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INVESTIGATION OF THE CONTACT STRESSES ON THE END FACES OF THE DRILL PIPE CONNECTION THAT INCLUDES THE TAPERED THREAD MANUFACTURED BY THE CUTTER LATHE TOOL WITH THE SPECIALLY MODIFIED CUTTING EDGE

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Abstract: Drilling tool joints are being manufactured using technology of turning machining. The result of this technology is the existence of a screw-shaped gap. The value of the pressure drop in the medium of the drilling fluid depends on the size of cross-section of this gap. In the case of the initial stage of permeability because the small looseness between the face ends of the pin and box appear , the pressure drop between the start and end of the screw gap can be 10 times. If the thread is made by using of the specially-profiled cutter it is possible to achieve a reduction in the height of the across section of gap by three times. In this case, in condition of the initial loss of tightness the pressure drop in the screw gap can be 100 times. Therefore the contact pressure between the face ends of the pin and the box at a consider torque value in the tapered thread increases relative to the normal state of tightness. The magnitude of the contact pressure increase in the case of partial permeability can reach a value of 1-10%.
Keywords: contact pressure, turning, tapered thread, tightness

RELEVANCE OF THE PROBLEM

Tightness is one of the operational parameters of a drill string. A drilling mud solution is pumped inside a drill string under a pressure up to 10 - 20 MPa. Its purpose is to rinse the drill bit from the sludge and transport it from the depths to the surface of the ground. The drill string consists mainly of drill pipes which are connected by means of drilling tool joint which consist of box 1 and pin 2 (Figure 1). Quickly screwing of pin and a box is possible due to tapered thread.

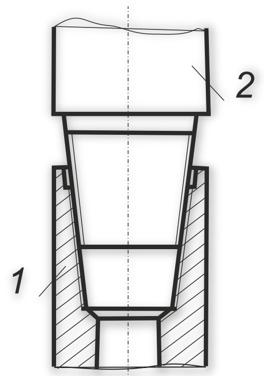

Figure 1. Scheme of drill tool joint.
Marking: 1– pin, 2 – box

The existence of a gap between the thread surfaces of the pin 1 and the box 2 (Figure 2) is on the obstacle of tightness ensuring. Due to the Interference fit screwing the box and the pin the process of tight closing of the face ends of the box 4 and the pin 5 with each other is provided (Figure 2). So the tightness is ensured by the quality of the face end manufacturing. It is because of the tight adjoining of these two ends of each other that avoiding the flow of the part of the drill solution from the inside tube to outwards is avoided. But thanks to the screw gap and deformation processes on the face ends that accompany the multiple process of screw driving of the drill pipes initially partial, and then the full depressurization of the connection occurs. Complete loss of tightness is the reason for replacing the drill pipe, or repairing of it.

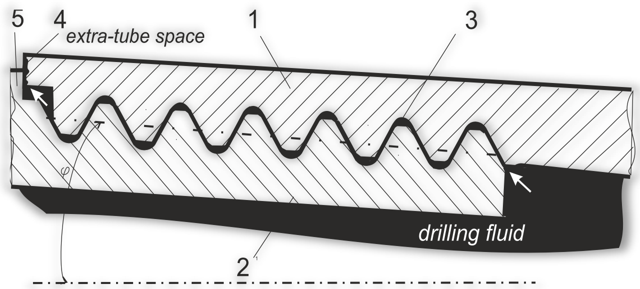

Figure 2. Scheme of screwing gap
in the drilling tool joint

Modern manufacturers of drilling tool joints use for it the process of turning [2]. Accordingly, the shape and size of the screw gaps must be provided by turning tool. In papers [3, 4] it is a question of the effect of the cross-sectional dimension of these gap channels on reducing the velocity of drilling mud solution in it during the first manifestations of permeability between the face ends of the pin and box. Decreasing the velocity may cause reducing of wearing on the thread surface because abrasive influence [4]. At that time, the operability of the drilling fluid which is the non-Newtonian fluid [5] may be such that, the pressure of the drilling mud in it can reduce if the cross-sectional dimension of the gap channel decreases. Therefore, it is important to determine the influence of the shape of the channel, and profile the cutting edge of the cutter to ensure the tightness and the value of contact pressure between the ends of the pin and box.

