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PROBABILISTIC ESTIMATE OF PDC DRILL BIT WEAR RATE

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ЙМОВІРНІСНА ОЦІНКА ВЕЛИЧИНИ ЗНОШУВАННЯ ДОЛІТ ТИПУ PDC

Purpose. To develop a probabilistic model of PDC drill bit wearing estimation according to the drilling time, drill solids and instrument design.

Methodology. The method is based on the experimental data of drill bit cutter run. Drill bit cutter wear rate can be described with a probabilistic function, parameters of this function have to be defined experimentally for particular cutters and drilling conditions. For wear rate probabilistic parameters, 3 types of the models are proposed to analyze: reliability of cutters and their failure due to margin wear rate caused by one type rock drilling; reliability of cutters and their failure due to margin wear rate caused by drilling different rocks; drill bit reliability and its failure due to the margin wear rate of its cutters. Drilling practice shows that wearing of the cutters is unbalanced: central cutters are the most worn out, while the peripheral ones are not worn out, as a rule. Blunting criterion of drill bit is proposed.

Findings. The article analyses the problems of estimation of the wear rate of PDC drill bit cutters and their remaining life. Technical guaranties of PDC drill bit cutters are developed with different drilling conditions considered. The blunting criteria of single bit cutters and whole PDC drill bit were reasoned considering cut rock characteristics, total drilling time and drill bit construction. Based on the experimental data, wearing probabilistic function was developed. The drill bit construction requirements, which provide total drilling time optimization, were defined.

Originality. The research advances of the method proposed in the paper include cutter and drill bit wearing process rationalization, as well as the development of drill bit wear criterion which allows enhancing efficiency of drill bit construction.

Practical value. A method of bit wearing probability determination depending on the drilling time, drilled rocks and bit construction was proposed. Drill bit blunting criterion was suggested.

Keywords: *wearing intensity, PDC drill bits, probability, rate of penetration, mechanical drilling speed, reliability, regression, probabilistic model*

General formulation of the problem and its relationship with important scientific and practical tasks. Practice of drilling shows that usage of modern drilling tools and equipment needs proper models of descriptive statistics to forecast drilling results and optimize the initial drilling parameters. Drilling equipment technical status is an actual problem of the drilling science because drilling equipment technical conditions specify the rate of penetration, drilling speed, and drilling costs. Thus, technical diagnostic is regarded as the base for drilling tool modelling and its remaining life forcast.

The generalized drilling data revealed that the main causes of PDC drill bit wearing are: wearing of chisels – 17%, chisel breaking – 30%, chisel shearing – 31%, chisel falling – 3%, no wearing – 19%. In other words, technological problems of bit production are the cause of their failure in 53% of cases. Moreover, the main causes of drill bit raising are: 19% – drilling tubes replacement, 3% – problems in a well hole, 3% – extreme decreasing of the rate of penetration (ROP), 3% – rig repairing, 72% – project deep attainment.

Complete usage of drilling tool minifies total drilling costs and drilling time; thus, methods of the drilling tool status diagnostics are widely implemented in the drilling practice. The most difficult objects for diagnostics include such downhole equipment as downhole motor and drill bit. In the drilling practice, drill bit status and its forecast enables avoiding many complications.

Analysis of recent research and publications, which the author used as a base, where current problem solving was initiated. Nowadays, a lot of actual data concerning drill bit running have been accumulated, including PDC drill bits. As a rule, these data are represented in drilling reports, and they form the base for statistical modelling of the drilling. Such data include the drilling regimes, rock characteristics, and drill bit parameters. It is well-known that experimental data of drill bit running do not correspond to the field drilling data, so theoretical drilling models do not match the practical applications, even if drilling models imitate downhole conditions. It can be explained by the drill bit and drill string vibrations, drill string hanging, etc. That is why field drilling data of the real bit running were chosen for statistical analysis and modelling.

Traditionally, random functions are used for analytical description of the technical system reliability function. For theses functions, the distribution law of time between failures and wearing rates is normal. Practice data show that this approach does not suit both drill bits and discrete cutters, because these and other drilling performance parameters are not distributed normally [1, 2].

