* — face packer; *8* — multi-row radial-axial bearing; *9* — radial metal rubber bearing; *10* — spindle shaft

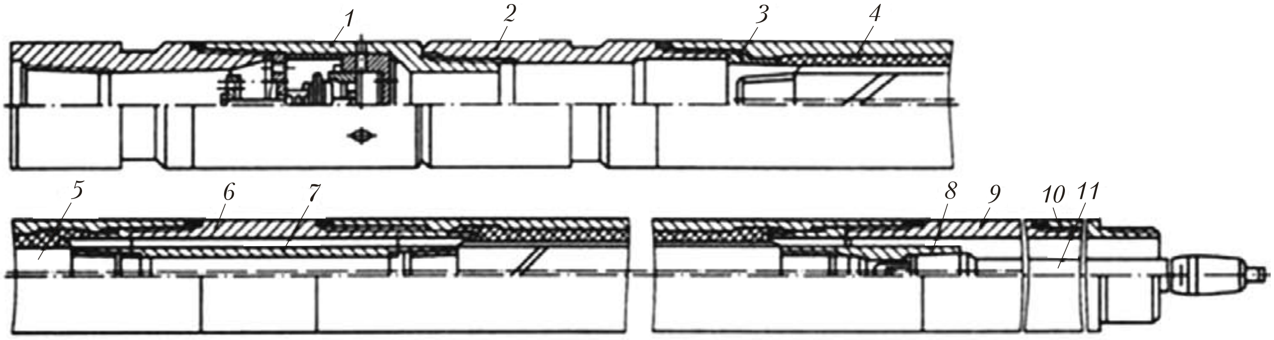

Fig. 8. Two-section screw motor with rigid connection of working bodies: *1* — valve; *2* — coupling adapter; *3* — bushing; *4* — stator; *5* — rotor; *6, 7, 9, 10* — adapters; *8* — coupling; *11* — shaft

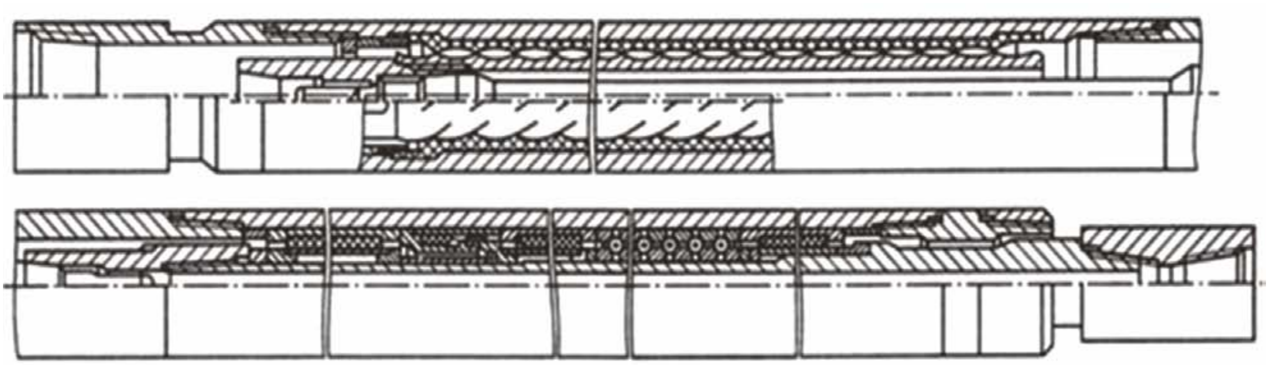

Fig. 9. Driving screw motor with hollow rotor

Stage III: cluster drilling. Application of directional drilling under difficult geographical conditions led to the creation of a new drilling technology, «cluster of multiple drilling» (CD or MD) (Fig. 4).

Stage IV: multihole drilling. Application of directional drilling under difficult geological conditions, as well as desire to gain a significant economic effect led to the creation of technology of multihole drilling (MHD) (Fig. 5).

Stage V: horizontal drilling. Application of directional drilling for drilling wells on hydrocarbons (particularly, in low-permeability horizons) stimulated the creation of deep horizontal wells technology (DHW).

Stage VI: horizontal directed drilling. Application of directional drilling and DHW led to the creation of trenchless technique for laying underground communications with the use of shallow wells bored by hori-zontal directed drilling (HDD) technology (Fig. 6).

Thus, more than 100 years ago, there was a seemingly insignificant breakthrough in drilling technologies. However, later the method of artificial deflection entailed the development of numerous innovations in the drilling industry.

50 YEARS OF SCREW DOWNHOLE MOTOR

Currently, there are two types of drive techniques for rotary drilling of wells: *a)* the top-drive drilling with the drive placed on the ground and *b)* and the down-drive drilling, with the drive located downhole.

In the first case, the ground drive imparts rotary motion to the rock cutting tool through the drill string. Rotating the drill string is very power-consuming. Also, with time, the rotating drill string wears down on the outside diameter.

In the second case, the submersible drive directly transmits the rotation to the rock cutting tool. In this case, the drill string does not rotate, so the down-drive technique is preferable for drilling of deep wells.

Turbodrills, electric drills, and screw engines are used as submersible drives. The turbodrills and electric drills are almost century old, while the screw downhole motor is a relatively new type of submersible motor [20, 21, 22, and 24]. One can mark eight stages of evolution of the downhole drilling motor.

