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# Ways to Optimize the Kinetic Parameters of Tricone Drill Bits

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**Abstract.** The improvement of the operation of roller cone bits, only drilling indicators are optimized, which include axial load, frequency of rotation, borehole diameter and rock fortress coefficient. The use of one or another roller bit can be justified by the physical-mechanical properties of rocks, which can have different values depending on the depth of drilling and the horizon. However, while resolving energy costs on the basis of the quality of the drill bits' interaction with the physical-mechanical properties of rocks and the condition of the cutters at the bottom of the well, which require high-tech solutions with scientific bases, it is possible to make the choice and justify a more efficient design of the drill bit. The article discusses a new method for determining the patency of a drilling cone bit using the determination of the workload of teeth and crowns based on kinematic calculations. Based on the kinematic parameters, the gear ratio of the cones, the specific indicators of contact and operation of the teeth on the bit crowns are determined, which in turn show the most loaded crowns. Based on these indicators, it is possible to determine crowns that are prone to breakage during the operation of bits. By this calculation was made a new program which by geometrical parameters of the tricone drill bit can show graphics of the work cones and crowns.

**Key words:** destruction, drilling, drill bit, kinetics, specific contact work, specific volume work

## Introduction

Drill bit-the main tool with which the destruction of rock on the face and is the construction of deep wells in the oil and gas industry, as well as drilling wells in the mining industry and exploration. Drill bits are also widely used in the construction of complex engineering structures-bridges, tunnels, mines and other facilities [2]. A drill bit is a complex mechanism, rigidly limited in volume by the diameter of the wells. The supports of its sections contain multi-row radial and thrust rolling and sliding bearings, in the most critical designs of the bits, the supports are sealed and oil-filled. Roller bits perform 90-95% of the total drilling volume. To solve the problem of increasing the volume of work on drilling with roller bits, it is necessary to study not only the mechanical improvement of the bits, but it is necessary to apply the theoretical basis for a more detailed analysis of the drilling process.

Due to the variety of drilling methods and physical and mechanical properties of rocks, rock-breaking tools are made of different types of impact on the rock and structural design. The roller bit is a complex mechanism, in the production process of which the performance of 414 sizes is observed. Dimensional chains of bits consist of 224 links, geometrically connected by linear and angular dimensions, performed according to different systems of tolerances and landings (Figure1).

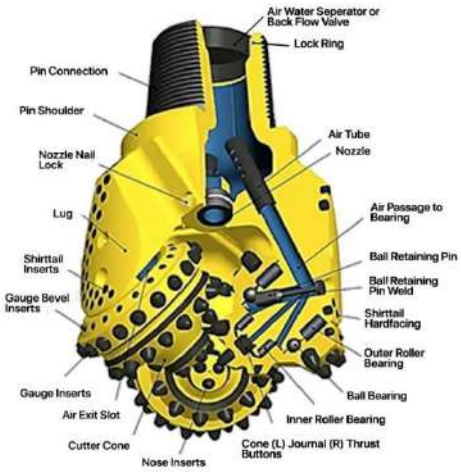


**Fig. 1.** - Tricone drill bits' elements

## 1. Methods and Materials

The roller bit is a one-time tool and in the process of operation undergoes significant statistical and dynamic axial loads and the action of alternating torque, in connection with which its design must be designed for an economically justified service life. The bit must meet the following basic requirements:

- to provide the maximum mechanical speed of drilling, the maximum penetration on a bit, operational reliability of riggings and a support of a bit, and durability of a support has to be higher since to 80% of cone bits fail owing to premature wear of elements of supports of drilling bits;
- to provide a receiving bore of a given diameter;
- have sufficient strength, excluding the destruction or deformation of parts under the action of maximum load;
- to have an optimal support design at the specified parameters of the drilling mode;
- to provide reliable lubrication system bearings cones;
- have a radial runout of the cones relative to the thread axis of not more than 0.8·10-3m and different heights of the cones relative to the thrust ledge of not more than 0.9·10-3 m;
- to have durable riggings cutters;
- to provide the necessary interaction time of the teeth with the rock.

The optimal drilling mode is understood as a harmonious combination of axial load, speed, torque and power on the bit, ensuring the maximum value of the mechanical drilling speed. The choice of operating parameters depends on the conditions of the well wiring, drilling method, design features of the bit used, its diameter, arrangement. Therefore, the drilling mode should be chosen on the basis of a comprehensive analysis of the available data, taking into account the obtained theoretical and experimental dependences. Optimization of drilling modes. In this case, the empirical dependence of the mechanical drilling speed on the axial pressure and the number of revolutions of the bit is constructed, i.e.:

$$V_M=f(P,n) \quad (1)$$

where $V_M$ – mechanical drilling speed, m/h;
P – axial load, kN;
n – the number of revolutions of the bit, rpm.

