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Justification of well drilling modes using collapsible drilling tools with multi-row cutting structure

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Abstract. Rational drilling modes for blast holes in open pit mining depend on the physical and mechanical properties of the rocks. Serially manufactured drilling tools often work in areas that do not meet the conditions of their application (especially in coal mines). The paper presents the design of a cutting bit of a cutting-rotational type with hard-alloy multi-row cutting structure, as well as the dependence of the power regimes of drilling with this bit on the of drill rocks strength.

1. Introduction

The basis of all industrial production is the mining industry, which extracts minerals and provides the raw material needs of not only Russia, but also other countries. The main volumes of the rock mass are prepared for excavation using the blasting method, one of the main production processes of which is blasthole drilling [1-3].

In open-pit mining, when drilling blasthole, the main method is cone drilling, but other types of drilling tools are also used. Each model of a drilling tool has a rather limited area of effective work. The same applies to other types of drilling tools. Due to the specificity of the mining and technological conditions for drilling in open-pit mining (shallow wells with alternating rocks of different strengths), the drill bit often works in an area that does not meet the conditions for its use. This leads to a decrease in technical and, as a result, economic indicators of drilling.

Currently, open-pit mining use solely roller cone bits, consisting of three sections joined by welding [4].

Technological and technical shortcomings of the applied roller cone bits are most significantly evident in coal mines, where complex structural ledges predominate with frequent alternation of drill rock strength in the range of f = 1–12 [5-7] (for example, in the conditions of the Chernogorsk coal mine). Under such conditions, the speed properties of cone drilling can occur only with the corresponding alternation of bits of types M, MZ, T and TK.

When drilling blasthole in open-pit mining over rocks of small (f < 6) and medium strength (f < 6–10) expensive serial wells can be successfully replaced by collapsible drilling tools of the cutting and cutting-rotational types [8].

A number of scientific teams of universities (SNFMMS, INRTU, KuzSTU, etc.) have done a lot of work to develop new highly effective types of collapsible drilling tools. Despite the fact that these drilling tools have a significantly lower cost than roller cones, high durability (L ≈ 2000 – 6000 P.m.) and high maintainability, they have a narrow area of rational operation (f = 2 - 8). Based on this, it is necessary to create new highly efficient types of drilling tools with an expanded area of rational operation.

2. Materials and methods

The team of the Department of Mining Machines and Complexes of the Siberian Federal University developed a collapsible drill bit with toothed-disc cutters (DRDF) equipped with two rows of hard-alloy cutting structure (Figure 1) [9], which effectively destroys complex rock masses with f = 2-10 and interlayers up to f = 12. This design of the drill bit is promising, but requires justification of rational operating parameters for blasthole drilling.

The bit is composed of the case and the nipple made in one, interchangeable toothed-disc cutters and foot pieces. The cutter has a double-row metal-ceramic cutting structure, located at an angle of 30^0 to the cutter body. To install the toothed-disc cutters in the body groove, turned 10^0 towards the cutting direction, the simplest sleeve bearing is used, consisting of an axis, two grooves. The axis is fixed by a stop collar. The case with the nipple and arms of the cutting elements are made as a whole using casting, toothed-disc cutters - stamping.

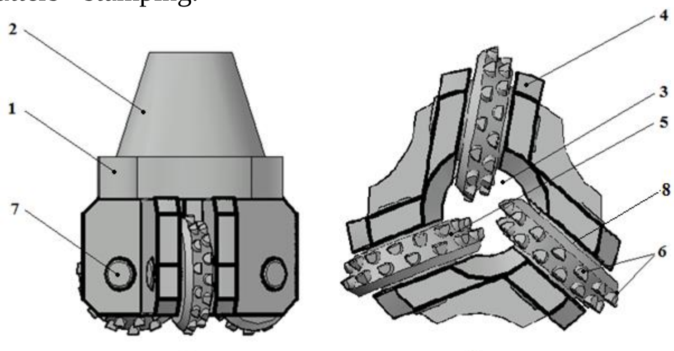

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Figure 1. Collapsible drill bit with disk cutters and two rows of hard-alloy cutting structure (DRDF-244.5-2): 1 - case, 2 - nipple, 3 - scavenge channel, 4 - arms of cutting elements, 5 – toothed-disc cutters, 6 - double-row metal-ceramic cutting structure, 7 - axis of the disk cutter, 8 - grooves.

