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DEVELOPMENT OF A BOTTOM HOLE ASSEMBLY FOR HYDROMECHANICAL DRILLING

The solution to the problems of long hole drilling and construction is possible through creation of downhole tools on a fundamentally new ideological basis, involving physical principles and engineering designs unconventional in the field of drilling equipment. It is important to take into account that drilling energy inputs increase with depth.

Following this concept, based on the tasks of geological exploration, a bottom hole assembly is developed and introduced into well drilling, with the design features and technological capabilities focused on a comprehensive solution to the problems of well drilling and construction.

In addition to the outer pipe and core receiver, the bottom hole assembly is equipped with the diamond step drill bits with a separate system of flushing channels, collectively realizing the effect of hydromechanical drilling. By introducing an expander turbulator into the bottom hole assembly to convert an upward fluid flow into a rotary upward flow, the problem of removing drill cuttings from under the step drill bit is effectively solved.

Production tests of the bottom hole assembly with core sampling were carried out at a complex deposit in Central Kazakhstan, in full-hole drilling for groundwater in the area of the Almaty Region.

According to the results of the production tests, hydromechanical drilling of wells is especially effective in case of using the diamond step drill bits. The presence of an expander turbulator in the bottom hole assembly makes it possible to significantly increase the intensity of removal of drill cuttings from the bottom hole, especially in full-hole drilling.

Keywords: *drilling, well, fluid, hydromechanical drilling, bottom hole assembly, drill bit, expander turbulator*

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Introduction

The objectives of long hole drilling with high-quality geological sampling are the reduction in energy input and the structurally intact coring.

The long hole drilling and construction at a higher quality level is possible using physical principles and resources earlier little-known in the field of drilling technique. One of such resources is energy of high-velocity water jets which burst from guide channels under high pressure and fracture materials.

A diagram of an experimental plant generating high pressure of water by means of two-step compression is proposed in [1]. It has the following parameters: water pressure of 100–500 MPa; jet guide nozzle diameter of 0.2–0.8 mm; guide nozzle–rock spacing of 2–200 mm.

Hydraulic percussion drilling technology enjoys intensive development in long hole drilling in coal mining. The mechanism of rock fracture in this technology consists in formation of a ring-shaped loosening zone in rock under the action of high-velocity particles and water jet impacts. As strength of rock lowers with formation of grooves, solid rock can be effectively fractured by cutting action of a drill bit [2]. The jet impact drilling technology is a noncontact rock fracture method used to increase penetration rate [3].

The study [4] describes application results of the radial jet drilling technology in five horizontal holes in a quarry. It is found that the geometry of the jet nozzle influences the penetration rate. Emitted jets intersect fractures in rocks at different angles, which affects the penetration rate of drilling. Drill cuttings removed from holes can be used to assess penetrability of rocks.

The research [5] shows that water jet drilling, as against rotor drilling, can increase penetration rate by 40% at decreased mechanical force applied to PDC drill bit by 30 to 52%.

There are many factors that govern destructive effect produced by water jets, including the impact force which should obligatory taken into account. In order to study the influence exerted by the shape of a contact surface on the jet flow pattern and on the impact force, the tests of the hole–jet impact planes were carried out at different pressures [6]. The backwater flow after jet impact on different-shape contact surfaces is reflective of the influence exerted by the contact surface shape on the impact force.

The research of destructive drilling by a high-pressure jet drill bit [7] describes branch drilling using downhole high-velocity jet nozzles. The structural parameters of the nozzles are calculated.

A special place amongst the water jet technologies used in mining is the method of hydromechanical rock fracturing [8] which integrates mechanical cutters or cones and high-velocity water jets. In this method, the water jet properly oriented relative to the power tool reduces the load applied to the tool, which expands the range of use of this method in fracture of strong rocks.

Hydroabrasive cutting of rocks involves a joint effect exerted on a material by high-velocity water jets and abrasive particles which are inside the jets [9, 10]. As a result, a slot of a certain depth and width is cut in a rock. The depth of the slot is 3–8 times larger than the depth of a cut in cutting with high-velocity water jets without an abrasive component added.

A series of implemented experiments proves that penetrability of rocks is a decisive factor in high-efficiency water jet drilling [4, 11].

An attempt to initiate and increase fractures in rocks by the joint mechanical and hydraulic impact was made in [12]. The rock fracture tests used the high-pressure water jets and roller cone bits with tungsten carbide inserts. It is found that the size and shape of an insert have a material effect on the intensity of fracturing. The authors deduce an inference that fractures present at the contact of the jet and rock facilitate penetration of water deeper in rocks at bottom hole. This effect is also possible in dense rock drilling if a pattern of cracks and grooves is preliminary created on the rock surface [13, 14].