**Table 1**. Drilling speed determination methods

| Name of method | Formula | Indication |
|---|---|---|
| By V. Maurer | $V_M=\frac{nP^2}{D^2}K_d$ (2) | *D* - the bit diameter, m; $K_d$ - the coefficient of drillability, depending on the rock properties, parameters of the washing fluid, the differential pressure type bits, wear his riggings, etc. |
| By G. Woods | $V_M=an(\frac{P}{D})^b$ (3) | *b* varies from 1.1 to 2.4 |
| By R. Kanningham | $V_M=a\frac{n^{0,5}P}{D}$ (4) | Where *a* is the experimental coefficient, for the determination of which the corresponding experiments are required. |
| By B.S. Fedorov | $V_M=an^xP^y$ (5) | |
| B.N. Kutuzov used the elliptic law for the function V(t) | $V=V_o\sqrt{1-(\frac{h}{h_k})^2}$ (6) | $V_0$ - the initial drilling speed of the new bit, m/min; *h* - the current total depth of penetration of the bit, m; $h_k$ - the maximum total depth of penetration (maximum resistance of the bit), m. |
| According to M.Bingham | $\frac{V_M}{n}=a(\frac{P}{D})^d$ (7) | *a* - the experimental coefficient, *d*-exponents does not fully take into account the influencing factors and does not have a sufficiently strict mathematical justification of the obtained functional relationship [3]. |
| By Y.F. Potapov and V.V. Simonov | $V_M=knP^{1,4-0,0002n}$ (8) | |
| By Woods | $V_M=an\left(\frac{P}{D}\right)^4$ (9) | |
| According to Eckel, Canon and Bingstein | $V_M=aPn^{0,5}$ (10) | |
| By Kathleen | $V_M=a+bPn^y$ (11) | |

| Name of method | Formula | Indication |
|---|---|---|
| Most foreign researchers have come to the conclusion that the ratio that determines the mechanical speed of $V_m$ with the amount of washing liquid providing the process should have the form proposed by M. G. Bingham | $V_M = k_b \cdot P^{\delta} \cdot n^{\alpha}$ (12) | $P$ - the axial load on the bit, $n$ - the bit rotation speed, $k_b$, δ and α - the parametric coefficients. The $k_d$ - coefficient in the literature is called the "coefficient of drillability", because it characterizes the ability of the rock to drill. It takes values of 0.2-0.8, can reach a value of 2.5 units [4]. The coefficients δ and α have different values for different authors [5]. The value δ is most often assumed to be equal to one, but there is also δ =0,6. The coefficient α mainly lies in the range of 0.4-0.75, for particular conditions can be equal to 0.1 or 1. For the above equation, it is assumed that the flow rate Q and the pressure of the drilling fluid provide high-quality (complete) cleaning of the face from the drilled rock without re-grinding it. |
| The Halley-Woods-Lubinsky model is common in the United States, the state of the well wiring process for any given time is determined by a three-dimensional vector in the state space - the current values of $V_M$, the degree of tooth wear and the degree of wear of the bit support [6]. | $V_M = k_{\alpha} \dfrac{\overline{P}^{\beta} \cdot r}{\left[a \cdot (D_t)\right]^b}$ (13) | Where: $\overline{P}^{\beta}$ - the axial load reduced to the bit diameter, $\overline{P}^{\beta} = P / D$ ; <br> $r$ – coefficient determining the type of rock: <br> - for hard rocks <br> $r = e^{\frac{100}{n^2}} \cdot n^{0.428} + 0.2(1 - e^{\frac{100}{n^2}})$ (14) <br> - for soft rocks <br> $r = e^{\frac{100}{n^2}} \cdot n^{0.75} + 0.5(1 - e^{\frac{100}{n^2}})$ (15) <br> $a(D_t) = 0.928 \cdot D_t^2 + 6 \cdot D_t + 1$ (16) <br> where $\beta$ - exponent of axial load; <br> $D_t$ - the relative wear of the teeth of the bit; <br> $b$-exponent of the bit arrangement wear function |
| Model of the company “Tenneco oil company”. In determining the optimal combinations of bit load and rotor speed to ensure minimum drilling cost, it is assumed that the mechanical speed and wear of the bit are functions of the bit load, rotation speed, rock characteristics, bit type and washing fluid | $V_M = \dfrac{k_d \cdot (P - P_0) \cdot n^a}{f(h)}$ (17) | $P_0$ – the load on the bit at which the penetration of the tooth into the rock begins, <br> $f(h)$ - characteristic of the state of the bit. |
| Model of Pogarskii A. A. for mechanical speed $V_M$ allows to take into account the influence of flow and pressure of the washing liquid and has the form [5] | $V_M = \dfrac{a \cdot \overline{P}^2 \cdot n^{\alpha}}{1 + b^4 \cdot \overline{P}^4}$ (18) | $a$ - the corresponding $k_b$, α - coefficient that have the same meaning as in other dependencies, but take different values. The coefficient $b$ depends on the flow rate of the solution $Q$ and the hydraulic power applied to the bit $N_b$ and for the maximum speed $V_M$=*max* is defined as $b=1/P$. |

