Providing high speed drilling of boreholes with portable pneumatic rock drills in emergency situations

V Gumenyuk, B Dobroborsky, O Gumenyuk, M Krupyshev
Peter the Great St. Petersburg Polytechnic University, Fire Safety Department, Saint-Petersburg, Russia

E-mail: vasiliiy.gumenyuk@mail.ru

Abstract The existing portable pneumatic rock drills are the most suitable for drilling and blasting operations in emergency situations due to their small mass and mobility. However, their main disadvantage is the low drilling speed due to insufficient feed force, especially when drilling holes vertically down. As a result of the development of a mathematical model of the drilling process by portable perforators, it was proposed to use light feeders while maintaining the total mass, increasing the drilling speed up to 2 times.

Keywords: safety, management, drilling, portable rock drills, pneumatic rock drills

1 Introduction
The systems of blast-hole rock drilling in medium and hard ground have been developed with various means such as percussive drilling and hammer drilling. They include: pneumatic, hydro-perforators and electric-powered hand hummer drills, which demand, to a great extent, physical efforts of its operators for transportation, setup and drilling thrust [1-5]. Additionally, these boring machines generate a high vibration level which is harmful for health of operator. In order to solve the problem modern industry produces fully mechanized large wheel-, rail- and track-mounted drill rigs. However, such drill rigs cost too much and require many time and efforts for moving, handling operations and odd jobs. Thus, the possibilities of its operative use in emergency situations are limited [10-13].

Among the above-mentioned portable drill rigs, air perforators are preferable because they can work in any climate conditions including explosion-hazardous and fire-dangerous situations.

The high rate of drilling speed requires the amount of drilling thrust has to be up to 1300 N, as shown at figure 1.

![Figure 1. Drilling speed – drilling thrust diagram](image)

During straight down drilling the drilling thrust is provided by mass of perforator and operator’s physical efforts. Usually, the mass is not more than 35 kg. The drilling thrust is 300 N. Total value of drilling thrust is 650 N.
During horizontal or deviated drilling the pneumatic supports with mass up to 16 kg are used [6-8]. They provide the necessary position of perforator balancing its mass by vertical direct force of support.

When horizontal and inclined drilling, pneumatic legs weighing up to 16 kg are used, which provide the necessary position of drill rock by balancing the weight of rock drill through the action of vertical thrust force of pneumatic leg. In this case it provides feed thrust partly[10].

On average, the feed thrust is 600 N. With operator’s feed thrust 300 N the total one is 900 N.

At Figure 2: a) pneumatic rock drill for horizontal and inclined drilling, b) rock drill for vertical down drilling.

![Figure 2. Portable pneumatic rock drills serial products. (a) pneumatic rock drill for horizontal and inclined drilling, (b) rock drill for vertical down drilling.](image)

As it is shown at Figure 1, drilling speed is higher when drilling angle or horizontal holes than vertical down.

Thus, the most actual problem is to increase drilling speed for vertical down drilling [9].

The weight of rock drill affects significantly, besides a drilling speed, its productivity, because the manual transportation and resetting of rock drill are carried out by operator’s physical efforts. Decades of experience in Russia and abroad show, that maximum weight of rock drill, including components, cannot be more than 40 kg, including jackleg – 52 kg.

2 Methods

The aim of this paper is to determine ways to increase drilling speed of portable pneumatic rock drills when drilling vertically down, keeping their properties as mobile and effective devices for drilling operations in emergency situations.

To determine the solution to this problem authors developed the mathematical model of drilling process for the system “operator - rock drill – drilling rod – drill bit – rock”, which allowed determining the influence of each element on the process.

