Air distribution system with the discharge action in the working cavity of downhole air hammer drills

VV Timonin, SE Alekseev, DI Kokoulin and B Kubanychbek
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: timonin@misd.ru

Abstract. It is proposed to carry out pre-mine methane drainage using underground degassing holes made by downhole air hammer drills. The features of downhole air drills are described. The downhole air drill layout with the simple-shape striking part is presented with its pluses and minuses. The researchers point at available options to eliminate the shortcomings. The improved layout of the downhole air hammer drill is suggested. The paper ends with the test data on the prototype air hammer drill, its characteristics and trial drilling results.

Hammering-action machines are long and successfully used in different rock drilling in surface and underground mines.

In coal mines, efficient operation of fully mechanized longwall system requires reducing methane concentration in mine air. This is achieved by pre-mine drainage and intense ventilation in roadways and mined-out area. The most productive method of pre-degassing is drainage hole drilling in a future extraction panel from delineating roadways. This method allows long small-diameter drilling [1].

In the mid-1900s in Russia, for the first time in the international practice, pilot air hammer drilling machines placed at the drill hole bottom were designed and manufactured—downhole air hammer drills. Such location ensures the best blow energy transmission to the hole bottom and allows higher penetration rate, longer and more straight directional drilling [2–4]. Compressed air is used as an energy supply and a cleanout agent, which makes the technology even more rational.

Located at the hole bottom, an air hammer drill is limited in dimension but imposed higher demands on blow energy and capacity. Hammering parts operate at the limit capacities. For this reason, reliability of the machines is a top priority.

Currently there is a trend toward higher pressure energy supply. Transition to higher pressure of compressed air ensures high power performance and, at the same time, creates even higher stresses in hammering parts.

An important factor governing reliability of hammering machines is stress raisors. Stress razors in steel are nonmetallic inclusions, thus, hammering parts should be made of high-pure steel. Furthermore, to avoid risk of failure and eliminate stress razors, it is expedient to develop the simplest designs for hammering parts.

Designed at the Institute of Mining, SB RAS, the downhole air hammer drill have a simple-shaped hammering part, which enhances its operating reliability (Figure 1) [5–7].
A feature of this layout is the controllable interconnected butt and annular chambers of power stroke and the constant-pressure chamber of idle stroke. This design enhances the strength of the hammering part, free from any internal channels, which is particular important for operation with higher pressure energy supply. The split bushing allows larger area of acting face of the hammering part in the power stroke, which is the basis for reaching increased capacity. This is the closed-type layout with the air exhaust to the hole bottom, which prevents the inner area of the hammer drill from abrasive particles and improves cleanout of the hole bottom from drill cuttings. The better and more complete cleanout of the hole bottom makes it possible to avoid energy loss in re-crushing of drilling cuttings.

In the discussed layout, exhaust is only possible from the power stroke chamber and not from the idle stroke chamber. The ‘parasitic’ volume inefficiently filled with compressed air is reduced. The reduction leads to the decrease in the air flow rate and enables engineering economic machines. High-pressure compressed air is mostly used in the work cycle period, which also contributes to economic efficiency of the machine.

It is possible to considerably simply a drill bit. The cavity between the hammering part and drill bit is a cavity of atmospheric pressure and need not sealing. This allows minimizing the number of seats on the drill bit, which reduces precision and quality standards and cuts-down manufacturing cost.

The centralized collision of the hammering part and the bit improves the power transmission due to decreased lateral vibration and lowers stresses in the colliding parts owing to more uniform distribution of impact loading in cross-sections.

Based on the presented basic layout, a line of downhole air hammer drills has been designed [8, 9]: ASH-46 for 46 mm-diameter hole drilling; P110GM—drilling diameter 100 mm; PV170—drilling diameter 155–170 mm, and P165 for coring in geological exploration. These machines are operated both in surface and underground mines and are suitable for wide-range pressure of energy source.