Specification of the unsolved issues of the problem which the article is devoted to. The main difficulty of the statistical modelling is the basic data separation and necessity of complicated work for their selection, processing, etc. Thus, this can explain that modern models of drilling, rate of penetration and long service life forecast are not described in the literature. It is worth emphasizing that such relations for rate of penetration for drill bits, which were produced in the USSR, are represented in the digests, but not for imported drill bits, which are widely used on the oil/gas fields.

The article purpose formulation. The purpose of this work is to develop PDC drill bit wearing probabilistic model with abrasive wearing and drill bit cutters loading considered.

The main research matter. To specify the parameters of wear rate distribution and to test diamond-carbide plate efficiency, an experimental stand was developed by the Institute of Superhard Materials (Ukraine). This stand was constructed on a base of the shaping-machine 7B36. These data are presented in scientific reviews at Institute of Superhard Materials (Ukraine) and were used by the article authors for PDC cutter wear rate generalization [3].

Efficiency tests were provided by rock cutting. Parameters of cut rock were: Torez (Ukraine) open pit strong grey sandstone, monomineral, with quartz cement layers, 530kg/mm^2 hardness. Experimental cutting regimes are given in table. Strain gauge transducer was fixed at the support of shaping-machine for cutting loading measurement (fig. 1, 2).

The cutter holder, which holds the diamond compact plate, was fixed in a dynamometer frame. This method can be used for diamond compact plate researching: to change a diamond compact plate and to measure loading at the same points. Cutter holder design provides 10 degrees' slope between the diamond compact plate and cut surface. Measuring system of the experimental stand registers the following drilling options: *Px, PY, PZ* – forces, cutting zone temperature increasing, cut length. Loading measuring error made up no more than 12%. The linear size of the worn diamond compact plate was regarded as the main option of the wearing resistance of the diamond compact plate. Worn area measurement was done by instrumental microscope (IM) (State Standard 8074-8, measurement error was 0,03mm).

The measuring scheme is presented in fig. 3. The experiment was conducted in the following way. The sandstone block (500x300x250 mm) was set up on the shaping-machine. Sandstone block surface deviation from the plane was no more than 0,1mm. Cutting deepness due to drilling practice were 0,5mm.

Experimental cutters were fully worn during the drilling process; it means that wearing area was larger than the diamond-carbide layer (0,8mm). Measurements of worn area were done for every 50–100m cutting path. Experimental data are presented in the table. Cutting regimes were: cutting speed – 0.55m/s; cutting depth – 0.5mm; traverse – 1.4m.

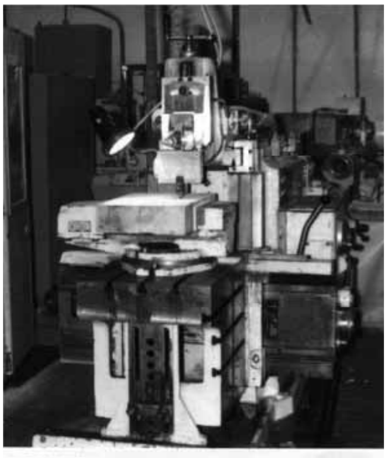

Fig. 1. General view of the experimental stand

Fig. 2. Strong grey sandstone cutting

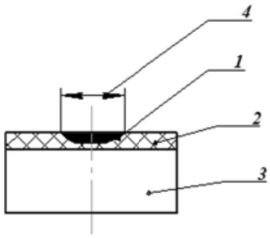

Fig. 3. Scheme of cutter wearing rate measurements: 1 – worn plate; 2 – diamond-carbide plate layer; 3 – cutter stud; 4 – worn plate breadth

These experimental data revealed that PDC cutter wear rates are not distributed normally. Moreover, normal distribution is not observed regarding wear rate for cutters performed under the same conditions, produced by the same technology, etc. Therefore, for PDC drill bit cutter wear modelling, it is appropriate to define wearing rate distribution first [4, 5].

