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IMPROVING RELIABILITY OF DRILL PIPE BY STRENGTHENING OF THREAD CONNECTIONS OF ITS ELEMENTS

It is recommended to include surface strengthening by plastic deformation into technological process of manufacturing boring pipes and nipples connecting them, which are made of 40XH steel. The main task of this strengthening operation is redistribution of technological tensile stresses in the material of thread roots, surface strengthening of the metal in the thread roots and formation of compression stresses in the metal, which are able to resist working stresses. The analysis of existing methods of surface plastic deformation showed that the only suitable method for qualitative treatment of thread roots is the method of vibrational-centrifugal strengthening. This method belongs to the group of dynamic methods of surface plastic deformation (SPD) and provision of high level of energy of metal deformation of strengthened part metal is its peculiar feature and advantage.

Purpose. Development of the method of vibrational-centrifugal strengthening suitable for qualitative strengthening of thread surfaces, its adaptation to strengthening the outer taper thread, definition of the key technological parameters of strengthening treatment. The main tasks of the research were development and production of strengthening appliances suitable for strengthening the taper thread, functioning on the fundamental principles of vibrational-centrifugal treatment. Development of schematics of original, out of standard vibration machines for strengthening the outer taper thread of boring pipes and nipples connecting them.

Methodology. Based on the theory of statistical similarity of fatigue failure, methods are proposed for defining mass reduction and materials consumption of cylinders as a result of efficient strengthening of their inner and outer cylindrical surfaces by means of vibrational-centrifugal treatment.

Findings. As a basis of the structure of the developed appliances for strengthening thread roots of taper thread, there is taken provision of dynamic impact interaction of deformable rollers; whose shape is similar to the thread root profile, through rolling of a massive roller. Due to a small area of contact of a deformable roller with thread root material and large values of deforming centrifugal force developed by the moving roller, the thread root metal is peened reliably and, most importantly, compression stress develops in it.

Originality. For the first time, highly efficient equipment for dynamic strengthening of thread surfaces has been developed which knows no equals in strengthening treatment internationally.

Practical value. The practical value is in improving reliability of drill pipes due to enhancing material strength of thread connections of their elements. Industrial implementation of vibrational-centrifugal strengthening treatment of thread elements of drill pipes, according to the authors, will decrease the number of cases of destruction of pipe constituents, which will contribute to decreasing repair and servicing time for drilling equipment, and will increase the borehole drilling rate.

Keywords: *boring pipe, nipple, taper thread, thread roots, metal, strengthening, plastic deformation, vibrational-centrifugal treatment*

Introduction. Many years' experience of drilling exploration and oil and gas producing wells as well as gained experience of operating rock drilling equipment and gear provides strong evidence of the fact that the major cause of drill-string failure is the failure (fracture) of thread connections of its constituent elements. Drill pipes of the string are connected through coupling adapters in the form of collars and nipples, on both ends of which there are placed threaded sections. Being a connecting thread in drill pipes, a taper thread with a

special section and curvature of a thread root is used. The drill pipe being used, the taper thread elements of boring pipes and coupling adapters are subjected to severe abrasion conditioned by repetitive make-up and break-out during replacement of drilling equipment. Moreover, when being in use, thread element metal is affected by tensile force from the total weight of the drill pipe, torsional force of the material conditioned by torque transmission from the drive power unit to the drilling equipment as well as by shock cyclic torsion loads at the starting and despinning of the drill pipe. While the smooth cylindrical surface of boring pipes as drilling pipe components bearing no stress concentrators reacts to operational load more

or less uniformly, the material of their thread elements is under much worse conditions. This is due to the fact that every coil of the thread surface at a site of its root actually acts as a stress concentrator. The repetitive shock loads at the starting and de-spinning of the drill pipe as well as strokes at drilling equipment entering the solid bed are taken by the thread coil material as shock alternate cyclic loads which condition initiation of fatigue micro-cracks at thread roots. Coalescence of micro-cracks results in a fatigue crack which intensively grows in size. Having undergone the period of origination, growing and critical size the fatigue crack damages the material density across the cross-section of the thread surface, that is there occurs a transverse fracture of the thread section of a boring pipe or a jointing nipple. At the same time, the fracture mainly occurs at the first-third starting coils of the maximum diameter of the outer thread surface. Predominantly, fractures and destructions of taper thread parts of boring pipes and their nipples occur at the stages of make-up and break-out of drill pipe elements on the drilling rig (Fig. 1). In this case, the pair of the boring pipe and tool joint with a broken threaded part is withdrawn from the drill pipe, replaced by other undamaged elements, and the drilling rig continues its operation.

The situation is much worse if the fracture of the taper thread section or nipple occurs in the drilled rock mass. Most frequently, this occurs at deep-hole drilling and while penetrating in hard rock stratum. The operation of the drilling rig is ceased for a protracted period of time until the broken section of drill pipe is seized with special catching devices and is drawn to the surface. Actually, this is an emergency situation at the drilling rig which takes much time and many resources to deal with. There have been occasions when due to inability to seize and raise up a broken section of the drill pipe, well-drilling had to be started again at a different site.

