Останнім часом велика увага приділяється організаційним заходам щодо підвищення якості продукції нафтового машинобудування, зокрема, впровадження систем менеджменту якості на базі стандартів ISO серії 9000. Проте не втратили своєї значимості технологічні методи забезпечення якості.

Розглянуто чинники, що впливають на якість циліндричної тонкостінної деталі в процесі експлуатації. Найбільш істотними факторами є зусилля, що діють на деталь в процесі її захоплення в затискному механізмі.

Проведено експерименти на дію навантажень на деталь, що затискають. Мета цих експериментів – встановлення впливу на напруги і деформації циліндричних тонкостінних деталей різних факторів. Основними факторами крім доданих сил є кут охоплення затискного елемента, довжина зіткнення його з деталлю, розподіл навантаження на зубцях затискного елемента.

З розвитком глибокого буріння і збільшенням навантажень, що діють на клинові захвати, зростають вимоги, що пред'являються до їх утримуючої здатності. Недостатня утримуюча здатність клинового захвату може призвести до пошкодження труби в місці затиску її клинами.

При цьому затискні зусилля діють в одній і тій же області труби, утворюючи стоншення шийки при тривалій експлуатації. Результатом таких пошкоджень є передчасний вихід бурильної труби з ладу і небезпека виникнення аварійної ситуації.

Істотний вплив на утримуючу здатність клинового захвату надають елементи його конструкції. Має значення також напружений стан бурильної труби, затиснутої в клиновому захваті. Розраховано оптимальні геометричні характеристики затискних губок. Найкращі показники дають рифлені губки з косою насічкою, що перехрещується. Розглянуто розподіл навантаження на зубцях затискних губок. Показано, що оптимальний розподіл навантаження на зубцях забезпечують губки з косою насічкою, що перехрещується. При цьому на 1-й зуб доводиться 26 % навантаження, на 2-й – 22 %, на 3-й – 19 %, на 4-й – 17 %, на 5-й – 16 %.

Результати отриманих даних дозволять внести такі зміни в конструкцію затискних пристроїв, які істотно підвищать їх утримуючу здатність і зменшать небезпеку виникнення аварійних ситуацій

Ключові слова: бурильні труби, клиновий захват, навантаження, напруги і деформації, утримуюча здатність

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STUDYING THE QUALITY OF DRILL PIPES CLAMPED IN A WEDGE CLAMP

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1. Introduction

A study [4] has shown that when fixing with grooved surfaces the estimation scheme to be considered should be the scheme of a uniformly distributed load. Based on this, the authors substantiated a possibility to apply the general theory of a cylindrical shell in order to calculate the displacements and stresses when pipes are fixed with rigid grooved jaws.

Of great importance for determining the magnitudes of displacements and stresses at different schemes of fixing pipes exposed to the action of the asymmetric and axisymmetric loads applied to a pipe is the character of dependence. Given this, it is a relevant task for oilfield engineering, oil and gas and other industries, to study those factors that influence the gripping capacity of clamping devices.

2. Literature review and problem statement

Paper [1] provides a guidance on the implementation of quality management systems based on the ISO 9000 series standards. Oil industry urgently needs to improve the quality of drilling equipment. This is due to large labor intensity and energy cost of oil extraction. Improving the quality of drilling equipment would make it possible to prolong the service life of pipes and avoid accidents [2]. However, in addition to organizational methods, of great importance is the technological methods to ensure quality.

Study [3] describes the design features of wedge clamps. However, the unresolved issues are related to damage to the body of a pipe from the clamping jaws with notched surface.

Work [4] reports results from studying the states of a pipe, sandwiched in a wedge clamp, under the action of the applied efforts. It has been shown that the main damage to a clamped pipe is due to the action of the clamping jaws. The unresolved issues are related to the unacceptable damage to a pipe arising in the process of repeated clamping, which could lead to an emergency. This is due to the action of a large number of factors affecting the state of a pipe.

Paper [5] addresses the influence of a drill pipe axis offset on its stressed state when it is clamped in a wedge clamp. It shows the kind of deformations that a pipe is exposed to during operation. It is noted that overcoming these difficulties requires a comprehensive study of all factors affecting the deformations and the stresses state of a drill pipe in the process of hoisting operations.