Table

Experimental data of diamond-carbide plate (∅8mm, drilling length 50m)

№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm	№	worn plate breadth, mm
sample 1: 95 units of diamond-carbide plate, experiment 1, (n=95, $\overline{x} = 0,285596$, S=0,118253, S^2=0,013984)																			
1	0,22	**11**	0,37	**21**	0,30	**31**	0,4	**41**	0,27	**51**	0,40	**61**	0,21	**71**	0,13	**81**	0,47	**91**	0,51
2	0,41	**12**	0,28	**22**	0,28	**32**	0,41	**42**	0,37	**52**	0,14	**62**	0,28	**72**	0,33	**82**	0,17	**92**	0,17
3	0,51	**13**	0,42	**23**	0,33	**33**	0,41	**43**	0,23	**53**	0,29	**63**	0,30	**73**	0,19	**83**	0,32	**93**	0,22
4	0,24	**14**	0,14	**24**	0,18	**34**	0,46	**44**	0,37	**54**	0,15	**64**	0,07	**74**	0,19	**84**	0,27	**94**	0,43
5	0,22	**15**	0,38	**25**	0,22	**35**	0,27	**45**	0,2	**55**	0,18	**65**	0,51	**75**	0,17	**85**	0,45	**95**	0,53
6	0,26	**16**	0,33	**26**	0,52	**36**	0,27	**46**	0,28	**56**	0,17	**66**	0,26	**76**	0,20	**86**	0,21		
7	0,33	**17**	0,52	**27**	0,46	**37**	0,44	**47**	0,30	**57**	0,45	**67**	0,28	**77**	0,40	**87**	0,25		
8	0,43	**18**	0,17	**28**	0,18	**38**	0,22	**48**	0,22	**58**	0,19	**68**	0,20	**78**	0,10	**88**	0,18		
9	0,19	**19**	0,22	**29**	0,32	**39**	0,55	**49**	0,32	**59**	0,48	**69**	0,23	**79**	0,25	**89**	0,11		
10	0,20	**20**	0,22	**30**	0,18	**40**	0,22	**50**	0,42	**60**	0,10	**70**	0,37	**80**	0,40	**90**	0,12		
sample 2: 85 units of diamond-carbide plate, experiment 2, n=87, $\overline{x} = 0,25837$, S=0,096848, S^2=0,00983																			
1	0,48	**11**	0,16	**21**	0,23	**31**	0,04	**41**	0,22	**51**	0,40	**61**	0,17	**71**	0,24	**81**	0,25		
2	0,03	**12**	0,32	**22**	0,48	**32**	0,15	**42**	0,23	**52**	0,14	**62**	0,23	**72**	0,18	**82**	0,15		
3	0,33	**13**	0,36	**23**	0,19	**33**	0,48	**43**	0,18	**53**	0,15	**63**	0,34	**73**	0,23	**83**	0,43		
4	0,22	**14**	0,25	**24**	0,31	**34**	0,46	**44**	0,44	**54**	0,24	**64**	0,22	**74**	0,14	**84**	0,25		
5	0,26	**15**	0,31	**25**	0,47	**35**	0,27	**45**	0,30	**55**	0,30	**65**	0,34	**75**	0,23	**85**	0,42		
6	0,58	**16**	0,20	**26**	0,37	**36**	0,27	**46**	0,21	**56**	0,21	**66**	0,21	**76**	0,27				
7	0,39	**17**	0,31	**27**	0,46	**37**	0,44	**47**	0,16	**57**	0,23	**67**	0,15	**77**	0,32				
8	0,21	**18**	0,37	**28**	0,28	**38**	0,22	**48**	0,20	**58**	0,50	**68**	0,27	**78**	0,24				
