Method of Calculating the Wear, ROP and PDC Bit Operating Time

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Abstract. The article deals with the questions of the operating time calculation technique for the cutting PDC element of cylindrical shape. The results of laboratory studies of PDC plates in the accelerated material testing facility (AMT-2) are presented in the course of experimental studies, wear of the cutting elements over time, the relationship between the abrasiveness of the rock and the development of the PDC cutting element has been studied. The carried out researches allowed not only to confirm some existing experimental results, but also to propose a new dependence of PDC wear prediction in different rocks, rate of penetration and bit operating time in order to predict the rate of penetration. This largely determines the economic efficiency of the drilling process, greatly simplifying the forecasting of the bit wear.

1. Introduction

PDC cutting element consists of synthetic diamond and a carbide base which relative wear resistance differs in 95-100 times, as a result the carbide base wears out faster, whereby the PDC self-sharpen to form the back angle \(\alpha\). The change in the blunt area size depends on the width of the cutting part \(F\), the length of the cutting part \(B\) and the back angle \(\alpha\).

PDC cutting element consists of synthetic diamond and a carbide base which relative wear resistance differs in 95-100 times, as a result the carbide base wears out faster, whereby the PDC self-sharpen to form the back angle \(\alpha\) \([1-4]\). The change in the blunt area size depends on the width of the cutting part \(F\), the length of the cutting part \(B\) and the back angle \(\alpha\).

\[
F = \alpha(F \times B), \text{ mm}^2
\]

In order to study the process of PDC plates wear and its intensity, we conducted an experiment in which the wear of the cutting elements over time was studied and a relationship was established between the abrasiveness and PDC bit operating time.

To determine the increase of the cutting area and height wear, we use the diagram (Fig. 1) which is relevant for the PDC of cylindrical form. The thickness of the diamond layer is taken as \(F\), and the size \(B\) is calculated basing on the wear height \(h\), according to the formula:

\[
B = 2\sqrt{R(R-h)^2}, \text{ mm}^2
\]

where \(R = 6,75\) mm is PDC radius.

The study of wear resistance was carried out at the accelerated material testing facility (AMT-2) with the horizontal axis of rotation. The installation is based on a desktop horizontal milling machine with an attached loading jig. The scheme of the laboratory installation AMT-2 is shown in Fig.2
In the case of the loading device, there is a spindle with a quill and a feeding mechanism, in the form of a rack pair. The test sample 4 is fixed in the holder 3 of the load device. The samples are rubbed along the generatrix of the abrasive wheel 5. (studies were carried out on the ПП 300x35x127 circles 6377K3 40SM1 produced by the Volzhsky Abrasive Plant, with certified hardness indicators). The abrasive wheel is rotated by the electric motor 1 through the reduction gear 2, the rotational speed of the wheel is 50 rpm. A path counter 6 is provided to measure the rubbing path.

The following conditions were fulfilled during the experiment: the pressure on the cutting edges of the wearing sample should not exceed 18 MPa - from the hardness conditions of the abrasive wheel used [5]. The abrasion rate should not exceed 2.24 m/s from the working conditions of the cutting edges of the bit with a diameter of 214 mm and the rubbing wear path should not be more than 942 m - from the conditions of the AMT-2 machine operation for 20 minutes at a speed of 50 rpm [6-8].
During the experiment the initial blunt area, the initial axial load, and the rubbing path of the PDC cutting element were determined. After the wear on the abrasive wheel, the wear of the cutting element was measured in height and a new value of the blunt area was determined. Determination of the final and average value of the specific load on the PDC during the abrasion process was made. The intensity of wear in height and in time was determined. Then the cycle was repeated. The results of the experiment are given in Table 1.

Table 1.

| № | Parameter                        | experiment No. |
|---|----------------------------------|----------------|
| 1 | Initial specific load $p_1^s$, MPa | 18 18 18 18 18 18 18 |
| 2 | Initial axial load $p_2^s$, N(kgf) | 22.5 51.0 65.5 77.2 87.3 96.1 104 |
| 3 | Initial blunt area $F_2^s$, mm²   | 1.25 2.83 3.64 4.29 4.85 5.34 5.78 |
| 4 | Experiment time $t$, min          | 20 20 20 20 20 20 20 |
| 5 | Sample size after the abrasion $H_i$, mm | 34.89 34.78 34.67 34.57 34.48 34.39 34.30 |
| 6 | Deterioration of sample in height $\Delta h$, mm | 0.12 0.11 0.105 0.1 0.095 0.092 0.09 |
| 7 | Final blunt area $F_f^z$, mm²     | 2.83 3.64 4.29 4.85 5.34 5.78 6.18 |
| 8 | Final value of the specific load $p_f^z$, MPa | 8 14 15.3 15.9 16.35 16.63 16.83 |
| 9 | Average value of the specific load $p_f^z$, MPa | 13 16 16.6 16.9 17.2 17.3 17.4 |
| 10| Intensity of wear in height and time $i_{h(t)}^{PDC}$, mm/min | 0.006 0.0055 0.00525 0.005 0.00475 0.0045 0.0045 |

The average value of wear rate in height in seven measurements is $i_{h(t)}^{PDC} = 0.00507$ mm/min with a coefficient of variation $K_i = 10.8\%$.

