Analysis of the roller bit lubrication system

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Abstract. The results of most studies conducted in the field of improving the reliability and performance of roller drill bits indicate the main cause of their failure, which is the failure of the bearing unit. We believe that work on improving the reliability and performance of roller bits lies in the modernization of existing or the development of fundamentally new lubrication systems for roller bits.

1. Introduction and Background
Drilling operations are an integral part of activities related both to the extraction of ore and non-ore mineral resources (MR) as well as oil and gas resources, and activities aimed at their exploration.

For a number of objective reasons, the mechanical method of rock fragmentation has become most prevalent. This method includes such types of drilling as: percussion rotary drilling (hardness of the rock $f = 6\div14$ according to Protodyakonov's scale), rotary roller drilling (hardness of the rock $f = 4\div14$) and rotary cutting drilling (hardness of the rock up to $f = 8$). These types allow performing drilling operations both in the softest and in the hardest rocks, subject to the selection of an appropriate rock cutting tool. Rotary roller drilling allows covering a significant range of rocks by hardness, which is the determining factor contributing to its significant share reaching up to 80-85% of all drilling operations [1,3]. Trends indicate that drilling volumes are going to increase. It is worth noting that roller drilling is one of the most expensive types of drilling, which is directly related to the cost of roller bits. For roller drilling, the cost of bits can exceed the cost of the drilling machine itself several times over a 10-year operation cycle [2,4,5], i.e. the cost of drilling tools can reach up to 50% of the total cost of MR extraction. Considering the above, we are setting a task aimed at improving the operational durability of the drilling tool and, as a result, reducing economic costs.

2. Materials and Methods
In this work, we used complex research methods including the analysis and synthesis of previously performed work on the destruction of frozen rock by a roller drilling tool. We studied the states of the massif at the bottom of the well (stress and strain), as well as the influence of the design parameters of drill bits on the drilling process.

3. Experimental Section
The progressing evolution in the roller bit construction today is represented by a variety of design solutions and layout options related to the location and number of rollers [6, 7]. Of all this variety, the most common design is a roller bit with three cylindrical, spherical or cone rollers. The arrangement of roller bits is very diverse, but it is possible to identify the main elements of the classification of roller bits, namely:
1. By body design.
   – box type bits. They have a cast body with welded legs and axles placed on them;
   – sectional bits. The body of the bit is welded from separate sections (legs).
2. By the destructive impact of the roller on the rock.
   – crushing. Minimal slide of the teeth when rolling the roller around the bottom;
   – crushing and sliding. In the destruction of the rock there is an effect of sliding of the tooth when rolling the roller (milling effect).
3. By the design of purging or flushing devices (availability of blowing for bearings).
   – central flushing;
   – side flushing;
   – central purge;
   – side purge;
   – combined purge.
4. By the number of rollers.
   – one-roller bits;
   – two-roller bits;
   – multi-roller bits.
5. By the design of the cutting structure of rollers.
   – milled teeth (depending on the design, separately working flanks of the tooth, end flanks, or the whole tooth can be reinforced);
   – teeth reinforced with hard alloys (wedge-shaped tooth, cone tooth, tooth of a different shape).
   – combined.
6. By the type of the bearing unit in the assembly:
   – rolling bearings;
   – one radial plain bearing, the rest - rolling bearings;
   – one radial plain bearing with a sealed oil-filled assembly, the rest - rolling bearings;
   – two or more plain bearings.
7. By the design of the assembly:
   – with unsealed assemblies (open);
   – with sealed assemblies (used at low speeds).
8. By the presence of a lubricator:
   – lubricator located directly in the bit body: by the type of drive: piston and diaphragm, see Figure 1;

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**Figure 1.** Oil-filled tank located in the bit leg. An oil tank 3 with a flexible diaphragm 2 is located in the upper part of the bit leg 4. The diaphragm is affected by pressure from the flushing fluid (air) and the lubricant enters the thrust bearing through channel 1. Between the roller 5 and the leg 4 there is a seal that prevents both the leakage of the lubricant and the ingress of drill cuttings into the bearing unit.
– the above-bit lubricator is located outside the bit body, in the end rod of the drilling assembly, see Figure 2.

