About creation of machines for rock destruction with formation of apertures of various cross-sections

I A Zhukov¹, L T Dvornikov¹ and S M Nikitenko²

¹ Siberian State Industrial University, 42, Kirov st., Novokuznetsk, 654007, Russia
² Federal Research Centre of Coal and Coal Chemistry at the Siberian Branch of the Russian Academy of Sciences, Leningradskij ave., Kemerovo, 650065, Russia

E-mail: tmmiok@yandex.ru

Abstract. The article presents the results of the experimental research of the high strength rock destruction by a bladeless tool. Rational circuit designs of disposing of indenters in the impact part of the drill bits and a diamond tool are justified. New constructive solutions of reinforcing bladeless drill bits, which allow drilling blast-holes of the various cross-section, are shown.

1. Statement of the problem

Elaboration of new and improvement of the known systems of development of the minerals are connected with wide application of drilling operations of different functions [1-5]. The primary way of destruction of high strength rocks is a percussive method. When striking blows on the tool, they can be transmitted to the destroyed object with the highest energy per time unit. Drilling without rotation of the tool round its axis [6], except for the rotation mechanism, allows essentially simplifying the drilling machine design and drilling blast-holes of any geometrical form. The percussive method of destruction can be realized by application of a bladeless tool – non-coring bits with indenters [7].

Commercial tests showed considerable advantages of indenters over the tool equipped with the blade in terms of endurance, the drilling rate, the specific charge of the firm alloy, expenses for drilling. Application of indenters in equipment of bits allows one to create almost an unlimited quantity of alternatives of crown designs using simple means. Changing, for example, their form, quantity and a disposition of circuit design for specified mountain-technological conditions of the deposit, it is possible to choose the most optimal equipment design. Now there are no well-founded recommendations for choosing the size, form, quantity of indenters and circuit designs and their optimal disposition on the chisel tool.

The project was financially supported by the Ministry of Education and Science of the Russian Federation within the Federal target program ‘Research and development of priority directions of scientific-technological complex development of Russia for 2014-2020’ (agreement No. 14.607.21.0028 from 05.06.2014, unique ID RFMEFI60714X0028).

2. Problem solution

For the purpose of acknowledging the possibility of rocks drilling without axial rotation of the tool, as well as revealing features of the penetration of bladeless indenters, experimental research [8] was conducted. During the experiment indenters were introduced into rocks by the universal testing machine ‘IK-500.01’ (Figure 1).
Drill bits of a cylinder-spherical form reinforced by indenters and placed on four circuit designs were used as the prototypes. They included a single indenter (Figure 2a), two indenters (Figure 2b), three indenters located at apexes of the equilateral triangle (Figure 2c), four indenters placed at apexes of the square (Figure 2d). The rock blocks with the sizes of 40×36×15 cm were used for destruction at the installation. The rock is presented by fine-grain and tight granite with strength factor $f = 18$ on the scale of Protodjakonov.

The experimental technique consisted in the following. The rock block was installed on the lower platform of the stand. A vertically oriented non-coring bit was fixed in the overhead part of the stand and so that it could rotate in the course of the test. With appropriate setting of the hydraulic station the speed and the maximum value of loading was established. After turning of the stand the contact between the bit and the granite block was installed. Then the crown loading with speed $V_H = 1 \text{kN/s}$ was shifted. The computer control system recorded a diagram of dependence of the crown penetration depth into the granite on the magnitude of the loading (a ‘force – penetration’ diagram). The first cycle of the test proceeded until the muck was destroyed and the tool penetration formed a characteristic hole under indenters. The subsequent test was carried out after cleaning a hole from the destroyed muck and installation of the non-coring bit into the same hole. The loading proceeded until applied force magnitude $F_{\text{max}} = 100 \text{kN}$ was achieved. After each test the analysis of the broken rock was made.

The above-mentioned diagram ‘force-introduction’ allow us to study the mechanism of rock destruction at dynamics by means of the tool. The diagram ‘force-introduction’ allows identifying the various stages of the process of tool introduction into the rock. The first section of the chart until the reduction of the load indicates the accumulation of elastic deformation resulting in the brittle fracture of the rock. The next section shows a sharp drop in the loading at a small depth of penetration. Then, under the almost constant loading, the depth of the tool penetration increases. This step corresponds to brittle fracture of the rock. Then the cycle is repeated.
3. Analysis of the results

During the experiment the following results have been obtained.