Boring pipes are made from hot-rolled mill products of carbon or structural alloy steel of two kinds, namely, the so-called ends upset for cutting connecting thread and weld-on connecting ends. The connecting ends are welded to the pipes with external upset to their ends using contact welding. The outer surface of weld seam after being cleaned from slag is given strengthening treatment through rolling. Thread sections (endings) of boring pipes and their tool joints and crossover joints are mostly made of alloy-treated steels of 38XHM, 36Г2С, 35ХГ2СВ brands by stamping with further mechanical operation, including cutting thread. To improve mechanical properties of the material, these details are tempered. Finally, after shape-generating cutting and final fit-out hardening operations in the thread surface material, particularly, in thread roots, technological residual tensile stresses develop. The above-mentioned operational loads on the thread surface of boring pipes and their connecting elements are also directed at extension of the surface layers of the material, i.e. they promote tensile stresses. Synergizing, technological and working

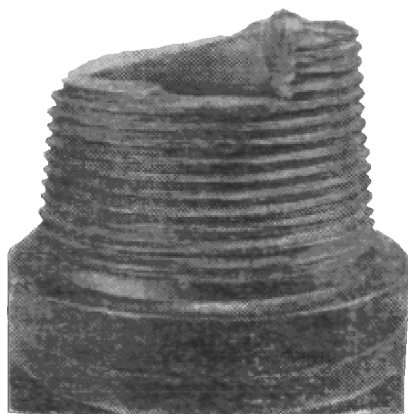


Fig. 1. A typical example of destruction of threaded part of a boring pipe, nipple or crossover joint

tension stresses, having acquired certain critical values, can contribute to appearance and further growth of micro-tracks. As mentioned above, micro-tracks can develop into fatigue cracks, which, in turn, promote destruction of the thread section of the boring pipe or its connecting elements.

To prevent formation of fatigue micro-cracks in the thread section material, at the closing stages of producing these parts it is necessary to introduce a technological operation which will provide formation of compression stresses in the root material of taper thread. Moreover, the gradient is so high that they will be able not only to level all prior technological tension stresses, but also to compensate stresses of operational loads.

Literature review. Among technological final fit-out operations which are capable of forming compression stress within the material of the processed part, the most relevant for processing thread roots are surface plastic deformations (SPD). Moreover, these are not shape-generating methods of SPD type of rolling or smoothing [1], but dynamic methods of strengthening which feature a high degree of the energy of distortion of the processed part material. Excellent exponents of these dynamic SPD methods are stamping, shock-vibrating machining and shot peening. However, regarding the strengthening of taper thread roots, none of the strengthening operations above has found its industrial application. Stamping appeared to be of little efficiency for such a general part as boring pipes. In shock-vibrating machining and shot peening, the energy of distortion of the processed part material is restricted by the speed and mass of deformable bodies (balls and beads) [2, 3]. Since in boring pipes and their connecting elements taper thread roots with a small rounded radius are to be strengthened, deformable bodies cannot get into the root of the thread surface and perform an effective impact action. The application of methods of heat and thermochemical strengthening with the use of high-frequency current also appeared to be insufficient for strengthening the material in thread roots. Here, the problem is related to difficulty in providing uniform heating of crests and roots of thread surface as well as to considerable energy consumption of hardening operation [4, 5]. Therefore, it must be admitted that nowadays we lack both the technology and the proper equipment to apply it, which can reliably strengthen the material of thread roots of boring pipes and their connecting elements with the purpose of reducing the risk of boring pipe destruction to a minimum.

Purpose. The purpose of the research is to develop the technological process and proper equipment to implement it for reliable strengthening of the outer thread surface of boring pipes and their connecting elements to enhance material strength of these parts and increase reliability of connecting taper thread of the elements of drill pipes.

The tasks of the study involved the following stages:

- analysis of operation loads and reasons of destruction of connecting thread of a drill pipe;
- analysis of modern technological processes of enhancing strength characteristics of the material of connecting thread of boring pipes;
- development of the technological process of surface strengthening of thread elements of boring pipes and their connecting nipples and crossover joints;
- development of schematics of the equipment for surface strengthening of thread roots of boring pipes as well as nipples and crossover joints for connecting them;
- experimental studies on efficiency of the process of vibrational-centrifugal strengthening of thread elements of drill pipes.

Results. The analysis of the influence of operation loads on drill pipe elements, the pattern of failure and destruction of their parts strongly suggests that roots of first coils of the outer taper threads of connecting elements bear the greatest load and, thus, are the most hazardous elements for destruction of a drill pipe. Moreover, both the outer thread surface on boring

pipes themselves and that on connecting nipples are in the same operation conditions and are equally prone to failure. Thus, to enhance the reliability of a drill pipe, it is necessary to strengthen the outer layer of metal in roots of taper thread and taper tool-joint thread as well as to provide formation of residual compressive stress within the strengthened metal. The latter is to resist destructive working tensile stress [6].

Methods of surface plastic deformation feature this capacity. However, as mentioned above, none of the known techniques is efficient for being applied to strengthen thread surface of drill pipes.

