Perspective Solutions for the Design of Drilling Tools

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Abstract. The article considers the ways to solve optimization problems of drill bits on a deterministic basis through studying and using the "Regularity of energy consumption of dynamic systems from resistance to motion forces", which directly indicates the causes of bit balling formation, the reasons for the insufficient stability of the bearing assemblies of the cones, the causes of instability of the drill bits at the bottom of the well. Theoretical grounded search was done to use certain methods for designing drill bits of cutting-abrasive type, working in the rotational steam mode, which determine uniform wear of armaments for all crowns of working matrices and uniform destruction of the rock through all of the annular bottom hole.

1 Introduction

Drilling equipment is the collective term used for machines that apply impact and rotation forces to drill (for the most part) surfaces and blast holes, and it is classified as top-hammer drilling, down-the-hole drilling, and rotary drilling rigs, depending on the operating method. There are numerous previous studies regarding drill bit, rock drilling, the transmission of impact energy, and drilling efficiency [1].

The drilling of oil, gas and blast holes are carried out using rock-cutting tools of roller cone types, which is, among a number of drilling equipment, the main bottomhole mechanism. They perform 85-90% of the volume of drilling. Drilling, on average by industry, is 50-55% of the cost of mining mineral deposits.

It is known that the process of drilling wells has two aspects, technical and technological. The technical aspect refers to the process of developing, designing and manufacturing drilling rock cutting tools, and the technological aspect refers to the process of optimal selection of drilling tools in accordance with the physical and mechanical conditions at the bottom of the well and the optimal modes of the drilling process: axial loads, rotational speed of tools and the amount of fluid (air) supplied to the bottom of the well.

It is necessary to bear in mind the fact that the conditions at the bottom of the well differ in geological regions. Therefore, not in all cases, optimization of the choice of drill bit will be optimal, which equally concerns the process of optimization of drilling conditions.

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The rock-destructive tool, which is the main bottomhole mechanism that directly destroys the rock and forms the face shape, and the shape of the borehole cross-section, is constantly studied by scientists and specialists, with the aim of improving it and developing new designs.

2 Main Body

2.1 Theoretical analysis

Some studies which have been conducted recently were mostly devoted to the improvement of the rock-destructive tool`s durability [2–6]. In many cases the researchers paid much attention to finding solutions of the selection problem and development of the materials for inset cutters.

The development of new roller cone and combined types of rock cutting elements of roller cone bits is a highly relevant scientific task, with the increasing volumes of roller cone drilling.

At the first stage of study some cases will be presented.

While drilling holes and wells in the cross sections of wells a pattern emerged: with n - blade tool (roller and cutting-abrasive types), n + 1 was obtained
a faceted form [7]. The explanation for this until recently has not been justified.

Further, the phenomenon of formation of the so-called "slurry cushion" was established. The explanation and this phenomenon was not found until recently.

In this regard, we note that all the formulas for the experimental derivation of mechanical drilling velocities were linked to the strength properties of rocks. But we got the paradox, which consists in the fact that mechanical drilling speeds in soft clay rocks were less than drilling in hard and firm rocks.

All the more paradoxical was the phenomenon of the so-called forming bit balling process. And this is due to the stickiness of the rock when drilling with cleaning mud and when drilling in clay interlayers. This phenomenon was very harmful, especially with the turbine drilling method and numerous sticking of drilling tools often leading to emergency situations. All of these paradoxical phenomena are explained only now, when a deterministic mathematical model of the drilling process was constructed.

Though it was possible to do this only in view of numerous theoretical and experimental studies and on the basis of electronic computing equipment.

We will dwell on these issues in more detail on the basis of our theoretical and experimental research. As practice has shown, it is only on the deterministic basis that it is possible to optimize both the geometrical parameters of drilling rock cutting tools and the technological parameters of the process of drilling wells of the most diverse size.

In order for theoretical studies in the field of rock-cutting tools to be in demand, as in the further development of mathematical modelling were significant, we proceeded from the following premises.

First, it was necessary to determine the correctness and efficiency of the calculated criteria for evaluating the operation of a drill bit of a particular structure or its modification. Then we obtained the criteria in absolute terms of the cost per meter of penetration. If one of the conditions is specified, and in our case it is the depth of implementation of the working protrusions, then we will get the criteria in relative values. Then, we can only judge that the new design or modification will be better for some time. And this will be reliable if the criteria are calculated on a deterministic basis, i.e. as explicit functions of geometric parameters. In our case, the criteria will appear as explicit functions of the geometrical parameters and interconnected rotation angles around the axes of rotation: the axis of rotation of the tool or the axis of rotation of the individual element. Here, this is the axis of rotation of the bit and the axis of rotation of the roller cone. This will be indicative of our research with respect to single-cone bits, the structures that we will consider in our work and rotation angles with a gear ratio equal to minus, this will concern bits operating in rotation mode around two parallel axes.