9	0,18	**19**	0,22	**29**	0,32	**39**	0,55	**49**	0,24	**59**	0,33	**69**	0,1	**79**	0,24				
10	0,15	**20**	0,33	**30**	0,28	**40**	0,15	**50**	0,42	**60**	0,37	**70**	0,27	**80**	0,35				
sample 3: 175 units of diamond-carbide plate, experiment 3 (n=176, $\overline{x} = 0,285596$, S=0,118253, S^2=0,013984)																			
1	0,15	**19**	0,44	**37**	0,16	**55**	0,21	**73**	0,14	**91**	0,22	**109**	0,14	**127**	0,14	**145**	0,28	**163**	0,48
2	0,17	**20**	0,25	**38**	0,49	**56**	0,34	**74**	0,20	**92**	0,31	**110**	0,21	**128**	0,20	**146**	0,13	**164**	0,33
3	0,14	**21**	0,15	**39**	0,25	**57**	0,16	**75**	0,32	**93**	0,12	**111**	0,24	**129**	0,30	**147**	0,23	**165**	0,35
4	0,20	**22**	0,29	**40**	0,18	**58**	0,21	**76**	0,39	**94**	0,20	**112**	0,23	**130**	0,37	**148**	0,27	**166**	0,19
5	0,22	**23**	0,24	**41**	0,27	**59**	0,27	**77**	0,32	**95**	0,25	**113**	0,29	**131**	0,34	**149**	0,25	**167**	0,35
6	0,20	**24**	0,30	**42**	0,12	**60**	0,17	**78**	0,19	**96**	0,21	**114**	0,15	**132**	0,18	**150**	0,35	**168**	0,18
7	0,30	**25**	0,32	**43**	0,19	**61**	0,18	**79**	0,13	**97**	0,19	**115**	0,15	**133**	0,25	**151**	0,23	**169**	0,17
8	0,17	**26**	0,56	**44**	0,27	**62**	0,38	**80**	0,31	**98**	0,14	**116**	0,48	**134**	0,12	**152**	0,17	**170**	0,23
9	0,18	**27**	0,43	**45**	0,22	**63**	0,17	**81**	0,25	**99**	0,19	**117**	0,31	**135**	0,14	**153**	0,13	**171**	0,26
10	0,19	**28**	0,15	**46**	0,24	**64**	0,18	**82**	0,18	**100**	0,14	**118**	0,21	**136**	0,17	**154**	0,51	**172**	0,15
11	0,31	**29**	0,23	**47**	0,20	**65**	0,23	**83**	0,23	**101**	0,19	**119**	0,17	**137**	0,50	**155**	0,15	**173**	0,13
12	0,48	**30**	0,04	**48**	0,15	**66**	0,28	**84**	0,43	**102**	0,18	**120**	0,21	**138**	0,49	**156**	0,25	**174**	0,22
13	0,15	**31**	0,33	**49**	0,15	**67**	0,18	**85**	0,25	**103**	0,21	**121**	0,22	**139**	0,28	**157**	0,21	**175**	0,41
14	0,14	**32**	0,25	**50**	0,27	**68**	0,19	**86**	0,22	**104**	0,24	**122**	0,26	**140**	0,43	**158**	0,21		
15	0,14	**33**	0,18	**51**	0,19	**69**	0,51	**87**	0,19	**105**	0,30	**123**	0,16	**141**	0,49	**159**	0,25		
16	0,15	**34**	0,20	**52**	0,16	**70**	0,23	**88**	0,12	**106**	0,29	**124**	0,22	**142**	0,16	**160**	0,26		
17	0,24	**35**	0,17	**53**	0,19	**71**	0,29	**89**	0,20	**107**	0,30	**125**	0,30	**143**	0,11	**161**	0,17		
18	0,19	**36**	0,38	**54**	0,20	**72**	0,17	**90**	0,42	**108**	0,16	**126**	0,22	**144**	0,12	**162**	0,20		

