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Influence of part-to-part gaps in air distribution system on operation of DTH hammer

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Abstract. The authors illustrate the role of pneumatic percussive machines in drilling. The article presents the elementary diagram of down-the-hole (DTH) hammer with the marked places of air leakages in the system of air distribution and describes and their influence based on the research data. The variation in the basic power characteristics of the machine is given as function of the size of gaps in the sliding joints. It is shown that the machine design can be improved by means of using elastic valve to allow discharge of air working chambers during the idle stroke of the hammer.

1. Introduction

Mineral mining industry both in Russia and in the world widely uses percussive machines driven by fluid energy source—compressed air, pressurized fluids or mixtures. Such machines operate in drilling hard rocks in underground and surface mines.

In the mid-1900s in Russia, the first prototypes of air-driven percussive machines were designed and manufactured. These machines were to be placed at the bottom of drill hole and named down-the-hole punchers (hammers). Such arrangement ensures best energy transfer to bottomhole and allows higher penetration rate and longer drilling. Compressed air is used as an energy source and a cleaning agent, which makes drilling even more rational. The introduction of that technology made it possible to break ore in long holes.

Drilling with DTH hammers is feasible in rocks of any hardness and jointing. These machines feature high productivity, reliability and simple maintenance. Drilling rate is independent of the hole length. Air flush system is also highly efficient. Down-the-hole equipment provides low noise and reduced deviation of drilling path from straight line. These advantages, as well as simplicity and relatively low cost make these machines highly attractive.

The piston in the pneumatic percussive machines is a part of the air distribution system. The piston is movable part, and its seat areas are made with clearances governed by the diameter. Air inevitably leaks through the clearances. Lack of sufficient knowledge on this point complicates mathematical modeling of the machine.

Analysis of the machine structure shows that influence of air leakage on performance is different per design. For instance in throttled and spay systems, air leakages weakly affect energy efficiency of machines and mainly result in the increased air consumption. In some air-driven hammers, air can leak in-between operative chambers of idle and power strokes. In this case, the influence of air leakage is more appreciable as it worsens energy efficiency of machines. Air leaks from the air feed line to the working chambers are the most hazardous. The number of leak places is of concern.



2. Design features of DTH air hammer

It is most often that clearance leakages take place in critical or supercritical regimes; for this reason, the mass air flow rate Q_{mass} , kg/s, is given by [1]:

$$Q_{mass} = f_{gap} \sqrt{\frac{2K}{K+1} \left(\frac{2}{K+1} \right)^{\frac{2}{K-1}} \frac{P}{\nu}},$$

where f_{gap} is the cross-section area of the gap, m²; K is the adiabatic exponent (for air, $K = 1.4$); P , ν are the absolute pressure and specific volume of compressed air in the chamber in front of the clearance, kg/m³.

It follows from the formula that the highest influence on air flow rate is exerted by the clearance cross-section area. At the same time, it is important where the leak occurs and how it influence the machine performance.

At the Institute of Mining, SB RAS, a basic diagram of air-driven hammer has been developed (Figure 1) to meet to the full extent the requirements imposed on the machines [2–4]. The closed air hammer circuit with air exhaust to the hole bottom prevents inlet of abrasive particles in the hammer and ensures best cleaning of the bottom from drilling chips.

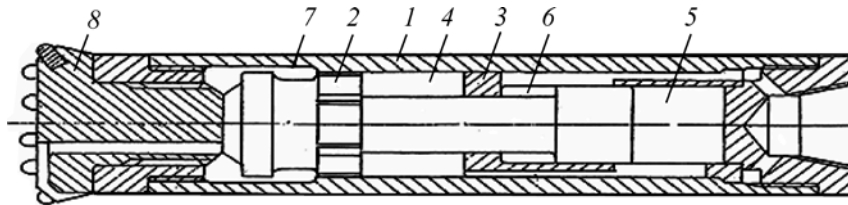


Figure 1. Basic diagram of DTH air hammer: 1—body; 2—piston; 3—air distribution barrel; 4—ring space of power stroke chamber; 5—end power stroke chamber; 6—constant-pressure idle stroke chamber; 7—counterbore; 8—drill bit.