2. LITERATURE REVIEW

In the works [6, 7] the calculating of the moment of screwing of the drilling tool joint, taking into account the pressure of the drilling mud, acting both in the inner of the pipe itself and in the gap channel is offered. Figure 3 shows the scheme for creating the required contact pressure between the ends of the box 1 and the pin 2.

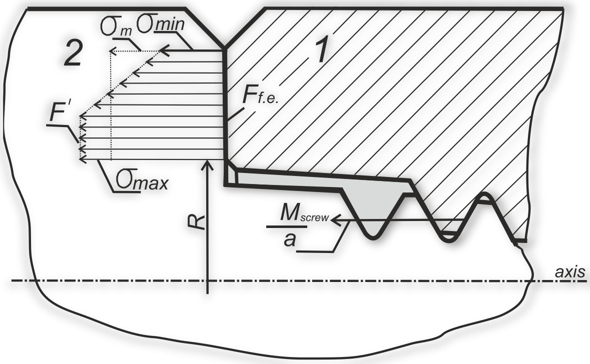

Figure 3. Scheme for determining the average contact pressure between the ends of the pin and the box in the screwed state of the drilling tool joint.

According to [6], the average contact pressure σ_m acting on the area $F_{f.e}$ must correspond to the equation (1):

$$\sigma_m = \frac{\frac{M_{screw}}{a} - \left(N + P_{m.s.} \cdot F_g\right)K_b}{F_{f.e.}}, \text{ (MPa)} \qquad (1)$$

where:

M_{screw} – torque of the pin and the box screwing (Nm);
σ_m – average contact pressure at the face ends (Pa);
F_g – the value of the thread gap section area (m^2);
$P_{m.s}$ – inside pressure of the mud solution (Pa);
N – external axial gravitational load (N);
a – constant value of the drilling tool joint, which takes into account the geometric dimensions of the tapered thread and screwing conditions (m).

If formula 1 is solved with respect to M_{screw} then it has the following form

$$M_{screw} = \left(\sigma_m F_{f.e.} + \left(N + P_{m.s.} \cdot F_g\right)K_b\right)a \text{ ,(kNm)}$$

In the works [7, 8], it is proposed that the torque of screwing be solved using a slightly different formula:

$$M_{screw} = \left(k \cdot \sigma_m F_{f.e.} + N \cdot K_b + \psi \cdot P_{m.s.} \cdot F_g\right) \cdot a \text{ , (kNm)} \qquad (2)$$

where:

$$a = 0{,}16 \cdot P + 0{,}5\mu'\left(D_p + 0{,}866 \cdot Dm\right) \text{ , (kNm)} \qquad (3)$$

P – pitch of thread;
D_p – mean diameter in a main plane of a tool joint;
D_m – mean diameter in a face end section;
μ′ – coefficient of friction at the thread surfaces, which is 0,09 for thread screwed with oil P-416, is 0,14 for covered thread and is 0, 3 for dry surface;
Ψ – coefficient of tightness of adjoining. According to [8] it should be taken ψ=1,5…3;
K_b – coefficient of external load of the drilling tool joint;
k – ratio of optimal tightening stresses and the boundary of fluidity of the connection material box which can be defined empirically [7, 8]. Figure 4 shows a graph for determining the coefficient k.

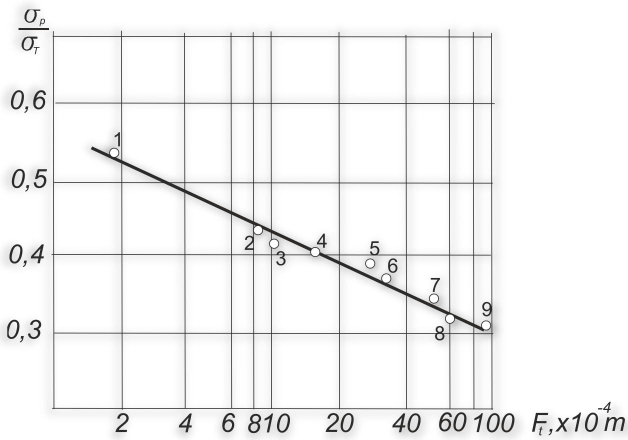

Figure 4. Definition diagram of the ratio of optimal tightening stresses and the boundary of fluidity of the connection material box

According to [7, 8, 9], the area of F_g and $F_{f.e}$ are calculated in cross-sections according to the scheme shown in Figure 5.

