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# WAYS OF IMPROVEMENT OF ROTARY BITS FOR OIL AND GAS WELLS DRILLING

At the modern stage of the improvement and elaboration of new tools for drilling and repair of wells, an agreement of geometric parameters and flow process properties is necessary not only of the tool as a whole or its functional systems, but of the component parts of the functional systems with an actual distribution per them of kinematics, power and energetic characteristics of the mode of its operation. Such approach to the solution of this problem requires a statement and fulfilment of detailed researches of work relating to a wear for each system of the tool and its components. For ex, as for a rotary bit's support its functioning and wear of bearings, sealing properties, a lubrication system operation, lubricants in specific conditions of the support's functioning.

Detailed research works, carried out at the university, allowed to underline weak parts of each system and concentrate efforts of the scientists, firstly, on the achievement of equal-strength of tool's components, and then, on the elaboration of it at a new qualitative level.

This article is based on researches of the mechanical processes in mining rocks and rock-destruction tools, which started under the leadership of professor L.A. Shreiner and were continued at USPTU under the leadership of Prof. M.P. Mavliutov [1] in the direction of a dynamic destruction of mining rocks when drilling and hydraulics of the zone attached to the well; Prof. A.I. Spivak [2]in the direction of mining rocks abrasion and wear-resistance of rock-destructive tools and Prof. G.V. Konesev [3] in the direction of tribotechnique, applying to the conditions of wells' drilling. At present, a complete school of researchers of these problems was formed at USPTU, and the authors of the represented article are included in this structure as well.

## GROUNDS OF DIRECTIONS OF AN IMPROVEMENT OF ROTARY BITS

Up-to date rotary bits have undergone a long evolution and gained a high degree of perfection. Researches carried out at USPTU, are directed at the improvement of main functional elements and systems of bits, namely: armament of rotary bits, supports, including the lubrication systems, and systems of flushing.

Solutions of resilient tasks of pressing-in of armament elements, applying to the achievement of an ultimate stressed condition (yield point) in a mining rock, from a viewpoint of a generalised requirement of strength of More [4], made up a theoretical basis for the improvement of armament of rotary bits. As the result, formulae were received for the calculation of a maximum intensity of touching stresses under elements of armament of main forms and formulae for the calculation of load intensity ($\mathbf{P_{i0}}$) for the armament of bits, conforming to the achievement of an yield point in mining rocks. A value $\mathbf{P_{i0}}$ was adopted as an individual unit one, when calculating dimensionless loads ($\alpha$) on tools.

$$á = \frac{P_i}{P_{i0}},$$

where $P_i$ – an intensity of axial load formed on a bit's armament.

The results of researches, received in the unit [5], simulating a movement of the element of the armament of a bit in the process of a mining rock destruction, made up an experimental basis for the improvement of the armament of rotary bits.
The results of the experiments showed:

1. An increase of the load and energy capacity of the destruction of mining rocks (a depressing effect) in comparison with zero and a positive tangential sliding is observed at a negative tangential sliding of the elements of the armament. Therefore, geometric parameters of the armament elements of rotary bits are required to agree upon with the kinematics of relationship with the face to avoid a depressing effect and a decrease of irregularity of the distribution of stresses in a body of the armament elements;
2. The distribution of the elements of the armament in crowns shall provide with a full destruction of a corresponding face to the crown provided the destruction areas are overlapped for 4…6-bit rotations. It required a task solution of the co-ordinated location of the elements in crowns.

The study of wear and destruction of a hard-alloy armament of the rotary bits in the conditions of deposits showed, that while destroying soft abrasive mining rocks, the main reason of a denudation and falling down of teeth of central crowns is a non-favourable "trace-to-trace" scheme of the destruction of a face with corresponding crowns. This phenomenon may be eliminated by a co-ordinated location of the teeth of central crowns in relation to peripheral ones. When destroying hard mining rocks, the weakest place is the armament of peripheral crowns. It is fixed, that an overload of peripheral teeth is conditioned by the fact that pre-peripheral face area is destroyed by crowns with a big step " trace-to-trace" with the formations of protuberances and cavities; meanwhile the protuberances in the face are located just opposite peripheral teeth and cause rather high curving loads on them. The elimination of the mentioned effect requires a principal alteration of schemes of teeth location in two-row peripheral crowns.