The most efficient way is to use multifactor relation for reliability modelling. This relation has to consider such parameters as accumulated wear rate, drilling regimes, and drillability. However, because of the necessity to use a lot of statistical data which can be obtained only experimentally, it is appropriate to limit the influence factors and to consider the most important of them. Wear rate relation was determined according to the experimental data. It means that this relation is not available for other drilling conditions: rock, drilling regimes, cutters, etc. the experimental data are the base for probabilistic models of reliability and cutter performance forming.

Since real cutter drilling conditions are a lot more complicated than experimental ones due to possible influence of stochastic factors, to define wear rate probabilistic parameters 3 types of models are proposed to analyze:

- failure of cutters caused by the margin wear rate obtained while drilling the same rock;

- failure of cutters caused by the margin wear rate obtained while drilling different rocks;

- failure of a drill bit as a whole caused by the margin wear rate of its cutting structure.

1. Probabilistic model of the reliability and failure of cutters caused by the margin wear rate obtained while drilling the same rock

Abrasive wear rate is determined by experimental distribution with $h(\tau_i)$ which is the average value of the square of the worn PDC layer of the actual area for the particular cutter at the particular time τ_i and standard deviation σ_h. It means that wear distribution is not normal, but it should be determined for the particular cutter (cutter layer material, cutter geometry, etc.) and the particular drilled rock.

The actual area of the PDC cutter layer is defined for the particular cutter due to downhole overlap scheme (fig. 4). The actual area of cutters will be fully worn during the drilling process, so the spatial form of the drill bit will be specified by combination of the form of worn cutters.

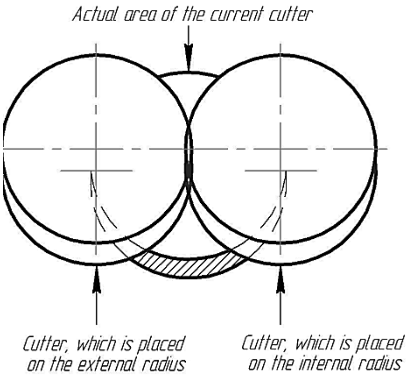

Fig. 4. Actual area definition

Blunting criteria $h_{кр}$ for the particular cutter is the full wearing of the actual area of the PDC layer.

Wearing process is random, so due to this process complication, wear rate increasing is regarded as a linear function within the normal wearing zone

$$h(\tau) = h + c_h \tau ,$$

where c_h is an average wear speed, which can be assumed as a constant value; values of c_h is defined experimentally.

Cutter failure probability caused by margin wearing rate can be specified by blunting criteria $h_{кр}$ compared with the wearing rate $h(\tau)$ and can be defined as

$$p(\tau) = f\left\lfloor -\left(h_{KP} - c_h \tau\right) / \sqrt{\sigma_h^2 + \sigma_{hK}^2} \right\rfloor ,$$

where $f(\tau)$ is experimentally defined wear rate distribution. Consequently, single cutter reliability can be defined as

$$1 - p(\tau) = 1 - f\left\lfloor -\left(h_{KP} - c_h \tau\right) / \sqrt{\sigma_h^2 + \sigma_{hK}^2} \right\rfloor .$$

Distribution of the period of cutters stability can be obtained on the base of wear rate distribution, since the distribution law of the period of cutters stability matches the wear rate distribution law with options: $T_И$ *an* average period of cutters stability to full wearing

$$T_И = h_{KP} / c_h$$

and $\sigma_И$ is standard deviation

$$\sigma_И = \left(\sqrt{\sigma^2{}_h + \sigma^2{}_{Kh}}\right) / c_h .$$

2. Probabilistic model of the reliability and failure of cutters caused by the margin wear rate obtained while drilling different rocks.

Actually, PDC drill bits are used for drilling different rocks with stable drilling regimes. It means that drilling rocks characteristics are the main parameters of the models.

As it was in the previous case, it is necessary to determine the distribution laws and their parameters for all drilling rocks.

Wearing process is random, so due to this process complication, wear rate increasing is regarded as a linear function within the normal wear zone

$$h(\tau) = h + \sum_{i=1}^{n} c_{hi} \tau_i ,$$

where c_{hi} and τ_i are average wear speeds and drilling time for the particular rock.

