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THEORETICAL STUDIES OF THE PROCESS OF CRACK FORMATION DURING ROTATIONAL IMPACT DRILLING



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This article is devoted to the study of the process of crack formation, which are actively manifested during rotational impact drilling. The studies conducted during the writing of the article show that simultaneously with the destruction of the bottom of the well, another process occurs – the formation of many cracks in the angular (peripheral) zones of the bottom and on the walls of the well, going to a depth of 5-10 mm. These cracks remain in the form of a dense network in the walls of wells and in the core (during its selection), and the depth of the cracks increases with increasing impact energy. An attempt was made to explain the mechanism of cracking in the core during impact-rotational drilling from the standpoint of the theory of off-center impact. However, the study of cracking occurred when drilling wells on blocks of rocks. With the rotary-impact method of drilling deep horizontal wells, the types and distribution of loads in the near-well array will be different. This article presents technologies that increase the volume of production in depleted fields. During the calculations, the dependences of the impact force of the transmitted seal (rock) depending on its compliance are given. In addition, a graph of the dependence of changes in the impact force of the striker on the anvil on the impact time with different malleability of the anvil is constructed. The process of forming a horizontal well, which is drilled with a continuous face in a shock-rotational way using hydraulic impact machines, is considered. To study the process model, the results of solving the problem of stress distribution around the trunk array of a vertical well were considered.

KEY WORDS: *cracks, impact-rotational drilling, stretching, deformation, rocks, compression.*

АЙНАЛМАЛЫ БҰРҒЫЛАУ КЕЗІНДЕГІ ЖАРЫҚШАҚТАРДЫҢ ПАЙДА БОЛУ ПРОЦЕСІН ТЕОРИЯЛЫҚ ЗЕРТТЕУ

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Бұл мақала айналмалы соқпалы бұрғылау кезінде белсенді түрде көрінетін жарықшақтардың пайда болу процесін зерттеуге арналған. Мақаланы жазу кезінде жүргізілген зерттеулер көрсеткендей, ұңғыма түбінің бұзылуымен бір мезгілде тағы бір процесс жүреді –табанның бұрыштық (перифериялық) аймақтарында және ұңғыма қабырғаларында көптеген жарықтар пайда болады, 5-10 мм тереңдікке дейін созылады. Бұл жарықтар ұңғымалардың қабырғаларында және керндерде (оны таңдау кезінде) тығыз тор түрінде қалады, ал соққы энергиясының жоғарылауымен жарықтар тереңдігі артады. Орталықтан тыс әсер ету теориясы тұрғысынан соққылы-айналмалы бұрғылау кезінде керндегі кре-

кинг механизмін түсіндіруге әрекет жасалды. Дегенмен, жарықшақтардың пайда болуын зерттеу тау жыныстары блоктарында ұңғымаларды бұрғылау кезінде орын алды. Терең көлденең ұңғымаларды бұрғылаудың айналмалы-соққы әдісімен ұңғыма маңындағы массивтегі жүктемелердің түрлері мен таралуы әртүрлі болады. Бұл мақала сарқылған кен орындарындағы өндірісті арттыратын технологияларды ұсынады. Есептеулер барысында оның сәйкестігіне байланысты өткізілетін пломбаға (тасқа) әсер ету күшінің тәуелділіктері беріледі. Сонымен қатар, соққының әртүрлі сәйкестігі үшін соққының соққы күшінің өзгерістерінің соққы уақытына тәуелділігінің графигі салынды. Гидравликалық соқпалы станоктардың көмегімен соқпалы-айналмалы әдіспен үздіксіз түптік ұңғымамен бұрғыланатын көлденең ұңғыманың қалыптасу процесі қарастырылады. Технологиялық модельді зерттеу үшін тік ұңғыманың ұңғыма маңындағы массивінің айналасында кернеуді бөлу мәселесін шешу нәтижелері ескерілді.