The results of researches, received on the stand, reproducing conditions of the operation of a hermetically closed support of the rotary bit are laid to the basis of the elaboration of a forced lubrication system of supports and the development of sealing elements. The measurement system allows registering loads on the support's elements, the friction moment and the temperature in the contact of the sealing friction. The researches showed, that at higher frequencies of the rotations, the lubrication system should provide with an excess pressure in the supports and the change of a lubrication material. The tests of sealing of rotary bits' supports, containing rubber elements, showed that an abrupt decrease of wear-resistance of the rubber is observed at some critical frequency of a rotary bit's rotation. This is explained by the fact that rubber possesses of a low heat conductivity and a low (approx. 110C deg.) temperature of the beginning of the destruction. Besides, the researches showed that the sealing of supports of HY type in a form of rubber-metallic sealing rings quickly break down, in case a wrong-designed joint rotation with a rotary bit is provided, and sealing of supports of AY type in a form of rubber rings – at a radial displacement of a rotary bit relatively to the support at a higher

wear of the support [6,7]. The presence of radial, axial and angular fluctuations of a rotary bit relatively to the trunnion reduces essentially a long service operation of serial sealing, and at exceeding critical values leads to a sudden failure. Therefore, the researchers' main attention was directed to the elaboration of technical solutions, allowing to compensate as much as possible radial, axial and angular fluctuations of a rotary bit, growing due to bearings' wear.

The analysis of fields data of a wear of supports of the bits 215,9Т3-ГАУ R40 allowed to suggest a proposal of a possibility of local and extensive seize in sliding bearings due to high contact pressures on the working surfaces at unfavourable combinations of clearances, due to which a distortion of the rotary bit occurs in relation to the trunnion. The possibility of seizes was confirmed experimentally in two ways: both when water entered the support, and when sealing remained unbroken. In the last case, a critical contact pressure for a big sliding bearing was approx. 150 Mpa [8].

Local seizes and stickings do not lead directly to a failure of the bit, but are accompanied with fluctuations of the resistance moment to the bit's rotation, which causes the armament's destruction. With simultaneous seizes in two or three rotary bits, a rise of the moment may be so large, that a driller understands it as a bit's failure due to the support. And the bit uplifted does not look like worn out completely. An extensive seize causes a rotary bit's jamming or a stall and cranking of bushings in rotary bits and, eventually, a bit's failure in relation to the support.

The seize in the supports is a catastrophic form of wear and shall be excluded. The solution of this task is carried out in three directions:

1. Improvement of the lubrication systems and sealing of rotary bits' supports, securing a reliable lubrication of bearings and excluding drilling solutions entering the supports;
2. Elaboration of flow process procedures on aligning of the distribution of contact pressures on the working surfaces of bearings;
3. Elaboration of lubrication materials with high tribo-technic properties.

A scientific basis of the design of a structure and a flushing mode of the bits is a field of velocity and pressure of a drilling solution at the face of a well and around it. Since it was unknown, a methods was elaborated at the university of its experimental research and, for the first time in the world, the field of velocity and pressure of a drilling solution were received at around-face area of the rotary bits with a various flushing scheme [1]. Then, the fields received were used by USPTU and other organisations (GANG named after Gubkin, Samara State Technical University, JSC "Volgaburmash") when elaborating new bits' design structures.

Decisions were laid in the flushing systems, which allowed to prevent erosions of flushing channels in the housing of a bit, erosions and fall- downs of nozzles, a drilling solution circulation inside the support and a lubricant's wash-out from it (with an unsealed support), reduce a repeated grinding at the face and in the area around the face of the bit. Besides this, it was recommended to reduce a consumption of the drilling solution by 25-30% when drilling wells, which allowed reducing essentially energy expenses and a depressing pressure at a well's face.