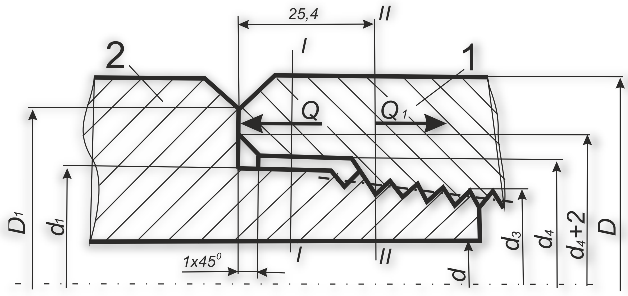

Figure 5. Scheme of the distribution of the clamping force components in the screwed state of the drill tool joint

So $F_{f.e}$ is the area near the face end of the box in the section I. The force Q acts in it. According to [7] Q is a component of formula 2:

$$Q = \sigma_m F_{f.e.} \text{ , (kN)} \qquad (4)$$

In this section, the area $F_{f.e}$ is defined by the formula:

$$F_{f.e.} = \frac{\left(D^2 - d_4^{\,2}\right) \cdot \pi}{4} \text{ ,(m}^2\text{)} \qquad (5)$$

Section II passes through the root of a pin which contacts with the first thread of the box. In this section papers [7, 9] suggest calculating the value of F_g according to the corresponding formulas. The component-force Q_1 acts in it. It in accordance to [7] is the element of formula 2:

$$Q_1 = N \cdot K_b + \psi \cdot P_{m.s.} \cdot F_g \text{ , (kNm),} \quad (6)$$

In this section, the area F_g is defined by the formula:

$$F_g = \frac{\left((d_1 - 2H)^2 - d^2\right) \cdot \pi}{4} \text{ (m}^2\text{),} \quad (7)$$

Reference [9] provides value on the data: a, F_g, F_{fe}, μ', K_b for various types of drilling tool joint.

The studies presented in [6, 7, 8, 9] take into consideration the effect of value $P_{m.s}$ on the magnitude of the torque of the M_{screw}. The specified value characterizes the internal hydrostatic pressure. It is thanks to it the pipes are tested for tightness using water or other liquid as a medium for transferring this pressure to all sides inside the drill string, including in the drilling tool joint. By the law of hydrostatics, the internal pressure of the liquid in the section I, section II and in the inner part of the pipe with the diameter d are the same. Thus, using the formulas 2, 3, 4, 5, 6, 7, it is possible to determine the value of the contact pressure at the box-pin face ends under conditions of complete tightness using the formula:

$$\sigma_m = \frac{\frac{M_{screw}}{a} - \left(N \cdot K_b + \psi \cdot P_{m.s.} \cdot F_g\right)K}{F_{f.e.}} \text{ , (KPa)} \quad (8)$$

However, in reality, the drilling fluid is not Newtonian fluid, which is water. This means that if the first signs of fluid leakage appear because of the non-tensions between the face ends of the box and the pin, then the laws of hydrodynamics come into force.

RESEARCH METHODOLOGY

— Simulation of the operability of the drilling fluid in the screw channel between the thread surfaces of the pin and the box

As in [3, 4], a virtual experiment to simulate the operability of a drill fluid is carried out in a Flow Simulation environment, under similar conditions for the tool joint tapered thread NC26:

- \# input and output of the channel are extended by rectilinear sections and finished with end faces for the possibility of creating virtual stubs LID1 and LID2;
- \# type of analysis is internal, since the working fluid is liquid and limited by the walls of the solid. The heat exchange is not taken into account, considering that the solid is cooled intensively by the flow of the solution through the central hole of the drill string and from the outside;
- \# parameters of the drilling solution: density 1200 kg/m³ and initial kinematic viscosity 10 sSt. The viscosity change characteristics are based on the Herschel-Balkley rheological model (Figure 6);
- \# the boundary conditions of the study are the pressure on the internal face of the input lid, equal to 10, or 5 MPa, and the pressure of the external medium (on the inner face of the initial cover), equal to atmospheric - 0,1 MPa;
- \# because the small size of the channel it is given rather high (the sixth in the gradation of automatic adjustment) the degree of split into the elements.
- \# the dimensions of the channel are applied as standard, and are executed with the help of a cutter, which makes it possible to reduce the cross-sectional area of the screw channel 2-3 times.