![Figure 2. Lubrication system with oil tank located in the end rod of the drilling assembly.](image)

The device is placed in the end rod of the drilling assembly and contains the oil tank 3 (formed between the inner surface of the rod 1 and the air supply pipe 2), the starting-regulating device 4 (mounted in the valve box) and the guide vane 5. In the gap between the pipe and the sleeve oil is mixed with air and then the air-oil mixture enters the bearing assemblies 10 through the gap 7 between the guide sleeve 6 and the bit body 9 and through the channel 8. Waste oil exits through the gaps between the legs and the ends of the rollers.

Modern industry produces a large number of types and sizes of three-roller drill bits for various tasks and working conditions. The use of the latest computer technologies in the design and development of three-roller drill bits made it possible to calculate the bit operation scenarios at the design stage, identify problem areas and find optimal solutions, reducing the proportion of field tests [8-14]. Modern high-precision equipment of manufacturers has improved the accuracy of manufacture and assembly of bits at all stages of assembly operations, which contributes to the increase of the bit life. Three-roller bits are successfully used to penetrate oil, exploratory, drilling and blasting as well as other holes for rocks of any hardness. Long-term observations, as well as a large number of research works aimed at studying the causes of bit failures, indicate that failure of a drill bit is in most cases caused by the destruction of the bearing unit, which in its turn can cause jamming of the roller [3, 4, 5]. Moreover, the failure of the bearing unit may occur before the life of the rock cutting element of the drill bit is over.

Figure 3 shows a process flow diagram of a roller bit in the course of its interaction with the bottom.
The operation of a roller bit can be represented in the form of three main processes.

First – the main (functional) process. The elements included in this process ensure the transfer of axial force from the feeding mechanism of the drilling machine to the massif, forming a contact patch with a certain row of teeth of the roller (design feature, reinforcement scheme). In order to comply with the ideology of roller drilling, namely, the alternate penetration of a tooth into the rock to a certain depth with the softening of intermediate pillars, it is required to ensure that the row of teeth is replaced with the next row, which is achieved by the rotation of the roller on the axle [27]. In case of drill bits with more than one roller, there is a successive rolling around the bottom of all the rollers relative to the axis of rotation (drilling assembly).

Second – a supporting process. The elements included in this process ensure the performance of the bit as a whole. Failure of any of the elements of this group leads directly to the bit failure. For example, a leakage or unsatisfactory operation of the sealing system leads to premature failure of the bearing unit, resulting in conditions which contribute to the jamming of the roller. This provokes premature abrasion of the roller cutting structure and increases the temperature of the bottom space, etc. The operation of the lubrication system in modes that do not properly provide heat removal and renewal of the lubricating layer in friction units causes increased wear, increased contact stresses, occurrence of sticking areas, and therefore an increase in gaps, misalignment of the bearing unit elements and the roller relative to the axle (leg), and destruction of the bearing unit.

Third – a sustaining process. Elements of this process are basic and are used to place and protect elements of the two preceding processes. If for any reason there is an integrity damage of the bit body or roller, further operation of the bit will be impossible.

It is worth noting that the failure of the elements of the first process affects the durability of the bit indirectly. If the roller cutting structure is worn out, but the remaining elements of the second and third processes are working, the bit can continue to work perfectly well, see Figure 4.

In this case, the performance will be lost, because under nominal operating conditions, the bit will not be able to provide the expected rate of penetration. The simplest thing to do in this situation is to increase the axial force. However, this will lead to accelerated wear of the bearing unit and premature
abrasion of both the bit body as a whole and the housing of the rollers themselves, and this is a direct path to the exposure of the bearing unit, see Figure 5.