Currently, attempts to build such dependencies are ongoing. However, it is quite obvious that there can be no universal dependence of such a plan, because, firstly, the conditions of rock destruction are constantly changing as the depth of drilling wells increases, and secondly, there is always an intensive re-equipment of drilling enterprises with bits of new, more advanced designs. Therefore, it is possible to take any of these dependencies and each time under changed conditions to determine experimentally the coefficients of ignorance. But in this case, there can be no question of forecasting and, therefore, of optimizing the process of destruction of the rock in General. From the joint analysis of the formulas, it follows that to predict the cost of a meter of penetration, it is necessary to predict the variables T and H, which is associated with the $V_M$ ratio

$$V_M = \frac{H}{T} \tag{19}$$

It follows that $V_M$ prediction should be sought through these variables. As you know, the total penetration of the bit depends on the efficiency of drilling when transferring optimal parameters to the drill bit. To determine the speed of drilling plays an important role in the introduction of the teeth of the roller on the rock. Theoretical studies of the characteristics of the introduction of teeth are based not only on the axial load but also on the shape of the teeth of the bit. Rotary drill bits are armed cutter in a gear or disk rims. Arrangement elements can be steel, milled in the body of the roller, or carbide, pressed into holes on the crown surfaces of the rollers. During designing roller bits, the placement of crowns on the surface of the balls is made so as to provide the necessary amount of overlap of the face and sufficient gaps between the crowns. Arrangement tends to be placed on the balls evenly. However, this is not enough to ensure a uniform loading of the crowns and the overall balls. The relative load of the various crowns of the bit balls depends on their vertical stiffness, determined mainly by the design of the support unit and the position of the crown on the ball [7].

The steel gear arrangement of the crowns is carried out in the form of blunted wedges by milling. The main parameters of riggings: the initial blunting, the length of the teeth (coincides with the width of the crown), the initial height of the teeth, the angle at the top of the wedge, the pitch of the teeth in the crown [8]. The carbide toothed arrangement of the crowns is made in the form of insert teeth made of tungsten cobalt alloy. Depending on the configuration of the working surface and the method of attachment in the body of the cones, carbide teeth of the following types are developed and manufactured: spherical, wedge-shaped straight, wedge-shaped inclined, polyhedral, conical, peripheral with a bevel, sub-caliber, corrugated, semi-corrugated, cap, sector, etc. [9]. An increase in rotation speed will bring about an increase in penetration rate, but within certain limits. In soft formations, where chips are produced by cutting/tearing actions, the increase in penetration rate is nearly proportional to the change in rotation speed (if the chips are all being cleared as soon as they are produced). The sliding of teeth complicates the operation of rollers on hard rocks as the rock breaks unevenly (Figure 2). Failing to completely clear the cuttings can also become a large problem at high speeds. The result is that there is little advantage in increasing the rotary speed above recommended levels. However, bit wear increases rapidly as rotation speed is increased, both for rollers and for hammer bits.

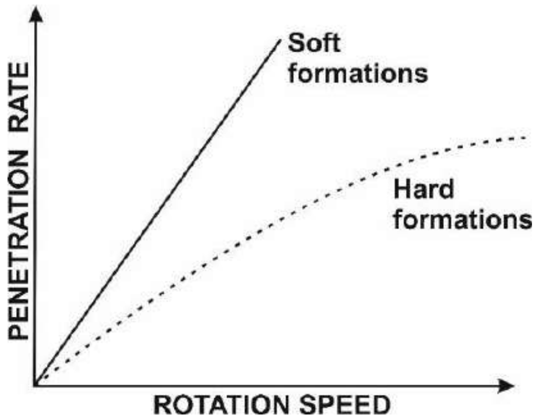


**Fig. 2.** - Relation between rotation speed and penetration rate for different formations [10]

The tooth of the bit is pressed into the rock by axial force and simultaneously makes a complex movement depending on the parameters of rotation of the roller and the bit, sliding along the face. At the same time, the adjacent tooth moves to the surface of the rock and strikes it. In the following moments of time, the load is redistributed from the first tooth to the second, and then the first tooth comes out of contact with the rock. Experimental studies of the interaction of individual elements of the drill bit with rock are performed according to the scheme of drilling with one tooth (Figure 3).