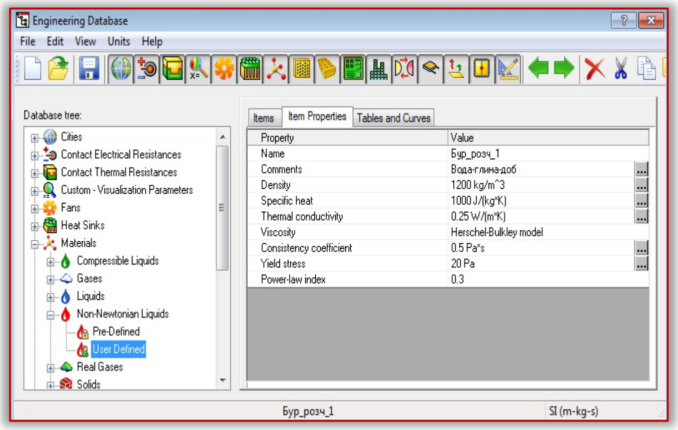

Figure 6. Fragment of the Float Simulation application with the parameters of the mud solution

RESEARCH RESULTS

The subject of the study in this experiment is the pressure. Figure 7 shows the diagram of the pressure distribution along the screw gap channel in the drilling tool joint with tapered thread NC26 in accordance to the standard API 7.

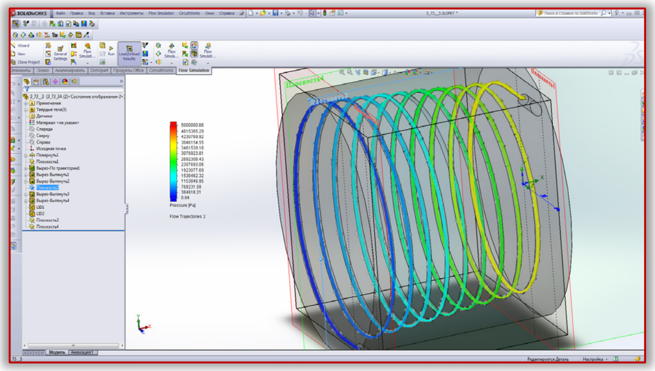

Figure 7. Distribution of pressure in a screw gap with a standard value of the cross-section

— Distribution of drilling fluid pressure in a channel with a cross section of normal size

Investigations show the absence of gaps in jets. Input pressure of central part of pipe 5 MPa due to a sharp decrease in cross-section of gap channel fells to 3.8 MPa. (yellow colour in the diagram). At the final thread (the largest diameter), the pressure dropped to a value of 0, 38 MPa. It indicates a pressure drop of 10 times in the process of flowing through the screw channel.

- **Distribution of drilling fluid pressure in a channel with a cross section of smaller size**

According to studies [10], the profile of the section can be obtained by lathe tool cutter in such a way that the working height of the profile h is greater than the usual one. Newly designed thread has the working height h *.

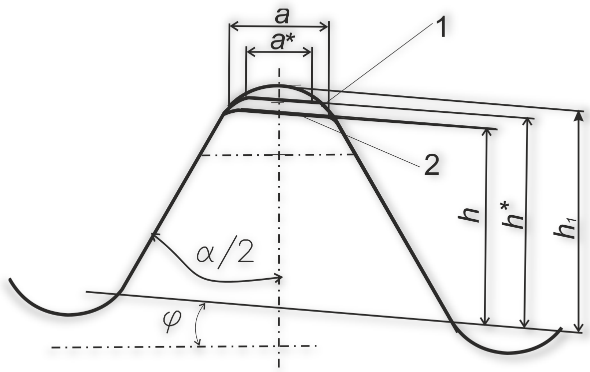

Figure 8. Scheme illustrating the technology of reducing the cross-sectional dimensions of the screw gap

Thus, the screw channel sharpened by means of a modernized profile cutter has root flat a_1 = 1mm. But usual cutter has standard size of root flat a = 1,65 mm. Figure 9 shows new small ABCD gap (gray colour) against the background of the old DEF gap (shaded). Thus, the technological gap is suggested to decrease by 0,328 mm, that is, from h_1 - h = 0,462 mm to h_1 - h * = 0,134 mm, which reduces the gap by 71% [11]. In this case δ=0,328 mm.