ТҮЙІН СӨЗДЕР: *жарықтар, айналмалы бұрғылау, созылу, деформация, тау жыныстары, қысу.*

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ ПРОЦЕССА ТРЕЩИНООБРАЗОВАНИЯ ПРИ ВРАЩАТЕЛЬНО-УДАРНОМ БУРЕНИИ

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Данная статья посвящена изучению процесса образования трещин, которые активно проявляются при вращательно-ударном бурении. Исследования показывают, что одновременно с разрушением забоя скважины, происходит другой процесс – формирование в угловых (периферийных) зонах забоя и на стенках скважины множества трещин, уходящих на глубину 5 - 10 мм. Эти трещины остаются в виде густой сети стенках скважин и в керне (при его отборе), причем глубина трещин возрастает с повышением энергии удара. Была предпринята попытка объяснить механизм трещинообразования в керне при ударно-вращательном бурении с позиции теории внецентренного удара. Однако изучение трещинообразования происходило при бурении скважин на блоках пород. При вращательно-ударном способе бурения глубоких горизонтальных скважин виды и распределения нагрузок в околоскважинном массиве будут иными.

Приведены технологии, увеличивающие объем добычи на истощенных месторождениях. В ходе проведения расчетов отражены зависимости силы удара передаваемой заделке (горной породе) в зависимости от ее податливости. Помимо этого, построен график зависимости изменений силы удара бойка о наковальню от времени удара при различной податливости наковальни.

Рассмотрен процесс формирования горизонтальной скважины, которая бурится сплошным забоем ударно-вращательным способом с применением гидроударных машин. Для исследования модели процесса были учтены результаты решения задачи о распределении напряжений вокруг приствольного массива вертикальной скважины.

КЛЮЧЕВЫЕ СЛОВА: *трещины, ударно-вращательное бурение, растяжение, деформация, горные породы, сжатие.*

Introduction. When developing a strategy for the construction of wells in old fields, oil companies are mainly guided by the need for drilling efficiency in combination with geological uncertainty. Many drilling contractors are adding new mobile drilling rigs to the equipment fleet and improving production processes in order to reduce unproductive time. Drilling contractors update existing drilling equipment fleets, including mobile drilling rigs, modernize existing rigs through the introduction of pumping equipment, solid phase content monitoring equipment, upper power drives, allowing to increase the return on technology in accordance with the requirements of oil producing companies [1,2].

The improvement of drilling technologies and cost reduction have radically changed the situation on the market. Now the reserves of those deposits that were previously considered unprofitable from the point of view of production are also taken into account. The main task is to balance the cost of the equipment used and its supposed advantages.

Various new drilling technologies are gaining popularity due to the need to increase production in fields with declining production. Often, it still turns out to be more expensive to start developing a new field than to increase its level in old fields. The following technologies have the potential for growth in mature fields:

1) rotary controlled systems;

2) advanced logging systems in the drilling process (pressure, sampling, logging of undiscovered rocks ahead of the bit);

3) real-time management of petrophysical data;

4) drilling on the depression;

5) coiled tubing drilling;

6) drilling process optimization programs, integrated bit/mortar/trajectory control services;

7) sector models and petrophysics;

8) development of improved models of PDC chisels;

9) gentle drilling fluids and improved control of the cleaning of the solution.

Optimal application of current or new technologies is the key to low-cost drilling of field wells in old fields. When planning new wells, operators should carefully consider the possibility of drilling horizontal wells in the oil reservoir zone [3].

Research methods and materials. The analysis of the research of domestic and foreign scientists shows that currently there are two main directions in the technology of opening productive formations: the technology of opening for repression, when the drilling mud exerts excessive pressure on the productive formation; the technology of opening at a negative pressure drop, when the penetration of drilling mud and its components into the bottom-hole zone of the formation is excluded.

Results and discussion. As the research review shows, when using even the most advanced types of drilling fluids, it is not possible to exclude a negative impact on the productive reservoir. In addition, drilling for repression has other disadvantages:

– the formation of a clay crust on the walls of the well, which often causes tool tacks, oil seal formation and reciprocating;

– a decrease in the quality of separation of layers;

– the possibility of absorption of drilling fluid;

– tightening, tacks under the influence of pressure drop;

– increased consumption of reagents for the preparation and stabilization of drilling fluids, etc.

In recent years, the use of drilling technology in depression conditions in the borehole-formation system has become increasingly widespread in the foreign practice of well construction.