Considering this fact, researchers of Lviv Polytechnic National University have developed a new method of surface strengthening using vibrational-centrifugal treatment, which appeared to be highly efficient both for strengthening treatment of smooth cylindrical and taper surfaces and for various structural part components, including those with radius blends and thread roots. First, its efficiency was shown while strengthening wheel hubs and flanges of aeroplanes; their life duration doubled compared to their unstrengthened counterparts. There were developed schematics of the equipment for strengthening the outer surface of boring pipes as well as the outer and inner surfaces of casing pipes using vibrational-centrifugal treatment; the purpose of the development was to increase the strength and reliability and to decrease their weight [8]. However, the fact that all the equipment and facilities to implement this method are ad-hoc ones and involve developing new strengthening elements for each kind of processed parts, is to be considered as a certain disadvantage of the vibrational-centrifugal strengthening treatment. That is why the devices of vibrational-centrifugal treatment for strengthening the surface of long-length parts have been developed whereas the devices for surface strengthening of boring and casing pipes, large-calibre artillery and tank tubes, chassis components of airplanes and others appeared to be inappropriate for strengthening thread surfaces [8].

An outstanding feature of vibrational-centrifugal treatment is in its capability of providing high levels of energy of deforming the material of processed parts. This is achieved due to the fact that in the capacity of an impact energy deformable bodies are used which contact with the material of a strengthened part, as well as inertial force of a massive roller which is rolled smooth against deformable bodies set in a separator plate. At the same time, rolling movement of the roller is provided due

to its vibrations, while the energy of deformation includes centrifugal force developed by the roller during its rolling movement as its constituent. These significant peculiarities are in the basis of the name of the newly developed strengthening method – vibrational-centrifugal strengthening treatment (VCST) [7]. The essence and peculiarities of this strengthening method will be considered more intelligibly when describing the developed strengthening equipment in the work.

Fig. 2 shows the schematics of a device for strengthening the surface of taper thread roots using the vibrational-centrifugal treatment; Fig. 3 shows a solid 3D-model of a strengthening head for vibrational-centrifugal strengthening of roots of taper thread of 3-121 type.

The processed part 1 with taper thread is securely fixed on a corbel piece 4 of an oscillating platform (not shown in Fig. 2). On the threaded shank with taper thread to be treated, a strengthening head with deformable bodies in the form of rollers 2 is set by screwing on. Profiles of the deformable rollers 2 and strengthened thread root of the part 1 are shown in Fig. 2. At the same time, the rounded radius of the deformable roller 2 is equal to the rounded radius of a root of the strengthened thread while the oblique angle of its flank surfaces is 2–3° smaller than the angle of the thread root. The deformable rollers 2 are made of XBT steel (containing chromium, tungsten, manganese) and are hardened to 58–62 HRC, which exceeds the hardness of the strengthened part 1 material by 5–10 units. The deformable rollers 2 are detachably mounted on axes 3 in holder blocks 7, which are fixed on guard rails 6, which are parallel to the cone element of the strengthened thread of the part 1. The deformable rollers 2, holder blocks 7 and guard rails 6 are fixed in a separator 5, which along with an eccentricity which is equal to a half of the whole depth of thread is loosely located above the treated thread surface. At the same time, the rollers 2 can rotate freely about themselves in the holder blocks 7, the holder blocks 7 can move along the guard rail 6, and the separator 5 can roll around the strengthened taper thread surface due to the eccentricity. At the beginning and at the end of the thread surface of the treated part 1 there are fixed limit switches (not shown in Fig. 1), which switch the rotation of the drive motor shaft to the opposite direction and, thereby, change the direction of circular vibration of the platform with the treated part 1 and strengthening device fixed on it. Above the separator 5 with the eccentricity there is set a roller 8 in the form of a cylindrical heavy ring. The eccentric-

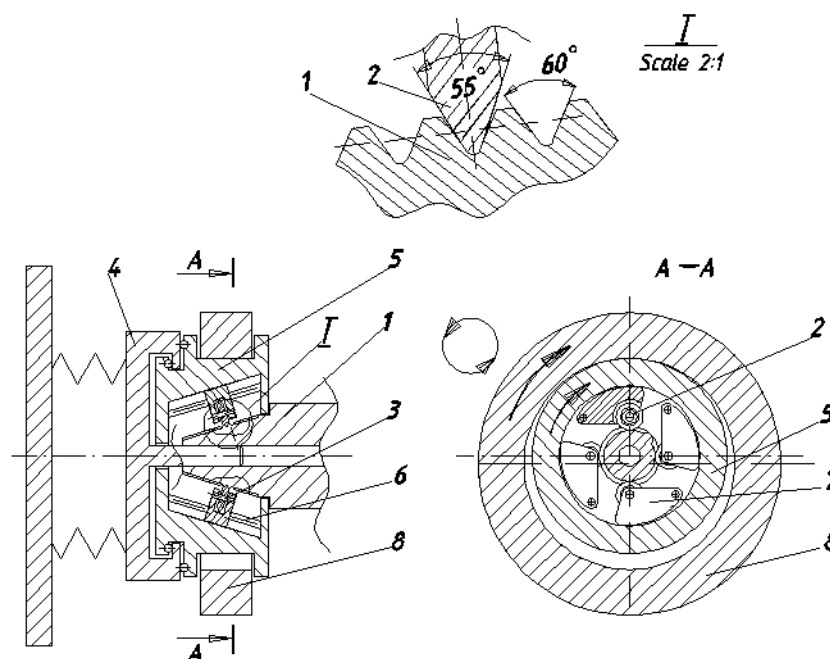


Fig. 2. Schematics of the strengthening head for treating taper thread roots through vibrational-centrifugal strengthening

ity of the roller 8 is selected to be equal to the vibrational amplitude of the drive platform which is set within the range of equality 2.5–3 of the values of height of the coil profile of the strengthened thread.

