Self-contained drilling assembly

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Abstract. Based on the analysis of technologies and equipment for the construction of borehole, the necessity and advantages of self-contained drilling assemblies are revealed and substantiated. The experience of engineering and application of such facilities is generalized. The key requirements to be imposed on a self-contained percussion drilling assembly are formulated. This paper can awaken interest of researchers and practitioners in mining machine engineering.

1. Introduction
The basic process in mineral exploration and mining is drilling. Drilling may be of various diameter, length and direction in rocks having different physical and mechanical properties. Advanced technologies in the mining industry impose new standards on drilling techniques and equipment, such as increased penetration rate, improved accuracy, borehole path changeability, lower weight and smaller size of drilling tools, operating cost saving, etc. [1, 2] To this effect, researchers persistently make every effort to improve and invent technologies and equipment for drilling.

2. A new and promising method of various diameter hole-making
A new and promising method of various diameter hole-making is drilling using machines equipped with a centerline for removal of drilling mud [3-5]. This method is advantageous for applicability in difficult geological conditions, under large inflows of water, in permafrost, or in exploration with core sampling. Another novel method offering high potential for drilling holes of large diameters to 3–6 m is using tangential–rotary picks was proposed at the Institute of Mining, SB RAS [6]. Evolvement and commercial-scale introduction of these methods can spur technological innovation in the mineral mining industry [7-10].

The routine method of drilling in present-day mineral mining is rotary–percussion drilling using drilling assemblies equipped with remote or down-the-hole pneumatic, hydraulic or another type drive. Rock breaking in this case takes place under the dynamic or static impact applied to the rock-breaking tool which is rotatable by the rock drill or drill pipe column. R&D activities aimed to improve rotary–percussion drilling equipment in Russia and abroad focus on finding and studying patterns of efficient rock–tool interaction [11-14], analysis of duty cycles of pneumatic [15–19] and hydraulic [20, 21] percussion machines, automation of drilling process, development of scientific framework for drilling automation engineering, as well as optimization of rock mass impact parameters depending on variable bottomhole conditions [22–26].

Advantages of the rotary–percussion drilling technologies are undeniable though large-size and expensive equipment sometimes prevents its application, for instance, in drilling in mine openings of
small cross-section. In such cases, it is expedient to use self-contained drilling assemblies. Benefits of the latter include: avoidance of drill rigs with rotator and feeder, and, thereby, elimination of auxiliary operations associated with extension and tear-down of drill columns; remote control of the rodless drilling assembly by an operator located far from the hole mouth, which improves mining safety; lower price of the drilling equipment and operating cost saving due to the absence of a drill rig; simple handling of the drilling assembly in confined areas of mines (which allows using this equipment promptly in case of rescue in emergency situations); drilling of various-purpose holes in small cross-section underground openings, when the known drilling machines are low-efficient or inapplicable; controllability of a number of rodless drilling assemblies by a single operator, which raises productiveness of labor in drilling.

3. The rodless drilling assemblies
Application of rodless drilling assemblies is exemplified below.

![Figure 1. Rodless drilling technologies and equipment.](image-url)
A widely spread method of drilling in compactable soil is vibro-impact punching (Figs. 1a and 1b). To this effect, it is possible to use air drills designed at the Institute of Mining, SB RAS. High capacity and reliability of these machines, as well as easy servicing and adaptability to confined site conditions are the major advantages of this equipment [27, 28].

The task tool of the air drills is a cylindrical body with inserted piston forced by compressed air to make to-and-fro motion and to hit the body. Under the impacts, the air drill body penetrates soil and makes a hole in it. Backward running of the machine is prevented by the friction forces on the side faces of the body. Thrust reverser enables backward motion.

