Experimental study of two-way hydraulic percussion device operation in vibro-impact drilling in rocks

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Abstract. The authors describe the physical model of a hydraulic percussion device with frequency adjustment using standard flow rate controller and impact energy adjustment using an original throttle control of flow distribution, which allows dragging the hammering piston before its back run. The operating cycle characteristics required for the analysis of this system dynamics are obtained in a series of tests. Recommendations on improvement of operation of the hydraulic percussion device are given.

1. Introduction
Hydraulic percussion machines with adjustable energy and frequency of blow attract increasingly much attention to date [1–5]. A special emphasis can be laid of design of adaptable impact devices [4, 5] with adjustable impact depending on strength of a treated material. Theoretically, in a standard simple-design hydraulic percussion device (self-oscillating system with feedback coupling between the hammering piston and the mobile element of air control with respect to the piston position), there is a strict coupling between these characteristics and the pressure fluid flow rate. Therefore, when it is required to control impact energy of a percussion device, the flow rate control needs additional elements to be included [6]. Earlier, the authors numerically studied dynamics of a positive displacement hydraulic percussion system capable to operate with and without the operation drag (the piston can only run back when a certain pressure is achieved in the system—a drag pressure) [6]. Later on, the authors presented experimental studies in the system with a throttle controlled drag (RF Patent No. 2321777) [7], which proved this design efficiency. For the improvement of the throttle control, a new design was proposed, with the control depending on pressure in the throttle system (RF Patent No. 2674289), which can be a prototype of the control for the adaptable hydraulic percussion device.

The Institute of Mining, SB RAS has engineered a prototype of a two-way hydraulic percussion device with the controllable power stroke chamber for wide-range application in mining and construction, with a fluid distribution system (RF Patent No. 2321777) and an adjustable throttle control. This paper describes the device and its testing data: performance curves, and the curves of pre-blow velocities and frequencies versus fluid flow rate and drag pressure.

2. Physical model of hydraulic percussion device, test bench and measurement-and-computation system
The hydraulic percussion device in Figure 1 has hammering assembly 1, including housing and hammering piston, and distributor 2 with a valve. On the body of the distributor, pressure accumulator 2,
adapters of pressure and drop lines, as well as adapters to connect pipes with hammering assembly 1. The device is mounted on a test bench in the form of a heavy frame with vertical legs 5.

![Figure 1](image1.jpg)

**Figure 1.** Test bench and physical model: 1—hammering assembly; 2—distributor; 3—pressure accumulators; 4—pressure sensors; 5—test bench legs.

This is a two-way hydraulic percussion device with controllable power stroke chamber. The piston weight is 5.2 kg, the piston areas are 3.33 cm² from the side of the power stroke chamber and 1.38 cm² from the side of the back run chamber, the back run length up to the command sent to the distributor to switch to deceleration and power stroke is 40 mm. The total weight of the device is 33.5 kg. The charge pressure of the accumulator is 2.8–3.0 MPa.

The test used an oil plant with pump NSH14, driven by motor with capacity of 5.9 kW and flow rate control MPG55–12. The control changes the pump flow in a range of 2–32 l/min. The safety valve is set to the pressure of 11 MPa. Dynamic performance recording uses pressure sensors AP12DN having accuracy class 0.3, displacement sensors RIDS-100FS and DLP-6 manufactured by Sensorika-M and fluid flow rate meter DV04.7 having accuracy class 0.3. The data were processed using a matching unit, analog-to-digital converter E-440 and PC with PowerGraph.

3. Experimental results and discussion

In the series of tests, flow control MPG55-12 was set at an ideal and constant no-load flow rate while throttles Thr1 and Thr2 which connected the control chamber with the pressure line and drop line, respectively (RF Patent No. 2321777).

Figure 2 gives the oscillograms (PowerGraph3.3 viewers) of the dynamic characteristics obtained in the tests of the hydro-percussion device: pressure in the accumulator, pressures in the power stroke chamber and in the back run, valve displacement, hammering piston travels and impulses of the flow rate meter at the ideal flow rate $q_0 = 15$ l/min and varied cross-sectional areas of throttle Thr1.

Table 1 and Figure 3 present the results of the four experimental series. Here, the area of Thr2 in the initial phase is constantly 0.64 mm² and Thr1 area is changed in the range of 0–0.42 mm². In this case, it is possible, at the set pressure in the control chamber at the starting movement of the valve, to vary pressure in the pressure line, at which the working cycle begins. The cycle beginning is assume to the moment of...
the piston start in the back run phase, and the pressure line pressure of this moment is assumed as the drag pressure \( p_{[d]} \).