Strengthening treatment of thread roots is conducted in the following way. On the platform, with the help of the corbel piece 4 the treated part 1 is fixed with the strengthening device being previously screwed on it. The platform with the treated part 1 and the strengthening device fixed on it is given circular vibrations with the amplitude which exceeds the height of the strengthened thread profile by threefold and has frequency of 15–24 Hz. At the same time, the direction of circular vibrations of the treated part 1 is perpendicular to its geometrical axis. Under the action of the circular vibrations of the treated part 1 the separator 5, which is set on it loosely and off-centre, and the roller 8 retract themselves into the rolling movement by the deformable rollers against the roots of the thread surface on the part 1. Moreover, the rollers 2 alternately come into an impact contact with the material of the thread roots of the strengthened part 1 in a circular sequence which is opposite to the direction of circular vibrations of the platform. During each period of vibrational motion of the platform each deformable roller 2 alternately strikes a blow against the material of the strengthened thread root and shifts over a small distance along the thread profile. Within one minute at vibrational frequency of the platform of 24 Hz and with four deformable rollers 2 available, approximately 4.5 thousand blows are struck and the rollers shift along the axis of the treated part within one coil of the strengthened thread. Having reached the outermost left or right coil of the strengthened thread, the support 4 throws over the limit switch, the platform reverses the direction of its vibrations and the supports with the deformable rollers 2 shift to the opposing edge of the thread surface changing again the whole thread root. The number of such repetitive changings is selected by means of experiments being guided upon reaching the required quality of strengthening treatment.

The major technological parameters of this strengthening process are the force of deformation of the strengthened part, amplitude and vibrational frequency of the drive platform, the number of repetitive moves of the deformable rollers along the strengthened thread root.

The force P_{def} , conditioning thickness of strengthening of the metal of a thread root is defined from the relation [8]

$$P_{def} = (m_{rol} \cdot \varepsilon + m_{sep} \cdot \varepsilon_{sep}) \omega^2,$$

where m_{rol} is the mass of the roller 8, whose value is selected by means of experiments; m_{cen} is the mass of the separator 5 with

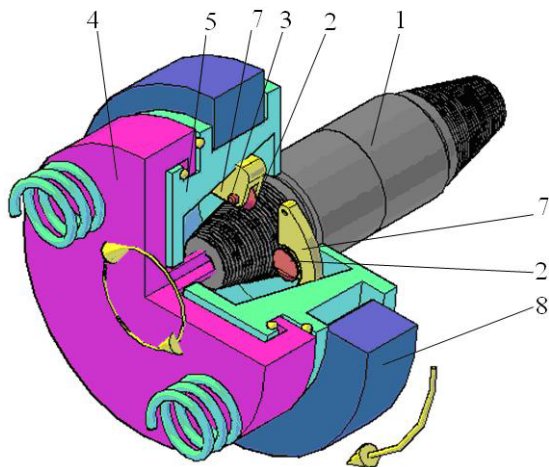


Fig. 3. Solid 3D-model of the strengthening head for vibrational-centrifugal strengthening of nipple 3-121 of a boring pipe:

1 – nipple; 2 – deformable roller; 3 – roller axis; 4 – corbel piece; 5 – separator; 6 – guard rail (Fig. 2); 7 – holder block; 8 – roller

holder blocks 7 and deformable rollers 2; ε is the eccentricity of the roller equal to the threefold height of the thread profile; ε_{sep} is the eccentricity of the separator 5 equal to one-half of the thread profile; $\omega = 2\pi f$ is the wave circular frequency of the drive platform; $f = 15\text{--}24$ Hz is vibrational frequency of the drive platform.

With the mass of the roller equal $m_{rol} = 6.5$ kg, mass of the separator $m_{sep} = 3.5$ kg, the eccentricity $\varepsilon = 8 \cdot 10^{-3}$ m and vibrational frequency of the platform $f = 24$ Hz, the value of the force of deformation reaches $P_{def} = 1317$ N. Contact stresses in the material of the strengthening part are defined from the functional connection [9]

$$\sigma_{con} = \frac{P_{def}}{S_{con}}.$$

Taking into account the fact that the contacting area of the deformable roller 9 with the surface of thread roots does not exceed $S_{con} = (2.5\text{--}3)$ mm², contact stresses reach the values $\sigma_{con} = (440\text{--}530)$ MPa, i.e. these are quite high values which are able to qualitatively rivet the surface layer of metal in the thread root.