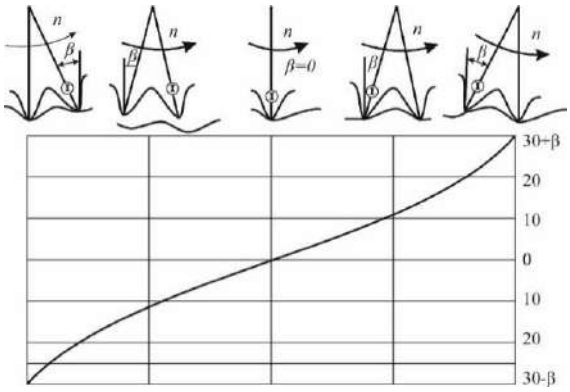


**Fig. 3.** – The scheme of interaction of a tooth of a roller with a face of a well [11]

Toothed crowns on the cones are arranged in such a way that they provide a complete defeat of the drilled surface. The teeth are formed in the form of wedges, the tops of which are located either in the axial planes of the cones, or are displaced relative to them at a certain angle. The main lateral surfaces of the teeth, as a rule, are flat with equal working surfaces in area, while the displacement of the axes of the cones relative to the axis of rotation of the bit is provided. Currently used methods of design of the roller drilling tool working with sliding gear arrangements, do not allow to ensure uniformity of distribution of volume work of destruction of the bottom face rock, between all crowns of arrangements taking into account the geometry of the teeth, their orientation, direction and slippage committed by them. In most experimental studies, the angular velocity of the cone was averaged within one revolution. However, as a result of experimental studies conducted on a special stand that allows to study the power and kinematic parameters of serial roller bits during direct drilling of the rock, it was established that the instantaneous gear ratios of the cones change in 1.4...1.75 times within one revolution [12]. At the same time, the minima of the instantaneous gear ratio fall on the vertical positions of the teeth relative to the face.

Drilling optimization: according to the proposed invention, the aforementioned goals can be reached by simultaneously implementing the following concepts, which allow for the mathematically determined optimal positioning of cutting elements on the surface of each cutter rotatably placed on a drill tool or drill bit:

1. By using an independent rolling cutter and varying the pitch between neighboring cutting parts, tracking while drilling on the bottom hole is completely eliminated;
2. The most effective spacing between succeeding penetrations while taking into account the mechanical characteristics of the rock to be drilled, the geometry of the cutting elements, and the orientation of the centerline of the cutting elements with regard to the surface of the cutter;
3. Through careful arrangement of cutting elements along cutter generatrices, harmful axial resonance frequency vibration of the drill bit or tool that restricts drilling the formation is significantly reduced [7].

In this regard, there was not a little change in the design of drill bits, which were justified only by the application of one or another type of change in the surface parts of the bits. But since the change in the location and number of teeth is of great importance, it should be borne in mind that the cost of the bit also depend on these indicators. Also, when changing these parameters, the change accounted for the load of other elements of the roller. From the diagram in Figure 3 it is seen that the teeth strike the face at the first pass with a step s close to the step of their placement in the crown. When re-passing, one part of the crowns strikes the face at the same points, and the other-with some offset along the step Δs (Figure 4). Step offset will be measured in the direction of rotation of the bit. Denote s0=Δs/s and call it the relative step offset. The value of s0 varies from 0 to 1. At s0, equal to 0 and 1, the face is affected "trace to trace". Tooth marks do not lie on the same radius of the bit. This means that at different times with the face interact different number of teeth and the actual coefficient of overlap of the face - a variable value in time. Let's estimate the actual overlap coefficient (ηf). For convenience, consider its relative value:

$$\eta' = \frac{\eta_f}{\eta} = \frac{\sum l}{\sum l_i} \tag{20}$$

where $\sum l$ is the number of teeth in contact at the moment. Definition $\eta'$ is a statistical problem.

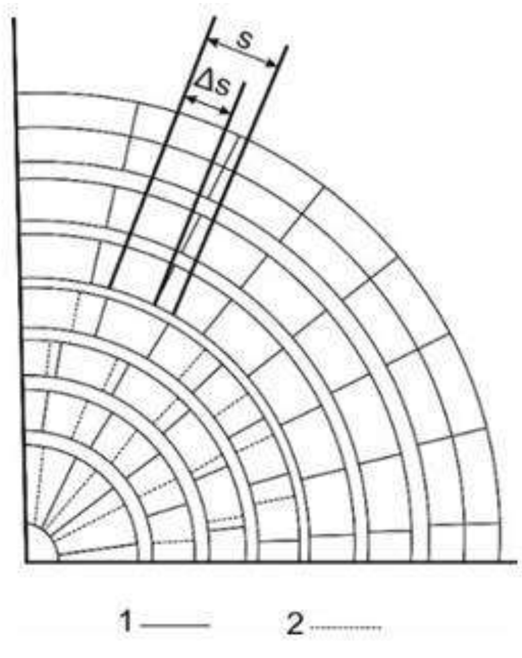


**Fig. 4.** - The scheme of defeat of a face by teeth of a bit of type T: 1-at the first pass; 2-at the second pass

The physical meaning of $\eta'$ is the proportion of $\sum l$ rigging simultaneously involved in the destruction of the bottom hole. The completeness of the destruction of the bottom hole is characterized by the defeat of the bottom, which is equal to the ratio of the face area, covered by the teeth of all the cones for one revolution of the bit, to the face area of the well:

$$\eta_c = \frac{\sum_{i=1}^{z} F_i \cdot \bar{l}}{\pi \cdot R_b^2} \tag{21}$$

where Fi - the cross-sectional area of the tooth; z - the number of teeth except for the cone pressed into reverse cones; i - the average gear ratio of the bit. This indicator is used to characterize the bits with carbide riggings.