A study into the thin-walled cylindrical components using a drill pipe as an example is reported in work [6]. It gives an analysis of various factors affecting the stresses state of the cylinder under the action of external forces. However, the work lacks experimental data [7].

The gripping capacity of notched surfaces is characterized by a coefficient of adhesion whose values vary according to different sources. The adhesion coefficients in different mechanisms were investigated in [8]. The authors proposed methods to improve the coefficients of adhesion for clamping mechanisms by improving their structural elements. However, not all factors were taken into consideration.

A new design of notches at jaws, manufactured by a specialized technology, was proposed in [9] in order to improve the gripping capacity of clamping devices.

Standards by the American Petroleum Institute (API) [10] indicate that the cause for breaking drill pipes are most often the cuts of pipes by wedges. Deep cuts at the surface of drill locks and connecting ends are left by the teeth of jaws at automatic and mechanized drilling keys.

The result of deformations due to clamping forces when threading the casing and pump-compressor pipes and couplings are the continuous channels formed along the cone threads, which lead to a disruption in air tightness. Analysis of the causes of failure of steel drill pipes has revealed that approximately 75 % of all defected pipes were broken due to imperfections at wedge clamps and to exceeding the permissible loads on a pipe. There are many more examples of shortcomings in the calculation, design, and operation of clamping devices. Given this, it should be noted that improving the gripping capacity of wedge clamps represents a scientific and practical importance to the oil industry.

The gripping capacity of wedge clamps is associated with the magnitudes and the character of stresses and deformations that occur in the body of a pipe at the place it is clamped with wedges. The stressed state and deformations of the pipe clamped with wedges were explored in other works as well. A similar study was undertaken at the California Institute of Technology jointly with companies Varco and McEvoy (United States).

Those studies addressed the influence of design elements at wedge clamps on the stressed state of a pipe; they provide recommendations for the calculation of drilling strings considering the axial and transverse loads.

Paper [11] shows that drill pipes are exposed to abrasive wear at the friction of their outer surfaces against the walls of a borehole or a casing column. The result of such a wear is the thinned neck of a pipe, which at exceeding the permissible magnitude can cause an emergency. Together with the deformation due to clamping effort, this factor negatively affects quality of a pipe during operation.

Experiments in study [12] demonstrated that in a defective pipe the residual wall thickness of 6 mm is critical and contributes to the destruction of a pipe's material. The material at this place starts to work in the region of plastic deformation; the geometrical dimensions change, there is a risk of metal's destruction.

An analysis of the scientific literature reveals that the overall understanding of the mechanism of wedge clamps' operation is treated with certain differences. Little attention has been paid to the impact of design of the clamping jaws. Some issues were covered insufficiently in the publications. Therefore, identifying a possibility to improve the gripping capacity of wedge clamps, as well as clamping mechanisms with the grooved surfaces of clamping jaws in general, necessitates a more detailed research.

The need to undertake a given study has existed for a long time. However, neither the scientific and technical literature, nor industrial practice by leading enterprises could provide any information about similar studies in recent years.

3. The aim and objectives of the study

The aim of this work is to study the influence of structural elements in a wedge clamp on its gripping capacity. That would help reduce the damage to drill pipes during hoisting operations and could improve the gripping capacity of wedge clamps.

To accomplish the aim, the following tasks have been set:

– to investigate load distribution due to a shear force over the teeth of notches at clamp jaws with inner cylindrical surface;

– to explore the stressed state of a clamped pipe;

– to define the impact of structural elements in clamping jaws on the gripping capacity of the clamping mechanism.

4. Studying the factors influencing the quality of a drill pipe during operation

4. 1. Determining the permissible inclination angle of the helix line of oblique notch

A common structural element in clamping devices are the jaws with grooved inner surface. They accept the three types of load: axial load P, torque M_{tr}, and the axial load P and torque M_{tr}, at the same time.

When a part is clamped by jaws with an internal cylindrical surface at the inclination angle of their notch less than the permissible one, there occurs the screw movement of the clamped cylindrical part along its axis if one uses jaws with a notch in the same direction. To avoid this, we determined the permissible inclination angle of the oblique notch for cylindrical jaws in a wedge clamp:

$$\left[\frac{\xi}{2}\right] > \operatorname{arctg}\frac{\mu\cdot\sin\dfrac{\gamma_1+\gamma_2+2\varphi}{2}}{\left(\cos\dfrac{\gamma_2-\gamma_1}{2}+\mu\cdot\sin\dfrac{\gamma_2-\gamma_1}{2}\right)\sin\varphi}, \qquad (1)$$

where γ_1 and γ_2 are the angles of a notch tooth profile; $\varphi=\operatorname{arctg} f$, f is the coefficient of friction between the teeth of a notch and a pipe's material; $\varphi_1=\operatorname{arctg} f_1$, f_1 is the coefficient of friction between the guides of jaws and a clamping device; μ is a conditional adhesion coefficient.

