

Enhancing down-the-hole air hammer capacity in directional drilling

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Abstract. The authors discuss the issue connected with drilling trajectory deviation and present the technique of rotary–percussion drilling with a down-the-hole air hammer. The article describes pilot testing of the air hammer drill PNB76 in Berezovskaya Mine. The ways of improving the air hammer drill are identified, and the basic diagram and R&D test data are given.

1. Introduction

One of the problems in hole-making in coal mines is to ensure straight-line drilling. A shortage of rotary drilling rigs is limited application in hard rocks [1]. Of special concern is drilling in hard rocks for the purpose of directional hydraulic fracturing in backs [2]. Furthermore, drilled holes often miss a targeted excavation and are lost, which worsens the drilling performance. With any method used, drilling trajectory is generally deviated due to the increased axial pressure exerted on a drilling assembly.

It is possible to ensure pre-set path of hole-making with the method of directional drilling [3, 4]; on the other hand, it needs extra expenses for positioning devices and tools meant to change travel trajectory of the drill head are required. A promising approach to straight-line hole-making is rotary–percussion drilling using down-the-hole air hammer drills. As compared with the other techniques, this method allows minimum pressing force between the drill head and the hole bottom, as well as low speed and minor torque transmitted to the drilling assembly, which enables minimized distortion of hole trajectory and ensures straight-line drilling [5].

2. Experimental research procedure

It is advisable to reduce the load on the drilling assembly even more with the down-the-hole air hammer drills having minimum diameter for the given drill rig. In this case, forces induced under percussive interaction between the drill head and the hole bottom are applied closer to the center of the hole bottom, which mitigates bending moments transmitted to the drilling assembly. Creation of a small-diameter hammer drill is a complex technological problem in as much as the cross dimensions of down-the-hole air hammer drills are strictly limited in this case and the possibility to generate acting faces of the wanted size is small. The scheme developed with the aim to enlarge acting faces of



an air hammer drill contains a number of chambers and the striking part area subjected to pressure is larger than the area of cross section of the housing cavity [6, 7].

Furthermore, straight-line drilling needs more uniform distribution of impact load at the hole bottom. The latter is achieved when the striking part and the tool collide at the center and the impact load is uniformly distributed in these parts. The central collision reduces lateral oscillation of the air hammer drill, which is beneficial for the straight-line drilling performance.

Based on the considerations presented above, at the Institute of Mining, a small-dimension air hammer drill PNB76 was designed [8, 9, 10]. Under order of Berezovskaya Mine, Spetsgidravlika LLC manufactured three PNB76 machines with the drill bits KNB76 (figure 1) for operation with the drill rig SBR-400 [11].



Figure 1. R&D model of the air hammer drill PNB76 with the drill bit KNB76.

After testing of serviceability in a mine, the air hammer drills were delivered to Berezovskaya Mine, Kemerovo Region, in autumn 2016. The commercial testing involved full-bottom process hole drilling with a diameter of 76 mm in rocks having strength of 90–120 MPa. The hole was intended to bypass water from an excavation to a lower-level drive. Drilling used the drill rig SBR-400 with the drill rods having diameter of 50 mm.

Drilling involved two methods, namely:

- rotary drilling with cutting bits;
- drilling with the down-the-hole air hammer drill equipped with a drill bit with spherocylindrical tungsten-carbide inserts.

3. Results and discussion

With the first method applied, the cutting bits failed within the first meters of drilling. Drill bits designed at Gornyi Instrument, Sibselmash and by specialists of Berezovskaya Mine failed too.

Drilling under the same conditions but using the down-the-hole air hammer drill PNB76 (figure 2) showed stable operation of the machine with the reliable lock mode. The power source for the air hammer drill was diesel compressor of an explosion-proof design. The compressed air pressure was 0.4 MPa at the flow rate of 6.0 m³/s. The 76 mm-diameter hole drilling rate in rocks having strength of 110–120 MPa made 70 mm/min. The drill rig SBR-400 operated in the regime of moderation. The fluid pressure was not higher than 5.0 MPa in the pressure line and not higher than 3.5 MPa in the feed line, which conformed with the driving torque not more than 300 Nm at the drilling assembly and the pulldown of the latter not more than 300 kg. Thus, the air hammer drill implemented the main drilling functions, and the detrimental effect of high torsional moments, which contributed to drilling deviation from a preset trajectory, was reduced.