Higher energy performance is also governed by the value of active areas of the hammering part, both on the side of the power stroke chambers, $S_p$, and on the side of the idle stroke chamber, $S_i$. The ratio of the values of these areas is important, too [10]. In order to obtain a pre-set length travel of the hammering part, it is required to generate a certain momentum of idle stroke, which depends on the active area of the hammering part on the side of the idle stroke chamber.

For the above-described layout, the theoretical range of the active areas is

$$0 < \frac{S_i}{S_p} < 0.5$$

Actually, as required by the design and strength of parts, this ratio is $S_i/S_p = 0.2 \ldots 0.3$. Using this ratio, it is possible to obtain the wanted length of travel of the hammering part but it is necessary to avoid negative effects such as leakage of compressed air from the main constant pressure chamber to the power stroke chambers.

As is evident from the ratio of the active areas, with the enlarged active area from the side of the power stroke chambers, the hammering part has a smaller active area on the side of the idle stroke chamber. A hammering part is a mobile part, and its seats are meet with clearances adjusted depending on diameter. Compressed air inevitably leaks in the clearances. During the idle stroke,
compressed air in the power stroke chamber, because of the considerable difference in the size of the active areas, creates appreciable resistance to the hammering part movement and limits its travel length. With the limited travel, the hammering part looses blow energy. Aimed to abate this effect, the design is added with a special elastic ring (Figure 2).

**Figure 2.** Circuit diagram of downhole air hammer drill PNB76R with the power stroke chamber discharge: 1—drill bit; 2—axle box; 3—housing; 4—front liner group; 5—hammering part; 6—elastic valve; 7—split collar; 8—rear-end liner group; 9—adapter; 10—annular chamber of power stroke; 11—but chamber of power stroke; 12—idle stroke chamber of constant pressure.

The elastic ring 6 installed in the groove of the front liner group 4 with the clearance on the side of the housing 3 acts as a discharge valve. When the hammering part 5 performs idle stroke, air compressed in the annular and but chambers of power stroke, 10 and 11, and air leaked in these chamber through clearances of movable seats of the hammer, is let out through that clearance and the groove in the front liner group to atmosphere. Inasmuch as the hammer areas on the side of the butt and annular power stroke chambers is several times larger than the hammer area on the side of the idle stroke chamber, compressed air in the butt and annular power stroke chambers decelerates idle travel of the hammer and reduces its length. Air discharge from the butt and annular chambers of power stroke after shutting-off the discharge through the elastic valve enables essential reduction in backpressure and, as a consequence, in resistance to the hammering part movement through the length of the idle travel of the hammer increases. During the power stroke, the hammering part undergoes effect of compressed air from the butt and annular chambers of power stroke at the higher value of the travel length, which increases the unit blow energy and the whole capacity of the machine.

The elastic ring–valve falls within the structure and has now adverse effect on the design simplicity of the downhole air hammer drill [11].

The prototype downhole air hammer drill PNB76R with the elastic valve and discharge of power stroke chambers during idle stroke has been manufactured. The machine was finished and tested in laboratory. During the tests, the pressure charts were recorded in the power stroke chambers at the main line pressure of 0.6 MPa. The pressure diagrams recorded in the machine with and without the elastic valve are shown in Figure 3.

It is seen in the pressure charts that in the idle travel, at the point of air inlet in the power stroke chambers, the pressure in PNB76R model is lower by 0.1 MPa than in PNB76 model, which decreases the idle stroke resistance and increases its length. It is noteworthy that the valve actuates, i.e. shuts the clearance at the housing wall, immediately after the point of air inlet in the power stroke chambers since the required pressure difference ahead and behind the valve is prompt and sufficient to stretch the valve. This face governs reliable actuation and stable operation of the hammering machine.

After processing the obtained pressure charts using the known procedure [12], the performance parameters of the two tested models of air hammer drills are presented in the table 1.