The opening of a productive reservoir at a depression or at a negative differential pressure in the borehole-reservoir system is a process in which the components of the drilling fluid do not enter the productive reservoir, but on the contrary, oil flows into the wellbore.

Unlike vertical drilling, horizontal drilling, due to the absence of static loads, significantly decreases the drilling speed (weighted drill pipes do not provide a load on the bit), and the penetration is carried out due to the hydrostatic load of the washing solution, the value of which depends on the power of the drilling pumps. Further, when drilling horizontal intervals, there is always a danger of the occurrence of a drilling tool being seized.

A characteristic feature of the impact-rotational drilling method using hydraulic shock systems is the use of less resistance of strong and very strong abrasive rocks to dynamic loads than static ones. As a result, the energy intensity of rock destruction with this method is significantly less than with other known methods. The practice of recent years has confirmed the high efficiency of impact-rotational drilling of wells and the feasibility of its use in combination with other known modern methods.

With the impact-rotational drilling method, the process of destruction of the bedrock of the magmatic formation occurs due to the chipping and crushing of the rock mass.

In the mode of rotary-impact drilling, which differs from rotary-impact drilling in that the drilling tool is embedded in the rock not only now of impact, but also in the intervals between impacts under the action of a significant static axial force reaching 1.5-2.0 kN per 1 cm of the blade length of the drilling tool, thereby forming a double effect of rock destruction – creating cracks and cutting the loosened mass.

Therefore, the use of rotary impact drilling in soft and medium-strength rocks, mainly sedimentary formations (oil and gas sector), requires comprehensive scientific research [5-7].

When exposed to a rock by high pressure, irreversible deformation is manifested. To do this, it is necessary to create a pressure at the bottom of the well that significantly exceeds the rock pressure and extend the area of action on high-pressure rocks far enough into the formation.

This can be done with the help of rotary impact drilling. The main external load during impact rotary drilling is shock pulses transmitted by the bottom of the well from the piston-striker by hydro-pulse generators – high-pulse hydraulic impact machines. The axial static force in this method plays a subordinate role and serves only to create a tight contact of the incisors with the rock (*Figure 1*).

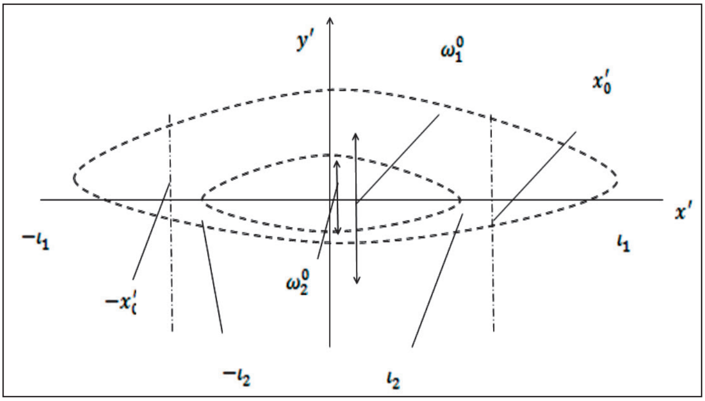

Figure 1 – **Diagram of the formation of an irreversible crack**
ω – the crack width, l – the crack length

Under the influence of the force of indentation, a compression area is formed in the rock, directed in all directions from the tooth. Tangential stresses σ arise in the rock on the contact contour, which, with an increase in the force G, reach the limit value, and a contour crack forms in the rock, which spreads deep into the rock along a cone tangent to the surface of the deformation sphere of the rock around the contact zone with the chisel tooth. With a further increase in the force on the limit stress region, it expands in the direction of the crack and at G_1, the crack increases along the conical surface (*Figure 2*).

Thus, there is a spasmodic effect on the rock. With a further increase in the strength of shock pulses and the time of their impact, several jumps of rock destruction (crack formation) can occur sequentially, but in practice, the operating values of axial loads provide up to two jumps of brittle fracture. The dependence of the axial load on the deformation of the rock up to two jumps of destruction has the form of a stepped curve [8].