We have chosen these design patterns of drill bits as a result of the fact that they operate in cutting and chipping mode without stress concentrations, and are also easily optimized with our criteria.

All this will concern the criteria for assessing the effectiveness of rock failure. And here the novelty will manifest itself in the design of single-cone bits, taking into account the two other parameters of the dynamics - the placement of the channel flushing and the method and design of the bearing assemblies of the rotating elements.

Secondly, and most importantly, we will use for the first time the results of the dynamics of these nodes, relying not on the results that follow from the regularity of the systems from the forces of resistance to movement. And the latter is especially significant, due to the fact that, you can always guarantee a one hundred percent forecast when drilling in any mining and mechanical conditions. And this is a very important point for practice.

So far, researchers and manufacturers of drilling tools have relied on only one of the criteria. All this is now important and relevant, since the effectiveness will be assessed across the full range of the dynamic characteristics of the rock-breaking drilling tools as design, manufacture and use in our work.

Obviously, the design of the drill bit with excellent dynamic characteristics of armament may show worse results in drilling if it has less stable sealing of the cones of the cutting edges or a less effective system for cleaning the bottom of the well with drilling mud.

According to the facts mentioned above, the drill bit must be considered as an element of a complex dynamic system, i.e. the dynamics of the drill bit are:

- the dynamics of armament;
- dynamics of flushing fluid;
- dynamics of supporting bearings.

Naturally, the dynamics of the thrust bearings are inherent only in drill bits of a roller cone type and is important to us.

When we consider the dynamic aspects of the components of the overall dynamics of the drill bit, it is necessary to have a clear understanding of both relationships. In other words, in the case of private optimization of the components identified above, the common dynamics of the drill bit that should be known: are these optimization tasks superimposed or not, do they contradict or complement each other, which is common in their formulation and solution methodology.

These questions are not rhetorical, as it may seem at first glance and, especially, with a more in-depth methodology for solving them, since these tasks are generally dynamic. And in the general case, their solutions should be based on the classical assumptions of analytical mechanics.

2.2. Optimization of drilling operations

Above, we have given a rather thorough analysis of theoretical studies on the dynamics of armament of drill bits. In varying degrees, we will still address these issues in our research when solving the tasks set for ourselves.

And now let us turn to one of the most interesting phenomena in the drilling of wells, namely, to the multifaceted shaping of the cross-section of wells. This phenomenon is almost always observed when drilling both with cutting-abrasive type bits and roller cone type bits. But what is interesting is that this phenomenon has fully manifested itself in the drilling of cannon barrels and has been known for a long time. And if, when drilling holes in metals, it was necessary to solve the problem of making the holes "roundness", which was carried out using sweeps, while drilling wells, there was a question about the dynamic stability of the drill bit as a dynamic system. But first of all it was essential to understand the physical essence of this phenomenon.

A thorough analysis of all theoretical and experimental methods for studying the dynamics of rock drilling tools currently does not have a comprehensive method for constructing a generalized criterion for evaluating the effectiveness of the drilling process on a deterministic basis, except for the particular case using relative specific contact and volume fracture works developed in Uzbekistan.

Therefore, additional theoretical and experimental studies of the overall dynamics at the bottom of a well on a different basis based on the energy consumption of dynamic systems from the forces of motion resistance were required [8].

Simultaneously, we need to reveal the physical essence of such components of the dynamics at the bottom of a well, such as the process of transverse oscillations of drill bits: at the bottom of the well, as the process of formation of "slurry pads" and "glands", as the process of sealing the supporting bearings of bits of the type of roller cone.

As our studies have shown, the efficiency of drilling was measured at different stages by different criteria depending on the depth of the drilled wells.

In this case, we have identified the following stages of optimization of drilling operations:
- in the form of functions of drilling rates from explicit parameters of drilling modes;
- in the form of the same functions of drilling rates from operating parameters with the inclusion of ignorance factors;
- in the form of drilling efficiency functions of the physical and mechanical properties of rocks;
- in the form of accumulating an information databank with the editing of methods for improving bits and drilling methods;
- in the form of building criteria for drilling efficiency on the basis of analytical deterministic models.

All these approaches were in demand and contributed to a positive effect at certain stages. As the wells deepened, it became clear that there is no unique formula for speed.