A slip of the part in jaws can be avoided by using the mirror-arranged notches at opposite jaws, as well as by using jaws with oblique intersecting notch.

4. 2. Load distribution over the teeth of clamping jaws due to an axial effort

We studied the character of an axial load distribution due to an axial shear force over the teeth of notch at clamping jaws (Fig. 1).

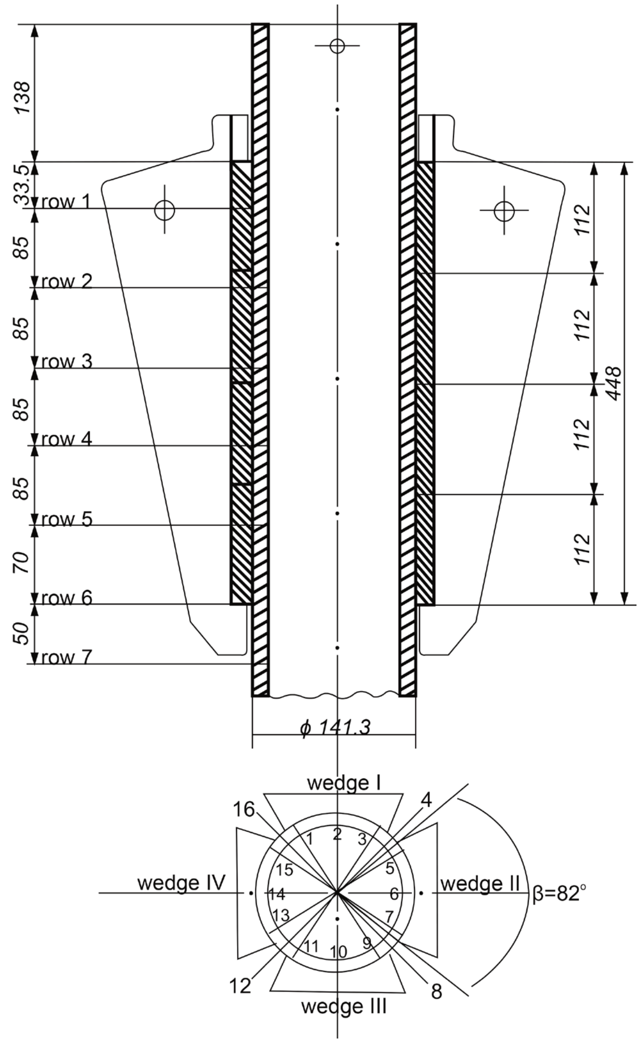

Fig. 1. Clamping a pipe at the wedge clamp

During operation of clamping devices, the axial load is distributed unevenly over the notch teeth. This affects the gripping capacity of clamping devices.

To investigate a load distribution, we used a scheme implying load distribution over the thread's turns [4]. The experiments were performed at a custom-made bench, equipped with hydraulic jacks. Results from the experiments are shown in Fig. 2. We investigated load distribution over the teeth of an asymmetrical profile of the straight, the straight intersecting, the oblique intersecting notches at jaws with an inner cylindrical surface.

For a finite number of teeth, the load N_i on any turn is determined from formula:

$$N_i=\left(\frac{V_m}{\sum\limits_{i+1}^{m}V_i}\cdot V_i-W_i\right)P, \qquad (2)$$

where P is the axial shear force;

$$W_i=W_{i-1}\left(1+\frac{\lambda}{\Delta}\right)+V_{i-2}\cdot\frac{\lambda}{\Delta}; \qquad (3)$$

$$V\ =V_{i-1}+W_i; \qquad (4)$$

$$V_0=V_1=1. \qquad (5)$$

Values for Δ_1 and λ_1 for the asymmetric straight notch are determined from formulae:

$$\Delta_1=\frac{1}{Gn}\left[\frac{k_1\cdot 180^\circ}{\pi\alpha\left(\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2\right)\left(R-H\right)}\times\ln\frac{\left(R-H+\dfrac{h}{2}+\dfrac{d}{\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2}\right)H}{\left(\dfrac{h}{2}+\dfrac{d}{\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2}\right)R}+\frac{h}{2F_1}\right], \qquad (6)$$

$$\lambda_1=\frac{t}{E}\left(\frac{1}{\omega_2}+\frac{1}{n\omega_1}\right), \qquad (7)$$

where d is the blunting of the notch tooth profile; ω_1 is the cross-sectional area of a jaw; ω_2 is the cross-sectional area of the clamped pipe; F is the area of the base of a part's protrusion; n is the number of jaws; E is the modulus of longitudinal elasticity; G is the shear modulus; k is a coefficient that accounts for the uneven distribution of tangential stresses.

Values for Δ_2 and λ_2 for the asymmetric straight intersecting notch are determined from formulae:

$$\Delta_2=\frac{1}{Gn}\left[\frac{k_2}{\left(\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2\right)^2}\cdot\frac{H-\left(\dfrac{h}{2}+\dfrac{d}{\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2}\right)}{H\left(\dfrac{h}{2}+\dfrac{d}{\mathrm{tg}\gamma_1+\mathrm{tg}\gamma_2}\right)}+\frac{h}{2F_2}\right], \qquad (8)$$

$$\lambda_2=\frac{a}{E}\left(\frac{1}{\omega_2}+\frac{1}{n\omega_1}\right), \qquad (9)$$

where $a=t$ is the step of notch in the direction of force P.

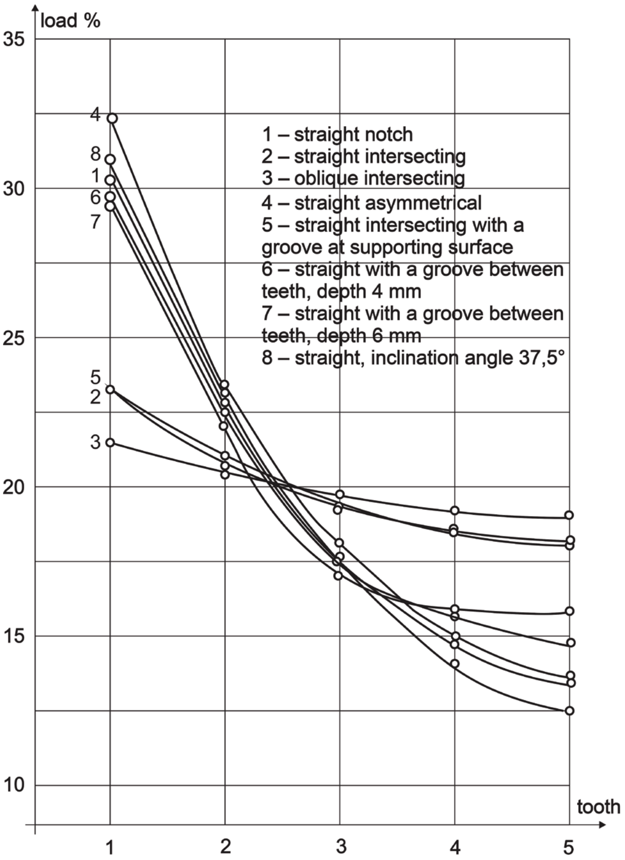

Fig. 2. Distribution diagram

For the asymmetric oblique intersecting notch, Δ_3 and λ_3 are determined as follows:

$$\Delta_3 = \frac{a}{bnG\cos\dfrac{\xi}{2}} \left[\frac{k_3 \sin\xi}{\left(\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2\right)^2} \times \frac{H - \left(\dfrac{h}{2} + \dfrac{d}{\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2}\right)}{H\left(\dfrac{h}{2} + \dfrac{d}{\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2}\right)} + \frac{h}{2F_3} \right], \qquad (10)$$

$$\lambda_3 = \frac{a}{E\sin\dfrac{\xi}{2}} \left(\frac{1}{\omega_2} + \frac{1}{n\omega_1} \right). \qquad (11)$$

We calculated variants for load distribution over the notch teeth for clamping jaws of different designs and different types of notches.

