Down-the-hole hammering machines for blasthole drilling

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Abstract.

Downhole pneumatic drill tools developed in Russia are widely used in blasthole drilling [1]. Percussion drilling consumes less energy in breaking medium-hard and very hard rocks, enables saving power of performance and allows using lighter equipment. Such drilling tool are highly productive reliable and simply maintained. Drilling rate is independent of the hole length, which allows long-hole drilling to be carried out in underground mines. It is also possible to drill larger diameter (to 350 mm) holes using lighter equipment. All that combined with the simplicity and relatively low price make these machines popular both in open pit and underground mining.

A feature of down-the-hole drill hammers is that their length and diameter are strictly limited by the diameter of a hole or the size of an underground opening.

Efficiency of drilling in medium-hard and very hard rocks depends on the value of blow energy \( A \) given by:
\[
A = p_{av} \cdot F \cdot s_p,
\]
where \( p_{av} \) is the average pressure in the power stroke chamber before exhaust; \( F \) is the effective area of impact piston on the side of the power stroke chamber; Saint-Petersburg is the impact piston travel length determined as the distance between the total power stroke length and the length of the travel between the exhaust start and the blow on a tool.

The blow energy depends on the value of the effective area \( F \).

The hole diameter strictly limits the diameter of the down-the-hole hammer body, it is not a simple task to increase the effective area of the impact piston. In this connection, it seems important to find how effectively cross-section area the hammer housing is utilized for the formation of the effective areas of impact piston. In most domestic and foreign designs, the utilization factor in this case is 80–90% [2].

The Institute of Mining has developed a layout to ensure 100% utilization of a cross-section area for the creation of the effective area \( F \) of an impact piston (Figure 1) [3–5].

The down-the-hole hammer structure includes two power stroke chambers and an intermediate idle stroke chamber. The annular head power stroke chamber 1 and the tail power stroke chamber 2 are connected via the channel 3. The chambers are operated by the air feed in the annular head chamber and exhaust from the tail chamber. In-between there is the idle stroke chamber 5 connected to the compressed air line. return air from the power stroke chambers is exhausted along the channel 5 in the wall of the cylinder 6 to the atmospheric air chamber 7. The impact piston 8 has three impact stages
with the diameters $D_1$, $D_2$ and $D_3$. The largest-impact stage diameter $D_1$ is equal to the cylinder diameter $D_c$. Compressed air can flow to the power stroke chambers through the clearance fits A and B. when the impact piston moves, compressed air enters the power stroke chamber, which allows alternate motion of the impact piston and blow on the anvil block at the end of each operating cycle.

![Figure 1. Layout of down-the-hole hammer.](image)

In this layout, the power stroke area $S_p$ is composed of effective areas from the sides of the head and tail power stroke chambers, while the idle stroke area $S_i$ exists only on the side of the compressed air line:

$$S_p = \frac{\pi}{4} (D_1^2 - D_2^2 + D_3^2); \quad S_i = \frac{\pi}{4} (D_3^2 - D_2^2);$$

It is important that irrespective of idle stroke area from which the force applied to the impact piston constantly resists the force from the side of the power stroke chambers, the condition below is always fulfilled:

$$S_p - S_i = S_c = \frac{\pi}{4} D_c^2,$$

where $S_c$ is the cross section area of the cylinder.

Thus, in the described layout, the power stroke area grows with the idle stroke area.

The analysis of the 50 years-long development in percussion drilling shows that compressed air pressure is continuously increased. The leading foreign companies had long ago passed to the compressed air pressure of 0.9–1.8 MPa [6]. At the present times, the designs of the increased air hammers and bits are being constantly improved and the driving pressure is grown. For example, Atlas Copco COP 64 DTH hammer for holes with a diameter of 156–178 mm uses pressure of 1.2–2.5 MPa.

Technical and economic advantages of increased pressures are: higher drilling rate and extended life of DTH hammers (drilling rate grows from 90–150 mm/min to 800–1000 mm/min in hard granite, while life grows from 300–500 drilling meter to 5000 m and more); possibility to essentially increase drilling depth; reduction in energy content of rock destruction. On the whole, cost per drilling meter is decreased too. High-capacity DTH hammers successively compete with the other drilling equipment for instance, auger drill rig capacity connected with the axial pressure on the too and, consequently, with the weight of the rig, has nearly come to an end and fails to ensure productivity of DTH hammers.

The application of the high-pressure compressed air opens wide horizons for structural improvement of DTH hammers, engineering of modern automated drill rigs and using wider range of exchangeable drill tools for the complete compliance with the technology purposes.

Structural features of the machines sources by compressed air of increased pressure are: closed type, i.e. perforation-free housing; exhaust of total air to bottomhole; valve-less air distribution, as a rule, which allows utilizing energy of expansion of compressed air at much higher potential when the compressed air pressure is high. Efficiency of such machines is highly essential.

Foreign-manufacture increased pressure drill rigs enjoy increasingly higher application in Russia. Atlas Copco delivers drilling rigs ROC L6, ROC L7, ROC L8, ROC L9 and Mustang A-32 CNS with DTH hammers COP 34, COP 54, COP 54 and ODEX system for casing while drilling. However, it
should be mentioned that the imported drill hammers and bits are expensive and the price tends to
grow higher. It is of the current concern to design domestic import-substituting machinery.