This assumption confirms the analysis for determining reasons of roller bit failures [17, 18, 21, 22]. Long-term observations show that the main reasons for the failure of the drill bit are caused by a malfunction of the roller bearing unit and the destruction of the body elements of the bit (abrasion of the legs). This is confirmed by the data obtained from one of the sites of CheremkhovUgol: the results of observations revealed that most of the failures were caused by abrasion of the bit body (Burmash), in particular, at the back of the legs, which led to the exposure of the bearing unit, causing its destruction by entering abrasive particles. One of the ways to solve this problem is to place the assemblies of the rollers inside the bit body. Thus, we exclude a “weak spot”, a roller leg that is prone to abrasion. However, it is worth noting that such improvements require a change in the proven technology for producing modern roller bits, which is currently very difficult to implement. Moreover, the performance of the bearing unit depends on the design of the assembly. Here are the main design elements: type of bearings used in bit assemblies, presence or absence of blowing of bit assembly bearings with compressed air, presence of a lubrication system and isolation from the external corrosive environment of the bearing unit. At the first stage of the development of roller bit designs and the introduction of a blowing technology for assemblies, the durability of roller bits was increased by 20-25% [6]. But the bearings continued to work under dry friction conditions. The next stage of improving the durability of roller bits was associated with the introduction of improvements to address issues related to the lubrication system of the bit bearings. The use of lubrication systems in bits allowed increasing the durability by 1.9-2.3 times [6]. Obviously, surveys aimed at intensifying drilling operations should be carried out along with the improvement of the lubrication system. The proposed design solutions allow placing the lubrication system in the body of modern bits, without requiring significant changes in the design itself, or placing them outside the bit body. There is a need to develop such a bit design, which would ensure the maximum mechanical rate of hole penetration.
with optimal drilling conditions, and maintain its performance over the maximum possible time interval.

4. Results and Discussion

Lubrication systems of modern domestic roller bits were developed in the 50-60s of the XX century. Due to the epochality of this period of time, the main requirements for lubrication systems were: simplicity of design, ease of manufacture and ease of placement in the rigid boundaries of the drill bit.

The first prototypes of lubrication systems introduced in the roller bit construction could ensure the operability of the bearing unit, since its life was longer than the life of the roller cutting structure. The roller bit life could not be provided with the materials that were used at that time in the manufacture of the roller cutting structure (statistics of 70-80s of the XX century confirms that a significant percentage of failures of roller bits consisted in wear and loss of the cutting structure [21]). However, with the development of the materials from which the teeth are made and the technology of fastening and positioning of the teeth, the durability of the bit cutting structure increased. The share of roller bit failures due to the wear of the cutting structure has significantly decreased. Currently, the main reason for roller bit failures is jamming of the roller on the assembly. In most cases, this failure occurs due to the destruction of the bearing unit, which is usually caused by poor cleaning of the bearing unit: from abrasive particles of the destroyed rock; from the wear particles of the bearing unit components. It is worth noting that a significant part in the operation of rubbing parts in plain bearings as well as rolling elements in the respective bearings is taken by the issue of compliance with the temperature conditions necessary for normal interaction of working surfaces. The presence of these reasons in one way or another is due to the lack of an operable lubrication system.

Current market conditions dictate new requirements, namely, increasing the performance of the bit at the lowest cost of its production. In other words, each bit must live its full lifespan before a failure of one or several elements occurs. Cases of the bit failure due to the failure of the bearing unit while maintaining the performability of the roller cutting structure become unacceptable. Ideally, you need to achieve a situation where the failure of one of the bit elements occurs simultaneously with the other bit elements, thereby ensuring an increase in the overall efficiency of the tool. If you prepare the system in more detail and consider a roller bit as a complex mechanism consisting of many elements with individual performance characteristics, reliability indicators and probabilistic values for failure, then you should strive to ensure that all elements of the roller bit have an approximately equal safety margin (failure of one of the elements leads to poor performance or failure of the entire bit, depending on the element).

So, today the main reason for the failure of a bearing unit is the destruction of rolling elements and tracks as a result of abrasive wear. This wear is due to the penetration of (fine) particles of the destroyed rock into the bearing unit. You need to understand the performance of existing systems for lubrication of roller bits and sealing of bearing units, as well as to look for new design solutions aimed at eliminating problems arising during the operation of roller bits.