The goal of this research is to develop a bottom hole assembly for hydromechanical well drilling.

Objectives:

Formation of a structural diagram of a bottom hole assembly for hydromechanical drilling;

Technical and economic performance evaluation of bottom hole assembly prototypes in hydromechanical drilling.

Research methods

Using the input data covered in the Introduction, configurations of bottom hole assemblies meant to implement the hydromechanical drilling effect were designed.

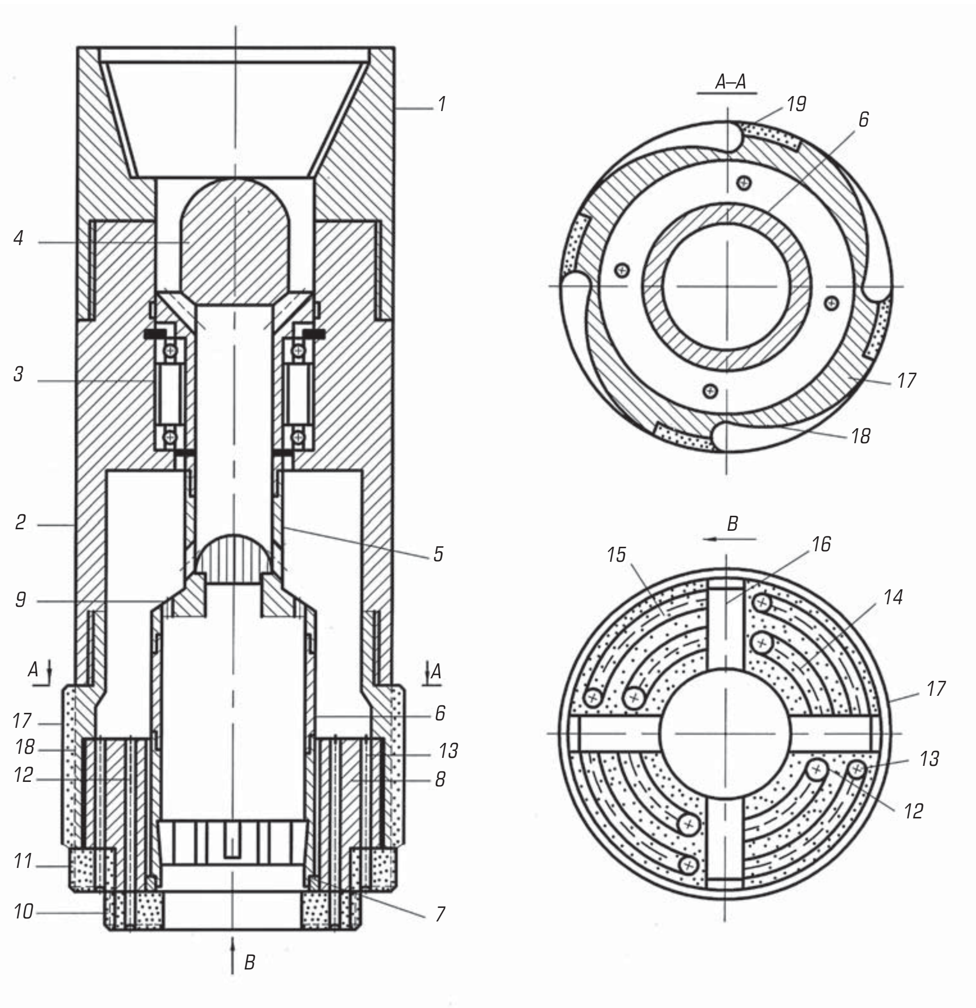

Fig. 1. Bottom hole assembly of hydromechanical drilling with coring

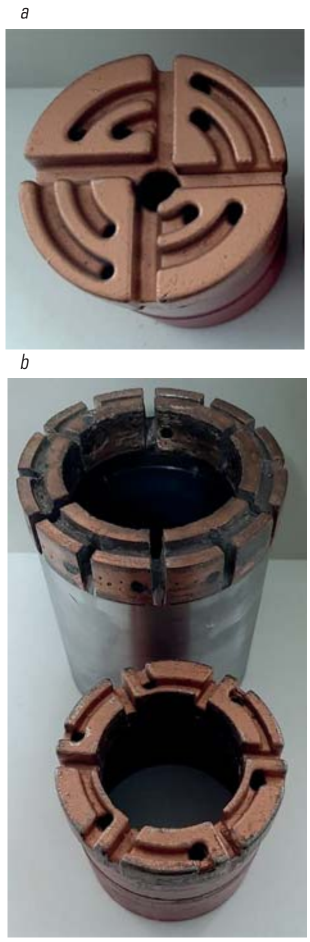

Fig. 2. Diamond drill bits for hydromechanical drilling:
a – with full hole; *b* – with coring

The bottom hole assemblies were designed pursuant to standard dimension of mining equipment and using procedural concepts adopted in general machine construction, namely, structural continuity, application field, method of inversion and linking.

