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The influence of geometrical parameters of the drill-rod on the ultimate axial feed force and the efficiency of drill cuttings removal during rotary drilling of holes

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Abstract. The article describes the design of an experimental drill-rod proposed by the research team of Siberian State Industrial University. The feature of the developed rod is the implementation of a cross-section in the form of a Reuleaux triangle. The influence of the geometric shape of the cross section of the experimental and commercially available rods on the technological aspects of their application is evaluated. Recommendations are given on the possibility of further improvement of the developed drill-rod design.

1. Introduction

The drill rod is an essential element of the drilling machine, designed to transmit torque and axial force to the cutter from the drilling rig drives. Structurally, the rods differ in cross-sectional profile, its dimensions, lock for the cutter, shank for fastening in the spindle of the drilling machine, length, free space to remove drill cuttings during drilling. The study of the geometric parameters of drill rods in order to determine their stability during drilling is an urgent scientific and practical task. The solution of this problem will improve the efficiency of rotary drilling of holes in coal mines.

This paper is devoted to the study of the design of an experimental drill-rod developed at Siberian State Industrial University, in comparison with the rods produced by industry.

2. Description of drill-rod designs considered in the study

A design feature of the experimental drill-rod [1] is a cross-sectional shape made in the form of a Reuleaux triangle (figure 1) [2]. The Reuleaux triangle triangle is a convex curve of constant width formed by three arcs of circles of radius R [3]. Such cross-section of the drill-rod provides a significant increase in its longitudinal and transverse rigidity. In addition, the cross-section of the rod along the oval curve does not contain stress concentrators along the perimeter of the section. Figure 1 shows: D is the diameter of the circle indicating the maximum size of the cross-section of the rod when placing it in the hole, d is the diameter of the washing hole.

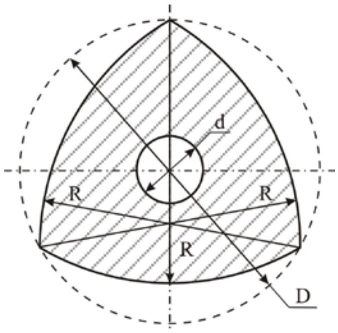

Figure 1. Cross section of an experimental drill-rod [1].

As analogues in a comparative study of the developed drill rod design, standard rods manufactured by Gortny Instrument LLC [4] were used. The cross-sections of the rods considered in this paper are presented in figure 2.

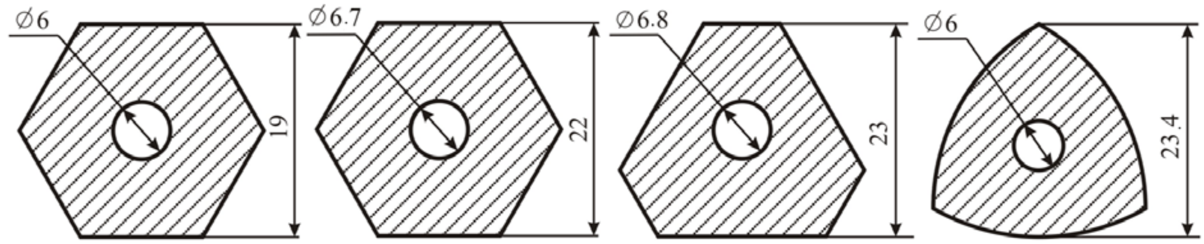

Figure 2. Cross sections of the rods for rotary drilling of holes considered in the study: (a) ShB 19-L/19-R17, (b) ShB 22-L/22-R17, (c) ShB 23-L/23-M16, (d) experimental.

3. Results and discussions

One of the main indicators characterizing the technological parameters of the rod is the ultimate axial force at which the rod ensures safe operation. The calculation of the critical force can be carried out according to the Euler formula, by presentation of the drill-rod in the form of a rod [5]:

$$F = \frac{\pi^2 E J_{\min}}{(\mu L)^2}, \tag{1}$$

where E is the modulus of longitudinal elasticity of the rod material, Pa; $J_{\min}$ – minimum moment of inertia of the rod cross-section, m^4; μ – coefficient of reduced length; L – rod length, m.