4.1. Sealed closed type lubrication system

The main advantage of these systems is the relative simplicity of the design, which contributes to a simpler (easier) placement of lubricant in the roller bit assemblies. At the core of these systems is one unchanging principle: when the bit is assembled, the lubricant is pumped into special oil tanks equipped with an elastic membrane. It was believed that during the operation of a drilling tool due to the effect of external pressure on the membrane, the lubricant had to be supplied to the lubrication units. However, during operation, there were cases of bit failure due to destruction and jamming of the bearing unit, and with further bit disassembling it turned out that the reason for this was the imperfection of the lubrication system. That is, a sufficient amount of lubricant in the lubricant tanks was not involved in the lubrication process. It means that the lubrication of the bearing unit was carried out only using the volume that managed to get into the bearing when the oil tank was filled. In the first prototypes of these systems, the impossibility of lubricant circulation in the bearing unit was due to the absence of branch ducts. The lubricant that got into the bearing during filling overheated
and was contaminated by wear particles of rubbing surfaces, as a result of which it lost its lubricating qualities.

4.2. Sealed closed type lubrication system with lubricant consumption compensation

The ideology of the flow compensation lubrication systems is as follows: it was believed that the unsatisfactory performance of the classical lubrication system lay in an insufficiently large tank for filling the lubricating material. Therefore, designs with an increased volume of the oil tank were proposed [23], which should have been enough for many-hours-long operation of the bit, without the need to lift it to the surface for refilling. However, both the classical lubrication system and the lubrication system with lubricant consumption compensation work using one and the same principle: supply of the lubricant to the friction zones should be performed using the impact of pressure on the oil tank, which is created by the flushing fluid or air used to clean the bit. For the operation of systems of this type, it is necessary to have an overpressure in the area of the membrane, which should exceed the pressure in the area of the roller assembly. But since this pressure is created by drilling mud or air, an excess is unlikely. From this it follows that, most likely, the lubrication of the assembly will be carried out only by the volume that entered the friction zones during refilling, with all the ensuing consequences.

4.3. Lubrication system with forced lubricant supply.

It is the most promising and efficient system, fundamentally different from those discussed above. The idea of this system is as follows: due to the impact of the actuator, lubricating material is fed through the underwater channels to the bearings of the roller bit assembly, which in their turn are a serious obstacle to the circulation of lubricant and are practically impassable for classical systems. Renewal of the lubricant is ensured by the possibility of lubricant circulation around the system, which ensures proper lubrication of the rubbing surfaces. Due to the force effect, the waste lubricant is displaced from the bearings with a new portion of the material. Theoretically, this should lead to an improvement in the operating temperature of the rubbing surfaces and create more acceptable conditions for the operation of bearings from the point of view of tribology. This system type solves the issue of lubricant circulation, but leaves open the following questions.

First, in the process of operation, the lubricant is contaminated by wear particles of the bearings. The simplest solution to this issue is to reduce the concentration of abrasive particles by continuous admission of a new portion of lubricating material. This solution is limited by the capacity of the oil tank. A design solution consists in the placement of two tanks in the end rod, the first one - to receive the waste lubricant, the second one - to accommodate the required amount of lubricant and the drive mechanism. The most attractive way to solve this issue is to dispose of the waste lubricant through the gap between the roller and the assembly into the bottomhole region.

Second, the gap between the roller and the assembly of the bit is large enough, which allows small abrasive particles to penetrate into the bearing unit. However, directly in the process of the roller bit operation, the penetration of drill cuttings through the specified gap is unlikely, since it is used to remove the waste lubricant material under pressure generated by the lubrication system drive. Penetration of particles is possible when the drilling assembly stops and there is no more head in the lubrication system, which creates the conditions for the penetration of rock particles into the bearing unit.

5. Summary and Conclusion

The three-roller bit, with all its flaws, continues to be the most versatile and widespread rock cutting tool.