A roller bit from the point of view of kinematics is a part of a spatial gear or friction mechanism with movable axes of working links-cones. The mechanism includes a leading element in the form of interconnected legs, the slave units - cutters and non-rotating component, for slaughter. The study of such a mechanism would not be difficult if the transfer relations, both average and instantaneous, from the body of the bit to each of the cones were known, that is, the ratio of the bit is:

$$i_j = \frac{\omega_j}{\omega_b} \tag{22}$$

where $i_j$ - the ratio of the bit body to the $j$-th cone; $\omega_j$ - the angular velocity of the $j$-th cone; $\omega_b$ - the angular velocity of the bit.

Analytically, it is very difficult to determine $i_j$. At destruction of firm rocks of frequency of rotation of cones are inversely proportional to numbers of teeths on peripheral crowns. This character of rotation is due to the fact that the teeth of the peripheral rims, destroying the face, form a toothed rack on it, which further determines the law of rotation of the cones. The step of the breaking line is close to the largest pitch of the peripheral $S_{max}$ crowns. It allows to estimate approximately the number of teeth of a rack the $z_t : z = \frac{2\pi R_b}{s_{max}}$. Received result is rounded up to the whole in the big party. Then the gear ratios of the cones are approximately equal

$$i_I = \frac{z_t}{z_I} \qquad i_{II} = \frac{z_t}{z_{II}} \qquad i_{III} = \frac{z_t}{z_{III}} \tag{23}$$

The total number of cutter teeth is selected from the conditions to achieve effective destruction of rocks and taking into account the set of teeth on the cutters. As a result of studies on this issue proposed the calculation of the number of teeth on the cutters produce in the following formulas [8]:

for plastic and elastic-plastic rocks:

$$Z = 3.14 \cdot \sqrt{\frac{R_b \cdot b \cdot (\frac{tgd}{2+\mu_1}) \cdot \sigma_{com}}{q_z}} \tag{24}$$

for elastic and elastic-brittle rocks:

$$Z = 3.14 \cdot \sqrt{\frac{E \cdot R_b \cdot c}{3 \cdot (1-\mu_1^2) \cdot q_z}} \tag{25}$$

where $\sigma_{com}$ – rock hardness corresponding to the tensile strength, kN/m$^2$.

$q_z$ – load acting on one tooth when it is introduced into the rock, kN;

d – the angle of sharpening of the teeth of the cones, deg;

b – the length of the sides of the tooth, m;

$R_b$ – the radius of the cutter, m;

E – modulus of rock elasticity, kN/m$^2$;

$\mu_1$ – the Poisson's ratio for rocks;

c – the width of the root face of the tooth, m.

Insufficiently studied, there is a question of influence of placement of crowns on cones on radius of a face on efficiency of drilling and durability of riggings of bits. Currently, the placement of crowns on the cones is made on the basis of the requirement of the necessary overlap of the face, taking into account the need for uniform placement of riggings on the cones. The strength characteristics of carbide teeth are significantly influenced by the quality of their surfaces. The presence of defects in the surface layer, which are stress concentrators, leads to an intensification of the tooth destruction process. The strength of carbide teeth depends on other technological factors, such as the method of pressing teeth [9]. It is also established that the durability of carbide teeth affects the stiffness of the connection "tooth-bit" [10]. Reducing this stiffness can improve the durability of carbide riggings. Thus, the durability of carbide riggings, limited by the destruction of teeth, depends on a large number of design and technological factors. In known studies, the general nature of the destruction of carbide teeth of roller bits has been studied in detail. However, most researchers did not set themselves the task of analyzing the number of destroyed teeth on each crown of each bit. In addition, research works have been conducted in different years on bits of different types and sizes, with significant differences in the design of riggings and support units, so even the data available in the literature is difficult to use.

**3. Results**

Many researchers also include uneven wear and failure of components of riggings and support assemblies of the cutters. Uneven wear is observed both when working off bits with milled riggings, and when working off bits with pin carbide riggings. At industrial working off of the first designs of spherical bits with carbide riggings their uneven wear was noted. The bits failed mainly due to the wear of the top of the first cone, chipping teeth on the peripheral crowns and jamming of the supports of the cones. In subsequent designs of bits due to changes in the geometric shape of the cones, increasing the diameter of the teeth and the manufacture of vertices on all three cones, it was possible to reduce the uneven wear and destruction of carbide riggings and improve the efficiency of the bits. However, it is not possible to completely eliminate the uneven wear and destruction of carbide riggings. The proportion of destroyed teeth, accounting for an average of each cone, also varies. The largest number of destroyed teeth in bits of both types falls on the first cone. Research works have shown that although in most cases the performance of the bits is limited by the stability of the support, the durability of the bits is also insufficient [11].

The main goal of many works was to increase the efficiency of tricone bits, seen on the way to optimize the process of destruction of rock during drilling. For this at the first must compose mathematical model of describing the mechanism of interaction between the riggings of the rollers adequately to the real dynamics at the bottom [12]. In some cases, a 3d model of the drill bit, which was created by EDEM software, was used to optimize the operation of the drill bit using mathematical modeling, force was applied to the center and body, vibration, penetration rate and wear were studied [13].