The coefficient of the reduced length μ shows how many times the length of a given rod fits in the length of a pin-ended rod, which has the same critical force as a given rod. The parameter μ is also determined by the method of fixing the loaded rod.

Considering various schemes of fixing a loaded rod [5] in relation to the conditions of the problem being solved, it is possible to imagine a drill-rod in the form of a rod, one of the ends of which is in a pin-ended position, and the second is pinched (figure 3). The pinched end of the rod is the end of the rod with a drill cutter fixed on it, which bumps up against the face of the hole. The coefficient of the reduced length of such diagram is μ = 0.7.

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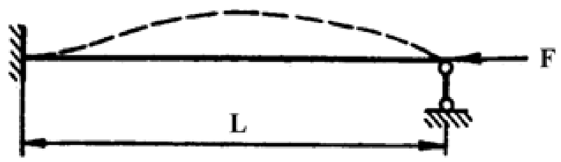

Figure 3. The method of fixing the end of the rod in the calculation [5].

It should be noted that the use of the Euler formula is possible only in cases where the flexibility of the rod λ exceeds the ultimate flexibility for the material $\lambda_{\max}$ from which the rod is made, i.e. $\lambda > \lambda_{\max}$.

The ultimate flexibility for the material can be determined from the formula [5]

$$\lambda_{\max} = \pi\sqrt{\frac{E}{\sigma}}, \tag{2}$$

where σ – the proportionality limit of the material, MPa.

Tentatively, we take steel grade 60C2 with the parameters $\sigma = 1175$ MPa, $E = 2.12 \cdot 10^5$ MPa as the material in the calculations [6, 7], often used for the drill-rods manufacture. Then, the value will be 42.2.

The flexibility of drill-rods is determined from the expression [5]

$$\lambda = \frac{\mu L}{i_{\min}}, \tag{3}$$

where $i_{\min}$ – the minimum radius of inertia of the rod cross-section, mm.

The minimum inertia radius of the cross-section can be represented as follows [5]

$$i_{\min} = \sqrt{\frac{J_{\min}}{A}}, \tag{4}$$

where A – the cross-sectional area, mm^2.

The calculation of the area and the minimum moment of inertia of the cross-section of each presented rods, as well as the area of free space through which the drilled rock is removed, was carried out in the compass-3D design system [8]. The diameter of the hole when calculating the area of free space was adopted 30 mm. The length of each studied drill-rod was 1 m. The results of the calculations are presented in table 1.

Table 1. Calculations results of the influence of the drill-rod geometrical parameters on the ultimate axial feed force and the efficiency of drill cuttings removal.

Dril-rod model	$J_{\min}$, mm^4	A, mm^2	$i_{\min}$, mm	λ	F, kN	S, mm^2
ShB 19-L/19-R17	7774	284.4	5.2	134.6	33.2	394.3
ShB 22-L/22-R17	13989.4	383.9	6	116.7	55.8	287.7
ShB 23-L/23-M16	14347.8	382.2	6.1	114.8	61	288.4
Experimental	12211.8	357.1	5.8	120.7	52.1	321.6

4. Conclusion

The results of the studies show that the closest analogues to the experimental rod in terms of the withstanding critical effort are serial drill-rods ShB 22-L/22-R17 and ShB 23-L/23-M16. The advantage of the proposed design of the drill-rod with a cross-section in the form of a Reuleaux triangle [1] is the large area of free space between the body of the rod and the hole. As a result, the removal of drilled rock becomes more efficient.

An additional effect of cleaning a hole from drill cuttinge when using an experimental drill rod can be obtained by its manufacture in a twisted form. In this case, the helical surface of the rod, driven into rotation by the drive of the drilling rig will be able to transport the drilled rock from the hole.

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