Efficiency increase of hard rock destruction with the use of eccentric pulses

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Abstract. The increase of efficiency of expendable well-drilling directly depends on the mechanism of rock destruction. The depth of hole coverage should be at the maximum possible value and equal along the whole contact area. The design features of performing rock-destruction tool in rotary drilling prevent the cutters, located on different distance from rotation axis, from working with equal intensity. The application of the shock pulses to a boring tool increases the mechanical drilling speed and sinking per revolution. One of the techniques for the efficiency increase is the application of impactor machines. On the other hand, the high values of mechanical drilling speed require the high values of impact energy which results in high power inputs energy consumption. The use of eccentric impact loading instead of central one can provide the enhancement of rock destruction efficiency, lower the power inputs, and decrease the risk of borehole deviation.

1. Introduction

One of the relevant issues of modern drilling engineering is the enhancement of rock destruction process. The basic measure in this area is mechanical drilling speed which depends on the combination of basic parameters – axial thrust, rotary speed of the tool, and expense of cleaning agent. The increase of the values of mentioned parameters does not always result in mechanical drilling speed increase as exceeding of these values can lead to different operating problems and breakdowns. The increase of the depth of bottom-hole coverage with the cutters of rock-destruction tool without exceeding of optimal parameters is a key to the enhancement of rock destruction efficiency.

2. Theoretical Background

The feature of embodiment of boring tool, based on rotation as a breaking force, consists in unequal performance level of cutters located on different concentric circles of the butt [6]. The linear speed of movement is higher than that of the cutters located further from the rotation axis. As a result, one can observe the decrease of sinking per revolution and mechanical drilling speed. It is caused by nonoptimal ratio of unit axial load and cutter load values.

This difference in performance is appreciable particularly in non-core drilling where the difference in linear speed (cutting rate *Vp*) of close and distant cutters can reach high values. Thus, the cutters which are close to rotation axis perform rock destruction with higher intensity (figure 1).

Another reason of efficiency decrease is overgrinding of drill cuttings which is carried out by peripheral cutters to a greater extent. It is due to the increase of hardening of isolated rock debris with its size reduction [1]. The multiple overgrinding also leads to the rise of power inputs and high wear rate of rock-destruction tool.

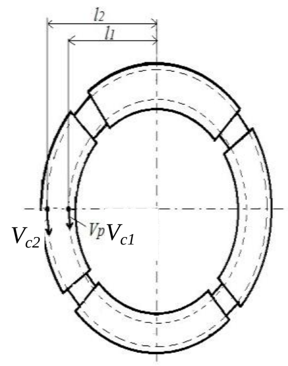

Figure 1. Scheme of diamond cutters performance analysis: V_{ci} – cutting rate; l_i – distance between rotation axis and cutter.

It allows making a conclusion that frequent contact of peripheral cutters with abrasive particles of drill cuttings creates conditions for their polishing. The farther is the location cutter from the rotation axis the higher is the value of its wear degree which occurs due to a greater amount of abrasive particles to contact (figure 2).

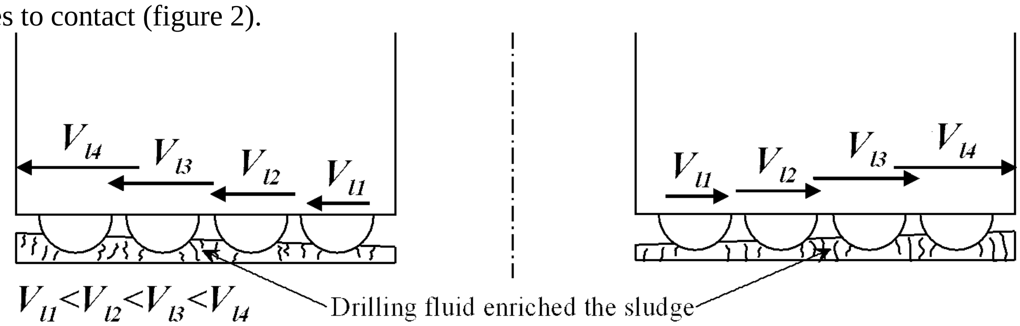

Figure 2. Scheme of unequal wear of rock-destruction tool cutters analysis: V_{li} – linear speed of movement of cutter *i*.

The quality of bottom-hole cleaning should be highly effective and, at the same time, the amount of drill cuttings contacting rock cutting elements should be minimal. It requires flow regime under the butt of boring tool to be turbulent and radially directed [5].

Considering foregoing, the search for the methods of intensification of rock destruction by the peripheral cutters is required. It should be noted that, according to the theory of rock failure, the ensuring of uniformity of cutters wear would enable the values of sinking per revolution and mechanical drilling speed to increase and therefore, to achieve the efficiency enhancement of hard rock destruction as a whole.