The operation of the DRDF at a face under the influence of the axial load P_{OS} is theoretically characterized by the following modes:
1. Steady mode. In this case, the rolling moments acting on the toothed-disk cutter are dependent on: $M_f > M_t$;
2. Anti-rolling mode. In this case, the rolling moments acting on the toothed-disk cutter are dependent on: $M_f < M_t$;
3. Blocked mode. Toothed-disc cutters work without rotation. In this case, the rolling moments acting on the toothed-disk cutter are: $M_f = M_t$.

Consider the operation of the DRDF-244.5-2 bit, taking into account the work [10]. In each well face zone, based on the condition that the axial load P_{OC} acting on the bit is evenly distributed on the number of toothed-disk cutters β and the number of teeth N located in the zone of rock destruction at a face.

Since each toothed-disk cutter theoretically simultaneously has 50% of teeth in the destruction zone and 50% in the cooling zone (non-working zone), the axial load P_3 per tooth is equal to:

$$P_3 = \frac{P_{\text{OC}1}}{\beta \cdot \frac{N}{2}} = \frac{2 \cdot P_{\text{OC}}}{\beta \cdot N}, H. \tag{1}$$

The axial load P_3 acting on the cutting structure (tooth) creates in each well face zone a reactive

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force P_3 acting on the tooth from the rock side, with $P_3 = R_3$.

On the rock in the central zone of the face (the top of the core), the axial load transmitted by the tooth of each toothed-disk cutter is acting and is equal to:

$$P_К = \beta \cdot P_З = \frac{\beta \cdot 2P_{ОС}}{\beta \cdot N} = \frac{2P_{ОС}}{N}, H, \quad (2)$$

where P_k - axial load acting on the top of the core in the central zone of the well face, H.

The cutting force P_p depends on the size of the destructible section of the rock; its physical and mechanical properties, taking into account the work [10] and is found by the equation:

$$P_p = в \cdot h \cdot K_k \cdot \sigma_{м.б}, \text{ Н}, \quad (3)$$

where $в$ - the length of the destroyed section of the rock, equal to the circumference of the toothed-disk rolling-cutter in sectors I, II, III, m:

$$\mathrm{B} = \frac{2}{5}\pi \cdot \mathrm{d_f}, \mathrm{m}, \quad (4)$$

h - the depth of cut of the toothed-disc cutter into the well face in a single revolution, taking into account the work [10] equal to:

$$\mathrm{h} = \frac{\mathrm{V_б}}{\mathrm{n_д} \cdot \beta}, \text{ м}, \quad (5)$$

where $V_б$ - well drilling speed, m/s; n_d is the total bit revolution around the axis O_1-O_1, c^{-1}; K_k - coefficient taking into account the incompleteness of contact of the destroyed area of the rock with the working part of the toothed-disk cutter,
K_k = 0.5–0.7; $\sigma_{м.б}$ - rock break-down point during mechanical failure, Н/м^2.

The drilling speed is determined by the formula:

$$V_б = \frac{P_{oc} \cdot n_{вр}}{5 \cdot П_б \cdot D_1^2}, \text{m/min}, \quad (6)$$

For the DRDF-244.5-2 bit with thirty teeth on a toothed-disk cutter ($\mu_П$ = 0.55; K_k = 0.5), the minimum axial load is determined by the formula:

$$P_{oc} > 0{,}43 \cdot d_ш \cdot h \cdot \sigma_{м.б} \cdot \beta, \text{ Н} \quad (7)$$

3. Results and discussion

The minimum values of the axial load $P_{OC\ min}$, providing a stable mode of operation of the drill bit DRDF-244.5-2, are presented in table 1.

