Energy efficiency evaluation of high-pressure DTH hammers

EM Chernienkov*, AYu Primychkin and LYu Belozertseva
Chinakal Institute of Mining, Siberian Branch, Russian Academy of Sciences, Novosibirsk, Russia
E-mail: *e.chernienkov@misd.ru

Abstract. The design of a domestically produced DTH hammer for drilling holes in rocks of medium and high strength is presented. Using the mathematical modeling method, the serviceability of the hammer at an energy source pressure of 2.4 MPa is proved. The results of DTH hammer prototype testing at lab and full scale are presented.

1. Introduction
Mineral exploration and mining involves drilling in rocks having different physical and mechanical properties, including strong and very strong rocks. Drilling technologies are imposed with certain requirements, namely, high capacity, low cost and high endurance of drilling equipment. Holes should be straight and have high quality walls [1].

The present-day drilling is commonly carried out using rotary percussion drilling equipment with down-the-hole or offset rock-breaking tools powered by air or fluids [2].

It is expedient to perform rotary percussion drilling using DTH air hammer. The shock source is located directly at the bottomhole, which ensures efficient fracture and straight-line drilling in rocks of high and medium strength ($\sigma = 30–200$ MPa). In this case, the power source is also employed as a cleaning agent to remove cuttings from the bottomhole.

One of the ways of improving this drilling technology is increasing the pressure of the energy source [3]. The modern compressor plants generate pressure to 3.2 MPa. DTH air hammers capable to operate at such pressure of compressed air are only manufactured abroad, in particular, in Sweden, USA, China, etc. Given the absence of the domestic manufacture equipment of the kind, Russian drillers totally depend on import, which poses a threat to the national energy and resource security [4].

Toward this problem solution, the Institute of Mining SB RAS designed a DTH air hammer drill for making holes with a diameter of 130 mm (Figure 1) in accordance with the high present-day requirements [5].

2. DTH air hammer test results
This DTH air hammer design features a few advantages. The slide valve-free system of air distribution allows using wide effective pressure range of compressed air, from 0.3 to 3.2 MPa. The absence of additional air-distribution means enables the energy source to affect the maximum area of the piston when accelerated, which elevates the impact energy of a machine of the same size. The back valve prevents sludging of the machine in drilling in water-cut rocks. The body of the machine has no radial perforations and can have walls of any thickness subject to hardness and abrasivity of rocks, which ensures long service life (as, as a consequence, saves drilling cost). Spent air is exhausted toward the bottomhole, which contributes to removal of cuttings from the bottomhole zone and prevents...
overgrinding of chips. Furthermore, the layout of exhaust openings allows using foamy agents to ensure the required velocity of the rising current in the annular space in drilling holes of larger diameters.

**Figure 1.** DTH air hammer: (a) structural layout (1—bit; 2—adapter axle box; 3—body; 4—piston; 5—split collar; 6—sleeve; 7—back valve; 8—transition adapter); (b) analytical model (T₁₉, T₉, Tₐ₉, Tₐ₉—one of the throttles; V₁—V₅, Vₐ₁, Vₐ₂, Vₐ₁, Vₐ₂—one of the volumes of working chambers).

The analysis of the work cycle of the DTH air hammer in the main line pressure range 0.6–2.4 MPa, as well as the machine design refinement was implemented using a component-based graph model.

We constructed an analytical model of DTH air hammer model P130 (Figure 1b). It comprises the basic parameters of the machine: volumes of working chambers, areas of passage, opening and shutoff points of channels, mass and areas of piston on the sides of the forward and backward strokes. This model allows varying the design factors of air distribution and controlling the energy outputs: impact energy and frequency, impact capacity, pre-blow velocity, specific air flow rate, etc.

**Figure 2.** The theoretical and experimental testing data of DTH air hammer: (a), (b), (c) assumption diagrams of air pressure in work chambers at main line pressures of 0.6, 1.2 and 2.4 MPa, respectively; (d) experimental diagram of air pressure in work chambers at main line pressure of 0.6 MPa; (e) general view of DTH air hammer prototype.

Applicability of this approach is described in [6, 7]. It enables experimentation without a full-scale specimen of the machine. The computer modeling made it possible to obtain assumption
diagrams of air pressure in working chambers of the machine within a work cycle at the compressure air pressure of 0.6, 1.2 and 2.4 MPa in the main line (Figures 2a–2c, respectively). It is seen that the increase in the pressure brings no violation to the machine stability, the work cycle is full and efficient, the unit blow energy and frequency grow. In order to reach the wanted energy and flow rate of the machine, the DTH air hammer design was amended.