The use of impactor machines such as hydraulic hammers and pneumatic impact tools enables increasing sinking per revolution due to a greater depth of penetration of cutters to a rock and improvement of energy intensity of rock failure at borehole bottom as well as lowering of wastes of axial load communicated to a boring tool through the system of drill pipes. The considerable experience of Atlas Copco (Sweden) company in the development and operation of pneumatic impact tools showed that the rise of mechanical drilling speed virtually is directly proportional to pneumatic air increase. The mechanical drilling speed of pneumatic impact tools like Cop performing solid rock failure at high air pressure reaches 15-25 meters per hour. Headway per bit also increases due to the improvement of energy intensity of rock failure at borehole bottom.

Efficiency indexes of hydropercussion drilling rise with the increase of the specific energy of single shock pulse. According to the authors of the research [3], the mechanical drilling speed rose three and a half times when energy of the shock pulse increased from 75 to 200 J. The lifetime of rock-destruction tool also increased in 7.4 times.

The tendency of development of modern engineering in the area of exploration drilling for solid raw materials is oriented towards rotary-percussion drilling (particularly in our country) with the application of high pressure pneumatic impact tools [3]. This is one of the most productive methods of shaft sinking. Some of the countries implement the combined method. Before the ore zone the drilling with reverse circulation of compressed air and sludge sampling is applied while in ore zone the core drilling is applied. The quality of deposit sampling is maintained at a considerable reduction of time and resources for execution of boring.

At the same time, the rise of air pressure, required for increasing of impact energy, consumes greater amounts of compressor energy which is quite expensive. Besides, application of axial shock pulses does not solve the main challenge of rotary boring – unequal performance of cutters located on different concentric circles of rock- destruction tool butt as the percussion energy is dispensed throughout borehole bottom (figure 3, *a*). As a result, it is necessary to develop method for enhancement of failing percussion action efficiency which is not connected with the increasing of expenses on cleaning agent and, as a sequence, on energy consumption. Different mechanic of rock failure should be applied instead.

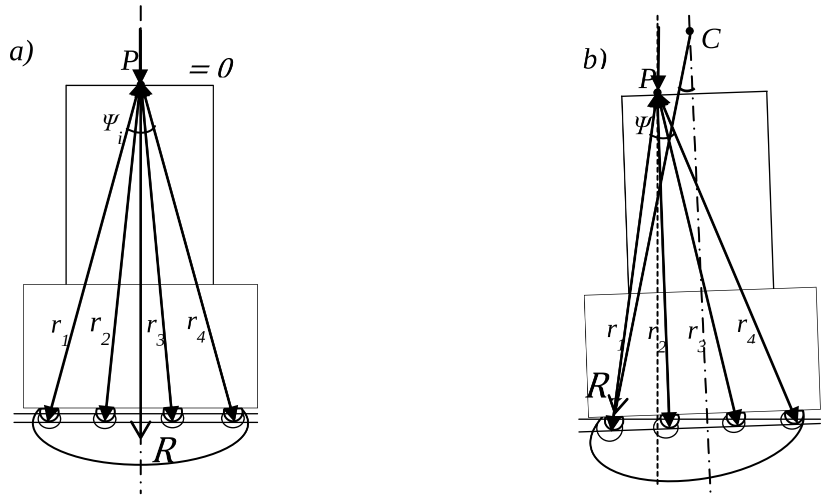

Figure 3. Scheme of the percussion rock failure process study:

a – central position of shock pulse; *b* – eccentric application of shock pulse.
P – impact force; r_i – the distance between center of percussion and rock cutting element;
Ψ_i – the angle between vertical line and direction from center of percussion to rock cutting element *i*; – angle between borehole axis and shock pulse vector R_y; R_y – shock pulse vector; *C* – center of gravity of hammer of pneumatic drill.

One of such methods can be the application of eccentric shock pulse [6] the vector of which is directed towards location of peripheral cutters (figure 3, *b*). Theoretical research has shown that maximum values of tensions are observed under the cutters located on the side of application of shock pulse [2]. Maximum values of tensions, herewith, exceed and minimum tension values are considerably lower than corresponding values of central percussion which are all equal.

This modification of the character of shock loading can provide the matching of wear rate and performance of the cutters throughout butt of rock-destruction tool.

Thus, eccentric application of shock pulses can provide the efficiency enhancement of boring in whole due to the improved mechanics of the process of rock failure, rise of mechanical drilling speed, and stabilization of boring tool performance.

3. Experimental research

Experimental work on the boring of rock slabs (marble and dolerite) at different regime parameters showed the efficiency of rotary-percussion drilling method with eccentric application of shock pulses. The inequality of eccentricity *E* for different rocks was demonstrated. Thus, the destruction of dolerite

– elastobrittle rock – is performed with isolated diamond cutter causing lateral chipping with low value of *E*. For marble, as a more plastic rock, higher values of *E* are observed as higher amplitude of lateral movement of the cutter is required [5].