For strengthening the outer taper thread of boring pipes using vibrational-centrifugal treatment, schematics of a vibration machine has been developed, which is shown in Fig. 4. The main elements of this vibration machine include a vibrating platform 2 set on pneumocylinders 1; at the end faces of the platform, corbel pieces 3 are placed with vibromotors 4 attached to them. On the platform 2 there are located supports 5 on which boring pipes 7 treated by strengthening are securely fixed by means of corbel pieces 6. The strengthening operation itself is performed with the use of resilient members of two strengthening heads 9 set on the platform 2. The design of the strengthening heads 9 is shown in Fig. 2. The platform 2 is set on the frame 10 with the help of the pneumocylinders 1; to decrease vibratory transfer, the frame is equipped with vibration-absorbing rubber dampers 11. At zero air pressure inside the pneumocylinders 1, the platform 2 is descended onto the frame 10 of the supports 12.

The technological operation of strengthening the thread surface roots of the outer taper thread of boring pipes on a vi-

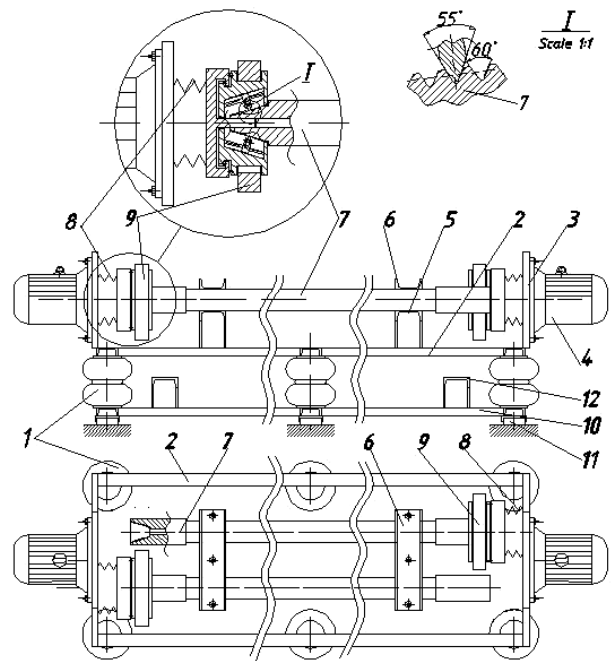


Fig. 4. Schematics of the vibration machine for strengthening taper thread roots of boring pipes by vibrational-centrifugal treatment

bration machine is conducted in the following way. At zero air pressure inside the pneumocylinders 1 and with the platform 2 on the frame supports 12 placed onto supports 5 of the platform, boring pipes 7 are set which are to be strengthened. This vibration machine is designed to strengthen two boring pipes simultaneously. The boring pipes 7 are set on the platform with their outer tool-joint taper thread facing the strengthening head 9 which is to be used for treating them. Manually, the strengthening heads 9 are screwed on the thread surfaces of boring pipes basing them on thread coils by means of deformable rollers of strengthening heads. With the help of corbel pieces 6, the boring pipes 7 are securely fixed on the platform 2 and, with pressurized air delivered to the pneumocylinders 1 from the control panel, the platform is levelled up from the supports 12 to the operational position. There are switched on all vibromotors which provide the platform 1 with circular plane-parallel vibrations with amplitude equal to at least two values of the profile height of the strengthened taper thread and frequency of 15–24 Hz. The circular vibration trajectory of the platform 1 is perpendicular to the geometrical axis of the strengthened boring pipes 7, which is provided by synchronous and in-phase rotation of shafts of both (left and right) vibromotors 4 attached to the corbel pieces 3. At the same time, the direction of rotation of a vibromotor shaft attached, for example, to the left corbel piece is opposite to the rotation direction of a vibromotor shaft attached to the right corbel piece 3. This is exactly what provides self-synchronization of the drive of the oscillating platform 2 and uniformity of the amplitude of its vibrations throughout the length of treated long-length boring pipes 7. Affected by circular vibrations of the platform 2, the rollers of strengthening heads retract themselves into the mode of vibrational support of their rotation which is accompanied by interaction of the deformable rollers with the strengthened surface of thread roots as well as with axial movement of the holder blocks with the deformable rollers throughout the strengthened thread surface. The self-retracting of rollers is possible due to the selection of their masses and sizes described above. The electrical diagram of vibromotor work control anticipates that the stand and reversing of rotation direction of their shafts occurs only after reaching full shift positions of the holder blocks of the deformable rollers of both strengthening heads. Then the vibromotors stop, an electrical signal for changing direction of their shaft rotation is given and the platform 2 takes vibrations in the opposite direction. Affected by these vibrations the holder blocks of the strengtheners move axially towards the opposing edges of the

thread surface, strengthening it repetitively, i.e. a repetitive processing step occurs. The number of changes in the vibration direction of the platform 2, i.e. the number of repetitive processing steps, is defined by means of experiments depending on requirements for the quality of strengthening treatment. At the same time, it is essential to consider the fact that an excessive number of repetitive changings can result in the so-called phenomenon of over-riveting of the material of strengthened surface of the part, which is highly undesirable because of adversely affecting strength characteristics of the treated material.