**Figure 2.** Oscillograms of pressure in the accumulator (pAcc), back run chamber (pA), power stroke chamber (pB), valve displacement (xV), piston travel (xP) and flow rate meter impulses (Iq) at the no-load pump capacity of 15 l/min, Thr2 cross-section area of 0.64 mm\(^2\) and varied Thr1 cross-section areas: (a) 0.42 mm\(^2\); (b) 0.28 mm\(^2\); (c) 0.14 mm\(^2\).

**Table 1.** Experiment and calculation data on growth of axially symmetric and flat induced fractures

| No-load flow rate \( q_0 \), l/min | Thr1 cross-section area, mm\(^2\) | Drag pressure \( p_{[d]} \), MPa | Pre-blow piston velocity \( v_I \), m/s | Blow frequency \( f \), s\(^{-1}\) | Input flow rate \( q \), l/min |
|-------------------------------|-------------------------------|------------------|------------------|----------------|------------------|
| 5.6                           | 0.42                          | 4.13             | 2.71             | 3.00           | 4.59             |
|                               | 0.28                          | 6.43             | 3.43             | 2.13           | 3.93             |
|                               | 0.21                          | 9.12             | 4.33             | 1.22           | 2.96             |
| 9.6                           | 0.42                          | 4.30             | 2.95             | 5.48           | 8.68             |
|                               | 0.28                          | 6.67             | 3.32             | 3.96           | 6.59             |
|                               | 0.21                          | 9.78             | 3.68             | 2.47           | 4.67             |
|                               | 2.25                          | 3.55             | 2.74             | 7.43           | 10.17            |
|                               | 0.42                          | 3.91             | 2.96             | 7.07           | 10.18            |
| 12                            | 0.28                          | 5.74             | 3.73             | 5.78           | 8.84             |
|                               | 0.21                          | 8.40             | 4.10             | 3.71           | 7.09             |
|                               | 0.14                          | 10.08            | 4.26             | 2.76           | 5.61             |
|                               | 0.49                          | 3.74             | 3.10             | 8.49           | 12.54            |
| 15                            | 0.42                          | 4.02             | 3.13             | 8.77           | 12.32            |
|                               | 0.28                          | 5.58             | 3.87             | 6.99           | 10.83            |
|                               | 0.21                          | 7.86             | 3.72             | 5.26           | 9.00             |
|                               | 0.14                          | 8.97             | 4.40             | 4.15           | 8.13             |
Figure 3 describes the pre-blow velocity $v_I$ and the blow frequency $f$ of the hammering piston as function of $p_{[d]}$. It is evident that the throttle control of the working cycle start is sufficiently efficient and allows three times adjustment of the drag pressure $p_{[d]}$. As $p_{[d]}$ is increased, the fluid feed to the percussion device decreases considerably (2 times approximately), the blow frequency $f$ lowers, and the pre-blow velocity $v_I$ of the piston increases. The reduction in the fluid flow rate and the piston blow frequency is governed by the pressure effect on the pump performance, while the increase in the pre-blow velocity of the piston is associated with the higher average pressure and energy stored in the accumulator before the start of the working cycle owing to the drag of the hammering piston.

At high flow rates $q_0$ (not given in Table 1 and Figures), the velocities and frequencies are high; for instance, at $q_0 = 32$ l/min, the piston velocity is $\sim 5$ m/s and the blow frequency is $\sim 15$ Hz. In this case, the operating mode of the percussion facility is changed, the immobility phase of the piston is absent, and the device switches to the continuous cycle. Unsteady operation of the device in some tests is due to incomplete operation of the valve as it has no time to recover its place after the end of the back run of the piston, and the piston hits upper sleeve and stops. This disadvantage is removed by higher pre-tension of the valve spring.

The curves of the pre-blow piston velocity and the drag pressure (Figure 3a) are linear at small $q_0$. When $q_0 > 11$ l/min the increase in $v_I$ at $p_{[d]} > 7$ MP decelerates. This fact needs a more comprehensive analysis; it is probably caused by the influence of the fluid temperature which differs more than 1.5 times per experimental series. The decrease in the blow frequency at the growing drag pressure is linear (Figure 3b).

4. Conclusions
The experimental research proves the efficiency of the throttle control of the working cycle of the hydro-impact device. The throttle control allows changing the drag pressure of the start of the back run of the hammering piston approximately by 3 times, which provides higher capacity of the percussion device, namely, the pre-blow velocity and the blow capacity of the piston increase. The device operates steadily in all test modes. Nonetheless, when the drag pressure is increased, the blow frequency lowers, which is probably associated with the pump model (NSH-14) used in the tests.

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