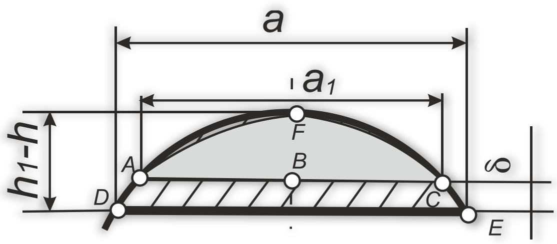

Figure 9. The exact scheme of reducing the cross-section of technological channel

Figure 10 shows a diagram of the distribution of pressure in a screw channel whose cross section is made as in Figure 9.

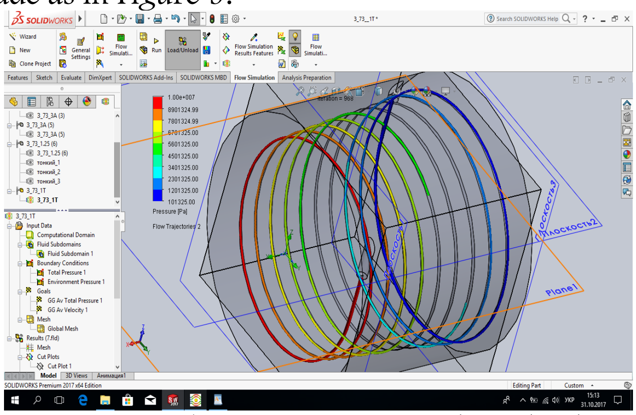

Figure 10. Distribution of pressure in the technological gap with a reduced cross-section

Investigations show the absence of gaps in jets. Input pressure of central part of pipe 10 MPa (red colour in the diagram) due to a sharp decrease in cross-section of gap channel fells to 0,1 MPa. (blue colour in the diagram). It indicates a pressure drop of 100 times in the process of flowing through the screw channel.

- **Design scheme for determining the clamping force of the ends of the box and the pin during initial loss of tightness**

According to studies of the distribution of pressure in the screw channel, which are illustrated by the diagrams in Figure 7 and 10, the authors suggest an alternative schema to the figure shown in Figure 5 for calculating the force of the clamping and contact pressure between the face ends of the pin and the box. Thus, in Figure 11, in addition to the figures 5 of the sections I and II, section III is also shown. This section passes through the plane of the smaller base of the pin. The first thread of the screw channel is located in it. According to the research in Figure 7 the last thread of the connection between the pin and box is placed in section II. Therefore, in the case of partial depressurization, the pressure in the drilling fluid between the planes I and II (grey medium in Figure 11) falls to 0,38 MPa and even to 0,1 MPa. Therefore, according to the authors, the component-force Q_1 in the section II is less than in the absence of the least depressurization, that is, in hydrostatic pressure conditions. [10]

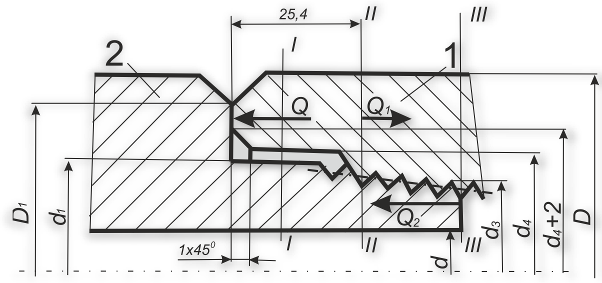

Figure 11. Scheme of distribution of clamping component-forces in screwed state of the drilling tool joint in the condition of partial depressurization

Instead, the hydrostatic pressure $P_{m.s}$ acting in the drilling solution effects on the inner end of the pin in the section III. It is the reason the component-force of Q_2 appears. It acts in the same direction as Q. It can be calculated by the formula:

$$Q_2 = \psi \cdot P_{m.s.} \cdot F_2 \text{ , (kN),} \qquad (9)$$

where: F_2 – area dimension of the smaller base of the pin. It can be calculated by the formula:

$$F_2 = \frac{\left((d_3 - 2H)^2 - d^2\right) \cdot \pi}{4} \text{ (m}^2\text{),} \qquad (10)$$

where: H – height of fundamental triangle of thread, mm.

