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IMPROVING THE RETENTION CAPACITY OF CLAMPING ELEMENTS

E. Afandiyev
PhD, Associate Professor*
E-mail: ertef4@gmail.com
M. Nuriyev
Doctor of Technical Sciences, Professor*
E-mail: mehman62@mail.ru
*Department of Standardization and Certification
Azerbaijan State University of Economics (UNEC)
Istiglaliyyat str., 6, Baku, Azerbaijan, AZ 1001

Аналіз відбракованих бурильних труб, які працювали в клинових захватах, показав, що основною причиною відбракування труб є зменшення стінки труби в результаті пластичних деформацій, через пошкодження поверхні труби зубцями плашок. При тривалому впливі навантажень відбуваються пластичні деформації циліндричних деталей, що може привести до неприпустимих пошкоджень і спотворень форми. У нафтовій промисловості при затиску бурильних і обсадних труб напруга на деяких ділянках в зоні захоплення перевершує границю текучості. При багаторазових затисканнях труби може відбутися зменшення стінки труби в області захвату, що призводить до передчасного виходу труби з ладу. Зминання труби відбувається не відразу при додавані навантаження, а поступово локальним пластичним деформуванням труби в різних точках по довжині та колу, де напруги перевершують границю текучості матеріалу труби. З метою запобігання неприпустимих деформацій труб в процесі пускооперацій були розглянуті можливості зменшення навантажень.

У зв'язку з цим особливу увагу було приділено конструкції затискних губок, що забезпечують підвищену утримуючу здатність, і технології їх виготовлення. Найбільшу утримуючу здатність забезпечують губки з косою рискою, що перехрещується. У таких губках зубці насічки розташовуються в «шаховому» порядку. Це дозволяє виключити утворення вертикальних канавок на тілі труби внаслідок проковзування її від осьового навантаження. Однак виготовлення таких насічок на внутрішній циліндричній поверхні затискних губок викликає певні труднощі. Це пов'язано з тим, що немає стандартних інструментів для виготовлення таких насічених поверхонь складної конфігурації. В результаті проведеного дослідження був сконструйований і виготовлений спеціальний інструмент, і розроблена технологія його виготовлення. Це дозволило полегшити процес нарізування на затискних губках насічок, що забезпечують надійний захват бурильних труб

Ключові слова: клиновий захват, бурильні труби, зусилля затиску, насічка губок, утримуюча здатність

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1. Introduction

During hoisting operations, drill pipes are repeatedly subjected to clamping efforts in the same region. At some points, the stresses of compression exceed the fluidity limit of the pipe metal. This causes local plastic deformations in the pipe capture area in the clamping mechanism. The consequence is the reduction of the pipe wall, which, in case of late rejection, leads to a danger of breaking the string of pipes.

In addition to clamping efforts, the emergence of deformations and stresses in a pipe is also affected by the shape and size of the elements in the clamping jaw notch. The largest retention capacity is demonstrated by clamping jaws with an oblique intersecting notch at the inner cylindrical surface.

It is a relevant task for machine building, oil and gas, and other industries to study the factors that affect the retention capacity of clamping devices.

2. Literature review and problem statement

The oil industry faces a constant need for improved drilling equipment. This is due to the high labor cost and energy intensity of oil production. Improving the quality of drilling equipment is aimed at extending its lifespan, in order to eliminate any possibility of an emergency. In this regard, the technological methods that ensure the quality of pipes are of great importance [1].

Paper [2] explores some of the design features of wedge grips, which are the most reliable devices for hoisting operations during wells drilling. However, no attention was paid to damage to the surface of the pipe by clamping jaws.

Work [3] shows that the damage to a pipe during hoisting operations occur largely due to the action of clamping jaws. The condition of the pipe is also influenced by a large number of factors, such as radial and axial loads, clamping force, column weight. It is shown that the evenest distribution of load on the teeth of clamping jaws is ensured by an oblique intersecting notch, which provides for a high retention capacity of clamping devices.

Studies [4–6] show the deformations that a pipe is exposed to during operation. It follows that in order to improve the retention capacity of clamping mechanisms, a comprehensive study of all the factors acting on the deformation of the drill pipe during hoisting operations is necessary. The authors considered the external factors acting on the stressed state of a cylindrical component. Grip ratios in clamping devices were analyzed. The authors proposed methods to improve the design of their elements in order to increase grip ratios. However, it is not possible to take all factors into consideration.