Based on Griffiths' theory of crack propagation in rocks, it can be concluded that with an increase in the crack size, the difference between the surface energy of the crack U and the elastic energy of the body W spent on crack formation does not change. Thus, an increase in the surface energy of the medium during the formation of a crack occurs

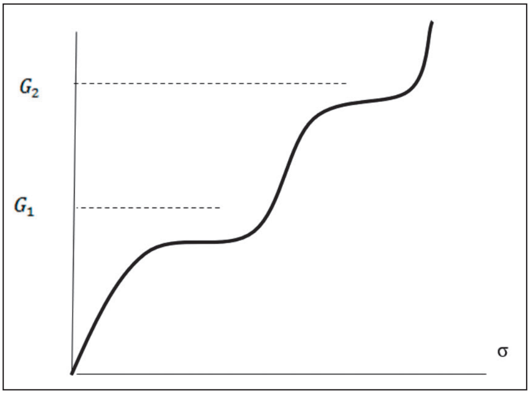

Figure 2 – **Abrupt formation of rock cracks under the action of axial load**

because of a decrease in the elastic energy of this medium. The crack parameters according to Griffiths' theory are found from the condition $\frac{\partial(V-W)}{\partial l}=0$ (l – the crack length).

Griffiths' approach to crack formation is called, in connection with the above, energy.

To determine the maximum crack width, i.e., its width near the well, we have the expression:

$$\omega_2^0=\frac{4(1-v_2^2)\left(\frac{E_2}{E_1}\right)Pl_2}{\pi E_2}\cos\vartheta_2^0\ln\frac{tg\left(\frac{\pi}{4}+\frac{\vartheta_2^0}{2}\right)}{tg\left|\left(\frac{\pi}{4}-\frac{\vartheta_2^0}{2}\right)\right|} \quad (1)$$

where E – Young's modulus; P – the initial load; l – the crack length; v – the Poisson's ratio.

As a result of the solution (taking into account the wave theory of impact), forces were obtained at the embedded end of the rod (at the chisel-rock contact), taking into account the malleability of the embedding β (i.e., the malleability of the rock to the insertion of chisel cutters into it). This is a distinctive feature of the solution from the well-known problem of Biderman *V.*, in which the end of the rod is considered free or rigidly fixed [9,10].

The forces at the end of the K rod are known to depend on the timing of the impact stages. Here are the formulas for the first two stages.

The first stage of impact ($0 \le t \le \frac{2l}{a}$)

$$P_{k1P}=P_{\kappa 31}-\frac{P_{\kappa 31}}{\exp\left(\frac{2l}{\beta EF}\right.} \quad (2)$$

$$P_{k31}=\frac{2V}{n\delta}\exp(-mt)\sin(nt) \quad (3)$$

The second stage of impact ($\frac{2l}{a} \le t \le \frac{4l}{a}$)

$$P_{k2P}=P_{\kappa 32}-\frac{P_{\kappa 32}}{\exp\left(\frac{2l}{\beta EF}\right.} \quad (4)$$

$$P_{\kappa 32}=\frac{2V}{n\delta}\left\{\exp(-mt)\sin(nt)+\frac{2m}{n}\exp(-m\theta)\left[\left(n\theta-\frac{m}{n}\right)\sin(n\theta)++m\theta\cos(n\theta)\right]\right\} \quad (5)$$

In formulas (2) and (3):
where l – the length of the rod; a – the velocity of the deformation waves in the side uponimpact; V – the speed of the load M when hitting the side:

$$n=\sqrt{\frac{1}{\delta M}}-\frac{a^2}{4\,\partial^2(EF)^2} \quad (6)$$

where M – weight of the cargo; δ – malleability of the impacted end of the rod; E – the elastic modulus of the rod material; F – the cross-sectional area of the rod:

$$M=\frac{a}{2\delta EF} \quad (7)$$

$$\Theta=t-\frac{2l}{a} \quad (8)$$

With a small length l of the removed rod, it is necessary to calculate the third stage of impact, etc. But at the same time, calculations quickly become more complicated.

Figure 3 shows the dependences of the impact force of the transmitted seal (rock) depending on its compliance. As expected, with an increase in the pliability of the rock, the impact force P decreases.