The process hole between excavations was drilled by the air hammer drill in three shifts. The hole was 40 m long, and it preserved the preset trajectory.

The further hole drilling with the air hammer drill PNB76 was terminated due to failure of the bits KNB76. The cause of the failure of the bits was that the hammer drill operating at the low air pressure

developed impact energy that appeared to be lower than the energy required for rock destruction, and the bits suffered from high-rate wear as a result. Unlike edge bits, bit inserts need higher loading. From practical knowledge of efficient rock breakage, the load on bit inserts is to be not less than 10 J. Inconformity with this standard is the cause of poor performance of drilling equipment.



Figure 2. Actual drilling by the drill PNB76 and the drill rig SBR-400 in Berezovskaya Mine, Kemerovo Region.

Based on the full-scale test data, some conclusions had been drawn, namely:

- directional straight-line drilling in hard rocks is feasible with the down-the-hole rotary-percussion air hammer drills;
- in order to ensure efficient drilling of holes with a diameter of 76 mm, it is required to increase impact energy developed by the proposed air hammer drill by 1.5–2 times based on improvement of its design and build-up of feed line pressure to 0.8–1.0 MPa;
- the new design of a bit with the tungsten-carbide edge inserts will enable efficient utilization of the method of rotary-percussion drilling;
- regular sharpening of the edge bits is required when dulling area reaches 3 mm.

In accordance with the conclusions drawn and based on the full-scale tests in Berezovskaya Mine, the Institute of Mining implemented design improvement for the air hammer drill PNB76 and engineered a new drill bit.

Aiming to increase energy of the air hammer drill at the pressure to 0.6 MPa, the air distribution system is equipped with an elastic valve intended to build-up pressure in the power stroke chamber [12, 13]. The layout of the improved design air hammer drill PNB76 is demonstrated in figure 3.

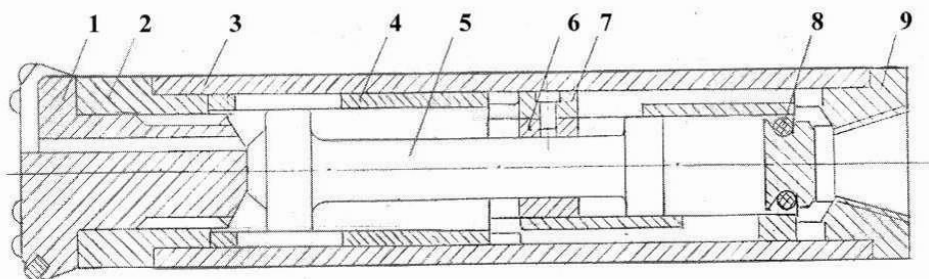


Figure 3. Improved layout of PNB76 hammer: 1 – drill bit; 2 – axle box; 3 – housing; 4 – front casing; 5 – striking part; 6 – C-ring; 7 – back casing; 8 – elastic valve; 9 – adapter.

This design allows the air hammer drill to operate at the standard pressure of 0.6 MP and under an increased pressure of 1.2 MPa, which enhances the machine generality. This approach makes it possible to update both small-diameter and large-diameter hammer drills. The design of the edge drill bit is shown in figure 4.

The R&D model of the modernized air hammer drill PNB76U was tested in a laboratory (figure 5).

During the tests, diagrams of pressure in the chambers of PNB76U air hammer drill equipped with an elastic valve were recorded at the air pressure of 0.6 MPa. These diagrams are presented in figure 6 in comparison with the pressure diagrams recorded for the air hammer drill PNB76 without the elastic valve.



Figure 4. Edge drill bit.