A study of clamping mechanisms involving drill pipes was also reported by the American Petroleum Institute (API) [4]. API standards indicate that drill pipe deformations are caused by cuts on their surfaces left by the teeth of dies from wedge grips or drill wrenches.

The stresses and deformations of oilfield pipes in the clamping mechanisms were also investigated in papers [7, 8].

All the cited studies addressed the effect of clamping device design elements on the stressed state and deformation of the pipe and provided recommendations to improve their design in order to enhance retention capacity.

It should be noted that drill pipes are operated under long-term stresses, which are close to the limit of fluidity. This could cause the material creep processes that are not currently included in the estimations of drill pipes. The result is the plastic deformations of a pipe wall and a decrease in its retention capacity. The processes of material creep could also be a consequence of the relaxation of stresses under long-term exposure to high-magnitude stresses. These processes were considered in work [9].

The technical literature practically lacks the dependences for engineering calculations and analysis of the loading schemes for the thin-walled cylindrical parts that are most common to clamping devices, as well as other components and structures analogous to them. Insufficient attention has been paid in the literature to recommendations for reducing stresses and deformations when fixing these components [10]. Therefore, it is an important task to tackle the issues on improving the retention capacity of clamping mechanisms in general and wedge grips with ribbed surfaces of clamping jaws in particular.

3. The aim and objectives of the study

The aim of this study is to improve the design of the wedge grip clamping jaws to enhance their retention capacity. The use of clamping jaws (dies) with an oblique intersecting notch produces the greatest effect compared to other types of notches. Their application would make it possible to reduce damage to drill pipes during operations in wedge grips. That would decrease the risk of accidents at hoisting operations, as well as other drilling operations.

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

– to devise, based on the proposed tools, a technology for cutting the teeth of the notch for clamping jaws whose inner surface is cylindrical, which have the greatest retention capacity;

– to determine the mechanism of operation of ribbed surfaces, taking into consideration their geometric features.

4. Patterns in cutting an oblique intersecting notch on jaws with an inner cylindrical surface

4. 1. The tool and technology of notch cutting

The best indicators of retention capacity are demonstrated by ribbed jaws with an oblique intersecting notch. However, the use of jaws with an internal cylindrical surface that have such a notch is constrained by the technological difficulties of making them. Existing methods for cutting the notch on round jaws are either unacceptable for an oblique cross-cutting notch or unproductive and require specialized equipment.

Given this, we have proposed a method for cutting the cross-cutting notch on jaws with an inner cylindrical surface using a specially designed tool [11]. Under this method, the oblique intersecting notch is cut at turning machines applying a specialized high-performance tool. A schematic of making this tool is shown in Fig. 1.

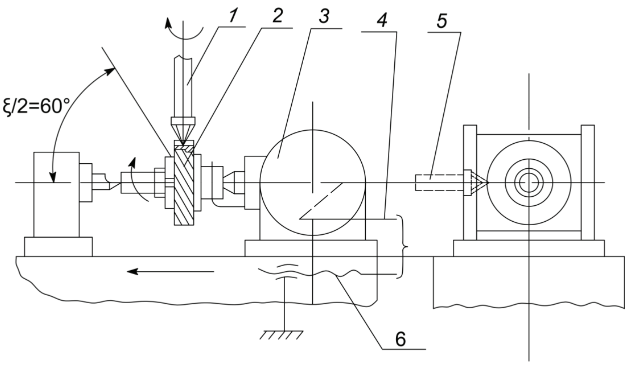

Fig. 1. Schematic of making the tool: 1 — cutter, 2 — disk, 3, 4 — elements of the machine, 5 — side view, 6 — running screw

The tool is made in the form of two disks, equipped with screw teeth. All grooves of the notch of the same direction are machined at the same tool configuration, obtaining the full profile of the notch over 4–5 runs. Two sets of cutting disks with the right and left direction of the grooves (Fig. 2) are used to cut the oblique intersecting notch. The cutting disks are fixed on the mandrel with dowels and nuts. Between the disks, the distance rings are arranged, providing an angular shift of the disks to half a step of the profile of their teeth. Therefore, the step of the profile of the disk teeth is twice the step of the profile of the notch being cut. This improves the technology of the tool manufacture, as well as its durability, due to the possibility of multiple sharpening.