After completing a certain number of required processing steps, the drive vibromotors are halted by air drain from the pneumocylinders 1; the platform 2 is descended on the supports 12 of the frame 10 and the strengthening heads 9 are screwed off the strengthened boring pipes 7. The fixing corbel pieces 6 and the treated parts 7 are taken off the platform and in their stead two succeeding boring pipes are set and the cyclic process of strengthening treatment continues in the sequence described above.

Apart from boring pipes, outer taper tool-joint thread is produced on transfer elements of the boring pipe which are called nipples. Nipples are hollow tubular parts 500–800 mm long depending on the type and size of boring pipes. On both ends of nipples thread, shanks with outer taper tool-joint thread are set. Their outer diameter and thread type are equivalent to respective sizes of boring pipes for connection of which they are designed. Both thread parts of boring pipes and nipples connecting them feature insecurity of fatigue failure in roots of initial coils of the maximum diameter of the thread taped on them. Nipples are produced through stamping mostly from alloy-treated steel 40HX with further mechanical operation, which includes cutting of taper thread, and hardening.

To increase reliability of drill nipples, it is recommended to include outer strengthening of thread surface roots by vibrational-centrifugal treatment into the technological process as being final fit-out operations. The schematics of the vibration machine for vibrational-centrifugal strengthening of thread roots of nipples is shown in Fig. 5.

The main structural elements of this vibration machine include a cylinder 3 resiliently mounted on the pneumocylinders 1 on the frame 2; to the end walls of the cylinder, vibromotors 4 are attached. The cylinder 3 is covered with a lid 5, whereas inside, supports 6 for fixing strengthening nipple 7 of the drill pipe on them are placed. On both thread shanks of the nipple the strengthening heads 8 are slipped by screwing in; accord-

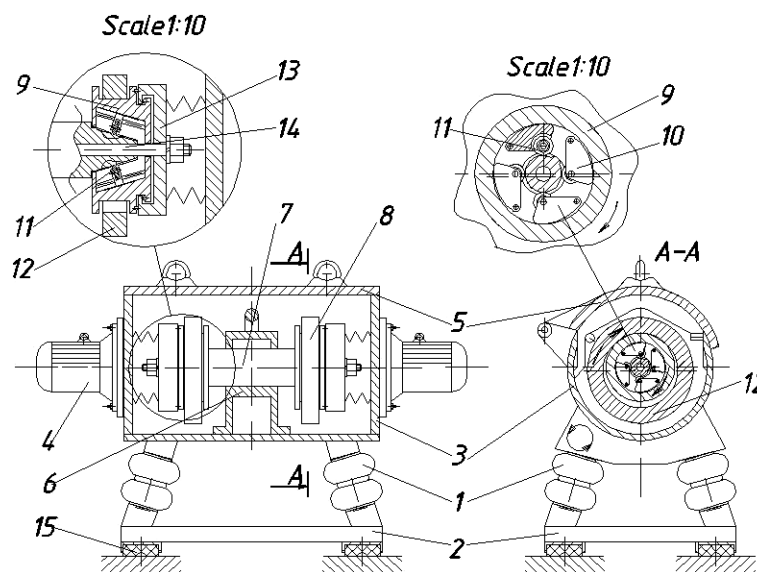


Fig. 5. Schematics of a vibration machine for vibrational-centrifugal strengthening treatment of taper thread roots of nipples of boring pipes

ing to their design structure, the strengthening heads 8 are identical to those in Fig. 2. Each strengthening head 8 consists of a separator 9 with holder blocks 10 fixed on axes in it; on the holder blocks, deformable rollers 11 are set whose profile is identical to that of strengthened thread roots. On the separator, a massive ring roller 12 is set without restraint with its possible rolling over the outer surface of the separator. The separators 9 are based on the strengthened nipple by means of corbel pieces 13, which are connected together by drag link 14, which runs along the internal opening of the strengthened nipple. To decrease the vibratory transfer to the foundation of the facilities, the frame 2 of the vibration machine is set on vibration dampers 15. On the side walls of the separator beside the first and the last coils of strengthened thread, limit switches are installed connected to the panel of control of the electric drive of the vibration machine (not shown in Fig. 5).

Strengthening of thread roots of nipples by the vibration machine is done in the following way. On the mounting table in advance, on a nipple 7 which is to be strengthened separators 9 of the strengthening heads 8 are installed by screwing on. At the same time, deformable rollers 11 are led alternately into thread roots of the nipple 7. The centering side support brackets 14 of the strengthening heads are braced together by means of the drag link 14, which runs along the internal opening of the nipple 7. Gathered together, the nipple 7 and the strengthening heads 8 are set inside the container 3 and securely fixed on the supports 6; the container is covered with the lid 5. From the control panel voltage is applied to the windings of vibromotors 4 whose unbalanced shafts rotate with frequency of 15 or 24 Hz (depending on the vibromotor type) opposite one another. The corbel pieces 3 of the vibration machine take circular vibration with the frequency which is equal to the rotation frequency of unbalanced shafts of vibromotors 4 and the amplitude equal to 2.5–3 of heights of the profile of the thread surface of the strengthened nipple. Because of the strengthened nipple 7 securely fixed on the supports 6, circular vibrations are given to the strengthening heads 8. The strengthening heads 8peen all the length of threads roots with the deformable balls stepwise. The mechanism of their work is identical to the mechanism described above (description, Fig. 2). As for strengthening boring pipe thread (description, Fig. 3) when all the holder blocks 10 reach the full shift position, rotation directions of the shafts of vibromotors 4 are switched over by the limit switches to the opposite rotational direction and repetitive strengthening steps are performed.