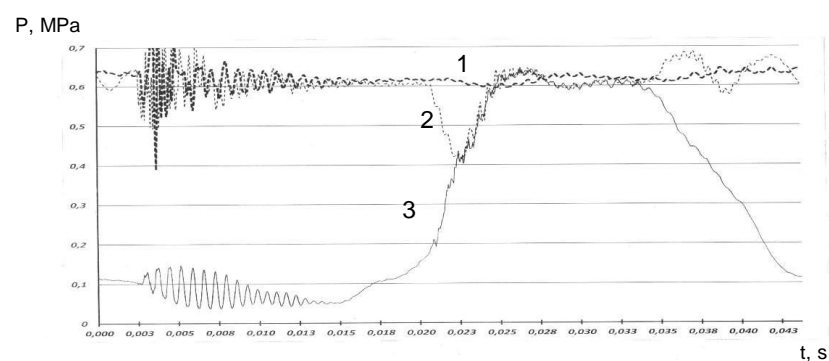


Figure 5. Tests of PNB76U hammer on the vertical test bench GD-251.

Apparently, pressure in the power stroke chamber at the end of the stroke is considerably higher in the air hammer drill PNB76U than in PNB76. This is the source to increase average pressure in the power stroke chamber and, accordingly, to enhance energy performance of the machine.

It is seen in the pressure diagram of PNB76U air hammer drill that the pressure difference between the feed line and the power stroke chamber is sufficient for timely actuation of the elastic valve, which ensures reliable start and operation of the machine. It is noteworthy that the time of the working cycle becomes shorter, which increases the impact frequency and the air hammer drill capacity.

After processing the diagrams using the known procedure [14], the main energy parameters of the two machines are summarized in table 1 below.



(a)

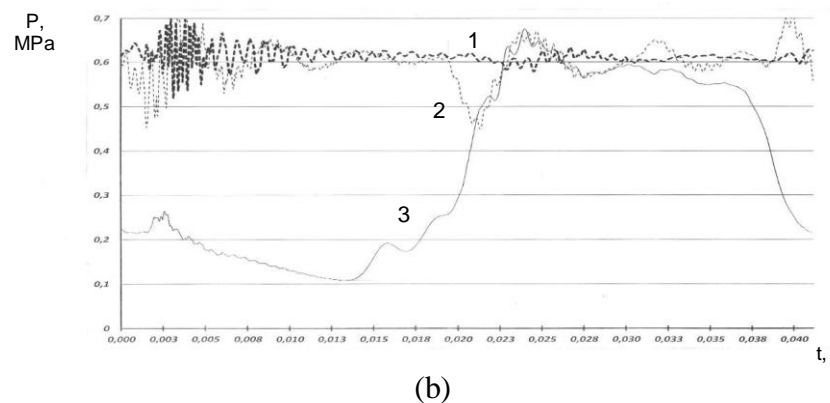


Figure 6. Pressure in the chambers of (a) PNB76 hammer drill without the valve and (b) PNB76U hammer drill with the valve: 1 – feed line; 2 – idle stroke chamber; 3 – power stroke chamber.

Table 1. Parameters of air hammer drills.

Parameters	PNB76 (without valve)	PNB76U (with valve)
Outer diameter of housing, mm		63.5
Length (without drill bit), mm		675
Weight		1.45
Air pressure, MPa		0.6
Impact energy, J	40	64.8
Impact frequency, min ⁻¹	1371	1456
Impact capacity, W	914	1573

After the tests, trial drilling using the drill rig NKR100M was undertaken in a block of granite having strength of 140 MPa (figure 7). Penetration rate made 100 mm/min.



Figure 7. Trial drilling in granite with PNB76U air hammer drill and NKR100M drill rig.

4. Conclusion

Thus, the basic diagram of the air hammer drill PNB76 allows including the elastic valve to enhance energy performance at the same capacity of the machine, namely, closed-type operation with the full exhaust of spent air toward the drill hole bottom, which improves removal of drill cuttings and enhances the hammer drill durability. During operation of the air hammer drill at the air pressure of 0.6 MPa, the unit impact energy is increased by 62 %, impact frequency—by 6 % and the impact capacity – by 72 %. These enhancements enable efficient operation of the air hammer drill both under standard and increased pressure of compressed air.

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