On this basis, the designed and practically approved bottom hole assembly consisted of an outer barrel, inner barrel (core receiver), diamond step drill bit and an expander turbulator.

The structural feature of the diamond step drill bit is a separate system of lateral flushing channels which open to ring grooves on the step bit butt end outside the zone of core forming. In this case, hydraulic impacts of high-pressure flushing fluid flow make a network of cracks on the stepped bottom hole, which weakens the impact strength of rocks, and this shows up notedly in drilling in soft and incoherent rocks.

The bottom hole assembly is added with an expander turbulator, with longitudinal external ledges to form cavities, which expand in the line of rotation and are closed by semicircular walls. After the expander turbulator was set between the diamond bit and outer pipe, the upward fluid flow became a rotary upward flow. This ensured intense removal of drill cuttings from the bottom hole by an upward flow force source generated in the annular region between the drilling string and the hole walls.

The structural features of the component elements provide certain technical capabilities of the bottom hole assembly, namely: transition to low values of axial load and rotation frequency of the drilling string, accompanied with reduction in energy input of hole making, preservation of shape and design path of the holes and increased stability of the hole walls in terms of sloughing and caving.

The 3D modeling of a diamond step drill bit used CAD system Compass 3DV14 Home conformable with the standards of EAEU. ArtCAM software was employed in manufacture of parts.

Planning of experimentation scope in field testing of the prototype bottom hole assembly in operating wells, as well as processing and systematization of the results assumed the concepts of probability theory — mathematical expectation, event probability, dispersion and accuracy of estimation.

Results and discussion

The bottom hole assembly of hydromechanical drilling with coring (**Fig. 1**) comprises an adapter *1* connected to an outer pipe *2* with an inner radial bearing *3*-centered rod *4* with channels for power fluid. At the bottom end, the rod *4* is connected via a hydraulic control valve *5* to a core receiver *6* with its bottom end entered in a stabilizer *7* set in the cavity of the diamond drill bit *8*.

At the top of the hydraulic control valve *5*, there are vertical orifices *9* connected with the internal walls of the core receiver *6*.

The diamond step drill bit *8* contains a cutter step *10* and a bulged-out back step *11* with the longitudinal channels *12* and *13*, respectively, entering the ring grooves *14* and *15* in the cutter step *10* and back step *11* and intersected with the gutters *16*.

Between the diamond drill bit *8* and outer pipe *2*, abutted on the back face of the bulged-out back step *11*, an expander turbulator *17* is situated, with the longitudinal ledges *18* which expand in the line of the cavity rotation and are closed by semicylindrical walls *19*.

Operating results of hydromechanical drilling bottom hole assembly and series-produced core-drill fittings NQ and HQ

Rock-breaking tool	Drilled length, m	Drilling regimes			Penetration rate, m/h	Core recovery, %	Energy input, kW/h
		Axial load, kgf	Rotation frequency, min^{-1}	Flushing fluid flow rate, l/min			
1. Series: (KB-IZAT) diameter 75.6 mm (NQ)	300	1800–2000	600–700	60–70	3.1–3.3	93	1.6–1.8
diameter 95.6 mm (HQ)	242	2200–2500	500–600	80–90	2.8–3.0	93	2.1–2.4
2. Hydromechanical drilling bottom hole assembly with diamond step dill bits: diameter 75.6 mm	275	400–600	400–500	35–40	2.7–3.0	98–100	0.7–0.9
diameter 95.6 mm	181	700–900	300–400	60–70	2.5–2.7	98–100	1.2–1.5

Figure 2 shows diamond drill bits for hydromechanical drilling with full hole (*a*) and with coring (*b*).

At the beginning of drilling, the power fluid flows through the adaptor *1* and, along the channels of the rod *4* and control valve *5*, enters the space between the core receiver *6* and outer pipe *2* which is rotated by the bearings *3* around the core receiver *6* immobilized by the stabilizer *7*.

Then, the pressure flow, along the longitudinal channels *12* and *13* in the diamond drill bit *8*, comes under the butt ends of the cutter step *10* and back step *11* and enters the ring grooves *14* and *15* intersected with the gutters *16*.

Underneath the cutter step *10* and the back step *11*, under the action of the pressure fluid flow, a fracturing pattern appears on the step-wise bottom hole due to reduced resistance of rocks to fracture, which is especially pronounced in drilling in soft rocks. Simultaneously, a portion of the flow, via the vertical channels of the hydraulic control valve, comes to a gap between the core and the walls of the core receiver *6*, and acts as a liquid lubricant which facilitates the core motion.