After completion of an experimentally determined number of repetitive strengthening changings, the delay relay of the control panel halts rotation of vibromotor shafts; the lid 5 of the container is opened, the clamping of the treated nipple 7 is unlocked and it is taken out of the container 3 together with the two strengthening heads 8. Another nipple prepared in advance to be treated is put inside the container along with the strengthening heads installed on it; the container is covered with the lid and a succeeding part is treated according to the procedure described above.

With the purpose of checking the efficiency of vibrational-centrifugal strengthening treatment of thread roots of drill pipe taper thread, there was treated thread of nipple adapters of a drill pipe of ПН 121/121 type. The strengthening treatment was performed with the rotation amplitude of the vibration machine container $A = 6$ mm, vibration frequency $f = 24$ Hz, duration of treatment – 18–20 minutes. The key design parameters were as follows: eccentricity of the separator $\epsilon_{sep} = 1.2$ –1.5 mm, mass of the separator $m_{sep} = 3.5$ kg, eccentricity of the roller $\epsilon = 8$ mm, mass of the roller $m_{rol} = 6.5$ kg.

As a result of the strengthening treatment, the metal in the tread root was peened to a depth of 0.15–0.25 mm at the same time, its surface micro-hardness increased to $4.6 \frac{GN}{m^2}$ with the degree of surface cold working 15–20 %. Certainly, significant

improvement of physical and mechanical properties in the boundary layer of the material of thread roots of outer taper thread, which was provided by strengthening, gives solid evidence of possible increasing reliability and strength of thread connections of a drill pipe [2, 10].

However, it is an unquestionable fact that quantitative and qualitative assessment of the degree of reliability requires long-term field testing of strengthened thread elements of drill pipes conducted at actual drilling setups. This should make the theme and purpose of further research on efficiency of applying vibrational-centrifugal strengthening to improve reliability of thread connections of drill pipes.

Conclusions.

1. Based on the analysis of working loads and influence of the technological process of producing thread elements of drill pipes on the stress state of their material, it is established that the cause of destruction of thread connections is the concentration of tensile stresses in surface layers of the materials of thread roots. It was found that the cause of destruction of taper thread connection of drill pipes is mainly creation and further growth of fatigue cracking at the section of thread roots of initial coils of maximum diameter of the taper thread.

2. With the purpose of compensating negative influence of working stresses, which condition formation of fatigue cracking in thread roots, it is recommended to include an additional strengthening operation in the technical process of manufacturing boring pipes and their connecting elements. The main tasks of this strengthening operation should be increasing the strength of the metal in thread roots and formation of residual compressive stresses in the surface layers of strengthened material; the stresses are to compensate negative technological and working tensions.

3. The key elements of the developed schematics of vibrational equipment for vibrational-centrifugal strengthening of thread element of boring pipes and their coupling adapters are strengthening heads, which function on the basis of vibrational-centrifugal strengthening. The particular feature of this strengthening method of treatment is capacity for providing high levels of inertia of distortion of the metal of thread roots due to the use of inertial force of a massive roller, which, affected by vibrations, is rolled throughout deformable rollers placed in the thread roots.

4. Increase in strength of the material of thread roots of connecting elements of drill pipes will contribute to improving reliability of drill pipes, decreasing risks of destruction of their thread elements, which will provide decreasing repair and servicing time for drilling equipment, and will increase the bore-hole drilling rate.

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Підвищення надійності бурильної колони зміцненням різьбових з'єднань її елементів

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Рекомендується включити до технологічного процесу виготовлення бурильних труб і з'єднувальних їх ніпелів, що виготовлені зі сталі 40ХН, операцію поверхневого зміцнення пластичним деформуванням. Основним завданням цієї зміцнювальної операції повинен бути перерозподіл технологічних напружень розтягу в матеріалі різьбової впадини, поверхневе зміцнення металу у впадині та формування в металі напружень стиснення, спроможних протистояти експлуатаційним навантаженням. Аналіз існуючих методів поверхневого пластичного деформування показав, що дійсно придатним для якісної зміцнювальної обробки різьбової впадини є метод вібраційно-відцентрового зміцнення. Цей метод належить до групи динамічних методів поверхневого пластичного деформування (ППД), а його характерною особливістю та перевагою є забезпечення високих рівнів енергії деформування металу зміцнюваних деталей.