The initial data for calculating the geometry of the tool are the following parameters of the clamping jaws:

1) diameter of the inner surface equal to the diameter of the clamped part D;

2) a notch step in the normal section t;

3) half the angle of the profile of the notch tooth γ;

4) the lift angle of the screw line $\xi/2$.

The following characteristics of the tool are determined:

– the number of tool teeth:

$$z = \frac{180}{\pi\alpha},$$

where α is the center angle is between the top and the base of the tool tooth in the end-face cross-section;

– the outer diameter of the tool D:

$$D_o = D + 2h,$$

where h is the height of the tooth notch;

– the height of the tool tooth h_t:

$$h_t \geq h + 2;$$

– half the angle of the tool's tooth profile:

$$\gamma' = \gamma - \alpha,$$

where

$$\alpha = \arcsin \frac{i}{D};$$

– a step of the screw line along which the machine is set:

$$T = \pi D \operatorname{ctg} \frac{\xi}{2}.$$

Based on the specified procedure, we have calculated and fabricated a tool to cut the notch on dies «140» in wedge grips, the type of PKR.

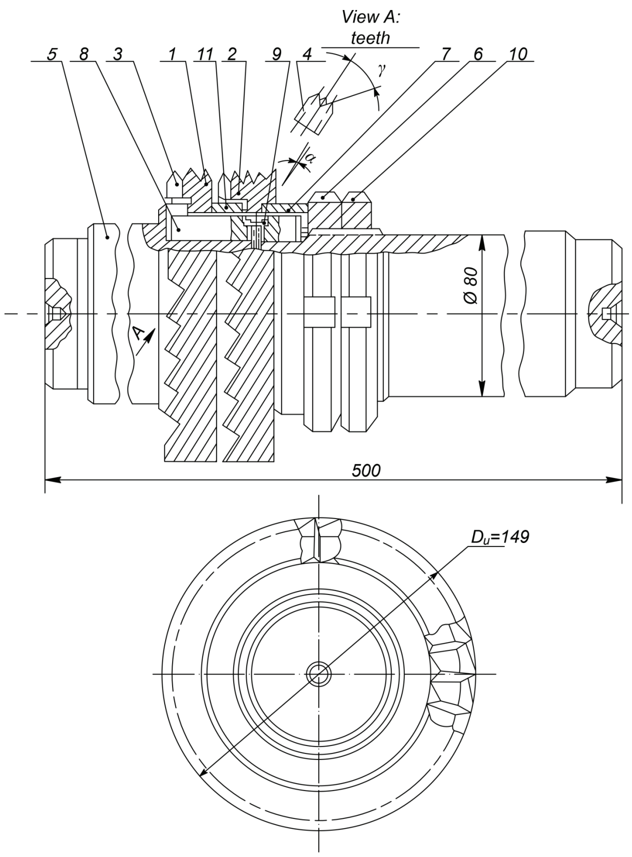

Fig. 2. A tool for cutting the teeth in clamping jaws with an oblique intersecting notch

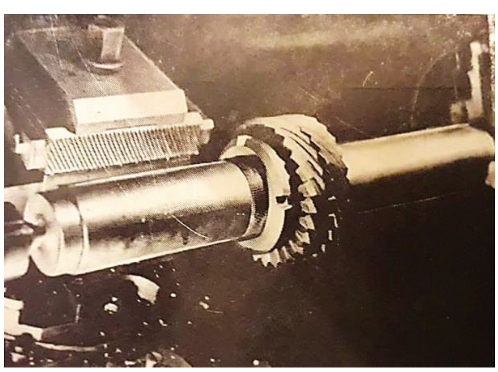

Fig. 3. A tool to cut oblique intersecting notches

4. 2. Analysis of the accuracy of notch cutting

When calculating, designing, and operating clamping devices, making them more durable requires the consideration of a combination of factors that determine the retention capacity of the clamping devices.

The retention capacity refers to the qualitative characteristic of the properties of clamping devices, meeting the requirements of the technological process, and determined by a set of influencing factors. These factors include a grip ratio, a base layout, structure of the working surface of clamping elements, the design of the notch at the ribbed surface of jaws, etc.

