On the determination of design and geometric parameters of a upper bit slurry grinder

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Abstract. Experimental and field studies have identified the rational geometric dimensions of elements of upper bit sludge grinder, ensuring its operation’s stability. Laboratory studies of upper bit device model showed that the amplitude of drum oscillations depends on the shaft rotation frequency, spring stiffness, and drum inertia moment. To determine the dimensions of working channels and drum openings of a upper bit device, the analysis of slurry samples from directional and horizontal wells was carried out. Designs of a slurry grinder for drilling wells with cone bits with diameters of 146 and 215.9 mm have been developed. Field tests showed that the use of the developed design of near-bit sludge grinder allows to increase the mechanical speed by 18% compared to the conventional method of drilling.

1. Introduction

The increase in oil and gas productions is inextricably linked with the increase in technical and economic indicators of the well drilling process. Well construction time can be reduced by increasing drilling speeds and using new types of rock cutting tools, new types of flushing fluids, a circulation system equipment (mud pumps, equipment for preparing and cleaning flushing fluids) as well as by reasonably improving equipment operation. A significant reserve in increasing the efficiency of drilling operations is the improvement of drilling techniques and technology based on the introduction of effective equipment for cleaning bottom holes from sludge [6]. The degree of perfection of flushing the well and equipment for its implementation significantly affects the successful, trouble-free well drilling. The quality of cleaning well bottom from sludge affects the mechanical drilling speed, the quality of wellbore, sinking and durability of bit, turbo-drill, and drill tool layout elements.

In horizontal drilling, all drill cuttings tend to sink to the bottom wall of well. To prevent the sedimentation and formation of sediment, it is necessary that particles of cuttings be in a suspended rather than entrained state [5]. But, the increase in supply and density of drilling fluid leads to the mudding of well walls [4, 6]. According to the literature, it is known that suspended particles can be transported in drill particles of a size of not more than 1–2 mm [3, 10–14].

To increase the efficiency of cleaning wells from sludge, a upper bit device has been developed. The device (Figure 1) is installed during rotary drilling (rotary method, downhole motors) over a bit. When drilling a well, the sub 2 rotates, drives the screw 3 and the rotor 4. The rotating sub 2 and the drum connected by springs 13 and 14 form an oscillating system. The auger directs the flushing liquid with slurry into the internal device cavity. The auger directs the liquid with the slurry in the axial direction and the radial direction, while the slurry is partially crushed due to impacts, small particles are sifted through the grid (2–3 mm mesh openings), large particles fall into the rotor and are radially...
rejected onto the reflector, further grinding of the slurry occurs. The final grinding occurs when large particles enter the channels 16 and crush them with the end face of the rotor. The purification of solution is facilitated by torsional vibrations of drum (mesh), which occur under the action of drum inertia, the fluid ejected by the rotor onto the eccentric reflector and spring forces [1].

Figure 1. Structural diagram of a upper bit slurry grinder

The stand is equipped with instrumentation: the TЭ-M1 tachometer, the Diana-2M vibration analyzer. To process the measurement results, the Atlant and Avrora-2000 software are used [9].

2. Methods and materials

The main dimensions of upper bit device model were determined by physical modeling, taking into account necessary conditions of geometric similarity and physical similarity of the model and nature [2, 8]. Some of the secondary processes that do not affect the operation of oscillatory system of sludge grinder were modeled approximately.

Figure 2 shows a diagram of a bench for researching a near-bit device model. The stand is designed to determine the optimal parameters of the near-bit oscillation system of the device: spring stiffness c, rotor speed n, moment of inertia of the drum Jb and the frequency and amplitude of drum vibrations depending on them. The stand consists of a frame 1, on which the supports are fixed 2. An electric motor 3, a speed controller 4 and a drum 5 are mounted on the supports 2. The engine transmits power to the speed controller 4 using a coupling 6. The drum is mounted on a shaft 7, which in turn is mounted on radial bearings 8. The rotation from the speed controller 4 to the drum 5 is transmitted by means of the coupling 9. The drum is mounted on the shaft with a clearance by means of centralizers 11. The drum 5 is connected to the centralizers by means of springs 12. For measuring the speed, the sensor 10, d To measure vibration – sensor 13.
3. Results

The stand tests were carried out under various conditions, changing the shaft rotation frequency $n$, spring stiffness $c$, and drum inertia moment $J_0$.