Outgone from under the diamond step drill bit *8*, the uprising flow with drill cuttings enters the longitudinal ledges *18* closed by the semicylindrical walls *19* of the expander turbulator *17* and passes into a rotational upward motion with intense removal of drill cuttings from the bottom hole and with formation of an upward force source of the flow in the annular clearance between the drill string and the hole walls.

The field tests of the prototype bottom hole assembly were carried out at a complex deposit in Central Kazakhstan. The geological section of the deposits consists of siltstone with strings of quartz, calcite and barite, veins of metachert, siliceous argillite, glomerates, quartz–carbonate and siliceous schist. The average drillability of rocks is 8–5. The drill hole angle is 70%.

Drilling used drill rig model CDH-1000 with flushing pumps NBZ-120/40 equipped with gauges. The flushing fluid was process water.

The data base for the analysis was taken as the performance of the series-produced core-drill fittings NQ and HQ in operation in comparable geological and geotechnical conditions of drilling.

The operating results of the prototype bottom hole assembly and core-drill fittings NQ and HQ are compiled in **Table**.

Figure 3 shows pictures of the core sampled by the hydromechanical drilling bottom hole assembly with a diameter of 95.6 mm (Fig. 3, *a*) and by the core-drill fittings HQ with the diamond rock-breaking tool KB-IZAT with a diameter of 95.6 mm (Fig. 3, *b*).

By the criterion of the core lumpiness per one drilling meter in the comparable geological and geotechnical conditions, it is seen how the hydromechanical drilling bottom hole assembly is more efficient in providing a structurally integral core as against the series-produced core-drill fittings HQ.

In full-hole drilling for groundwater, the bottom hole assembly comprised: a diamond step drill bit with the cutter step diameter of 95.6 mm and the back step diameter of 215.9 mm, with impregnated diamonds, an expander turbulator and an outer pipe with a diameter of 196 mm.

The geological section represented tuff, loam and sandstone. The drillability of rocks was 7.9. The drilled hole was vertical.

The drilling regime included the axial load of 600–800 kgf, the rotation frequency of 100–150 min^{-1}, the flushing fluid flow rate of 90–110 l/min and the fluid pressure of 1.2–1.8 MPa.

The length of the production drilling was 30 m and the penetration rate was 3.0–3.5 m/h. No difficulties or accidents took place during the test drilling.

Design features and technological capabilities of the prototype bottom hole assembly of hydromechanical drilling materialize through:

• advanced fracturing of the step bottom hole, replicating the step shape of the diamond drill bit, accompanied with reduction in rock resistance to fracture;

• protection of coring from the power fluid impact and occurrence of a liquid lubricant between the core and the core receiver;

• enhanced intensity of removal of drill cuttings from the bottom hole with elimination of overgrinding.

The production testing proves that the hydromechanical drilling bottom hole assembly designed in conformity with the standard dimension of drilling for groundwater is efficient in operation in difficult conditions of alternating hardness rocks.

Efficiency of the bottom hole assembly as against the series produced core-drill fittings NQ and HQ shows up as: the reduced energy input; the structurally integral coring and the increased penetration rate.

The bottom hole assembly with the larger diameter coring, better resistive to fracture and erosion by water can be used in mine shaft sinking and in prospecting/ventilation/water drain hole-making.

Summary

After reviewing the trends of the drilling technique and technology development in the world, and based on the problems of deep-level geological exploration, the bottom hole assembly meant for the end-to-end long hole drilling is designed, manufactured and field-tested.

The application conditions and the performance of the bottom hole assembly are governed by its design features, namely, by the step shape of the diamond drill bit, by the separate feed of the pressure power fluid to the step bottom hole and by the turbulation of the upward fluid flow together with drill cuttings.

In specific geological and technical conditions of drilling, the production test results have proved the applicability and efficiency of the drilling bottom hole assembly.

Conclusions

The prototype bottom hole assemblies for hydromechanical drilling are designed and manufactured.

As compared with the series-produced core-drill fittings NQ and HQ in comparable geological and geotechnical conditions of operation, the bottom hole assembly of hydromechanical drilling provided reduction in drilling energy input to 40–50%. The integral core recovery reaches 98–100% as against 93% in drilling by the series-produced core-drill fittings NQ and HQ, and the increase in the penetration rate of drilling attains 8–9%.

Fig. 3. Core sampled by:
a – hydromechanical drilling bottom hole assembly – 95.6 mm; *b* – series-produced core-drill fittings HQ with diamond rock-breaking tools KB-IZAT Ш 95.6 mm

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