After the tests, trial drilling was carried out in the dry air, using drilling rig NKR100M, in granite (strength 140 MPa) under compressed air pressure of 0.6 MPa (Figure 4). Drilling speed was 110 mm/min.
Figure 3. Pressure charts in the power stroke chambers of downhole air hammer drills: (a) PNB76 model without discharge valve; (b) PNB76R with discharge valve; 1—main line pressure; 2—idles stroke chamber pressure; 3—pressure in the butt and annular chambers of power stroke.

Table 1. Performance parameters of downhole air hammer drills

| Parameter                        | PNB76 (without valve) | PNB76R (with discharge valve) |
|----------------------------------|------------------------|-------------------------------|
| Outward diameter of housing, mm  | 63.5                   |                               |
| Length (without drill bit), mm   | 675                    |                               |
| Weight of hammering part, kg     | 1.45                   |                               |
| Compressed air pressure, MPa     | 0.6                    |                               |
| Hammering part travel length, mm | 79                     | 93                            |
| Blow energy, J                   | 57                     | 71                            |
| Blow frequency, min⁻¹            | 1450                   | 1456                          |
| Capacity, W                      | 1378                   | 1723                          |

Figure 4. Trial drilling in granite by PNB76U (improved) and drilling rig NKR100M.
To sum up, the introduction of an elastic valve to discharge power stroke chamber in the design of downhole air hammer drill PNB76R resulted in the increase in the hammering part travel length by 30% and in the gain in the blow energy and capacity by 25%. The discharge valve removes the physical disadvantage of the given air distribution circuit, namely, small area of the hammer on the side of the idle stroke chamber as compared with its area on the side of the power stroke chambers, and enables utilizing all advantages of the circuit. This design is serviceable both at the standard and increased pressure of compressed air.

References
[1] Klishin VI et al 2007 Drilling equipment engineering for coal mines *Fundamental Problems of Geoenvironment Formation under Industrial Impact: Sci. Conf. Proc.* Novosibirsk: IGD SO RAN (in Russian)
[2] Hungerford F 2013 Evolution and application of in-seam drilling for gas drainage *International Journal of Mining Science and Technology* Vol 23 pp 543–533
[3] Kondratenko AS, Timonin VV and Patutin AV 2016 Prospects for directional drilling in hard rocks *J. Min. Sci.* Vol 52 No 1 pp 129–134
[4] Timonin VV, Kokoulin DI, Alekseev SE and Kubanychbek B 2016 Straight-path drilling facilities for coal mines *Problems of Development of Mining Sciences and Mining Industry: Sci. Conf. Proc.* Novosibirsk: IGD SO RAN (in Russian)
[5] Alekseev SE 1997 RF Patent 2090730, 11.05.95
[6] Repin AA, Alekseev SE and Pyatnin GA 2009 RF Patent 2343266, 02.07.2007
[7] Repin AA, Alekseev SE and Karpov VN 2012 RF Useful Model 121854, 04.05.12
[8] Repin AA, Kokoulin DI, Alekseev SE, Karpov VN and Shakhtorin II 2014 Small-size air hammer for long directional drilling in underground coal mines, *Prospects of Innovation Development in Coal Mining Regions in Russia: Sci. Conf. Proc.* Prokupievsk (in Russian)
[9] Alekseev SE, Timonin VV, Kokoulin DI, Shakhtorin IO and Kubanychbek B 2015 Development of small-size downhole air hammer for investigation hole drilling *J. Fundament. Appl. Min. Sci.* Vol 2 pp 187–193 (in Russian)
[10] Repin AA, Alekseev SE, Timonin VV and Karpov VN 2015 Analysis of the compressed air distribution in the down-the-hole air hammer, *Miner’s Week–2015 Conf. Proc.* pp. 475–482 (in Russian).
[11] Petreev AM and Primychkin AYu 2016. Ring-type elastic valve operation in air hammer drive *J. Min. Sci.* Vol 52 No 1 pp 135–145
[12] Esin NN 1965 *Procedure for Testing and Perfection of Air-Driven Hammers* Novosibirsk: SO AN SSSR (in Russian)