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THE QUESTIONS OF THE DYNAMICS OF DRILLING BIT ON THE SURFACE OF WELL BOTTOM

ZAGADNIENIA DYNAMIKI NARZĘDZI WIERCĄCYCH NA POWIERZCHNIĘ DNA OTWORU WIERTNICZEGO

The purpose of this study was to investigate the dynamics of drilling bit on the well bottom as a function of their geometrical parameters. The frame of this method for this study includes former existed objective data on the unstable drilling devices as cantilever suspension. Research methods and calculation results are as follows: square coverage by tools blade working in different rotation regime; radius of the inscribed and circumscribed circle which leads to introduce and prospectively and solve problems on process optimization of mining rock at drilling the well bottom.

Keywords: mining rock, drilling, drilling bit

W artykule przedstawiono wyniki badań dynamiki narzędzia wiercącego podczas urabiania dna otworu wiertniczego w funkcji jego parametrów geometrycznych. Przedstawiona metoda badawcza oparta jest na dostępnych danych o występujących przypadkach niestabilnej pracy narzędzi wiercących. Metody badawcze i wyniki obliczeń są przedstawione w następujących obszarach: powierzchnia pokrycia przez ostrze narzędzia dla różnych prędkości obrotowych; problemy optymalizacji procesu urabiania skały na dnie otworu wiertniczego.

Słowa kluczowe: górotwór, wiercenie, koronki wiertnicze

Dynamic model of behavior of drill bits on the surface of well bottom should be described in a deterministic manner. Only then we can construct objective criteria for evaluating performance of drilling tools in the process of destruction of rocks, directly dependent on the initial data, and primarily on the geometric parameters of rock-breaking drilling tools (Kalinin, 1968).

First, we need to have a reasonable response to the first two questions.

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Clear answers to these questions gives energy consumption pattern of dynamical systems from the motion resistance forces (Steklyanov, 2001, 2012), which states that all dynamic systems operate in three different energy-costly and permanent in form: centric, eccentric and Bicentric driving modes.

Constructing energy consuming functions of any form of a dynamical system in the three modes of motion in the system of coordinates $N\varepsilon i$ (where N – energy consumption in the form of contact paths, ε – eccentricity, i – ratio), we find that the motion in Bicentric mode area with minimum energy consumption, which is limited from high level of energy consumption in centric, from low level of pairs of rotations in Bicentric and leap of energy costs from zero to a level of energy costs of centric mode of motion. This area is called «energy-consuming trap», because there are variational principle of least action (Buchgolz, 1965; Kolesnikova, 2005), which claim that dynamic systems always look for the least action, i. e the path of least energy consumption. Hence, it is easy to understand that a dynamic system in any case tends to be «energy-consuming trap». However, for this, system needs to acquire eccentricity. And after that the system itself, according to mentioned principles, will reduce this eccentricity to a minimum, under the law given by certain conditions.

Therefore, drilling bits are dynamically unstable on the surface of the well bottom. And this is our answer to the first question.

The answer to the second question lies in the fact that n – sided tool can function Bicentric mode, rolling only in $n + 1$, $n + 2$, ..., $n + m$ polyhedra, where the values of the faces are the distance between the tops of the blades.

It is obvious to assume that the system has the minimum amount of energy in $n + 1$ – polyhedron, because in this case the cost of energy from the motion resistance forces will be the least amount of energy in a relatively centric mode, i. e while rotating about the given geometric axis of the tool; and relatively the energy consumption in Bicentric mode rolling n – polyhedron (of the tool) within $n + 2$, $n + 3$, ... – polyhedra, which is quite understandable.

Here, only it should be noted that roll n – sided polygons formed by the tools provided within the $n + 1$ – sided with negative and variable ratios, i. e if the instrument is set to clockwise rotation, the rolling will materialize counterclockwise. Depending on this, border variables' center eccentricities will change.

