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Optimization of rock destruction parameters when drilling wells

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Mathematical models of optimization of rock destruction process during well drilling are considered. In most models, the criterion for optimization is the speed of mechanical drilling. According to the authors, this criterion does not allow optimal use of chisels. A method for determining the energy consumption of the process by measuring technological parameters is proposed. Primary converters of load on the chisel, drilling pressure of the drilling mud and other technological parameters are designed and manufactured. Analog signals are converted into digital. The pulsating signals are smoothed mathematically. The optimization criterion is the minimum value of process energy consumption

Keywords: drilling, drill bit, rock, optimization

Оптимізація параметрів руйнування гірської породи при бурінні свердловин

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Запропоновано математичну модель взаємодії долота та породи при бурінні свердловини. На основі закономірностей технологічних параметрів розраховано енергоємність процесу буріння. Нова модель дає можливість спрогнозувати, за яких параметрів буріння свердловини енергоємність цього процесу є мінімальною. Практичною цінністю даної моделі є можливість рекомендувати оптимальні параметри процесу буріння свердловини в гірських породах. Автором, зокрема, відзначено, що пошуку оптимальних параметрів процесу бурінні свердловини присвячено достатньо багато робіт. Однак, в більшості моделей за критерій оптимізації прийнято механічну швидкість буріння, що, на думку автора, не дає можливості оптимально використати породоруйнівний інструмент. Проаналізовано, що особливостями технологічного процесу буріння свердловин являється те, що до нього немає прямого доступу тому, що породоруйнівний інструмент знаходиться на вибої свердловини, а її глибина за звичай сягає декількох тисяч метрів. Крім того при роботі інструмент знаходиться як правило в обертанні. Також відзначено, що основними параметрами процесу буріння свердловин являються навантаження на породоруйнівний інструмент, швидкість його обертання та кількість промивної рідини. Встановлено, що підведена енергія розподіляється на руйнування породи, руйнування самого інструменті та частково на виділення тепла. Обгрунтовано оригінальний спосіб визначення енергоємності процесу буріння свердловин за допомогою вимірювання його технологічних параметрів. При цьому за критерій оптимізації пропонується приймати мінімальне значення енергоємності технологічного процесу, тобто слід визначити такі параметри буріння, за яких мінімізуються енерговитрати на одиницю об'єму вибуреної породи. Запропонований спосіб реалізовано в програмно-технічному пристрої та апробовано за виробничих умов. Технічну новизну розробки захищено патентом на винахід

Ключові слова: буріння, долото, гірська порода, оптимізація

Introduction

The peculiarities of the technological process of well drilling are that it does not have direct access to it. The powder tool is located on the wells, and their depths reach several thousand meters [1-3].

In addition, when working, the tool is usually rotated. The main parameters of the drilling process are the load on the bit, the speed of rotation and the amount of washing fluid.

Energy-gighed is distributed to the destruction of the rock, the destruction of the instrument itself and partly to heat.

Many works is devoted to finding the optimal process parameters. In most models, the optimization criterion is the mechanical speed of drilling. According to the authors, such criterion does not allow the use of a tool to be optimally. The proposed method of determining the energy intensity of the process by measuring technological parameters. In this case, the optimization criterion is the minimal value of the energy intensity of the technology process, that is, such drilling parameters are minimized by the power of energy per unit of volume.

The proposed method was implemented in the program-technical device and tested in production. Patent No. 8696 received.

Review of the research sources and publications

Finding the optimal ratio of the mode and technological parameters of the well drilling process, which is the axial load on the drilling bit, the speed of rotation of the bit, the performance of the washing fluid, there has always been a lot of attention.

So in the period from 1932 to 1940 director of the Groznensky Research Institute was V. Fedorov. Empirical dependence of mechanical drilling speed on adjustable parameters was obtained

$$V_M = a\, n^x\, G^y \tag{1}$$

where: a, x, y are the coefficients that depend on the characteristics of the rock and the method of drilling;
n is the frequency of rotation of the bit;
G is the load on the bit.

For example, according to L. Sturmann, in turbine drilling in the rocks of the Kashir world
$x = 0.7$; $y = 1{,}1$; $a = 0.0024$.

Subsequently, many mathematical models and techniques were developed for the optimal management of the technological process of drilling (Shishkin O., Pozarsky A., Leonov O., Eiffel R., Brewda G., Guhizad M., Halle-Woods, Young etc.).