The factors that can be studied are three main groups of parameters that include drilling equipment properties, rock properties, and environmental conditions. The properties of the equipment and environmental conditions are variable parameters, as the characteristic properties of the rock cannot be changed. In addition, the abrasiveness of the rock also affects the ability to drill the rock. Parameters used to predict drilling capacity include rock physical properties, rock chemical properties and rock drillability [14]. As a result of the detailed analysis of the conducted researches concerning dynamics of riggings, it is established that the complex approach to research of dynamics of a drill bit as a whole is necessary. The design of a drill bit with excellent dynamic characteristics in terms of arrangement can show worse results during drilling wells, if it will have a less stable sealing of the supports of the cones or a less effective system of cleaning the bottom of the well from the drilling fluid. In connection with the above, the drill bit must be considered as an element of a complex dynamic system, i.e. the dynamics of the drill bit.:

– dynamics of arrangement taking into account fluctuations at the bottom of the well;
– washing fluid dynamics;
– the dynamics of the thrust bearing.

The dynamics of the support bearings is inherent only in the drill bits of the roller type. When considering 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 the case of partial optimization of the above components of the overall dynamics of the drill bit, it is necessary to know: are these optimization tasks overlay tasks or not? Are they contradictory or complementary? What is common in the methodology of their formulation and solution? The solution of these problems should be based on the classical provisions of theoretical mechanics. To date, the goal - to increase the efficiency of tricone bits is viewed by optimizing the process of rock destruction during drilling. For this, an appropriate mathematical model is needed that describes the mechanism of interaction between the cutter armament adequately to their real dynamics in the bottom hole. The destruction of rock by drill bits can be assessed through the definition of two parameters, as specific contact and specific volumetric work of destruction and are presented as follows [16]:

$$A_s = \frac{A_{tw}}{S} \tag{26}$$

where, $A_s$ - specific contact work of destruction, kg.mm/mm;

$A_{tw}$ - the total work spent on the deformation and destruction of the rock during the indentation of the stamp, kg.mm;

S - area of the flat base of the cylindrical stamp, mm$^2$.

$$A_V = \frac{A_{tw}}{V} \tag{27}$$

where, $A_v$ - specific volumetric work of destruction, kg.mm/mm$^3$, V - volume of deformed rock, mm$^3$.

The following rules are designed in order to address these issues throughout long-term theoretical and experimental study on the effectiveness of tricone drill bits.

1. Using tricone roller bits, the effectiveness of rock destruction is functionally dependent on two kinetic criteria. [15]:

- from the relative specific contact work of destruction.

$$\left(A_j^{'}\right)_I = \frac{S_j F_j i}{\Delta S_j},\ \left(A_j^{'}\right)_{II} = \frac{S_j F_j i}{\Delta S_j},\ \left(A_j^{'}\right)_{III} = \frac{S_j F_j i}{\Delta S_j} \tag{28}$$

where $A_j'$ -relative specific contact work of destruction of teeth of j-th conditional crown, N*mm/mm$^2$ [17];

$S_j$ - the contact path of the tooth of the unit area of the j-th conditional crown at the same contact with the face of the well, mm;

$F_j$ - the force of resistance to the movement of the teeth of the unit area of the j-th conditional crown in contact with the rock at the bottom of the well;

N; *i* - gear ratio of the roller; $\Delta S_j$ - contact area of the tooth apex of the j-th crown of the cone of unit length and width, mm$^2$.

– from the relative specific volume work of destruction

$$A_k^{''} = \left(\frac{S_{j,k} F_j z_j d_j i}{V_k}\right)_I + \left(\frac{S_{j,k} F_j z_j d_j i}{V_k}\right)_{II} + \left(\frac{S_{j,k} F_j z_j d_j i}{V_k}\right)_{III} \tag{29}$$

where $A_k''$ -relative specific volume work destruction of teeth of the j-th crown on the k-th ring face of the well, N*mm / mm$^3$ [16], $S_{j,k}$ - the contact path of the teeth of the j-th rings on the k-th ring faces of the well, mm; $z_j$ - number of teeth on the j-th crown, PCs; $d_j$ - number of conventional crowns of unit width on the j-th crown, PCs; $V_k$ - volume of the destroyed rock on the k-th ring face, mm$^3$.

2. Kinetic criteria for evaluating the performance of drill bits in the form of (28) and (29) are generally functions of the parameters of the bit-rock-energy triad. Under the parameters of the triad is accepted [15]:

- bit -a complete list of geometric parameters of the rock-breaking tool, which depend on its kinetic model and strength properties of its components and parts;
- rock - physical and mechanical properties of rock, taking into account the conditions of its destruction, depending, for example, on the shape of the bottom hole, the quality of cleaning the bottom-hole zone of sludge, etc.;
- energy - the parameters of the drilling mode taking into account the transformation of energy components when feeding them to the rock-breaking elements (teeth).

3. The kinetic criteria are explicit functions of the geometric parameters of the drill bits (28) and (29).

4. According to the physical sense, the relative specific contact work of destruction in the form (1) determines the intensity of abrasive wear of the teeth of the j-th crowns of the cones [17]:

$$A_j' = \frac{1}{T_2} \tag{30}$$

where $T_2$ – time of mechanical drilling, hour;

5. On physical sense relative specific volume work of destruction in the formula defines intensity of destruction of a rock by teeth of j-th crowns of cones on k-th ring faces of a well [18]:

$$A_k'' = V_M \tag{31}$$

where $V_M$ – mechanical drilling speed, m/h.