Ratio is to be called the relationship of angular velocities around a mobile center to the angular velocity about a fixed center. So cone ratio is the ratio of its angular velocity around its axis – ω_2 to the angular velocity about the axis of the bit – ω_1 i. e

$$i = \frac{\omega_2}{\omega_1} \tag{1}$$

Physically, this means – how many times cone turn around its axis in one revolution of the bit. As for the drill bit cutting-shearing action, then this dynamical system will search for and find the mobile center of rotation in the plane of the borehole. It is in this case will have a variable within certain limits.

There remains only the question of in which case the energy consumption is less than centric mode of motion, i. e while rotating the tool around its constructively predetermined axis or bicentric, i.e. to rolling n – gon $n + 1$ – gon. In this case we will test the hypothesis at overlapped area by rotating double flute in $n + 1$ – gon, of course, with n blades.

We now find the total area to be coated on the surface of double flute face during its rotation around the fixed center in Bicentric mode (Fig. 1). There are two blades OA and OB.

Rotating the blade around the point A, we obtain for the third area of the sector turnover $S'_{sector.ABC}$, т.е.

$$S'_{sector\ ABC} = \frac{\pi(2R)^2}{6} = \frac{4\pi R^2}{6} = \frac{2\pi R^2}{3}$$

For full turn we find, S'_{total} i. e

$$S'_{total} = \frac{3 \cdot 2\pi R^2}{3} = 2\pi R^2$$

It is easy to see that the value of the area covered by double flute exists in the form of $S = 2 \cdot \pi R^2$

Thus, the area of overlapping double flute for one revolution around the fixed center motion in the centric and Bicentric modes are equal, i. e

$$S_{total} = S'_{total} = 2\pi R^2$$

We now find the parameters of formed holes while moving in double flute Bicentric mode. In this case, it is important for us to know the radii of the inscribed and circumscribed circles.

Fig. 1 shows that the radius of formed hole, i.e. the radius of the orifice is $R_{inscr} = O_1K$.

We have $AC = 2R$. Then

$$GK = \frac{2R}{2}\text{tg}15° \ \text{ a } \ O_1G = \frac{1}{3}BG$$

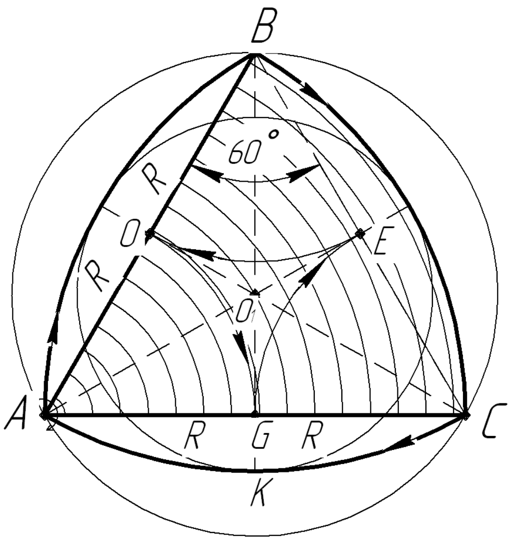

Fig. 1. Scheme for calculating the contact area of dihedral bit on the surface of the well bottom in one revolution around the specified center

Consequently the radius orifice O_1K is found:

$$R_{inscr} = GK + OG = \frac{2R}{2}\text{tg}\frac{60°}{4} + \frac{1}{3}R\sqrt{3} = \frac{R + \sqrt{3}R\,\text{tg}15°}{\sqrt{3}} =$$

$$= \frac{R + \left(1 + \sqrt{3} \cdot 0{,}2674\right)}{\sqrt{3}} = \frac{R + \left(1 + 1{,}732 \cdot 0{,}2674\right)}{1{,}732} = 0{,}8394R$$

The radius of the circumscribed circle – R_{circ} is found:

$$R_{circ} = \frac{2}{3}BG$$

i.e.

$$R_{circ} = \frac{2}{3} \cdot 2R\cos 30° = R \cdot \frac{4 \cdot 0{,}866}{3} = 1{,}155R$$

Thus, while moving on the surface of double flute slaughter for formed holes, we have:- Equality of coverage area

$$S = S' = 2\pi R^2$$

– the radius of the inscribed circle (orifice) is

$$R_{or} = R_{inscr} = 0{,}8394R$$

– the radius of the circle formed holes is

$$R_{circ} = 1{,}155R$$

We now carry out a similar study in the motion of three-blade tool in the centric and Bicentric modes of motion (Fig. 2). The length of the blades are taken $AO = BO = CO = R$.