Consequently, the contact pressure on the face end of the pin and box can be calculated by the formula:

$$\sigma_m = \frac{\frac{M_{screw}}{a} - (N \cdot K_b - \psi \cdot P_{m.s.} \cdot F_2)K}{F_{f.e.}}, \text{ (KPa)} \quad (11)$$

— **Examples of calculation of the value of the contact pressure for the pin-box face ends of the drilling tool joint of ZU108 in condition of hydrostatic pressure and in condition of the initial loss of tightness**

In the example, the reduced section of the screw gap is applied as in paragraph 3.2. Therefore component–force Q_1 is calculated without taking into consideration the action of the hydraulic pressure of 0.1 MPa in section II.

Table 1. Data for calculating the value of the contact pressure at the pin-box face ends of the drilling tool joint ZU 108

№	Name of dimension	Symbol of dimension	Value of dimension
1	Coefficient of tightness of adjoining	ψ	1,5
2	Coefficient of friction at the thread surfaces	μ'	0,14
3	Coefficient of external load of the drilling tool joint	K_b	0,64
4	Ratio of optimal tightening stresses and the boundary of fluidity of the connection material box	k	0,4
5	Constant value of the drilling tool joint, which takes into account the geometric dimensions of the tapered thread and screwing conditions (m)	a	0,0127
6	Torque of the pin and the box screwing (Nm x 10^3)	M_{screw}	20 or 6
7	Inside pressure of the mud solution (Pa x 10^6)	$P_{m.s}$	10
8	Area dimension of the smaller base of the pin (m^2 x 10^{-4})	F_2	8,91
9	External axial gravitation load (N x 10^4)	N	10
10	Minor diameter of a drilling tool joint (m x10^{-3})	d	54
11	Diameter of the minor base of the pin (m x10^{-3})	d_3	71,29
12	Major diameter of a drilling tool joint (m x10^{-3})	D	108
13	Diameter of a drilling tool joint in a face end section (m x10^{-3})	D_1	103,5
14	Diameter of the major base of the pin (m x10^{-3})	d_1	86,13
15	Inside diameter of a box in a face end section (m x10^{-3})	d_4	87,7
16	Height of fundamental triangle of thread (m x10^{-3})	H	5,487
17	Pitch of thread (m x10^{-3})	P	6,35
18	Area of the across section on the face end I_I (m^2 x 10^{-4})	$F_{f.e}$	32,6
19	Area of the across section on the first thread of a box II_II (m^2 x 10^{-4})	F_g	22.5

Table 1 summarizes all the necessary data for calculating the contact pressure in both full tightness and partial permeability conditions.

The datum row number 8 is calculated by the formula 10. Data rows No. 5, No. 18, No. 19 are derived from reference data [9] and can be calculated using formulas 3, 5, 7. Datum row №4 is derived from reference datum [9] and can be defined from Figure 4.

After substituting data from table 1 in formulas 8, 11, the following results are obtained:

At M_{screw} = 20 x 104 Nm, the contact pressure at the box-pin cross-section is 400 Pa x 10^6 (formula 8) in the case of full tightness and is 406 Pa x 10^6 (formula 11) in the case of partial permeability.

At M_{screw} = 6 x10^4 Nm, the contact pressure at the box-pin cross-section is 61,5 Pa x 10^6 (formula 8) in the case of full tightness and is 68 Pa x 10^6 (formula 11) in the case of partial permeability .

Consequently, the growth of contact pressure can be from 1.5% to 10.5%.

CONCLUSIONS

- Tapered thread is machined by turning tool. As a result this thread has a screw gap channel. Their across dimensions are dependent on profile of cutting edge. The value of the pressure drop inside of the drilling fluid in this gap depends on these dimensions. According to the hydrodynamic conditions in the medium of the drilling fluid, that is, if there is a slight permeability from the non-densities between the ends of the pin and the box face ends, the pressure drop in the screw gap channel may have 10 times the dimension. If to make the tapered thread using the tool with the special profile of the cutting edge, then it is possible to achieve a reduction in the height of the gap three times: from 0,460mm down to 0,140 mm. In this case, if there is also a slight permeability, then the pressure drop in the screw gap can be 100 times.
- Under normal hydrostatic conditions, the contact pressure between the ends of a pin and a box does not depend on the across dimension of the screw gap. In the event of an initial depressurization, the contact pressure at a consider torque value increases relative to the same pressure in hydrostatic conditions of the drilling solution. The magnitude of the this increase is 1,5 up to 10%.

Note:

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