As the result of the statistical analysis of various functional relationships the diagram ‘force – introduction’ allowed us to determine that the hyperbolic function is the closest to the truth:

\[ P_i(h) = k_1 + k_2 \cdot \sqrt{k_3^2 + h^2}, \]

where \( P \) – value of the loading, \( h \) – depth of tools’ penetration, \( k_i \) – empirical coefficients that characterize the object of destruction, \( i = 1, 2, 3 \).

The physical meaning of coefficients \( k_i \) is the compliance of the object of destruction with the tool. The resulting function describes adequately the experimental results and allows one to judge the effectiveness of the tool.

During penetration of the single indenter under the bonding pad a tightly pressed and quite thin bowl-shaped layer of the rock is formed. Its diameter is slightly less (1…2 mm) than the diameter of the hole. The other part of the destroyed muck represents less pressed shattered layers of the muck removed without considerable efforts by a sharp object.

During simultaneous penetration of two, three, or four indenters (Figure 3) the muck part located between indenters is destroyed by the large-scale spalling. At an optimum distance between three next indenters \( l_i = 1…2.5 \, d_i \), located at the apexes of the equilateral triangle, there is a 1.5…2.5-fold increase in the total volume of destruction on the average.

![Figure 3. The hole resulted in during simultaneous penetration of three indenters.](image)

1 – a strongly compacted layer of the muck, 2 – a zone of the shattered muck, 3 – a contour joint of the hole, 4 – a zone of the large-scale spalling

According to the analysis results of the obtained diagram «force - penetration», the distribution of the magnitude of the applied forces on the number of simultaneously introduced indenters is set. If the force per one indenter is related to the volume of fracture (Figure 4), the most optimum scheme from the point of view of energy consumption will be that in which three indenters are located at the apexes of the equilateral triangle.

![Figure 4. The estimation of volume of the destroyed muck.](image)
Thus, the experimental verification of the interference effect of closely spaced and, at the same time, introduced indenters provides the effect of simultaneity. Assuming a particular value of the diameter of the blast-hole, it is possible to find such mutual bracing of three indenters which allows drilling the aperture holes without the tool rotation around its geometrical axis. This type of drilling mode provides an opportunity of obtaining apertures of a non-circular cross-section. It is also necessary to note that the figure formed by the next indenters should not necessarily be a precise equilateral triangle; the angle between the sides can be in the range of $60 \pm 12^\circ$. Instances of the recommended circuit designs of indenters’ disposition on the working part of non-coring bits are shown in Figure 5.

![Figure 5. Rational circuit designs of indenters’ dispositions.](image)

In Figure 6 the bit with the rational disposition of indenters, by means of which churn drilling with the participation of the author, a blast-hole of the rhombic cross-section is obtained.

![Figure 6. Drilling of a blast-hole of the rhomboid cross-section.](image)

4. Conclusion

New aspects of the drill bits and a diamond tool provide a possibility of the short-hole drilling of the various cross-section including a non-circular one, when in the sharp corners of the drilled blast-hole, stress concentrators are created and there are possibilities of purposeful influence on the array with an essential decrease in drill footage.

References

[1] Lipin A A 2005 J. Physical-technical problems of development of mineral resources 2 74
[2] Smolyanitsky B N, Tishchenko I V, Chervov V V, etc. 2009 J. Physical-technical problems of development of mineral resources 4 65
[3] Yungmeister D A, Sudenkov J V and Pivnev V A 2011 J. Mountain Inform.-Analyt. Bullet. 8 288
[4] Saruev L A, Pashkov E N, Ziyakaev G R and Kuznetcov I V 2013 J. Mountain Inform.-Analyt. Bullet. S4(1) 482
[5] Zhukov I A, Molchanov V V 2014 J. Advanced Materials Research 1040 699
[6] Dvornikov L T, Zhukov I A 2007 J. Mountain Inform.-Analyt. Bullet. 9 269
[7] Zhukov I A, Dvornikov L T 2009 J. Mining Equipment and Electromecanics 2 23
[8] Zhukov I A, Tsvigun V N 2009 J. MachineStructure 19 125