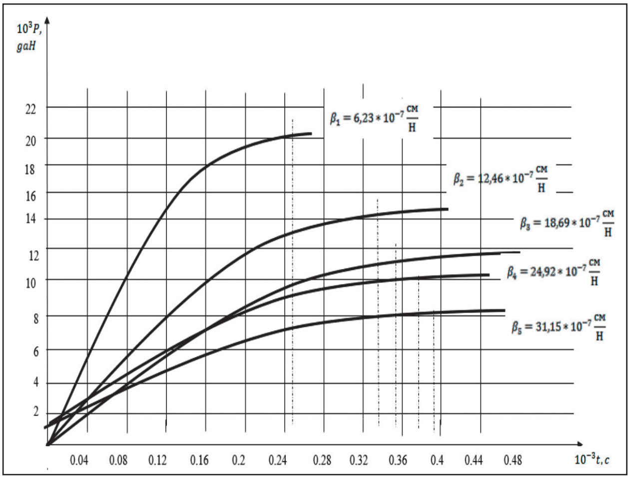

Figure 3 – **Change in the force of the striker's impact on the anvil P_H from the impact time *t* with different anvil compliance β**

Let's consider the process of forming a horizontal well, which is drilled with a continuous face in a shock-rotational way using hydraulic impact machines.

The analysis of the solution of the mentioned problem shows that the vertical stresses deprived of the weight of the overlying rocks ($\sigma_z = \gamma_n z$, where γ_n is the specific gravity of the overlying rock layers; z is the depth of the selected rock elements) increase with depth.

The stresses σ_r, σ_θ, on the contrary, decrease rapidly, since they are inversely proportional to the square of the current radius *r*:

$$\sigma_r = f_1\left(\frac{r_1^2}{r^2}\right); \sigma_\theta = f_2\left(\frac{r_1^2}{r^2}\right) \tag{9}$$

r is the radius of the well 2.

In this regard, they were not considered when forming the process model. The second assumption was that the well is drilled with a solid face, which, under high-frequency impact, is affected by numerous points of damage to the face from the working elements of the bit. The third assumption in the development of the model is that the mentioned set of points for the defeat of the face are replaced by an equivalent pressure P_y by the latter and equal to:

$$P_y = \frac{P_{max}}{F_3} \tag{10}$$

where P_{max} – the maximum force of the shock pulse acting on the face from the generator;

F_3 – the area of the well face.

Considering the accepted assumptions, the process model represents a cylindrical shell with a flat bottom, simulating the faces and walls of wells (*Figure 4*) [11].

The outer surface of the shell (its side surface and bottom) is under pressure of high-lying rocks $P_в=\gamma_n$ z, the inner cylindrical surface and bottom are under pressure of drilling mud $P_q=\gamma_g$ z.

In addition, the bottom from the inside experiences an equivalent internal pressure due to shock loads from the side of the water hammer and determined by formula 10. It is required to determine the increase in voltage at the junction of the bottom with the cylindrical surface of the shell.

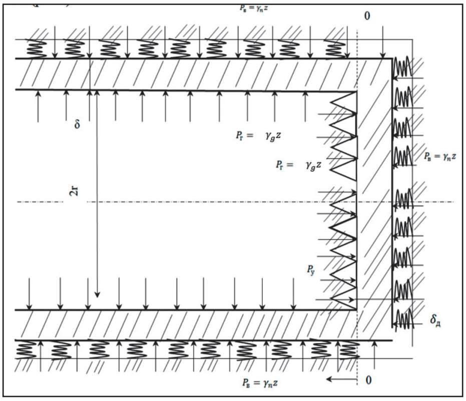

Figure 4 – **A model of a bottomhole section of a well formed by a shock-rotational method using a hydraulic hammer**

The problem is solved according to the moment theory in the following sequence.

The cylindrical rigidity of the shell is determined:

$$D = \frac{E\delta^3}{(1-\mu^2)} \tag{11}$$

where E – the modulus of elasticity of the rock shell material, for rocks of medium hardness; $E\approx(4\text{-}6)\times10^{10}$ Pa; δ – the thickness of the cylindrical shell, m; μ – the Poisson's ratio.

The coefficient α of attenuation of the «surge» of stress at the junction of the bottom and the cylindrical part of the shell is determined.

$$\alpha = \frac{\sqrt[4]{3(1-\mu^2)}}{\sqrt{r\delta}} \tag{11}$$

where r – the radius of the (inner) cylindrical shell.