As for the manufacturability and overall strength to abrasive stability of structural elements of tricone drill bits, by this parameter, the single-cone drill bits are in an obvious advantage.

However, the designs of both single and tricone drilling bits on a well-known deterministic basis so far do not solve the optimization problem of the stability of drill bits at the bottom of the well, designs optimization of the bearing assemblies of the cones, optimization of the dynamics of cleaning the bottom holes of the drill cuttings.

It turned out that these optimization tasks can only be solved on the basis of studying and using the "Regularity of energy consumption of dynamic systems from resistance to motion forces", which directly indicates the causes of bit balling formation, the reasons for the insufficient stability of the bearing assemblies of the cones, the causes of instability of the drill bits at the bottom of the well [8]. And this caused a detailed study of this pattern and served as an object theoretically grounded search for methods to design drill bits of cutting-abrasive type working in the rotational steam mode, which determine uniform wear of armaments for all crowns of working matrices and uniform destruction of the rock through all of the annular bottom hole.

3 Results and discussion

Obviously, the Bingham formula is significantly filled in both theoretical and practical aspects on a deterministic basis equally along with the dynamics of armament work.

As for the ways to solve optimization problems of drill bits on a deterministic basis, we primarily proceeded from the Muperty-Langrange principle which is formulated in the following formulation:

"The actual movement of the holonomic conservative system between two given configurations A and B differs from the possible kinematic movements made between the same configurations and with the same total energy in that for the actual movement the full variation of the Lagrange action is equal zero."

Mathematically, this means that for actual movement:

$$\Delta\int_0^{t_1} 2T dt \equiv W = 0 \tag{1}$$

The function:

$$W = \int_0^{t_1} 2T dt = \int_0^{t_1} \sum_{j=1}^{n} m_j v_j^2 dt \tag{2}$$

is called Lagrange action and is always positive and limited only from below.

Here we use the notation: T - kinetic energy, Nm/s; m - the mass, N; v - speed, m / s; t - time, sec; n - the number of particles, pieces

The founder of this principle was Maupertuis (1744) with the following formulation: "For the actual motion of a particle, the integral of *vds*, taken over the segment of the trajectory between any two of its points, is at least compared to the same integrals taken over segments of other curves, drawn between the same points. "

Based on the research we carried out on the model closely according to the formula of the drill bit of cutting and abrasive type (blade bit, PDC bit).

On the basis of a matrix in the form of a flat circle, a given number of points contacting a rough surface is shown below (Fig. 1). We denote the energy expended by the protrusions of the disk in the forms:

$N_1 = N_1(\omega_1)$ - in the centric mode,

$N_2 = N_2(\omega_1, \varepsilon)$ - in eccentric mode

$N_3 = N_3(\omega_1, \omega_2, \varepsilon)$ - in bicentric mode,

where ω1, ω2 - the angular velocity of rotation around the fixed and moving centers, respectively; ε - eccentricity.

In this case, the general formula for calculating the energy from the forces of resistance to the movement of all protrusions is:

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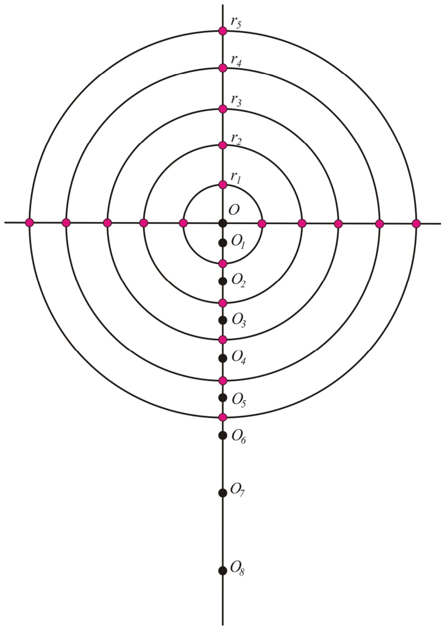


Fig. 1. Diagram of a disc with protrusions in contact with a rough surface for calculating their contact paths in centric, eccentric, and bicentric rotation modes.

$$N = \sum_{j=1}^{n} \frac{S_j F_j}{T_j} \quad (N \cdot m / s) \tag{3}$$

where *Sj* is the contact path of the *j-th* protrusion for one revolution of the disk, m;

F_j is the resistance force of the *j-th* protrusion on the contact path, n;

T_j - time for one revolution of the disk around the center O_1, s;

n - the number of projections on the *j-th* crown, pcs.

Thus, we have established the dimension of energy (power).