Specifically, at the optimal design of jaws with oblique intersecting notch the load is distributed as follows: tooth 1 – 26 %; tooth 2 – 22 %, tooth 3 – 19 %, tooth 4 – 17 %, tooth 5 – 16 %.

Other design options of jaws yield a worse load distribution over the teeth (Fig. 2).

1. In terms of the uniformity of load distribution, the types of notches are arranged in the following order, starting with the greatest uniformity:

– oblique intersecting=120°;
– straight intersecting;
– straight.

2. The load is distributed more evenly over the teeth of the symmetric profile.

3. The load is distributed more evenly at:

– an increase in the blunting angle of the notch tooth profile;
– an increase in the pitch and inclination angle of the notch.

4. A groove between teeth contributes to a more uniform distribution, with a deeper groove matched by a more uniform distribution.

5. Increasing the cross-sectional area of a jaw and a part improves the uniformity of load distribution over the teeth.

4. 3. Choosing the shape of a notch tooth depending on a material of the clamped part

The amount of residual contact deformations is affected by the shape of the notch tooth top, that is the magnitude of blunting. The choice of a blunting magnitude depends on the strength characteristics of a material of the clamped part. Underlying the calculation is the approximate energy method for determining the efforts that cause the plastic flow of metals.

We studied the penetration of a jaw's tooth into the body of a drill pipe with a diameter of 140 mm, sandwiched in a 4-wedge clamp. Full specific effort considering the friction will equal:

$$q_m = q_0\sqrt{1+2\mu}, \qquad (12)$$

where

$$q_0 = \frac{2.4\left|\tau_k\right|}{\mu},$$

μ is the coefficient of friction.

We determined the maximal deformations of the section of loading a pipe when it is clamped with smooth jaws and grooved jaws. Loading sections are divided into 7 rows vertically and 8 columns (Fig. 1). Results are shown in Tables 1, 2.

Table 1

Pipe deformation when it is clamped with smooth jaws

	W at *Q*=416.5 kN								*W* at *Q*=631.12 kN							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	6.7	4.8	5.2	5.4	4.9	5.4	5.0	5.2	5.4	5.6	4.4	6.0	5.1	4.9	5.1	5.0
2	79.2	63.4	79.4	64.7	76.2	65.1	77.3	61.7	117.4	86.1	114.7	90.3	116.1	90.1	115.4	84.2
3	77.3	62.9	78.3	64.2	79.4	62.7	76.1	63.1	113.2	91.4	115.1	88.1	116.2	89.3	117.5	90.4
4	78.9	60.3	80.1	66.3	81.7	63.2	77.9	64.2	115.2	88.2	116.0	86.3	117.1	87.4	114.9	86.1
5	76.1	59.0	77.6	65.1	79.3	59.7	78.2	64.0	113.9	87.3	116.7	84.2	114.1	86.0	118.0	88.7
6	72.4	60.7	75.3	60.9	76.1	61.2	75.9	65.2	110.3	85.6	111.4	90.2	115.9	91.1	112.3	87.9
7	5.5	5.0	5.1	5.7	6.1	4.9	4.7	5.1	5.6	5.0	6.7	4.9	5.2	6.9	5.3	5.4

Table 2

Pipe deformation when it is clamped with grooved jaws

	W, μm at *Q*=416.5 kN								*W*, μm at *Q*=631.12 kN							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	3.8	2.9	3.6	2.4	3.1	2.7	2.1	2.0	3.7	2.6	2.9	2.7	3.6	3.1	2.2	1.9
2	41.2	33.7	40.9	32.3	37.1	30.8	40.6	31.1	60.4	47.1	60.9	47.3	61.8	48.4	63.0	50.1
3	66.2	52.3	65.9	51.6	63.2	50.4	65.1	50.8	97.2	69.4	99.3	65.4	102.1	70.6	102.4	70.9
4	80.8	65.1	79.1	64.3	78.7	63.9	80.6	65.0	117.3	93.7	118.0	93.9	118.7	94.2	119.3	94.5
5	65.7	53.8	64.3	52.9	62.1	51.7	64.1	52.1	96.6	69.1	98.7	65.8	100.1	69.2	100.3	69.1
6	40.4	32.4	38.2	31.6	36.5	31.8	39.3	30.2	59.1	48.7	59.3	49.2	58.4	48.1	60.1	49.6
7	2.9	2.1	2.6	1.7	2.6	2.0	2.1	1.4	2.8	2.4	2.9	1.8	2.9	2.1	2.0	1.6

4. 4. Determining the deformations and stressed state of a pipe sandwiched in a wedge clamp

When holding a string of drill pipes by wedge clamps during hoisting operations the stresses at some points of the drill pipe exceed the yield stress, leading to plastic deformations. In this regard, studying the stresses and deformations when thin cylindrical parts are clamped in clamping mechanisms is of great practical importance.