The operation of clamping devices with ribbed clamping jaws is conditionally divided into two stages: the introduction of notch teeth into the material of the fixed part under the influence of the clamping force, and the attachment to the fixed part of the shifting force, which seeks to move it relative to the jaws. To test the technological capabilities of the proposed method and to calculate the accuracy of the elements in the designed tool, we analyzed the accuracy of cutting an oblique intersecting notch at the cylindrical working surface of jaws in a pneumatic PKR-type wedge grip.

Among the elements of the notch on a clamping jaw, the main effect on its retention capacity is exerted by the height of the teeth of the notch and the amount of their blunting. Therefore, the accuracy in the execution of these parameters of the notch determines the accuracy of the technological process of cutting an oblique notch.

There is a functional relationship between the width of the blunting area of the tooth notch d and the height of the tooth h (Fig. 3):

$$d = t - 2h\operatorname{tg}\gamma,$$

where t is the step of the notch.

In this regard, all technological factors that affect the accuracy of obtaining the predefined height of the tooth affect at the same time the accuracy of obtaining the width of the blunt area. Errors in the step and angle of the tool's teeth profile, due to the inaccuracy of the manufacture and the inaccuracy of the mutual arrangement of cutting disks on the mandrel, affect only the accuracy of the size of the blunting area in the notch teeth.

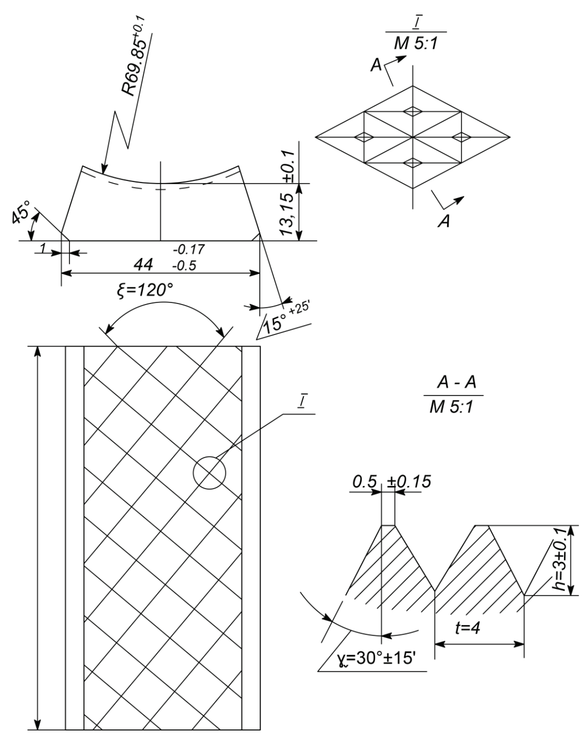

Fig. 4. Sketch of a clamping jaw with an oblique intersecting notch

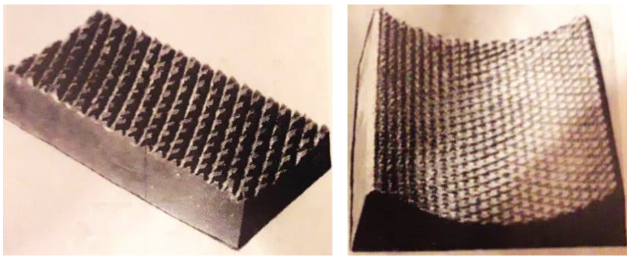

Fig. 5. Clamping jaws (dies) with an oblique intersecting notch

The technological factors that characterize the process underlie the calculation of the cutting accuracy of an oblique intersecting notch. We have estimated the magnitudes of the primary errors caused by these factors, as well as the total error in the execution of the height of the notch tooth and the width of the blunting area.

An analysis of the accuracy of mechanical machining of jaws with an oblique intersecting notch has revealed that the proposed technology ensures the accuracy of the height and width of the area of the notch tooth within the tolerances for these sizes.

We have investigated the distribution of load over the teeth of the oblique intersecting notch of jaws with an inner cylindrical surface.