After the amendment based on the mathematical modeling, a research prototype of the machine was manufactured and tested at the lab scale (Figure 2e). Using the program and procedure from [8], the pressure diagrams (Figure 2d) of air in the idle and power stroke chambers at the standard energy source pressure of 0.6 MPa were processed. The comparison of the assumption and actual diagrams (Figures 2a and 2d) of air pressure in the work chambers at the same main line pressure shows that deviations of such parameters as the unit blow energy and frequency, and the air flow rate in these diagrams are not higher than 7%. This proves that the model sufficiently accurately and completely describes operation of a real machine. The Table 1 describes the energy performance of the test DTH air hammer model at different pressures of compressed air.

| Description                          | Value       |
|--------------------------------------|-------------|
| Drilling diameter, mm                | 134, 152    |
| Machine body diameter, mm            | 120         |
| Length without bit, mm               | 1110        |
| Weight without bit, kg               | 65          |
| Piston weight, kg                    | 16          |
| Pressure, MPa                        | 2.4 1.2 0.6 |
| Unit blow energy, J                  | 830 474 220 |
| Blow frequency, s⁻¹                  | 23 18 13    |
| Impact capacity, kW                  | 19 8.5 2.8  |
| Air flow rate (at 2.0 MPa), m³/min   | 31.5 15.6 7.5 |

The full-scale tests of DTH air hammer model P130 were carried out in partnership with Sibir Mining and Engineering at Borok quarry in the Novosibirsk Region. The tests included blasthole drilling in granite having the uniaxial compression strength of 120–140 MPa using Atlas Copco Rock L8 drill at the energy source work pressure of 2.1 MPa. The drilling penetration rate in the tests made 0.6–0.8 m/min on the average. This value is comparable with the efficiency of the air drill hammers produced by the world’s top manufacturers (Atlas Copco, Numa).

3. Conclusions
The new design of the DTH air hammer for drilling in medium and high strength rocks is advantageous for the wide range of compressed air pressure (0.6–2.4 MPa), back valve preventing the machine from sludging when drilling is carried out in water-cut rocks, no perforations in the body walls and for the air exhaust toward the bottomhole. The mathematical and simulation modeling has proved the new design machine efficiency in operation at higher pressures. The energy efficiency of the machine at different pressure of energy source is evaluated. The full-scale tests show the high capacity of the machine (drilling penetration rate), which is comparable with the capacity of air drill hammers of foreign manufacture.

Acknowledgements
The study was supported by the Russian Foundation for Basic Research, Project No. 19-35-90058.
References

[1] Eremenko VA, Barnov NG, Kondratenko AS and Timonin VV 2016 Method for mining steeply dipping and thin lodes Gorny Zhurnal No 12 pp 45–50

[2] Oparin VN, Timonin VV, Karpov VN and Smolyanitsky BN 2017 Energy-based volumetric rock destruction criterion in the rotary-percussion drilling technology improvement Journal of Mining Science Vol 53 No 6 pp 1043–1064

[3] Timonin VV, Alekseev SE, Karpov VN and Chernienkov EM 2018 Influence of DTH hammer impact energy on drilling-with-casing system performance Journal of Mining Science Vol 54 No 1 pp 53–60

[4] List of Priority and Critical Products from the Point of View of Import Substitution and National Security Ministry of Industry and Trade of the Russian Federation 2015

[5] Alekseev SE 1997 RF Patent No 2090730 Byull. Izobret. No 26

[6] Primychkin AYu, Kondratenko AS and Timonin VV 2016 Determination of variables for air distribution system with elastic valve for down-the-hole pneumatic hammer J. Fundament. Appl. Min. Sci. Vol 3 No 2 pp 141–145

[7] Primychkin AYu and Belozercova LYu 2019 Influence of elastic valve parameters on energy characteristics of a ring pneumatic impact machine J. Fundament. Appl. Min. Sci. Vol 6 No 3 pp 116–121

[8] Timonin VV, Chernienkov EM and Timko TV 2019 Automated analysis of operating cycles of impact machines IOP Conference Series: Earth and Environmental Science pp 012074