## Elaboration and test of sealing units of rotary bits supports

At present time, much attention is paid to the resistance of hermetically sealed rotary bits' supports. The main direction in a foreign practice is an elaboration of hard-alloy socket combined sealings. These sealings possess a resistance, exceeding

the resistance of supports of bits substantially, but the technology and materials are such, that they make prices of bits much more expensive.

Technological designs of not expensive sealings are elaborated in USPTU, satisfying a resistance of up-to-date hermetically sealed supports of bits and allowing to operate them at higher frequencies of the rotation. In order to exclude a negative effect of the radial wear of bearings at the friction moment and sealing's resistance, a design of the radial –socket seal with a developed deformation characteristics was elaborated with the usage of serial sealing rings [9]. The elaborated seal in comparison with a serial radial one have the following advantages:

1. It allows to fill the support with a lubrication and pump it via the lubrication system in the same procedure as in bits with supports of type НУ, e. g., under pressure, exceeding a pressure of the seal's opening. Pressures of the deployment at the seal tested are as follows:

| | | | | |
|---|---|---|---|---|
| Tension, mm | 0.3 | 0.6 | 0.9 | 1.2 |
| Pressure of opening, Mpa | 0.62 | 0.85 | 1.10 | 1.45 |

2. It provides with a reliable operation in conditions of radial and angular fluctuations of a rotary bit, occurring in the process of a support wear;
3. Fluctuations of a lubrication pressure in the support at the axial fluctuations of a rotary bit create an effect of self-relief of the seal (of the friction contact rubber ring-socket of the bearing bushing). For ex., when a rotary bit moves to the foot in the cavity of the support, a pressure of the lubricant is growing, then it is transferred to the rubber ring and unloads it relatively to the bearing's bushing socket, decreasing a friction moment in the seal. When the rotary bit moves from the foot, the pressure in the cavity is reducing and, under the action of differences of pressures in the well and in the support, the rubber ring presses itself against the socket of the bushing. However, this pressing shall not be excessive, because a force of compression of the seal is decreasing due to lessening of the tension. Besides, the rubber ring's pressing against the socket of the bushing is partially compensated by a friction of the rubber ring against the trunnion's surface and the metallic ring.

## Elaboration and test of over-bit's lubricators

Researches of work of the systems of lubrication of the supports of НУ type of the rotary bits at higher frequencies of the rotation [10] showed, that in order to strengthen their resistance, it is necessary to create an excess pressure in the supports and implement an uninterruptible changing of the lubrication material with a minimum consumption 1…2 cm3/min. This task was solved with the application of over-bit's lubricators. The excess pressure in the support secures pressing-in the lubrication material through the support (a forced lubrication), which, in its turn, reduces the moment of friction of the seal against the socket of the rotary bit and excludes its rotation with the rotary bit, as well as improves essentially the lubrication of bearings. Finally, it does not brings to only to the improvement of supports' resistance, but allows as well increasing essentially an allowable rotation frequency of bits.

The main problem while elaborating designs of over-bit lubricators was securing a stable delivery of the lubrication material into the system of lubrication of

the support of a rotary bit. For this purpose, two types of controllers of the lubrication material consumption were well grounded analytically and experimentally and manufactured at USPTU, the description and designs of which are given in work [7].

1. Controller to maintain a stable excess pressure in the cavity of the support, functioning on the principle of a differential valve-cutter.
2. Controller to maintain a stable consumption of the lubrication material through the support, functioning on the principle of changing its hydraulic resistance (length of slot) in accordance with the alteration of differential pressure at the bit.

Serial oils MC-20 as well as hypoid oil and lubrication of series CD [11] developed at USPTU were used as lubrication materials. As the result of tests at deposits, an increase of passage at the bits was received by 85% and the resistance of bits by 68%.