So the authors of the work [4, 10] suggested the following models

$$V_t = V_0\, e^{-kt}\,; \tag{2.1}$$

$$V_t = V_0\, (1 + \alpha t)^{-p}\,; \tag{2.2}$$

$$V_t = V_0\, (1 + \alpha t)^{m}\,; \tag{2.3}$$

where: k, p, m are the coefficients that are selected experimentally;
V_0 is the initial mechanical speed of drilling;
t is the current time.

Such expressions are valid only when the geological and technical conditions do not change, which is rare in practice. In addition, as the bit wear, the mechanical speed decreases, the specific load on the rock also decreases.

The author of the work [8] states that the effectiveness of the volume destruction of the breed with a roller-cone bit is achieved provided

$$G = a\, p_ш\, S_k \tag{3}$$

where:
G is the load on the bit;
α is a factor coefficient;
$p_ш$ – hardness of the breed when pressing the stamp;
S_k is the total area of the supporting teeth.

With $p_ш \times S_k \leq G$, the process takes place in the volume area, with $p_ш \times S_k < G$ - in the area of destruction from fatigue, or even in the abrasion area.

The task of determining mechanical speed due to the change in the area of contact of the supporting teeth is covered in the work [11].

We must agree with the authors of work [13] where the basic principles of building automated control systems for drilling wells are formulated. How good are your models?

Can they be used to improve your drilling processes?

These are questions often posed in relation to real-time model applications, including models integrated with drilling control.

Do the models fulfill requirements with regards to accuracy and calculation speed?

Can the data be applied by the models to both interpret the state of the process and provide reliable input for calculations?

Can the rig equipment be used safely and securely to control the processes? This paper seeks to answer these questions and further elaborate on current activities and near-term challenges in drilling automation.

While static models are generally accepted, the use of dynamic models is emerging. In real-time model applications, it has been found that rig equipment analysis is necessary to assess applicability or upgrading requirements.

Controlling machines for drilling operations using outputs from models has been successfully achieved. This paper provides examples of recent developments within drilling automation, drawing from applications of closed-loop control systems in the North Sea.

Challenges regarding interpreting state-of-the-process are discussed, with respect to existing rig instrumentation, while examining the need for enhanced surface and downhole sensors.

Mathematical models used with the drilling control system must communicate regularly with the drilling process to extract information from sensors and provide updated control commands for automation. How sensor data is applied through models to enable automation functionality is also illustrated.

Definition of unsolved aspects of the problem

As a result of the load and rotation, a rotary moment is formed on the chisel. On the mouth of the well, the total moment is controlled, which is formed at the expense of the moment at the chisel and the moment of rotation of the drilling column. Its value can be verified by the calculated method.

Problem statement

Therefore, the purpose of this work is to create a mathematical model of interaction of the chisel and the breed by which energy costs are minimized.

Basic material and results

Torque at rotor when drilling (Nm):

$$M_{кр} = 9740\frac{N_{bk} + N_d}{n}\ , \qquad (4)$$

where: N_{bk} – the power required to rotate the WT drilling column,

N_d – the power required to rotate the WT rotor,

n is the speed of rotation of the table of the rotor rpm.

The power required for the rotation of the drilling column is determined by the formula of Fedorov V.

$$N_{bk} = c_1 \cdot n^{1.5} \cdot D_d^{0.5} \cdot \gamma_p\ d_{bt}^2 \cdot L_{bt}, \qquad (5)$$

where: c_1 is a coefficient that depends on the well curvature (for vertical wells $c_1 = 13.5*10^{-4}$);

D_d – the diameter of the bit m,

γ_p – the density of the drilling mud kg/m^3,

d_{bt} – diameter of drill pipes m,

L_{bt} – the length of drill pipes m.

The power required to rotate the bit (kW)

$$N_d = c_2 \cdot n \cdot D_d^{0.4} \cdot G_d^{1.3} \cdot 10^{-4}\ , \qquad (5)$$

where: c_2 – coefficient of hardness of the breed (for sandstones $c_2 = 6$).

The task of the driller is to find the optimal value of the first two parameters in which the recess will be effective.

In this case, the criterion, as a rule, is the mechanical speed of the deepening, which according to the author cannot be the optimal criterion, since the intensity of wear bit is unknown.

The author of the work [6] states that the use of intellectual systems in the drilling of oil and gas wells will make it possible to effectively solve a number of tasks:

– reducing the degree of wear of the drilling bit;

– reducing the number of descent and lifting operations required to replace worn bit;

– increasing the time of operation of the bit; increase of mechanical velocity;

– improving the control of the well wall;

– reducing the vibrations of the drilling column and the potential reduction of the number and frequency of failures of equipment on the efficiency;

– reducing the manifestations of drilling of drilling mud and reducing the time required to solve the disappearance of circulation;

– reducing the time required to perform hunting operations; reduction of the freezing of drill pipes;

Reduction of the time required to solve the problem of scattering the well and twisting the drilling column.