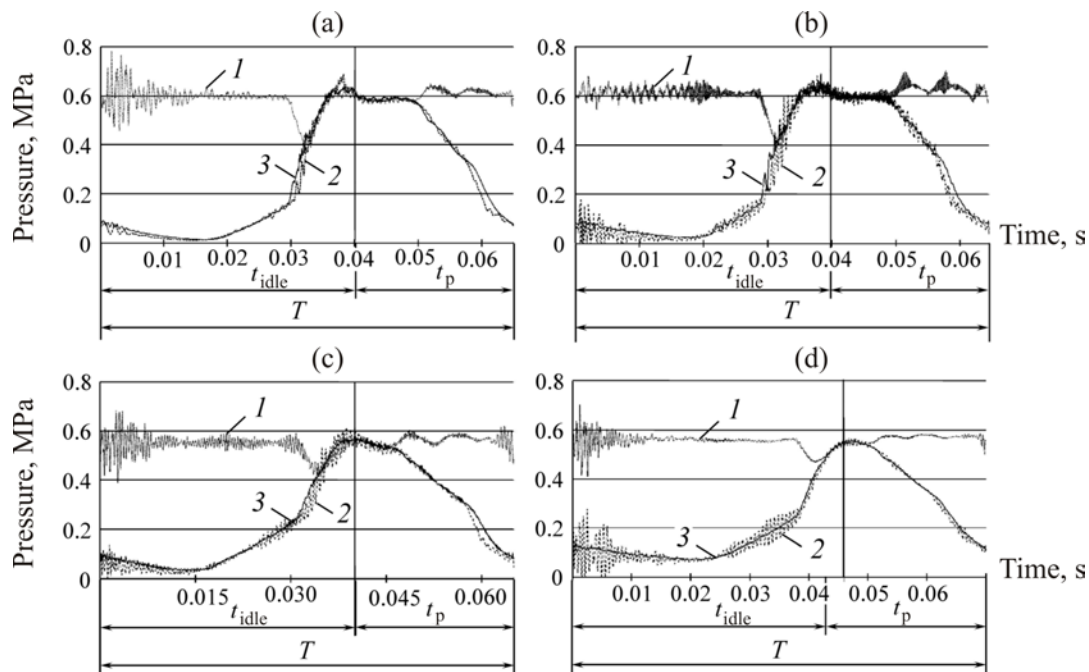


Figure 2. Pressure in the power and idle stroke chambers at (a) $S = 0.587 \text{ cm}^2$; (b) $S = 0.747 \text{ cm}^2$; (c) $S = 1.207 \text{ cm}^2$; (d) $S = 1.527 \text{ cm}^2$: 1—pressure p_{idle} in the idle stroke chamber, MPa; 2—pressure p_{ring} in the ring power stroke chamber, MPa; 3—pressure p_{end} in the end power stroke chamber, MPa; t_{idle} —idle stroke duration, s; t_p —power stroke duration, s; T —cycle time, s.

In this circuit, it is most hazardous when leakages take place in gaps of running fits of piston 2 and barrel 3. During idle stroke of the piston, additional inflow of compressed air in the power stroke chamber obstructs travel of the piston. Since the idle stroke area is comparatively small, leakages can be influential and, thus, their admissible value should be determined. For the more precise estimation of influence exerted by air leaks on the machine energy efficiency, full-scale testing was undertaken.

By the basic diagram above, DTH air hammer PV170 has been designed and manufactured for hole drilling with diameter of 170 mm using energy source with a wide pressure range from 0.6 to 2.0 MPa. The weight of the piston is 17.1 kg.

The tests were carried out on vertical lab bench with recording of pressure charts in the twin chambers of power stroke and in the in-between idle stroke chamber. A blow marker was involved in the tests. The pressure charts were recorded at different adjustments of the machine with the total clearance area S of 0.587, 0.747, 1.207 and 1.527 cm². The compressed air pressure was 0.6 MPa (Fig. 2).