It is known [3] that pneumatic pressure *P* is proportionate to unit weight of hammer (*Q/F*) and shock pulse angle *Д* and, therefore, eccentricity of shock load application *E*. Thus, decreasing of *E* can lead to decreasing of air pressure *P*, required for efficient percussion hard rock failure. This tendency was confirmed by experimental research results.

It is also known that rotary-percussion drilling efficiency is dependent on distance *r* between center of percussion and the butt of rock-destruction tool. Both factors are interdependent and their ratio should be tuned empirically.

To estimate the influence of combination of these factors (*E*, *r*, energy of single percussion) on the efficiency of rock failure, a number of additional experiments were carried out. The experiments were conducted with the planning procedure of complete factorial experiment which can reduce the number of experiments without loss of reliability of research.

Based on experimental results, the mathematical models of mechanical speed and sinking per revolution–vs–regime parameters at different values of *E* and *r* curves were drawn. For convenient results presentation, the curve was drawn with maximum values of mechanical drilling speed obtained from mathematical models (figure 4). At minimum value of *E* the successive distance decrease leads to the gradual rise of mechanical speed.

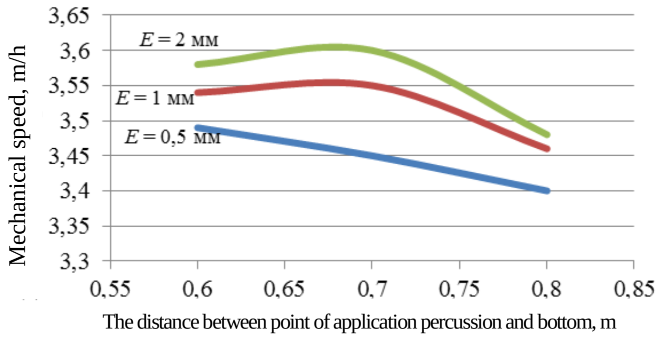

Figure 4. Mechanical speed dependence on *E* and *r*.

With increasing of *E* the ambiguous influence of *r* on rock failure process was noted. Thus, at value *E* = 1 mm the maximum mechanical speed was reached at *r* = 0.7 m and its subsequent decrease promoted the speed reduction but not less than the value at maximum distance from borehole bottom.

The similar tendency is observed with increasing of E up to 2 mm (figure 3). It indicates that the distance value 0.7 m is optimal for current *E* values, and for *E* = 2 mm to a greater extent.

The reduction of efficiency indexes of rock failure with maximum drawing close to the borehole bottom (at all other parameters being equal) can be explained that with *r* reduction the shock load vector is directed closer to borehole axis which prevents the shock pulse energy from being implemented in full.

4. Research with Autodesk software

For the highest performance the tensions under cutters should exceed the compression rock strength. The axial stress under each cutter is equal and their linear motion speed is different. Therefore, the attainment of high values of mechanical speed requires greater expenditure of energy.

The shifting of shock pulse application results in redistribution of tensions in boring tool and, as a sequence, on borehole bottom. Maximum tension values are located on the side of center of shock load application and the minimum values are on opposite. The difference between these tensions rises with increasing of *E*.

To investigate the influence of eccentricity values on tensions arising in wellbore zone at the moment of eccentric impact, the computer models were developed by AutoCAD Mechanical and

Autodesk Inventor software. The example of such model is present on figure 5, *a*. The different tension values are colored accordingly to special scale to the left.

A number of curves (figure 5, *b*) based on computer models were drawn reflecting the change of tension values for different values *r*. The analysis of diagrams allowed us to highlight the most significant moments which indicate the positive influence of eccentricity of shock load on the drilling performance.

Axial stress values are proportionate to penetration of cutters into rock. With the increasing of *E* the tension values on the side of shock load center rise which indicates the higher depth of bottom-hole coverage. As a result, the mechanical speed increases but excessive penetration of cutters, however, can negatively affect the boring process.

Lateral stress, aroused with the shifting of shock pulse application center, thus promoting the level increase of the destructed rock due to the lateral movement of cutters. The vibrations created in the rock face increase the chip loading. However, with the increasing of *E* the transverse vibrations can negatively affect the core-forming and wellbore wall durability.

Equivalent tensile stress values allowed us to find the energy losses depending on *E* and *r* values. The highest energy losses were observed at maximum values of dot E and r which can be due to partial energy conversion into torque loads.

In general, all these conclusions confirm the experimental results mentioned above.