Following this way, cutter failure probability caused by margin wearing rate can be specified by blunting criteria $h_{кр}$ compared with the wearing rate $h(\tau)$ and can be defined as

$$p(\tau) = f\left[-\left(h_{KP} - \sum_{i=1}^{n} c_{hi} \tau_i \right) / \left(\sqrt{\sigma_h^2 + \sigma_{hK}^2} \right) \right] ,$$

where $f(\tau)$ is experimentally defined wear rate distribution. Thus, single cutter reliability can be defined as

$$1 - p(\tau) = 1 - f\left[- \frac{\left(h_{KP} - \sum_{i=1}^{n} c_{hi} \tau_i \right)}{\left(\sqrt{\sigma_h^2 + \sigma_{hK}^2} \right)} \right] .$$

Distribution of the stability period of cutters can be obtained on the base of wear rate distribution law, considering that the distribution law of the stability period of cutters corresponds to the wear rate distribution law with options: $T_И$ an average stability period of cutters to full wearing

$$T_И = h_{KP} / \left(\sum_{i=1}^{n} c_{hi} \tau_i \Big/ \sum_{i=1}^{n} \tau_i \right)$$

and $\sigma_И$ is standard deviation

$$\sigma_И = \left(\sqrt{\sigma^2{}_h + \sigma^2{}_{Kh}}\right) / c_h .$$

For possible relation between wearing rates for different drilled rocks, it can be hypothesized that

$$c_{hi} \cdot \tau_i = const ,$$

where c_{hi} and τ_i – average wear speed and drilling time for full wearing for the particular rock. But this idea was not checked experimentally.

3. Probabilistic model of the reliability and failure of a drill bit as a whole caused by the margin wear rate of its cutting structure.

The next stage of modelling considers the issue of PDC drill bit equipment (set of cutters) reliability. At this modelling stage two problems arise: cutter wearing irregularity and blunting criteria $h_{кр}$ definition.

Drilling practice shows [6] that wearing of the cutters is irregular: central cutters are the most worn, whereas the peripheral ones are not generally worn (fig. 5). According to the downhole overlap scheme, the central cutters make the most contact with rocks. Central cutters have the biggest actual area, which gets fully worn during the drilling process. Central cutters drilling operate under most severe conditions, since they do the first furrows. The second and third cutters do furrows later. This scheme of the downhole deepening provides decreasing of the power inputs for rock destruction because the following furrowing needs much less energy due to rock chipping and abrasion, but not cutting.

Fig. 5. Worn PDC cutters (drill bit-Read Hycalog 11 5/8 DS 66)

As a rule, wearing irregularity can be explained by the cutting loading irregularity regardless the similar cutter geometry, drilling regimes, etc. Thus, to considering wearing irregularity due to cutters placing, it is worth regarding arbitrary placed cutter reliability as

$$p^*(\tau) = p(\tau;k) =$$

$$= f\left[-\frac{\left(h_{KP} - \sum_{i=1}^{n} k_1 \cdot k_2 \cdot c_{hi}\tau_i\right)}{\sqrt{\sigma_h^2 + \sigma_{hK}^2}}\right],$$

where k_1 is the coefficient of wear intensity caused by cutter placing.

The issue of loading distribution among cutters has been well-developed regarding drill bits with circling cutters (planetary drill bit, roller drill bit). Firstly, the idea of loading decrease from the centre to the periphery was hypothesized in the 1950-ies; moreover, the work of the drill bit was identified with that of the sliding bearing. It was admitted that unit loading is directly proportional to the distance to the centre of the bit. However, this supposition was not verified in practice. For the model drill bit this conclusion is not available because of the drill bit construction. The same conclusion was made in works of Soviet drilling engineers where the process of rock destruction by cutters, which were placed at the different distances from drill bit centre, was analyzed. If cutters, which are placed at the R_1 and R_2 $(R_1 > R_2)$ radii from the drill bit central line, rotate to the angle γ and pass the length l_1 and l_2, they will intrude into the rock within the distances h_1 and h_2 accordingly. Thus, the first cutter angle of slope is larger than the second one: $h_1/l_1 > h_2/l_2$. As far as the cutter angle of slope is proportional to the unit loading, it can be proposed that cutter unit loading is inversely proportional to the distance between the cutter and drill bit central line. So, to define k_1, coefficient of wear intensity due to cutter placing, it is suggested to use the formulation