Stage I: the invention of downhole drilling motor (DDM); a single-lobe, single-section motor (Fig. 7). In 1962, M. Harrison (Houston, USA) has designed a volumetric screw hydraulic motor using a Moineau's gyratory screw pump. This DDM is characterized with a high rotation speed.

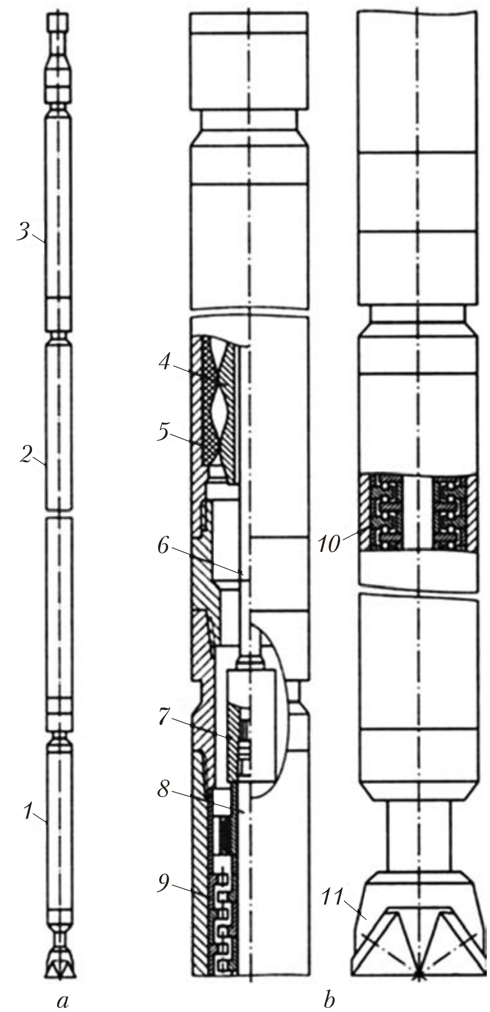

Fig. 10. General view of (*a*) and diagram (*b*) of the modular turboprop engine: *1* — spindle; *2* — turbine section; *3* — screw module; *4, 5* — rotor and stator of screw pair, respectively; 6 — torsion bar; *7* — connection of torsion bar with shaft of turbine section; *8* — shaft of turbine section; *9* — turbine stage; *10* — spindle axial bearing; *11* — bit

Stage II: multiple-lobe motor. A hydraulic downhole motor whose working parts are designed based on a planetary gear driven by the energy of washing fluid. In 1966—70, S.S. Nikomarov, M.T. Guzman and their colleagues (Moscow, USSR) designed a rotary engine having a screw pair with a significantly larger number of lobes, which enabled increasing torque and reducing rotation speed.

Stage III: sectional screw motor. Partitioning of working bodies was one of the most promising ways of increasing the durability of screw pairs (Fig. 8). This technique enables applying DDM under complicated drilling conditions.

Stage IV: controlled DDM with bent sub and curved body. This type of screw motor was designed in connection with the fact that DDM started to apply not only for vertical drilling of deep wells, but also for directed drilling.

Stage V: DDM with an adjustable angle of curvature of the spindle section. This type of DDM was designed for directional and horizontal drilling of deep wells.

Stage VI: DDM with a hollow rotor. This type of screw motor enables reducing length and weight of the motor and improving significantly the stability of the rotor connection to the shaft of the spindle. This design improves energy performance and efficiency and ensures reduced vibration of the motor (Fig. 9).

Stage VII: expanding DDM. This type is based on the conventional downhole drilling motor and has an advanced motor with an increased torque for speeding up the destruction of rocks.

Stage VIII: turboprop engine. The modular turboprop engine consists of three main components: the spindle, the turbine section, and the screw module (Fig. 10). The design foresees different options for aggregation of these components. Depending on tasks, one can use such options: the spindle and the screw module; the spindle and turbine section; the spindle, the turbine section, and the screw module. These options can be assembled both at workshop or directly on wellbore. The modular turboprop engines organically combine the stability of power characteristics and high rigidity of moment curve, which ensures higher performance of bits as compared with the use of turbodrill or screw motor.

Currently, the DDM is effectively used for drilling of deep wells, directed and horizontal wells, for repair of wells, as well as for drilling of cement and sand plugs. The diameter of DDM manufactured varies from 42 to 240 mm.

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ЮВІЛЕЇ ІННОВАЦІЙНИХ БУРОВИХ ТЕХНОЛОГІЙ

Огляд літератури

Розглянуто процеси утворення алмазного породоруйнівного інструменту: крупноалмазної бурової коронки; дрібноалмазної бурової коронки; коронки оснащеної синтетичними алмазами; армованої композиційними матеріалами з використанням алмазів. Наведено етапи інноваційного розвитку бурових технологій.

Ключові слова: алмазна бурова коронка, штучне викривлення ствола свердловини, гвинтовий забійний двигун.

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ЮБИЛЕИ ИННОВАЦИОННЫХ БУРОВЫХ ТЕХНОЛОГИЙ

Обзор литературы

Рассмотрены процессы создания алмазного породоразрушающего инструмента: крупноалмазной буровой коронки; мелкоалмазной буровой коронки; коронки оснащенной синтетическими алмазами; армированной композиционными материалами с использованием алмазов. Приведены этапы инновационного развития буровых технологий.

Ключевые слова: алмазная буровая коронка, искусственное искривление ствола скважины, винтовой забойный двигатель.

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