The Use of New Wear-Resistant Materials in the Development of Two-Level Bits with a Balanced Resultant Moment at the Drilling Flight

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Abstract. Two-level bit with a planetary reducer is described in the article. The thrust ball bearings of the planetary reducer are supposed to be replaced by bearings with inserts from grounded PDC plates. The scheme of this bearing is given, the research on its bearing capacity is carried out. The results of PDC cutters' tests for wear depending on depth and penetration in rock are also given. The test results for PDC wear resistance are given in conditions of drilling a well with standard cutters and the cutters that have undergone cryogenic-magnetic treatment. The results of tests on wear resistance of standard PDC plates, PDC plates with leached subsurface layer, and leached PDC plates, covered with additional diamond coating are given. Therefore the existing technologies allow to increase the PDC wear resistance in two-level bit by 1.7-2 times compared to the standard PDC plates. The reasons of the PDC plates chipping are considered, the link between the torque at the drill string and the probability of the PDC plates' chip is discussed.

1. Introduction
Currently, the volume of drilling wells with cutting bits, such as PDC, is constantly increasing. Bit has become the basic tool of drilling equipment, working on the principle of cutting - chipping, since cutting is the most effective mechanism of rock destruction means, because the tensile and break strength of the rock is less than the compressive strength. High wear resistance of PDC plates in the bit itself does not reduce the sharpness of uneven wear of the peripheral cutting elements located near the axis of the bit. Therefore, one of the ways to increase the drill bit production is to consider the possibility of improving the two-level bit developed at the Department of Oil and Gas Engineering and Technology of SRSPU(NPI), Patent RU No. 2577351, with rotation from DDM via the planetary gear group.

The increase in the running time of the bits requires overcoming other limitations that reduce the final drilling speed and the number of runs that determine the economic performance of the wells.

The life of frictionless bearings in a planetary gear group is such a limiter. With the increase in drilling depth the hardness of rocks increases, requiring an increase in the load on the bit and, consequently, more durable bearings. In comparison with frictionless bearings, the plane bearings withstand higher loads due to the fact that they are distributed over a large bearing area.

So, the planetary gear group for a two-level bit with a diameter of D = 215 mm, the thrust single bearing No. 8122 (145 × 110 × 25) allows an axial load of R = 145 kN on the drill string. Currently,
according to the data [1], it has become possible to replace the thrust ball bearings with thrust PDC bearings consisting of a pair of rings polished to each other with inserts from PDC. The performed tests of carrying capacity of bearings are shown in Fig. 1.

![Figure 1. Dependence of the vertical load on the sliding speed, separating the areas of natural wear of PDC inserts and their thermodestructive failure.]

Figure 2 shows the type of thrust bearing with inserts of diameter $d = 13.5$ mm. For the size of bearing No. 8122 with the outer diameter $D = 145$ mm and the internal diameter $d = 105$ mm, we accept 22 PDC inserts with a diameter $d = 13.5$ mm. The total support area that gets the axial load will be $S = 3100$ sq. mm. Then, with a slip velocity $V = 1.5$ m/s and a specific load $P = 100$ N / sq.mm, the permissible axial load on the bearing is $P_{oc} = 310$ kN.

![Figure 2. Type of thrust bearing (sliding couple) with PDC inserts. 1, 2 - rings of the bearing case; 3 - PDC with diameter $d_n = 13.5$ mm.]

Based on laboratory data [2, 3], the PDC bearing operation in a well at typical values of cutting speeds and axial loads per bit can be measured by several thousand hours.

Further improvement of PDC cutters goes in different directions:
1. Cryogenic-magnetic treatment - Patent RU No. 2566523.

Figure 3 shows the results of comparative tests of 112 mm diameter crowns with standard PDC cutters and with cutters after cryogenic magnetic treatment.
Figure 3. Figure 3 shows the results of comparative tests of 112 mm diameter crowns with standard PDC cutters and with cutters after cryogenic magnetic treatment. ● - wear flat; ■ - rate of penetration; ♦ - bit gage; dashed line – cryogenic-magnetic processing; solid graph – standard boring tool.

Figure 4. Test results of PDC cutters for wear depending on the depth of hole penetration in the rock in meters 1 - standard cutters; 2 - cutters with cobalt removed from the surface.

2. Etching of synthesized diamond tablets in acids for leaching cobalt [4, 5]. Creation of the plate called TSP (Thermally Stable Polycrystalline) on this basis. The wear tests' results of standard PDC-cutters and the ones after cobalt etching, depending on the depth of well penetration in the rock in meters are shown in Figure 4 [6, 7].

3. Hardening of PDC cutters of drill bits by applying a polycrystalline diamond (PCD) layer to their cutting surface. The results of the abrasive wear tests are shown in Fig.5 [4]. The solid line represents the dependence for the cutters with PCD coating, and the dotted line - for the uncovered
cutters. We see that the coated wear PDC is 1.7 times lower than the wear of PDC cutters without coating.

Figure 5. Tests' results for wear resistance of PDC cutters with PCD coating and without coating. 1. PDC-cutters with a leaching depth of Co 10 μm; 2. PDC-cutters with a leaching depth of Co 10 μm and a PCD coating.

The cutting speeds and the friction paths of the cutters most distant from the axis of the bit rotation are aligned on the stages on the two-level bit (Figure 6a). But the uneven loading of the cutting PDCs remains on each stage within its larger and smaller diameter.

To "equalize" the wear of the cutters within a stage, it is advised to install PDC with PCD coating on peripheral cutting lines, as their wear resistance is 1.7 times higher than of standard PDCs.