When planning the experiment, the value of the root mean square value (RMS) of drum vibration velocity was chosen as the optimization parameter [7]. The RMS depends on the following factors: the number of shaft revolutions, spring stiffness, and the moment of drum inertia. Figures 3 and 4 show the results of measuring the vibration drum velocity.

![Figure 3](image)

**Figure 3.** The graph of the dependence of the RMS vibrational velocity of the drum on the shaft rotation frequency at $J_0=0.0036$ kg·m² and springs of different stiffness

It can be seen from the graphs that when the shaft rotational speed increases to 200–275 rpm, the RMS vibration speed increases. At a shaft rotation frequency of 250–275 rpm, a resonance phenomenon is observed. Recommended values of the shaft speed of the model are 50–200 rpm. With increasing spring stiffness, the RMS vibration speed decreases. With increasing moment of inertia of
the drum, the RMS vibration velocity increases. The most optimal drum is with a moment of inertia $J = 0.0036 \, \text{kg} \cdot \text{m}^2$.

Stand studies of the oscillatory system of slurry grinder confirm the operability of upper bit system of the grinder grinder. The results of theoretical and experimental studies show sufficient convergence. To verify the accuracy of determining design-geometric parameters and verify the operability of upper bit device, field trials are necessary.

Designs of a slurry grinder for drilling wells with cone bits with diameters of 146 and 215.9 mm have been developed (table).

Requirements for the construction of upper bit slurry grinder: 1) ensuring the work reliability when performing all technological work on drilling wells; 2) providing a gap between the well wall and the drum; 3) length not more than 600 mm; 4) the outer diameter is less than the diameter of turbodrill (layout of drilling tool bottom); 5) connecting threads should allow installation over a bit; 6) the drum is mounted on a shaft with an axial and radial clearance of 2 mm; 7) minimum manufacturing cost.

**Figure 4.** The graph of the dependence of the RMS vibrational velocity of the drum on the shaft rotation frequency at $c = 750 \, \text{N/m}$ and various moments of inertia of the drum

| Table 1. Technical characteristic of near-bit Sludge Grinder |
|----------------------------------------------------------|
| **Parameters of near-bit sludge grinder** | For bit diameters 215.9 mm | For bit diameters 146 mm |
| Outer diameter, mm | 190 | 126 |
| The outer diameter of the drum, mm | 185 | 121 |
| Drum inner diameter, mm | 168 | 109 |
| The shaft's outer diameter, mm | 123 | 70 |
| Internal shaft diameter, mm | 85 | 48 |
| Overall length, mm | 510 | 500 |
| Drum length, mm | 264 | 264 |
| Connecting thread, mm | Z-117 | Z-86-upper, Z-88-lower |
| Diameter of the drum cells, mm | 2.5 | 2.5 |
| Screw diameter, mm | 157 | 103 |

The geometric dimensions of slurry grinder elements were determined using the results of stand tests of the model and the results of theoretical studies of the upper bit system of slurry grinder.

The diameter of drum was determined:
where $D_a$ is the outer diameter of drum of model, $K_a$ is the simulation coefficient.

The inner and outer diameters of shaft, screw and the inner diameter of the drum were determined in a similar way.

The linear size of slurry grinder drum was determined:

$$L_d = L_{a} \ast K_i$$

where $L_{a}$ is the drum length of the model, $K_i$ is the simulation coefficient.

The stiffness of the spring connecting the shaft to the drum is determined by:

$$C_{np} = C_a \ast K_e$$

where $C_a$ is the stiffness of the model spring, $K_e$ is the coefficient of spring simulation.

To determine the size of working channels and holes of the upper bit sludge grinder drum, we analyzed the sludge samples from the following directional and horizontal wells.

Horizontal production wells No. 138Г, No. 140Г, No. 141Г, Shakshinskaya area, the Bashneft’ oil joint stock company. The layout of drilling tool: the 123.8 SL62P bit, the DR-106 screw downhole motor, the CTT telesystem, SBT-73. The drilling was carried out by a clayless polymer-salt solution with a flow rate of 0.010 m³/s. The axial load on the bit is 6 tons. Sludge samples were taken during drilling of the horizontal part of the trunk, depth 2100–2250 m, Tournaisian layer, hard rocks.