Hole-making in compactable soil can also use soil drifters (Figure 1d). Such drilling facilities include a gearmotor, output and gear shafts, eccentric conical and cylindrical rollers, serially turned around the longitudinal axis of the drifter and capable of independent rotation, and sealer elements placed between the rollers. Shaft rotation makes the drifter move on in soil. The conical rollers make a hole and the cylindrical rollers expand and trim it (Figure 1c). The conformity of the helix leads, formed by points around which the rollers are turned, and the helix lead of roll of the rollers on the hole wall, as well as the cone angle of the rollers and the fitting conical helix leads stabilizes the tool and eliminates its slip in soil penetration.

For drilling in incompatible and strong rocks, an autofeed device is proposed for DTH drills [29]. This device has a front-end brake to prevent movement of the drill toward the bottomhole. The device is driven toward the bottomhole by the impacts applied to the rock-breaking tool and the body with brake. The brake represents a spring cutting cylinder which is pushed apart and remains in the hole when the device is removed from it. The same operating mode is a feature of the structural layout of the rodless DFH rotary–percussion drill (Figure 1d). Moreover, there is another back-end brake made as a row of sawtooth plates pressed to the hole walls by the center-located helical spring.

Inventor E.P. Varnello, Institute of Mining, SB RAS designed rodless air-hammering assembly BPP-1A [29] (Figure 1e) for drilling in coal and rocks having strength up to 30 MPa. The hammering piston inside the body moves to and fro under the action of compressed air and hits the rock-breaking tool and the front end of the body, which advances the assembly along the hole. The back-end brake prevents unwanted displacement of the body in the line of the bottomhole. Assembly BPP-1A was tested in mines. The assembly operated without any fault during the tests. Drill holes were cylindrically shaped and straight lined. Specifications of the drilling assembly are presented in Table 1.

| #   | Description                             | Value     |
|-----|----------------------------------------|-----------|
| 1   | Drill hole diameter, mm                | 125       |
| 2   | Drill hole length, m                   | 50        |
| 3   | Rated compressed air pressure, MPa     | 0.6       |
| 4   | Blow energy, J                         | 180       |
| 5   | Blow frequency, Hz                     | 11.1      |
| 6   | Compressed air flow rate, m³/s         | 0.135     |
| 7   | Average penetration rate, m/s          | 3.3 x 10⁻³|
| 8   | Assembly length, mm                    | 1618      |
| 9   | Assembly weight, kg                    | 53        |
| 10  | Starter weight, kg                     | 32        |
| 11  | Reverser                               | Available |
| 12  | Clean-out                              | Air       |
| 13  | Hole inclination from the horizon      | 0–90      |

Table 1. Specifications of rodless drilling assembly BPP-1A.

The Institute of Mining, SB RAS proposed also the method of adjustable path drilling (Figure 1f) [30, 31]. Here, there is a special rock-breaking tool, air/fluid or other source-driven hammering devices, setting tool and actuation/switch-over control. During drilling, impactor 1 alternately hits one of the sides of rock-breaking tool 2, which makes the tool turn in the force-and-aft plane and, thereby, break
rocks on the bottomhole. At a certain turn angle, switch-over 4 actuates impactor 1 to hit the other side of rock-breaking tool 2. Fixtures 5 and 8 hold, fixture and press the tool. The operation control is implemented using hoses 6 and 7. The change in the drilling path is possible through the special operation algorithm of the impactor.

In this drilling technique as against the other existing methods, penetrators of the rock-breaking tools deliver oblique impacts on rock, which considerably lowers energy input in the fracture process [32]. Furthermore, there is no need to rotate the rock-breaking tool around the hole axis, which saves from using a pipe column. The tool is pressed to the bottomhole and is advanced in the hole using a spacer. A drill rig is also withdrawn from the process, which considerably cuts down the cost of the equipment.