$$k_1 = \left(\frac{h_i}{l_i}\right) / \left(\frac{h_{\max}}{l_{\max}}\right), \tag{1}$$

where index “max” is used for the most protrusive cutter (touching the downhole first); index “i” is used for the analyzed cutter. Drilling deepness can be defined for every cutter depending on the worn actual area.

4. Criteria of bit blunting.

As far as the main criteria of drill bit operation is the diameter of drilled well, the blunting criteria $h_{кр}$ for all drill bit equipment can be defined as a value of admissible diameter decreasing. For example, there are such grades of diameter loosing: 1/16”, 2/16”, 3/16”, 4/16”, etc. These cutters have the longest cutting length due to their placing, but their wear rate defines the bit blunting. It means that certain constructive decisions should be proposed to decrease the wearing of these cutters. For example, regarding (1), it is proposed to decrease deepness of cutting or to use additional blades to place cutters to decrease cutting length, etc.

Conclusions. Due to this approach, it certain recommendations can be made to the drill bit design. Firstly, visible examining of worn cutters shows that only the active area of cutter layer is worn fully. It means that the drill bit cannot be used for drilling because of admission diameter loosing, but cutter layer is worn only partially. As far as the drill bit cutter is worn irrationally, much of the PDC layer (over the active area) is not worn at all. For its full wearing it is proposed to increase the active area by PDC cutters placing to avoid their cutting layer overlapping. Another way to provide full PDC layer wearing is to construct diamond compact as a mosaic pattern: actual area is made of diamond compact, other area of cutter layer is made of different superhard material. The technology of mosaic cutters is not developed yet, despite the fact that idea of mosaic cutters was well known in the 90s. Another idea which has not been developed yet concerned the production oval shaped of PDC cutters. This idea was not implemented either. Thus, the most acceptable way to provide the full area of diamond compact wearing is to place PDC cutters to avoid their cutting layer overlapping.

For the most distant placing cutters, it can be proposed to decrease deepness of cutting or to use additional blades to place cutters to decrease cutting length, etc.

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Мета. Розробка ймовірнісної моделі оцінки величини зносу бурового інструмента залежно від часу буріння, розбурюваних порід і конструкції інструмента.

Методика. Методика базується на експериментальних даних відпрацювання різців доліт. Величина зносу різців бурових доліт може бути описана ймовірнісною функцією, параметри якої визначаються експериментально для різців певних типорозмірів і умов буріння. Запропоновано для оцінки параметрів імовірнісної моделі розглянути три випадки: надійність різців і їх відмова у зв'язку з досягненням граничного зносу при бурінні однієї породи; буріння з досягненням граничного зносу різців.

Результат. У роботі аналізуються проблеми оцінки величини зносу різців доліт типу PDC, а також їх залишкового ресурсу. Розробляються технічні гарантії надійності різців даного типу доліт з урахуванням різних умов буріння. Обґрунтовано критерій оцінки зносу одиничних різців долота в цілому залежно від часу буріння різних порід і конструкції долота. На основі експериментальних даних побудована функція зносу одиничних різців і долота в цілому. Визначені вимоги до конструкції інструмента, що забезпечують збільшення часу використання долота.

Наукова новизна. Раціоналізація опису процесу зносу як одиничних різців, так і доліт у цілому, а також розробка критерію оцінки зносу долота дозволяє оптимізувати конструкцію інструменту.

Практична значимість. Запропоновано метод визначення ймовірності величини зносу доліт у залежності від часу буріння, розбурюваних порід і конструкції долота.