Field tests of over-bit lubricators with the piston movement from overhead to downwards detected its disadvantages:

1. the cavity's contamination with sludge over the piston and locking it when filling, in case rules of maintenance were not observed;
2. In case a wear of the piston takes place and a slight quantity of drilling solution enters the lubrication, this solution is involved in the bit's lubrication system.

These faults were eliminated with the elaboration of the lubricator with the movement of the piston upward from down position [7].

A wide application of over-bit lubricators is restrained by the necessity of channels' drilling in the bits for the lubrication delivery to the supports in the conditions of drilling enterprises. This operation shall be implemented at factories-manufactures of bits. The bits for the application with the over-bit's lubricators do not require compensators of pressure, that makes them considerably cheaper. Approx. 50 bits are used with one over-bit's lubricator.

## Grounds, elaboration, tests and introduction of lubrication materials for the rotary bit's supports

A specific character of conditions for the application of lubrication materials in the supports of rotary bits is concluded in a wide range of the usage and a high level of power and energetic loading of bearings, dynamics of functioning, a deficit of lubrication material, a possibility of the relationship with aggressive components of a flushing liquid. Therefore, when elaborating new lubrication materials, components were selected whose efficiency increased together with an increase of energetic load of the friction contact. An expedient selection of a base of the lubrication material and additives was fulfilled, that would assist to form films of tribo-polymers and chemical combinations, modifying the surface of friction. Theoretical preconditions of the components' selection are represented in [3]. The amount of energy that releases is much more than enough, when bearings of supports of bits are in operation, in order to form protection films of a polymer and hemo-sorption type on the surfaces of friction. A high heat-intensity of work of the supports of bits, in case if a heat-removal (cooling) is improperly provided, becomes a reason of undesirable phase transformations in metal and a decrease of wear-resistance of the tool. Therefore, while making a choice of lubrication components, their thermo-physical and reologic properties were taken into account. Low-viscous systems as per cooling have undoubted advantage if compared with plastic lubrications.

An important result of the lubrication quality is its stability to thermo-destruction and oxidation. All components of the lubricants were selected taking into account avoiding these phenomena.

Existing general recommendations, based on the experience of the usage of thermo-moisture-proof lubricants in techniques applying to the operation of specific friction units and existing recommendations for the selection of additives of a special designation for the lubricants are not sufficient for the conditions of work of bearings of the supports of bits. Additional experimental works were required on special stands, simulating energetic parameters of the relationship of bodies of the friction of real units. Therefore, when elaborating lubricants for the supports of rotary bits, a principle of co-operative improvement of tribo-technic properties was realised for each of the components included in the recipe's structure. Meanwhile, effects of an adsorption protection of friction surfaces, formations on the friction surfaces of servo-vitas metal-plucking films (at the expense of which, the actual area of the contact increases in dozen times) and the formation of wear-proof films by the purposeful reconstruction of metal's crystallites in a thin surface layer.

Long-serviced and reliable units of the hermetically closed supports, elaborated at USPTU for bits with supports of a HY type, insulating the lubrication material from a flushing liquid, sludge and gas allow refusing the traditional approach of the usage in the supports of rotary bits plastic lubricants and use in them half-liquid lubricants with high tribotechnic properties. The researches carried out allowed to create a series of efficient lubricants for the supports of various design constructions, which according to their operation properties surpass native and foreign analogues.

1.The lubricant for hermetically closed oil-filled supports of rotary bits – Series СД[11]. The results of comparative tests of the lubricant СД and other lubricants, used in bits with hermetically closed supports, carried out on a special stand, simulating an operation of a big roller bearing of the bit with the support of type HY as per specific power, are represented in Table 1. The plastic lubricant XG-107 (USA) is taken as a base one.

It is seen from Table 1, that the lubricant СД possesses the highest wear-resistant properties, in the medium of which an energetic capacity of wearing of steel increases essentially (in 5…15 times) in comparison with the lubricant XG-107. X-ray researches showed that in a surface layer of the bit's steel, being used in the medium of the lubricant СД, heterogeneity and concentrations of stresses occur less.