Мета. Створення методу вібраційно-відцентрового зміцнення, придатного для якісного зміцнення різьбових поверхонь, його адаптація до зміцнення конічної зовнішньої різьби, визначення основних технологічних параметрів зміцнювальної обробки. Основними задачами дослідження були розробка й виготовлення придатних для зміцнення конічної різьби зміцнювальних пристроїв, функціонуючих на основі вібраційно-відцентрової обробки. А також розробка принципових схем оригінальних нестандартних вібраційних машин для зміцнення зовнішньої конічної різьби бурильних труб та з'єднувальних їх ніпелів.

Методика. На підставі теорії статичної подібності втомного руйнування запропонована методика визначення зменшення маси та матеріалоемності циліндричних деталей у результаті ефективного зміцнення їх вну-

трішніх і зовнішніх циліндричних поверхонь вібраційно-відцентровою обробкою.

Результати. В основу конструкції розроблених пристроїв для зміцнення різьбових впадин конічної різьби покладено забезпечення динамічної ударної взаємодії роликів, що деформують, форма яких повторює профіль різьбової впадини, обкочуванням масивного обкатника. Завдяки незначній площі контакту деформуючого ролика із матеріалом різьбової впадини та великим значенням розвинутої рухомим обкатником деформуючої відцентрової сили, якісно приклепується метал різьбової впадини, а головне, – у ньому формуються напруження стиснення.

Наукова новизна. Полягає в тому, що вперше розроблені високоефективні пристрої для динамічного зміцнення різьбових поверхонь, аналогів яким немає у світовій практиці зміцнювальних обробок.

Практична значимість. Складається у підвищенні надійності бурильних колон завдяки підвищенню міцності матеріалу різьбових з'єднань їх елементів. Промислове запровадження вібраційно-відцентрової зміцнювальної обробки різьбових елементів бурильних колон, на думку авторів, зменшило би кількість випадків руйнування складових колони, що сприятиме зменшенню часових затрат на ремонт і обслуговування бурильного обладнання, підвищуватиме швидкості буріння свердловин.

Ключові слова: бурильна труба, ніпель, конічна різьба, впадина різьби, метал, зміцнення, пластичне деформування, вібраційно-відцентрова обробка

Повышение надежности буровой колонны упрочнением резьбовых соединений ее элементов

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Рекомендуется включить в технологический процесс изготовления буровых труб и соединяющих их ниппелей, которые изготовлены из стали 40ХН, поверхностное упрочнение пластическим деформированием. Основной задачей этой упрочняющей операции должно быть перераспределение технологических напряжений растяжения в материале резьбовых впадин, поверхностное упрочнение металла во впадине резьбы и формирование в металле напряжений сжатия, способных противостоять эксплуатационным напряжениям. Анализ существующих методов поверхностного пластического деформирования показал, что единственным пригодным для качественной упрочняющей обработки резьбовой впадины есть метод вибрационно-центробежного упрочнения. Этот метод принадлежит к группе динамических методов поверхностного пластического деформирования (ППД), а его характерной особенностью и преимуществом есть обеспечение высоких уровней энергии деформирования металла упрочняемых деталей.

Цель. Создание метода вибрационно-центробежного упрочнения, пригодного для качественного упрочнения резьбовых поверхностей, его адаптация к упрочнению конической внешней резьбы, определение основных технологических параметров упрочняющей обработки. Основными задачами исследования были разработка и изготовление пригодных для упрочнения конической резьбы упрочняющих приспособлений, функционирую-

щих на основных принципах вибрационно-центробежной обработки. А также разработка принципиальных схем оригинальных нестандартных вибрационных машин для упрочнения внешней конической резьбы буровых труб и соединяющих их ниппелей.

Методика. На основании теории статического подobia усталостного разрушения предложена методика определения уменьшения массы и материалоемкости цилиндрических деталей в результате эффективного упрочнения их внутренних и наружных цилиндрических поверхностей вибрационно-центробежной обработкой.

Результаты. В основу конструкции разработанных приспособлений для упрочнения резьбовых впадин конической резьбы положено обеспечение динамического ударного взаимодействия деформирующих роликов, форма которых повторяет профиль резьбовой впадины, обкаткой массивного обкатника. Благодаря незначительной площади контакта деформирующего ролика с материалом резьбовой впадины и большим значениям развитой движущимся обкатником деформирующей центробежной силы, качественно проклепывается ме-

талл резьбовой впадины, а главное, – в нем формируются напряжения сжатия.

Научная новизна. Состоит в том, что впервые разработано высокоэффективное оборудование для динамического упрочнения резьбовых поверхностей, аналогов которому нет в мировой практике упрочняющих обработок.

Практическая значимость. Состоит в повышении надежности буровых колонн благодаря повышению прочности материала резьбовых соединений их элементов. Промышленное внедрение вибрационно-центробежной упрочняющей обработки резьбовых элементов буровых колонн, по мнению авторов, уменьшит количество случаев разрушения составляющих колонны, что будет способствовать уменьшению временных затрат на ремонт и обслуживанию бурового оборудования, повысит скорости бурения скважин.

Ключевые слова: *буровая труба, ниппель, коническая резьба, впадина резьбы, металл, упрочнение, пластическое деформирование, вибрационно-центробежная обработка*

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