Find the area circumscribed blades AO, BO, CO when turning around constructively given center O. It will be equal

$$S_{total} = 3\pi R^2$$

In the Bicentric mode, these work surfaces of bits will alternately rotate around the tops of the blades.

Turning around point A, we need to find a total area for $^1/_4$ turn around the fixed center in the form of (Fig. 2).

$$S'_{total} = 2S_1 + 2S_3 + S_2$$

Obviously the area $\Delta - BOB'$ is found

$$S_{\Delta BOB'} = S_{sector.ABB'} - S_{\Delta ABC} = S_1$$

Whereas

$$S_{sector.Aec'} = \frac{(AB)^2\pi}{12} = \frac{(AD)^2\pi}{12} = \frac{\pi 3R^2}{12} = \frac{\pi R^2}{4}$$

$$S_{\Delta ABC} = \frac{1}{2} AB \cdot OD = \frac{1}{2} R\sqrt{3} \cdot \frac{R}{2} = \frac{\sqrt{3}R^2}{4}$$

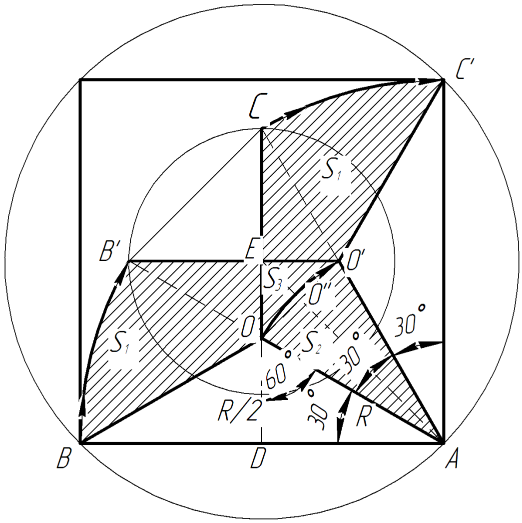

Fig. 2. Scheme for calculating the areas of contact for three working surfaces bit (three-point bit) instrument on the surface of well bottom

Then,

$$S_1 = \frac{\pi R^2}{4} - \frac{\sqrt{3}R^2}{4} = \frac{(\pi - \sqrt{3})R^2}{4}$$

Now we find the area in the form of S_2

$$S_2 = S_{sector.AOO'} = \frac{\pi R^2}{12}$$

And the area S_3 is found

$$S_2 = S_{\Delta AB'O'} - S_2 = \frac{\sqrt{3}R^2}{4} - \frac{\pi R^2}{12} = \frac{R^2(3\sqrt{3} - 2\pi)}{12}$$

Now the total area covered by the blades for $^1/_4$ turn is found:

$$S'_{total} = \frac{2R^2\left(\pi - \sqrt{3}\right)}{4} + \frac{2R^2\left(3\sqrt{3} - 2\pi\right)}{12} + \frac{\pi R^2}{12} =$$
$$= \frac{R^2\left(2\pi 3 - 6\sqrt{3} + 6\sqrt{3} - 2\pi + \pi\right)}{12} = \frac{5\pi R^2}{12}$$

For a complete turn, apparently, the total area will be four times more, i. e

$$S' = 4S'_{total} = \frac{4 \cdot 5\pi R^2}{12} = \frac{5\pi R^2}{3}$$

We now find the radii of the circumscribed and inscribed circles of Δ-s *AOO″* and *OO″E*.

