Determination of rational cutting parameters while drilling intermediate by ring

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Abstract. The article analyzes the problem of reducing the cost of changing bits during deep drilling of directional wells due to the rational choice of operational parameters in the process of sinking rocks that alternate in strength. The authors propose a technology to control drilling parameters on the basis of preliminary information on the limits of rock strength over sections of the well, which allows to increase the bit flight and reduce the energy intensity of the drilling process.

1. Introduction

Analysis of research in the field of improvement of cutting drilling tools indicates the impossibility of creating structures that do not change during deep drilling and are optimal for the entire range of drilled rocks [1-8]. The bit is repeatedly replaced during the drilling process, which increases the time for tripping, decreases the average rate of penetration and economic indicators. A rational solution to the problem is an adaptive chisel, automatically adapting to changes in the physical and mechanical properties of the rock. Self-regulation of the tool depending on the physicomechanical properties of the face should be based on the implementation of the optimal parameters of the rock cutting process.

Modern ideas on the mechanics of destruction of soils and rocks are based on the existence of defects in the structure of the rock and the anisotropy of the physicomechanical properties. A cutting angle that intensifies the tension and shear in the compressed volume of the rock stands out among the numerous factors that influence the resistance of soils and rocks to cutting [6]. It is known that soils and rocks practically do not resist stretching and collapse along sliding lines from shear forces [6].

The fundamentals of the theory of cutting and digging the soil, laid by academician V.P. Goryachkin, received rapid development in the writings of many of his followers, which resulted in the specific resistance to cutting and digging of soils of varying degrees of strength, determined experimentally in relation to dump and bucket working bodies. The work of V.V. Sokolovsky, which developed the basis of the theory of limiting equilibrium of a granular medium with adhesion, takes a special place in the studies of the interaction of working bodies with the environment. The disadvantage of his theory is the idea taken from soil mechanics: soil destruction under passive pressure on a fixed retaining wall
imitating a moving working body. However, the calculation of the soil destruction zones according to
V.V. Sokolovsky gave impetus to the development of graph-analytical methods of A.N. Zelenin [6] and
E.I. Berestov [3].

The physical and mathematical model of cutting soil and rock while drilling a well with varying
physico-mechanical characteristics was developed with the aim of using the same bit on soft and hard
rocks in order to increase the bit's flight and reduce the total length of tripping, i.e. increase bit versatility.
The model consists of three parts:
• determination of the axial and circumferential forces on the bit;
• definition of a family of optimal combinations of limit normal and tangential stresses;
• algorithm of control of regime parameters of drilling.

2. Determination of axial and circumferential force on the bit
In relation to the cutting bit, the cutting angle is the angle of inclination of the front face of the tool to
the borehole wall. It is convenient to present the diagram of the forces acting on the cutter by turning
the well along the diameter d, and replacing the cutter with a slider with an inclined blade (Figure 1).
Such a scheme is similar to the interaction scheme of a screw-nut threaded pair. The elevation angle α
of the screw surface of the cutter blade corresponds to the cutting angle, and the screw pitch h
corresponds to the tool feed per revolution. The cutter removes chips of length πd and thickness h under
the action of axial force P in one revolution. The force R of interaction between the cutter and the rock
is deflected from the normal to the helical surface by an angle φ of external friction of the cutter on the
rock. The circumferential force T is related to the axial force P by the ratio:

\[ \frac{T}{P} = \tan(\alpha + \phi) \]  

Let’s express the forces:

\[ T = \tau_v \cdot \pi \cdot d \cdot h, \]
\[ P = \sigma_c \cdot \frac{\pi \cdot d^2}{4}, \]  

where: \( \tau_v, \sigma_c \) – core material strength limits for shear and compression.

3. Definition of a family of optimal combinations of limit normal and tangential stresses
The family of optimal combinations of limit normal and tangential stresses is determined using the
theory of limit stress states of connected environments with the joint action of normal and tangential
stresses [6].
The ratio of normal and tangential stresses $\sigma/\tau$ for connected environments is determined by the Coulomb’s law:

$$\tau = c_0 + \sigma \cdot \tan \rho,$$

where: $c_0$ – specific grip;
$\rho$ – internal friction angle.

In the case of limiting stresses (destruction by drilling), taking into account expressions (2), we have:

$$\frac{\tau_s}{\sigma_c} = \tan \rho + \frac{c_0}{\sigma_c}$$$ (3)

In relation (3), the angle of internal friction $\rho$ is unknown. We define it by applying the theory of the ultimate stress state of the soil and rocks in the form of a diagram (Figure 2). The diagram is based on two points $\sigma_c$ and $\tau_v = c_0$, obtained during laboratory tests of cores for uniaxial compression and net shear, respectively. The tangent to the Mohr limit circles of compression and shear limits the region of rock destruction under the combined action of normal and tangential stresses. The points of the circle 3 determine the family of optimal ratios $\tau_v/\sigma_c$, at which only tensile and shear stresses are present in the drilled rock.

![Figure 2. Diagram of limit stress state of rock:](image)

1, 2, 3 – limit circles of stresses of compression, shear, and tensile, respectively.

The optimum cutting angle is determined by the ratio:

$$\alpha = 90^\circ - (\rho + \theta)$$

where: $\rho$ – internal friction angle;
$\theta$ – shear angle.

$$\tan \rho = 1 - \left(\frac{2 \cdot c_0}{\sigma_c}\right)$$

$$\theta = 45^\circ - \frac{\rho}{2}$$
4. Algorithm of control of regime parameters of drilling

Optimal control of the drilling regime is possible only by changing the cutting angle. With an unregulated bit, only approximate adherence to the coordinates belonging to circle 3 is possible in order to prevent compression forces in the drillable volume. If possible, it is necessary to maintain the balance using the following relations arising from the diagram (Fig 2):

\[
\frac{T}{P} = \tan(\alpha + \varphi) = \frac{4 \cdot h \cdot \left(1 - \frac{2 \cdot c_0}{\sigma_c}\right)}{d}
\]

(4)

With the change of \(c_0/\sigma\), the axial force \(P\), the supply of flushing fluid affecting \(\varphi\), chisel \(h\) feed can act as regulating parameters. Such an almost optimal (rational) regulation of the process parameters will allow to pass the problem area by the same bit, i.e. increase the bit flight and reduce the energy intensity of the well drilling process.

Economic analysis and decision-making on the effectiveness of savings on tripping operations with the possible risk of reducing the mechanical drilling speed should be made taking into account the specific mining and geological conditions.

5. Conclusion

We proposed a technology to control drilling parameters on the basis of preliminary information on the limits of rock strength over sections of the well, which allows to increase the bit flight and reduce the energy intensity of the well drilling process.

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