Figure 6b shows a bit with a planetary gear group, in which a PDC bearing is installed instead of a thrust ball bearing, and PDC cutters with PCD coating are used instead of PDC cutters (15 and 16). Wear resistance of such bit is 1.7 times greater than the primary version of the two-level bit.

The drilling and spudding stages made in the form of independent solids of revolution and located coaxially lean on shank 1 which has a tool-joint thread.

However, the operating times of drill bits reinforced with PDC depend not only on wear, but also on breakage of cutting elements. Analysis of the treated bits state shows that the number of worn and broken cutting elements is approximately the same. PDC breakdowns are mainly of two types:

- chips from the action from the front face forces;
- chips from the action from the back face forces.

The strength characteristics of the PDC significantly exceed the strength characteristics of the rocks. So the hard-alloy PDC base has a hardness of 86-91 HRA, a flexural strength of 1000-1800 MPa, an impact strength of 2-7 J/cm², a compressive strength of 2000 MPa, and a Young's modulus of 890 GPa.

Consequently, breakdowns can occur only from impact loads.

Changes in the amount of cutting forces and torque on the bit lead to the appearance of torsional oscillations at the drilling station, the propagation velocity of which exceeds 2400 m/s. When the torsional wave passes through the bit, the cutters of the rock are impacted, resulting in a PDC breakdown with the probability of P ≤ 0.2.
Figure 6. Two-level bit with planetary gear group. I - Planetary gear group; II - stabilizing two-level bit of cutting type; 1,2 - shank and stabilizer of the drilling stage; 3 - cutting blades of the drill stage; 4 PDC cutting elements; 5,6 - stabilizer and cutting blades of the drilling stage; 8,9,10,11 - the central shaft, the carrier, the central wheel and the gear ring of the reducer, respectively; 12 - satellites of a planetary reducer; 13 stationary housing of the planetary reducer; 14 thrust bearing: a - ball bearing; b - PDC; 15 - cutting PDC of drilling stage with PCD coating; 16 - Cutting PDC of the spudding stage with PCA coating.

To prevent the torsional vibrations, it is necessary to free the drill string from the transfer of torque to the bit. This is possible if the torque on the spudding stage $M_1$ and on the drilling stage $M_2$ is equal in absolute value but opposite in direction, i.e.:

$$[M_1] = -[M_2]$$

The cutting forces and the required torque values depend on the thickness of the sheared layer of the rock. The thickness of the sheared rock layer depends on the rock properties, the bit design and the process parameters of drilling.

$$h = \frac{V_{ROP}}{n} \times z \times \frac{P_{OS}}{P_{K} \times F_z}$$

where $n$ is the bit rotation speed, rpm;
$z$ - number of cutting PDCs in the cutting line;
$V_{ROP}$, mm/s mechanical drilling speed;
$V_0$ - drilling speed modulus, mm/s;
$P_{OS}$, MPa - the specific load on the cutting edges of the bit.

Then:

$$V_{ROP} = \frac{(V_0 \times P_{OS})}{(P_{K} \times F_z)}$$

Substituting the value $V_{ROP}$ in formula (2), we obtain:
or, for the required thickness value of the sheared rock layer, the required axial load is determined by the formula:

\[ P_{0s} = (h \times n \times z \times P_R \times F_z) / (V_0 \times 60) \]

Knowing \( h \), cutting force during drilling is determined by the formula

\[ P_z = \mu_1 \times R \times F_z + (R_N \times h \times B \sin \beta + \mu_2 \times \cos \beta) / (2 \sin \tau \times \sin(\tau + \delta)) \]

Where \( R_d = 0.24 \) P_k rock resistance to breaking;
\( R_{sk} = 0.08 \) P_k - rock resistance to shearing;
\( \mu_1 = 0.35 \) - friction coefficient during breaking;
\( \mu_2 = 0.4 \) - friction coefficient during shearing;
\( \tau = 25^\circ \) - the angle of rock cleavage;
\( \delta = 105^\circ \) - the angle of cutting (for \( \beta = -15^\circ \) is the front rake);
\( B = 2 \times \sqrt{R^2 - (R - h)^2} \) - the width of the sheared rock layer at the layer thickness \( h \) (mm);
\( R = 6.75 \) mm radius of the round PDC plate.

Then the torque on the drilling stage will be

\[ M^2_{tor} = \sum_i^1 (P^2_{z1} + 2z^2_1 + z_1^2 + P^2_{z2} + 2z^2_2 + z_2^2 + \ldots + P^2_{zn} + 2z^2_n + z_n^2) \text{, kNm} \]

where \( P^2_{z1} + 2z^2_1 + z_1^2 \) is the cutting force, the installation radius and the number of PDCs in the first cutting line in the drill string.

\[ M^1_{tor} = \sum_i^1 (P^1_{z1} + 2z^1_1 + z_1^1 + P^1_{z2} + 2z^1_2 + z_2^1 + \ldots + P^1_{zn} + 2z^1_n + z_n^1) \text{, kNm} \]

where \( P^1_{z1} + 2z^1_1 + z_1^1 \) is the cutting force, the installation radius and the number of PDCs in the first cutting line on the spudding stage.

Resultant torque on the bit is

\[ M_r = M^1_{tor} - M^2_{tor} \]

By approximating the torque modulo values on the drilling and spudding stages, torsional vibrations on the drill string can be prevented and the number of PDC breakages from shocks generated by torsional vibrations can be reduced.

2. Conclusion

Therefore, at present the existing technologies allow to increase the PDC wear resistance by 1.7 - 2.0 times in comparison with standard plates, but there are no technologies to increase the toughness or strength of the PDC for bending. That is why developments to reduce the longitudinal, transverse and torsional vibrations of the drill string, causing PDC breakdowns remain topical.

3. References

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