Various design solutions were developed and implemented. Some of them have passed the test of time and are successfully used in the roller bit construction. Others did not go into production due to the complexity of implementation, or due to the complexity of the bit design itself, which inevitably leads to an increase in the cost of the tool that is already not cheap. All these stages of development and improvement made it possible to determine the most efficient design of a roller bit bearing unit consisting of: large roller bearing, retaining drill bit bearing, plain bearing and foot bearing (location
of elements from the base of the roller). The current state of research aimed at improving the quality of bits and their performance confirms the dependency of the reliability of bits on the life of bearing units. Increasing the durability of the adopted layout of a three-roller bit lies in the improvement of the lubrication system. Preference should be given to the use of systems with a forced supply of lubricant to friction pairs. It is necessary to conduct research aimed at improving the insulation or complete sealing of the assembly from the external environment. The implementation of a fully sealed assembly is complicated by the extreme operating conditions of the drilling tool: high contact stresses, high abrasive ability of the environment, high temperatures. All this requires the development of specific sealing devices capable of functioning in the specified conditions. In their turn, such devices will be demanding on the technology and quality of their manufacture. It is necessary to ensure maximum manufacturing accuracy at all stages of bit production in order to minimize possible distortions and misalignment of elements. This, in its turn, will inevitably entail a rise in the price of an already expensive drilling tool. The use of drill bits with sealed assemblies (complication of the bit design and increase in the cost of the tool) may be efficient for deep holes: mining, technological, exploratory [28]. With a small proportion of terminal operations in the total time interval allocated for penetrating a hole. Lifting of the drilling assembly from the deep to replace the bit is a time consuming operation. It is necessary to ensure that the penetration of the hole is carried out by one bit, the required performance of which can be ensured by sealing the bearing assemblies [29].

Drilling and blasting holes, as a rule, have small depths and a significantly larger number of terminal operations associated with the descent and lifting of the drill assembly and the movement of the drilling machine, so it becomes possible to replace a dysfunctional drill bit without additional downtime by combining the bit change operation with one of the terminal operations. The most promising bits for the production of these holes are tools with a forced lubrication system and removal of waste material through the gap between the roller and the assembly into the bottom of the well.

The issue of using bits with sealed assemblies in drilling and blasting operations may be economically unjustified and requires additional research.

References
[1] Bovin K A 2017 Analysis of operation of drilling equipment for blasting holes in open pits of the Krasnoyarsk Territory and Khakassia Mining Research and Information Bulletin (scientific and technical journal) S38 pp 135–143
[2] Butkin V D, Gilyov A V 2010 Selection and rational operation of drilling tools and machine tools in open pits: monograph (Krasnoyarsk: Siberian Federal University) p 236
[3] Gilyov A V, Shigin A O, Doronin S V, Gilyova N N 2011 Methods for calculating the hardness in the design of the actuating devices of drilling machines Modern high technologies 1 pp 132–134
[4] Shigin A O, Gilyov A V, Shigina A A 2013 Stresses and durability of roller bits when drilling complex structural rock massifs Mining Research and Information Bulletin (scientific and technical journal), 4 pp 325–333
[5] Katanov B A 2003 Main causes of wear of roller bits and ways to reduce it Mining machines and automation 2 pp 13–14
[6] Peretolchin V A 1993 Engineering, technology and experience of drilling in open pits (Moscow: Nedra) p 286
[7] Peretolchin V A, Strabykin N N, Dolgun Ya N 1968 Analysis of the causes of failure of roller bits and ways to improve their durability Proceedings of Irkutsk Polytechnic Institute 49
[8] Shigin A O 2013 Designing adaptive working drilling machines for complex structural rock massifs: monograph (Krasnoyarsk: Siberian Federal University) p 156
[9] Gilyov A V, Shigin A O, Chesnokov V T, Belorezov I R 2013 Improving the efficiency of operation of drilling equipment at mining enterprises: monograph (Krasnoyarsk: Siberian Federal University) p 372
[10] Ismakov R A, Moguchev A S I, Matveev Yu G, Popov A N, Le Hyu T 2005 Development and bench testing of radial compaction of roller bit assemblies for medium and high rotational speeds Oil and Gas Engineering 2005 3 pp 71–77