The zone (boundary) of the influence of the edge effect is calculated:

$$l_0 = \frac{\pi}{\alpha} = \frac{\pi\sqrt{r\delta}}{\sqrt[4]{3(1-\mu^2)}} \tag{12}$$

The abscissa X is counted from the junction of the cylindrical shell with the bottom.

The condition of compatibility of linear (Δ) and angular (θ) displacements of the bottom (index «d») and the cylindrical shell (index «C») at x=0 (junction) is written in general form:

$$\begin{cases} \Delta_p^c + \Delta_Q^c + \Delta_{M_0}^c = \Delta_p^d + \Delta_Q^d + \Delta_{M_0}^d \\ \theta_p^c + \theta_Q^c + \theta_{M_0}^c = \theta_p^d + \theta_Q^d + \theta_{M_0}^d \end{cases} \tag{15}$$

The right-hand sides of the equation for a flat bottom have the form:

$$\begin{cases} \Delta_p^d = 0; \ \Delta_Q^d = \frac{-Q_0(1-\mu_d)r}{\delta_д E}; \ \Delta_{M_0}^d = 0; \\ \theta_p^d = -p_1 \frac{r^3}{8(1+\mu_d)D_d} =; \theta_{Q_0}^d = 0; \theta_{M_0}^d = \frac{12(1-\mu_d)M_0}{E_d \delta_d} \end{cases} \quad (16)$$

The left parts of the equation for the junction of the bottom with the cylindrical shell (at x = 0) are equal to: 7

$$\left. \begin{array}{c} \Delta_p^c = -p_2 \frac{r^2}{\delta E}\left(1 - {}^{\mu}/_{2}\right); \ \Delta_Q^c = -\frac{Q_0}{2\alpha D}; \ \Delta_{M_0}^c = -\frac{M_0}{2\alpha^2 D} \\ \theta_p^c = 0; \theta_Q^c = \frac{Q_0}{2\alpha^2 D}; \ \theta_{M_0}^c = \frac{M_0}{D\alpha} \end{array} \right\} \quad (17)$$

In equations 16,17.

$P_1 = P_2 + P_y - P_в = \gamma_ж z + \frac{P_{max}}{F} - \gamma_n z$ is the total pressure acting on the bottom;

$P_2 = P_2 - P_в = \gamma_ж z - \gamma_n z$is the total pressure on the cylindrical shell.

Substitute (15) and (16) in (17):

$$\left. \begin{array}{c} -P_2 \frac{r^2}{\delta E}(1 - 0{,}5\mu) - \frac{Q_0}{2\alpha^3 D} - \frac{M_0}{2\alpha^2 D} = 0 - \frac{Q_0(1-\mu_Д)r}{E_d \delta_d} + 0 \\ 0 + \frac{Q_0}{2\alpha^2 D} + \frac{M_0}{D\alpha} = -P_1 \frac{r^3}{8(1+\mu_d)D_d} + 0 + \frac{12(1-\mu_Д)M_0}{E_d \delta_d^3} \end{array} \right\} \quad (18)$$

Solving the system with respect to M_0 и Q_0 we get:

$$M_0 = \frac{CP_2 - RP_1}{B} \quad (19)$$

$$Q_0 = \frac{1}{A}\left[-P_2 \frac{r^2}{\delta E}(1 - 0{,}5\mu) - \frac{(cP_2 - DP_1}{B2\alpha^2 D}\right] \quad (20)$$

Formulas (19) and (20) denote:

$$A = \frac{-1}{2\alpha^3 D} - \frac{(1-\mu_d)r}{\delta_d E_d} \quad (21)$$

$$B = \frac{-1}{A4\alpha^4 D} + \frac{1}{\alpha D} - \frac{12(1-\mu_d)}{\delta_d E_d} \quad (22)$$

$$C = \frac{r^2(1-0{,}5\mu)}{2A\alpha^2 D\delta E}; \ R = \frac{r^3}{8(1+\mu)D} \quad (23)$$

To analyze formulas (19), (20) and their practical application for the calculation of cracking, we consider the following:

– the average value of the elastic modulus for a cylindrical shell and bottom, represented by a rock, we take $E = 6\times10^{10}$ *Pa*;

– Poisson's ratio $\mu_Q = \mu_Д = 0{,}3$;

– average well radius $r_c = 0{,}095$ *m*;

– the thickness of the bottom and the thickness of the cylindrical shell are assumed to be the same and equal to $\delta_Q = \delta_Д = 0{,}01$ *m*.