6. The penetration of the bit also depends on the relative specific contact work and the relative specific volumetric work, since:

$$H = V_M \cdot T_2 = A_k'' \cdot \frac{1}{A_j'} \tag{32}$$

The first and second provisions demonstrate the objectivity of the kinetic criteria, the third shows the possibility of actually changing the kinetic criteria by altering the geometric parameters of drill bits, the fourth and fifth establish the necessity of changing the kinetic criteria in order to improve drill bits, and the sixth establishes the economic criteria for evaluating drill bit performance [19].

During one cycle of axial reciprocating motion of the bit body, the angular velocity of the bit under the influence of changing in magnitude and direction of the dynamic load changes slightly, even in the steady-state drilling mode [20].

Keep in mind that the teeth working on the ring faces of the well, which are covered by the crowns of adjacent cones, have distinct values for particular contact and volumetric works of destruction. As a result, attention must be drawn to the extreme values of a particular contact and a certain volume of destructive activity.

The experience of solving optimization problems on the basis of comparative analysis of kinetic (dynamic) criteria showed the following.

1. The geometric properties of the teeth and their number must be used initially when optimizing practically any roller bit design.

2. The issue of guaranteeing equal load of supports of neighboring cones on the alignment of minimal volume operations of destruction of crowns of adjacent cones is the most promising optimization challenge.

With its more precise geometry and logical functioning under the defined geological and technological parameters, the roller bit will perform more effectively thanks to these recommendations.

The above recommendations have two aspects: technical-the recommendation of a more perfect geometry (design) of the bit, technological-the recommendation of a more rational design of the bit for given geological and technical conditions of drilling.

Drilling tricone bits fail, having exhausted their potential capabilities or the arrangement of the cones, or their supports. As is known, the level of penetration of the teeth of the cones into the rock is also an important parameter determining the efficiency of drilling [21]. Wear of the teeth of the cones is observed when the load on the bit is insufficient for the introduction of the tooth into the rock [22]. And the specified phenomena-wear (chip) of teeth of bits and wear of supports, as a rule, have local character, i.e. wear of riggings of bits and their supports comes with advance, respectively, on one of crowns at one of bit.

The above is in full accordance with the kinetic characteristics:

- the specific relative contact work of destruction;

- the specific relative volume work of destruction, or rather with the relations of their extreme values.

Specific contact work of destruction characterizes relative intensity of abrasive wear of teeth of crowns of adjacent cones, and specific volume work of destruction characterizes relative intensity of destruction of rock on adjacent ring faces of a well (Figure 5).

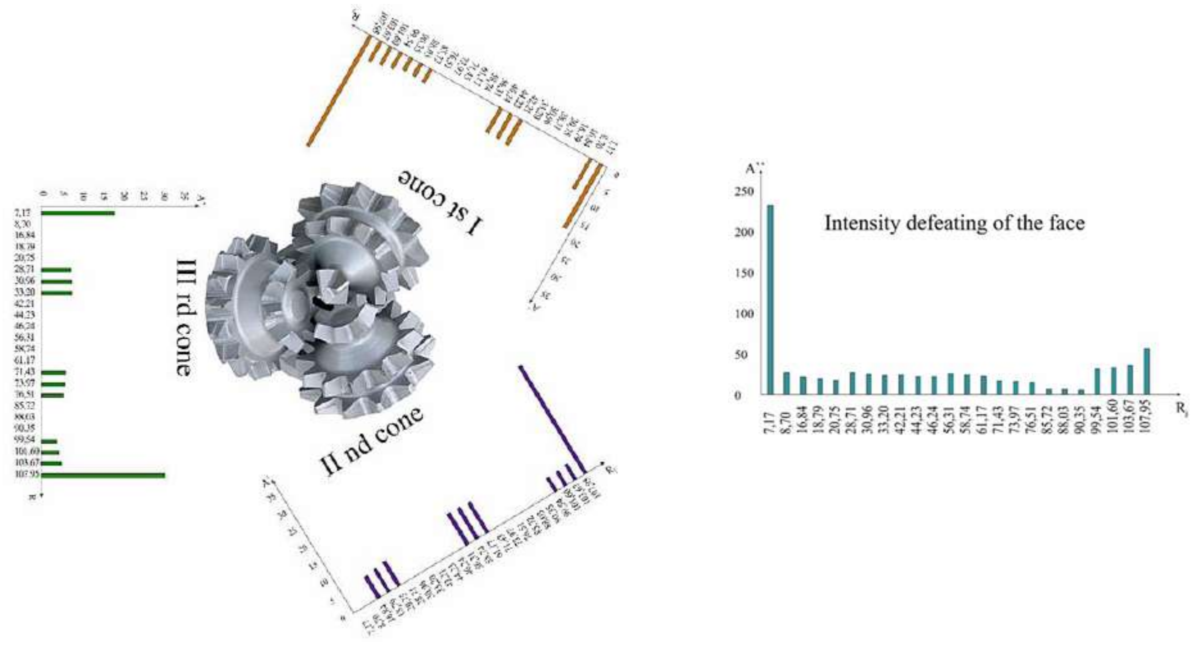


**Fig. 5.** - Kinetic passport of tricone bit 215.9

Values can accurately predict which of the crowns of adjacent cutters of the bit will wear out ahead and by a set of teeth which cutters have a greater chance of a chip and which one of the crowns defines the upper bound of the real mechanical speed of drilling, which foot the adjacent cutters will be more loaded and, therefore (Table 2), will have rapid wear [23].