With F_j = const = 1, T_j = const = 1, we construct an algorithm for calculating N_1, N_2 and N_3 for the projections of the disc we have chosen.

For centric driving mode we have:

$$N \sim 2\pi \sum_{j=1}^{n} 4 r_j , \tag{4}$$

where r_j - the distances of the centers of the j-th protrusions to the center of the disk, or the same as the radius of the rims. In our case, r_j = 2; 4; 6; 8; 10. For an eccentric motion mode, we will perform calculations for ε = 0.5; 1; 3; 5; 7; 9; 11; 16; 20.

For the bi-centric mode of motion, we use the formulas for calculating the contact paths of the hypocycloidal and epicycloidal curves, according to which the projections of the selected disk will make movements:

$$\left. \begin{aligned} x_j &= \varepsilon \cdot \sin\varphi + r_j \cdot \sin(\varphi + \psi), \\ y_j &= \varepsilon \cdot \sin\varphi + r_j \cdot \cos(\varphi + \psi). \end{aligned} \right\} \tag{5}$$

The formula for calculating the contact path of the j-th protrusion will be:

$$S_j = 2\int_0^{\pi}\sqrt{A_j + B_j\cos\psi}\,d\psi, \qquad 6)$$

Where
$$A_j = \frac{1}{i^2}\left[\varepsilon^2 + r^2(1+i)^2\right] \qquad (7)$$

$$B_j = 2r_j\frac{\varepsilon}{i^2}(1+i) \qquad (8)$$

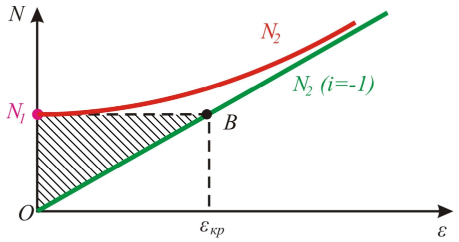
$\varepsilon = (R - r_j)$ - eccentricity, m;

R - the radius of the circle within which the disk rolls, m;

$i = \frac{\psi}{\varphi}$ - gear ratio;

1. In order to visually compare the energy expended in various modes of operation of dynamic systems, we present graphical representations of the functions $N_1 = N_1(\omega_1)$, $N_2 = N_2(\omega_1, \varepsilon)$ *and* $N_3 = N_3$ (i, ε) in the coordinate system *ONεi.* These calculation results show the following: 1. The function $N_1 = N_1(\omega_1)$ is linear, the definition domain of which is the point of the *ON* axis $(0 < N_1 < \infty)$.

2. The function $N_2 = N_2$ (ω1, ε) is a quadratic (hyperbolic), the domain of definition of which is the plane ONε. In this case, each point of the ON axis, i.e. the value of the function N_1 corresponds to a well-defined function N_2, emanating in the form of a hyperbola from a neighborhood of this point. We note immediately that the asymptotes of these hyperbolas are the bottoms of the corresponding hyperboloids, i.e. modes of pairs of rotations $N_3 = N_3$ (i = -1, ε). (Fig. 2).



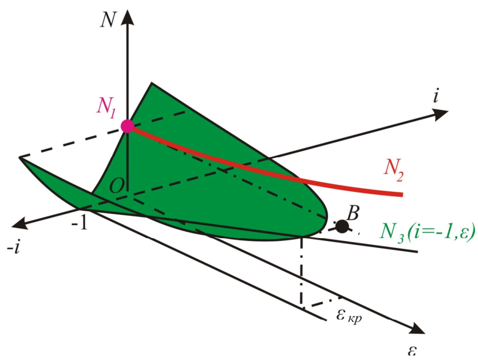


Fig. 2. Energy trap of the function N3 (i, ε).

All the above studies were done for clarity and simplification of calculations.

In fact, the resulting pattern is true:

1) at any combination of geometrical parameters of both flat and bulk bodies moving in the medium of resistance;
2) in any flat or spatial motion of bodies;
3) upon contact with solid, liquid and gaseous environment.

4 Conclusions

(1) According to the studies, it has been established that the transitions of drill bits from the centric mode to the eccentric mode are associated with oscillations of the axes of the drill bits at the bottom of a well.
(2) The energy-consuming mode of the dynamic system at each moment in time in the coordinate system is represented on hyperbolic curves and on hyperboloid surfaces in space. Below this level is an area with minimal energy consumption, leading to the process of bit balling formation, which excludes the bit working in the pair rotation mode with the specified process of rock destruction at the well bottom and uniform wear of the work items regardless of their location along the bit diameter.

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