The experiments were conducted to determine the impact of the following factors:

– the type of notch at clamping jaws on gripping capacity;

– the capture angle of a clamping jaw, the clamp length, that is the length of contact between a part and jaws, on the stressed state of the clamped part;

– the inclination angle of a wedge (for wedge mechanisms) on the deformation of a part;

– the design of a clamping jaw on the distribution of load over teeth.

At the experimental setup that imitated the process of a hoisting operation, a pipe branch was clamped with a self-clamping wedge mechanism via jaws I, II, III, IV with grooved surfaces.

Studying the stresses and deformations that occur at clamping the thin-walled cylindrical parts often employs strain measurements [7]. However, there are certain difficulties in the fabrication of a strain gauge for experimental studies at clamping long cylindrical components (exceeding 1,000 mm in length, a 120 mm bore diameter). These difficulties are related to the preparation of the inner surface of a pipe branch, which measures deformations; to the precise gluing of the large number of strain gauges; as well as to the construction of specialized equipment for a given process.

We have chosen the appropriate scheme for gluing the strain gauges at the inner surface of a sample (Fig. 3). We examined a pipe branch of a drill pipe of hardness grade E, a diameter of 141 mm and wall thickness Δ=10 mm, a length of 1,000 mm; strain gauges were glued at its inner surface along a length of 700 mm.

To determine the amount of longitudinal and transverse deformations, each point hosted two strain gauges. The inner surface of the pipe branch, over a length of 800 mm, was machined, to prepare the gluing, at an upgraded lathe cutting machine for deep cylindrical holes.

We selected foil strain gauges the type of FPKA (Russia) with a 10–100-ohm resistance. The gauges were mounted using stencils that formed vertical columns. We applied varnish VL 931 for gluing, which requires heat treatment. The pipe branch was heated to a temperature of 80 °C at a custom-made furnace, which is an asbestos cement pipe with a diameter of 240 mm. At the outer surface of the furnace there is a cut screw groove in which we laid a spiral made of a nichrome wire with a diameter of 1 mm (R=13 ohms, power P=3.5 kW).

To press the sensors to the surface with a force of 1–4 kG/cm^2 we used a rubber pipe with its ends tightly closed with caps, which was stuck in the pipe branch and filled with air through the nipple to 1.5 at. Further thermal treatment of the pipe branch and the rubber pipe was applied jointly.

We gradually increased the furnace temperature by changing the voltage at its terminals over one hour, to 70 °C, over four hours – to 140 °C. The pipe branch then cooled off along with the disabled furnace. After drying, the strain gauges were checked; we mounted output connectors at terminals RPZ-30 attached to the pipe branch. The sensors that are glued at each point are connected in half-shunts with their shared points connected.

