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Automated analysis of operating cycles of impact machines

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Abstract. The results of research and analysis of operating cycles of hydraulic and pneumatic impact machines are described. The effectiveness of programming support in engineering of new machines and development of working models is substantiated. The analysis of a construction design is performed to enhance its energy efficiency.

1. Introduction

The costs of drilling can make 30% of the cumulative expenditures in drilling-and-blasting [1]. For this reason, drilling equipment is of particular concern.

Drilling is now mostly performed by rotary-percussive method using down-the-hole air-driven hammers (DTH). From the international experience, the range of DTH use is from 110 to 250 mm, large diameter hole-making involves roller-bit drilling. In rocks with uniaxial compression strength more than 100 MPa, air percussion drilling is more efficient though the penetration rate lowers slightly as hole length increases as the impact impulse source is located directly at the bottomhole. Such percussion layout allows high-accuracy drilling path [2].

The downhole hydraulic hammer drills driven by fluid under pressure to 0.4 MPa ensure higher penetration rate in hard rocks as compared with DTH air hammers. On the other hand, hydraulic hammer drill can be used in low-jointed rocks; otherwise, the drilling column is highly likely to become stuck due to inefficient mud flush at high flow rate of drilling fluid [3].

The Theory, Design and Operation of Mine Drilling Equipment Workshop held by the Chinakal Institute of Mining in 2017 has shown that the domestic manufacturers of DTH hammers lack tools and procedures to determine energy parameters of hydraulic and air-driven pulse-generating systems. Downhole machines are designed with the present energy parameters without estimations of their values.

Hydraulic and air hammers with free piston allow varying drilling mode. There are three modes: pre-drilling (energy source pressure is lower than its operating pressure); normal drilling mode; bottomhole cleaning (higher consumption of energy source). The impulse action of impact machines is largely influenced by physical and mechanical properties of rocks, energy source supply pressure, etc. [4, 5]. Therefore, it is necessary to find exact energy parameters for different operating modes of downhole impact machines.

Foreign developers of downhole pneumatic percussion equipment increased impact energy by means of rising pressure of energy source (by now to 3.5 MPa). According to the foreign experience, the domestic DTH hammer designs should satisfy a few requirements such as: wide range of compressed air pressure (1–3 MPa); back valve to prevent sludging-up in drilling in water-cut rocks and using air-and-water mixture; no perforation holes in the walls of the drill housing to avoid early



wear under friction of drill fines; air exhaust to the bottomhole; valve-free air distribution system; high efficiency ($0.85\text{--}1.1\text{ m}^3/\text{kW}\cdot\text{min}$); long life of piston ($3/5$ thou m—granite/basalt) and drill bits ($0.6/1.2$ thou m—granite/basalt) [6].

2. Development stages of downhole impact machine

At the present time, development of a downhole impact machine includes:

- setting required characteristics (hole diameter, useful life, energy source pressure, etc.);
- developing basic diagram (no valve; back valve);
- simulation modeling (air distribution system design with CAD software [7] to determine patterns of inlet and outlet edges, volumes of work chambers, length of power stroke, etc.);
- construction diagram;
- manufacturing (production effectiveness);
- benchmark testing (determination of actual energy characteristics for further debugging of the machine);
- industrial trial (in-situ operation).

Energy parameters of air distribution system are determined at the Institute of Mining using the procedure proposed in [8]. Figure 1 demonstrates the block diagram of a test bench. Using the control panel, the blow time is recorded based on the signals from the impact sensor *1*, and the air pressure charts in the working chambers and supply line are recorded based on the readings from transducers *2* and *3*, respectively. Then, the analog signals from the transducers are sent through the amplifier to the analog-to-digital converter and loaded to a computer file.

As a rule, when the pressure charts are recorded, one working cycle is processed. In case of unsteady-state operation of the impacting mechanism, the most typical working cycle is selected, and the resultant force is plotted as function of the cycle time. The plot is then interpreted based on Sudnishnikov's theorem on "movement of mass during action of force" [9].

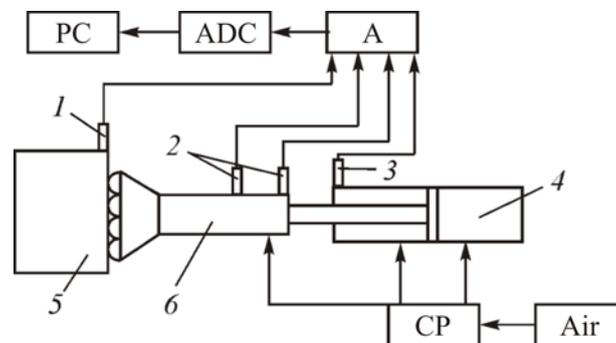


Figure 1. Block diagram of test bench: *1*—impact sensor; *2*—transducers of pressure in the chambers of power and idle strokes; *3*—transducer of air pressure in supply line; *4*—pneumatic actuator of feed; *5*—rock specimen; PC—personal computer; ADC—analogue-to-digital converter; A—amplifier; CP—control panel.

Determination of areas and centers of gravity of the impulses takes much labor, especially in case of the impulses of complex geometrical form [8].

For the interpretation of the pressure charts, the Institute of Mining has developed a program in the object-oriented language C# (Figure 2). The program is supported by various versions of Windows OS. A user downloads huge data text files and displays them in graphical form. Windows of the program menu interact with each other. For the convenience, the analog window offers prompting messages. The program accelerates the process of interpretation of large bulks of data as against the grapho-analytical method. One more advantage consists in visual display of data and intuitive interface adaptable to a specific user. The program also enables addition of modules and windows, which

widens its application field. Furthermore, the program searches and treats possible errors, e.g., in entry of input data of parameters. Each error and its cause are identified in an individual dialog box, which allows prompt error control.

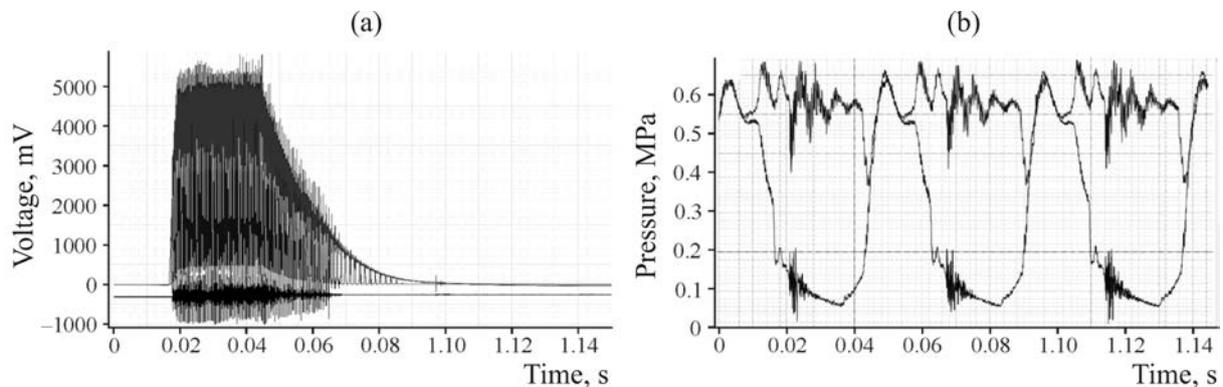


Figure 2. Illustration of automatic calculation of working cycles: (a) work diagram of the machine; (b) operating cycles after processing.

3. Conclusion

The computation program for working cycles of percussive machines computerizes determination of energy parameters of air- and hydraulic-driven percussive machines with a free moving piston. Sampling of a number of impact cycles improves accuracy of the energy parameters.

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