Such functionality can be ensured by building an intellectual system based on a database hierarchy and knowledge of oil.

A similar system is proposed in [5] where for the detailed characteristics of the drilling brigade it is necessary using the developed computer system from the controlled point, i.e. from the drilling installation, automatically transmit information to the dispatch point:

1) the actual depth of the well;

2) types and duranological recommendations (for example, at mechanical speed, piercing on a bit, time of flight, etc.), which will allow to ensure the fulfillment of routine tasks and delivery of wells with minimal costs and high quality. In [9], a dimensionless energy criterion was used to describe complex processes of rock destructiontion of all possible technological processes (operations) on the drill;

3) some technological parameters (on request). Considering the information received, we can conclude that the drilling team is completed with a drilling team and adherence to tech

$$h = \frac{W}{M \cdot v_p^2}\ , \qquad (7)$$

$$W = \alpha(V)[U_0 + W_k] \qquad (8)$$

where: $M = \rho\ V;$

$[U_0+W_k]$ – the sum of the potential and kinetic energies of the elements of the rock structure in the area of destruction;

$\alpha(V)$ is the coefficient of explosive effect;

V is the volume of the focal area;

ρ is the density of the rock;

v_P is the speed of the wave.

Therefore, the equation (4) and (5) allow you to quantify the optimal energy range.

When calculating the energy criterion [7] of the voluminous destruction of the mountain in the drilling process requires information about the proportion of ore and rocks in combination with the value of longitudinal speed

$$k = \frac{e(t)\alpha}{V_p(t) p v_p^2}\ , \qquad (9)$$

where: $e(t)$ is the energy consumed by a drilling tool for the destruction of the rock in the control area of the well;

α – the estimated coefficient of seismic influence of underground explosive work;

$V_p(t)$ – the volume of broken rock in the control area of the well.

Among the controlled drilling parameters, the ratio of load on the bit to its diameter and the speed of rotation are distinguished.

Dependence of drilling speed on the above parameters and taking into account the wear of the working surface of the chisel is the appearance

$$\frac{dF}{dt} = f\left(\frac{W}{d_b}, N, h\right), \quad (10)$$

where: f is the penetration rate,
h – wear of the height of the bit, n is the speed of the bit.

The mathematical model [11], was accepted as a basic, which used the finalized model A. Paradise.

$$V_M = \frac{nG^2Q}{(1+b_n n^4)(1+b_G G^4)(1+b_Q Q^4)}, \quad (11)$$

Model Restriction:

$$G_{min} \le G \le G_{max}; \quad (12.1)$$

$$n_{min} \le n \le n_{max}; \quad (12.2)$$

$$G_n \le N_n; \quad P_c Q \le N_p \quad (12.3)$$

where: V_M – mechanical speed of passage;
k_b is the ratio of the breed of breed;
n – speed of rotation of the bit;
G – axial load on the bit;
Q – pump performance;
b_n, b_G, b_Q – coefficients that determine the shape of the curve $\upsilon_m = f(n, g, q)$;
G_{min}, G_{max} – minimum and maximum load on the bit;
n_{min}, n_{max} – minimum and maximum speed of rotation of the bit;
N_P – mechanical power of the drive on the bit;
$N_p = Q \cdot P_C$ – the power of the drive on the chisel;
P_C – the pressure of the solution in the riser.

The main one in this model is the criterion of "maximum mechanical piercing V_M=max", where the optimization of the drilling process with the help of the target function is carried out.

The listed and other models as a criterion determine the mechanical speed of drilling (Fig. 1), which can be disagreed, since the maximum speed can lead to the early destruction of the labor tool, so the method of controlling the wear of the latter is offered on the basis of determining the energy intensity of the process of destruction of the rock.