Table 1

Relative energetic capacity ($A_0$) of steel wear 14ХН3МА

| Lubricants | $A_0$ at specific power in Vatt/mm$^2$ | | | | |
|---|---|---|---|---|---|
| | 0,10 | 0,15 | 0,20 | 0,25 | 0,27 |
| XG-107 | 1 | 1 | 1 | 1 | 1 |
| Dolotol НУ | 3,10 | 6,70 | 9,40 | 7,60 | 3,85 |
| СД | 5,70 | 8,50 | 13,0 | 15,0 | 10,0 |
| УссА | 1б15 | 1б60 | 1б70 | 0б60 | - |
| ЛПИ-27 | 1,33 | 1,65 | 0,01 | - | - |

The bits with hermetic supports, filled with the lubricant СД, at the stage of experimental-industrial tests were worked in various drilling conditions, namely: at high-rotation and low-rotation drilling modes, at washing-out by water and clay

solutions, at small and large drilling depths, at various areas. The lubricant СД provides with a stable increase in the passage for a bit and its resistance, due to which a run drilling speed increases by 8,5…21%. Upper values of the run speed conform to the conditions, when a mechanic drilling speed increases. An increase in the mechanical drilling speed was provided practically always, when drilling enterprises managed to realise recommendations on the usage of test bits with high axial loads.

2.Lubricants for non-hermetic supports of the bits.

Bits with non-hermetic supports are used in a wide range of axial loads and rotation frequencies in various, as per aggressiveness, media. In these conditions a plastic lubricant shall be kept well in the cavity of rotary bits and possess high tribo-technic properties. A type of the hardener, mostly, defines maintenance properties of the plastic lubricants. A main volume of the plastic lubricants is manufactured with the usage of hardeners based on soaps of synthetic fat acids. Non-organic hardeners are used considerably much less. The disadvantages, reducing an efficiency of the application of such lubricants in the opened supports of the bits are as follows:

1. Lubricants based on sodium soaps lose maintenance properties in case of water's contact.

2. Lubricants based on calcic, complex calcic and lithium hardeners are characterized by a low ultimate strength of displacement, that in case of the presence of even a small differential pressure in a bit's support, the lubricants have a tendency to be pressed out and washed out from the cavity of the rotary bit;

3.Lubricants based on non-organic hardeners possess a low temperature limit of the application (up to 373 K), above which the hardener coagulates inevitably, and they have non-satisfactory conservative properties and a high cost.

The researches, carried out at USPTU [3,12,13], showed that compositions of some polymers possess high cohesion and adhesion properties to bit's materials. The lubricants elaborated on their basis are capable to protect the cavity of a rotary bit from entering of a drilling solution, and realise effects of a convection heat-exchange inside the cavity of a rotary bit, reducing by this, a heat-intensity of the operation of friction units. The products of wear are removed from the area of friction in due time and fresh lubricant enters the contact area. Below are given characteristics of the elaborated lubricants.

The lubricant СДП-1 for the supports of rotary bits with a polymer hardener and a complete set of anti-wear additives [14], which has high wear-resistant and adhesion properties. The introduction of special tribopolymer-forming additives based on politetraftorethylene allowed receiving lubricant СДП-2 with a higher index of scratch and securing better retaining in the cavity of the rotary bit [15].

Lubricants Ипм and CTM are elaborated for drilling in aggressive media.

The lubricant for rotary bits Ипм [16] assists to a better protection of the friction surface of bit steels from sulfur-hydrogen corrosion due to the fact, that a screen is formed on the metal as the result of high adhesive properties and a stability of special addition to aggressive media. The lubricant CTM [17] is designated for the operation in hydro-abrasive media.

The improvement of lubricants for bits by additives is necessary to struggle with negative results of hydrogen saturation of the friction surfaces. Operation conditions of bearings of supports of bits are favorable for a display of hydrogen wearing of their elements. In order to reduce a negative influence of hydrogen wearing on wear-resistance of bit's steels, two types of additives are applied in the lubricants of series СДП: coordination-linear metal-containing polymers and high-

dispersed cuprous-containing powders. Values of tribo-technical properties of the lubricants are represented in Table 2.