In general terms, drilling process can be described by differential equation:

\[
\frac{dh}{dt} = f(j_p, n, Q_1, \psi, f_m, Q_0),
\]  

(1)
Considering that the relationships among the components of this system are sequential, the differential equation may be presented as:

\[
\frac{dh}{dt} = f(j_p) \cdot f(n) \cdot f(Q_t) \cdot f(\psi) \cdot f(f_m) \cdot f(Q_b)
\]  

(2)

When developing the mathematical model, the influence pattern between operator’s physical activity and his working capacity was studied. It was determined by circles of biochemical reactions when working in emergency situations. The studies were carried out using the test chamber which is shown at Figure 3:

**Figure 3.** The test chamber for studying the patterns of load effects on an organism

### 3 Results

The test chamber allows imitating different conditions of operators’ work when drilling down, changing such parameters as weight of rock drill, drilling thrust, local vibration frequency and working posture.

The study using computer program “Loqis 2003.1en” found dependence between operator’s fatigue and drilling thrust.

General view of dependence “operator’s fatigue – operator’s critical force” for emergency situations is shown at Figure 4.
As is seen from Figure 4, the biochemical reaction intensity in operator’s organism follows the law of mass action. In this case, when a multiple loads are applied on operator’s organism simultaneously, related to his physical efforts, work posture and psycho physiological state in conditions of emergency situation it can be described sufficiently in terms of differential equation:

\[ Q_b = Q_{\text{max}} k_Q e^{-k_R t}, \]  

(3)

Where \( Q_b \) – operator’s critical force, \( Q_{\text{max}} \) – starting effort, \( k_Q, k_R \) – correction coefficients.

Using speed drilling – rock drill characteristics relationship, and also characteristics of drill steel and drilling bit, hardness of rock, drilling thrust, considering equation (3), the differential equation for the drilling system is derived:

\[ \frac{dh}{dt} = k_\Sigma (c_1 Q_T^2 + 2c_2 Q_{\text{max}} k_Q e^{-k_R t} + c_3), \]  

(4)

c_1, c_2 – correction coefficients,

\[ k_\Sigma = F_h \frac{f_m}{\Delta h \cdot S} \cdot \psi \cdot \frac{4V_m}{\pi d_{hl}^2} \cdot n, \]  

(5)

\( F_h \) - force of the blow of piston, \( f_m \) – hardness of rock, \( \psi \) – energy-transfer coefficient, \( \Delta h \) – drill depth, \( S \) – contact area, \( V_m \) – volume of destroyed rock, \( d_{hl} \) – hole size.

Solving the equation, we can write down the dependence of hole depth within a given period of time versus basic rock drill parameters and drilling conditions as the formula:

\[ h = k_\Sigma (c_1 Q_T^2 - 2c_2 Q_{\text{max}} k_Q \frac{e^{-k_R t}}{k_R} - c_3 k_Q^2 Q_{\text{max}}^2 \frac{e^{-2k_R t}}{2k_R} + c_2). \]  

(6)

Analysis of the dependence obtained for the emergency situation, when the main task is to reach a maximum of drilling speed, shows that the most perspective way is to use light feeders mounted on more light rock drill, in this case the total weight doesn’t change.

One of possible solutions is the drilling device at Figure 5.
As is seen from Figure 5 the drilling device consists of portable pneumatic rock drill 1 pneumatic drawworks 2, flexor 3 and anchor 4.

Before starting the work an anchor 4 is mounted in a earlier drilled hole, a flexor 3, one end of which is connected up to pneumatic drawworks 2, fixes to anchor 4 by its other end.

When operating, the compressed air is supplied to pneumatic drawworks 2, under which it pulls a flexor 3 and an anchor 4 gets locked. In this case a flexor 4 pins a rock drill 1 to the ground.

Total force of drawworks and weight of rock drill allows reaching the maximum of drilling speed which, how it was established experimentally, is greater up to 200 per cent compared when drilling without use of feeder.

Thus, the use of mathematical model of drilling process allows determining the most perspective ways to solve the problem of increasing drilling speed in emergency situations, keeping mobility, speed of command and high work capacity of operators.

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