[11] Bulyukova F Z, Moguchev A I 2011 Improving the design of assemblies and roller bit cutting structure for directional drilling conditions Scientific Research and Innovation 5(1) pp 60–61

[12] Matveev Yu G, Popov A N, Ismakov R A, Blinkov O G, Moguchev A I, Samohodov Yu I 2001 Developments to improve the sealing and lubrication systems of high-speed roller bits Transactions of the Mining Institute 148 -1 pp 161–163

[13] Ismakov R A, Matveev Yu G, Moguchev A I 2003 Development and improvement of forced supply systems for the lubrication of roller bit assemblies Oil and Gas Engineering 1 pp 95–103

[14] Chernov S V, Moguchev A I 2008 Development of a sealing device for the roller bit assembly for directional drilling of wells 59th Scientific and Technical Conference of Students, Postgraduates and Young Scientists p 124

[15] Qiu Y L, Li S B, He W and Han C J 2011 Application of Multi-Layer Composite Membrane in Tricone Bit Bearing Advanced Materials Research 314–316 pp 62–65

[16] Ryczyniak M and Rajchel G 2014 The analysis of technology of drilling with roller bits on the Carpathian foreland area in the years 1995-2011 AGH Drilling, Oil, Gas 31(1) p 135

[17] Yashkym R and Slipchuk A 2019 Assessment of reliability and criteria for improving the quality of rock cutting equipment of tricone drilling bits for well-boring especially hard rock Bulletin of the National Technical University «KhPI» Series: New solutions in modern technologies 5(1330) pp 77–85

[18] Kershenbaum Y M, Kaminskii Y A and Amdur M A 1974 Improving the durability of the roller bearing for drill bit supports Chemical and Petroleum Engineering 10(6) pp 537–538

[19] Xu Z X, Jia Y, Zhou J, Wu C, and Liu Y 2014 Hybrid Drill Bit Combining Fixed-Cutter and Roller-Cone Elements Exceeds Expectations in Challenging Application in Tarim Basin, China IADC/SPE Asia Pacific Drilling Technology Conference

[20] Rafezi H and Hassan F. 2018 Tricone bit health monitoring using wavelet packet decomposed vibration signal 5th International Conference on Control, Decision and Information Technologies (CoDIT)

[21] Ghosh R, Schunnesson H, and Kumar U 2016 Evaluation of operating life length of rotary tricone bits using Measurement While Drilling data International Journal of Rock Mechanics and Mining Sciences 83 pp 41–48

[22] Das M K, Sarkar S, and Choudhary B S 2018 Experimental and numerical analysis of rotary tricone drill bit and its wear prediction Journal of the Brazilian Society of Mechanical Sciences and Engineering 40(8)

[23] Maurer W C 1975 Patent search and review on roller-bit bearings seals and lubrication systems State-of-the-art

[24] Peltier B P, Cooper G A, and Curry D A 1987 Use of Torque Analysis To Determine Tricone Bit Bearing Failure Proceedings of SPE Annual Technical Conference and Exhibition

[25] Hightower W J 1964 Proper selection of drill bits and their use Proceedings of SPE Mechanical Engineering Aspects of Drilling and Production Symposium

[26] Drill bit seal Sealing Technology 1 p 14

[27] Miller T W and Cheatham J B 1971 Rock/Bit-Tooth Interaction for Conical Bit Teeth Society of Petroleum Engineers Journal 11(02) pp 162–170

[28] Nixon M S and Walter J C 1993 Unique Rock Bit Cutter Fabrication Technology Provides Bit Design, Performance, and Reliability Breakthroughs SPE Annual Technical Conference and Exhibition

[29] Schmidt S R, Wittry A E, Burr B H, and Kelly J L 1991 Metal Bearing Seal Technology Improves Drilling Efficiency of Rolling Cutter Bits in High-rpm North Sea Applications SPE/IADC Drilling Conference