Table 1. The minimum values of axial load ensuring stable operation of the drill bit DRDF-244.5-2.

Rock strength classification	Rock strength coefficient, f	Average value of $\sigma_{m.b}$ [a], MPa	h[b], m/ob	$P_{oc\ min}$, кН	
				β = 2	β = 3
Weak and quite weak	2	18,2	0,00485	12	17
Moderate	4	35,0	0,00465	21	34
Moderate and quite strong	6	60,0	0,00442	35	52
Storng	8	74,3	0,00424	41	62
	10	86,0	0,00374	42	64
Very strong	12	112	0,00298	44	66
	14	146,5	0,00221	42	63

[a]- the average value of the rock strength during disintegration;
[b] - the depth of the toothed-disc rolling-cutter cut into well face.

According to the Table 1, it can be seen that with rock strength f < 12, rational values of axial load increase, and with values f > 12 rational values of axial load necessary to ensure stable operation of the DRDF bit decrease. The highest values of P_{OC} are in rocks with a coefficient of strength f = 10–12.

The decrease in P_{OC} during drilling of rocks having f > 12 is explained by a sharp decrease in the depth of the toothed-disc rolling-cutter cut into the well face (h).

When analyzing formula (7), it can be seen that, other things being equal, only the depth of cut h of the toothed-disc cutter into the well face in a single revolution and the ultimate strength of the rock while disintegration affect the P_{OC}:

$$P_{oc} = f\,(h; \sigma_{м.б.}). \tag{8}$$

It can be assumed that the change in axial load on the drilling tool is characterized by a relative indicator of the disintegration efficiency in the well face, which is as follows:

$$P_{oc} = h \cdot \sigma_{м.б}, \mathrm{H{\cdot}ob/m} \tag{9}$$

The dependence of the relative indicator of the disintegration efficiency in the well face on the rock strength is shown in figure 2.

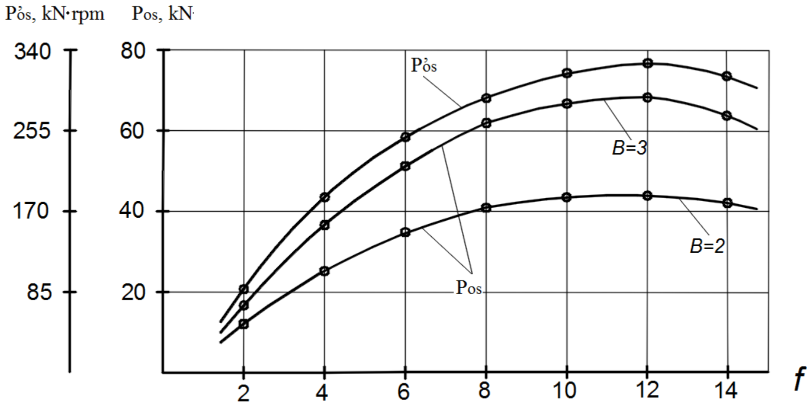

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Figure 2. The dependence of the power regimes of drilling wells with DRDF bits on rock strength (P'$_{os}$ - a relative measure of disintegration efficiency).

4. Conclusions

Multi-row cutting structure of bits with toothed-disc rolling-cutters expands the field of their rational use in rocks characterized by a coefficient of strength according to Protodyakonov scale, from f ≤ 10 to f ≤ 12. Rational operating modes of the DRDF bits depend on the physicomechanical properties of drill rocks. In this case, the values of the axial load providing a stable mode of the bit operation, with an increase in the strength of the rock mass to f ≤ 12, increase, and at f > 12 they decrease. This is due to a significant decrease in the depth of cut into the well face.

The criterion for evaluating the rational power regimes of well drilling can be a relative indicator of the disintegration efficiency, taking into account the dependence of the depth of cut of a drilling tool into the rock on its physical and mechanical properties.

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