Considering the mentioned assumptions, the cylindrical rigidity of the bottom and shell formula (6) will be $D_c = D_d = 5495\ H/m$, and the attenuation coefficient $\alpha_c = 33{,}8\ \frac{1}{m}$.

It should be noted that with other real parameters of horizontal wells, the values are insignificant. Substituting these values into formulas (21, 22, 23) to determine A, B, C, R, and then their obtained values into formulas (19, 20), we obtain the following equations for calculating Q_0 and M_0;

$$\begin{cases} M_0 = 0{,}092 * 10^{-3}P_2 - 3{,}481 * 10^{-3}P_1 \\ Q_0 = -0{,}27 * 10^{-3}P_2 - 122 * 10^{-3}P_1 \end{cases} \quad (24)$$

Normal stresses σ_m, σ_t and tangential stresses τ arise in the boundary zones (the place of interface of the shell with the bottom), determined by the formulas:

$$\left. \begin{matrix} \sigma_m = P_1 \frac{r}{2\delta} \pm 6\frac{M_x}{\delta^2}, \sigma_t = P_1 \frac{r}{\delta} + \frac{\Delta T}{\delta} \pm 6\frac{K_x}{\delta^2} \\ \tau = Q_x/\delta \end{matrix} \right\} \quad (25)$$

The values $P_1 \frac{r}{2\delta}$ and $P_1 \frac{r}{\delta}$ correspond to the momentary theory, and the added terms $\pm 6\frac{M_x}{\delta^2}, \frac{\Delta T}{\delta}, \pm 6\frac{K_x}{\delta^2}, Q_x/\delta$ are associated with the edge effect associated with the moment theory. The «+» sign refers to the inner surface of the shell, and the «-» sign refers to the outer.

The additional members are determined by the following formulas:

$$M_x = \frac{Q_0}{\alpha}(e^{-\alpha x}\sin\alpha x) + M_0(e^{-\alpha x}\cos\alpha x + e^{-\alpha x}\sin\alpha x) \quad (26)$$

At x=0 (coupling of the bottom with the shell).

$$M_{x=0} = M_0 = 0{,}092\times10^{-3}P_2 - 3{,}481\times10^{-3}P_1 \quad (27)$$

Then the voltage σ_m, considering (27), will take the form:

$$\sigma_m = P_1\frac{r}{2\delta} \pm 6\frac{M_x}{\delta^2}(0{,}092\times10^{-3}P_2 - 3{,}481\times10^{-3}P_1) \quad (28)$$

Similarly, the tense σ_t,τ are determined according to the methodology described in the paper. At the same time, the analysis and comparison of the voltages σ_m, σ_t,τ shows that the voltage σ_m significantly (4-5 times) exceeds other voltages [12,13].

Therefore, in the future we will analyze the effect of the stress σ_m on the strength of the joint of the shell with the bottom, depending on its internal radius (the diameter of the well) and the magnitude of the acting loads.

The following initial data were taken for analysis:

– the depth of the well $z = 1000\ m$, the specific gravity of sedimentary rocks $\gamma_n = 25000\ {}^{H}/_{m^3}$, the specific gravity of the drilling mud $\gamma_j = 12000\ {}^{H}/_{m^3}$, the thickness of the bottom (face)-0.01m.

The pressures P_1 and P_2 are respectively equal:

$$\begin{matrix} P_1 = P_y + (\gamma_g - \gamma_n)z = \frac{P_{max}}{F_3} + (\gamma_g - \gamma_n)z, \\ P_2 = (\gamma_g - \gamma_n)z \end{matrix} \quad (29)$$

For the analysis, the value of the maximum force of the shock pulse was set, which was then divided by the area of the bottom F_3 (bottom hole) to obtain the maximum pulse pressure $P_y = {}^{P_{max}}/F_3$.