To this effect and using the described layout, DTH hammer model PV170 was designed and
tested on a laboratory and commercial scale. Test drilling was carried out using SWDB165 drill rig of
Swedish design and Chinese manufacture, at the compressed air pressure of 1.38 MPa. The drill rig is
a property of Novosibirskvzryvпром. The tests were conducted at Borok quarry near Novosibirsk, in
drilling granite with the strength of 120–140 MPa (Figure 2). The DTH hammer demonstrated high
efficiency.

Later on, the drill rig and DTH hammer were tested at Koen quarry in Toguchin district of the
Novosibirsk Region, in drilling diabase with the strength of 140–160 MPa (Figure 3).

The next test stage was operation of PV170M DTH hammers with Swedish drill rigs CM760D at
the compressed air pressure of 1.6 MPa and ROC L8 at the compressed air pressure of 2.4 MPa by
Sibir Mining and Technology Company (Figure 4 and 5, respectively). The operation was performed
at Iskitim open pit mine (Novosibirsk Region) in drilling marmorized limestone with the strength of
110–130 MPa.

All in all, 22 holes with the diameter of 170 mm and 16.5 m long were drilled. The drilling rate
was 400 mm/min. At the Koen quarry, 13 holes 13 m in length were drilled at the compressed air
pressure of 1.2 MPa and drilling rate of 266 mm/min. During the testing, total drilling length made 645
m at the sustained efficiency of DTH hammers.

The modern downhole drill hammers driven by the compressed air of increased pressures should
possess essential life. Some DTH hammers of foreign manufacture gave life to 5000 meter and more.

Durable operation of a machine, alongside with strength of basic parts, is governed by wear of
friction parts. In air-driven percussion machines, impact piston is a part of the air distribution system.
This movable part has seats with clearances the sizes of which depend on the diameter. It is
unavoidable that compressed air leaks in the clearances. In the described layout, compressed air leaks in the clearances A and B (Figure 1). The influence of the enlarged clearances under wear of contact surface on the performance of DTH hammer was studied.

![Figure 6. Pressure charts on power stroke and idle stroke chambers: (a) $S_{AB} = 0.587$ cm$^2$; (b) $S_{AB} = 0.747$ cm$^2$; (c) $S_{AB} = 1.207$ cm$^2$; (d) $S_{AB} = 1.527$ cm$^2$; pressure $p_i$ in the idle stroke chamber, MPa; pressure $p_{hp}$ in the head power stroke chamber, MPa; pressure $p_{tp}$ in the tail power stroke chamber, MPa; $t_i$—idle stroke time, s; $t_p$—power stroke time, s; $T$—cycle duration, s.](image)

The studies were carried out on vertical laboratory test bench GD-251 with the recording of pressure charts in the two power stroke chambers and idle stroke chamber (Figure 6). During the tests, the total cross-section area of the clearances was varied as $S_{AB} = 0.587; 0.747; 1.207$ and $1.527$ cm$^2$. The compressed-air pressure was 0.6 MPa. The beginning and end of the cycle were determined by a blow marker.

Using the pressure charts, the basic characteristics of the hammer were found (Table 1).

**Table 1.** Basic characteristics of DTH hammer model PV170 at varied total cross-section area of clearances.

| Clearances cross-section area $S_{AB}$ cm$^2$ | Blow energy A, J | Blow frequency n, min$^{-1}$ | Recoil coefficient $k_o$ | Blow velocity v, m/s | Impact piston travel L, mm | $t_i/t_p$ |
|--------------------------------------------|------------------|---------------------------|----------------------|-------------------|--------------------------|---------|
| 0.587                                      | 208.84           | 922.37                    | 0.21                 | 4.95              | 82                       | 1.45    |
| 0.747                                      | 206.95           | 928.07                    | 0.26                 | 4.92              | 84                       | 1.47    |
| 1.207                                      | 160.09           | 929.04                    | 0.29                 | 4.32              | 73                       | 1.61    |
| 1.527                                      | 159.55           | 857.14                    | 0.29                 | 4.33              | 71                       | 2.03    |
The change in the blow energy $A$ and blow frequency $n$ as function of $S_{AB}$ is shown in Figure 7.

![Figure 7: Curves of blow energy, blow frequency and clearances cross-section area in DTH hammer. ▲—unit blow energy, J; ♦—blow frequency per minute.](image)

Evidently, the value of the total cross-section area of clearances has an essential influence both on the unit blow energy and frequency. These characteristics directly govern performance of an air-driven hammer. The cross-section area of clearances depends on the correct attachment of movable joints, quality of manufacture and, largely, on the wear of friction parts. In order to reduce the value of the total cross-section area of clearances, it is recommended to make grooves on adjacent surface, which decreases wear of the surfaces and air leakage. It is also possible to apply different coatings and sealers of immovable joints of the structure.

The proposed layout is suitable for the import-substituting manufacture of DTH hammers with wide pressure range of compressed air and high performance. The simple form of the impact piston without inside cavities, as well as the rational manufacture technology provide the required strength of the part under high impact loading. The influence of the growth of clearances under wear of movable parts is evaluated, which allows more accurate determination of service life of the structure.

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