$$R_{circ} = R(\cos 15° + \sin 15°) = R(0{,}2588 + 0{,}9659) = 1{,}2247R$$

$$R_{inscr} = EC = OC - OE = R - OE = R\sqrt{R^2 \sin^2 15° + R^2 \sin^2 15°} =$$
$$= R - R\sqrt{2\sin^2 15°} = R(1 - 0{,}2588\sqrt{2}) = 0{,}634R$$

Thus, in the motion of the three working bits (such as PDC) on the surface of the bottom, orifices have:

– the area covered by three blades when moving in the centric mode

$$S = 3\pi R^2$$

– when moving in the Bicentric mode

$$S' = \frac{5\pi R^2}{3}$$

– the radius of the orifice is (inscribed circle)

$$R_{or.} = R_{inscr.} = 0{,}634R$$

– the radius of the circumscribed circle formed by the holes is

$$R_{circ.} = 1{,}2247R$$

Now we find the same ratio when the design of the tool will have four equal blades.
In the centric mode when the total area of motion is found

$$S_{total} = 4\pi R^2$$

Next, we need to consider the mode of a tetrahedral rolling tool in the pentagon (Fig. 3).
In this case we need to calculate the total area S' in the form of

$$S' = S_1 + 2S_2 + 2S_3$$

1. The area S_1 is found in the form of sector of a circle with a radius of $2R$ vertex angle 18°, i.e.

$$S_1 = \frac{\pi(2R)^2}{20} = \frac{4\pi R^2}{20} = \frac{\pi R^2}{5}$$

2. The area S_2 is found as the difference between the area of Δ and the sum of the areas *A′O′D* Δ and *EOD* sector *DOO′*.
i.e.

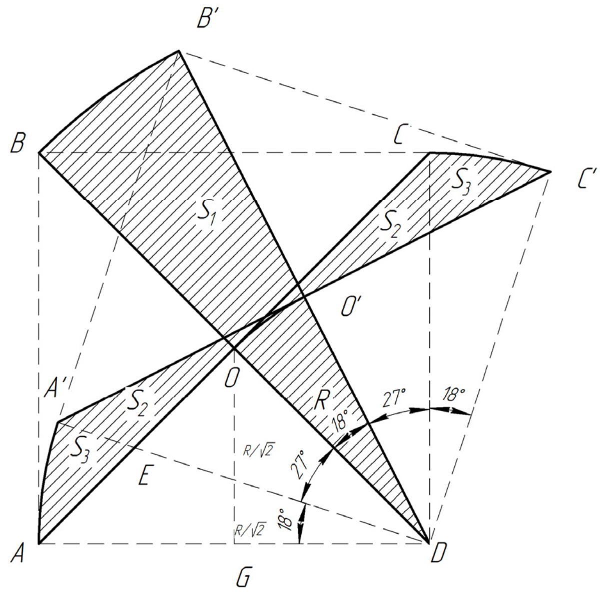

Fig. 3. Scheme for calculating the contact area on the surface of the quadrangular tool face formed holes

$$S_{\Delta A'O'D} = (S_{\Delta EOD} + S_{sector.DOO'}) = S_2$$

Whereas

$$S_{sector.DOO'} = \frac{\pi R^2}{20}$$

$$S_{\Delta A'O'D} = S_{\Delta AOD} = \frac{1}{2} AD - OG = \frac{1}{2} 2R\sqrt{2}\,\frac{R}{\sqrt{2}} = \frac{R^2}{2}$$

Here

$$AD = \frac{2R}{\sqrt{2}} = R\sqrt{2}; \quad OG = \frac{R}{\sqrt{2}}$$

And

$$S_{\Delta EOD} = \frac{1}{2} OE \cdot OD = \frac{1}{2} R\,\mathrm{tg}27° \cdot R = \frac{R^2 \mathrm{tg}27°}{2}$$

Whereas

$$OE = R\,\mathrm{tg}\,27°; \qquad OD = R$$

And finally find

$$S_2 = \frac{R^2}{2} - \left(\frac{R^2 \mathrm{tg}27°}{2} + \frac{\pi R^2}{20}\right) = \frac{R^2(20 - 10\mathrm{tg}27° - \pi)}{20}$$