The pressure charts were processed using the known procedure [5]. The main parameters of the machine were determined using the pressure charts (Table 1).

Table 1. Main parameters of PV170 DTH hammer at different total areas of clearances

Total clearance area S , cm ²	Blow energy A , J	Blow frequency n , min ⁻¹	Recoil factor k_o	Blow velocity v , m/s	Piston travel length L , mm	t_{idle} / t_{power}
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 relationship of the energy efficiency characteristics A and n with the value of S is shown in Figure 3. It is seen that the total area of clearances most affects the unit blow energy.

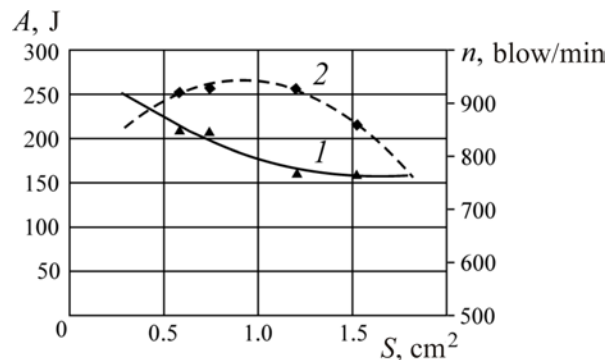


Figure 3. Unit blow energy A (1) and blow frequency n (2) versus clearance cross section area S .

During the idle stroke, air inflow in the power strike chamber, due to large difference between the values of the effective areas of the piston, impedes and shortens travel of the piston. Due to this constraint, the piston fails to increase blow energy during the power stroke.

Aiming to slacken this effect, the structure is added with a special elastic ring to act as an unloading valve (Figure 4) [6].

The elastic ring 6 in the groove of the front barrel 4 with a gap relative to the inner wall of the body 3 acts as an unloading valve. During the idle stroke travel of the piston 5, air compressed in the ring 10 and end 11 power stroke chambers after exhaust as well as leaked air inflow in these chambers from the clearances of running fits of the piston can pass to the atmosphere through these clearances and grooves in the front barrel.

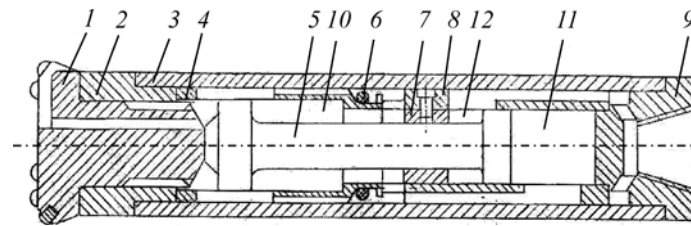


Figure 4. Basic diagram of PNB76R DTH hammer with power stroke discharge: 1—drill bit; 2—axle box; 3—body; 4—front barrel; 5—piston; 6—elastic ring; 7—separation ring; 8—back barrel; 9—adaptor; 10—ring power stroke chamber; 11—end power stroke chamber; 12—idle stroke chamber at constant pressure.

Since the piston area on the side of the power strike chambers in several times larger than on the side of the idle stroke chamber, compressed air in both power stroke chambers decelerates idle travel of the piston and cut its length. Air outlet from the end and ring power stroke chambers after exhaust is shut by the elastic valve makes it possible to reduce counter pressure and, as a consequence, to slacken resistance to the piston movement, and the idle stroke travel of the piston lengthens in the meanwhile. During the power stroke the piston is longer under the action of compressed air pressure from the side of the power stroke chamber due to the longer travel, which elevates energy of unit blow and impact capacity of the machine in whole.

The elastic ring valve conveniently fits in the structure of the air hammer without violating the design simplicity [7]. The further research has shown that the use of such unloading valve allows higher unit blow energy by 20%.

3. Conclusions

The research has shown that the increase in the area of gaps in the mobile joints in the air distribution systems considerably worsens energy efficiency of the machine, mainly, due to reduced energy of unit blow. This drawback can be reduced by using an elastic valve to discharge air from both power stroke chambers during idle stroke of the piston, which lengthens the power stroke travel of the piston and increases the unit blow energy.

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