Production directional wells No. 106 and No. 107, area – Yubileynaya, the Bashneft’ oil joint stock company. The layout of drilling tool: the 215.9 TD61AXLK bit, the D5-195 screw downhole motor, the UBTS-178 weighted drill pipes 100 m long, SBT-127. The drilling was carried out by a clayless polysaccharide hydrophobizing low-carbonate solution with a flow rate of 0.028 m³/s. The axial load on bit is 15 tons. Sludge samples were taken from a depth of 1208-1210 m, Kizel-Cherepetsk horizon, hard rocks.

Production well No. 486, area – Belebeyevskaya, the Bashneft’ oil joint stock company. Drilling cutting 347 m to a depth of 2015 m. The geological section is composed of hard rock. The layout of the drilling tool: the 215.9 TD61AXLK bit, the D5-195 screw downhole motor with a rotation speed of 15 rpm. The sludge samples were taken from a depth of 2050–2052 m (Mullinsky horizon).

Production well No. 3114, area – Leonidovskaya, the Bashneft’ oil joint stock company. Drilling cutting 455 m to a depth of 1555 m. The geological section is composed of hard rock. The layout of the drilling tool: the 215.9 TZ-GAU R590 bit, UBTS-178 100 m long. Drilling was carried out by a clayless polysaccharide hydrophobizing low-carbonate solution with a flow rate of 0.03 m³/s, using the D5-195 downhole screw motor with a rotation speed of 90 rpm. The sludge samples were taken from a depth of 1546–1548 m (Nizhne-Famensky horizon).

Also, sludge removal was investigated when drilling directional sections of wells No. 452 and No. 331 on Tuimazinskaya Square of the Bashneft’ oil joint stock company. The layout of drilling tool: the ENP 142.9 KS bit, UBT-108 8 m long, SBT-73. The bit load was 30–50 kN, the riser pressure was 7 and 10 MPa for wells No. 452 and No. 331, respectively. The drilling was carried out with a clay solution with a flow rate of 0.010–0.013 m³/s, using a rotor with a rotation speed of 72 rpm. The geological section is composed of hard and hard rocks. Sludge samples were taken from a depth of 1730 m from well No. 331 and 1178 m from well No. 452.

According to the study results, the largest particle size of sludge was 25 mm. With a margin, we select the diameter of input channels of the upper bit slurry device equal to 30 mm. The diameter of output channels (holes in the drum) is 2.5 mm.

The study of the effect of upper bit sludge grinder on the mechanical speed and drill bit penetration during drilling was carried out at well No. 27B / 180 of the Mellyaneft’ area of the Tatneft’ oil joint stock company drilled for technical water supply. The well drilling was carried out by the YPB 343 drilling rig, the NB-40 pump. Drilling was carried out with a clay solution with a flow rate of 4 l/s, using the R-25 rotor with a rotation speed of 120 rpm. The bit load is the weight of the tool. The well depth is 102.5 meters. The layout of drilling tool: the 215.9 MFG bit; the upper bit slurry shredder with a diameter of 190 mm; weighted drill pipes with a diameter of 147 mm and a length of 4.65 m.
Using a slurry grinder, 93.5 m were drilled in the interval 9.0–102.5 m in 26 hours. The mechanical speed was 3.59 m/h. Sludge, crushed to 2 mm, was stably carried to the surface by a stream of washing liquid. The wear of bit and the working elements of grinder is negligible (Figure 5).

Figure 5. The main details of near-bit sludge grinder after field tests: 1 – hole for sludge suction; 2 – auger

4. Conclusion
Experimental and field studies have identified the rational geometric dimensions of upper bit sludge grinder elements, ensuring its operation’s stability. An upper bit sludge shredder is efficient: during the well drilling process there were no failures (parts breakdowns). Large particles of crushed sludge are 1.7–2.5 mm. The mechanical drilling speed due to the stable removal of crushed sludge by the flushing fluid increased by 18%. upper bit slurry shredder is recommended for widespread adoption to increase the efficiency of drilling vertical, deviated and horizontal wells.

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