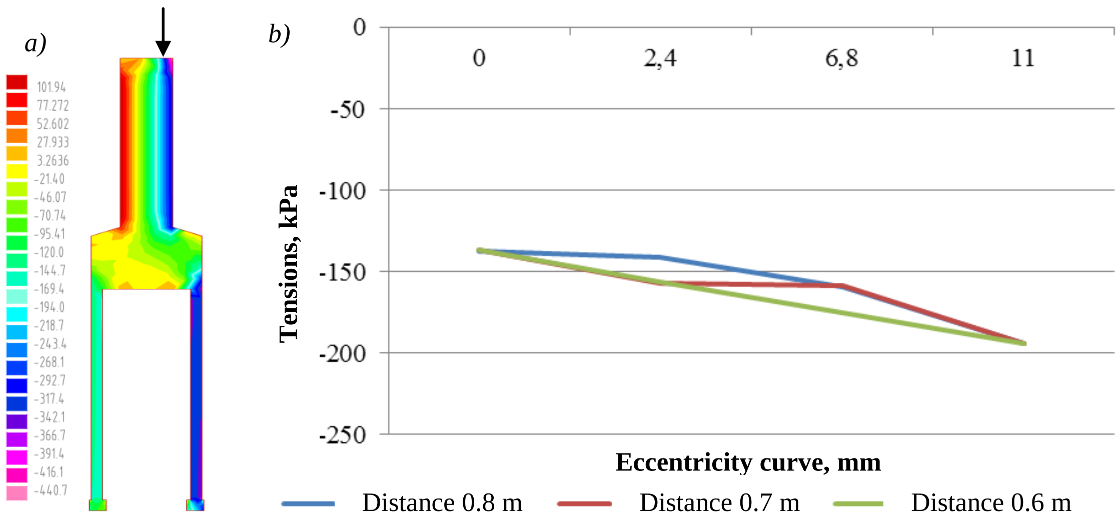

Figure 5. *a* – Graphic model of tensions, arising in core tube; *b* – Tensions-vs-eccentricity curve.

5. Possible ways for implementation of suggested technique

The results of the research have shown that the maximum performance of rock failure requires the decreasing of *r* and at the same time the tuning of optimal value of eccentricity of shock load. The implementation of such scheme is possible in non-core drilling by constructive change of rock-destruction tool.

Figures 6 and 8 show bit design examples, which are able to transform the central impact into eccentric one. The bit on figure 6 is applied for rotary-percussion drilling which is characterized by low and medium energy values of single percussion and high shock pulse frequency. The principle of operation is in changing of shock pulse vector direction directly in bottom hole area. Joint 2, established in the center of bit case 1, changes the direction of shock pulse by horizontal cranking due to virtue of elastic insert 3 which also serves as a shock absorber. Vector changes its direction so that it can get to peripheral part of the butt of rock-destruction tool 4.

The bit on figure 7 is applied for rotary-percussion drilling which is characterized by the high energy of single percussion. The design feature of the bit is movable anvil 2 which is hammered by anvil block 3 and can alleviate the influence of warp on the bit case 4 and therefore to prevent the tool from damage. Metal insert 3 changes the direction of shock pulse vector from rotation axis to the peripheral side of the butt of rock destruction-tool 6. The spring 7 in combination with the elastic insert 8 promotes the lateral movement of cutters with regard to hinged joint 5.

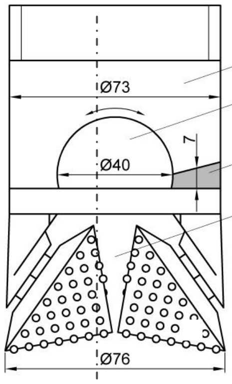

Figure 6. The bit for rotary-percussion drilling.

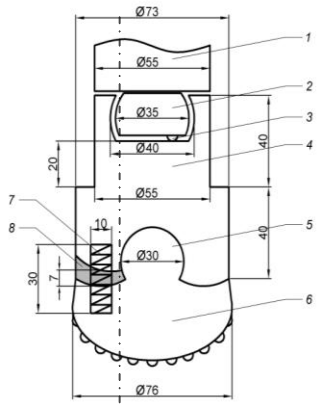

Figure 7. The bit for percussion-rotary drilling.

6. Conclusion

The results of analytical and experimental research demonstrated the rise of the mechanical speed and sinking per revolution. In our opinion, this can occur due to the deflection of shock pulse vector from rotation axis. In combination with certain ratio of E and r it directs the percussion energy to peripheral (working) part of the butt of diamond crown bit and increases the penetration of cutters into the rock. As a sequence, the performance of cutters located on different concentric circles of rock-destruction tool equalizes.

Thus, the boring with the application of eccentric shock pulses:

- can be applied in both coring and non-core drilling
- enables the performance to rise without increasing of power inputs, including sampling of core and drill cuttings
- lowers the risk of borehole crooking
- lowers energy intensity power consumption of rock failure process
- can be implemented by presented constructions of rock-destruction tool.

7. References

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