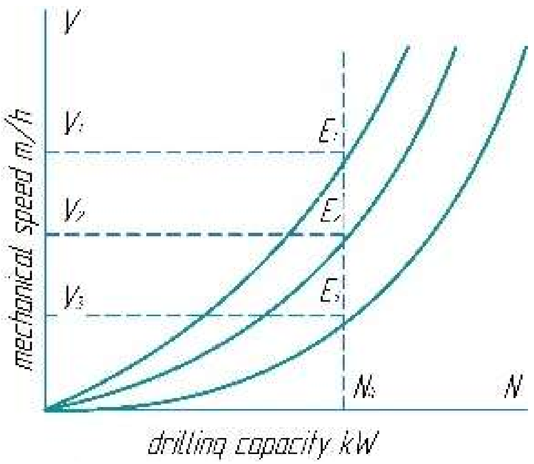

Figure 1 – Dependence of speed on power

The method uses the fact that the intensity of wear in time depends on the resistance of the rock of its mechanical destruction. Each array of rock is characterized by its value of energy consumption ea. and the time necessary for its destruction of DT and is determined by the bite of *Nd* and the thickness of the layer.

Thus, the measure of wear of the chisel is associated with the energy intensity of the process and the time of operation of the eaves.

Figure 1 shows the dependence of mechanical drilling speed on the supply power for different values of the energy intensity of rock. The task of controlling the current value of the wear of the chisel during drilling is reduced first to the indisputable measurement of the energy intensity of the process and the time of passing the homogeneous layer.

Since the geological section of the well, as a rule, consists of various sediments (Fig. 2) of which the energy intensity is different, the degree of wear of the chisel in different layers will be different.

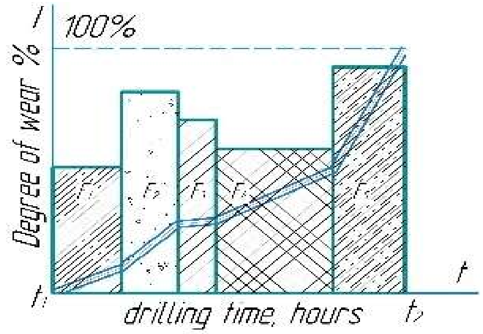

Figure 2 – Dependence of wear on time

The energy intensity of the process is defined as energy consumption per unit volume, that is, the volumetric energy intensity of the rock. (Fig. 3). By integrating the energy integrity of the process over time is obtained.

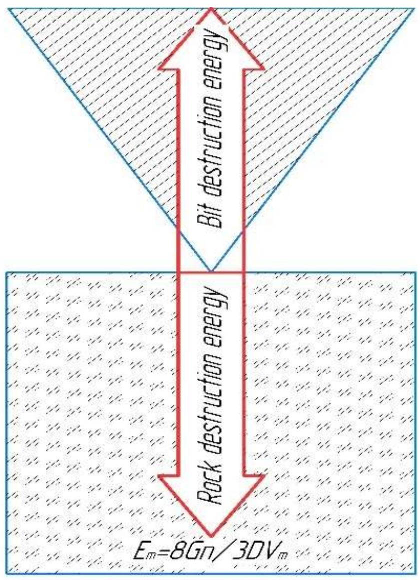

Figure 3 – Energy distribution

$$E_d = \int_{t_1}^{t_2} E_m dt \ . \qquad (13)$$

The instantaneous value of the energy consumption of the process is determined by the supply power and mechanical drilling speed v_m

$$E_m = \frac{N_d}{\pi R^2 V_m} \frac{joile}{m^3} \ ; \qquad (14)$$

where: πr^2 is the area of the well.

When drilling wells, measuring technological parameters, determined to the bit power

$$N_d = M_d \ \omega ; \qquad (15)$$

where: M_d is the moment on the bit;
ω is the angular speed of rotation of the bit,

$$M_d = M_p - M_{xo} \ ; \qquad (16)$$

where: M_r is the moment on the rotor;
M_{xo} is the moment of idle rotation of the drilling column.

For the criterion of deepening of the well, you need to take a minimum of energy consumption of the drilling process

$$E_m = \frac{4G\omega D}{3\pi D^2 V_m} = \frac{8Gn}{3DV_m} \ ; \qquad (17)$$

where: N is the speed of the bit;
G – load on the bit;
D – diameter of the bit;
V_m is a mechanical drilling speed.

Accumulated Data on Energy Baters can be used to promptly determine the wear of the latter

$$I = \frac{1}{E_d} \sum_{i=1}^{n} E_i \Delta t_i = \frac{1}{E_d} \int_{t_1}^{t_2} E_m dt \ ; \qquad (18)$$

This method of determining the wear of the chisel is protected by patent [12].

The proposed model was implemented in the "Corunde" software and tested in the conditions of drilling of wells in the DGP "CHNG".

Conclusions

Therefore, proposed mathematical model of interaction of chisel and rock. On the basis of the character of technological parameters, the energy intensity of the drilling process is calculated.

The model calculates in which parameters the energy intensive is minimal. Optimal parameters are recommended for drilling.

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