It is not possible to investigate the wear resistance on rocks in laboratory conditions, because of the considerable volume of the experiment, so we compare the results of the abrasive and rock-hardening abrasion tests on the abrasive wheels and on the rock by an indirect method based on the wear of the tool with PDC when drilling a well with the depth of 85.2 m in 3 hours 50 minutes.

When carrying out the research on AMT-2 with the duration of the experiment $t = 20$ min, at the frequency of abrasive wheel rotation $n = 50$ rpm, the rubbing path at the initial specific load $P_d = 18$ MPa is:

$$L_s = \pi \times D_{aw} \times n \times t = \pi \times 300 \times 50 \times 20 = 942 \text{ m}.$$  

Then, for the entire testing period (7 measurements before replacement range) the overall rubbing path taking into account the reduce of the abrasive wheel diameter was $\sum_1^7 L_{mp} = 6500$ m and PDC wear in height was $\Delta h = 0.7$ mm. Such PDC wear occurred during well drilling with the bit of 85.2 m in diameter 112 mm at a speed of 250 rpm after 3.8 hours. So, this rubbing path (cutting path) of the rock-cutting element is:

$$L_s = \pi \times d \times n \times t = \pi \times 112 \times 250 \times 230 \approx 20220 \text{ m}.$$
The wear resistance of the cutting elements ($I_{PDC}$) is defined as the ratio of rubbing path (cutting path) to PDC wear in height during the experiment. Then PDC wear resistance when tested in abrasive wheels will be:

$$I_{PDC}^1 = \sum_i L_i \times (\Delta h_{PDC}^i)^{-1} = 6500 \times 10^3 \times 0,7^{-1} = 9,28 \times 10^6 \text{ mm/mm}$$

Where $\sum_i L_i$ - is rubbing path of PDC on the abrasive wheel for all time of the experiment;

$\Delta h_{PDC}^i = 0,7 \text{ mm}$ – is total wear of PDC in height.

PDC wear resistance on the rock is the ratio of the cutting path during the observation period to the PDC wear in height:

$$I_{PDC}^2 = L_s \times (\Delta h_{PDC})^{-1} = 20220 \times 10^3 \times (0,7)^{-1} = 2,88 \times 10^7 \text{ mm/mm}$$

We see that the PDC wear resistance on the rock is 3 times more than on the abrasive wheel.

For practical purposes it is important to know the intensity of the PDC wear in time on the rock:

$$i_{h(1)PDC}^2 = i_{h(1)PDC}^1 \times (a_2 \times a_1^{-1})^{0.3} \text{ mm/min};$$

where $a_2$ – is rock abrasiveness, mg;

$a_1$ – is circle abrasiveness, mg.

Knowing $i_{h(1)PDC}^2$ and permissible wear of the drilling bit diameter, we can determine the time t of the tool according to the formula:

$$t = \Delta D \times 2 \times i_{h(1)PDC}^2, \text{ s}$$

where $\Delta D = 2h$, mm – is permissible wear of cutter tool in diameter.

The maximum value of the cutting element blunt area is given by:

$$F_Z^{\text{max}} = F \times B = F \times 2\sqrt{R^2 \times (R - h)^2}, \text{ mm}^2$$

where $F$ – is PDC diamond layer thickness, mm;

$B$ – is calculated from the wear in height $h$, mm.

Then, the drilling schedule is set up with a cyclic increase in the axial load $P_1$ at each interval:

- spudding;
- run-in of a new tool;
- increasing the load as $F_Z$ increases;
- load increase $P_2$ to the limit value.

When determining the operating time of the rock cutting tool (RCT), the main condition is the selection of the mode in which $P_1$ is always bigger than $P_3$ (bulk destruction mode) where:

$$P_3 = P_2 \times F_Z^{-1}.$$

Calculating the drilling speed in each interval, the average speed during the drilling time t is determined by the formula:

$$V_{ROP} = V_0 \times P_1 \times P_3^{-1} \text{ mm / s}.$$

Then the operating time of $L$ bit is given by:

$$L = V_{ROP} \times t, \text{ m}.$$

2. Conclusion

Thus, accelerated laboratory PDC durability studies on abrasive wheels AMT-2, allow to set the intensity of the PDC wear height in time, that in its turn, makes it possible to perform calculations of ROP and operating time of the tool.
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