3. The area S_3 is found as the difference between the area of the sector DAA' area and Δ in the form of AED

$$S_3 = \frac{2\pi R^2}{20} - \frac{R^2(1-\text{tg}27°)}{2} = \frac{R^2(2\pi - 10 + 10\text{tg}27°)}{20}$$

here

$$S_{\Delta AED} = S_{\Delta AOD} - S_{\Delta EOD} = \frac{R^2}{2} - \frac{R^2 \text{tg}27°}{2}$$

Consequently, S'_{total} is found:

$$S'_{total} = \frac{4\pi R^2}{20} + \frac{2R^2(10 - 10\text{tg}27° - \pi)}{20} + \frac{2R^2(2\pi - 10 + 10\text{tg}27°)}{20} =$$
$$= \frac{R^2(4\pi + 20 - 20\text{tg}27° - 2\pi + 4\pi - 20 + 20\text{tg}27°)}{20} = \frac{6\pi R^2}{20} = \frac{3\pi R^2}{10}$$

However such areas should be five, then S'_{total} is found in the form of:

$$S'_{total} = \frac{5 \cdot 6\pi R^2}{20} = \frac{3}{2}\pi R^2$$

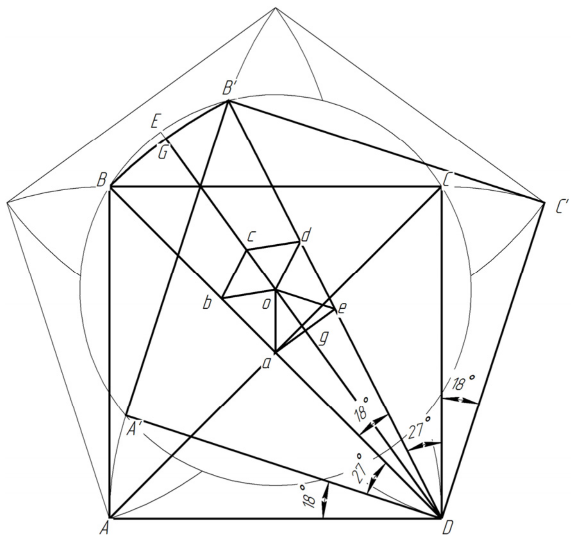

Fig. 4. Scheme for calculating the inscribed and circumscribed circles due to rolling tetrahedron in pentagon

We now find R_{inscr} and $R_{circ.}$, considering Fig. 4.

$$R_{inscr} = OE = DE - OG = 2R - (DG + OG) = 2R - (R\cos 9° + OG\,\text{ctg}36°) =$$
$$= 2R - R(0{,}9877 + 0{,}1564 \cdot 1{,}376) = 0{,}7971R$$

The radius of the circumscribed circle – R_{circ}. Is found from the condition (Fig. 4)

$$R_{circ.} = OD = DG - OG = R\cos 9° + OG\,\text{ctg}36° = R\cos 9° + R\sin 9° \cdot \text{ctg}36° =$$
$$= R(0{,}9877 + 0{,}1564 \cdot 1{,}376) = 1{,}2029R$$

So, we have

$$S = 4\pi R^2$$

$$S' = \frac{3}{2}\pi R^2$$

$$R_{inscr.} = 0{,}7971R$$

$$R_{circ} = 1{,}2029R$$

The studies provide a basis to the following conclusions:

1. Drilling bits as dynamical systems on the surface of well bottom cannot operate in a rotation around the axis of the well (in centric mode), since the output of them takes less energy mode (Bicentric) with cantilever suspension tool it is easily acceptable.
2. Output of drilling bits in the motion of Bicentric mode from the point of energy consuming view and the possibility of the drilling bit is not in the same plane by bending drill string.
3. Significant differences in the values of the radii of the inscribed and circumscribed circles with respect to the nominal diameter of the tool require careful consideration of the dynamic aspects of drilling bits as the conservation of the defined transverse dimensions of the well in terms of finding the optimal dynamics of mining drill bits in Bicentric mode in the future.

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