Then, given several values of the radius of the well, we calculate, considering the mentioned initial data, the voltage σ_m.

Similar calculations made it possible to develop a nomogram to determine the required value of the impulse force P_{max} for the implementation of cracking in the angular zone of the bottom of the well, depending on the diameter of the latter and the strength parameters of the drilled rock.

Along the abscissa, the radius of the well is deposited, and along the ordinate axis – stresses in the near-well array, and tensile stresses are fixed on the lower part of the ordinate, and compressive stresses are fixed on the upper part. Graphical dependences of $P_{max} = f(r)$ are shown for three values of P_{max} ($30 \times 10^4 H$, $35 \times 10^4 H$ H, $40 \times 10^4 H$).

The dotted line shows the tensile and compressive strength limits of the drilled rock

The nomogram (*Figure 5*) allows you to determine the required impulse force from the generator for the implementation of cracking, depending on the diameter of the borehole being drilled. For example, with a well radius of $r = 0.095\ m$, shock pulses of at least $P_{max} = (37\text{-}38) \times 10^6\ H$ are needed (considering that the tensile strength of rocks is significantly less than that of compression) [14].

The next step should be the process of opening the cracks that have formed, which are in a closed state. To do this, it is necessary to use the technology of hydraulic fracturing by injection under pressure of a two-phase flow.

In addition, by a given value, it is possible to determine the maximum diameter of the well at which cracking will occur in the angular zone of the face.

For example, the intersection of the inclined line $P_{max} = 40 \times 10^4\ H$ with the horizontal dotted line 1-1 allows us to conclude that the maximum diameter of the well will be $r \approx 0.098\ m$.

And finally, according to a given value, it is possible to recommend a type of hydraulic impact machine capable of implementing fracturing in the radial direction in a near-well array.

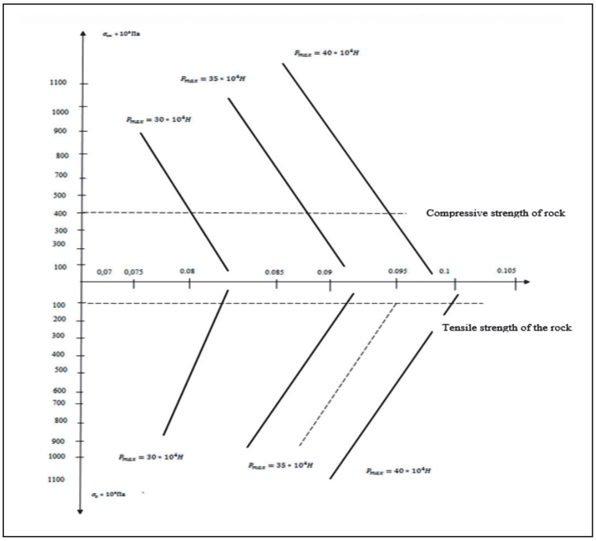

Figure 5 – **Nomogram for determining the maximum force of shock pulses of a hydraulic impact machine depending on the diameter of the well at which cracking occurs**

Conclusion. This article discusses the peculiarity of the impact-rotational drilling method using hydraulic shock systems. Based on reasonable assumptions, a model of the shock pulse transmission process was adopted, representing a cylindrical shell with a flat bottom, which simulates a bottom hole and an array adjacent to the walls of the well.

For the accepted process model, the problem of stress distribution in a horizontal near-well array is solved, considering the effect of pressure of overlying rock layers and drilling mud on its walls and bottom, as well as pressure at the bottom from pulsed loads transmitted by a shock pulse generator.

It is shown that the determining stresses causing cracking in the walls of the well are radial tensile stresses acting at the junction of the face with the walls of the well.

The obtained dependences on the stress distribution allowed us to construct a nomogram that allows us to determine the diameter of the well at which cracking occurs in the angular zones of the well, if the values of the maximum force of the shock pulses transmitted by the generator (hydraulic shock machine) are known, and, consequently, to determine the necessary parameters of the latter [15,16].

Gratitude. BR21881822 related «Development of technical solutions to optimize geological and technical operations during drilling and oil production at a late stage of field operation» according to Agreement No. 394-TFP-23-25 dated 11/15/2023 with the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

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