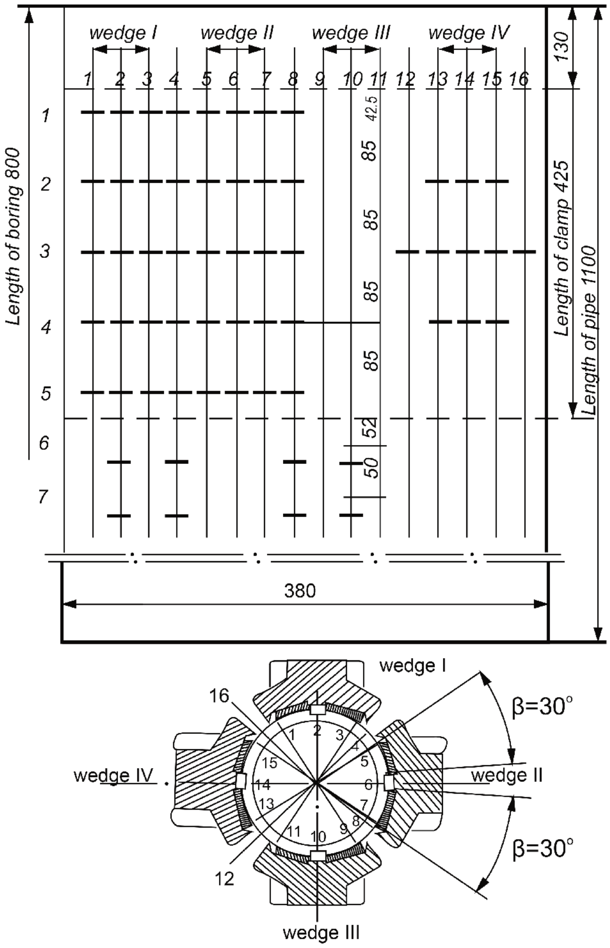

Fig. 3. Schematic showing the gluing of strain gauges

Readings from the strain gauges when loading the pipe branch at the experimental installation were acquired from the automated deformation measuring device AID-2M (Russia) via a 100-point switch. The results were treated using formulae:

$$\sigma_x = \frac{E}{1-\nu^2}\left(\varepsilon_x + \nu\varepsilon_y\right), \tag{13}$$

$$\sigma_y = \frac{E}{1-\nu^2}\left(\varepsilon_y + \nu\varepsilon_x\right), \tag{14}$$

where ε_x, ε_y is the relative deformation, recorded by the device, from the deformations of vertical and horizontal strain gauges, respectively; E is the modulus of longitudinal elasticity; ν is the Poisson's ratio.

At the experimental setup, the deformation meter was loaded with a radial clamping force 4Q to 700 tons and the axial stretching effort up to 120 t. The results were recorded and processed.

The proposed technology for the fabrication of the deformation meter ensures a 98 % reliable operation of the sensors while the experiment takes a minimum time to acquire a large number of measurements.

5. Discussion of results of studying the influence of various factors on the gripping capacity of the clamping mechanism

The results obtained relate to the fact that we studied the pipes that had defects resulting in unacceptable damage in the process of hoisting operations. Results of the study are given in Tables 1, 2 and shown in the diagram (Fig. 2).

Our study has made it possible to establish dependences for determining the magnitudes for deformations and stresses that occur in a pipe at different schemes of fixing it under the influence of the asymmetric and axisymmetric load applied to the pipe. These dependences are justified by the fact that during a long-term operation of pipes their deformations due to the action of clamping forces at the same places lead to the thinning of the pipe's neck. This factor increases the risk of an emergency resulting from the breakage of a column.

A feature of the drill pipe operation clamped in a wedge clamp is that in the process of hoisting operations the clamping efforts occur at the same section. This gradually leads to plastic deformations of this section and the formation of the thinned neck of the pipe that could lead to an emergency.

Special features of the proposed method for calculating load distribution over the teeth of a notch at clamping jaws are that it makes it possible to select such characteristics for the elements of clamping devices that would ensure their high gripping capacity.

Certain limitations of the current study are associated with labor-intensive industrial tests of new designs for clamping elements. The disadvantages of this work include the fact that the study involved the drill pipes only, although key findings could be applied to other types of pipes.

The current research could be advanced by applying the results obtained for pipes made from different kinds of materials and considering other types of loads.

6. Conclusions

1. It was established that the largest gripping capacity is demonstrated by jaws with oblique intersecting notch, whose fabrication required designing specialized tools. Our experiments have confirmed that an increase in the capture angle of clamping jaws reduces the stresses and deformations in a part. The application of a slope angle of the wedge of 12°, that is larger than the angle of friction, reduced the peak deformations in a pipe by 70 % while reducing the load by 21 %. This is because in this case the «self-installation» of the component of a clamping mechanism (the wedge) occurs throughout the entire period of clamping.
2. We have studied the stressed state of a clamped pipe. It has been shown that an increase in the cross-sectional area of the clamping jaw leads to a better distribution of loading over the teeth of a notch. We have clarified the character of distribution of the clamping force when clamping a thin-walled cylinder in a wedge clamp.
3. The influence of structural elements of the clamping jaws on the gripping capacity of a clamping mechanism has been defined. We have experimentally determined the impact of factors operating in the process of clamping a pipe in a wedge clamp on its gripping capacity. To conduct stress measurements, a technology has been devised for manufacturing a meter of deformations arising in a pipe under the influence of clamping and stretching efforts.

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