Table 2

Speeds of 14ЧР3МА steel wear
at friction in lubricants of different composition

| Lubricants | Speed of steel wear in mcm/h at load intensity in N/mm | | | | |
|---|---|---|---|---|---|
| | 200 | 300 | 400 | 500 | 600 |
| ХО-249 | 0.08 | 0.20 | 0.22 | 0.41 | 0.73 |
| Dolotol H | 0.15 | 0.22 | 0.28 | 0.52 | 0.98 |
| СДП-1 | 0.08 | 0.12 | 0.16 | 0.18 | 0.22 |
| СДП-2 | 0.13 | 0.14 | 0.18 | 0.30 | 0.48 |
| ИПм | 0.04 | 0.09 | 0.11 | 0.14 | 0.18 |
| СДПЛ | 0.12 | 0.12 | 0.13 | 0.18 | 0.23 |
| СТМ | 0.13 | 0.15 | 0.18 | 0.32 | 0.45 |

Indices of rotary bit's lubricants washing-out from the cavity of rotary bit are presented in Table 3.

Table 3

Rotary bit's lubricants washing-out

| Lubricants | Washing-out in % at water $T^o$ in K | | | |
|---|---|---|---|---|
| | 293 | 313 | 333 | 353 |
| 1 | 2 | 3 | 4 | 5 |
| ХО-249 | 0 | 0,9 | 1,5 | 8,3 |
| Долотол-Н | 0 | 2,5 | 2,9 | 9,3 |
| СДП-1 | 0 | 0 | 2 | 6 |
| СДП-2 | 0 | 0 | 0 | 1,8 |
| ИПм | 0 | 0 | 0,07 | 10,2 |
| СДПЛ | 0 | 0 | 1,1 | 12,8 |
| СТМ | 0 | 0 | 1,0 | 2,0 |

Physical and chemical properties of the elaborated plastic lubricants are represented in Table 4.

Table 4

Physical and chemical properties of bit's lubricants

| Index | Lubricants | | | | | | |
|---|---|---|---|---|---|---|---|
| | XG-249 | Долото л Н | СДП-1 | СДП-2 | ИПм | СДПЛ | СТМ |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| Temp-ture of drop falling, K | 458 | 458 | 373 | 430 | 450 | 395 | 420 |
| Penetration at 298 K | 265-295 | 250-310 | 280 | 150-170 | 220-280 | 190-230 | 180-190 |
| Strength yield at 293 K, Pa | - | 600 | 700 | 1000 | 1000 | 800 | 750 |
| Viscosity at 293 K, Pa c | - | 170 | 180 | 3550 | 180 | 220 | 150 |
| Evaporability at 373 K for 1 hour, % | - | 0 | 2-3 | 1,2 | 0,5 | 1,2 | 1,0 |
| Colloid stability, % | - | 10 | 5 | 5 | 3 | 6 | 3 |
| Lubricating properties at FRMF:$И_3$ $P_k$,Н | -<br>1000 | 75<br>890 | 75<br>940 | 80<br>1000 | 75<br>1100 | 75<br>1200 | -<br>- |

The analysis of tables 2-4 shows, that the elaborated lubricants have tribo-technic indices high enough and they are kept well in the cavity of a rotary bit.

All elaborated lubricants have been subject to a wide experimental-industrial approbation in various regions of CIS and showed high maintenance properties.

**CONCLUSIONS:**

1. The research works at USPTU are carried out successfully, directed to the improvement of indices of functioning of rock's destroying tools due to the development of all its functional systems.
2. Various technological design structures of seals are elaborated, conforming to the resistance of hermetically closed supports of rotary bits.
3. The forced lubrication of support of rotary bits on the basis of over-bit lubricators with the application of the proposed lubricant allow to increase substantially (by 65-85) the passage for a bit and its resistance.
4. The new lubricants elaborated at USPTU are not expensive and have high maintenance properties.

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