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

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

where P is the axial shifting force;

$$W_1 = W_{i-1}\left(1 + \frac{\lambda}{\Delta}\right) + V_{i-2} \cdot \frac{\lambda}{\Delta}; \quad (2)$$

$$V = V_{i-1} + W_i; \quad (3)$$

$$V_0 = V_1 = 1.$$

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

$$\Delta_3 = \frac{a}{bnG\cos\frac{\xi}{2}} \left[\begin{array}{l} \dfrac{k_3 \sin\xi}{(\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2)^2} \times \\ \times \dfrac{H - \left(\dfrac{h}{2} + \dfrac{d}{\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2}\right)}{H\left(\dfrac{h}{2} + \dfrac{d}{\mathrm{tg}\gamma_1 + \mathrm{tg}\gamma_2}\right)} + \dfrac{h}{2F_3} \end{array} \right], \quad (4)$$

$$\lambda_3 = \frac{a}{E\sin\frac{\xi}{2}} \left(\frac{1}{\omega_2} + \frac{1}{n\omega_1} \right), \quad (5)$$

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

The method and the tool for cutting an oblique intersecting notch were tested when cutting notches on the dies of a wedge grip, the type of PKR. These dies were successfully tested at a bench and industrially at the Sangachal Drilling Authority (Baku, Azerbaijan Republic). The experiments were conducted at a specially made bench equipped with hydraulic jacks, imitating the operation of a wedge grip. We examined the branch pipe of a drill pipe, *E* strength group, with a diameter of 141 mm and a thickness of the wall of 10 mm and a length of 1,000 mm. The pipe was exposed to the radial clamping force of up to 700 tons and the axial stretching effort up to 120 tons. Among jaws with different types of notches, the best result in terms of the uniform load distribution was demonstrated by jaws with an oblique intersecting notch.

5. Discussion of results of studying the tool and technology for cutting an oblique intersecting notch

A special feature of the drill pipe, sandwiched in a wedge grip, is that during hoisting operations the clamping efforts fall in the same region. This gradually leads to the plastic deformations of this region and the formation of a thinning cervix of the pipe, which could lead to an emergency. Therefore, the use of ribbed jaws with an oblique intersecting notch that have the best retention capacity could reduce the peak deformations of a clamped sample by 30–50 % while reducing the load by 23 % [3].

Our calculations of the load distribution over the teeth of the notch, (1) to (5), showed that the evenest distribution occurs over the teeth in the oblique intersecting notch.

The complexity of the design of clamping jaws with an oblique intersecting notch is predetermined by the impossibility of making it using existing standard methods and tools. Given that the ribbed jaws with an oblique intersecting notch provide the greatest retention capacity during hoisting operations, their use would increase the time of failure-free operation of drill pipes by 10–12 %, as well as reduce slippage at clamping that forms scratches.

Even though our study was limited to drill pipes, the main findings could be applied to other types of cylindrical parts. In particular, such cylindrical components as casings, sleeves, barrels, etc.

The solution to the task of improving the retention capacity of clamping mechanisms is in the field of improving the elements of clamping mechanisms, in particular, ribbed jaws. To a certain extent, this is facilitated by the use of dies with an oblique intersecting notch. However, it has not yet been possible to industrially produce such dies due to organizational and resource constraints.

The current study could be further advanced by taking into consideration other types of loads and different pipe materials.

6. Conclusions

1. In order to improve the elements of the clamping mechanism design, which would reduce damage to drill pipes due to the action of clamping efforts during hoisting operations and increase their retention capacity, the tool and the technology for cutting the notch teeth of the clamping jaws with an inner cylindrical surface have been devised. Such a design, implemented by using the proposed tool and the cutting technology, demonstrates the greatest retention capacity. The technology of making such jaws has been

developed for standard metal cutting equipment; and a batch of such jaws has been produced, which passed bench and industrial tests.

2. We have investigated the operational mechanism of the ribbed surfaces of clamping jaws taking into consideration their geometric features. It implies that when a pipe is clamped the tooth of the notch penetrates the body of the pipe causing plastic deformation. When the same section of the pipe is repeatedly clamped, its wall decreases as a result of the deformation. The so-called «thinned neck» is thereby formed, which could lead to an emergency if the pipe is in operation for a long time. Our analysis of the accuracy of mechanical machining of jaws with an oblique intersecting notch has revealed that the proposed technology ensures the accuracy of the height and width of the area of the tooth notch within the tolerances for these sizes.

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