In terms of the self-sustained drilling assembly design, researchers E.P. Rusin and G.N. Khan from the Institute of Mining, SB RAS studied lengthwise rotary (screw) impact [33]. In this case, a hammering body moves progressively with simultaneous rotation around its own longitudinal axis. The screw impact is transmitted to a rock-breaking tool and, then, to rock. Rock is fractured in oblique percussion drilling, which is less energy-hungry and can enhance drilling efficiency at the same energy consumption [32]. It is possible to eliminate motor to rotate the assembly and, accordingly, the drilling column. As a result of the experimental research, a promising engineering solution and functional diagram were proposed for efficient screw impact (Figure 1g).

Hammer 1 and shank 2 of drill bit 3 make a nonself-stopping crew pair which carries out alternate motions with simultaneous leftward rotation. The colliding ends of hammer 1 and bit 3 are manufactured as screw surfaces 4 and 5, respectively, with opposite (rightward) rotation.

4. The engineering solution for the implementation of self-contained rodless percussion drilling assembly

Technological innovations in mineral exploration and mining impose new requirements on drilling technology and equipment. This calls for more extensive research in the field of self-propelling drilling assembly design and engineering. The currentness of the research is evident and indubitable.

Based on the review and analysis of the developed and tested drilling assemblies for soil and rocks, the design philosophy principles formulated for a new self-sustained percussive drilling assembly include: implementation of percussion drilling as the least energy-consuming method owing to efficient design of rock-breaking tool, with high potential to enhance drilling capacity; use of air, fluid or combination sources of energy for hammering and clean-out; advance and removal of the drill assembly by impacts, which eliminates the assembly jam while step-type feeders can cause jamming of the assembly in the hole, or its deviation from a preset direction; no in-built rotator, which essentially simplifies design and enhances operating reliability of the drilling assembly (it is necessary to find new engineering solutions to avoid an in-built rotator to make the rock-breaking tool rotate during drilling.

Based on the review and analysis of the domestic and foreign research, an engineering solution was proposed for the self-contained rodless percussion drilling assembly in conformity with the design philosophy principles above. The functional diagram of the assembly is shown in Figure 2.

The assembly is composed of a percussion mechanism, an original-design rock-breaking tool with cutting inserts and a spacer (not shown in Figure 2) to prevent movement of the assembly in the direction from the bottomhole.

During drilling in hole 1 in rock mass 2, rock-breaking tool 3 is pressed to bottomhole 4. Impactor 5 is actuated and strikes with hammer 6 at end 7 of rock-breaking tool 3. The rock-breaking tool moves forward under the action of the blows and simultaneously rotates around its own axis in the transverse plane relative to hole 1. The rotation of the tool takes place due to the torque generated by the reaction forces of rock mass 2 in interaction with special spiral-shaped
blades 8 equipped with cutting inserts 9. The spent energy source is used to clean bottomhole 4 and to remove drilling fines from hole 1 via channel 10.

The feature of this design is that rotation and progressive advance of the rock-breaking tool in the hole are implemented by the same hammering unit, which enables lower energy input in the drilling process. Damage takes place over the whole area of the bottomhole under oblique impacts of the tool.

Efficiency of the proposed drilling assembly, rock-breaking tool design and the tool–rock interaction parameters in drilling can be defined by physical modeling of rock destruction by impacts, which requires an original test-bench to be developed for the experimental studies. Such studies aimed to determine conditions for this percussion drilling technique, as well as to adjust geometry and energy of the new equipment are planned for the nearest future.

5. Conclusions
The author has reviewed the technologies and equipment in rodless drilling in soil and rocks. It is of the current concern to engineer self-propelling and self-contained drilling assemblies for medium and high strength rocks to ensure and advance technological innovations in mineral mining. The basic requirements imposed on the self-contained percussion drilling assembly being designed are formulated.

The engineering solution for the implementation of self-contained rodless percussion drilling assembly is proposed. The feature of the proposed design is that rotation and progression of the rock-breaking tool in a drill hole are executed by the same hammer source.

The avenues of the further research are identified to determine conditions of the proposed drilling method and to adjust geometry and energy characteristics of the novel drilling machine.

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