**Table 2**. Analysis of the kinetic passport of the drill bit

| Ring sections on the face from the periphery to the center | | | The intensity of wear of the crowns (in arbitrary units) A' | | | | | | The intensity of the stope lesion (in conventional units |
|---|---|---|---|---|---|---|---|---|---|
| | | | First cone (gear ratio i = 1,458) | | Second cone (gear ratio i = 1,427) | | Third cone (gear ratio i = 1,442) | | |
| j | R | D | Z | A' | Z | A' | Z | A' | A" |
| 1 | 107,95 | 3,248 | 11,0 | 31,492 | 14,0 | 29,464 | 16,0 | 30,431 | 57,414 |
| 2 | 103,67 | 2,067 | 11,0 | 5,711 | 14,0 | 4,223 | 16,0 | 4,949 | 36,855 |
| 3 | 101,60 | 2,066 | 11,0 | 5,114 | 14,0 | 3,884 | 16,0 | 4,438 | 33,964 |
| 4 | 99,54 | 2,066 | 11,0 | 4,572 | 14,0 | 3,699 | 16,0 | 4,016 | 31,751 |
| 5 | 90,35 | 2,317 | 11,0 | 3,538 | | | | | 7,180 |
| 6 | 88,03 | 2,317 | 11,0 | 3,592 | | | | | 7,483 |
| 7 | 85,72 | 2,316 | 11,0 | 3,734 | | | | | 7,990 |
| 8 | 76,51 | 2,538 | | | | | 13,0 | 5,606 | 15,195 |
| 9 | 73,97 | 2,538 | | | | | 13,0 | 5,839 | 16,372 |
| 10 | 71,43 | 2,538 | | | | | 13,0 | 6,084 | 17,665 |
| 11 | 61,17 | 2,431 | | | 11,0 | 8,222 | | | 23,687 |
| 12 | 58,74 | 2,430 | | | 11,0 | 8,397 | | | 25,199 |
| 13 | 56,31 | 2,430 | | | 11,0 | 8,580 | | | 26,867 |
| 14 | 46,24 | 2,017 | 9,0 | 7,008 | | | | | 22,616 |
| 15 | 44,23 | 2,016 | 9,0 | 7,049 | | | | | 23,797 |
| 16 | 42,21 | 2,014 | 9,0 | 7,094 | | | | | 25,107 |
| 17 | 33,20 | 2,248 | | | | | 6,0 | 7,685 | 24,359 |
| 18 | 30,96 | 2,245 | | | | | 6,0 | 7,566 | 25,763 |
| 19 | 28,71 | 2,240 | | | | | 6,0 | 7,451 | 27,406 |
| 20 | 20,75 | 1,971 | | | 3,0 | 6,644 | | | 19,391 |
| 21 | 18,79 | 1,959 | | | 3,0 | 6,262 | | | 20,315 |
| 22 | 16,84 | 1,942 | | | 3,0 | 5,973 | | | 21,812 |
| 23 | 8,70 | 1,622 | 1,0 | 8,638 | | | | | 27,728 |
| 24 | 7,17 | 1,404 | 1,0 | 18,074 | | | 2,0 | 18,020 | 234,820 |

**Conclusions**

The bit arrangement is designed unsatisfactorily. The peripheral crown of the third cone, the second from the periphery of the crown of the second cone, and the second from the periphery of the crown of the first cone are where the minimal values of particular volume works fall. Uneven distribution of the drilling's maximum load will have a negative impact on the bit's stability. After analyzing the existing bit, it is possible to determine the main directions for increasing the efficiency of the bits, using kinetic data, which are possible in three consistent solutions:

1. By equidistant load of supports of adjacent cones.
2. On the way to increase the overall (minimum) intensity of rock destruction.
3. On the way of saving carbide riggings. Structure sketch

The economic effect will be determined:

- in the first case - by increasing the durability of the bit;
- in the second case - by increasing the mechanical speed of drilling;
- in the third case - by reducing the cost of the drill bit. In the General case, an effective solution can be found at the intersection of these paths.

The development of recommendations is based on solving the following sequence of tasks:

1. Analysis of the kinetic passport of the drill bit's basic design.
2. Calculation of ways to improve its design.
3. Calculation of a novel geometric parameter combination for the bit that provides the best kinetic passport.
4. Comparative evaluation of the bit's performance based on the kinetic passports of the suggested design.

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