Ключові слова: *інтенсивність зносу, бурові долота типу PDC, імовірність, проходка, механічна швидкість буріння, надійність, регресія, імовірнісна модель*

Цель. Разработка вероятностной модели оценки величины износа бурового инструмента в зависимости от времени бурения, разбуриваемых пород и конструкции инструмента.

Методика. Методика базируется на экспериментальных данных отработки резцов долот. Величина износа резцов буровых долот может быть описана вероятностной функцией, параметры которой определяются экспериментально для резцов определенных типоразмеров и условий бурения. Предложено для оценки параметров вероятностной модели рассмотреть три случая: надежность резцов и их отказ в связи с достижением предельного износа при бурении одной породы; бурение различных пород с достижением предельного износа резцов.

Результат. В работе анализируются проблемы оценки величины износа резцов долот типа PDC, а также их остаточного ресурса. Разрабатываются технические гарантии надежности резцов данного типа долот с учётом различных условий бурения. Обоснован критерий оценки износа единичных резцов долота в целом в зависимости от времени бурения различных пород и конструкции долота. На основе экспериментальных данных построена функция износа единичных резцов и долота в целом. Определены требования к конструкции инструмента, которые обеспечивают увеличение времени использования долота.

Научная новизна. Рационализация описания процесса износа как единичных резцов, так и долот в целом, а также разработка критерия оценки износа долота позволяет оптимизировать конструкцию инструмента.

Практическая значимость. Предложен метод определения вероятности величины износа долот в зависимости от времени бурения, разбуриваемых пород и конструкции долота.

Ключевые слова: *интенсивность износа, буровые долота типа PDC, вероятность, проходка, механическая скорость бурения, надежность, регрессия, вероятностная модель*

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EVALUATION OF THE ADEQUACY OF THE STATISTICAL SIMULATION MODELING METHOD WHILE INVESTIGATING THE COMPONENTS PRESORTING PROCESSES

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ОЦІНКА АДЕКВАТНОСТІ МЕТОДУ ІМІТАЦІЙНОГО СТАТИСТИЧНОГО МОДЕЛЮВАННЯ ПРИ ДОСЛІДЖЕННІ ПРОЦЕСІВ РОЗБРАКУВАННЯ ДЕТАЛЕЙ

Purpose. Evaluation of the adequacy of the statistical simulation modeling method developed for examining the measurement error effects on the results of components presorting while their acceptance inspection.

Methodology. Parameters of components presorting calculated by statistical modeling method are compared with parameters of presorting which were determined by common alternative methods:

- graphic-analytical – according to the National Standard ГОСТ 8.051-81 (appendix 2);
- numerical integration of definite integrals in the equations of the mathematical model of the process.

Findings. For the purpose of the measurement error distributions according to the normal law as well as equal probability law it is shown that the calculated parameters do not differ significantly from the parameters listed in the standard. Thus the adequacy of the statistical simulation modeling method is confirmed.

It was found that the method is distinct in simplicity of calculations on a PC, clearness of the obtained results and the possibility of their accurate interpretation.

The statistical simulation modeling method can be used for modeling of both random and systematic measurement errors.

Originality. The mathematic models and statistical simulation modeling methods of acceptance inspection of the geometries of components and calculation of the parameters of their presorting are developed.

Practical value. On the basis of the developed mathematical models, the guidelines on the computer modeling using the method of Monte Carlo presorting processes during the acceptance inspection are compiled. The realization is carried out on the basis of Microsoft Excel program. Methodical instructions are used in academic activities. They can be used in the process of drafting business plans for making decisions during pre-production, which is characterized by a stochastic character, including for the purposes of enterprises of mining machinery.

Keywords: *acceptance inspection, statistical modeling, presorting, measurement error, adequacy*

Problem formulation. Quality of engineering products equally depends on technology of its manufacturing and control effectiveness. Prestart passive acceptance control is widely used by manufacturers and consumers of production. The components or their geomeytrical elements are sorted into accepted and non-acceptable ones during the reception control.

Measurement error of components controlled geometrical parameters leads to acceptance of compo-

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